MUNICIPAL SOLID WASTE TO ENERGY CONVERSION PROCESSES

Economic, Technical, and Renewable Comparisons

GARY C. YOUNG

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PREFACE

In the many years of practicing engineering as a profession from research and development to commercial plant operations, I observed over time that many good ideas never came to fruition. The good ideas were typically blocked by those who did not understand the technology behind the good idea and/or by those ideas supported by others with vested interests or agendas. Thus, the quotation presented here keeps the true professional aware of potential roadblocks in order to be successful.

> "*Show me an agenda and it likely will lead you astray.*
> *Give me technology and it will lead you to prosperity.*"

In all my professional work experiences from research and development, process development and design, construction, start-up and operation of commercial plant operations, and waste management always played a role in the final outcome of a plant's commercial profitability. My exposure, interest, and professional knowledge in gasification of hydrocarbons began in the late 1960s while working in the energy industry. When my exposure to plasma gasification technology began in the early 2000s from listening to a seminar by Dr. Circeo, the practical process benefits of plasma gasification technology for the management of wastes became apparent and caught my professional interest. After several years of further scientific inquiry into plasma technology, it became obvious that a proven technology was available to manage a wide variety of solid wastes, such as municipal solid waste (MSW), to produce energy and valuable recyclable by-products with essentially no wastes. Further economic assessment of the plasma gasification process on MSW indicated a proven process of commercial viability.

Thus, this book was undertaken to inform the public, teachers, professors, public officials, city, state, federal governments, businessmen, and businesswomen on how the proven plasma gasification technology can be used to manage MSW and generate energy and revenues for local communities in an environmentally safe manner with essentially no wastes. Furthermore, currently generated MSW can be processed with this proven plasma gasification technology to eliminate air and water pollution from landfills. It is my professional hope that this proven and economic plasma gasification technology for the management of MSW will be understood and embraced by the reader so as to lead to prosperity.

PROFESSIONAL BIOGRAPHY

Dr. Gary C. Young, Ph.D., P.E., is a knowledgeable professional in research, development, economic assessment, and commercialization of industrial processes. Dr. Young has over 40+ years of industrial experience in processes involving energy, food, agricultural, chemical, and pharmaceutical businesses. He has done consulting in areas of research and development, troubleshooting plant operations and process bottlenecks, maintenance, engineering, and environmental challenges. Dr. Young has successfully commercialized new processes from the laboratory to process development, engineering, procurement, construction, training, and start-up with final management of the production operation. Furthermore, a new agricultural herbicide process was successfully completed from the laboratory to full-scale commercialization without the need for a pilot plant. Dr. Young is the inventor of many patents. He has work experiences with CONOCO, Stauffer Chemical Company, Beatrice Foods Company, Monsanto Company, and Carus Chemical Company.

Current "technical and commercial economic" interests are with the conversion of "waste solids to energy" such as electricity and fuels. In addition, Dr. Young recently developed a novel thermal process for converting carbon dioxide (CO_2) from a gaseous stream into energy and fuels.

Dr. Young holds B.S., M.S., and Ph.D. degrees in Chemical Engineering from the University of Nebraska. He is a licensed professional engineer in the states of California, Texas, Illinois, Iowa, and Wisconsin. Dr. Young is the founder and owner of Bio-Thermal-Energy, Inc. (B-T-E, Inc.).

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CHAPTER 1

Introduction to Gasification/Pyrolysis and Combustion Technology(s)

HISTORICAL BACKGROUND AND PERSPECTIVE

Archeological studies demonstrate that Trash-Garbage-Waste was generated by Native Americans in Colorado about 6,500 BC in North America. Based upon archeological assessment of the waste site, the Native Americans in that ancient clan generated 5.3 pounds of waste per day as compared to 2.5 pounds per day for middle-class Americans today. The first municipal dump in the Western world is credited to the Athenians of Greece about 500 BC. In Jerusalem/Palestine, the New Testament of The Bible mentions Sheol was likely a dump outside the city of Jerusalem and became synonymous with "Hell." In 1388, the English parliament barred waste disposal in public waterways and ditches. Recycling was mentioned in 1690 when Rittenhouse Mill, Philadelphia, made paper from recycled fibers of waste paper and rags. In Nottingham, England about 1874, a new technology known as "the Destructor" was used to manage garbage; it involved systematic burning, i.e., incineration. The first garbage incinerator was built in the United States on Governor's Island, New York about 1885. It was reported in 1889 around Washington, D.C., that there was lack of places for refuse. Also, the first recycling/sorting of rubbish in the United States occurred in New York around 1898.[1]

Landfills became popular in the 1920s as a means of reclaiming swampland while disposing of trash. Then in 1965, the Federal government of the United States enacted the first Federal solid waste (SW) management laws. In 1976, the Resource Conservation and Recovery Act (RCRA) was created for stressing recycling and hazardous waste management, which likely was instigated by the discovery of Love Canal.[1]

This proves that since the creation of mankind, humans have generated waste. But waste disposal was not a problem when we had a nomadic existence; mankind simply moved away and left their waste behind. In addition, populations concentrating in urban areas necessitated better methods for management of waste. With the initiation of the industrial revolution, waste management became a critical issue. The

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population increase and migration of people to industrial towns and cities from rural areas resulted in a consequent increase in the domestic and industrial waste (IW), posing threat to human health and environmental issues of water quality, air pollution, and land toxicity issues. As the American population grew and people left the farms for life in the city, the amount of waste increased. But the method of getting rid of the waste needed to improve. We continue to dump it. Today, about 55% of our garbage is hauled off and buried in sanitary landfills.

Municipal solid waste (MSW) is garbage that comes from homes, businesses, and schools. Today, this garbage is disposed of in "municipal solid waste landfills" so the garbage does not harm the public health, or land, water, and air environment. MSW landfills are not dumps for the new landfills are required to have liners, leachate collection systems, gas collection equipment, groundwater monitoring, and environmental reporting requirements so as to protect the health and welfare of the community.

Our population is still growing and we are producing more garbage, even with the recycling efforts in full operation. We have come to the "place in time" where the momentum of TECHNOLOGY can help "protect human health and welfare," and thus the environment, by creating an infrastructure design, creation and building of sustainable MSW processes that can turn our WASTE PROBLEM into useful GREEN ENERGY for the betterment of ALL.

INTRODUCTION

The management/treatment of SWs by thermal pyrolysis/gasification technology is increasingly viewed as the best suitable and economically viable approach for the management of wastes such as: residential waste (RW), commercial waste (CW), IW, and MSW, which can be a mixture of these wastes. Various types of Thermal Processes using pyrolysis/gasification technology will be discussed and also why plasma arc gasification process was selected as most attractive for commercial viability.[2–4] The various types of thermal processes based upon pyrolysis/gasification technology are pyrolysis, pyrolysis/gasification, conventional gasification, and plasma arc gasification. One additional thermal process was also considered, which is based upon combustion technology and is known as mass burn (incineration). The key product from these thermal gasification technologies is the conversion of MSW into synthesis gas (syngas), which is predominantly carbon monoxide (CO) and hydrogen (H_2), which can be converted into energy (steam and/or electricity), other gases, fuels, and/or chemicals, and will be discussed in detail throughout this book.

One approach or option for the use of the key product from the conversion of MSW into syngas by a thermal process is for generation of steam and/or electricity in a powerhouse. This approach or "Power Option" will be discussed later in Chapters 2, 4, 5 and 7.

Another approach to the management of MSW is the "BioChemistry Option" (biochemical or biological technologies), which by necessity operates at conditions appropriate for living organisms/microbes. Consequently, the reaction rates are lower and these technologies require feedstock that is biodegradable. One, therefore, could conclude that these biochemical technologies have limitations for applicability for treating MSW compared to the thermal processes. Thermal processes are brute force chemical reaction approach to the management of MSW feedstock in comparison to the finesse of biochemical/biological reactions and consequent limitations of feedstock acceptance. However, the real niche for biochemical processes is to take the syngas (predominantly, CO and H_2), produced by a thermal process, and have the biochemical process (bacteria/microbes) convert the syngas into products such as fuels and chemicals, for example, ethanol, methanol, etc.[5,6] This approach or "BioChemistry Option" will be covered in Chapter 3 with a case study.

Another approach could be labeled the "Chemistry Option," which converts syngas into fuels and chemicals by catalytic chemistry. A catalyst that is used typically is called Fischer–Tropsch catalyst. Thus, a thermal process can be used to produce syngas from MSW and then convert the syngas into chemicals by Fischer–Tropsch chemistry. This "Chemistry Option" is also covered in Chapter 3 with a case study.

Lastly, one could consider landfill gas (LFG) as an approach, which involves the use of microorganisms to produce LFG *in situ* within the landfill. LFG is predominantly methane (CH_4) and carbon dioxide (CO_2) gas, i.e., approximately 50% CH_4 and CO_2. LFG is extracted from landfills with a system typically comprising gas collecting from wells at the landfill to a central point, a gas processing plant, and a gas delivery pipeline to customer(s). LFG could be used in a boiler, dryer, kiln, greenhouse, or other applications. A basic drawback of LFG facility is that the microorganisms producing the LFG leave behind *in situ* landfill leachate as a by-product of the microbiological process that can contaminate soil and groundwater. Even with the latest designs and use of liners in landfills, no LFG system is fail-safe. Another negative factor is that an LFG facility just depletes the energy value of the landfill wastes by using up the most easily biodegraded organics in the MSW. Thus, a lesser energy value of MSW remaining in the landfill after an LFG facility will make it more difficult economically to justify a future MSW management system to eliminate the landfill. In summary, an LFG process just skims off the energy leaving a degraded MSW mess behind to be dealt with later at a much greater cost to any future management system. Thus, this approach is not discussed further as a suitable approach both economically and environmentally.[7,8]

These basic approaches for the management of MSW are schematically shown in Fig. 1.1, whereby the options for the syngas are numerous.

Key Thermal Processes will be discussed next with emphasis upon the conversion of MSW to syngas and an assessment of each process with a thorough technical and economic analysis.

WHAT IS PYROLYSIS?

Pyrolysis can be defined as the thermal decomposition of carbon-based materials in an oxygen-deficient atmosphere using heat to produce syngas.[9] No air or oxygen is present and no direct burning takes place. The process is endothermic.

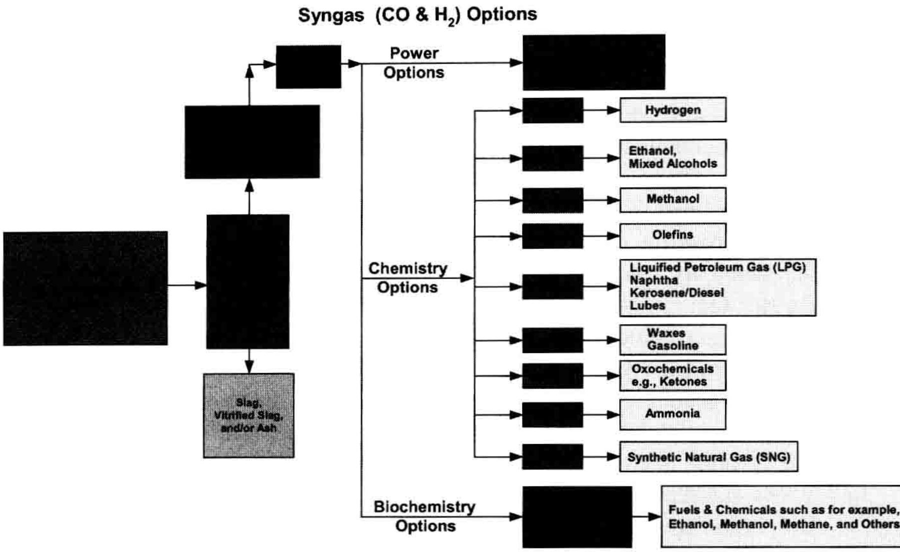

FIGURE 1.1 MSW to Energy, Gases, Fuels, and Chemicals.

Typically, most organic compounds are thermally unstable, and at high temperatures, the chemical bonds of organic molecules break, producing smaller molecules such as hydrocarbon gases and hydrogen gas. At high temperatures, the gaseous mixture produced comprises predominantly the thermodynamically stable small molecules of CO and H_2. This gaseous mixture of CO and H_2 is called "syngas." This latter stage of the thermal process is known as gasification.

A typical pyrolysis process is illustrated in Fig. 1.2.

As illustrated in Fig. 1.2, feedstock as MSW is preprocessed to remove profitable recyclables. Then the preprocessed material is fed into the pyrolysis reactor where an indirect source of heat elevates the contents to a temperature between 1,200 and 2,200°F to produce raw syngas overhead and a bottom ash, carbon char, and metals from the reactor. Some report the pyrolysis process to occur at a reactor temperature between 750 and 1,650°F.[9] The pyrolysis process occurs in an oxygen-deficient (starved) atmosphere.

The syngas cleanup step is designed to remove carry-over particulate matter from the reactor, sulfur, chlorides/acid gases (such as hydrochloric acid), and trace metals such as mercury.

Syngas is used in the power generation plant to produce energy, such as steam and electricity, for use in the process and export energy. The export energy is typically converted into electricity and supplied/sold to the grid.

The bottoms from the reactor are ash, carbon char, and metals. The carbon char and metals have use as recyclables in industry. However, the ash from the pyrolysis process is usually disposed of in a landfill, which is one of the major environmental shortcomings of the pyrolysis process when used for MSW management.

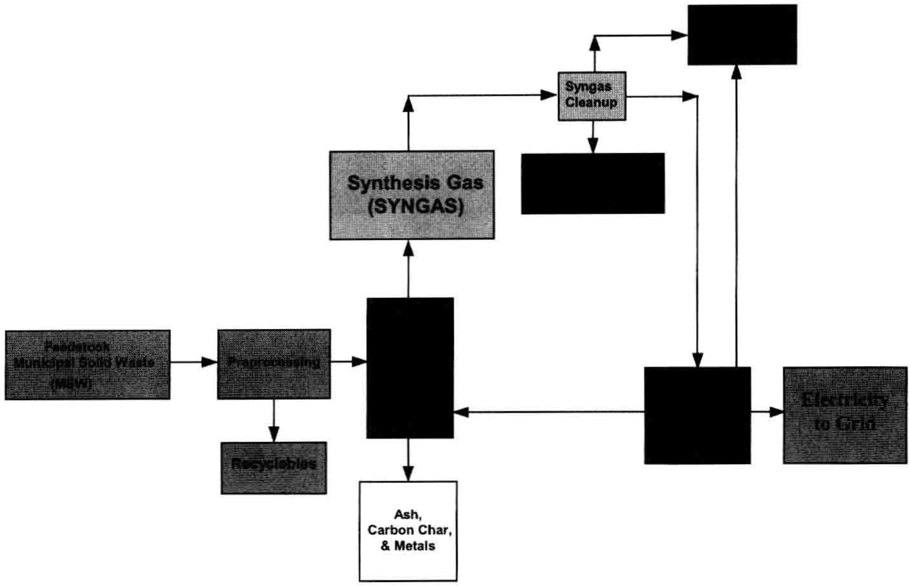

FIGURE 1.2 Process Schematic, MSW to Electricity via Pyrolysis.

WHAT IS PYROLYSIS/GASIFICATION?

Pyrolysis/gasification is a variation of the pyrolysis process. Another reactor is added whereby any carbon char or pyrolysis liquids produced from the initial pyrolysis step are further gasified in a close-coupled reactor, which may use air, oxygen, and/or steam for these gasification reactions. As shown in Fig. 1.3, a controlled amount of air/oxygen is fed into the pyrolysis/gasification reactor whereby some of the char and pyrolysis liquids react, i.e., there is combustion with oxygen. The combustion reactions (exothermic reactions) are controlled so as to supply sufficient heat for the pyrolysis reactions (endothermic reactions), yielding a temperature typically between 1,400 and 2,800°F. Sometimes the pyrolysis/gasifier conditions are stated as 750–1,650°F for the pyrolysis zone and 1,400–2,800°F for the gasification zone. In addition, steam is supplied to the reactor for the chemical reactions that yield CO and H_2.[9]

Pyrolysis/gasification reactor operates predominantly in an oxygen-starved environment, since the combustion reactions (exothermic reactions) quickly consume the oxygen producing heat sufficient for the pyrolysis reactions (endothermic reactions), resulting in a raw syngas exiting the reactor. The raw syngas is cleaned up of carry-over particulate matter from the reactor, sulfur, chlorides/acid gases (such as hydrochloric acid), and trace metals such as mercury. Syngas is used in the power generation plant to produce energy, such as steam and electricity, for use in the process and export energy. The export energy is typically converted into electricity and supplied/sold to the grid.

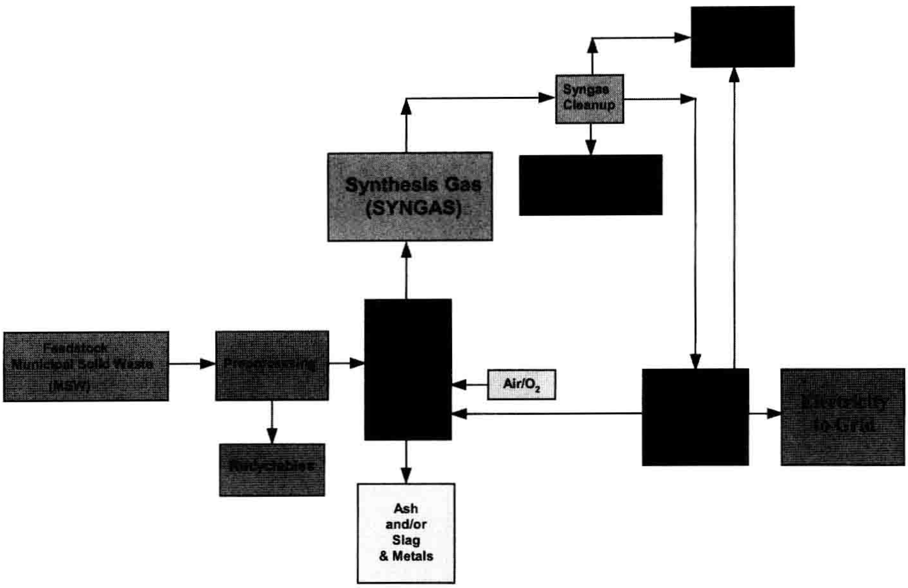

FIGURE 1.3 Process Schematic, MSW to Electricity via Pyrolysis/Gasification.

The bottoms from the reactor are typically ash, slag, and metals depending on the temperature of the pyrolysis/gasification reactor. The metals find use as recyclables in industry. However, the ash and/or slag is typically disposed of in a landfill, which is one of the major environmental shortcomings of the pyrolysis/gasification process when used for MSW management.

WHAT IS CONVENTIONAL GASIFICATION?

Conventional gasification is a thermal process, which converts carbonaceous materials, such as MSW, into syngas using a limited quantity of air or oxygen.

The conventional gasification conditions are sometimes between 1,450 and 3,000°F. Steam is injected into the conventional gasification reactor to promote CO and H_2 production.

For simplicity, some basic chemical reactions in the gasification process are:

$$C + O_2 \rightarrow CO_2 \tag{1.1}$$

$$C + H_2O \rightleftharpoons CO + H_2 \tag{1.2}$$

$$C + 2H_2 \rightleftharpoons CH_4 \tag{1.3}$$

$$C + CO_2 \rightleftharpoons 2CO \tag{1.4}$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \tag{1.5}$$

$$C_nH_m + nH_2O \rightleftharpoons nCO + (n + {}^{1}\!/\!_{2}m)H_2 \tag{1.6}$$

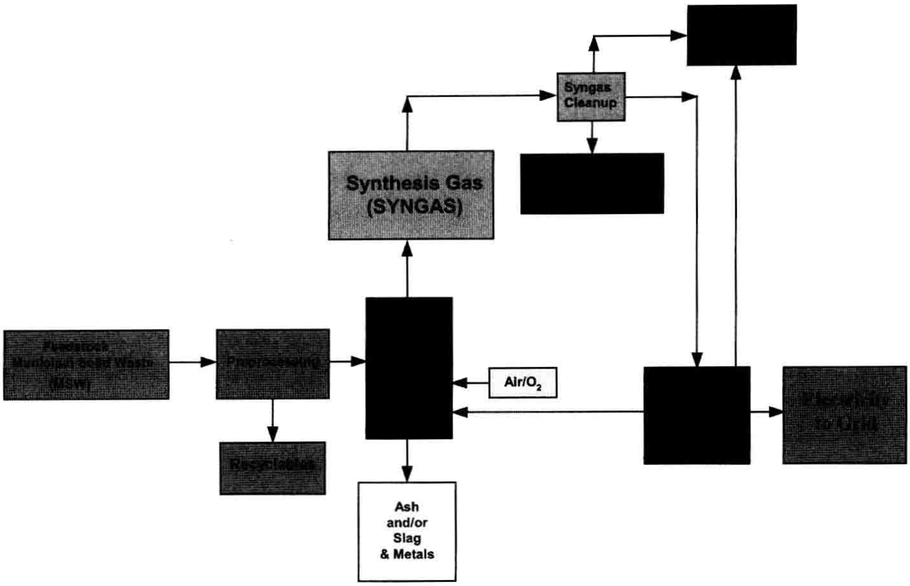

FIGURE 1.4 Process Schematic, MSW to Electricity via Conventional Gasification.

Thus, CO, H_2, and CH_4 are the basic components of the gasification process producing the gaseous mixture. Of these components, the gaseous mixture comprises predominantly of CO) and H_2. Equation (1.1) shows the carbonaceous components of the MSW as carbon (C) that reacts with oxygen (O_2) to produce limited combustion but with the necessary heat for the syngas reactions (Eqs. (1.2–1.5 and 1.6)).

Figure 1.4 illustrates a typical conventional gasification process. As shown, a controlled amount of air/oxygen is fed into the conventional gasification reactor whereby some feedstock material reacts, i.e., there is combustion with oxygen. The combustion reactions (exothermic reactions) are controlled so as to supply sufficient heat for the predominantly syngas reactions (endothermic reactions), yielding a temperature typically between 1,450 and 3,000°F. The raw syngas exits the reactor and is cleaned up of carry-over particulate matter from the reactor, sulfur, chlorides/acid gases (such as hydrochloric acid), and trace metals such as mercury. Syngas is sent to the power generation plant to produce energy, such as steam and electricity, for use in the process and export energy. The export energy is converted to electricity and supplied/sold to the grid.

The bottoms from the conventional gasification reactor are ash and/or slag and metals depending upon the temperature of the conventional gasification reactor. However, the ash and/or slag from the reactor bottoms is usually disposed off in a landfill which is one of the major environmental shortcomings when used for MSW management.