MacViro
Engineering and Environmental Science

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Ms. Anne-Marie Fowler
Manager Solid Waste Services
City of Ottawa
Department of Transportation, Utilities & Public Works
Utility Services Branch, Solid Waste Division
4475 Trail Road, RR #2
Ottawa, ON K0A 2Z0

Re: Ottawa IWMMP Phase 2 Report on System Options for the Longer Term

Dear Ms. Fowler:

MacViro Consultants Inc. is pleased to provide this Report.

This report identifies options for the management of residual wastes. The options identified here are new and emerging technologies, and most have yet to be proven on a large scale. These systems are therefore identified as possible options for the longer term.

If you have any questions regarding this report, please do not hesitate to contact me.

Yours truly,
MacViro Consultants Inc.

D.O. Merriman

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I. Introduction

This report will provide an overview of new and emerging post diversion residual mixed waste management technologies currently being developed and implemented.

The technologies for processing the waste remaining after the source separation of recyclable and compostable materials can be classified according to the following categories:

1. Physical processes
2. Biological processes
3. Thermal processes
4. Chemical processes

These broad categories include established technologies as well as new and emerging technologies.

In the physical processing category, the use of material recovery facilities (MRFs) for recovery of recyclables is a generally well-proven method, with numerous facilities in North America and other parts of the world. This same technology can be applied to residual mixed wastes to recover additional recyclable materials and produce a refuse-derived fuel (RDF). There are also new and emerging technologies that involve the production of an RDF for combustion or gasification via novel methods.

In the biological processing category, aerobic composting and anaerobic digestion are two fairly well established methods for managing source-separated organics. These technologies can also be considered for residual solid wastes, although the resulting compost or digestate may be difficult to market. These technologies were discussed in the September 2003 Phase 2 Report. Ethanol fermentation is a new technology that has been tested at the bench scale and is being explored for MSW in America, and will be discussed in this report.

In the thermal processing category, mass-burn, modular and RDF incineration are well-known processes, with numerous large-scale facilities in Europe and North America. New and emerging technologies use various processes to create a synthetic gas (syngas) from the waste. Five types of gasification processes will be discussed in this report: fixed bed gasification, fluidized bed gasification, high temperature gasification, plasma arc gasification and pyrolysis.

None of the well-established methods for processing mixed waste residuals fall under the chemical processing category; while some technologies may have a chemical processing component, they are better characterized by another description such as biological or thermal processing. Three new and emerging technologies that have been classified as chemical processes are: hydrogen reforming followed by catalytic conversion to produce ethanol; advanced thermal treatment to produce fuels, and acid hydrolysis to produce industrial chemicals.

This report represents the current state of knowledge in Ontario regarding new and emerging technologies for processing post diversion mixed MSW. The information has been gathered through two separate open Request for Expressions of Interest (REOI) processes conducted by the City of Toronto and the Region of Niagara. This information was supplemented with a review of available literature. Since any vendor with a method for processing waste was invited to submit an EOI under the Toronto processes, it is expected that most new technologies that could be expected to emerge in Ontario in the near future were captured by these REOI processes and are discussed in this report.

2. Physical Processes

The category of physical processes is used to describe technologies that do not involve changing the chemical makeup of waste, unlike thermal, biological and chemical processes. They are focused primarily on separating the waste into components that can be more easily recycled or processed further by biological, thermal or chemical processes.

Physical processes do not provide a complete solution for residual mixed waste, but serve as the front-end processing step for other processes that act on the chemical makeup of the waste.

Technology Summary

Mechanical processing consists of a series of steps to separate the individual components of the waste for recovery of materials and preparation of refuse-derived fuel (RDF). The steps involved in mechanical processing for RDF include:

- Removal of large and bulky items
- Sorting and sizing (including recovery of recyclable materials)
- Production of RDF
- Combustion or gasification of RDF (at an offsite location)

The first step is removal of large, bulky items, which will be separated and sorted into categories. Large item categories include: yard wastes; ferrous metals; building products (construction/demolition debris); and tires. The materials may be processed by shredding, grinding, or other processes prior to sending the materials to further processing or end markets.

Materials are then placed on a conveyor belt to be carried through a number of processing steps.

Automated bag opening will remove the materials from the bags (by a bag-breaker – a device consisting of a number of rotating knives). A combination of manual and automated sorting is used to remove plastic film. Ferrous metals are then removed using a magnet.

Plastics (PET, HDPE, other plastics) and marketable paper fibres are removed manually.

The remaining materials, primarily non-marketable plastics, fibres and organics, are then prepared for use as RDF. Mechanical processes such as shredding and grinding, which may be followed by compression of the material into pellets, are most common for the production of RDF.

Another method for preparing RDF involves a drying step before the separation steps. Drying prior to separation yields cleaner recyclable products and an RDF with higher energy value. The material is put into aerated containers, similar to those used for aerobic composting. The difference from standard in-vessel composting is that no moisture is added and the material stays in the containers for a shorter time. Air is blown into the containers, and the material heats up as a result of biological activity. The heat and air flow act to dry out the material, which is then stabilized (as long as it remains dry, <12% moisture), and suitable for separation steps.

A variation on this "biological" drying involves using an external energy source to heat the air and dry the material.

Some physical processing technologies use steam to sterilize the waste, break down cellulosic materials and strip off labels and other contaminants from inorganic recyclables. This makes the waste more amenable to manual separation.

Diversion from Landfill

The output products of physical processes include paper, plastic, glass and metals for recycling. Those products that have a well-developed market, such as ferrous metals, aluminium, PET and paper, are easily marketed. The mixed broken glass and grit from the process is difficult to market. Some vendors claim this material can be used as aggregate in road construction but the viability of this market is questionable.

The RDF produced is suitable for combustion or gasification in a thermal process. A combustion or gasification facility must be found for the RDF, which involves approvals and siting that can be difficult. The end use of RDF has the same considerations as the thermal technologies discussed in Section 4.

The amount of diversion from landfill depends on end markets being found for recyclables and a suitable use for the RDF. If no use for the RDF is found, it must be landfilled. If an RDF utilization site is found and all recyclables are marketed, a diversion level of up to 90% might be achieved. If no end user is found for the RDF, a diversion level of 60% or less may result.

Emissions

Air Emissions

Mechanical RDF production facilities that have no onsite energy utilization do not have a point source for air emissions – odour from processing areas would be the main consideration in terms of air emissions from the facility itself. However, the site at which the RDF is utilized must be in compliance with Ontario air emission regulations including Guideline A-7.

Wastewater Discharge

Water is not involved in any of the processing steps and therefore wastewater would not be a significant concern, other than normal servicing requirements for staff washrooms, washdown of processing areas, etc.

Solid Residue

The solid residues are the non-recyclable residual materials from processing. These would need to be landfilled.

Commercial Status

The mechanical RDF production technologies are generally well developed, although technologies that use steam are in early stages of development. There are a number of plants in operation in Europe at scales of 85,000 tonnes per year or more.

Net Energy Output

Mechanical RDF production processes have no energy output on their own. The energy output is a result of combustion or gasification of RDF at an offsite facility. Net electrical output from RDF combustion is generally around 500 kWh per tonne of RDF processed.

Cost Factors

If an RDF utilization site is available, a mechanical RDF production plant can potentially have a relatively low cost in relation to other new and emerging technologies. The cost of utilization of the RDF, however, will increase overall costs and is dependent on the thermal energy conversion technology used.

Public Acceptability of Technology

Physical waste processing technologies are generally acceptable to the public, as there are no significant air emissions issues. The important hurdle is the site at which the RDF is to be utilized, as it will likely encounter significant public opposition.

3. Biological Processes

Biological processes are those involving bacteria and other microorganisms that convert organic components of the waste stream into more benign and useful products. The biological processes consist of three general categories:

- aerobic composting;
- anaerobic digestion; and
- ethanol fermentation.

As noted in the introduction, aerobic composting and anaerobic digestion are well established and understood. They have been discussed previously in the Phase 2 Report of September 2003. Therefore, only ethanol fermentation and its implications are discussed below.

Technology Summary

Ethanol fermentation is a biological process, in which organic material is converted by acid hydrolysis to simpler compounds, such as sugars. These fermentable compounds are then fermented by yeast to produce alcohol (ethanol) and carbon dioxide, the ethanol is then concentrated via distillation, purified and/or mixed with petroleum to produce vehicle fuel.

The main components of the waste stream that can be converted by fermentation are food wastes, some yard wastes such as leaves and grasses, animal wastes and paper fibres. Materials that are biodegradable but not converted to a significant extent by most fermentation processes under normal operating conditions include wood wastes, bones and laminated paper. Non-biodegradable materials that cannot be fermented include plastics, glass, metals and textiles.

Key components of an integrated residual waste treatment system based on ethanol fermentation are:

- Initial removal of large and unsuitable items
- Recyclable materials recovery and removal of contaminants via mechanical pre-processing
- Initial hydrolysis process (conversion to simpler compounds)
- Fermentation of organics
- Post-fermentation purification of ethanol (by distillation or filtration)
- Gasification of solid residuals (to provide process heat)
- Treatment and disposal of wastewater

Fermentation technologies use an initial tip floor removal of large or unsuitable materials, followed by mechanical pre-processing to remove recyclables and contaminants, and shredding of the material.

The material is then processed through vessels using various processes for the purpose of hydrolysing (breaking down to simpler compounds) the material. This may include high temperature, acid treatment and/or high pressure, depending on the technology. Following the initial hydrolysis phase, the slurried material is then fermented to produce alcohol, which is then purified through distillation and/or filtration to produce the desired fuel-grade quality ethanol.

Ethanol fermentation is effective primarily on cellulose and lignin based wastes (i.e., organics and fibres). Like other biological processes, ethanol fermentation is not effective in converting the non-biodegradable components of the waste stream. Physical separation before and/or after biological processing is required to recover and divert other materials.

The diagram on the following page gives a general process flow for ethanol fermentation in comparison to other biological processing technologies.

Diversion from Landfill

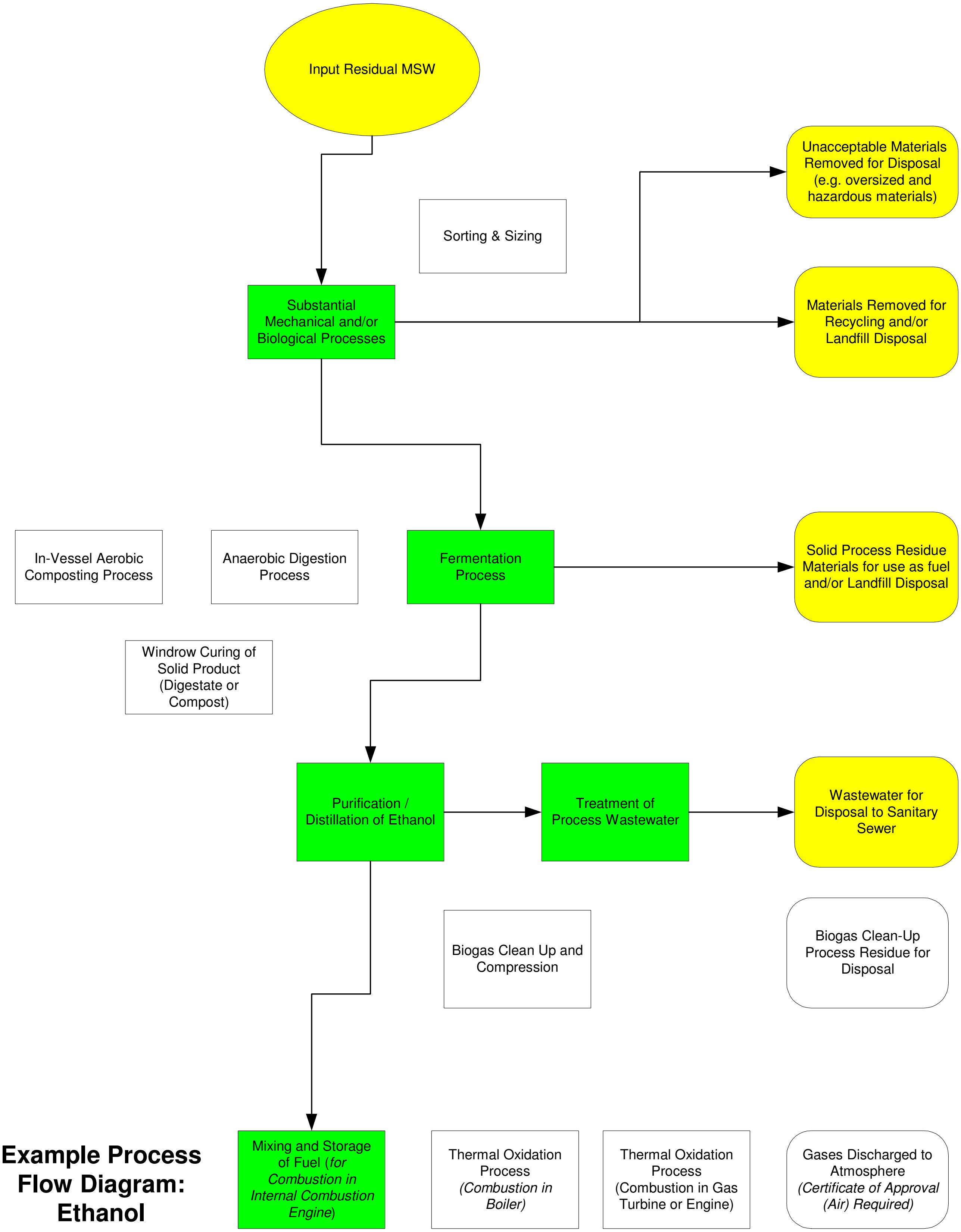
Ethanol fermentation using pure grain feedstocks is an established process. However, its application for the processing of MSW is new and has not been proven beyond demonstration scale. Therefore it is uncertain which components of the waste stream can be successfully processed. It is known that since ethanol fermentation is a biological process, it can process only biodegradable components of the waste stream: organics (including food and yard waste) and paper fibres. Diapers and sanitary products are examples of other materials that can be processed by composting and anaerobic digestion; it may be possible to process these by fermentation as well but little information is available on the fermentation of these components. The suitability of fermentation, like all biological processes, depends on the waste stream to be processed. Waste streams that are high in biodegradable and cellulosic components and low in non-biodegradable components are most suitable for processing by fermentation. Waste streams with a high proportion of non-biodegradable fractions are less suited for processing by fermentation.

Some plastics, glass and metals could be recovered through front-end processing (i.e., a dirty MRF). The marketability of recyclables recovered from a mixed-waste stream in a dirty MRF is generally poorer than that of recyclables from a source-separation program.

As the fermentation process acts only on the liquid stream, there would be a significant quantity of residual solids. Some technologies recycle the solids back to the first hydrolysis stage to convert more to liquids. One technology proposes gasification of the solid residuals to provide heat for earlier stages of the system.

The intended product is a fuel-grade ethanol. Adding ethanol to gasoline is an environmentally friendly way of increasing the octane rating of gasoline. There is clearly a demand for transport fuel in Ontario, but it is unknown whether the product from an MSW fermentation process would be accepted into this market at an economically viable price.

Due to the newness of the technology and the lack of mass balance information, no estimate can be made regarding the amount of diversion that will result from this type of technology. It is expected that ethanol fermentation may have a landfill diversion potential that is similar to or possibly better than the other biological processing technologies (i.e. no low grade compost to try and market).



Example Process Flow Diagram: Ethanol Fermentation Facility

Emissions

Air Emissions

Ethanol fermentation technologies may need to mitigate odour in waste receipt areas and biological processing areas. Negative pressure in the buildings with venting through a biofilter is required.

Some ethanol fermentation technologies have a gasification and combustion component for the solid residuals, as noted previously. The air emissions from the syngas combustion would need to meet Ontario regulations, including Guideline A-7.

Ethanol fermentation has a positive impact with respect to greenhouse gas emissions. The process would generate emissions of CO_2, which is intended to be captured and sold. Although there is no direct energy generation in the system, the conversion of the waste to ethanol fuel stores the energy in chemical form, for later use in a vehicle engine. This has the dual function of recovering energy from the waste and displacing the use of fossil fuels that would have been necessary to produce the equivalent amount of energy.

Wastewater Discharge

Ethanol fermentation takes place in the liquid phase, using most of the water in the waste. The purification processes would leave a significant portion of this liquid as wastewater.

As fermentation of mixed wastes has not yet been carried out beyond demonstration scale, very little is known about the character of the wastewater that would be produced. Since it is a result of processing of organics, it is expected that it would generally be high in nutrients (phosphorus, nitrogen) and suspended solids, and may exceed the local sewer use by-law standards for these parameters. The wastewater requirements may be dealt with by including payment of a municipal sewer surcharge as part of operating costs, or installing wastewater treatment components such as clarifiers and aeration tanks.

Solid Residue

Very little information is available on the character of solid residues. It is expected that they would need to be landfilled. Technologies that gasify the solid residuals would have ash resulting from the thermal process, which would likely need to be landfilled.

Commercial Status

All of the fermentation technologies are at an early stage of commercialization. None has a commercial scale plant that is currently operating. One company installed and operated its equipment for a 4-month test period at a cellulose-to-alcohol facility owned by the Tennessee Valley Authority. There is a full-scale MSW fermentation plant under development in Middletown NY, but its construction has not yet commenced.

Energy Output

The energy output from the ethanol fermentation technologies is in the form of ethanol fuel, which is blended with gasoline for use in a vehicle engine. Due to ethanol's high oxygen content, gasoline-ethanol blends have more complete combustion than gasoline alone, which reduces exhaust levels of carbon dioxide and smog precursors. Ethanol has less energy per litre than gasoline, but has a higher octane level, which can improve fuel economy in automobile engines that are designed to take advantage of the higher octane level.

Cost Factors

The relative cost of ethanol fermentation of MSW is unknown, due to the lack of operating data and the fact that minimal information is available.

Factors influencing costs are:

- Facility capital and operating costs
- Marketability and value of ethanol fuel.
- Solid residuals. If a use or market were found for residuals from the system, this would decrease costs. It is expected that solid residuals would most likely need to be landfilled.
- Recyclables. Prevailing rates for metals will dictate revenues from this source.

Public Acceptability of Technology

Ethanol fermentation of MSW is unknown to most of the general public, although the use of fermentation to produce alcohol from grain feedstocks is well established and known almost universally. Since the process itself is well established and familiar, using microorganisms to carry out processes that occur in nature, it is expected that it would be perceived positively by the public. Until the technology is introduced, however, public response cannot be predicted with certainty.

4. Thermal Processes

This section summarizes the advanced thermal technologies available for residual waste processing. There are a number of different types of processing technologies, which are listed below:

- Fixed bed Gasification
- Fluidized Bed Gasification
- High Temperature Gasification
- Plasma Arc Gasification
- Pyrolysis

All of these technologies can be categorized as a form of gasification, or as pyrolysis generally followed by thermal oxidation. The individual advanced thermal technologies are described in Appendix A.

The following is a summary of the advanced thermal systems technologies as a group, and the points noted below generally apply to all of the technologies in this category, although there may be exceptions.

Technology Summary

Advanced thermal systems (gasification and/or pyrolysis) involve the thermal breakdown of solid materials into a gaseous constituent (syngas), a solid char residue, and in the case of pyrolysis, a liquid constituent. The process of converting carbon-containing materials into combustible gas is endothermic, i.e. requires external energy. This process energy is either provided by allowing a very limited amount of the volatiles in the feedstock to combust in the reactor (gasification), or heat is added from external sources in the absence of oxygen (pyrolysis). The effect is the same: volatiles in the feedstock are converted to syngas, which may be used for a variety of purposes, such as fuel or as a chemical feedstock.

The following are key components of an integrated residual waste treatment system based on advanced thermal technology, and includes utilization of the products of the process:

- Sorting and sizing (in some cases extensive refuse derived fuel production)
- Recyclable materials recovery
- Thermal gasification/pyrolysis process to create synthesis gas (syngas)
- Syngas clean-up
- Thermal oxidation process of syngas
- Emissions treatment

Before gasification or pyrolysis can occur, solid waste is generally subjected to some form of preparation. Depending on individual thermal process requirements, this can range from coarse shredding and sorting, to elaborate front-end processing involving fine shredding, drying, recyclable material recovery and mechanical sorting to produce a homogeneous refuse derived fuel (RDF).

All components of typical municipal solid waste (MSW) can be fed into the system, but only the volatile fraction of the waste (for example food and yard waste, paper fibres, sanitary products, plastics, and wood) will be utilized. Advanced thermal systems appear well suited for the processing of post-diversion residuals feedstock, since they can process all but inert materials. They could also accept and process selected residuals from upstream composting and recycling operations.

Syngas consists primarily of carbon monoxide, hydrogen, carbon dioxide and nitrogen, and has a heating value of about one third that of natural gas. The heating value of the syngas can be enhanced by using oxygen-enriched process air. Syngas must generally be subjected to a cleaning process before it is utilized for the generation of heat. After cleaning, syngas can be used as fuel for reciprocating engines or gas turbines, or it can be combusted in a steam boiler to generate steam under utility conditions (with good combustion control) the same way that natural gas is used. Syngas can also be used as a feedstock for the synthesis of chemical compounds.

The solid residue exiting an advanced thermal process is generally inert. Portions can be recycled (e.g. metals) but the majority of this material generally requires landfilling. Some technologies offer a vitrification process that melts the residual inerts into a glass-like slag, which could be used as construction aggregate (if it is accepted by the market place).

Diversion from Landfill

Many advanced thermal processes that produce syngas require a clean homogeneous feedstock, and metals and other inerts are removed to the extent practical and necessary at the beginning of the process. In some cases, they are recovered at the end of the process. Metals are generally recycled. Inert materials, such as glass, ceramics, and grit are either landfilled, or vitrified (in which case it is assumed that these can be recycled as construction aggregate).

Most technologies involve utilization of the syngas on-site for the generation of heat and electricity.

System residuals requiring landfill disposal include rejects from front-end processing, by-products from the syngas and/or flue gas cleaning process, and process inerts (if not vitrified). Conservatively assuming that the front-end rejects, gas cleaning by-products, and end-of-process inerts would be landfilled, then a diversion from landfill of about 70% could be achieved. If most of the inerts could be utilized and included in the vitrified slag, then up to 95% of the incoming waste could be diverted (by weight). Residue from thermal processes generally has a higher density than unprocessed MSW. If diversion were considered on a landfill volume basis, rather than a weight basis, then the diversion rate provided by these technologies would be considerably higher.

Fate of Contaminants

The fate of specific contaminants depends on the feedstock, the process temperature, and the type of pollution control equipment used. Emissions, effluents and residues would be made to meet applicable Ontario regulatory standards. The following are general comments on common contaminants of concern:

- Heavy metals. Depending on the temperature of the gasification process, low boiling point metal compounds will vapourize and become entrained in the syngas. Typical metals found in syngas include mercury, cadmium and lead. These must be removed by downstream gas scrubbing equipment, either before or after syngas combustion, or both. Technologies for the removal of heavy metals from gases are well established and proven.
- Volatile organic contaminants. These contaminants will be contained in the syngas, and will be broken down during the syngas combustion process, where heat reduces them to carbon dioxide and water, the same as in the combustion of any other organic material. Some ultra high temperature thermal processes will destroy these contaminants during the gasification stage.
- Dioxins and Furans. The formation of dioxins and furans will be minimized because of the reducing conditions of the gasification process. If any of these species of contaminants do form, the majority can be removed downstream using conventional air pollution control equipment.
- Acidic gases. Acidic gases may form during the gasification process, and need to be dealt with during the syngas cleaning process. This involves applying neutralizing chemistry, which is well understood.
- Oxides of Nitrogen (NO_x). NO_x is unlikely to be formed in the reducing conditions of the gasification process. NO_x may appear during the combustion of the syngas and could be abated in the same way as in the combustion of other fuels.
- Carbon Monoxide (CO). The formation of CO during the gasification process is desirable, since CO is an essential burnable component of syngas. During combustion of the syngas, the CO must be fully converted to CO^2, as in any good combustion process.

Emissions

Air Emissions

The production and use of syngas results in a single air emission stream. Generally, raw syngas contains a number of contaminants, and treatment needs depend on the final application. If the syngas is to be combusted in reciprocating engines or turbines, then an extensive cleaning process is required to remove harmful particulates, tars and other contaminants that could damage the engines or turbines. If the syngas is directly fired in a boiler for steam production, then very little, if any, pre-combustion cleaning of the syngas needs to be done.

If the syngas is combusted in a steam boiler to generate steam under utility conditions, there is a need for post boiler air pollution controls, the extent of which depends on how well the syngas has been treated/cleaned before being burned in the boiler. Most providers of advanced thermal processes have indicated that air emissions from their systems would meet Ontario Regulations including Guideline A-7.

Compared to disposal of residual wastes at a landfill without landfill gas recovery, applying gasification or pyrolysis would likely result in a net reduction of greenhouse gas (GHG) emissions. If the receiving landfill has extensive landfill gas recovery, using gasification to generate power would still have the advantage of offsetting fossil fuel use (and associated greenhouse gases) from traditional coal fired power plants. If syngas is converted into chemical products that are not combusted, then additional GHG credits might accrue. This requires further investigation.

Wastewater Discharge

Wastewater emissions are only likely if some form of water cooling or scrubbing is proposed. Typical systems could consist of wet quenching to cool hot gases by spraying water into the gas, and condensing the water out at a later stage in the process. Wet scrubbing typically involves passing the cooled gases through a series of water trays or sprays to remove certain target contaminants. These are conventional technologies, and wastewater discharges are generally treated to meet local sewer use by-laws.

Solid Residue

Solid residue can be produced from several sources:

- Pre-gasification processing. All systems require some degree of up-front processing to prepare the feedstock for gasification. Residue from this process can be undesirable materials such as hazardous wastes (which would have to be disposed at an appropriate facility), recyclables such as metals, and inerts that generally require landfilling.
- Char coming from the gasification or pyrolysis process. Most processes landfill the char because the remaining energy in the char is not economically recoverable. If the char and residual inerts are vitrified, all remaining carbon is consumed, and the vitrified slag is assumed recyclable.
- By-products from gas treatment. This material will usually be landfilled. Some stabilization may be required in order to make the material acceptable for disposal at sanitary landfills designed for MSW.

Commercial Status

The commercial status of the thermal technologies attempting to enter the Ontario market ranges from pre-bench scale to commercial scale. Additional information is discussed in Appendix A.

There appear to be no advanced thermal technologies operating with MSW on a commercial scale in North America. Most of the full scale operating facilities are located in Japan and Europe.

Net Energy Output

Gasification and pyrolysis focus on the conversion of the energy contained in a solid material into a gas. In most cases the syngas is combusted to produce electricity. Typically, a portion of the heat and power are used for the process, and the balance is sold to the grid.

Net power output depends on the overall design; some supplier claims appear very optimistic and would need to be verified. Facilities that combust the syngas to produce steam and electricity can generally be expected to produce about 500kWh of net power to the grid for each tonne of solid waste processed. This is in a similar range to that recovered from mass burn energy-from-waste (EFW) facilities. Efficiencies can be increased if the waste heat from the system is used for district heating or other purposes (cogeneration). On the other hand, processes with high internal energy use, such as ash vitrification, yield significantly less net energy output.

Cost Factors

Existing gasification and pyrolysis facilities for municipal solid wastes are known to have capital and operating costs that are higher, or at least as high as more traditional mass burn energy from waste systems. Overall costs are expected to be in excess of $100 per tonne. High temperature and plasma-based systems could cost in excess of $300 per tonne. Factors influencing costs are:

- System complexity. Whereas mass burn systems utilize an integrated concept for combustion and energy recovery, gasification and pyrolysis systems consist of several distinctly separate processes, i.e. materials preparation, gasification/pyrolysis, syngas cleaning, syngas utilization. More pieces of equipment translate into higher costs.
- Process efficiency. The thermal efficiency of the process may suffer if the syngas has to be cooled/quenched for cleaning before it is utilized in a boiler.
- Residuals. If carbon-bearing char is not utilized, energy is lost to landfill. If char is utilized, the system complexity increases.
- Front end processing. Technologies that require a high level of waste preparation before the gasification process have higher capital and operating costs associated with this step.
- Value of products. If power is recognized as “Green” it can possibly be sold at a premium rate via the public grid.
- Cogeneration. If markets for low-grade heat are situated nearby, this would provide an additional revenue source.
- Recyclables. Prevailing rates for metals will dictate revenues from this source.

Public Acceptability of Technology

Advanced thermal systems using gasification and/or pyrolysis are almost unknown to the general public. Although the technologies have been available for many decades, they have rarely been applied to MSW because of their complexity and costs.

The attraction of advanced thermal systems is that they can recover the energy from the waste stream without directly burning the MSW. Technically, they are distinct from old incineration technology.

The visual appearance and acceptance will vary, depending on the use of syngas proposed. If the syngas is cleaned and then used for combustion in reciprocating engines or a combined cycle power plant to make electricity, then this would give the facility the appearance of a chemical plant combined with an energy producing facility.

Where the syngas is combusted in a boiler to make steam, systems can look very much like mass burn EFW facilities, since there would be the same type of waste receipt structure at the front end, and similar air pollution controls at the back end of the system. Most importantly, these systems would have an emissions stack, which many people associate with conventional combustion.

5. Chemical Processes

Chemical technologies are the last general category of new and emerging technologies for waste processing. These involve a combination of physical, chemical and/or thermal processes to convert the feedstock into a saleable energy or construction product. None of the chemical processes are proven beyond the bench scale and relatively little information is available for any of them. The main difference from the thermal processes is that while energy recovery is the main focus for thermal processes, the chemical processes below are focused on creating chemicals or other products. The processes and their intended products are as follows.

- Hydrogen reformation and catalytic convertion to produce ethanol
- Advanced thermal treatment process to produce industrial chemicals and fuels
- Acid hydrolysis to produce industrial chemicals

Technology Summary

Chemical processes involve the chemical processing of solid waste materials into a gas, liquid and/or new solid. The gas and liquid product enters into a second chemical process to create a final usable output product.

An overview of the key common components of these integrated residual waste treatment systems based on chemical processes are:

- Sorting and sizing (in most cases)
- Recyclable materials recovery
- Creation of gas, liquid and/or solid to be processed
- Sterilization or cleaning of output product
- Emissions treatment
- Wastewater treatment and disposal
- Odour control

The following are brief descriptions of some of these technologies.

Hydrogen Reforming and Catalytic Conversion

One chemical technology produces gas as a result of shredded, screened waste entering into a hydrogen reformer, which results in the production of a syngas. Little information is available on the technology for this process. The produced gas is cleaned and enters into a catalytic converter to produce heat or ethanol. The solid residues require disposal.

Thermal Cracking to Produce Chemicals and Fuels

Organics are the target feedstock for the process to produce fuel. The incoming waste is slurried, heated under pressure, and then flash cooled to a lower temperature and pressure to release gaseous products. The flashed liquid is then separated by density in a liquid separator where the high value oil is extracted and sent for further refinement in a post-processing loop. The slurry is re-heated to drive off water and light oils from the solids. The light oils are separated from the water and sent to a high temperature cooker that cracks them into high value industrial chemicals and fuels.

Acid Hydrolysis

The incoming residual mixed waste stream is first processed to separate the organic biomass material from the other components of the waste stream. Some of these other components can be recycled while the balance of the inorganic residue material is landfilled.

The remaining organic material is processed via acid hydrolysis to produce chemical products. These chemical products that can be marketed include furfural, formic acid and levulinic acid. Additional processing is required to recover the acid for re-use in the hydrolysis process and to clean up the wastewater discharge stream.

Implications

Due to the newness of these technologies and the lack of information available for any of them, it is not possible to make an evaluation of landfill diversion, emissions, energy output, cost factors or public acceptability of the technologies. As none of the technologies are proven beyond a bench scale, none of these chemical technologies are expected to be a major factor in managing waste in the near future.

Appendix A - Thermal Process Details

AI Fixed Bed Gasification

Technology Summary

Fixed bed gasification involves the thermal conversion of solid materials into a gaseous constituent (syngas), and a solid char residue. The process takes place in a gasifier with a fixed bed, where the waste flows through the gasifier by gravity (vertical fixed bed) or is moved by transfer rams (horizontal fixed bed). Gasification is a process of partial combustion in which the material is deliberately combusted with less than stoichiometric air. The heat from this combustion is used to sustain the generation of combustible gases by endothermic reactions. These gasification reactions convert the remainder of the volatiles in the feedstock to syngas (primarily CO and H_2), which may be used for a variety of purposes, such as fuel and chemical feedstock.

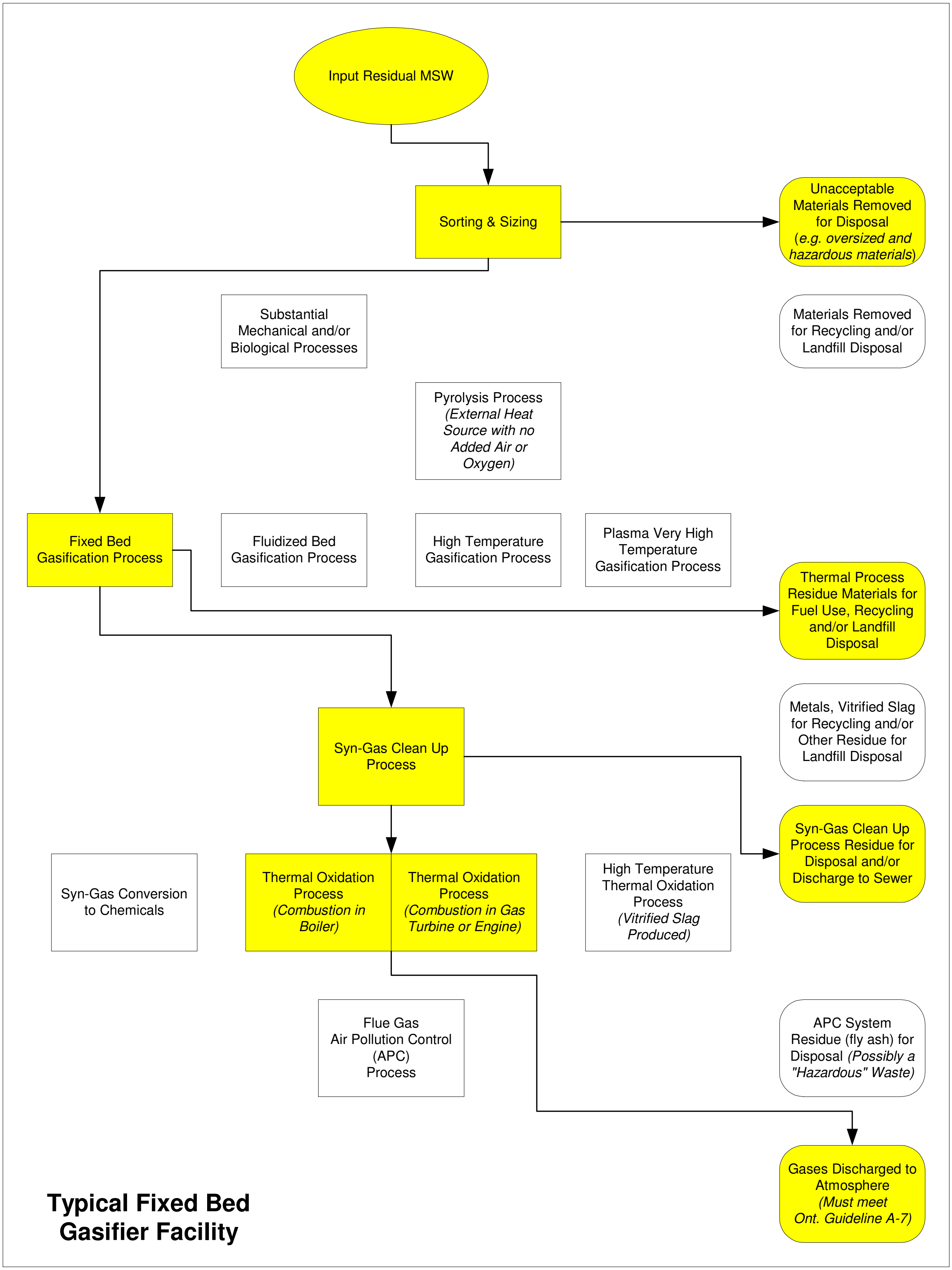
Most fixed bed gasification systems work with minimal pre-processing.

A flow diagram of the process is shown on the following page.

Commercial Status

The commercial status of the different fixed bed gasification technologies ranges from pre-bench scale to demonstration scale.

Worldwide, there are very few commercially operating fixed bed gasification facilities for municipal solid wastes, and there are none in North America. The main reasons are market economics, environmental legislation, and government support. The only verifiable facility among the fixed bed gasification technologies is a demonstration facility in Australia.



Typical Fixed Bed Gasifier Facility

A2 Fluidized Bed Gasification

Technology Summary

Incoming residual mixed waste requires extensive front end processing prior to fluidized bed gasification. This processing generally involves the production of a RDF as described in the preceding Section 2.

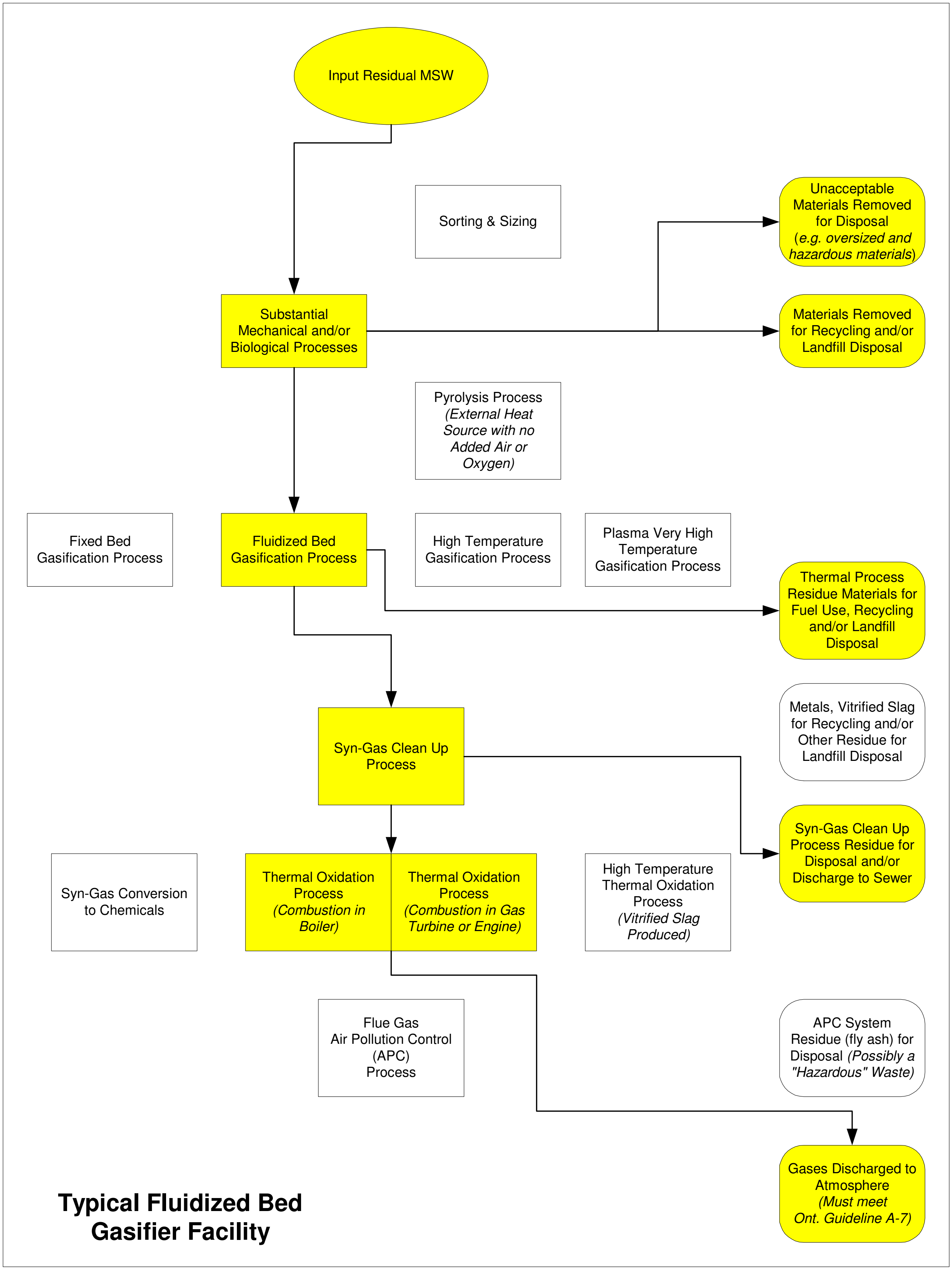
Fluidized bed gasification involves the thermal conversion of solid materials into a gaseous constituent (syngas), and a solid char residue on a fluidized bed, which is a layer of non-reactive sand particles in turbulent motion. The sand bed fluidizes and expands when air is forced into the bed from below, thus creating a highly turbulent motion or “boiling action”. Fluidized bed technology is well proven for incineration systems. When applied to gasification, it results in an efficient thermal process with good materials and process control.

A flow diagram of the process is shown on the following page.

Commercial Status

The commercial status of the different fluidized bed gasification technologies ranges from pre-bench scale to commercial scale.

Worldwide, there are only a few commercially operating fluidized bed gasification facilities for municipal solid wastes, and there are none in North America. The main reasons are market economics, environmental legislation, and government support. Most of the facilities are in Japan, with some in Europe. Commercial facilities utilizing fluidized bed gasification primarily process selected industrial wastes.



Typical Fluidized Bed Gasifier Facility

A3 High Temperature Gasification

Technology Summary

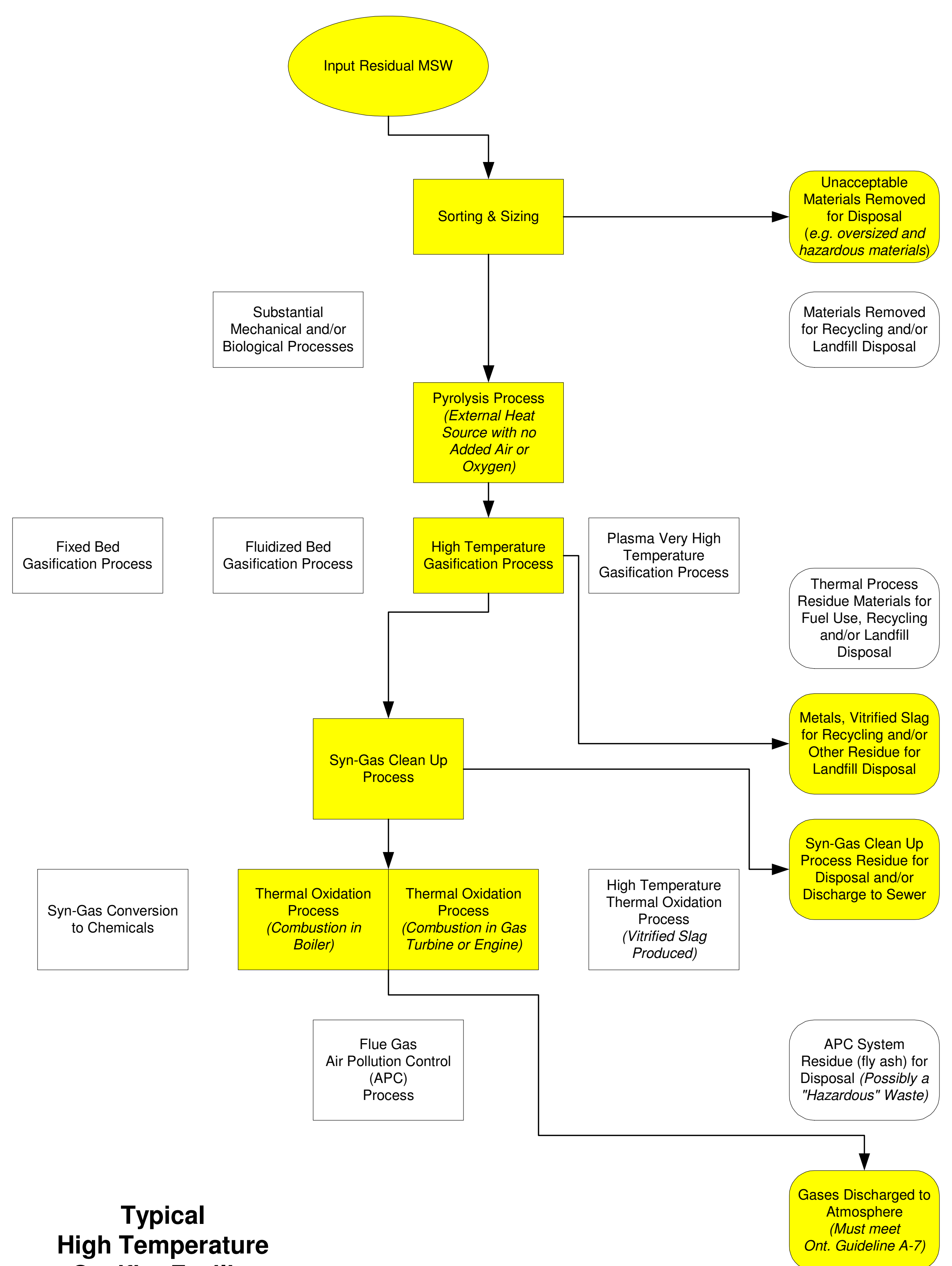
High temperature gasification involves the thermal breakdown of solid materials into a gaseous constituent (syngas), and a solid char residue. The process takes place at a temperature of over 1200°C, whereas fixed bed and fluidized bed gasification use temperatures of 1000°C or less. Like other forms of gasification, the required process heat (which is higher than that required for fixed bed or fluidized bed gasification) is taken from a limited combustion of the volatiles in the feedstock under sub-stoichiometric conditions in a reactor.

High temperature gasification has the advantage of producing a vitrified slag that should be easier to recycle into construction aggregate than non-vitrified solid residues from lower temperature thermal processes. A flow diagram of the process is shown on the following page.

Commercial Status

The commercial status of the different gasification technologies ranges from pre-bench scale to commercial scale.

Worldwide, there are only a few commercially operating high temperature gasification facilities for municipal solid wastes, and there are none in North America. The main reasons are market economics, environmental legislation, and government support. Most of the facilities are in Japan and Europe.



**Typical
High Temperature
Gasifier Facility**

A4 Plasma Arc Gasification

Technology Summary

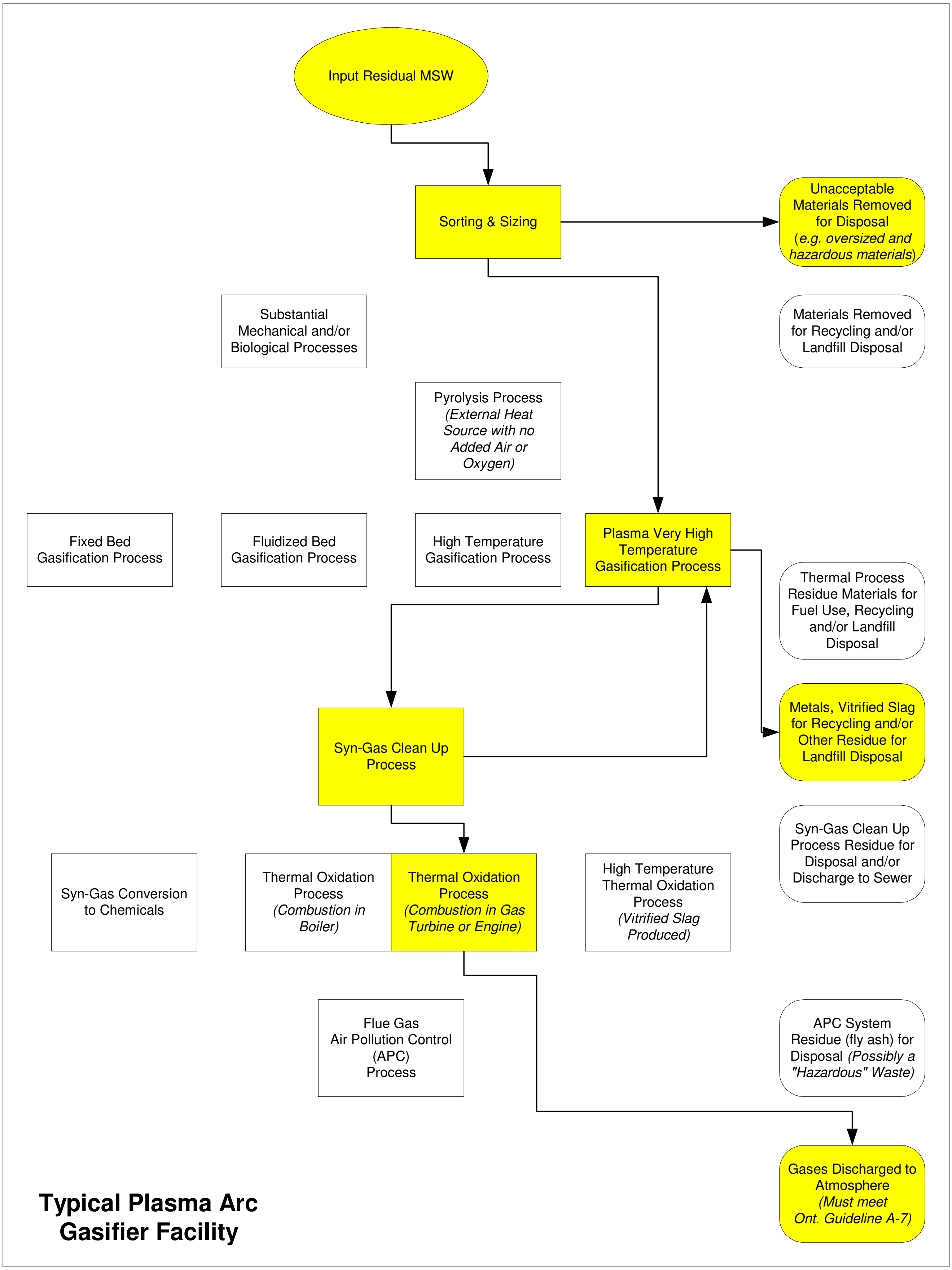
Plasma arc gasification involves the thermal breakdown of solid materials into a gaseous constituent (syngas), and a solid char residue. The energy for the gasification process is provided by an electrical arc generating very high process temperatures (up to 8000°C), which converts volatiles in the feedstock to syngas.

Plasma arc gasification also produces a vitrified slag that should be easier to recycle into construction aggregate than non-vitrified solid residues from lower temperature thermal processes. A flow diagram of the process is provided on the following page.

Commercial Status

The commercial status of the different plasma arc gasification technologies ranges from pre-bench scale to commercial scale.

Worldwide, there are only a few commercially operating plasma arc gasification facilities for municipal solid wastes, which all appear to be in Japan. There are none in North America.



Typical Plasma Arc Gasifier Facility

A5 Pyrolysis

Technology Summary

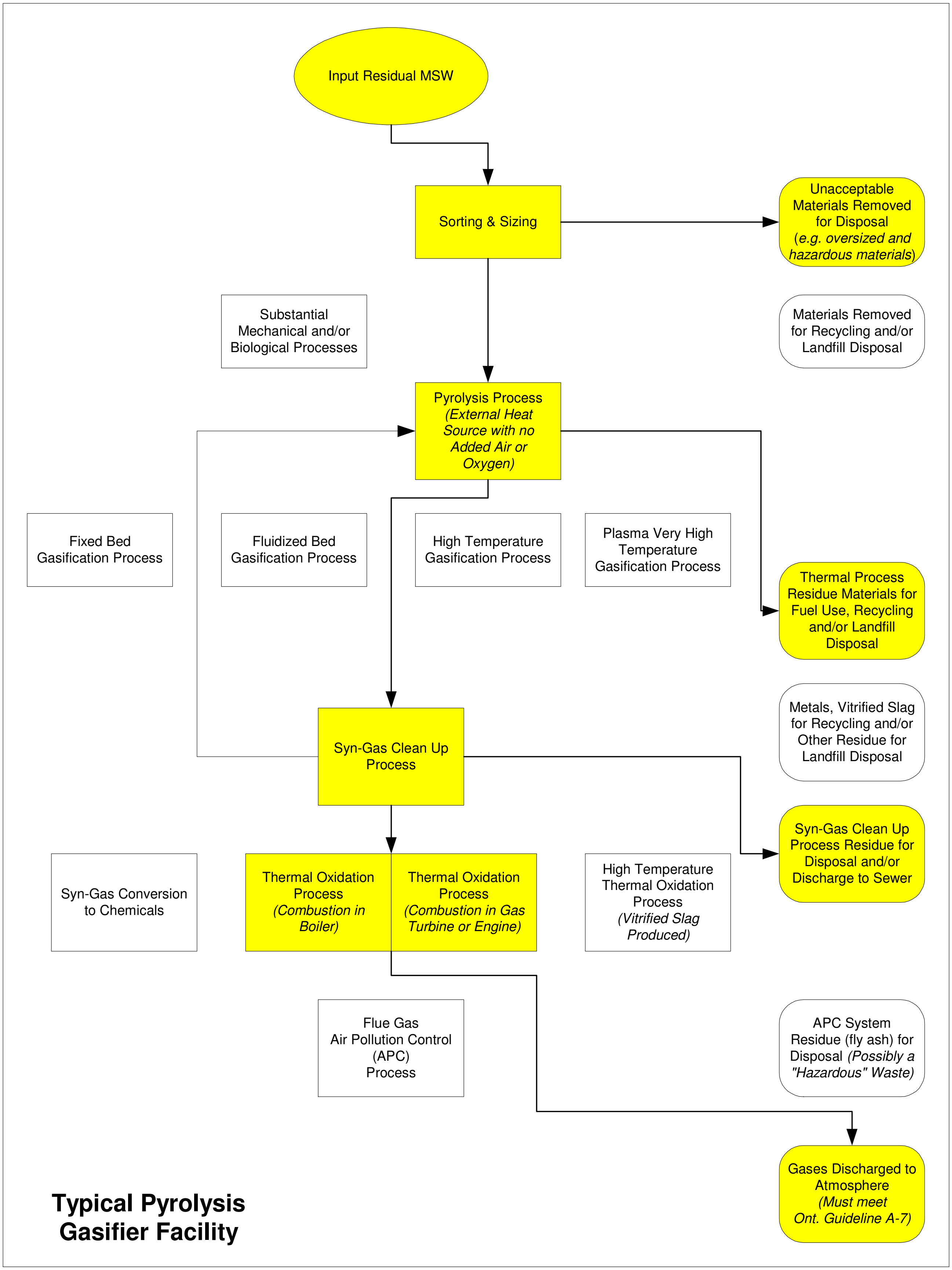
Like gasification, pyrolysis involves the thermal breakdown of solid materials into gaseous, liquid and solid materials. The difference between gasification and pyrolysis is that pyrolysis does not involve limited combustion, but instead uses an external heat source to heat the reaction chamber in the absence of oxygen.

A flow diagram of the process is shown on the following page.

Commercial Status

The commercial status of the different pyrolysis technologies ranges from pre-bench scale to fully commercial.

Worldwide, there are very few commercially operating pyrolysis facilities for municipal solid wastes, and there are none in North America. The main reasons are market economics, environmental legislation, and government support. The oldest operating pyrolysis system is in Germany, where landfill fees are high, and the German Federal and State governments paid the capital costs for the facility, which was built for research purposes.



Typical Pyrolysis Gasifier Facility