**Self-Sustaining Plastic Waste Pyrolyzer/Combustor Power Plant**

*Design Team*
Paul Conroy, Dave Garufi, David Laskowski
Shane McElroy, Jeffrey Young

*Design Advisor*
Prof. Yiannis Levendis

**Abstract**

With nonrenewable fuel sources dwindling in the world, the search for new sources of energy has intensified. A pyrolysis/combustion process provides an alternative energy source which reduces pollution and recycles waste plastics. This pyrolysis solution uses vaporized plastics as a fuel to release thermal energy through combustion, which can be harvested for power. The design will be a self-sustaining pyrolyzing/combusting system with high energy output and clean emissions. Initial design ideas were developed through research of previous patents and analysis of a small scale lab model. A refined design option has been selected which involves integration of the combustion and pyrolysis chamber through a common partition. Heat from the combustion chamber conducts through this partition and enables pyrolysis to occur in the neighboring chamber. Preliminary experiments have been performed to determine the feasibility of this design by modeling the pyrolysis chamber with an outside heating source. Using experiments and calculations, a final design was developed. The design was tested and determined that it is sufficient in creating a high net energy output. A pyrolyzer/combustor has not yet been accepted by the world as a new clean power initiative, but this design may allow that to change.
The Need for Project

The world is facing environmental hardships caused by burning fossil fuel and producing a record amount of plastic waste. A plastic waste pyrolyzer/combustor power plant can solve both of these issues. With rising power demands and growing environmental concerns, the current energy system will need to be updated soon. Burning fossil fuels is contributing to air and water pollution. Additionally, there are an estimated thirty million tons of non-biodegradable plastic waste going into landfills every year in the United States (Rep. 1). The proposed project looks to use the plastic waste to convert to clean energy. Research has found that by first vaporizing the plastic, through a process called pyrolysis, and then combusting the gas, the harmful emissions are greatly reduced. This project looks to design self-sustaining pilot plant that runs on plastic waste.

The Design Project Objectives and Requirements

The objective of this project is to design a self-sustaining pyrolyzer/combustor that can convert plastic waste into clean energy.

Design Objectives

This project designs a theoretical pilot plant that can convert solid plastic waste to energy at a rate of 500 kg/hr, per the client’s specifications. A small-scale physical prototype will be assembled to convert plastic waste pellets at a rate of 200 g/hr. The plastic waste needs to be continuously fed into the system, in order to endlessly run. To create a self-sustaining system, 15-25% of the heat released in the combustion chamber will be recycled to run and sustain pyrolysis. The remaining 75-85% of heat released from the combustion will exit the chamber in order to be harvested for energy.

Design Requirements

To convert the solid plastic into almost 100% gas, the temperature in the pyrolysis chamber will be 800°C. In order to minimize emissions with an oxygen-rich/fuel-lean atmosphere, the fuel to oxidant equivalence ratio needs to be less than 1. Additionally, the oxidizer gas will be preheated to facilitate ignition (Rep. 3).

Design Concepts Considered

Three main design concepts were considered in attaining a final design; nested rotating chambers, an inline heated screw feeder design, and an integrated stack.

Inline Heated Screw Fed Design

The inline screw fed design works similar to an extruder. It will have different heating sections where the plastic would undergo phase changes. The screw in the middle would be pushing the material along the whole way. However, this design would need to use an outside
heating source which would not fulfill the main design goal of the system being self-sustaining (Rep. 5.2).

**Nested Rotating Chamber Design**

The nested rotating design has two rotating chambers. The inside chamber is the combustor and the outside chamber is the pyrolyzer. The heat generated in the combustor would heat the pyrolyzer. This design has both good and bad concepts. The combustor in the middle gives for a large area of heat transfer. However, because it is rotating there are many difficult design challenges that will have to be overcome (Rep. 5.3).

**Integrated Stack System Design**

The integrated stack design has a pyrolyzer on the top and the combustion chamber on the bottom. The heat generated in the combustion chamber would be used to heat the pyrolyzer by conduction through a common partition. This system fulfills the main design goal of a self-sustaining system (Rep. 5.4).

**Recommended Design Concept**

The design involves a pyrolyzer chamber, where plastic waste enters and vaporizes, stacked above a combustion chamber, where the pyrolyzed gas is burned. The flame from combustion heats a common plate, sustaining pyrolysis in the pyrolyzer chamber, creating a self-sustaining system.

**Design Description**

The design chosen was the integrated stack design. This design was chosen due to its feasibility and cost (Rep. 6). In this design, the plastic waste will enter the pyrolyzer through a gravity fed valve system along with nitrogen. Once pyrolyzed, the gas will exit the combustion chamber and flow to a Venturi mixer where it will be mixed with an oxidant. The mixture will be ignited in the combustion chamber. Approximately 25% of the heat from this flame will be used to heat the pyrolyzer and the rest will be harvested for energy production.

In order to start the process, there needs to be an outside heating source that will preheat the pyrolyzer. Natural gas was chosen for the initial startup because it bears similarity to the gas produced from pyrolyzing plastics and, most importantly, it is readily available. The gas will only be used to start the pyrolysis process and will be shut off once pyrolysis begins.

**Analytical Investigations**

Extensive analytical analysis was done to determine the proper sizing, flow rates and heat losses of the small scale prototype. First,
the necessary amount of oxygen and nitrogen were found using stoichiometry to be 0.353 g/s and 0.455 g/s respectively. Using these numbers, the amount of heat needed to pyrolyze the plastic waste and heat the incoming nitrogen was found to be 451 Watts. Next, a ceramic insulation blanket was chosen to minimize heat losses. The total energy loss using one inch of insulation over the entire prototype was calculated to be 300 Watts using circuit analysis.

The Venturi mixer was then designed to completely mix the oxidant and the pyrolyzed gas. In order for the gas and oxidant to mix, the oxidant must penetrate at least half way into the gas flow. Using formulas provided by Professor Levendis, four quarter inch oxygen lines and a one inch gas line were found to provide proper mixing for the system’s flow rates.

**Experimental Investigations**

Experimentation has proved design concepts and developed new focuses. To prove that conduction through a common plate can be suitable for pyrolysis, plastic pellets were inserted into hollow ball of aluminum foil (Rep. 8.3). The ball had a spout to release the pyrolyzed gas. A Bunsen burner was placed under the foil to act as the combustion chamber. After 20 seconds, the gas exited the spout and combusted due to the Bunsen burner flame extending to the spout.

To simulate the pyrolyzer chamber with a nitrogen input, a standing tee pipe fitting was used as the pyrolyzer chamber, a seen in the left image. The bottom was plugged to represent the common plate. Again, the chamber was heated by a Bunsen burner flame. However, the temperature of the chamber rose to only about 500°C because the fitting was not insulated. The plastic still pyrolyzed, but there was some soot created in the chamber. This showed that the prototype would need insulation to hold in the heat and to limit any heat losses and to minimize harmful emissions (Rep. 8.4).

**Key Advantages of Recommended Concept**

This project’s main advantage is that it uses an alternative energy source that is not widely used today. From this main advantage there are other smaller advantages. This is a very clean process, meaning that there is a small carbon footprint. This is opposed to burning the plastic in a garbage incinerator that gives off a lot of carbon
monoxide, soot and other harmful emissions. Additionally, it reduces world waste by totally disposing of something that would otherwise be put into the ground and have to go through hundreds of years of decomposition. Lastly, it is self sufficient. The power plant is able to directly feed off of the energy created in the combustion process.

Financial Issues

A theoretical pyrolyzer/combustor pilot plant is estimated to generate $850,000 per year; however there are costs for nitrogen supply and maintenance that will lower the net revenue. Total cost for building the small scale prototype was $750. Cost to run this device is $1.04 per hour, which is the cost of nitrogen required for the process. A large scale pilot plant is estimated to generate $850,000 per year in gross revenue by producing power at a wholesale value of $0.02 per kWh. This number does not include the cost to purchase nitrogen, overhead or wages for factory workers. If nitrogen was purchased from a supplier, the cost would outweigh the generated revenue, therefore a nitrogen generator would necessary or alternatively, the process could be couple with another process that produces nitrogen as a byproduct.

Recommended Improvements

Plastic waste feeding was not a main focus for this design. Future improvements would involve a dedicated continuous feeder for the pilot plant. Future improvements would be making the pyrolyzer/combustor plant connected to a plastic shredder, thus taking full plastic bottles instead of pellets or shredded waste. Since the plastic bottles are not virgin plastic, a purifying system could be integrated to make the waste as close to as virgin hydrocarbons, as possible. Also, the continuous feeder was integrated from another design group which created a feeder for a pyrolyzer/combustor in a lab setting. The power plant could have a large unique feeder, since the size is so much larger than a lab setting.