

# GASIFICATION USING ROTARY KILN TECHNOLOGY

Report By:  
Richard L. Fosgitt, P.E.  
Wilcox Professional Services  
5859 Sherman Avenue  
Saginaw, MI 48604

Report for:  
Cirque Energy, LLC  
168 East Center Street  
Ithaca, Michigan 48847

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### Appendix A – HTI Previous Experience

## 1.0 GASIFICATION OVERVIEW

### 1.1 Introduction

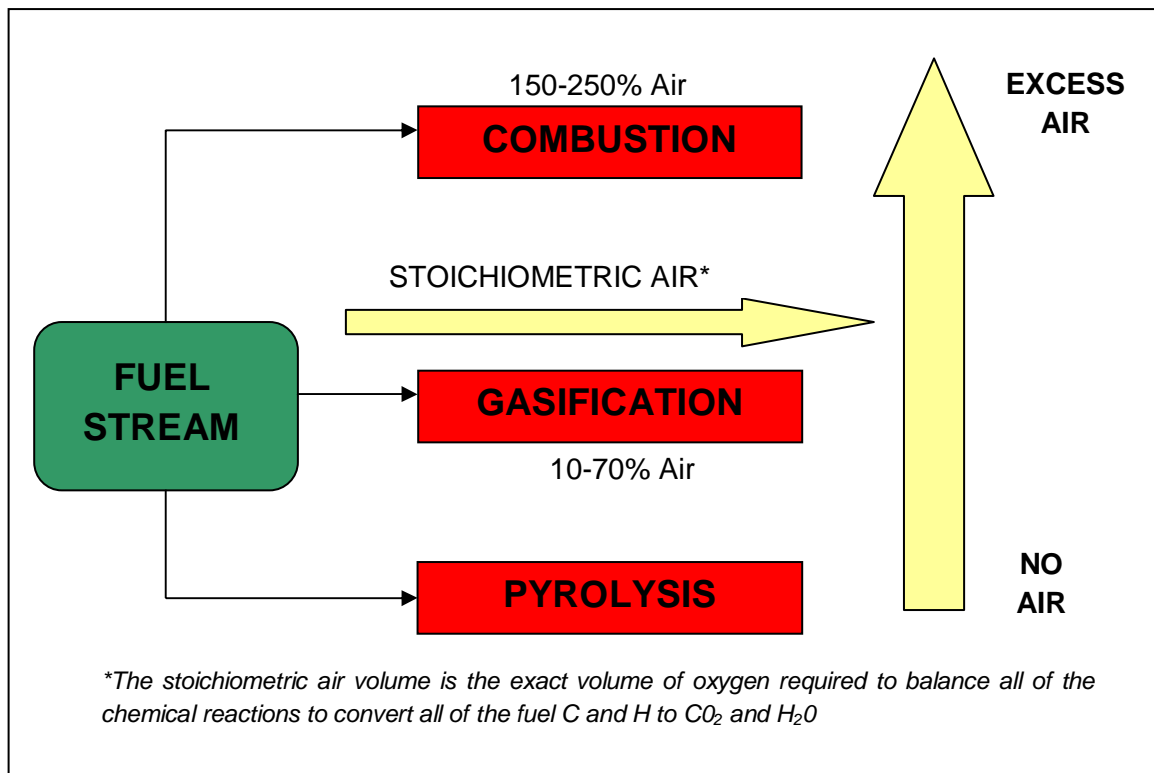
Gasification means incomplete combustion of a carbon-based fuel in a starved air environment resulting in production of combustible gases consisting of Carbon monoxide (CO), Hydrogen (H<sub>2</sub>) and traces of Methane (CH<sub>4</sub>). This mixture is called producer gas, synthesis gas or simply **syngas**. The syngas has a calorific value, or potential heat content, typically equivalent to 25% that of natural gas. The syngas may be burned directly in a secondary combustion unit (or thermal oxidizer), in internal combustion engines, used to produce methanol and hydrogen, or converted via the Fischer-Tropsch process into synthetic fuel.

Gasification offers distinct advantages over traditional combustion of a fuel:

1. Feedstock flexibility – Gasification can produce syngas not only from coals having a wide range of heat values but also from low-value carbon feedstocks such as biomass, municipal wastes, agricultural wastes, and sludges. This flexibility increases the economic value of these resources and lowers costs by providing industry with a broader range of feedstock options.
2. Product flexibility – The syngas produced by gasification can be converted into many valuable products, ranging from electricity and steam to liquid fuels, basic chemicals, and hydrogen. Integration of multiple products gasification into industrial applications increases opportunities for added revenues since plant operations can focus on the most lucrative products, provides economies of scale associated with production of multiple commodities and increases opportunities for added revenues.
3. Near-zero emissions – Gasification systems can meet the strictest environmental regulations pertaining to emissions of sulfur dioxide (SO<sub>2</sub>), particulate matter, and toxic compounds such as mercury, arsenic, selenium, cadmium, etc.. Further, gasification provides an effective means of capturing and storing or sequestering carbon dioxide (CO<sub>2</sub>), a greenhouse gas. The carbon dioxide produced during gasification is present at much higher concentrations and at higher pressures than in streams produced from conventional combustion, making them easier to capture.
4. High efficiency – Gasification can be integrated with other technologies for advanced power generation. The resulting systems are highly efficient, squeezing more value from each pound of feedstock. Systems using advances in gasification and related components can achieve efficiencies of up to 60 percent, compared with an efficiency limit of 40 percent for conventional plants.

## 1.2 Gasification Fundamentals

Thermal conversion processes can be divided into three categories; combustion, gasification and pyrolysis with each being dependent on the concentration of available oxygen. As can be seen in the figure below, combustion occurs with an excess of available oxygen, gasification is a partial oxidation process requiring an oxygen concentration below the stoichiometric level, and pyrolysis occurs in the complete absence of oxygen. In other words, gasification and pyrolysis limit or prevent oxidation. In this report we use the term “gasification” to include both starved air gasification and pyrolysis.

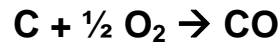


In the presence of air, heat causes organic materials to burn. Burning or oxidation is what occurs in typical power plant combustion units. In addition to the heat released, the burning of a fuel creates nitrogen oxides, sulfur dioxide, particulate matter, carbon monoxide, carbon dioxide, acid gases, and other hazardous air pollutants that must be removed via pollution control equipment.

In a gasifier, the carbon-based fuel undergoes several different processes:

1. The pyrolysis (or devolatilization) process occurs as the carbonaceous particle heats up. Volatile organic compounds (i.e. methane, CH<sub>4</sub> and other hydrocarbons) are released and char is produced, resulting in up to 70% weight loss. The process is dependent on the properties of the fuel and determines the structure and composition of the char, which will then undergo gasification reactions.

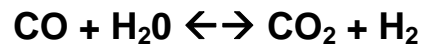
2. A partial combustion process occurs as the volatile products and some of the char reacts with oxygen to form carbon dioxide and carbon monoxide, which provides heat for the subsequent gasification reactions. The balance of the uncombusted volatiles are mixed with the resulting syngas. Letting **C** represent a carbon-containing organic compound, the basic reaction here is



3. The gasification process occurs as the char reacts with carbon dioxide and steam (from fuel moisture) to produce carbon monoxide and hydrogen, via the reaction



4. In addition, the reversible gas phase water gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen.



In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be burned to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide. In the end, the syngas produced by the entire process includes volatile organics (primarily CH<sub>4</sub>) carbon monoxide CO, hydrogen H<sub>2</sub>, water vapor, and traces of non-useful products such as tar and dust.

It should be noted that there is no defined line between combustion and gasification. By definition, gasification occurs at any point below 100% stoichiometric air. The lower the air volume, the more pure the syngas produced, as less full combustion occurs. When a gasifier fails to perform, typically combustion occurs as oxygen levels increase.

### **1.3 Types of Gasifiers**

Several different types of gasifiers with multiple variants are currently in commercial use. The basic types are summarized in the following sections and in the Table following Section 1.3.4.

#### **1.3.1 Close Coupled Gasification (Multi-stage Combustion)**

Several technology vendors now offer a technology aimed at gaining improved performance over traditional biomass boiler systems. These technologies are referred to as hybrid biomass gasifiers/combustors, close coupled gasifiers or staged combustion units. These systems are often contained within a single vessel where a gasification zone is established to vaporize the volatile gases from the solid fuel. The heat for this reaction is driven by carbon remaining on the reciprocating grate. The combustion chamber above the gasification zone will mix the volatile gasses with combustion air and transfer the heat from the gas to generate steam from the feedwater.

#### **1.3.2 Fluidized-bed gasifier**

Fluidized-bed gasification systems, in which the combustible gas is generated by feeding the biomass into a hot bed of suspended, inert material (commonly sand), generally offer improved

performance, but with greater complexity and cost. The fluidized bed design produces a gas with low tar content but a greater level of particulates as compared to fixed-bed systems. Advantages that fluidized-bed gasification systems have over fixed-bed gasification systems include improved overall conversion efficiency and the ability to handle a wider range of biomass feedstocks. Typically, these systems are also close-coupled, meaning that the syngas is combusted immediately above the gasification zone within a single combined gasification/boiler vessel.

Many new biomass power plants use fluidized-bed technology. The chief disadvantage to this technology is high initial capital cost and high on-going O&M costs and efforts that lead to availabilities typically only around 80%.

### **1.3.3 Fixed Bed Gasifier**

The counter-current fixed bed ("up draft") gasifier consists of a fixed bed of fuel (e.g. biomass) through which the air flows in a counter-current configuration. The ash is either removed dry or as a slag. The slagging gasifiers have a lower ratio of steam to carbon, achieving temperatures higher than the ash fusion temperature. The nature of the gasifier means that the fuel must have high mechanical strength and must ideally be non-caking so that it will form a permeable bed, although recent developments have reduced these restrictions to some extent. The throughput for this type of gasifier is relatively low. Thermal efficiency is high as the gas exit temperatures are relatively low.

The co-current fixed bed ("down draft") gasifier is similar to the counter-current type, but the air flows in a co-current configuration with the fuel (downwards, hence the name "down draft gasifier"). Heat needs to be added to the upper part of the bed, either by combusting small amounts of the fuel or from external heat sources. The produced gas leaves the gasifier at a high temperature, and most of this heat is often transferred to the air added in the top of the bed, resulting in an energy efficiency on level with the counter-current type. Since all tars must pass through a hot bed of char in this configuration, tar levels are much lower than the counter-current type.

Syngas from fixed bed gasifiers is typically fed to a secondary combustion chamber, or oxidizer, where the syngas is combusted to create hot exhaust gases that are used to create steam in a heat recovery boiler.

### **1.3.4 Rotary kiln gasifier**

Rotary kiln gasification systems use a rotary kiln similar to those commonly found in use in the cement, lime, and hazardous waste industries. Fuel is fed into the upper end of a slowly rotating kiln along with a controlled amount of air. As the fuel travels through the kiln, the tumbling action causes mixing with air and the gasification process occurs. Syngas is captured within the kiln and is directed from the high side of the kiln. Rotary kilns have significant advantages over fixed bed gasifiers in that fuel type and particle size are not design dependent, thus the kiln has the ability to use a variety of fuels over time. The chief challenge in the use of rotary kiln gasifiers is the ability to control air, which is discussed in detail in subsequent sections of the report.

Syngas from rotary kiln gasifiers is typically fed to a secondary combustion chamber, or oxidizer, where the syngas is combusted to create hot exhaust gases that are used to create steam in a heat recovery boiler.

**COMPARISON OF GASIFIER TYPES**

	<b>Close Coupled</b>	<b>Fluidized Bed</b>	<b>Fixed Bed</b>	<b>Rotary Kiln</b>
<b>Typical Fuel Type</b>	Woody biomass	Woody biomass, poultry litter, tire derived fuel	Woody biomass, poultry litter	All types of biomass, litter, sludge, MSW, ag wastes
<b>Fuel Size Requirements</b>	Specific, usually chips <2"	Specific, usually chips <2"	Specific, usually chips <2"	All sizes, dependent only on feed system
<b>Size Available</b>	1-25 MMBTU/hr	100-1000+ MMBTU/hr	5-25 MMBTU/hr	25-150 MMBTU/hr
<b>Example Manufacturers</b>	Hurst, McBurney, AES	Babcock & Wilcox, EPI, Foster Wheeler	HTI, Nexterra, Chiptec	HTI, ICM, Recycling Solutions
<b>Advantages</b>	<ul style="list-style-type: none"> <li>• Simple systems easy to operate</li> <li>• Good for small installations and building heating use</li> </ul>	<ul style="list-style-type: none"> <li>• Available in large capacities for utility installations</li> <li>• Proven technology in power industry</li> </ul>	<ul style="list-style-type: none"> <li>• Simple systems easy to operate</li> <li>• Economical installation cost</li> <li>• Low O&amp;M cost</li> <li>• Very low emissions</li> </ul>	<ul style="list-style-type: none"> <li>• Fuel versatility; able to change over time with no modifications</li> <li>• Low maintenance and O&amp;M costs</li> <li>• Low emissions</li> <li>• Long history of use in kiln and combustion applications</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>• Too small for utility size installations or high pressure steam</li> <li>• Unable to use variable fuels</li> </ul>	<ul style="list-style-type: none"> <li>• High installation cost</li> <li>• High O&amp;M costs</li> <li>• Unable to use variable fuels</li> <li>• Extensive air pollution control required</li> </ul>	<ul style="list-style-type: none"> <li>• Too small for utility size installations</li> <li>• Only able to use specific fuel in original design</li> <li>• Little control for turndown</li> </ul>	<ul style="list-style-type: none"> <li>• Very few manufacturers with experience</li> <li>• Previous technologies have had limited ability to control air for deep gasification</li> </ul>



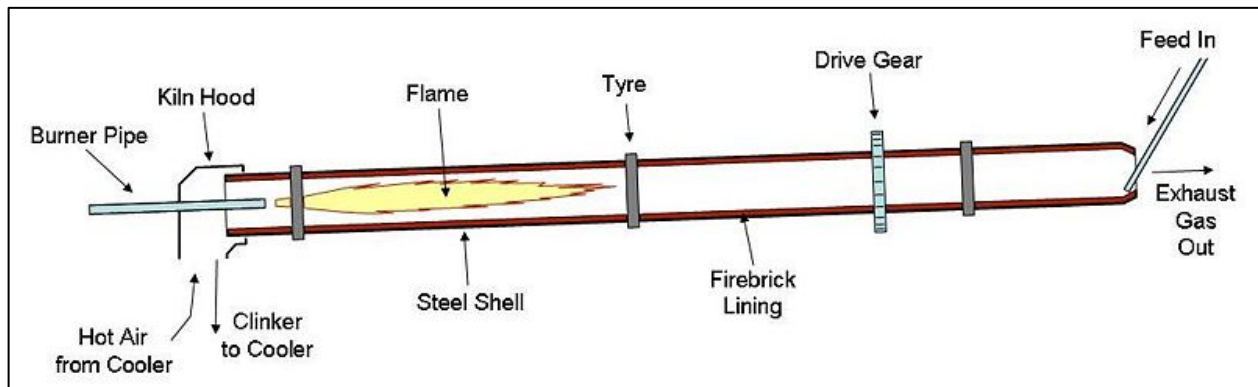
## 2.0 Rotary Kilns

### 2.1 Traditional Use of Rotary Kilns

A Rotary kiln is a thermal processing device traditionally used to raise materials to a high temperature (calcination or oxidation) in a continuous process. Materials produced using rotary kilns include:

- Cement
- Lime
- Refractories
- Metakaolin
- Titanium dioxide
- Alumina
- Vermiculite
- Iron ore pellets

Rotary kilns are also used in wide application as incinerators, for the combustion and destruction of materials such as solid and liquid hazardous waste, medical waste, contaminated soils, waste sludges, and municipal solid waste.



*Typical Rotary Kiln (image from Wikipedia)*

A rotary kiln is essentially a slow moving, i.e. rotating, refractory-lined steel cylinder. To facilitate the movement of waste material, it generally slants downward from the feed end to the outlet end. The kiln is heated to high temperatures and as material passes through the kiln, waste is evaporated, organic materials are volatilized and combustion begins. Generally, rotary kilns can be designed to operate at temperatures between 1400 and 2600 degrees Fahrenheit. The kiln's end product can be either ash or slag, depending on the mode of operation and the initial characteristics of the waste that is fed to the kiln.

Key elements of rotary kiln design are the end seals, drive assembly, kiln refractory and control systems. The end seals are designed to minimize leakage of air into the system and prevent escape of combustion gases. The drive assembly must supply enough torque to rotate the kiln

under all operating conditions. The refractory lining (tile) protects the kiln shell from overheating and chemical attack. At the same time, it provides a hot surface to aid in ignition and combustion of waste. Refractory surfaces near the feed inlet are designed for resistance to high impact and thermal shock loads. In the discharge area, refractory must withstand chemical attack and slag penetration.

## **2.2 Rotary Kiln Gasifiers**

A rotary kiln gasifier is a variant on a traditional rotary kiln whereby the amount of air to the kiln is restricted to allow gasification to occur. Instead of combustion exhaust gases, syngas is produced and is subsequently burned in a secondary combustion chamber or thermal oxidizer.

The principal challenge with creating a rotary kiln gasifier is effective control of air. The particular challenges include:

- Kiln end seals – effective end seals to prevent air entering. Effective seals include overlapping steel collars, as gaskets tend to burn or deteriorate over time.
- Fuel feed – a method of fuel feed to prevent unwanted air entering with the fuel. Effective fuel feeds are a continuous auger feed, whereby the fuel acts as the plug to prevent air infiltration.
- Introduction of air – air traditionally enters a kiln through the low end, which tends to cause full combustion and hot spots near the air entrance. The “holy grail” of rotary kiln gasification, which to date has been minimally achieved, is some method of uniform and controllable air introduction throughout the length of the kiln.
- Fuel/air mixing – the rotational pattern causes some fuel on the bottom of the kiln to be minimally exposed. Past efforts have included adding fuel lifters to cause more suspension and mixing of the fuel. This method tends to cause more combustion and creation of particulates that must be dealt with.
- Ash removal – a method to prevent air infiltration at the ash discharge. Good methods include ash falling into a water bath that both cools the ash and prevents air from entering the kiln.
- Slag prevention – prevention of ash slagging from high temperatures. Proper control of the airflow in the kiln keeps slagging to a minimum.

All rotary kiln gasifier designs strive to find the right balance to minimize combustion, optimize production of syngas, minimize operator inputs (automation), provide low maintenance, and perform with predictability and high reliability.

### 2.3 Callidus Technologies Rotary Kiln Gasifiers

Callidus Technologies (currently a division of Honeywell) is a global manufacturer, expert and research company devoted to combustion technologies and air pollution control equipment. In particular, Callidus specializes in thermal oxidizers and historically produced a rotary kiln gasification system that is in use at several North American wood product facilities today.

The Callidus gasification systems were built in 1999-2002 and are used for gasification of mill wastes to provide thermal heat for steam generation, raw product drying, and subsequent destruction of dryer and mill exhaust gases through regeneration of the gas stream through the thermal oxidizer system. These systems are currently operational at **Norbord** ([www.norbord.com](http://www.norbord.com)) oriented strand board (OSB) mills in South Carolina and Alabama, a Del-Tin OSB mill in Arkansas, and other mills in Canada. The Callidus systems each feature a series of three rotary kiln gasifiers coupled thermal oxidizers that subsequently generates up to 300 million BTU per hour heat that is used for generation of steam in heat recovery steam generators (HRSG's).



Callidus system at Norbord mill in Kinards, South Carolina – Picture shows the three vertical thermal oxidizers at each rotary kiln and the wood fuel feed conveyors.

A description of the Callidus system follows:

The heat energy system is a Callidus Closed Loop Gasification System (CLGS), which gasifies biomass fuel, which is bark, sawdust, sander dust, chips, crosstie chips, and other residual wood materials and a small amount of used oil, which is generated onsite, in a rotary kiln to produce a combustible gas used as fuel in a secondary combustion chamber (SCC).



*One of three rotary kiln gasifiers at Norbord*

The CLGS is a 300 MMBtu/hr unit that uses natural gas as a secondary fuel source for start-up. The CLGS consists primarily of a fuel feed system, three rotary gasifiers, three secondary combustion chambers (SCC), hot air heat exchanger, recuperative heat exchanger, hot oil heat exchanger, heat recovery boilers, ESP, induced draft fan, and exhaust vent stack.

The system is considered closed loop in that the hot air supplied to the dryers returns to the system as combustion air and is not released to the atmosphere until after the VOCs are destroyed and the particulate captured. The press vent and dryer exhaust gases, laden with VOCs, pass through a recuperative heat exchanger to be heated to 875°F before being routed into the rotary gasifier and SCC. The rotary gasifier is operated in the starved air mode, where the oxygen level is too low for complete combustion to occur. As a result combustible gases are formed, primarily carbon monoxide (CO) and hydrogen (H<sub>2</sub>). The gasifier has a wood fuel residence time of approximately 60 minutes.

The flue gas leaving the gasifier is oxidized in a vertical secondary combustion chamber (SCC) to assure complete destruction of any remaining VOC, fine wood particles, and CO. The remainder of the dryer exhaust gas is used as an oxygen source to complete the combustion process in the SCC.

The hot flue gases leaving the SCC pass through a series of heat exchangers to extract heat required for the different processes of manufacturing. The cooled flue gases pass through the ESP to remove any suspended particulate. The flue gases are then exhausted out the vent stack with the aid of an induced draft fan.



*One of three HRSG boilers at Norbord*

### **2.3.1 Callidus System at Norbord, Kinards, SC**

On May 24, 2010, a site visit was conducted at the Norbord OSB mill in Kinards, SC. The purpose of the visit was to gain an understanding of the operating history and current operations of the Callidus gasification system in use at the plant. Significant findings from the meeting include the following:

1. The Callidus system was installed 10 years ago when the Norbord plant was originally constructed in 2000. Over the life of the system, there has typically only been three (3) weeks per year downtime.
  - 8760 hours annual – 504 hours = 8246 = 94.2% availability
2. Fuel used is pine chips/bark with an average 48% moisture content. The plant uses an average of 550 tons of fuel per day

- 550 tons / 3 kilns = 183 tons/kiln = 7.63 tons/hr = 15,000 lbs/hr per kiln
  - 15,000lbs x 5500 btu/lb = 84 MMBTU/hr per kiln average feed
3. The plant has difficulty controlling oxygen/air consistently into the gasifiers. This is their single biggest concern. In particular, the gasifiers have air control problems in fuel bed – as air only enters through high side/fuel entry end and via an auxiliary air input on the low end of the kiln. The plant operator states the system would work better if he could get air introduced into the fuel bed (i.e. underfire air). The plant has installed lifters to provide more mixing/aeration of fuel to get full gasification, but this has increased particulate loading to the multicyclones and ESP system. In addition, the gasifiers operate at a temperature of approximately 1200 degrees Fahrenheit, which indicates that the gasifiers are most likely operating near combustion conditions.
  4. Boilers produce 80,000 #/hr each at 300 psig; 240,000 #/hour total steam generation. Temperature of gases to boiler is about 1400 deg F.



*Rotary kiln, oxidizer tower, and fuel feed system*

## 2.4 HTI Gasification Systems

Heat Transfer International (HTI), from Grand Rapids, Michigan has a patented starved air thermal gasification process that has been successfully used in industrial settings for 40 years. Their gasification technology has been used primarily for the purpose of clean destruction of waste materials. Today, the technology is alternatively being used for destruction of a fuel to create heat and energy.



*Construction of an HTI Fixed Cell Gasifier and Oxidizer*

It should be noted that HTI manufactures two types of gasifier units, depending on the type and quantity of fuel anticipated to be used:

1. Fixed Cell or Retort Gasifier – This type of gasifier is used when a constant, uniform fuel is available. The fuel should be consistently sized and has a consistent moisture content. Fuel is introduced into a static pile within the retort. A typical design capacity for a retort is up to 25 MMBTU/hour heat input.



*HTI Rotary Kiln Gasifier*

2. Rotary Kiln Gasifier – This type of gasifier consists of a rotating shell similar to a cement kiln. Because of the turning and mixing action, variation in fuel size, shape, type, and moisture content can be accommodated. A typical design capacity for a rotary kiln is up to 100-120 MMBTU/hour heat input.

## 2.4.1 Historic HTI Gasification Systems

Heat Transfer International has experience with the design and construction of rotary kiln gasifiers installed over 35 years through the previous experience of their chief engineer, Robert Graham and his company Presque Isle Engineering. The following is a partial listing of the experience with rotary kilns (see Appendix A for a complete HTI experience listing).

CUSTOMER	DESCRIPTION
<b>Biomass Development center (2010)</b> Kentwood, Michigan	Rotary kiln gasifier with ceramic heat exchangers. Development plant designed to test <b>all types of carbon-based fuels</b> and recover heat.
<b>Nan Ya Plastics (2002)</b> Taipei, Taiwan	(2) starved air rotary kiln gasifiers with ceramic heat exchangers. WTE plant designed to destroy <b>hazardous and non-hazardous industrial waste</b> and recover heat.
<b>Colorado Incineration Services (1992)</b> Denver, Colorado	8 TPD central burn, starved air rotary <b>medical waste</b> gasifier with ceramic heat exchanger and dry scrubbing. Turnkey retrofit including permitting.
<b>City of Galax (1985)</b> Galax, Virginia	55 TPD <b>municipal solid waste</b> rotary gasifier with heat recovery boiler and dry scrubbing.
<b>SCA Chemical Services, Inc. (1981)</b> Chicago, Illinois	Commercial <b>hazardous solids and liquid wastes</b> facility. EPA-permitted to destroy in excess of 40,000 gallons per day of hazardous waste materials. This rotary kiln gasifier was the largest hazardous waste facility permitted in the United States at the time.
<b>The Upjohn Company (1981)</b> Kalamazoo, Michigan	Turnkey rotary kiln gasifier installation. designed to destroy <b>medical waste, hazardous solvents and municipal solid waste</b> . Supplied complete with heat recovery, particulate, and acid scrubbing equipment.
<b>Eastman Kodak Company (1975)</b> New York	Design and supply of complete gas Rochester, quenching and scrubbing system applied to customer's rotary kiln incinerator.





*HTI rotary kiln for Nan Ya Plastics Taiwan, 2002*

#### **2.4.2 HTI Next Generation Rotary Kiln Gasifiers**

Heat Transfer International (HTI) has developed an improved rotary kiln gasification technology that will provide state of the art air control for the gasification of carbon-based fuels.

HTI's latest kiln technology deals with how to take a rotary kiln to a lower oxygen level in order to reduce the rotary exit gas temperature/bed temperature, which in turn allows better syngas production and also allows the kilns to deal with a wider variety of materials with low slagging temperatures. The main goal of this innovation is providing a method to allow the air to come up under the rotating bed of material and not be introduced on top as was done in the past. Air introduced on top of the pile (down the center) is how every incinerating rotary works and is how every starved air rotary currently built is designed.

As discussed, when air is introduced on top (down the center) of the bed of material in the rotary the first material that sees the oxygen first wants to move to combustion. That is why rotary kilns have not been used in a DEEPLY starved air gasification mode. The change is not a big change, but it is the magic bullet that allows the use of a rotary kiln in a deeply starved air gasification mode.

HTI's newest technology uses a gas-permeable ceramic refractory lining in the rotary kiln. This refractory is installed to allow air to be introduced throughout the length of the kiln under the fuel

bed, thereby providing optimum gasification control conditions. Although this refractory may sound exotic, it exists for several other industrial uses including:

1. High temperature diesel exhaust particulate filters – the refractory is used to filter micro particulates from diesel exhaust. This usage demonstrates the ability of the refractory to resist plugging, which would be of concern in the proposed use.
2. Hydrogen gas separation – similar refractories are used with pores at the molecular level for separation of hydrogen gas. The pores are sized to allow only hydrogen gas (H<sub>2</sub>) to pass through, blocking all other gases.

HTI has proven the use of gas permeable refractory in laboratory gasifier settings, without plugging or operational issues. Scale-up and applicability to larger gasifiers is not expected to be difficult. In addition, it should be noted that should the use of the refractory fail, the rotary kiln gasifier would simply revert to use as a normal rotary kiln gasifier with over-fuel (center) air control. This fail-safe mode has proven commercial applicability in all previous HTI installations as well as in the Callidus system applications.

### **3.0 Conclusions**

In summary, we support the intention of Cirque Energy to develop projects using the Heat Transfer International (HTI) rotary kiln gasification technology in conjunction with steam turbine generators. We believe that this technology is superior to other technologies available for the following primary considerations:

1. Modular Rotary Kiln – HTI’s rotary kiln design is modular, so that projects can be developed to use the same system design, selecting the number of repeatable components as required to meet each individual project’s needs.
2. Low Emissions – Gasification is widely recognized by State and Federal permitting agencies as the best available control technology to provide the lowest possible air emissions. This equates to high public acceptance of new projects in addition to lower overall system and operational costs.
3. Gasification Experience and Technology – HTI has unparalleled industry experience with gasification systems and design. Their new generation rotary kiln design with improved air control will provide optimum gasification control with the flexibility offered by use of a rotary kiln.

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# **Appendix A**

## Previous HTI Project Experience

## **HEAT TRANSFER INTERNATIONAL (HTI), formerly PRESQUE ISLE ENGINEERING**

HTI specializes in custom-designed, starved air systems that process solids, sludges and hazardous liquids. The front-end gasifiers range from batch style tray furnaces to ram-fed gasifiers to shredder-auger-fed rotary kiln gasifiers.

Successful permitting by our engineers has been accomplished in many states, including Maryland, Michigan, Illinois, Colorado and Utah. Materials fired ranged from municipal solid waste, hazardous PCBs, Saran fumes, explosive sludges, plastic scrap, trash, medical waste and biomass. Several of the permits had heat recovery, primarily boilers, however, in some cases the customers supplied the backend equipment and PIE was responsible for material handling, gasification and oxidation front-end lines only.

For approximately 25 years, Robert G. Graham owned a shop and R&D lab in Sanford, Michigan that employed engineers and skilled trades that designed, fabricated and lined the custom equipment to meet customer specifications. In the future all of this engineering and shop fabrication will be performed by Heat Transfer International (HTI). David Prouty is President of HTI, (4720 44th Street SE, Kentwood, Michigan 49512, telephone 616-551-5420). All of Mr. Graham's intellectual property has been transferred to HTI where he is under contract as the corporation's senior application engineer.

### **REFERENCES**

#### **CUSTOMER**

#### **DESCRIPTION**

Michigan Sugar Company

105 MKB hot air furnace. Dual fuel firing capability for rotary pulp dryer.

Dow Chemical Company  
Midland, Michigan

High temperature, high pressure preheater.  
6.5 MKB pressure vessel design.

Phillips Petroleum  
Borger, Texas

Liquid polymer gasification system with 85,000 lb/hr superheated steam waste heat boiler. System features a pyrolyzing/oxidizing design.

Southeast Oakland County  
Incinerator Authority  
Madison Heights, Michigan

Two emergency vent stacks installed upstream of a retrofit scrubbing system on an existing municipal waste incinerator.

Dow Chemical Company  
Midland, Michigan

Liquid bromine incineration system complete with wet wall quench and acid scrubbing system.

Dow Chemical Company Midland, Michigan	High temperature process heater complete with unique finned coil design and explosion relief.
General Mills Toledo, Ohio	Complete turnkey propane storage, pumping and firing system, including everything from 90,000 gallon storage tanks to burners and fuel management system.
Ford Motor Company Dearborn, Michigan	High temperature, high pressure laboratory test furnace with elaborate control system to simulate engine exhaust for catalytic converter testing.
Owens-Corning Fiberglas Delmar, New York	High temperature fume incinerator for oven exhaust.
Owens-Corning Fiberglas Newark, Ohio	High temperature fume incinerator for oven exhaust.
Owens-Corning Fiberglas Fairburn, Georgia	High temperature fume incinerator for oven exhaust.
Huron Portland Cement Alpena, Michigan	Two refractory-lined kiln feed hoppers; turnkey installation.
Owens-Corning Fiberglas Newark, Ohio	High temperature fume incinerator for oven exhaust.
Huron Portland Cement Alpena, Michigan	Completely self-contained and portable kiln ignition system.
Detroit Edison Company St. Claire, Michigan	Two primary air duct heaters. These units directly heat mill air to allow the firing of low-sulfur western coal.
Detroit Edison Company St. Claire, Michigan	Second order. Two mill air duct heaters similar to that described above.
Cleveland Cliffs Iron Co. Ishpeming, Michigan	Complete modernization of existing power-house firing system.
J. M. Huber Corp. Borger, Texas	Multiple waste incinerator systems, complete with 250,000 lb/hr superheated steam, waste heat boiler. This system has been retrofitted to generate electrical power.
Eastman Kodak Company Rochester, New York	Design and supply of complete gas quenching and scrubbing system applied to customer's rotary kiln incinerator.

BASF Wyandotte Wyandotte, Michigan	Designed and supplied burners, prepiped valve trains, burner management and controls for conversion of (3) utility type boilers for waste gas firing. Each burner is capable of firing (4) different fuels. (9) burners total and (30) fuel trains.
Phillips Petroleum Company Toledo, Ohio	Conversion of existing package boiler to waste oil firing.
Dow Chemical Company Midland, Michigan	Chlorinated fume gasification/scrubbing system. Unit supplied turnkey, complete with flame safety, controls, fans, stack, ladders and platforms.
Cleveland Cliffs Iron Co. Ishpeming, Michigan	80 MKB hot air furnace utilizing universal suspended wall system.
Hunt Wesson Ford Toledo, Ohio	Complete turnkey conversion of existing package boilers.
Canada Carbon Company Alberta, Canada	300 MKB off-gas combustion system, complete with 150 ft of refractory-lined Ductwork, controls, flame safety, etc.
Cleveland Cliffs Iron Co. Ishpeming, Michigan	200,000 lb/hr package boiler installation. Turnkey.
Owens-Corning Fiberglas Toledo, Ohio	Pilot plant for test-firing of various liquid waste materials.
Owens-Corning Fiberglas Valparaiso, Indiana	Full scale incinerator to fire materials tested under above contract.
Allied Chemical Corp. River Rouge, Michigan	Coke oven gas-firing system, complete with burner management, oxygen trim and combustibles analyzing type controls.
U.S. Corps of Engineers Aberdeen, Maryland	Turnkey installation of gasfier and exhaust scrubbing system to destroy over 1,000 hazardous materials, including spent munitions and toxic nerve gas.
BASF Wyandotte Wyandotte, Michigan	Incineration system to destroy hazardous acrylonitrile waste.

The Upjohn Company Kalamazoo, Michigan	Turnkey rotary kiln gasifier. System designed to destroy medical waste, hazardous solvents and municipal solid waste. Supplied complete with heat recovery and particulate and acid scrubbing equipment.
SCA Chemical Services, Inc. Chicago, Illinois	Commercial hazardous solids and liquid wastes facility. EPA-permitted to destroy in excess of 40,000 gallons per day of hazardous materials. This rotary kiln primary chamber was the largest hazardous waste facility permitted in the United States.
Englehard Industries Newark, New Jersey	Hazardous materials processed in (8) starved air gasifiers for precious metals recovery. System complete with heat recovery and gas scrubbing.
Chrysler Corporation St. Louis, Missouri	Oven exhaust fume incinerator with heat recovery.
Dow Chemical Company Midland, Michigan	Modify existing utility-size boiler for hydrogen gas firing.
Johnson-Matthey West Deptford, New Jersey	Second precious metal recovery gasifier similar to Engelhard Industries.
Chrysler Corporation Windsor, Ontario	Oven exhaust incinerator with heat recovery.
General Motors Baltimore, Maryland	(7) fume gasifiers with heat exchangers for paint oven heating.
Kimberly-Clark Atlanta, Georgia	(3) high pressure, directly fired air heaters.
Owens-Corning Fiberglas Valparaiso, Indiana	Waste firing system to revamp incinerator.
City of Galax Galax, Virginia	55 TPD MSW gasification system with heat recovery and dry scrubbing.
Engelhard Corporation Seneca, South Carolina	Manifolded starved air gasifiers with heat recovery similar to the Newark plant.
Colorado Incineration Services Denver, Colorado	8 TPD central burn, starved air medical waste gasifier with ceramic heat Exchanger and dry scrubbing. Turnkey retrofit including permitting.



Green River Biomedical Co.  
Green River, Utah

Designed and permitted 25 TPD medical waste gasification plant. Plant was set up to handle medical waste from 7 states.

Jenludel Processing Company  
Memphis, Tennessee

Similar to Green River except plant was designed to recover heat and produce steam for Cargill.

Witco (continental Carbon Co.)  
Sunray, Texas

All-ceramic, two-pass heat exchanger test. Worked with DuPont Lanxide to test full-size exchanger at 2500°F in carbon black pilot plant.

Nan Ya Plastics  
Taipei, Taiwan

(2) starved air rotary gasifiers with ceramic heat exchangers. WTE plant designed to incinerate hazardous and non-hazardous industrial waste and recover heat.

### **CERAMIC, AIR-TO-AIR HEAT EXCHANGERS**

In the early 1980s a sophisticated test center was constructed in PIE's shop to test ceramic materials for patented and patent-pending, high temperature, shell and tube heat exchangers. The proven exchangers were then incorporated into aluminum remelt furnaces, a lost-wax process and incinerators.

Customers included Alumax Foils, Alumax Mills, Bodine Aluminum, Southwire Aluminum (three systems purchased over seven years), Johnson Matthey and Etho Power.