Report

# Alternative MSW Technologies Report

**Landfill of North Iowa**
**Project I.D.: 11L010**

**Landfill of North Iowa**
**Clear Lake, Iowa**

**January 2012**

Landfill of
North
Iowa

Foth

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January 10, 2012

Bill Rowland, Director
Landfill of North Iowa
15942 Killdeer Avenue
Clear Lake, Iowa 50429

Dear Bill:

RE: Alternative Technologies Analysis

Foth Infrastructure & Environment, LLC (Foth) is pleased to submit the report Alternative MSW Technologies Report, Landfill of North Iowa (LNI) to you and your Board. Foth has provided in this report historic perspectives on gasification and pyrolysis, and an overview of the Creative Energy System (CES) process. Additionally, the contents of this report contain a preliminary economic analysis.

As we discussed, Foth will be providing comments on the proposed CES contract under separate cover.

Thank you for the opportunity to conduct this analysis and provide LNI with this report.

Sincerely,

Foth Infrastructure & Environment, LLC

Curtis L. Hartog, P.E.
*Senior Technology Manager*

# Alternative MSW Technologies Report
# Landfill of North Iowa

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# Alternative MSW Technologies Report
# Landfill of North Iowa

Project ID: 11L010

Prepared for

Landfill of North Iowa
15942 Killdeer Avenue

Clear Lake, Iowa 50428

Prepared by

Foth Infrastructure & Environment, LLC

January 2012

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# Landfill of North Iowa

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## Executive Summary

Foth Infrastructure & Environment, LLC (Foth) was retained by the Landfill of North Iowa (LNI) to evaluate pyrolysis and gasification as a method to process municipal solid waste (MSW) with a particular focus on the proposed process provided by Creative Energy Solutions, Inc. (CES). LNI also requested an analysis of potential impacts to staffing at LNI should the CES plant become operational. Foth was also requested by LNI to review the proposed contract provided to LNI by CES. However, the contract was not provided to LNI in time to be included in this report. Foth will provide LNI with comments on the CES contract in a separate letter report to LNI

Pyrolysis and gasification processes have been applied to MSW streams since the 1970's. The plants constructed were primarily pilot scale plants. The early plants experienced challenges with the waste feed system and the technology for pollution control was not developed at the time of the pilot plants in the 1970's through the 1990's. There were significant challenges with scaling up a pilot plant to a commercial scale plant. None of the early pyrolysis or gasification plants are operational today. During the early 2000's, there has been a resurgence of interest in pyrolysis and gasification as a method to manage MSW and create "green" energy. Several large governmental agencies in California have requested information of pyrolysis and gasification. In 2007, the County of Los Angeles selected Interstate Waste Technologies and NTech Environmental, two gasification technologies, to continue to be developed with the hopes of a large scale commercial facility. However, to date there are no commercial scale MSW pyrolysis or gasification facilities operating in North America. The closest to operating is believed to be the Enerkem gasifier in Edmonton, Alberta; and that is expected to be operational in 2012. There are currently an estimated 592 vendors worldwide offering some form of conversion technology that could be applied to MSW.

Foth also analyzed the waste stream received at LNI in 2011. The analysis indicated the MSW waste system averages between 160 to 235 tons per day. However, when the Iowa waste characterization is applied to the LNI waste stream, only 90 to 133 tons per day of MSW is suited for pyrolysis or gasification processes. For a 90 to 133 tons per day gasification facility, the expected outputs would be, approximately, 3,000,000 cubic feet of syngas, 3.2 tons of ash, and 0.9 tons of tar. If the facility accepts 130 tons per day, outputs increase to 4,600,000 cubic feet of syngas, 4.7 tons of ash and 1.3 tons of tar. For a pyrolysis process, the outputs vary depending on the temperature of the pyrolysis process. Given the range of temperatures for a pyrolysis process the outputs would be syngas 11-32 tons, oils 16-81 tons, and char 22-78 tons.

The economics of gasification and pyrolysis are not well published. Most recently, the Solid waste Association of North America (SWANA) published expected tip fees for a commercial scale gasification or pyrolysis plant in the range of $100-$300 per ton. However, tip fees are dependent on the inputs and outputs of a particular process and can vary considerably from plant to plant.

Emissions from pyrolysis and gasification plants can be treated to meet air pollution regulations using readily available air pollution control equipment. Any liquid discharges from a plant can also be treated to achieve discharge limits. Ash and residue from a pyrolysis or gasification plant can be tested to verify it can be placed in a landfill.

Impacts to LNI staffing are believed to be minimal. The CES plant will take some of the MSW waste stream and perhaps some of the C&D waste stream. However, given the 2011 waste data for LNI, even with the CES plant, LNI would still receive 165 to 250 tons per day. This tonnage would include C&D wastes, CES plant rejects, and ash from the CES process. The reduced tonnage to LNI is estimated to increase landfill life by 25-30 years.

A preliminary economic analysis of the CES plant indicates the economic viability of the proposed plant is questionable. Given the low purchase power prices and the capital and operating cost for such a plant, it is challenging to be economically viable without high power purchase agreement revenues. This could pose a potential risk to LNI. LNI should consider requesting CES to provide a confidential economic analysis to LNI for review to ensure the viability of the plant prior to committing to a contract.

# List of Abbreviations, Acronyms, and Symbols

| | |
|---|---|
| BTU | British Thermal Unit |
| C&D | Construction and Demolition |
| CES | Creative Energy Solutions |
| EPA | Environmental Protection Agency |
| ESP | Electrostatic Precipitator |
| Foth | Foth Infrastructure & Environment, LLC |
| HCI | Hydrogen Chloride |
| IAC | Iowa Administrative Code |
| IES | International Environmental Solutions |
| KWH | Kilowatt-Hour |
| LNI | Landfill of North Iowa |
| MSW | Municipal Solid Waste |
| PM | Particulate Matter |
| RDF | Refuse Derived Fuel |
| RO | Reverse Osmosis |
| SCR | Selective Catalytic Reduction |
| SNCR | Selective Non-Catalytic Reduction |
| TCLP | Toxicity Characteristic Leaching Procedure |
| TPD | Tons Per Day |

# 1 Introduction

Foth Infrastructure & Environment, LLC (Foth) was retained by the Landfill of North Iowa (LNI) to evaluate alternative solid waste management technologies with a focus on gasification and pyrolysis. The following report provides an overview of gasification and pyrolysis, an analysis of the proposed Creative Energy Systems (CES) pyrolysis plant, as well as analysis of the potential impacts to LNI should the proposed plant be constructed and operated successfully. Foth also provides conclusions and recommendations for LNI in regards to alternative technologies and strategies for the LNI to consider.

## 2 Purpose of Report

The overall purpose of this report is to provide LNI with an understanding of gasification and pyrolysis processes as it applies to municipal solid waste (MSW), and to evaluate the pyrolysis process proposed by CES to Mason City and LNI. Additionally, LNI has requested Foth review the proposed contracts provided by CES, as well as evaluate the potential impacts to LNI. LNI has not received a contract from CES so the evaluation was not completed. Should LNI receive a contract from CES, Foth will provide an evaluation of the contract via letter report to LNI.

# 3 Scope of Report

The scope of this report was developed by Foth and LNI to meet the needs of LNI in evaluating the alternative technology proposed by CES and to obtain a broader understanding of gasification and pyrolysis as it applies to MSW. Both gasification and pyrolysis sections of this report include descriptions of the process, history of the process, potential inputs and outputs from the process, vendors and plants in North America, economics studies (if published), and environmental considerations.

This report also provides analysis of the proposed CES plant. The analysis includes the potential operating scenarios, environmental considerations, permitting steps, and a preliminary economic analysis from the data provided by CES, and data gathered by Foth.

Finally, this report provides an analysis of the potential impacts to LNI should the proposed plant become operational. The report examines impacts to staffing, how LNI will handle plant rejects, ash and residue from the plant; closure and post closure fund impacts; facility life; and identify potential risks and mitigative measures to LNI.

The scope also includes conclusions and recommendations to assist LNI with this potential plant and future alternative technology vendors. The recommendations provided are based on Foth's experience with other public solid waste agency's efforts with alternative technology vendors and Foth's long history of working with public solid waste agencies in Iowa.

# 4 Alternative Technologies

This section evaluates the specific alternative technologies of gasification and pyrolysis. The technology evaluation is specific to the application of the technology to MSW. It is important to note that the specific technologies of gasification and pyrolysis have been in other industries for decades; however, application of the technology to MSW is relatively new and has not been successfully implemented in North America.

## 4.1 Gasification

### 4.1.1 Description and History

### 4.1.1.1 Description

Gasification is a thermal process that converts carbon based materials into a syngas. The process uses limited amounts of air or oxygen. Some gasification processes also inject steam to promote the production of carbon dioxide and hydrogen.[1] Gasification that uses air in the process typically produces a low BTU fuel that is nitrogen rich. Thermal gasification dissociates water from the waste into hydrogen and oxygen.[2] Gasification typically operates at temperatures ranging from 1450°F to 3000°F.

Production of energy from gasification using MSW has three major processes:[3]

1. MSW Handling and Processing
2. Conversion of MSW into Syngas
3. Power Conversion

MSW handling and processing is the first step in the gasification process. Receipt of MSW is typically completed in a building to control odor and windblown litter. The building is sized to handle the expected daily waste input and the waste storage area is typically large enough to store two to three days of waste to assure adequate waste input should interruption in the waste flow occur.

In order to remove recyclables and inerts or inert materials in the waste stream, the waste receiving area typically has a recycling facility and some method of shredding or grinding for the MSW so it can be sent to the gasification chamber efficiently. Size reduction is often required for more efficient handling of materials.[4] Additionally, the size reduction process allows for further metals removal and drying of the waste before the gasification process.

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[1] Young, Gary C. Municipal Solid Waste to Energy Conversion Process. John Wiley & Sons, Inc. 2010. Page 3

[2] Alemeda Power & Telecom, Investigation into Municipal Solid Waste Gasification for Power Generation. May 27, 2004. Page 6

[3] Ibid.

[4] URS Corp "Evaluation of Alternative Solid Waste Processing Technologies", Sept 2005, Page 2-4

The gasification process that converts the MSW into syngas can be completed in either fixed or fluidized bed configurations. The reactions that occur in a gasification process are:

1. $C + O_2 \rightarrow CO_2$
2. $C + H_2O \rightarrow CO + H_2$
3. $C + CO_2 \rightarrow 2CO$
4. $C + 2H_2 \rightarrow CH_4$
5. $CO + H_2O \rightarrow CO_2 + H_2$
6. $CO + 3H_2 \rightarrow CH_4 + H_2O$

The reactions are all reversible and are dependent on the pressure, temperature, and oxygen in the reactor.[5]

Fixed bed gasifiers are designed with a grate to support the MSW in the reactor zone. The downside of fixed bed gasifiers is the syngas yield can be variable in composition and quality. Fixed bed gasifiers are easier to design and operate compared to fluidizer beds, but are not well suited for large scale operations.[6] Two typical fixed bed gasifier designs include downdraft and updraft. Both feed MSWs from the top of the gasifier. The advantage of the updraft gasifier is that no pretreatment of the waste (i.e. drying) is required. Additionally, the syngas leaving the process is typically cooler than with a downdraft gasifier. [7]

The fluidized bed gasifiers typically use a solid material such as coarse sand or limestone as a bed of solid fuel. Waste is introduced into the reactor either on top of the bed or into the bed. Fluidized bed can be either bubbling fluidized bed or circulating fluidized bed reactors. Typically, fluidized bed reactors are used for larger capacity applications than fixed bed reactors[8]

#### 4.1.1.2 History

The history of gasification dates back over 50 years. Gasification has been used for the production of fuels at refineries.[9] Gasification of waste started almost 30 years ago. More than 20 processes were developed in the 1970's. Thirteen of the processes were operated at greater than 10 TPD.[10] Of all the gasification start-ups in the 1970's, only one remains outside of Paris, France. Failure in the early MSW gasification plants can be attributed to[11]:

1. Most of the processes intended to gasify or pyrolyse the raw MSW, i.e. no separation was envisioned. In combination with the proposed techniques, this often led to a more or less endless number of mechanical problems, shut-downs, sintering and so on.

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[5] Krigmont, H. (1999), "IBGCC Power Generation Concept: A Gateway for a Cleaner Future." Allied Environmental Technologies, white paper.www.alentecinc.com/papers/IGCC/ADVGASIFICAATION.pdf

[6] Klien, A. (2002). Thesis. "Gasification: an alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes." Columbia University.

[7] Ibid.

[8] Ibid.

[9] Gasification of Waste 101, Biocycle, April 2006

[10] Rensfelt, E and A Ostman. IEA Biomass Agreement. Subtask 6-Gasification of Waste, 1996. Page 7-8.

[11] Ibid., Page 5-6

2. The basic knowledge about waste and gasification/pyrolysis was poor. In several cases not even an acceptable analysis of the waste was at hand, and the heterogeneity of the raw material was underestimated. Both short-term (hours, day-to-day), and long-term (seasonal) variations have to be considered.

3. Scaling-up in the capacities of the units was too fast.

4. The fact that pyrolysis/gasification is a complex chemical conversion was seriously under-estimated. Several of the processes were "inventions" treating the process as a "thermal process".

5. Most of these process efforts included a fixed bed reactor, the ideas coming from coal gasification and old-time biomass gasification or metallurgical processes. The most common equipment is a shaft reactor with a bottom temperature of about 1000°C. The experience from fixed bed reactors found problems feeding waste to the reactor, difficulties in the reactor process and ash management challenges.

6. Most of the systems were pyrolysis/gasification producing tar or a mixture of tar and gas. Only a few of the processes included gas cleaning. The tar-rich gas caused problems on the gas side as well as condensation, clogging, etc. in the pipes to the combustor. The Garrett/Occidental process, with advanced recycling and thermal treatment on the other hand, probably was before its time, and included many new technologies.

During the 1980's and 1990's, several technological advances have occurred which have addressed some of the challenges experienced in the 1970's. Additionally, fluidized bed reactors have become common, as have the production of refuse derived fuel (RDF) to allow for more advanced pretreatment of the waste to reduce reactor problems.

The following table shows the gasification projects from the 1980's and 1990's. Most were based on the gasification of wood pellets. Wood provides a stable fuel source and pellets are easy to convey and handle as a fuel stock.

# Table 4-1

# Gasification Projects From the 1980's and 1990's

| Designation | Gasification/ Pyrolysis | Reactor Technology | Waste Fuel (Tested or Intended For (?)) | Product; Gas/ /Liquid | Operation |
|---|---|---|---|---|---|
| Applied Eng. Company | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Batelle Pacific Northwest Lab. | Gasification | Fixed Bed | MSW, Wood Waste | Gas | Lab. Abandoned ? |
| Bio-Solar | Gasification | Fixed Bed | Wood Pellets | Gas | Lab. Abandoned ? |
| C.H.H. Technology Inc. | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Century Research Inc. | Gasification | Fixed Bed | Agricultural Waste | Gas | Commercial |
| D.M. International Inc. | Gasification | Fixed Bed | Wastes | Gas | Commercial |
| EZ Manufacturing Company | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Forest Fuels Manufacturing Inc. | Gasification | Moving Bed | Wood Waste | Gas | Commercial |
| Halcyon Associates Inc. | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Maschinenfabrik A. Lambion | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Maschinenfabrik Augsburg-Ntimberg AG | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Westwood Polygas Ltd | Gasification | Fixed Bed | Wood Waste | Gas | Demo |
| National Synfuels Inc. | Pyrolysis/ Gasification | Moving Bed | Wood Waste | Gas | Dev. Unit |
| Alberta Industrial Development | Gasification | Fluidized, Bubbling | Wood Waste | Gas | Dev. Unit |

| **Designation** | **Gasification/ Pyrolysis** | **Reactor Technology** | **Waste Fuel (Tested or Intended For (?))** | **Product; Gas/ /Liquid** | **Operation** |
|---|---|---|---|---|---|
| Batelle Columbus | Gasification | Fluidized, Dual Bubbling Bed | Wood Waste RDF (?) | Gas | Dev. Unit |
| Energy Product of Idaho | Gasification | Fluidized, Bubbling | Wastes | Gas | Demo |
| Omnifuel | Gasification | Fluidized, Atmo. Bubbling Pressurized | Wood Wastes RDF (?) | Gas | Demo |
| Sur-Lite Corporation | Gasification | Fluidized, Bubbling | Wastes | Gas | Commercial |
| Universal Energy Intemat. Inc. | Pyrolysis | Moving Bed | MSW | Gas | Commercial |
| Energy Resources Company Inc. | Pyrolysis | Fluidized, Bubbling | Wood Waste | Gas | Demo |
| VynckeWarm te-techniek | Gasification | Moving Bed/Fluidized Bed | Wood Waste | Gas | Commercial |
| Thermoquip | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Dansk Termo Industri | Pyrolysis | Fixed Bed? | Agricultural Waste | Gas ? | Demo |
| ABB | Gasification | Fluidized Bed | Plastic Waste | Gas | Dev. Unit |
| Fritz Werner | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Imbert | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| KHD-Humboldt Wedag | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Rotopyr | Pyrolysis | Moving Bed | Plastic And Rubber Waste | Liquid? | Demo |
| Deutsche Babcock | Pyrolysis | Moving Bed | MSW | Liquid? | Demo |
| EFEU GmBH | Gasification | Fixed Bed | Wood Waste | Gas | Demo |

| **Designation** | **Gasification/ Pyrolysis** | **Reactor Technology** | **Waste Fuel (Tested or Intended For (?))** | **Product; Gas/ /Liquid** | **Operation** |
|---|---|---|---|---|---|
| Chevet | Gasification | Fixed Bed | Wood Waste | Gas | Dev. Unit |
| Touillet | Gasification | Fixed Bed | Wood Waste | Gas | Dev. Unit |
| Creuzot- Loire/ /Frama | Gasification | Fluidized Bed | Wood Waste | Gas | Demo |
| TNEE | Gasification | Fluidized Bed | Wood Waste | Gas | Demo |
| CEMAGREF Carbonizer | Gasification | Fixed Bed | Wood Waste | Gas | Dev. Unit |
| GA-10 (20) (Duvant) | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Pillard | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Entropie SA | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| BECE | Gasification | Fixed Bed | Wood Waste | Gas | Demo |
| Gotaverken Energy System | Gasification | Fast Fluidize | Wood Waste | Gas | Commercial |
| Thalapnat AG | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Century Research Inc | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Rolla, Univ of Missouri | Gasification | Fluidized Bed | Wood Waste, Agricultural Waste | Gas | Dev. Unit |
| Biosyn | Gasification | Fluidized Bed | Wood Waste | Gas | ? |
| EPI | Gasification | Fluidized Bed | Wood Waste | Gas | Commercial |
| Pyrenco | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| SYNGAS | Gasification | Fixed Bed | Wood Waste | Gas | Demo |
| Biotherm | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Cross Cut | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| Dekalb Agriresearch | Gasification | Fixed Bed | Agricultural Waste | Gas | Commercial |
| HalyconAss.I | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |

| **Designation** | **Gasification/ Pyrolysis** | **Reactor Technology** | **Waste Fuel (Tested or Intended For (?))** | **Product; Gas/ /Liquid** | **Operation** |
|---|---|---|---|---|---|
| Pendu Gas | Gasification | Fixed Bed | Wood Waste | Gas | Commercial |
| PRM | Gasification | Moving Bed | Agricultural Waste | Gas | Commercial |

It is notable that most of the technologies shown in Table 4-1 are not commercially available today. From the seventies, there seem to be none for MSW/RDF beside the Andco-Torrax process.

Most of the fixed bed reactors have capacities less than 10 MW (updraft) or less than 1 MW (downdraft) and for most of the technologies gas cleaning is not incorporated. This reflects the local energy situation where small scale utilization of- primarily - wood waste is beneficial. Regarding MSW and RDF it can be argued whether the small scale (fixed bed) gasification is a reasonable technique in relation to society's handling of (waste) material. This, however, touches on a more system or political question - whether wastes should be handled locally or in large scale, centralized units.

Between 1990 and today, several supplies of gasifiers for MSW have emerged. Juniper Research has identified over 80 technology suppliers for gasification.[12] Juniper Research indicates only 9% are at commercial scale.

In 2004, the University of California completed an Evaluation of Conversion Technologies for the State of California where input was requested from specific technology vendors. The following U.S. Vendors responded:[13]

| | |
|---|---|
| Bioengineering Resources, Inc. | Fayetteville, AK |
| Community Power Corporation | Colorado |
| Omnifuel Technologies | Citrus Heights, CA |
| Emery Energy Company, LLC | Salt Lake City, UT |
| Energy Products of Idaho (EPI) | Coeur d’Alene, ID |
| FERCO | Norcross, GA |
| FosterWheeler Energiaoy | Clinton, NJ |
| Gas Technology Institute | Des Plaines, IL |
| Improved Converters (ICI) | Sacramento, CA |
| Interstate Waste Technologies | Malvenn, PA |
| Pacific Northwest National Lab | Richland, WA |
| Renewable Resource Alliance | California |
| ThermoEnergy | Little Rock, AR |
| Thermogenics, Inc. | Albuquerque, NM |

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[12] Juniper Consultancy Services Ltd. Presentation

[13] Evaluation of Conversion Technologies CIWMB, 2004

The study was updated in 2009, which included responses from the following gasification system vendors:[14]

| | |
|---|---|
| Agricultural Waste Solutions, Inc. | California |
| Coaltec Energy USA, Inc. | Illinois |
| Genahol, LLC | Ohio |
| InEnTec Energy Solutions | Washington |
| PRM Energy Systems, Inc. | Arkansas |
| Taylor Biomass Energy, LLC | New York |

Many of the 2004 system vendors did not respond in 2009.

Several municipalities in California have issued request for qualifications for conversion technologies. In 2007, the County of Los Angeles selected two gasification technologies to continue to be developed for eventual commercialization. These vendors included Interstate Waste Technologies and NTech Environmental.[15] The City and County of Santa Barbara and other cities have followed the lead provided by the County of Los Angeles and are evaluating implementation of gasification to manage MSW.

### 4.1.2 Inputs and Outputs with Iowa Waste Characterization

This section examines the potential inputs and outputs of a gasification system. Inputs are based on the State of Iowa waste characterization study completed in 2011 and tonnage data supplied by LNI. Outputs are estimated based on published data on gasification processes and mass balances adjusted for the inputs from LNI's waste stream.

#### 4.1.2.1 Inputs

Inputs into gasification processes are assumed to be waste from LNI. Waste quantities were generated from LNI data provided for 2011. Foth received a detailed list of all waste loads accepted at the LNI between January 3, 2011 and December 13, 2011. This list included wastes categorized using the LNI Material Codes (which were also provided). Foth's analysis of the data began by re-categorizing the data into the following two categories: MSW or C&D. The MSW fraction of the total waste stream is the main potential fuel source of interest. While some C&D waste may be capable of being gasified, load composition may not allow for the specific materials to be effectively sorted and sent to a gasifier. Therefore, C&D waste was not considered in this analysis.

With the data re-categorized, each day was divided into morning and evening to determine if there was significant variation in the amount of MSW received during different periods of the day. Figure 4-1 shows the maximum daily sum of MSW received during the morning and evening as well as the total daily sum of waste received at the LNI based on the data provided.

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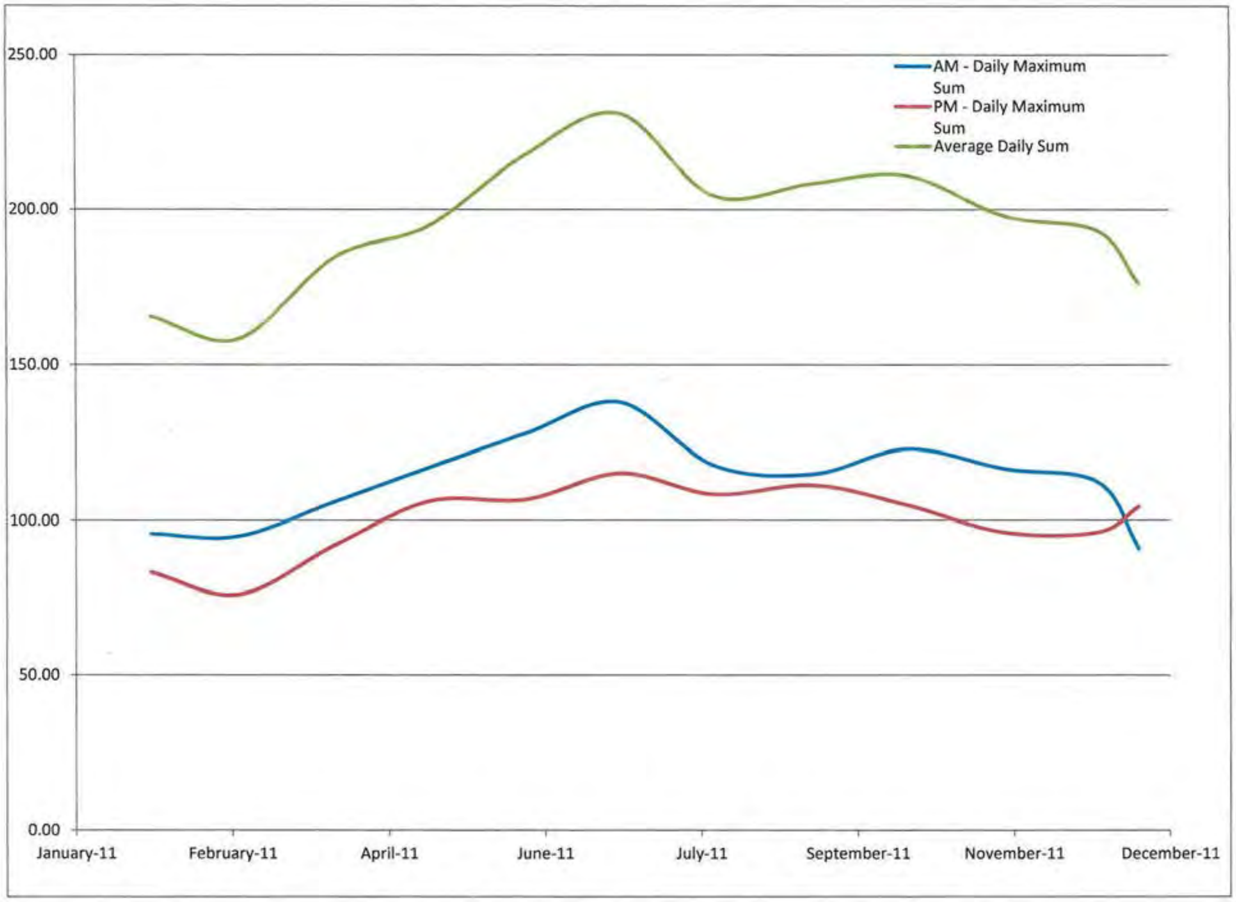
[14] Conversion Technologies Status Update Survey, CIWMB, April 2009

[15] Los Angeles County Conversion Technology Evaluation Report, Phase II Assessment. October 2007, ES-8.

## Figure 4-1

## MSW Received in 2011

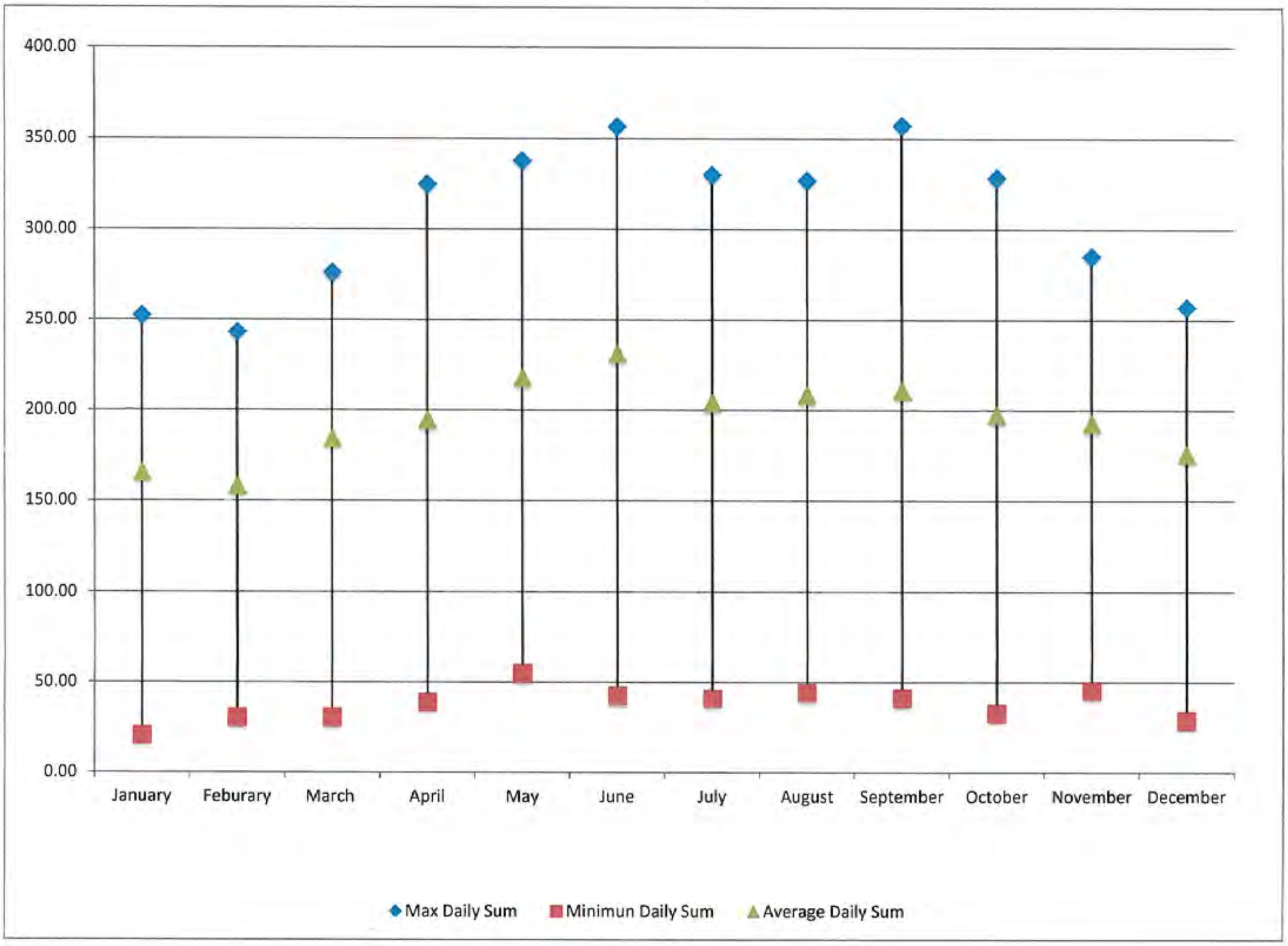


The results of this analysis indicate that in general the LNI receives about 10-15% more waste during the morning (a.m.) hours. However, the waste received at the landfill is relatively constant with time of day and averages between 160 and 235 tons/day depending on time of year. Additionally, the seasonal variation in waste amounts received is apparent and an increase in waste amount during the summer months (May-September) was observed.

Foth also examined the variability of waste received during each day on a monthly basis. Figure 4-2 shows the minimum, maximum, and average daily sum of waste received during each month. For example, the minimum daily amount of waste received for all days in January was 20 tons, the maximum was 252 tons and the average was 165 tons. The minimum daily tonnages are typically during Saturdays when LNI is only open during the morning. However, if these results were removed from the analysis, the minimum and average daily tons of waste received would only slightly increase and there would be no effect on the maximum daily tons of waste received.

# Figure 4-2

## Minimum, Maximum, and Average Daily Sum of Waste Received



One additional important factor to note is that the data analyzed by Foth includes all MSW; not just the portion of MSW that can be used to create RDF. There is typically a 35-40% reduction in in material when going from MSW to RDF, which is made up of metals, plastics, and other inerts not suitable for gasification.

Using the 2011 waste characterization study conducted by the Iowa DNR,[16] the MSW delivered to LNI is estimated to comprise of:

- *Paper – 20.2%*
- Metal – 5.0%
- Glass – 2.0%
- *Organic – 31.7%*
- C&D – 11.0%
- Plastic – 14.5%
- Durable – 2.8%
- HHMs – 0.4%
- Other – 12.4 *(4.6% Organic)*

* Italics indicate suitable for gasification

Therefore, of the estimated 160-235 tons/day of MSW received, the actual waste available for gasification is approximately 90 to 133 tons per day (56.5%). The remaining waste would be residuals sent back to the landfill for disposal or recycling. Since metals only comprise of 5% of the MSW waste stream (attributable to good recycling programs), residuals returned to the landfill would be in the range of 62 to 91 tons per day.

### 4.1.2.2 Outputs

For a gasification system that accepts an estimated 90 to 133 tons per day of MSW, the expected outputs include syngas and ash material. The syngas will require some clean-up before use which will also create some additional by-products that will need to be managed. If the plant uses RDF in the gasification process (which is most common), the amount of syngas produced is estimated to be 1.1 $m^3$/kg (35,230 $ft^3$/ton) [17]. Syngas is a low BTU source ranging 400 to 500 BTU/cubic feet. The amount of ash produced in a gasification process is estimated to be 143 lbs. of ash per ton at RDF.[18] Additionally, a gasifier will produce a tar residue (depending on gasifier temperature) and a filter ash from the syngas clean-up. TPS Termiska published data on gasifier performance indicating that gasification of domestic waste will produce 10g/kg (304 lbs. /ton) of filter ash residue.[19] However, during operation the TPS Termiska gasification process produced only 71 lbs. of ash per ton of domestic waste which is slightly lower than other gasification processes.

For the LNI waste stream of 90 to 133 tons per day, the expected outputs would be:

| | **90 TPD** | **133 TPD** |
|---|---|---|
| **Syngas** | 3,170,700 c.f. | 4,685,590 c.f. |
| **Ash** | 3.2 tons | 4.7 tons |
| **Tar** | 0.9 tons | 1.3 tons |

Syngas, ash, and tar production are dependent on gasification temperature, but the values presented above are appropriate for this level of study. Further mass balance may be warranted when actual facility operating data is available.

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[16] Mid-Atlantic Solid Waste Consultants, Table 3-2 "2011 Detailed Residential Waste Composition", Page 3-5.

[17] "Thermal Methods of Municipal Waste Treatment." L-Tech Innovation LTD. 2003. Page 41.

[18] "Case Study on Waste-Fuelled Gasification Project, Greve in Chianti, Italy." IEA Bioenergy Agreement – Task 36. D.L. Granutstein. June 2003, Page 11

[19] Ibid.

### 4.1.3 North American Vendors and Plants

Currently, there are no commercially operated gasification plants in North America using MSW. There are two operational demonstration plants (Enerkern in Westbury, Quebec and ZeGen in New Bedford, Massachusetts) and four under construction[20] (Vero Beach, Florida; Pontotoc, Mississippi; Montgomery, New York; and Edmonton, Alberta). There are an unknown amount of gasification vendors at any one time on North America. The latest estimate is there are approximately 592 companies offering conversion technology development services. There are an estimated 175 companies offering gasification processes and 47 offering plasma gasification processes.[21]

### 4.1.4 Published Economic Studies

Economic studies for gasification plants in North America have not been published. Most of the plants in North America in the pilot stage have limited data available. The economics of a pilot plant may not be relevant to a full scale plant. Recently published information on gasification economics indicates a tipping fee of $100-$300 per ton with capital costs in the range of $275,000 per ton per day of waste capacity (a 250 TPD plant capital costs would be $68.75 million).[22]

Economic analysis of an MSW fueled gasification plant in Greve in Chianti, Italy reports capital costs were $20 million with an additional $13 million upgrade for a 200 tons per day RDF gasifier ($165,000 per ton per day). No operating costs for this plant were available.[23]

TPS Termiska gasification plant published a capital cost of $171 million ($1996) for a 1,200 tons per day plant ($142,500 per ton per day). Annual gross operation and maintenance costs were $35.6 million ($1996) with electrical revenues of $16.2 million annually. The net cost for the process was estimated to be $38.91 ($1996) per ton of MSW.[24]

Various other economic studies were completed at small pilot plants and attempts were made to estimate “scaled up” plant costs.[25] However, the gasifiers were based on coal or wood pellets and are not applicable to this study.

### 4.1.5 Environmental Considerations

Gasification as a process can produce emissions below regulated limits. However, the Integrated Waste Technology plant in Karlsruhe, Germany did have operational challenges that did cause

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[20] O’Brien, Jeremy K. “Waste Conversion Technologies.” MSW Management. January/February 2012 Page 13-18

[21] Gershman, Harvey W., “Waste to Energy and Conversion Technologies under the Commercial Microscope.” Presented at the Waste Conversion Congress West Coast. December 6, 2011. San Jose, California.

[22] O’Brien, Jeremy K. “Waste Conversion Technologies.” MSW Management. January/February 2012 Page 13-18

[23] “Case Study on Waste-Fuelled Gasification Project, Greve in Chianti, Italy.” IEA Bioenergy Agreement – Task 36. D.L. Granutstein. June 2003, Page 11

[24] Rensfelt, E. “Swedish Biomass Gasification Activities.” TPS Termiska Processor AD. March 2011.

[25] Granatstein, D.L. “Fluidized Bed Gasification as a Means of Converting Waste to Energy.” Natural Resources, Canada, Ontario, CA. 2004

environmental damage.[26] However; good engineering, construction, and operations can mitigate most, if not all, environmental concerns.

The primary environmental issue for gasification is air emissions. Air emissions controls and processing systems will be required for a gasification plant.

Air emissions controls may include:

- When syngas is combusted in a boiler, reciprocating engine, or gas turbine, automated combustion controls and furnace geometry (for boilers) designed to optimize residence time, temperature, and turbulence to ensure combustion.
- For combustion of syngas in a boiler, low-$NO_x$ burners and/or a Selective Non-Catalytic Reduction (SNCR) system for reduction of $NO_x$ emissions. Selective Catalytic Reduction (SCR) is typical for exhaust gases from reciprocating engines and gas turbine.
- Baghouse (fabric filter) for removal of particular matter from flue gases.
- Activated carbon injection (followed by a baghouse) for removal of trace metals (such as mercury).
- Wet scrubber for removal of chlorides/HCI (may produce salable HCI).
- Wet, dry, or semi-dry scrubber for $SO_2$ (may produce salable gypsum).
- Final baghouse for removal of fine particulate matter after dry or semi-dry scrubbers.

Air emission control equipment to accomplish this syngas and/or flue gas clean-up is commercially available and is able to reduce air emissions to levels well below regulatory limits.[27]

There is little published air emission data on gasification plants operating on MSW or RDF. The Greve in Chianti, Italy, plant had limited air emissions data, but indicated emissions below regulated limits. Emissions from gasification may cause fuel burned nitrogen to form ammonia or hydrogen cyanide which could require catalytic cracking to treat the syngas.[28]

Gasification does have the potential to form dioxins. However, the production of dioxins is relative to the oxygen concentration of the syngas. Since gasification requires limited amounts of oxygen for the process, dioxin formation is unlikely. In two gasification plants in Europe, dioxin levels were below the detection levels.[29]

Other environmental considerations include water and residual disposal. The liquid used for syngas cooling can be cleaned up to surface water discharge standards using conventional equipment and processes. Additionally, the liquid is usually recycled in the plant which further

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[26] "Thermoselect Reality Check." http://www.greenaction.org/incinerators/documents/factsheet_ThermoselectRealityCheck.pdf" viewed December 4, 2011

[27] "Evaluation of Alternative Solid Waste Technologies." Prepared for the City of Los Angeles by URS Corporation, September 2005. Page 2-14 and 2-15.

[28] "Thermal Methods of Municipal Waste Treatment." L-Tech Innovation LTD. 2003. Page 40.

[29] Ibid.

reduces discharge. Residuals disposal from gasification of MSW is expected to be similar to ash disposal for MSW combustion. Ash disposal for MSW combustion is well regulated to protect human health and the environment.

## 4.2 Pyrolysis

### 4.2.1 Description and History

#### 4.2.1.1 Description

Pyrolysis is the thermal breakdown process of carbon based materials in an oxygen-deficient atmosphere using heat to produce syngas. The process does not allow air or oxygen so there is no direct burning of the waste material.[30] Based on descriptions of several United States based projects, most at the pilot level, managing MSW through pyrolysis appears to require several process steps:

- Pre-processing, this typically includes a bag opener, a sorting or screening system to separate non-organic recyclables, and a shredding or size reduction process.
- Drying, this involves evaporation of moisture from the waste feedstock. This typically occurs through heating the feedstock before it enters the pyrolysis system. A second opportunity for drying, quenching, occurs late in the pyrolysis system and refers to rapidly cooled to decompose (e.g., vaporize) waste into a mixture of gas, liquid, and solids.
- Recovery and refinement of oils, gases, and solids.
- Power generation or gas combustion, typically to support on-site processes.

Pilot and demonstration projects also note the need to clean the output gases, possibly through an electrostatic precipitator (ESP) or wet scrubbing process.

The result of these processes is intended to be the transformation of MSW into pre-separated recyclable materials and three process components; gas, liquid, and solid.

#### 4.2.1.2 History[31]

Pyrolysis processes as applied to MSW began in North America in the 1970's. Two particular projects were the San Diego Flash Pyrolysis Facility and the Andco-Torrax Pyrolysis system. A summary of both projects is provided.

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[30] Young, Gary C. Municipal Solid Waste to Energy Conversion Process. John Wiley & Sons, Inc. 2010. Page 3

[31] Milton, Wilson E. et. al. "Engineering and Economic Analysis of Waste to Energy Systems" EPA-600/7-78-086. May 1978

### San Diego Pyrolysis Facility, Occidential Research Corporation

A full-scale MSW pyrolysis facility, the 200 TPD San Diego Flash Pyrolysis Facility has been constructed in the United States. The San Diego facility was intended to be operated as a demonstration project only prior to development of a much larger 1,000 to 2,000 TPD facility. The facility was constructed and operated by the Occidental Research Corporation (Occidental) under a turnkey contract with San Diego County and some financial support ($4.2 million) from the EPA.

Construction on the facility began in February 1976. Following a seven-month shakedown period, a planned third party, one-year testing and evaluation phase began in August 1977. The facility was closed in July 1978.

The facility was intended to run waste receiving and pre-processing operations eight hours per day, six days per week (2,496 hours per year) with all other operations intended to run 24 hours per day, six days per week (7,488 hours per year). Despite this planned schedule, during the eleven months between the start of the third party evaluation and facility closure, the pyrolysis system operated only 140 hours. The facility was never able to complete EPA's requirement for 72 hours of consecutive operation.

The limited amount of operating time was "attributed to excessive mechanical problems and breakdowns experienced throughout the plant, especially in the pyrolysis system." Operating problems were reported to occur at all stages of the processing, including an inability to dry feedstock to design specifications, an inability to replace outside heating fuel sources with internally produced pyrolytic gas, and problems separating solids and gases that led to blockages in a variety of waste handling and material delivery systems. Taken as a whole, the problems led to the production of a pyrofuel, the intended facility output, that did not meet market specifications for moisture content and thus, heating values.

### Andco-Torrax Pyrolysis System

The Andco-Torrax Pyrolysis (Andco) System was intended to convert MSW into a usable gas, which could be burned to produce heat and generate steam. It was demonstrated in Eric County, New York, beginning in 1972. Additional commercial (full-scale applications) facilities were reported as under construction in Europe in 1977 and 1978.

The Andco system report provided design and operating assumptions and cost projections for facilities at three sizes; 331 TPD, 992 TPD, and 1,653 TPD. At the 992 TPD design through put level, a facility was assumed to have a utilization factor of 85 to 90 percent per year and some system redundancy (i.e., back-up systems) necessary for production reliability. Site requirements were estimated at eight (8) acres for staging, buildings, load-out, and traffic flow.

The 992 TPD facility was projected to produce 2,449 TPD of steam at 493 pounds per square inch (psia) and 234 TPD of potentially reusable slag. Emissions include hydrochloric acids, sulfur oxides, nitrous oxides, carbon oxides, and hydrocarbons. Use of an electrostatic precipitator for cleaning air emissions was recommended as a means to meet federal air quality standards for $CO_2$ existing at the time.

The study concluded that the system was likely to be competitive with oil-based steam generators where tipping fees of approximately $10 per ton (approximately $44.30 in 2011 dollars) were charged on incoming MSW. Neither the San Diego or Andco Torrax systems are operational today.

### 4.2.2 Inputs and Outputs with Iowa Waste Characterization

For analysis of the pyrolysis system inputs a study of the projected waste flow was completed using data provided by LNI for 2011. The study is discussed in Section 4.1.2.1. The key result is the total waste available into the process is 90-133 tons per day.

Outputs for a pyrolysis process are dependent on the temperature of the process. The three outputs from a pyrolysis process include syngas, liquid, and char.

#### 4.2.2.1 Syngas

The syngas produced in a pyrolysis process contains hydrogen, methane, carbon dioxide, carbon monoxide, ethylene and ethane. The percentage of each compound is the syngas varies with the temperature of the pyrolysis process as shown in Table 4-2.[32]

Table 4-2
Percentages of Components in
Syngas from Pyrolysis of MSW

| | % by Volume | | | |
|---|---|---|---|---|
| **Gas** | **900°F** | **1200°F** | **1500°F** | **1700°F** |
| Hydrogen | 5.56 | 16.58 | 28.55 | 32.48 |
| Methane | 12.43 | 15.91 | 13.73 | 10.45 |
| Carbon Dioxide | 33.50 | 30.49 | 34.12 | 35.25 |
| Carbon Monoxide | 44.77 | 31.78 | 20.59 | 18.31 |
| Ethylene | 0.45 | 2.18 | 2.24 | 2.43 |
| Ethane | 3.03 | 3.06 | 0.77 | 1.07 |

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[32] Tchobanaglous, George, Hilary Theisen and Samuel Vigil. Integrated Solid Waste Management: Engineering Principles and Management Issues. Page 628

Typical syngas composition from the Purox pyrolysis process (2700°F) is shown in Table 4-3. [33]

## Table 4-3
## Syngas Composition from Purox Pyrolysis Process

| Gas | Percent (%), Dry Basis |
|---|---|
| Hydrogen | 24 |
| Carbon Dioxide | 40 |
| Carbon Monoxide | 24 |
| Methane | 5 |
| Acetylene | 0.7 |
| Ethylene | 2.1 |
| Ethane | 0.3 |
| Other Hydrocarbons | 2.35 |
| Nitrogen | 1 |
| Argon | 0.5 |
| Hydrogen Sulfide | 0.05 |

### 4.2.2.2 Liquids

Liquids provided from pyrolysis processes contain tars and oils composed of acetic acid, acetone, methanol, and other hydrocarbons. Liquid production is somewhat influenced by the pyrolysis temperature but only a few pounds of difference in liquid production was observed when pyrolysis temperatures ranged from 900°F to 1700°F. Higher temperatures produce less liquid.[34] Liquids for a pyrolysis process are referred to as tars. Liquids can be refined and further processed to make fuel.

### 4.2.2.3 Char

The final product of the pyrolysis process is a solid, called char, which consists of pure carbon and inert materials from the MSW feedstock. According to an editorial from a Regional Director of a pyrolysis system vendor, char is typically a non-toxic, non-hazardous product with a heating value of 7,000 to 8,000 BTUs per pound and may have value as a fuel source or potential soil additive.[35]

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[33] Farberow, Carrie, and Kevin Bailey. “Green is Seen in Fertilizers. A New Approach to Municipal Solid Waste Management.” University of Oklahoma. May 1, 2007. Page 8.

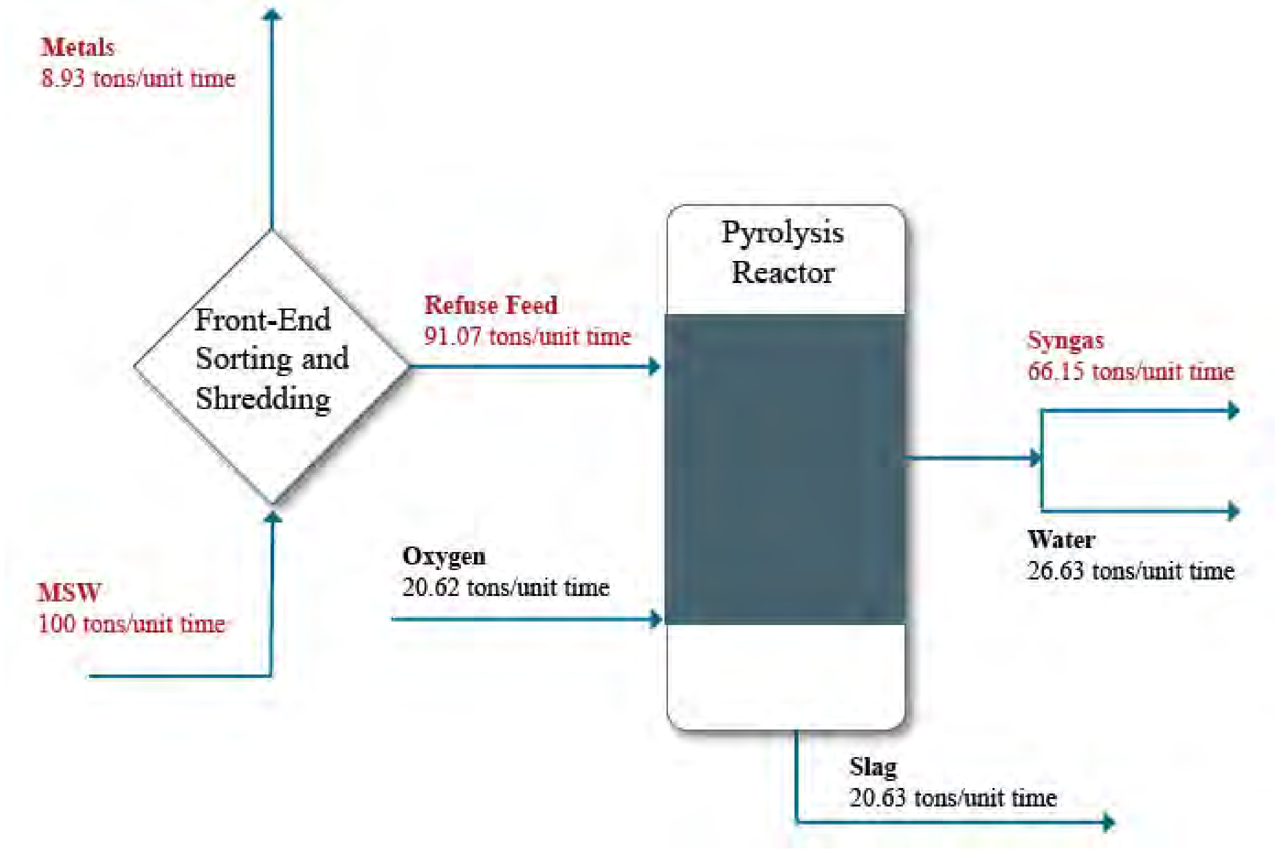
[34] Tchobanaglous, George, Hilary Theisen and Samuel Vigil. Integrated Solid Waste Management: Engineering Principles and Management Issues. Page 628

[35] Doble, Bill. “Pyrolysis for Low Cost Waste Disposal and Generation of Electricity. http://eco-web.com/editorial/03280.html

#### 4.2.2.4 Mass Balance

The mass balance for pyrolysis systems has not been well studied. Studies on the Purox Pyrolysis system yielded the following mass balance:[36]

Figure 4-3
Purox Pyrolysis Mass Balance



In a study of pyrolysis of RDF in Japan, at 932°F with a residence of 30 minutes, outputs were 28% by weight liquids, 30% by weight gases and 42% by weight solids.[37]

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[36] Farberow, Carrie, and Kevin Bailey. "Green is Seen in Fertilizers. A New Approach to Municipal Solid Waste Management." University of Oklahoma. May 1, 2007. Page 8.

[37] Kuen-Sung Lin, et. al. "Prolysis Kinetics of Refuse Derived Fuel." Fuel Processing Technology 60 (1989). Page 103-110.

Mass balance from the San Diego Flash Pyrolysis facility is provided in Table 4-4[38]

### Table 4-4
### Pyrolysis Mass Balance for Flash Pyrolysis (lbs.)

| Temp (°F) | Refuse [1] | Gases | Pyroligneous Acids and Tars[2] | Char | Mass Accounted For |
|---|---|---|---|---|---|
| 900 | 100 | 12.33 | 61.08 | 24.71 | 98.12 |
| 1200 | 100 | 18.64 | 18.64 | 59.18 | 99.62 |
| 1500 | 100 | 23.69 | 59.67 | 17.24 | 100.59 |
| 1700 | 100 | 24.36 | 58.70 | 19.67 | 100.73 |

1 On an as-received basis, except that metals and glass have been removed.

2This column includes all condensable and the figures cited include 70 to 80 percent water.

Using the expected tonnage of 90 to 133 tons per day from the LNI and the mass balance shown in Table 4-4, the expected outputs would be:

| Temp (°F) | Syngas (tons) | Oils (Tons) | Char (Tons) |
|---|---|---|---|
| 900 | 11.1 - 16.4 | 55.0 - 81.2 | 22.2 -32.9 |
| 1200 | 16.8 - 24.8 | 16.8 - 24.8 | 53.3- 78.7 |
| 1500 | 21.3 - 31.5 | 53.7 - 79.4 | 15.5 - 22.9 |
| 1700 | 21.9 - 32.4 | 52.8 - 78.1 | 15.9 - 23.5 |

Depending on the temperature of the process, pyrolysis generates significant amounts of oil and char that must be managed. Char can be used (if tested) for a potential soil amendment because it is mostly carbon. However, the oil produced can contain significant amounts of water and contaminants that would need to be addressed in order to use the oil.

Syngas produced tends to be a low BTU syngas that also would require some clean up to be beneficially used in a turbine or internal combustion engine.

### 4.2.3 North American Vendors and Plants

Pyrolysis processes are in commercial use by the metals industry for fracking contaminated non-ferrous scrap. Additionally, pyrolysis processes are used to convert polymers back to petrochemicals.[39] There are several pyrolysis systems in Japan and other countries that use MSW as a feedstock. MSW is typically used in combination with other wastes such as industrial waste, petcoke, auto shedder residue, and medical waste. Pyrolysis plants operating using MSW as a feedstock are in Japan, Europe, Australia, and Indonesia.[40] There are no known commercial MSW pyrolysis plants in North America.

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[38] Drobny, N.L., et. al. “Recovery and Utilization of Municipal Solid Waste (SW-10c) U.S. EPA 1971 Page 77

[39] “Thermal Methods of Municipal Waste Treatment.” Biffaward Prograrnme on Sustainable Resource Use. 2003 Page 28.

[40] “Evaluation of Emissions of Thermal Conversion Technologies Processing Municipal Solid Waste and Business.” U.C. Riverside. June 21, 2009 Page 38-41

### 4.2.4 Published Economic Studies

With the lack of plants in North America, no published economic studies are known. Recent published information on pyrolysis plants with MSW feedstock indicted tipping fees for new facilities would be in the range of \$100-\$300 per ton with capital costs approximated as \$275,000 per design ton per day.[41]

### 4.2.5 Environmental Considerations

Environmental considerations for pyrolysis processes with MSW feedstock include air emissions and the remaining char. While pyrolysis processes also can produce a liquid, the liquid can be refined at a refinery. If the pyrolysis process produces a non-refinable liquid, then reverse osmosis and/or carbon absorption may be needed to cleanse the liquid component prior to discharge.

Air emissions from pyrolysis processes were evaluated from the International Environmental Solutions (IES) pyrolysis plant in Romoland, California (a small test facility) and from a pyrolysis and gasification plant in Nagasaki, Japan using Thermoselect process. [42]

The IES process utilized an air pollution control system consisting of a selective non-catalytic reduction unit for $NO_x$ control, a baghouse to capture particulate matter (PM) and a scrubber to control acid gases and volatile metals.

Emissions from the IES system from the compliance test report are shown in Table 4-5.[43]

Table 4-5
IES Air Emissions, Romoland, California (2006)

| 30 Tons per day MSW<br>Emissions ($mg/N\text{-}M^3@7\%O_2$) | Measured | US EPA Standard |
|---|---|---|
| PM | 5.75 | 20 |
| HCL | --- | 40.6 |
| Nox | 129 | 308 |
| Sox | 0.44 | 85.7 |
| Hg | --- | 50 |
| Dioxins/furans (mg/N-M3) | 0.000581 | 13 |

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[41] O'Brien, Jeremy K. "Waste Conversion Technologies." MSW Management. January/February 2012 Page 14-15

[42] "Evaluation of Emissions of Thermal Conversion Technologies Processing Municipal Solid Waste and Business." U.C. Riverside. June 21, 2009 Page 16

[43] South Coast Air Quality Management District Memorandum, "Evaluation of Source Test Report – International Environment Solutions, Romoland, California." April 18, 2007.

The Theroselect process is a pyrolysis and gasification process to increase the quantity of syngas produced from MSW. The Thermoselect process is used in Japan to process MSW, MSW and industrial waste, and a new plant (2007) that processes wood chips.[44]

Emissions from the Thermoselect Nagasaki plant for 2006 are provided in Table 4-6.[45]

## Table 4-6
## Thermoselect Air Emissions, Nagasaki, Japan (2006)

**300 Tons per Day**
**Pyrolysis and Gasification**

| **Emissions ($mg/N\text{-}M^3 @ 7\% O_2$)** | **Measured** | **Japanese Standard** | **US EPA Standard** |
|---|---|---|---|
| PM | <4.7 | 15.4 | 20 |
| HCL | 11.6 | 126 | 40.6 |
| Nox | --- | 320 | 308 |
| Sox | --- | 225 | 85.7 |
| Hg | --- | --- | 50 |
| Dioxins/furans (mg/N-M3) | 0.025 | 0.14 | 13 |

The char output from pyrolysis consists of volatile matter, fixed carbon and ash. The quantity of each substance would depend on the temperature of the process. As temperature increases the amount of volatile matter and fixed carbon decrease while the amount of ash increases. [46] No specific testing of the char using standard test methods was identified.

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[44] "Evaluation of Emissions of Thermal Conversion Technologies Processing Municipal Solid waste and Business." U.C. Riverside. June 21, 2009 Page 17

[45] Kenou-Kennen, Kankyou-Kumiai. "Emissions Data of JFE Nagasaki Plant." Compliance Source Test report, April-June 2006.

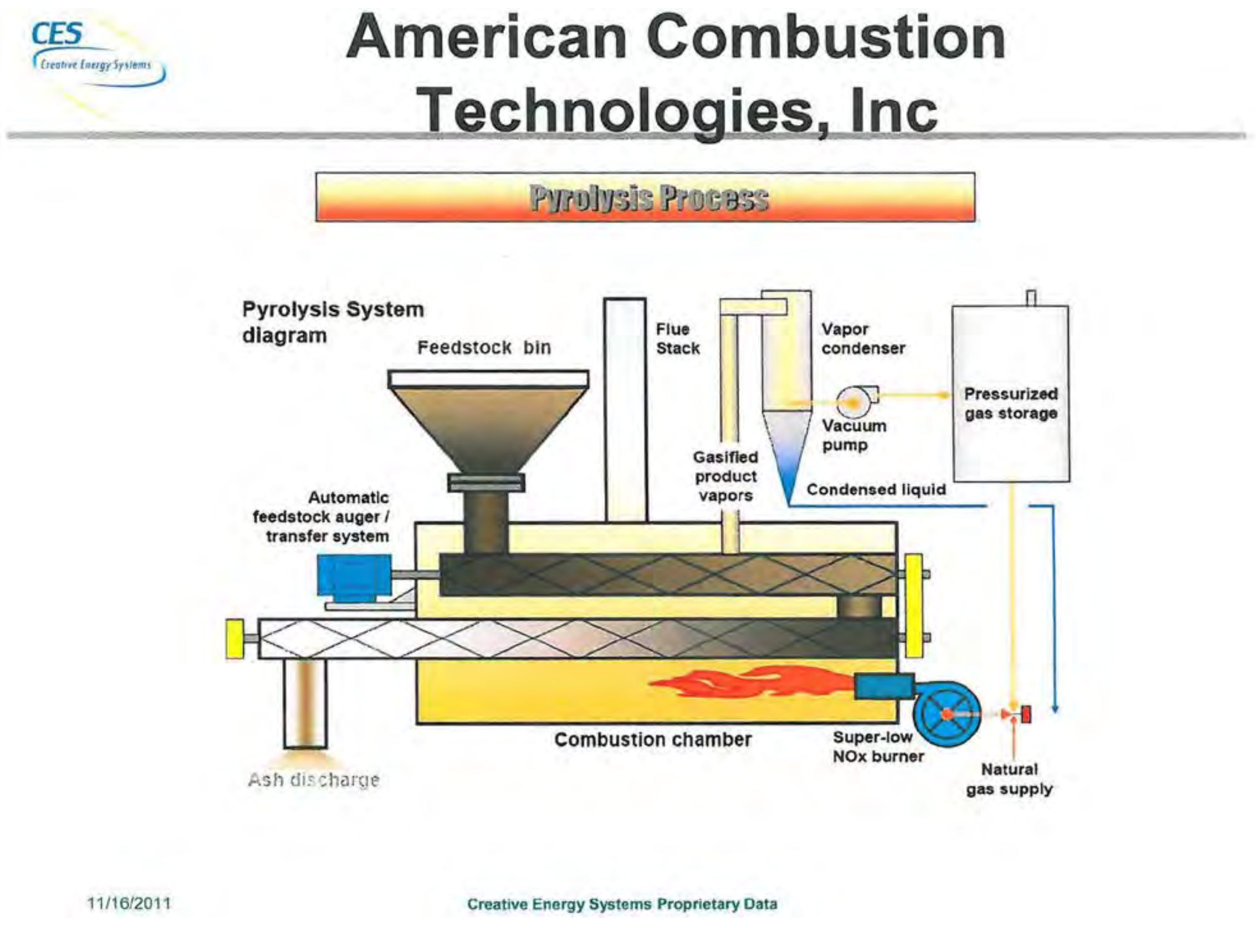
[46] Drobny, N.L., et. al. "Recovery and Utilization of Municipal Solid Waste (SW-10c) U.S. EPA 1971 Page 77.

# 5 Analysis of CES Proposed Plant

## 5.1 Technology

The proposed CES plant is based on the IES process.[47] The IES process is an Advanced Pyrolysis Treatment Thermal Conversion system that consists of a retort chamber and syngas clean-up equipment. Waste is fed by a screw conveyor into the retort chamber. Air locks are used to minimize air intrusion and fugitive emissions. Ash and char exit the retort chamber through a lock hopper. The IES plant in Romoland used air pollution control equipment to treat the syngas after the thermal oxidizer and waste heat boilers. Treatment includes selective non-catalytic reduction for $NO_x$ control, baghouse for particulate matter (PM) capture, and a scrubber for acid gases and volatile metals.[48] The proposed process from CES is provided in Figure 5-1.[49]

Figure 5-1
Proposed Process from CES



American Combustion Technologies, Inc

Pyrolysis Process

11/16/2011

Creative Energy Systems Proprietary Data

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[47] Yavorski, Joseph D., "Creative Energy Systems, Inc. Open Questions Public Meeting." November 16, 2011.

[48] "Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass" U.C. Riverside. June 21, 2009, Page 16.

[49] Yavorski, Joseph D., "Creative Energy Systems, Inc. Open Questions Public Meeting." November 16, 2011.

However, CES is proposing to use the syngas from the process to produce an estimated 10 MWe using a turbine generator. The syngas would be cleaned prior to the turbine generator. However, CES also indicated steam power may be used. For this analysis, it is assumed the syngas will be cleaned and burned in a turbine.[50]

Using the syngas as the fuel for the turbine will require two steps to process the syngas prior to the turbine. The first is to cool the syngas so it can be cleaned using standard gas cleaning technologies. The proposed process is expected to operate at 1300°F - 1800°F, which converted baghouse and air pollution control equipment cannot operate in. For example, baghouses are designed to remove PM from the gas stream using a fabric filter to capture the PM inside the bag. Typical baghouse temperatures range from 300°F to 500°F for coal boilers[51], thus cooling then treating the syngas prior to use in the turbine will be needed for the CES process.

The proposed gas turbine generator is to produce 10 MWe. Turbine heat inflow requirements vary by manufacturer and model. Given the anticipated syngas output from the process using LNI waste at 90-133 tons per day, it is likely the turbine will require additional natural gas to operate at capacity.

## 5.2 Environmental Considerations

The pyrolysis/gasification system proposed by CES is the IES process that was tested in the Romoland, California installation in 2006. The process tested a system operating on 30 tons per day of MSW. The system was ducted to a thermal oxidizer that was equipped with a natural gas fired burner. The exhaust from the burning syngas (with the natural gas) was then vented to waste heat boilers for energy recovery. The gases were then treated using a selective non-catalytic reduction unit, a baghouse, and a scrubber.[52]

For the system tested in Romoland, emissions were well below U.S. EPA standards.

For the CES system proposed at LNI where the syngas is cleaned and used to power a turbine generator to produce 10 MWe of energy, emissions data is not available. It is likely similar emissions controls, as used in the Romoland application, will be used on the proposed plant. The emission controls are effective at controlling emissions below regulatory thresholds. However, as previously discussed, the syngas is likely to require considerable cooling before going through emissions controls. Emission controls effectiveness will be monitored during plant start-up to verify the emission controls function properly and the emissions are below regulatory requirements. There may also be a continuous emissions monitoring system installed in the plant to continuously verify the emissions meet regulatory standards.

The ash, char, and tar residual from the process will require toxicity characteristic leaching procedure (TCLP) testing prior to disposal. This test is an industry standard test for unknown or

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[50] Ibid.

[51] USEPA. "Lesson 5: Fabric Filter Design Review" http://yosenite.epa.gov/oaqps. SI: 412A Fabric Filter Operation Review.

[52] Yavorski, Joseph D., "Creative Energy Systems, Inc. Open Questions Public Meeting." November 16, 2011.

questionable materials that are placed in landfills. The TCLP test is conducted in accordance with EPA method 1311[53]

Method 1311 attempts to simulate landfill liquids moving through the waste materials (leaching) and releasing chemicals into the liquid phase. The method can be used with water, some form of aciclic water to simulate leachate, and actual leachate. Test results are compared to existing leachate test results to determine if the material (in this case ash or char) would contribute to the contamination levels for the existing leachate, such that the leachate would require special disposal.

Previous analysis of pyrolysis char from MSW[54] indicated the char consists of some volatile matter, carbon and ash. At the temperatures proposed by CES of 1300°F to 1800°F, the char material is likely to contain about 8% volatile matter, 80% carbon and 12% ash. Of concern would be the contents of the volatile matter of the waste stream. However, being a small portion of the waste stream, it is anticipated that the char would be able to be disposed of in a MSW landfill in Iowa.

Another environmental concern would be the liquid generated from the pyrolysis process. For a 125 tons per day plant using the IES process, independent calculations[55] indicate evaporated water (of which some would condense) would be 38,586 tons per year (9,245,000 gallons per year) or about 18 gallons per minute if all was condensed. The water would contain contaminates from the waste stream and would require treatment prior to discharge. Treatment may include reverse osmosis and carbon filtration. No data is available on the contaminant concentrations for the liquid from the IES process. However, existing water treatment methods are believed to be adequate to treat the water to discharge standards.

## 5.3 Permitting

The proposed CES plant is likely to require permitting for solid waste storage and processing (567 IAC, Chapter 104), construction of the facility (567 IAC, Chapter 22), operating the facility (567 IAC, Chapter 22), discharge of water to the surface NPDES (567 IAC, Chapter 60 et. seq.), along with other local zoning and use permits.

The solid waste permit will include details for construction and operating the facility in accordance with Chapter 104, Sanitary Disposal Projects with Processing Facilities. Chapter 104 establishes requirements for equipment such as hammermills, hydropulpers, air classifiers, metals separation equipment, sludge processing and storage containers and facilities. It is anticipated the CES process will include a hammermill or similar metal separation equipment, and some method of storing the waste. Chapter 104 requires hammermills to have dust suppression, fire, and explosion control. All rejected materials are to be stored in leak proof containers. Metals separation equipment must be installed at a point in the process that

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[53] U.S. EPA Method 1311. Toxicity Characteristic Leaching Procedure. SW-846. http://www.epa.gov/epawaste/hazard/testmethods/sw846/pdfs/1311.pdf. Accessed 1/3/2012

[54] Drobny, N.L. et. al. Recovery and Utilization of Municipal Solid Waste. U.S. EPA sw-10c. 1971. Page 77

[55] "Los Angeles County Conversion Technology Evaluation Report – Phase II." Alternative Resources, Inc. October 2007. Page 5-46

minimizes potential organic contamination of the metal. Finally, the area used to store the waste material prior to processing must have:

- Smooth, impervious easily cleaned base (floor).
- Leachate collection facilities.
- Prevent runoff for entire facility.
- An enclosed roof to prevent litter.

Operation of the facility requires that all equipment be cleaned daily (unless less frequent cleaning is approved by the Department), emergency access is provided at all times, solid waste is not stored for more than 72 hours, solid waste is only deposited when an operator is on duty, and the area is completely fenced and locked when an attendant is not on duty.

The solid waste permit is not anticipated to be difficult for CES to obtain or maintain throughout the life of the proposed facility.

Air permitting in Iowa has two separate permit requirements. The first is a construction air permit. The construction air permit Section of the Iowa DNR Air Quality Bureau reviews designs and performance objectives for sources to determine if the proposed source will be in compliance with state and federal requirements. If a facility is likely to meet the air emissions criteria, then a construction permit will be issued.

The proposed CES plant is considered a pyrolysis process. However, the syngas produced would be cleaned and burned by a turbine generator. It is likely emission standards could be met using conventional equipment. It is likely some form of emission testing (stack testing) will be required as part of the Air Construction Permit to verify performance.

Once the construction air permit has been issued, the facility would receive a Title V operating permit. This permit would define how the facility is operating in regards to air emissions. The permit also addresses the reporting requirements, any monitoring that is required, and how to handle emergency episodes. The Title V permit for the proposed CES plant should be able to be obtained depending on the results from testing conducted during the initial plant start-up.

Water that is part of the pyrolysis process can be disposed in a couple ways; (1) to the surface or (2) to the wastewater treatment facility. The CES plant intends to discharge water generated by the plant to the Mason City wastewater treatment plant.[56] The water reclamation facility treats 6.5 million gallons of wastewater per day and has a permit from the Iowa DNR.

CES proposes to use reverse osmosis (RO) for the treatment of water when required for release.[57] While RO systems are effective at contaminant removal, the remaining solution can requires advanced treatment or alternative disposal methods. CES will need to consider

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[56] Creative Energy Systems Open Question Public Meeting. November 16, 2011. Slides 47-48

[57] Ibid. Slide 47

methods to handle the concentrated RO reject water. A pre-filter, like a carbon filter, may be needed to ensure appropriate contaminant level concentrations for discharge water.

### 5.4 Preliminary Economic Analysis from Known Data

Foth conducted a preliminary economic analysis for the proposed CES plant based on data provided by CES.[58]

Capital costs for the pant were estimated by CES to be $35,000,000 with the majority (approximately $30,000,000) being for equipment. The capital costs were reported to be $35,000,000 for the plant, land, construction, etc. The funds were being obtained from Forbes Financial Services with a ten (10) year payback. Bonds are assumed to have a yield of 3.5% per year. Foth believes the 3.5% bond rate is conservative for this type of facility.

Operation costs are based on the employee breakdown provided by CES. CES stated a total of 53 jobs would be created. Those 53 jobs are broken down to 36 blue collar jobs with an average salary of $27,583.33 and 17 white collar jobs averaging $62,590.23 per year. The average pay does not include the estimated $10,000 per year per employee for fringe benefits. Using the values supplied by CES, total annual employment costs are estimated to be $2,587,044.61. Foth considered the employee costs as the operations costs in the economic analysis.

Maintenance costs for pyrolysis systems are not published. However, Foth has estimated maintenance costs for Refuse Derived Fuels (RDF) facilities. The Newport facility in the Twin Cities, Minnesota, processes 1,700 to 2,000 tons per day of MSW into RDF. In 2006, annual maintenance costs for fixed equipment were estimated to be $1,000,000 annually. Electricity, utilities, and insurance were estimated in 2006 to be $915,000 annually. Correlation to a proposed 250 ton per day pyrolysis process is estimated to be $500,000 per year for general maintenance. This does not include turbine maintenance so the value is considered conservative.

Total operation and maintenance costs per year are estimated to be $3,087,045.

The preliminary economic analysis provided in Appendix A assumes a 10 MW facility that is operating for 5.5 days each week (like LNI) with availability of 90%. Operating the turbine generator for 286 days will yield 68,640,000 kwh per year. Power purchase agreement costs were inputted at 0.04/kwh.[59] The analysis does not include any portion of the tip fee or recyclable sales agreement. The analysis also establishes the bond yield rate at 3.5%. This may be low considering the potential bond rating. Finally, there is no consideration of the potential to purchase additional fuels to run the turbine. The CES plant was based on 250 tons per day. As was shown in section 4.1.2.1, LNI would not send the plant 250 tons per day after processing; the actual tonnage to the pyrolysis plant would be in the range of 90 to 133 tons per day. The reduced waste flow was not evaluated in the economic analysis.

The analysis indicates the plant may not be economically viable without a portion of the tip fee or higher revenues for electric purchase. It is unlikely that electric purchase rates will be

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[58] Ibid. Slides 8, 12-13

[59] Alliant Energy. Phone discussion with Kim King on January 6, 2012.

established at the approximate breakeven point of $0.07/kwh, thus tip fees at the plant may need to increase to support plant operation. It is important to note the economic analysis provided is very conservative in nature and does not account for all potential costs of a proposed plant. To ensure long term plant economic viability, LNI may consider requesting CES provide complete economic analysis of the proposed plant.

# 6 Impacts to the Landfill of North Iowa

## 6.1 Staffing

The current staff at LNI consists of a Director, one (1) Scale Attendant, one (1) Education Coordinator, one (1) Accountant, two (2) Hazardous Materials Technicians, four (4) Operators, and one (1) Control Person. The hours of operation for the landfill are Monday through Friday, 8:00 a.m. to 4:30 p.m. and Saturday 8:00 a.m. to 12:00 noon. Employees generally work during the landfill hours with some additional time at the end of the day used for daily cover operations. Most of the staff works in excess of 40 hours per week.

Given the hours of operation of the landfill, staffing appears to be adequate for landfill operations.

For the proposed CES plant, impacts to staffing are not anticipated to occur. Considering the expected waste that will be sent to the CES process of 160 to 235 tons per day with the remainder either being direct hauled to LNI (e.g. demolition waste) or being delivered to LNI from the CES plant (e.g. plant rejects). The actual daily tonnage to LNI is estimated to range from 165 to 250 tons, including C&D.

## 6.2 CES Plant Rejects Management

The proposed CES plant is estimated to receive 160 to 235 tons per day, five (5) days per week. However; after processing, 30-45 tons per day are anticipated to be recycled (metals and plastics) and 38-56 tons per day rejected, or sent back to LNI. These rejected tons are primarily inert materials that made it into the residential waste stream. LNI will be required to dispose of these inerts when they are sent to the landfill.

## 6.3 Ash/Residue Management

As presented in Section 4.2.2, the proposed CES plant will produce 20-25 tons of ash or char per day. The ash is proposed to be disposed at LNI. The current Iowa Solid waste Rules only addresses MSW, C&D and coal combustion residue disposal. However; it is anticipated that LNI will be permitted to accept ash from the proposed CES plant through a permit amendment. If the proposed CES plant becomes operational, LNI should consider whether a separate cell should be developed for ash residue from the plant. This analysis is beyond the scope of this report, but a cost/benefit analysis, along with a risk and mitigation analysis should be conducted prior to LNI requesting a permit amendment for ash disposal.

Another potential residual that may be disposed at LNI is the dust and air pollution control waste that can be generated. While small in quantity, the material will require TCLP testing to verify the chemicals in the waste will not leach at lconcentrations that could create compliance violations for LNI. Acceptance of this material is likely to require a permit amendment.

For both the ash and residue disposal at LNI, Foth recommends LNI develop specific testing and acceptance requirements, disposal procedures and emergency action procedure for the materials. The procedures should clearly identify the required testing, acceptance criteria, hours of acceptance, placement of the materials at LNI, disposal methods, emergency procedures, and any required hauling procedures that must be implemented to take the material from the proposed

CES plant to LNI, including the route, load covering, inclement weather procedures, pretreatment, equipment cleaning after disposal, inbound/outbound weighing and record keeping and reporting.

## 6.4 Impacts to Closure/Post Closure Funding

LNI currently uses a local government dedicated fund as the mechanism for funding closure and post closure. The local government dedicated fund has a ten (10) year pay in period for new landfill cells. Thus, the impact to the funding source is minimal since tipping fees stay with LNI. However; cell development will be extended so that the new cell construction would be delayed, thus increasing the payment into local government dedicated fund for new cell would also be delayed. This is likely to have some positive impact on the overall finances LNI, but a complete analysis is beyond the scope of this report.

## 6.5 Impacts to Landfill and Facility Life

The proposed CES plant, if operational, will extend the landfill life. Based on the tonnage estimates in Section 6, the landfill life is anticipated to be extended by 53%-57%. This extension in landfill life is expected to have a financial benefit to LNI as long as tip fees are retained by LNI as CES has stated. Current landfill life is estimated to be 50 years. With the CES plant, anticipated life of the landfill would be extended to 75-80 years.

## 6.6 Identification of Potential Risks and Mitigation

In regards to the CES proposed plant and structure indicated where LNI would retain most of the current tip fee for all waste going to the CES plant, potential financial risks are minimal. However, there is always a risk of future contract changes that may have detrimental impacts on LNI. The LNI Board should closely examine any contract changes and evaluate short and long term impacts to LNI from the proposed changes.

Environmental risks from the proposed CES plant would be in the disposal of the ash/char and disposal of the air pollution control residuals. The risk being that unauthorized, toxic, or hazardous waste would enter the landfill. These risks can be mitigated by appropriate testing of the materials prior to shipment to LNI and adequate operational procedure used at the CES plant. All deliveries of ash/char and air pollution control residuals must be tested and the test results provided to LNI prior to shipment. Through adequate processes at CES and LNI, the risk of acceptance and disposal of unauthorized materials can be mitigated.

# 7 Conclusions and Recommendations

Based on the information provided in this report, the following conclusions are made:

- Both gasification and pyrolysis processes have been demonstrated using MSW in pilot tests.
- Both gasification and pyrolysis require some form of waste pretreatment and drying prior to conversion.
- Published economic studies (limited) indicate both gasification and pyrolysis processes would require a tip fee of $100-$300 per ton.
- Air emissions from gasification and pyrolysis can be controlled with available equipment to meet air quality requirements.
- Ash and other residuals can be tested prior to disposal to meet regulatory standards.
- The process proposed by CES operates at 1,300°F to 1,700°F with no air. The syngas produced would be cleaned to operate a turbine generator.
- It is likely that CES could obtain all permits for the proposed plant.
- LNI is expected to retain its entire staff if the CES plant is operational. The LNI waste stream contains materials that could not be processed by CES and require landfill disposal.
- LNI facility life would be extended 25-30 years if the CES plant is operational.
- Potential environmental risks to LNI for the CES plant can be mitigated.
- Economic analysis indicates the economic viability of the CES plant is questionable.

Foth recommends LNI request from CES a confidential economic analysis to remove any questions concerning the economic viability of the CES plant. Additionally, LNI should participate in permit reviews for the plant to ensure any residual, ash, or air pollution control wastes are properly tested before disposal. Finally, LNI should thoroughly review any contract for waste disposal provided by CES to make sure the system viability environmental performances, and residuals management requirements are met. Foth also recommends LNI consider adopting an unsolicited proposals policy to provide a path for technology vendors in the future. This policy would inform proposers of requirements for unsolicited proposals to be evaluated by LNI.

# Appendix A

# Preliminary Economic Analysis

# Foth Infrastructure & Environment, LLC

## CES Estimated Economic Analysis

| Assumptions | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| kWh/year Output (10Mw generator) | | 68,640,000 | 68,640,000 | 68,640,000 | 68,640,000 | 68,640,000 | 68,640,000 | 68,640,000 | 68,640,000 | 68,640,000 | 68,640,000 |
| P - Factor | 100.0% | | | | | | | | | | |
| Project Investment | - | | | | | | | | | | |
| Equity | (35,000,000) | | | | | | | | | | |
| Debt | 35,000,000 | | | | | | | | | | |
| ITC credit | - | | | | | | | | | | |
| Interest Rate (Bond) | 3.50% | | | | | | | | | | |
| Inflator - 1 (Wages) | 2.50% | | | | | | | | | | |
| Inflator - 2 | 0.00% | | | | | | | | | | |
| Franchise payment to City | 0.00% | | | | | | | | | | |
| % of Assets Grant eligible | 0% | | | | | | | | | | |
| Grant % | 0% | | | | | | | | | | |
| YEAR | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Revenues** | | | | | | | | | | | |
| kwh/yr (assumes 90% available. No line loss) | | 61,776,000 | 61,776,000 | 61,776,000 | 61,776,000 | 61,776,000 | 61,776,000 | 61,776,000 | 61,776,000 | 61,776,000 | 61,776,000 |
| PPA Rate (assumes inclusion of REC) | | $0.04000 | $0.04000 | $0.04000 | $0.04000 | $0.04000 | $0.04000 | $0.04000 | $0.04000 | $0.04000 | $0.04000 |
| Other Revenue | | - | - | - | - | - | - | - | - | - | - |
| Total Revenues | | 2,471,040 | 2,471,040 | 2,471,040 | 2,471,040 | 2,471,040 | 2,471,040 | 2,471,040 | 2,471,040 | 2,471,040 | 2,471,040 |
| **O&M Expenses** | | | | | | | | | | | |
| O & M Expenses (wages + $500,000) | | 3,087,045 | 3,164,221 | 3,243,327 | 3,324,410 | 3,407,520 | 3,407,520 | 3,407,520 | 3,407,520 | 3,407,520 | 3,407,520 |
| Gas Purchases | | - | - | - | - | - | - | - | - | - | - |
| Total Expenses | | 3,087,045 | 3,164,221 | 3,243,327 | 3,324,410 | 3,407,520 | 3,407,520 | 3,407,520 | 3,407,520 | 3,407,520 | 3,407,520 |
| **Interest Expense** | | 1,225,000 | 1,120,579 | 1,012,504 | 900,646 | 784,873 | 665,048 | 541,029 | 412,669 | 279,817 | 142,315 |
| Operating Income | | (1,841,005) | (1,813,760) | (1,784,791) | (1,754,016) | (1,721,353) | (1,601,528) | (1,477,509) | (1,349,149) | (1,216,297) | (1,078,795) |

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