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### LESSONS LEARNED FROM THE 1970s EXPERIMENTS IN SOLID WASTE CONVERSION TECHNOLOGIES

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#### ABSTRACT

Countless proposals for conversion technologies applied to municipal solid waste (MSW)<sup>c</sup>, such as gasification, many of which include mechanical processing of the MSW prior to the thermal conversion steps, have generated significant interest and press over the past few years. Many community groups and local officials are being pressured by developers to view these technologies as better and more politically acceptable alternatives to mass burn waste-to-energy facilities. From a historical perspective, most (but not all) of the basic technologies being promoted today are not new, but are variations of technologies that were evaluated and tested during the 1970s for use in processing and converting MSW.

This paper presents overviews and several case studies of the MSW conversion technologies that were developed and tested during the 1970s including MSW processing and gasification technologies, and sets forth:

- Lessons learned from those experiments.
- Based upon the lessons learned, recommended rules of engagement for those contemplating evaluation or use of a processing and/or conversion technology.
- A practical application of the above lessons learned and rules of engagement to the plasma arc gasification technology currently being promoted by a number of developers.

The contents of this paper should be carefully considered by anyone contemplating the merits and feasibility of any MSW processing and/or conversion technology being promoted today or in the future.

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<sup>c</sup> As used in this paper, MSW refers the heterogeneous solid waste that is normally collected from households and commercial establishments by packer truck type collection vehicles and compactor or non-compactor roll off containers. It excludes homogeneous wastes, select wastes and other wastes not normally collected as described in the first sentence of this footnote.

## **BRIEF HISTORY OF RECOVERING ENERGY FROM HOUSEHOLD AND COMMERCIAL SOLID WASTE<sup>1,12</sup>**

Recovering the energy contained in MSW in the U.S. first began on a small scale in New York City in 1897 based upon facilities that the Commissioner of Sanitation, Colonel Waring, had seen in Europe. In 1905, Colonel Waring built a large incinerator with waste heat recovery and electric generation capacity. The steam generated by the combustion process was used to drive a conveyor belt onto which the solid waste was deposited and recyclable materials were removed at picking stations prior to the remaining waste being combusted. At night the steam also turned an electric generator which powered the lighting on the Williamsburgh Bridge. Starting in 1938, engineers in NYC and other large cities experimented with shredders to try and make the waste more homogeneous in order to improve the consistency of the electrical generation process. They also theorized that the up-stream removal of metal, glass and other inerts, along with the use of mechanical mechanisms to continuously feed the refuse, rather than the batch feeding that was then being used, would provide for more uniform combustion.

By comparison, Europe had many steam district heating systems in both large and small cities and towns, and after World War II, many of them started generating some or all of the steam from MSW. They experimented with various grate designs to continuously feed and combust the MSW and also experimented with replacing the refractory lined combustion chamber with waterwall tubes covered with a thin layer of refractory to protect the waterwalls in order to both eliminate air infiltration and increase the amount of heat recovered. In the 1960s, U.S. engineers started to design MSW combustion facilities using these European techniques, with varying degrees of success. In the early 1970s, most of the existing refractory lined MSW combustion facilities were shut down following the simultaneous passage of the 1970 federal Clean Air Act and the creation of the US EPA, because the cost of the new air pollution control devices required to meet the new air emission standards was several times higher than the original cost of the incineration facilities.

From the late 1960s through the 1970s, combustion of unprocessed MSW (mass burning) was viewed unfavorably by the public, in large part due to the perception created by the older generations of refractory incinerators which emitted black smoke from their stacks. Many municipalities and companies therefore shifted their focus to extracting the energy from the MSW by other means. Burgeoning energy costs, reflected in the value of recovered electricity, encouraged the energy recovery strategy. At various times in the 1970s, headlines would declare "There's Gold In Garbage". This paper deals with two of those methods, specifically, gasification of MSW and mechanical processing of MSW to create a refuse derived fuel (RDF).

In addition to gasification and RDF, some of the other methods that were tried in either pilot or full scale facilities are listed below<sup>12</sup>. With the exception of

capturing and using landfill gas, these methods/processes were not made commercially viable in the U.S. for MSW feedstocks, despite varying amounts of research and development.

- Production of ethanol.
  - Enzymatic hydrolysis of cellulose followed by fermentation.
  - Acid hydrolysis of cellulose followed by fermentation.
- Production of methane.
  - Anaerobic digestion -WMI Refcom, Pompano Beach, FL.
  - Fixed and fluidized bed digestion.
  - Alkali pretreatment.
  - Plug flow digestion.
  - Capturing landfill gas.

## **GASIFICATION**

### ***General Introduction To Gasification Of Solid Waste***

Efforts to gasify solid waste materials are not new. Development of facilities that produce a relatively clean gas or oil from homogeneous solid waste materials began over 70 years ago, while development of facilities to gasify MSW began more than 40 years ago. In the 1970s these facilities were developed and marketed under the name of the chemical process that they use, namely "pyrolysis".

Pyrolysis, also known as destructive distillation, is the thermal decomposition of material in an oxygen free atmosphere, which breaks the materials into simpler molecules. Longer molecules break into smaller, lower molecular weight molecules, beginning with the weakest bonds at 237<sup>0</sup>F. Virtually any organic material can be decomposed by pyrolysis into simpler molecules, and with suitably long exposure at sufficiently high temperatures, they can be completely broken down. Pyrolysis of most materials yields three principal products: hydrocarbon gases, hydrocarbon liquids (condensed at room temperature from gases or vapor), and char (a particulate of carbon black and ash).

Pyrolysis is an ancient art. It was practiced by pre-biblical Egyptians<sup>2</sup> for the production of charcoal, fluid wood tar and pyroigneous acid, useful for embalming. Ancient Egyptian, Roman, African, and Southeast Asian cultures made charcoal, pigments and wood distillate fuels by heating biomass or other substances such as pitch, underground with little or no air.<sup>10</sup> Prior to World War I, pyrolysis had been used for many decades in the US to convert wood to charcoal, acetic acid, methyl alcohol and acetone. In the nineteenth century, illuminating gas was manufactured almost entirely by pyrolysis.<sup>10</sup> This technology has been commercially available for homogeneous waste materials such as rice hulls, nut shells, wood chips, sawdust, cardboard and packing materials for over 50 years.

Pyrolyzing MSW as a feedstock produces a mix of gaseous products, high molecular weight tars, water

insoluble oils and a solid residue. The amounts of the different products vary depending upon the rate of heating and the final temperature. In general, the higher the heating rate and the higher the final temperature, the greater the fraction of the initial waste that is converted into the gaseous and liquid products. High temperature processes produce a medium Btu gas (300-350 Btu/ft<sup>3</sup>). Lower temperature processes produce a gas and/or vapors, that when cooled to room temperature, partly or fully condense into a flammable oil. The gas is mainly composed of hydrogen, methane, carbon monoxide, carbon dioxide, hydrocarbons and water vapor.

One of the first pyrolysis systems used on MSW was constructed by the City of San Diego<sup>2</sup> in 1968. This system was used until 1979 to experiment on the feasibility of pyrolyzing refuse. The report of those experiments concluded that MSW can be successfully pyrolyzed, resulting in noncondensable gases, liquids and a solid residue of carbonaceous material or char. The principal investigator also observed that "It would seem, therefore, that any optimum pyrolysis based system for material as heterogeneous and diverse as municipal refuse should include a reliable, fool-proof method for getting the material into and out of the pyrolysis chamber." (Hoffman, page 4)

The Bureau of Mines Pittsburgh Energy Research Center (BuMines, PA)<sup>2</sup> designed and constructed a laboratory scale pyrolysis unit in 1929 that was designed as a research tool. The research unit used a vertical furnace heated with nickel-chromium resistors as the pyrolytic chamber heat source and had recovery trains to trap the pyrolytic products for analysis. In 1968, in conjunction with Firestone, and Goodyear, BuMines, PA studied the pyrolysis of shredded used tires. Although technical feasibility was proven, the economics of a large facility hoped for by the tire industry (300 tpd) appeared to be unfavorable. In 1970 and 1971, BuMines, PA conducted a series of pyrolysis experiments on MSW from the Fairfield Aerobic Mulch Corp. in Altoona, PA that had been shredded and had the metal and glass removed. These experiments demonstrated that the material could be pyrolyzed successfully in their unit and, within a certain temperature reaction range, the resultant product would be an oil at room temperature rather than a gas.

Another historical waste pyrolysis system was developed by a private company named Pan American Resources<sup>3,10</sup> (PAR), of Albuquerque, NM. In the 1930s PAR sold batch fed pyrolysis units that were widely used on farms and ranches to pyrolyze haystack bottoms, waste feed, and dried manure. The material was packed into an airtight container that was bolted shut and placed into an oven and the pyrolyzed gases from the container were used for cooking, space heating and lighting. In the late 1950s,

PAR patented an air lock system to allow continuous feeding of the waste materials. Their unit, named the Lantz converter, consisted of a sealed, externally heated, cylindrical retort revolving slowly around an inclined axis. Waste was admitted through the patented air-lock system and pyrolyzed at temperatures of 900<sup>0</sup>F to 1,500<sup>0</sup>F depending upon the waste composition. A 50 tpd unit processed several kinds of industrial waste from the Naval Ammunition Depot in Concord, CA between 1962 and 1964. Additionally, a 50 tpd unit was operated at the Ford Motor Company assembly plant in San Jose, CA in 1968 - 1969, processing waste generated by the Ford plant. While the pyrolyzer performance was considered very good, the processing system of the shredder and conveyors constantly failed and as a result, the facility ceased operation.

In the 1970s, several pyrolysis technologies using MSW and a feedstock were under development using the following processes:

- Indirectly heated solid waste.
- Directly heated solid waste.
- Use of horizontal or slightly inclined rotary cylinders as the pyrolysis chamber.
- Use of a vertical shaft or vertical cupola as the pyrolysis chamber.
- Heating the waste to a relatively low temperature.
- Heating the waste to a relatively high temperature.
- Using a variety of heat sources such as (i) a pure oxygen torch, (ii) heated air (using natural gas) and (iii) combusting solid waste in a starved air mode. The oxygen (either pure or in the air) would result in a combustion zone and when the oxygen became exhausted in the upper end of the combustion zone, which would produce hot gases, and the hot gases rise above the combustion zone and would pyrolyze the MSW.

Eventually they all failed for a variety of technical and economic reasons.

During the 1980s, various companies<sup>10</sup>, including Pan American Resources, Entropic Technologies, and Conrad/Tuttle Technologies continued to try to develop commercial scale facilities to pyrolyze MSW, funded by themselves and grants from federal agencies, but none were successful.

Also during the 1980s, a joint venture of Westinghouse and Pyrolysis Systems, Inc., in collaboration with the New York State Department of Energy Research and Development, the NYS DEC and the US EPA built a prototype, mobile 6 tpd plasma arc pyrolysis system, said to be the first of its kind, intended to process Love Canal cleanup wastes. It was a 45 foot long device designed to operate on sludges containing dioxins, PCBs and other hazardous chemicals at 10,000<sup>0</sup>C to produce a gas containing 50% hydrogen, 30% carbon monoxide and

20% nitrogen. The facility was given a permit to operate near Buffalo, NY, however problems developed with rapid refractory degradation at operating temperature, and the project was cancelled by the company before commercial operation could commence.

Below are four case studies of the best known and well documented MSW pyrolysis facilities from the 1970s that were constructed by four well known and technically sophisticated US corporations. Many more facilities were proposed by countless other developers, but most, if not all, were never constructed. The four case studies represent some 1,500 tpd of processing capacity, with a total estimated construction cost of approximately \$55 million in roughly 1975 dollars or \$140 million in 2009 dollars (inflated at the CPI).

#### **FOUR CASE STUDIES OF PYROLYSIS GASIFICATION FACILITIES USING MSW**

##### **Monsanto Landgard Medium Temperature Gasification<sup>4,5,8</sup>**

In 1967 Monsanto decided to develop a pyrolysis system as a solid waste management option. They first developed a laboratory model of a direct fired continuous feed pyrolysis unit using a medium temperature rotary pyrolysis kiln that was built and operated in Dayton, OH. Monsanto then decided to build a pilot sized pyrolysis unit near St. Louis, MO, to develop scale-up data for designing a full-sized plant. Trial handling of MSW began in 1969 and continuous operation at a feed rate of 35 tpd waste was demonstrated by early 1970. The pilot plant was dismantled in late 1971 after all testing was completed.

In July 1972, the city of Baltimore, MD applied to the US EPA for a grant to demonstrate Monsanto's "Landgard" system with a full scale pyrolysis facility that would process 1,000 tpd of the city's MSW using a single kiln. This represented a unit process scale-up factor of approximately 30-fold based on Monsanto's 35 tpd pilot unit. The grant for demonstration of an energy recovery system under Section 208 of the Resource Recovery Act of 1970 was for \$6 million of the estimated \$15 million construction cost. The state loaned the city \$4 million towards the construction price and the city contributed \$5 million. The city awarded Monsanto a design/build contract with a money back performance guarantee, with Monsanto's maximum liability capped at \$4 million, about 25 percent of the construction price. The facility was intended to produce steam for sale to Baltimore Gas and Electric Company for use in the downtown district heating and cooling system. After acceptance, ownership and operation of the facility would revert to the city. The net owning and operating cost was projected to be \$5.85/ton which included amortization of capital.

The original process design<sup>8</sup> of the facility consisted of:

- Two 50 tph shredders to shred the incoming waste.
- A 2,000 ton capacity live bottom storage bin to store the shredded waste.
- Twin rams to feed the single pyrolysis vessel.
- A pyrolysis vessel comprised of a refractory lined horizontal rotary kiln rated at 46 tph, measuring 18 feet in diameter and 100 feet long and rotating at 2 revolutions per minute.
- A heating concept based on combusting a portion of the MSW (using 40 percent stoichiometric air) plus No. 2 fuel oil at the rate of 8 gal/ton of MSW.
- Off-gas flow in the kiln was counter current to the flow of the MSW and was to exit the kiln at approximately 1,200°F.
- Gases were projected to have a heat content of 75-100 Btu/scf and were to be combusted in an afterburner with additional air introduced to complete combustion.
- The fully combusted hot gases were to pass through boiler projected to generate 200,000 lbs/hr of steam.
- The gases were to pass through a wet scrubber, a mist eliminator, and a reheater for plume suppression before being discharged to the atmosphere.
- The solids leaving the kiln would be water quenched and have the ferrous metal removed by a magnet. The remaining solids were expected to be a "glassy aggregate".

Construction began in early 1973 and was completed in December 1974. However, upon commencement of operation it soon became apparent that extensive changes would be required in mechanical and pollution control equipment. The changes were expected to add 50 percent to the original project cost. The retrofit work commenced in January 1976 and was paid for by a combination of funds from the US EPA, Monsanto and the city. After some initial changes, the modified facility was started up in May 1976 but still exhibited problems. Some of the problems could be mitigated by drastically reducing the MSW feed rate.

In February 1977, Monsanto withdrew from the project and recommended that the city convert it to a conventional mass-burn facility. A Monsanto official summed up the status of the facility by stating that "The major problems identified in the early stages of operation have been fixed. New problems, however, have surfaced and there exists the potential for further problems to develop." (Solid Waste Management magazine, March 1977, page 78) However, the city believed that the system had sufficient technical merit to warrant further investment. In February 1978, the city shut down the facility to make additional changes, and the facility reopened in 1979 at a throughput rate of 600 tpd and operated on a three and a half day per week basis. The facility ceased operation sometime between 1979-1981. Procurement of a mass burn facility on the same site was commenced by the Northeast Maryland Waste Disposal Authority in September 1980,

and demolition of the pyrolysis facility commenced in December 1982 to allow the Wheelabrator Baltimore mass burn facility to start construction in May 1983.

Some of the key technical issues that the pyrolysis facility faced were:

- Employing a too large unit scale-up factor.
  - Using a unit process scale-up factor of 30 is not unusual in the chemical process industry that made up Monsanto's core business, but cannot be realized in the MSW processing industry where complex multiple phase interactions and unpredictable materials handling behavior are critical to the heat transfer and chemical processes. This was exhibited by, among other things:
    - ✓ The refuse, the temperature gradient and the gas stream not behaving in the large kiln as they had at 35 tpd.
    - ✓ There was much more particulate matter in the gas stream than there was in the pilot scale system, rendering the installed air pollution control system ineffective.
    - ✓ Due to the larger than expected particulate loading (which also contained heavy metals), there were problems meeting environmental air emission limits.
- The conical silo storage bin for the shredded refuse and the retrieval systems did not operate as designed and were eventually abandoned.
- The shredders were prone to explosions.

#### **Occidental Research Corporation (Formerly Garrett Research And Development Company, Both Subsidiaries Of Occidental Petroleum Corporation) Gasification To Oil<sup>4,7,8</sup>**

Garrett proposed to use a flash pyrolysis process and then condense the gas into an oil that could be transported and combusted. A 4 tpd pilot plant was constructed and tested in La Verne, CA in 1974.

In August 1975 construction started on a 200 tpd facility in El Cajon, San Diego County, CA. The estimated construction cost of \$10 million was funded by a \$3.5 million US EPA demonstration grant, \$4.5 million equity contribution from Occidental Research Corp. and \$2 million from San Diego County. The unit process scale up from the pilot plant was approximately a factor of 50. The net operating cost was projected to be \$11.25/ton, which did not include amortization of capital. After acceptance, ownership and operation would revert to San Diego County.

The original process design<sup>8</sup> of the facility consisted of:

- Incoming MSW would be shredded to a particle size of 2 inches or less.
- An air classifier would then separate the "light" fraction (which was projected to be the combustible fraction)

from the "heavy" fraction (which was projected to be the noncombustible fraction).

- The "light" fraction would then be dried to a moisture content of 3 percent, screened to remove any remaining inorganic material and shredded again to a particle size of minus 14 mesh (almost a powder, it must pass through a screen having 14 openings per inch in each direction).
- The pyrolytic reaction was to take place in a vertical reactor 30 feet tall and 8 inches in diameter. The fine shredded material was to be carried into the base of the reactor where it would be mixed with burning char. Both materials would be carried into the system by spent combustion gasses from an auxiliary char burner. In the reactor the hot glowing char and processed MSW would be rapidly mixed as the suspension passed upward under turbulent flow conditions. Reactor temperature was to be maintained at approximately 900°F. Because the pyrolytic reaction was projected to occur so rapidly, the gaseous products formed were not expected to be exposed to the high temperature long enough for them to thermally degrade. The result was projected to be that when the gases were cooled down to ambient temperatures the compounds formed would be organic liquids rather than gases.
- After removal of the char, the 900°F gases were to be rapidly cooled by a venturi quench system using recirculated product oil in an oil recovery collection train. The oil production rate was projected to be 1 barrel of oil per ton of processed MSW.
- The produced oil was projected to be low in sulfur and to contain approximately 10,500 Btu per pound compared with 18,200 Btu per pound for No. 6 fuel oil.
- The outlet gases from the oil recovery system would be further cooled in a packed bed scrubber before being returned to the process.
- The "heavy" fraction and other rejected material was to pass by a magnetic drum for the recovery of ferrous metal, and a sand-sized, mixed color, glass cullet of +99.7 percent purity was to be recovered from the remaining inorganic material by selective crushing and screening followed by froth floatation.

The facility experienced significant cost overruns during construction and started operation in late 1976. When the facility started operation, it experienced significant operational problems and numerous modifications were tried. In seven test runs between December 1977 and March 1978, the pyrolysis unit produced about 100 barrels of oil from approximately 100 tons of MSW. In March 1978, after investing approximately \$9 million, Occidental suspended test operations. In March 1983, San Diego County accepted an offer of \$160,000 for the scrap value of the facility and the facility was demolished.

## Union Carbide Purox High Temperature Gasification<sup>4,6,8</sup>

In 1968, Union Carbide began development of the Oxygen Refuse Converter Purox Process, a high temperature vertical shaft pyrolysis chamber that uses oxygen in lieu of air. Union Carbide's Tarrytown Research Center, NY studied the problem of MSW disposal, evaluated various processes, and conducted some experiments. It was concluded that the oxygen converter approach was worth further intensive effort. From 1970 through 1972, first and second generation pilot scale furnaces were constructed and tested, the largest one being a 10 foot tall packed column retort with a capacity of 5 tpd. In 1972, Union Carbide, in connection with the City of Mount Vernon, NY applied for a US EPA research demonstration grant. The EPA decided not to award a grant.

In 1973 Union Carbide used their own funds to proceed with construction of a 200 tpd prototype facility at Union Carbide's plant in South Charleston, WV. The unit process scale up factor from the second generation pilot scale furnace was a factor of 40. At the time of construction of this facility, Union Carbide was projecting a net owning and operating cost for a 1,000 tpd facility of \$4.50/ton which included amortization of capital.

The original process design<sup>8</sup> of the facility consisted of:

- A vertical shaft furnace where MSW would be introduced at the top through an interlocking feeder.
- Pure oxygen, at the rate of 400 lbs/ton of MSW would be blown into the base of the MSW column where it would react with carbonaceous char fraction of the solid residue remaining after the pyrolysis of the MSW.
- The char would combust in the presence of the pure oxygen at a temperature high enough to melt (slag) any noncombustible material in the char. This molten metal and glass was to drain continuously into a water quench tank to form a hard, granular, glassy material.
- The hot gases formed by the combustion of the char in pure oxygen would rise through the descending MSW providing the heat needed to dry and pyrolyze the incoming solid waste.
- No external fuel supply was projected to be needed.
- In the upper portion of the chamber, the gases would be cooled as they dried the incoming MSW.
- The temperature of the exiting gas was projected to be 200<sup>0</sup>F and to contain considerable water vapor, some oil mist and minor amounts of undesirable chemicals.
  - To remove those components, the exiting gas would pass through an electrostatic precipitator, an acid adsorption column and a condenser.
- The resulting cleaned gas was projected to have a heating value of 300 Btu/ft<sup>3</sup> and was projected to be substantially free of sulfur.
- The resulting gas was also projected to be free of nitrogen since air is not used in the combustion of the char. It was projected that the gas could be combusted in

existing natural gas fired boilers if the nozzles were enlarged in inverse proportion to the lower gas heating content.

Operation of the prototype facility started in April 1974 and problems arose immediately. At the end of 1974 the facility was shut down to install a shredder, and the facility reopened in April 1975. The facility was shut down soon after for further modifications and reopened in August 1975 only to be shut down for additional modifications in November 1975. The facility continued to operate sporadically between 1975 and 1977. In 1977, US EPA funded a test demonstration of co-pyrolyzing MSW and sewage sludge at the facility, and the test was reportedly successful.

At the end of 1977 the facility was permanently shut down when Union Carbide decided it had enough information to design large scale facilities. At that point, Union Carbide had spent over \$10 million in research and development and decided to market the system.

In 1976 Dutchess County, NY selected Union Carbide to design and build a 700 tpd facility, although the facility was never constructed. Union Carbide entered into negotiations with Westchester County, NY in 1977 to build a 1,000 tpd facility to serve the county, but negotiations broke down due to cost considerations. Also in 1977 Union Carbide proposed on a facility for Seattle, WA where a chemical company would use the gas as feedstock for making either methanol or ammonia, but again negotiations broke down due to cost considerations. Union Carbide submitted a proposal to Pinellas County, FL in January 1978 for a 2,000 tpd facility, but again was not selected due to cost considerations. Union Carbide subsequently announced that they were stopping marketing efforts until the technology could be made more cost effective. They never resumed marketing the technology.

## Torrax Systems, Inc. (A Division Of Carborundum Corporation)<sup>4,8,9</sup>

Supported by a US EPA demonstration grant, a 75 tpd pilot plant was constructed by Torrax Systems, Inc., (a division of Carborundum Corporation) in 1971 in Orchard Park, Erie County, NY. The unique proprietary feature of the process was a silicon carbide (carborundum) shell and tube heat exchanger to preheat combustion air. It started operation in 1972 and was in intermittent operation until 1974 when Erie County voted to abandon the Torrax experiment as economically unfeasible for the region.

In May 1976, the Carborundum Corporation licensed the Torrax pyrolysis process to Andco to develop facilities in various parts of the world. In February 1980, Andco started construction of a 100 tpd pyrolysis demonstration

facility to service the Walt Disney World Resort Complex (50 tpd) and Orange County, FL (50 tpd) with the facility scheduled to become operational in September 1981. The estimated \$11 million construction cost was funded by Walt Disney Productions and the US Department of Energy. The facility was to be operated by Reedy Creek Utilities, Inc., a wholly owned subsidiary of Walt Disney Productions, and was expected to supply approximately 15 percent of the air conditioning and heating demands at the complex.

The original process design<sup>8</sup> was similar to the Union Carbide Purox system except that:

- Instead of oxygen, air preheated to 2,000<sup>0</sup>F was used to achieve the high temperatures in the pyrolytic vertical shaft.
- The preheated air was provided by burning natural gas in a heat exchanger designed by Carborundum.
- Since air was used to release the heat for drying and pyrolysis, the pyrolytic gas was much higher in nitrogen than the gas produced by the Union Carbide Purox system.
- The MSW would be pyrolyzed in the lower zone in the shaft furnace with high temperature preheated air at a projected temperature of 1,500<sup>0</sup>F. The pyrolytic off-gas would then be combusted in a second chamber at 2,500<sup>0</sup>F and would be used to generate steam in a boiler.

The facility commenced operation in September 1982 and immediately experienced operational problems. After spending a total of \$15.5 million, the facility was shut down in March 1983 due to cost concerns. It reportedly burned 200 cu. ft. of natural gas per minute compared to the original projection of 78 cu. ft. per minute, used twice the electricity as was originally projected, had trouble controlling the temperature zones and never processed more than 85 tpd. Although it was reported that modifications could be made to cure those issues, no further investment was ever made.

#### **SUMMARY OF FOUR EXPERIMENTAL SOLID WASTE PYROLYSIS FACILITIES**

All four pyrolysis technologies:

- Worked in that they gasified the MSW and produced a medium Btu gaseous or oil fuel product.
- Involved large, high-risk unit process scale up factors. As a consequence, many of the results of the pilot scale tests were found not transferable to the prototype facilities.
- Suffered from a variety of materials handling and processing problems, some of which were solved but at the price of lengthy startup and shakedown periods and modifications to the facility that required additional capital expenditures and loss of projected revenues.
- There were no technical issues with the gasification heat sources, they all worked as projected.

- Cost more to construct and operate than originally projected.
- Initial projections by the developers of net owning and operating costs were all unrealistically low.
- Were not able to achieve the projected throughput rates, which caused additional increases in the unit cost.
- Exhibited environmental problems such as meeting air emission and liquid discharge limits.

#### **EXPERIMENTS WITH MECHANICAL PROCESSING OF MSW - REFUSE DERIVED FUEL (RDF)**

##### **Introduction**

All of the gasification experiments eventually involved some type of mechanical processing of the MSW prior to gasification. We therefore believe it is pertinent to review the major mechanical processing experiments and conversion technologies that also took place in the 1970s and into the early 1980s to derive additional lessons learned.

RDF was developed on two basic concepts:

- Process the MSW to produce a fuel that could be sold to coal fired utility power plants and industrial coal fired boilers to co-combust with coal with limited special handling or furnace modifications to the existing boilers.
  - The theory was that the savings of the capital and operating cost of not having to construct and operate MSW-fired boilers, air pollution control facilities and electric generation facilities (which mass burn facilities needed to have), would more than offset any potential increased processing and boiler modification costs.
- Process the MSW to a coarse RDF and combust it on-site in dedicated furnace/boilers or co-combust it with coal in a modified existing coal fired boiler.
  - The theory was that this type of process would allow companies who did not possess a proprietary mass burn grate license to obtain market share in the MSW energy recovery industry.

The first two facilities to shred, classify and co-combust RDF were developed as two parallel experimental facilities, and were both initiated through demonstration grants from the US EPA. A separate experimental materials recovery facility was developed during the same time frame by the US Bureau of Mines.

- Dry RDF<sup>11</sup> - This project was jointly funded by the US EPA, the city of St. Louis, MO and the Union Electric Company. It began as a feasibility study in 1968 and in 1970 construction began on installing a shredder. Operation commenced in 1972, and in 1973 an air classifier was added to classify the shredded MSW and magnetically remove the ferrous metal from the "light" fraction. The classified RDF was then fired pneumatically in an existing pulverized coal fired boiler. The facility processed MSW at the rate of approximately 100 tpd.

Although the experimental facility proved that the concept worked, there were many materials handling problems, and the experiment ended in 1976.

- Wet RDF<sup>11,12</sup> - Based on development work performed in 1967, the US EPA approved a demonstration grant in 1970 to the Black Clawson Company (a manufacturer of pulp and paper making equipment, which was a subsidiary of Parsons & Wittemore), to construct and operate a wet RDF manufacturing system in Franklin, OH. The system was based on pulp and paper mill technology where water was added to the MSW, then the resulting mixture was ground in a wet pulper. The pulped slurry then entered a wet cyclone where the inerts were to be extracted, and finally into a mechanical dewatering device where the wet mass was pressed down onto a screen. The product was to be combusted in an on-site dedicated fluid bed furnace/boiler or piped to a manufacturing facility for making felt paper for asphalt roofing shingles. This demonstration facility had a design capacity of 150 tpd and normally processed 30 – 40 tons in an 8 hour day from 1971- 1974.
- Materials Recovery by the Bureau of Mines College Park Metallurgy Research Center, MD (BuMines, MD)<sup>11</sup> - In 1973 BuMines, MD started to investigate techniques to recover the energy and materials in MSW. BuMines, MD built a 1 tph RDF and materials recovery system that operated a few days per week from 1974 through 1978 using MSW collected in the metropolitan Washington, DC area to obtain data on waste composition and to develop data from which to project the value of the various materials that were recovered. The process was complex and involved: (i) for RDF production a primary shredder (flail mill), light air classifier, ferrous removal by magnetic separation, primary air classifier, trommel, secondary shredder, and a secondary air classifier; and (ii) for the materials recovery system, the non-magnetic “heavy” fraction consisted of the separation of non-ferrous metals by an eddy current separator, wet separation of glass from organics by flotation of the organics, separation of glass from ceramics by froth flotation, drying the glass and then sorting by color using an optical sorter.

Beyond these three basic pilot facilities, numerous companies and municipalities built small and large scale facilities using various types of RDF technologies and equipment with various degrees of success and failures. The process trains varied, but most started with shredders. The remainder of the equipment (air classifier, trommels, pneumatic conveyors, belt conveyors, pan conveyors, heavy media separators, color sorters, live bottom storage and retrieval systems, pelletizers, wet pulpers, etc.) were standard pieces of equipment used in various industrial processes such as mining, grain processing, food processing, pulp and paper manufacturing and were set up in different order by the various developers.

Table 1 lists most of the RDF facilities<sup>12,13</sup> that were constructed, operated for varying periods of time but are now all closed. These twenty facilities represent some 20,000 tpd of processing capacity. Using the known capital costs plus the capital costs for the facilities with unknown capital costs extrapolated at the average known capital dollars per ton of daily capacity, the authors arrive at a total estimated construction cost of approximately \$670 million in roughly 1978 dollars, or \$1.7 billion in 2009 dollars (inflated at the CPI).

**Table 1  
Constructed RDF Facilities (Now Closed)**

Location	Developer	Start-Up Date	Capacity (tpd)	Capital Cost <sup>12</sup> (Millions)
Akron, OH	City & Teledyne National	1979	1,000	\$50
Albany, NY	RDF-City & Energy Answers, Boilers-New York State	1981	700	\$22
Ames, IW	City (operated for a long period of time)	1975	200	\$6
Baltimore County, MD	County & Teledyne National	1978	1,000	\$9
Bridgeport, CT	CRRA & CEA	1979	1,800	\$53
Chicago, IL	City	1977	1,000	\$16
Columbus, OH	City	1983	2,000	\$153
Haverhill/Lawrence, MA	Refuse Fuels, Inc.	1984	1,300	
Hempstead, NY	Town, Black Clawson	1980	2,000	\$73
Lakeland, FL		1982	300	
Lane County, OR	County & Western Waste	1979	500	\$2
Madison, WI		1979	400	
Milwaukee, WI	American Can Company	1977	1,200	\$18
Monroe County, NY	County & Raytheon	1980	2,000	\$50
New Orleans, LA	WMI & NCRR	1979	750	\$9
Niagara Falls, NY	Hooker Chemical	1981	2000	\$57
Pueblo, CO		1979	200	
St. Louis, MO	City & Union Electric	1971	300	
Tacoma, WA	City, Boeing	1978	500	\$5
Pigeon Point, New Castle County, Wilmington, DE	Delaware Solid Waste Authority, Crouse Group, Kidde Constructors	1984	1,000	\$60

Some large facilities (listed below) are still operating today. The facilities are:

- Bangor, ME (PERC)
- Biddeford, ME (MERC)
- Dade County, FL (converted from wet to dry processing)
- Detroit, MI
- Hartford, CT
- Honolulu, HI



- Palm Beach County, FL
- Rochester, MA (SEMASS)
- Southeastern Public Service Authority (SPSA)

There are also a number of smaller RDF facilities that were constructed in Minnesota that are reportedly still operational.

Of the twenty closed facilities listed in Table 1, we have selected the below four case studies of facilities that were built and failed. They are set forth in order to present some lessons learned by these failed experiments in processing MSW. These four facilities were selected because they are some of the largest and most well known and well documented RDF facilities and as with the gasification case studies, involved some of the largest and best financed US companies and municipalities.

#### **FOUR CASE STUDIES OF RDF FACILITIES USING MSW**

##### **City Of Chicago<sup>14</sup>**

In late 1973, the city of Chicago and Commonwealth Edison embarked on a 1,000 tpd RDF production project modeled after the St. Louis/Union Electric Company prototype. Since Chicago installed two processing lines, the unit process scale up factor from the St. Louis prototype was a factor of 5. The facility was constructed next to Commonwealth Edison's Crawford pulverized coal fired power station and was operated by the city. The construction cost was \$16 million, with a design processing capacity of 1,000 tpd. Commonwealth Edison was to purchase the RDF and combust it in the Crawford station power plant. The RDF process included coarse shredding, air classification, cyclone, fine shredding and pneumatic conveying to storage bins at the Crawford power station. The facility started up in February 1977. There were significant problems from the beginning both in making the RDF and combusting it in coal fired boilers. Since the burn-out time of RDF particles is significantly longer than pulverized coal, a burn-out grate is necessary. Crawford had no grates. Further, the RDF contained a large fraction of fusible, non-combustible matter that both accumulated and fouled the boiler surfaces and overloaded the boiler bottom ash handling equipment. The city spent an additional \$5 million from February 1977 through December 1979 making modifications to the facility plus paying the salaries of facility staff, but could not solve the problems which made the RDF unsuitable for combustion in the existing boilers. In December 1979 the facility was shut down by the city.

##### **Combustion Equipment Associates/Occidental Petroleum Corporation<sup>15</sup>**

In 1972, Combustion Equipment Associates (CEA) in conjunction with Arthur D. Little, Inc. began construction

of a 1,200 tpd facility in East Bridgewater, MA to separate materials for recycling and, from the residuals, to produce a powdered, low ash RDF from solid waste that could be fired in utility boilers and burned in suspension. CEA named the RDF powder Eco-Fuel. The facility became operation in 1974, had a significant number of problems and processed waste far below its design capacity. A fatal explosion and fire led to closure of the facility in 1977. It was never reopened.

From 1973 through 1976 the Connecticut Resources Recovery Authority (CRRA) went through a request for qualifications/request for proposals and negotiation process which resulted in CRRA contracting with a joint venture of CEA and Occidental Petroleum Corporation (OXY) to design, construct and operate CEA's proprietary Eco-Fuel RDF process in Bridgeport, CT.

The construction cost was \$53 million, with a design processing capacity of 1,800 tpd using two identical processing lines. Since the processing train used at Bridgeport was significantly different than what was installed in East Bridgewater, there was no scale up factor, and the large-scale facility was constructed without a prototype. United Illuminating, the local utility, was to purchase the Eco-Fuel and co-fire it with oil in their existing boilers. The RDF process involved coarse shredding in a flail mill, magnetic separation, size classification with a trommel, air classification, addition of an embrittling agent (sulfuric acid) to the light fraction, putting the embrittled material through a hot ball mill which fractures the embrittled material into a fine powdered fuel which was then pneumatically conveyed to storage silos. The facility started up in May 1979, and in January 1980 United Illuminating successfully test burned Eco-Fuel in one of their boilers.

The facility had a variety of operational problems including two explosions and odor complaints. Additionally, the utility faced several challenges associated with the use of Eco Fuel, including meeting the permit requirements for SO<sub>2</sub>. By using sulfuric acid as the embrittling agent, Eco Fuel had a high sulfur content, and the utility had to burn more expensive low sulfur oil when it was using Eco Fuel to remain within the SO<sub>2</sub> limits contained in the operating permit for the facility. When low sulfur oil was not available, the utility could not burn Eco Fuel, which hurt the economics of the project and resulted in reduced processing rates. The utility's highest utilization was in March 1980 when it combusted a total of 507 tons of Eco Fuel.

The contract between CRRA and CEA/OXY stated that if commercial operation did not commence on March 1, 1978, CEA/OXY was obligated to pay debt service. After making several debt service payments, CEA filed for

reorganization under Chapter 11 bankruptcy in October 1980. The facility ceased processing solid waste in November 1980. OXY continued to make debt service payments and operate the transfer station network, but sent the MSW to area landfills rather than the Eco Fuel facility.

In May 1983, CRRA solicited proposals for either operation of the facility or alternative technologies. In July 1984 CRRA settled all disputes with OXY for a \$40 million payment by OXY to CRRA. In March 1986 construction of a 2,250 tpd mass burn waste-to-energy facility commenced on the same site as the failed Eco Fuel facility. The Wheelabrator facility became operational in 1989.

### **Monroe County, NY<sup>16</sup>**

Based upon a 1971 solid waste management study, Monroe County, NY issued a request for proposals in 1974 and selected Raytheon Service Company in 1975 to construct a 2,000 tpd RDF facility. The construction cost was \$50 million for two identical processing lines drawing on the St. Louis design with a unit process scale up factor of 10. The NYS Dept of Environmental Conservation supplied \$15 million toward the construction cost and the rest was financed by a county general obligation bond. The RDF process involved coarse shredding, air classification, and fine shredding. The product was conveyed to surge bins where the RDF was compacted in transfer trailers for delivery. The unit process scale up from the St. Louis prototype was a factor of 10, and the scale up from the BuMines, MD prototype was a factor of 40. Construction of the facility commenced in the fall of 1976 and became operational in October 1979. An RDF receiving and “fluffing” station was built by the county at the nearby Rochester Gas and Electric Company’s (RG&E) power plant. There were many operational problems, and many modifications were made to the facility over time. The facility never processed more than 500 tpd, and normally operated at 150 to 200 tpd. The only user of the county’s RDF, RG&E combusted approximately 300 to 500 tons per week. In 1984, after the county had invested a total of \$70 million in capital cost and subsidized the operation of the facility at a rate of approximately \$5 million per year (for a total investment cost of well over \$80 million), the county mothballed the RDF facility, and in 1985, the county permanently shut down the RDF operation.

### **Black Clawson (A Subsidiary Of Parsons & Whittemore)<sup>17,18</sup>**

#### **Hempstead, NY<sup>17</sup>**

Based upon the work that Black Clawson performed pursuant to a US EPA demonstration grant for construction and operation of a wet RDF manufacturing

system in Franklin, OH (see above RDF Introduction), Black Clawson was awarded a contract to build a 2,000 tpd wet RDF processing facility by the Town of Hempstead, N.Y. in 1974. Black Clawson established a subsidiary, the Hempstead Resource Recovery Corporation (HRRC) to contract with the town of Hempstead. The contract provided for three RDF processing lines where water was added to the MSW and the resulting slurry was charged into a hydropulper where it was to be chopped to a reduced size.. The heavy components were intended to sink to the bottom for removal through a door. The remaining slurry would be pumped to a centrifuge, where the heavy inorganics were intended to drop to the bottom and be removed and the lighter combustible fraction sent to a dewatering press, pressed to 50% moisture and conveyed to storage bins. The product would then be fed into waterwall boilers. The heavy fraction was to go through additional processing steps to separate ferrous, nonferrous and glass as products. The unit process scale up from the Franklin, OH prototype was a factor of 4 based upon design capacity and a factor of 16 based upon required differences in operating regimes. It also appeared that some of the sophisticated materials recovery systems were from the BuMines, MD experiments with scale up factors ranging from 20 to 30.

Construction commenced in June 1976 with start up in January 1979. Almost immediately there were problems. In May 1979, the president of the HRRC resigned and the president of Parsons & Whittemore took over. Facility employees went on strike in June of that year over issues of odors and unacceptable working conditions and odor complaints from the public were also received. The facility operated in extended shakedown until March 1980 when HRRC shut it down due to a payment dispute with the town. The discovery of dioxins in the air emissions by the EPA forced the facility to remain closed and the facility never reopened. In 1985 the town contracted with American Ref-Fuel to build a 2,500 tpd mass burn facility on the same site, and it became operational in 1989.

### **Dade County, FL<sup>18</sup>**

From 1974 through 1976, Dade County initiated and continued through a request for proposal process to select a firm to design, build, and operate a resource recovery facility. The county contracted with Black Clawson/Parsons & Wittemore to build a 3,000 tpd facility. To finance the project, \$137 million in bonds were issued in January 1978 backed by the full faith and credit of the state of Florida. The RDF process included four lines, each with a hydropulper, junk remover, dump pump and liquid cyclone separator (to separate the light organics from the heavier inorganics) plus one dry shredding line. The light organics from the hydropulpers were conveyed to a dewatering device and then pneumatically conveyed to one of four boilers which drive

two steam turbine electric generators. The heavy fraction was processed for ferrous metal recovery by magnetic separation, plastic recovery using heavy media separation, aluminum recovery using an aspirated shaking table, separation of electrical and nonelectrical conductors with a high tension electrostatic drum separator, separation of glass from ceramics using an optical sorter and separation of the colored glass into clear, amber and green with a second optical sorter. The unit process scale up from the Franklin, OH prototype was a factor of 5 based upon design capacity and a factor of 18 based upon required differences in operating regimes. Like Hempstead, it also appeared that some of the sophisticated materials recovery systems were from the BuMines, MD experiments with scale up factors ranging from 20 to 30.

The facility began operation in January 1982 and continued to be operated by Parsons & Wittemore until June 1985 when the county and Parsons & Wittemore settled numerous disputes (including payment of the capital cost, recovery of interest during and after construction, the amount of the operating fee, air and groundwater pollution control violations and odor complaints). Following the settlement, Parsons & Wittemore ceased to be the operator of the facility. The county had issued an RFP for a new operator and had selected Montenay Power Corporation (now Veolia), who took over operations the same day that Parsons & Wittemore left, under an 18 month operating agreement. The county issued \$101 million in bonds in September 1985 to pay for the settlement with Parsons & Wittemore and to make improvements to the facility and the county's solid waste system. The wet processing system and most of the materials separation systems have since been removed and the facility operates today as a dry RDF facility with on-site combustion. Ferrous and non-ferrous metals are also recovered.

### **Summary Of All The Experimental Mechanical Processing Of MSW In RDF Facilities**

The RDF technologies were adversely affected by a number of factors, including:

- Had either:
  - Large scale up factors, which made many of the results of the pilot scale tests or prototype facilities not transferable to the larger facilities; or
  - No scale up factors where the large scale facility was built based upon theoretical designs, development-stage components and/or modifications of other RDF facility process trains to try to solve the problems that had been encountered.
- Suffered from a variety of materials handling problems that were worked on during lengthy startup and shakedown periods with additional capital expenditures and significant loss of projected revenues but eventually were not solved at all or solved incompletely.

- An inherent and continuing challenge exists in this aspect of facility design due to the complex and variable materials handling characteristics of MSW. The combination of properties that vary geographically and seasonally with processes (shredding, handling, classifying etc.) that are not easily analyzed or simulated makes for uncertainty and risks in process design. Experience has shown that this uncertainty leads more often to failure than to success followed by delays, new investment and derating events that destroy project economics
- Data indicated that fragments of unburned char that lifted from spreader stoker RDF combustion chambers into the gas stream participated in dioxin/furan formation to a degree exceeding that in mass burn systems.
- Contamination of the RDF with noncombustible components causes a reluctance by third parties to use the RDF in off-site boilers due to:
  - High particulate loading which overwhelms existing pollution control equipment.
  - Slagging and tube fouling causing high boiler maintenance, unit outages, and loss of heat recovery efficiency.
  - Large quantity of inerts causing the existing ash handling system to be overwhelmed.
- Cost more to construct and operate than originally projected. This was very significant in co-firing configurations where new burnout grates, combustion air fans and enhanced ash handling equipment were needed.
- Revenues from RDF sales were lower than originally projected and the utilities had no incentive to purchase the RDF because they had to pass the savings on to their customers.
- Quantities of materials requiring landfilling were higher than originally projected.
- Bypass of RDF rejects to landfills explicitly and substantially fails the fundamental goals of the solid waste management plans, which were:
  - Minimize the utilization of landfills.
  - Maximize energy recovery (there was a significant amount of combustible material in the rejects being sent to landfills).
  - Maximize materials recovery.
- In most cases, the overall facility (packer truck receiving area to stack) failed to have the technical coherence and enforceable process guarantees available from a single design/build/operate firm. The opposite was generally true for mass burn systems constructed in the 1980s and early 1990s.
- Operating factors and energy income were often lower than the design basis, directly affecting the underlying income expectations, and causing stress meeting debt service and operating costs.

### **LESSONS LEARNED BY DESIGN ENGINEERS**

- To avoid a large number of operational problems that can overwhelm development of the next larger sized

facility, unit process scale up factors should be no more than one third larger (an increase of no more than a factor of 1.33) than a commercially operating facility.

- Avoid the attitude when thinking about failed similar technologies that “They failed, but we know better, so we will succeed immediately”. Be prepared to face and solve problems. Remember that the designers of the failed facilities also felt that they knew better.
- Perform the research necessary to understand:
  - What has been tried.
  - What has succeeded and why.
  - What has failed and why.
  - Recognize that history shows that a significant risk will remain and that you should still expect unpleasant surprises.
- Materials handling issues, the achilles heel of MSW processing:
  - MSW whether unprocessed or processed (shredded and/or RDF) bridges and binds to itself in storage facilities, and pyrolysis chambers.
  - MSW shredders can be expected to experience explosions, leading to increased down time and, perhaps, employee injury or death.
  - Shredded MSW is very abrasive, it will quickly abrade and perforate pneumatic conveying pipes and relatively quickly make nozzles feeding combustion chambers and the holes in pelletizer dies larger than they are supposed to be.
  - MSW does not “flow”, it has to be dragged where you want it to go and it will be kicking, screaming and fighting all the way.
  - RDF feeding systems can be expected to feed at an irregular rate with periodic blockages and re-starts. This kind of energy input pattern is very problematic for almost any combustion system and steam market (e.g. industrial use or turbogenerator).
- MSW and the products of various processes:
  - Characteristics will vary from community to community and season to season, so success in one community at one time does not guarantee success elsewhere.
  - Chemistry is important, including compounds that produce corrosive gases or micropollutants or ash materials that can fuse and slag.
  - Heat release rate (Btu/hr) is the fundamental scale of facility capacity and not mass rate (tons per day).
  - Designs need to be based upon potential extreme values of various characteristics and components. Designing to the “average” condition will lead to trouble.
  - Unit processes are not perfect.

✓ Many of the contemplated markets (and income streams) for the “combustible” and “non-combustible” fractions of RDF processes were negated by cross contamination.

- Every process component is critical:
  - The success or failure of a process does not only depend upon one specific “jewel” that is unique to that process, all the process components have to work or the entire process will fail. Most systems involve a series of steps such that interruption or outage of one step shuts down the entire line. The incoming waste does not pause.
- The less you handle and process MSW, the higher the probability you have of succeeding.

### **LESSONS LEARNED BY THE MIDDLE MANAGEMENT OF THE DEVELOPERS (BOTH PUBLIC AND PRIVATE SECTORS)**

- Do not use unsupported cost, performance and/or environmental claims to entice potential clients and/or upper management to rely on or invest in such technologies.
  - When you do not deliver on claims, it will come back to bite you and the positive buzz generated by those claims turns to a very negative buzz (pyrolysis became known in the industry as “paralysis”).
- Only make claims that can be supported by data from a facility that operates at a similar scale and on similar types of MSW and judge “similar” very cautiously.
- New technologies should be classified as unproven, experimental or emerging and should be viewed as having significant risks prior to being proven to be technically and economically viable at a commercial scale and over an extended time period.
- When dealing with commercially unproven technologies, whatever your engineer tells you, double or triple the projected costs and time schedule, extend the start-up period, cut the projected revenues at least in half and then add contingencies. Allow space and funds to re-work the system.
  - Research and development of MSW processing systems is very expensive and time consuming.
- Demand confirmation (contracts) demonstrating the validity of markets for energy and material by-products in the quantities and with the quality that data show is credible.
- Evaluate and decide if you want to accept the technical, financial and political risks inherent in developing new MSW processing and/or conversion technologies.
- Be prepared to experience failures prior to obtaining success.

## **RULES OF ENGAGEMENT FOR ELECTED OFFICIALS, STAFF AND SOLID WASTE PROFESSIONALS BASED UPON LESSONS LEARNED**

- Insist on using only proven technology that is operational at close (within 33%) to the size required and on similar types of solid waste prior to moving forward with such a system.
- Do not believe claims made by developers, take an “I’m from Missouri, show me” approach.
  - Request data that backs up those claims such as:
    - ✓ Process flow diagram.
    - ✓ Heat and material balance diagrams.
    - ✓ Process Piping & Instrumentation Diagrams.
    - ✓ Equipment specifications.
    - ✓ Air emissions data.
    - ✓ Analysis of liquid discharges.
    - ✓ Analysis of solid discharges.
    - ✓ Capital and operating costs & revenues
  - If such data is not forthcoming, the technology is most likely not functional and should not be pursued further.
  - Regarding claims of confidentiality,
    - ✓ If some of the process, mass and heat balance diagrams are claimed to be confidential or proprietary, have your engineering consultant sign a confidentiality agreement with the developer so they can examine the data and render opinions to you as to whether or not those data support the claimed performance and costs.
    - ✓ If environmental performance data are claimed to be confidential, the technology is most likely not functional and should not be pursued further.
- Face the fact that local government officials and staff are not expert in these technological and contractual issues:
  - Have independent experts analyze any facilities and data presented by developers.
  - Engage qualified technical, legal and financial experts to assist in negotiating any contracts proposed by developers.
  - Avoid public endorsements by highly placed officials or staff that may be awkward to reverse if problems or disappointments arise in the future.
- Exploring new technologies shows a very progressive attitude, however, it is also risky and there is a significant probability of failure.
- Do not plan to rely on unproven, experimental or emerging technologies until they are proven.
- Do not finance unproven, experimental or emerging technologies.
- Never use taxpayer/ratepayer dollars to be the first one in the world or, perhaps, even the first one in the U.S. to use a new technology.
- Perform the research necessary to understand:
  - What has been tried.
  - What has succeeded and why.
  - What has failed and why.
- Recovering energy from MSW started in the U.S in the early 1900s and many technologies have been proposed and tried since it began. In all that time, progress has been evolutionary, not revolutionary and has not sprung, fully formed from pilot or laboratory scale tests.
  - Be skeptical of claims of a revolutionary new process, in over 100 years of experience, it hasn’t happened yet.
  - If the claims seem too good to be true, they probably are.
  - Request data to back up claims. If the data are not forthcoming, the claims are probably unfounded.
- *As George Santayana (1863-1952,) a Spanish born American Philosopher, Poet and Humanist who made important contributions to aesthetics, speculative philosophy and literary criticism said:*  
**“Those who do not learn from history are doomed to repeat it”**

## **APPLYING LESSONS LEARNED TO PROPOSED MSW FACILITIES USING PLASMA ARC TECHNOLOGY**

As an example of applying the lessons learned principles described above, consider the several technology systems currently being offered based on plasma arc technology.

- Based upon the laws of thermodynamics, free moisture, within the feedstock to gasification systems producing a “synthetic gas,” greatly reduces the yield of synthetic gas because energy from the heat source is used to vaporize the free water rather than to produce synthetic gas. Thus, such systems benefit greatly from some kind of waste pre-drying step to maximize the production of the synthetic gas.
- Gasification of the feedstock involves transferring heat from some source into the waste material. It was demonstrated by the 1970s experiments that MSW shredding and size classification to (i) reduce the cross-sectional area of the waste constituents and (ii) produce a more homogeneous feedstock greatly facilitate the rate of heat transfer and the chemical reactions.
- The synthesis gas is both hot and combustible, therefore great care is needed to minimize inflow of air or outflow of synthesis gas so effective and reliable air-lock waste feeders must be developed.

- A practical and reliable air-tight means of discharging the high temperature residue must be developed.
- A series of synthetic gas treatment stages are required to eliminate tars and control the several air pollutants generated in the process and which are contained in the synthetic gas (particulates to which heavy metals are attached, HCl, H<sub>2</sub>S, PAHs ammonia and amines etc.).
- One or more energy conversion steps (boilers, turbines, gas engines etc.) or chemical conversion processes (ethanol fermenters, Fischer-Tropsch catalytic reactors, etc.) are needed to yield the products that can provide the revenue needed to offset the capital and operating costs of the facility.
- Demonstrated markets for the products (perhaps after refinement and purification to meet market specifications) are necessary.
- All of the above involve many equipment, materials and materials handling issues that are critical to on-line availability and obtaining a sustainable gasification reaction.

The above may not be an all inclusive list of the issues that need to be resolved, for as a Monsanto official stated in 1977 when they abandoned the Baltimore pyrolysis facility “The major problems identified in the early stages of operation have been fixed. New problems, however, have surfaced and there exists the potential for further problems to develop.”

Many of the developers “offering” plasma arc technology focus the eyes of the potential buyer only on the glittering “jewel” of the plasma arc torch. But this is not enough. The authors concur that a plasma arc torch is, indeed, very hot and that if (i) MSW preparation, (ii) materials handling, (iii) obtaining a stable and continuous pyrolytic reaction, (iv) gas cleaning and (v) product processing and marketing steps are successfully achieved, such processes will be very interesting and may have a place as “available technology.”

However, the phrases after the “if” are the topic of this paper. Indeed, using a plasma arc torch as the energy source in a shaft furnace configuration is very similar to the Purox and Torrax technologies, and using it in a horizontal rotary kiln is very similar to the Monsanto technology. With the breadth and depth of process development and high temperature materials skills of Union Carbide, Carborundum Company and Monsanto brought to bear, these “other problems” as outlined above were not satisfactorily solved in a technically, environmentally and economically sound manner.

To date, the authors are unaware of, and have not reviewed any comprehensive and unequivocal data set that demonstrates a “packer truck receiving area to stack” plasma arc facility that confirms that the above issues

have been satisfactorily addressed. Many of the developers “offering” plasma arc systems say that there are facilities in Japan that operate on MSW, however, the data that the authors say should be supplied by developers to back up their claims (see 2<sup>nd</sup> bullet under “Rules of Engagement”) have not, to the authors knowledge, been supplied in the public realm, although numerous requests for such data from various communities to those developers have been made.

None of the developers offering such systems appear to have proposed solutions to the full set of issues, listed above, that defeated similar MSW processing/pyrolysis systems that were built in the 1970s, nor the issues that faced the plasma arc facility that was built, operated on Love Canal cleanup wastes and abandoned in the 1980s. We wish these new set of technology developers well in solving the above critical issues prior to trying to sell communities on the notion that they can rely on this technology as their basic MSW processing system without any backup.

We concur that the use of the plasma arc torch is an innovative energy source, but we await the satisfactory demonstration and data review that shows that the entire story is in hand.

*If not, the authors may feel, as Yogi Berra said:*

**“It’s déjà vu, all over again”**

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