“Renewa-Barrel” Biogas Digester

Team Pope Francis

Professor McTernan
Engineering Design 100, Section 021
Joe Garnett, Chris Winner, John Ott, Stephen Sheetz
Mission Statement

We strive to engineer a sustainable use for waste barrels which both reduces industrial and biological waste while providing society with clean energy. We aim to develop an apparatus for recycling Arcelor Mittal’s waste products. Instead of disposal into a landfill, we will reuse the waste barrels in a profitable, marketable, and sustainable solution.

We developed a biogas digester which converts biological waste into usable, clean methane “natural gas.” Through prototyping, we worked at minimizing the required materials and maximizing possible storage and output of methane gas.

Customer Information: ArcelorMittal

ArcelorMittal is the world’s leading steel and mining company, with global influence in all steel markets. These include, but are not limited to, the automotive, construction, appliance, and oil industries. ArcelorMittal is also the leader in research and development of the steel industry; they are consistently devoted to producing the safest and most sustainable steel.

ArcelorMittal annually produces 91.2 million tonnes of steel, which is about 6% of the world’s steel output. They produce a majority of this steel in the Americas, and Europe, but are focusing efforts to grow in emerging markets including Brazil, India, the Middle East, and China. Figure 1. shows a steel smelting plant. Figure 1. shows a steel smelting plant Tubarã, Brazil. [1]
steel blast furnace located in Tubarão, Brazil. The focus on emerging markets is not only an effort for company growth but a righteous effort for the growth of the global economy in underdeveloped nations.

In addition to steel production, ArcelorMittal is a global leader in the mining business. They produce 70.1 tonnes of iron ore and 8.8 tonnes of coal per year, with these values growing annually. In 2013, ArcelorMittal invested more than $270 million in research and development of safer and greener processing steel in all sections of supply chain. They are devoted to implementing perpetually cleaner processing with mechanisms such as Ultra-Low CO₂ Steelmaking. The research continually helps to reduce both the company and their customer’s environmental impact. [1]

**Customer Needs**

As a global leader in producing sustainable steel, ArcelorMittal is committed to maximizing output while minimizing their production waste stream. Our objective is to design a system which will reduce ArcelorMittal’s waste stream by reusing, transferring or recycling one or more of their given outputs. The provided waste products include used plastic barrels, steel drums, plastic totes, and unusable wooden pallets and bricks.

**What is a Biogas Digester?**

A biogas digester is a machine that uses anaerobic digestion to convert organic materials such as manure, plant material, and food waste into clean, usable methane gas. The digester is air tight, prohibiting the presence of oxygen from the reaction that occurs within the containers of the machine, facilitating anaerobic breakdown of the biomass [2].
Anaerobic digestion is the decomposition of biodegradable materials by bacteria in the absence of oxygen. These bacteria include acidogens, acetogens, which form acetic acid, and methanogens, which form methane gas [2]. There are four steps of anaerobic digestion, which are hydrolysis, acidogenesis, acetogenesis, and methanogenesis, portrayed in Figure 2 [2].

The first step of anaerobic digestion is hydrolysis, which is the interaction between a large polymer and water that results in the decomposition of that polymer into simple monomers [2]. During this step, the organic compounds in the biodegradable material are broken down into simple sugars, amino acids, and fatty acids. Acidogenesis is the next step in the anaerobic digestion process, which is when monomers are converted into volatile fatty acids [2]. Other products include hydrogen sulfide, carbon dioxide, and ammonia. Following acidogenesis is acetogenesis. The acetogens take the volatile fatty acids produced in the previous step and convert them into mostly acetic acid [2]. Carbon dioxide and hydrogen gas are also products of this process. The fourth and final step of anaerobic digestion is methanogenesis. Methanogenesis takes the products from the previous steps and convert them into usable methane gas, water, and carbon dioxide [2].
Idea Selection Process

After researching ArcelorMittal we used the presentation and the information they had given us to determine our customer needs. Each member of our team brainstormed and came up with a possible design to help reuse the waste of ArcelorMittal that could promote sustainability and reduce the wastes being put into landfills.

Our four ideas included: a biogas digester, a composter, a barbecue smoker, and hydro barrels. The biogas digester, which we eventually came to the decision to create, would be constructed out of two 55gal barrels by using one barrel as a holding chamber where the actual anaerobic process would be carried out, and the other for the actual methane to feed into and be held until needed. The composter idea consisted of us using one 55gal drum and cutting a small square opening in it to feed compost in it. Then we would drill holes in the sides of the barrel to allow air flow for the composter since it is an aerobic process. For a barbeque smoker, the barrel would be cleaned out and then cut in half. Inside one of the halves, a grill rack will be attached along with grease pans underneath. After the grill rack is attached, two chains and two hinges would be added to the other half of the barrel. The hinges and chains will then be attached to the barrel with the grill rack. Finally, a hole will be cut in the top of the barrel, which will act as a smoke stack. Lastly, the hydro barrels was an idea that consisted of using multiple plastic 55gal drums. For this idea, you would attach the barrels on their side in the desired grid such as 3x3 or 4x4 by connecting them with PVC piping and placing it securely in a moving body of water such as a river. Then attach fins cut from the metal 55gal drum to catch water, thus turning a turbine and generating hydro-electricity. In deciding which ideas would help satisfy our customer needs we first needed to rank our customer’s needs by importance. We did this using an Analytic
Hierarchy Process Chart [chart 1]. This chart helped us decide which needs we needed to focus on when evaluating our design ideas.

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Sustainability</th>
<th>Ease of Use</th>
<th>Environmental Impact</th>
<th>Assembly</th>
<th>Marketability</th>
<th>Sum</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>0.25</td>
<td>1.5</td>
<td>0.25</td>
<td>4.5</td>
<td>10%</td>
</tr>
<tr>
<td>Sustainability</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.5</td>
<td>1</td>
<td>8.5</td>
<td>19%</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>4.5</td>
<td>10%</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3.5</td>
<td>1</td>
<td>12.5</td>
<td>28%</td>
</tr>
<tr>
<td>Assembly</td>
<td>0.667</td>
<td>0.667</td>
<td>1</td>
<td>0.286</td>
<td>1</td>
<td>0.5</td>
<td>4.119</td>
<td>9%</td>
</tr>
<tr>
<td>Marketability</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>11</td>
<td>24%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45.12</td>
<td></td>
</tr>
</tbody>
</table>

Using Chart 1 we determined that our top customer needs when making our product are environmental impact, marketability, sustainability, cost, and ease of use. These needs were then placed into a concept generation matrix [chart 2] along with our various ideas to determine which idea would satisfy our customers need the best.
Using chart 2 we found that the best concept to meet all of our customer needs is a biogas digester. Even though the biogas digester and the composter both scored scores of 4 we decided that the most plausible prototype would be for a biogas digester because the process could be simulated to show that the prototype could actually work. This matrix also helped us understand that our other two ideas, the smoker and hydro barrels, were not as successful in meeting the
client's needs, thus we chose not to continue with those ideas. An early sketch of our idea can be found in figure 4. After we created this sketch we created a cross sectional view in SolidWorks to show an animated design of our prototype shown in figure 5.

[Figure 4] An early Sketch of our biogas digester design

[Figure 5] Cross sectional view of a SolidWorks design of our original sketch.
Prototype Selection Process

Prototype 1

Our first prototype simulated the use of a two chamber biogas digester and methane holding tank. Using three “Smart Water” bottles, one rubber tube and multiple straws, we constructed two “tanks,” both with an entrance and exit tubes through the caps of the bottles. The first chamber, the biogas digester, worked effectively as an airtight anaerobic digester. The second chamber, the methane holding pressure tank, was designed with two bottles, one with the top cut off and one with the bottom cut off. Filling the “bottom” bottle (with the top cut off) with water would allow for an airtight tank which would expand as the methane gas is produced by the digester. This is achieved by placing the “top” bottle (with the bottom cut off) into it. Adding a weight to the top of the filled, extended tank, and closing the methane output valve (from the digester) would allow the holding tank to be pressurized for practical use of burning methane gas. This prototype can be seen in figure 6.
### [Chart 3] Prototype 1 Testing Plan and Results

<table>
<thead>
<tr>
<th>Need/Feature/Requirement</th>
<th>Describe Test</th>
<th>What is a “pass”?</th>
<th>Materials/Tools Needed to Run Test</th>
<th>Did it Pass?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produce Methane</td>
<td>Methane was simulated using a straw in the digestion tank.</td>
<td>If methane can be simulated by adding air to the tank and it stays in the digester.</td>
<td>Straw Bottles</td>
<td>Yes by using a straw we were able to simulate the creation of methane gas in the digestion tank.</td>
</tr>
<tr>
<td>Transfer Methane to Holding Tank</td>
<td>Once methane is created, or simulated, in the digester barrel, a valve is opened to allow the methane to transfer into the holding tank.</td>
<td>If the simulated gas is transferred to the holding tank through the rubber tubing the test is a pass.</td>
<td>Bottles Straw Rubber Tubing Clamps</td>
<td>Yes the gas was transferred into the holding barrel when the valve was opened.</td>
</tr>
<tr>
<td>Hold Methane Until Use</td>
<td>With both valves closed the barrel would remain buoyant in the water, holding the methane gas.</td>
<td>If the barrel holds the methane gas without allowing it to escape.</td>
<td>2 Bottles Valves Rubber Tubing Water Weight</td>
<td>No, the bottles we were using had the same diameter which did not allow them to fit inside each other. This prevented the methane from being trapped until it was needed.</td>
</tr>
<tr>
<td>Expel Methane</td>
<td>When the methane has been trapped in the holding tank the final valve is opened to expel the methane to be used by the consumer.</td>
<td>If the methane is successfully and travels through the tubing.</td>
<td>2 Bottles Valves Rubber Tubing Water Weight</td>
<td>Because the simulated methane was not successfully held in the holding tank it was not able to be expelled properly.</td>
</tr>
</tbody>
</table>
Observations of Prototype 1

The first prototype had a flaw: the Smart Water bottles were of the same diameter and could not fit inside each other when cut. These observations can be seen in chart 3. From this we learned that the Renewa-Barrel holding tank would need to have a larger “bottom” part of the holding tank than the top, so it would be able to fit in, and extend when methane is produced. We felt that the rest of the prototype was a success. The only downside was that the simulated methane could not be held if the holding barrels had the same diameter. We wanted an airtight apparatus to hold the methane but we would need to seek other options instead of two of the same bottle.
Prototype 2

When designing our second prototype, we found a water bottle with a larger diameter than the Smart Water and implemented it into our design. This can be seen in figure 7. We feel this will help hold the methane more effectively. By placing the top barrel with weights in a larger bottom tank we can pressurize the methane for it to be expelled for use later. Another aspect that was changed for prototype 2 was along with using a straw to blow air into the digester portion, a mixture of Mentos and diet coke was put in the digester to produce carbon dioxide which will act as the methane and fill the chamber. This process can be seen in figures 8 and 9. With the carbon dioxide we will then use the same process of opening and closing the valves to allow the gas to travel into and out of the holding tank.
## Chart 4: Prototype 2 Testing Plan and Results

<table>
<thead>
<tr>
<th>Need/Feature/Requirement</th>
<th>Describe Test</th>
<th>What is a “pass”?</th>
<th>Materials/Tools Needed to Run Test</th>
<th>Did it Pass?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produce Methane</td>
<td>Methane was simulated using a straw in the digestion tank. Also Mentos and Diet Coke were combined to produce carbon dioxide</td>
<td>If methane can be simulated by adding air or gas to the tank and it stays in the digester.</td>
<td>Straw, Bottles, Diet Coke, Mentos Candy</td>
<td>Yes by using a straw we were able to simulate the creation of methane gas in the digestion tank. Also the Diet Coke and Mentos created carbon dioxide which was held in the digester.</td>
</tr>
<tr>
<td>Transfer Methane to Holding Tank</td>
<td>Once methane is created, or simulated, in the digester barrel, a valve is opened to allow the methane to transfer into the holding tank.</td>
<td>If the simulated gas is transferred to the holding tank through the rubber tubing the test is a pass.</td>
<td>Bottles, Straw, Rubber Tubing, Clamps</td>
<td>Yes the gas was transferred into the holding barrel when the valve was opened.</td>
</tr>
<tr>
<td>Hold Methane Until Use</td>
<td>With both valves closed the barrel would remain buoyant in the water, holding the methane gas.</td>
<td>If the barrel holds the methane gas without allowing it to escape.</td>
<td>2 Bottles, Valves, Rubber Tubing, Water, Weight</td>
<td>Yes, by changing the diameter of the bottom barrel we were able to fit the top barrel in. When the gas was transferred the top barrel rose in the water and the gas was held in the holding tank.</td>
</tr>
<tr>
<td>Expel Methane</td>
<td>When the methane has been trapped in the holding tank the final valve is opened to expel the methane to be used by the consumer.</td>
<td>If the methane is successfully expelled and travels through the tubing.</td>
<td>2 Bottles, Valves, Rubber Tubing, Water, Weight</td>
<td>Yes, when the exit valve was opened the weights on top of the barrel pushed the top barrel into the water which expelled the gas which could then be attached to any object that uses natural gas.</td>
</tr>
</tbody>
</table>
[Figure 7] Prototype 2 of Biogas Digester

[Figure 8] Digestion Tank with Mentos and Coke

[Figure 9] Isometric View of whole biogas digester and holding tank.
Observations of Prototype 2

The result was an efficient, airtight digestion and storage of methane gas. We achieved this result by the test shown in the following video. The gas was successfully created and traveled through the digester and the holding tank. By using the mixture of Mentos and Diet Coke we were able to simulate the slurry that would be produced by the compost in the digester. It also created an airtight seal in the digester because the height of the slurry was higher than the pipe that the compost was added to, so very little gas escaped before the valve was opened to transfer the gas into the holding tank.

Business Plan

Our business plan for our Renewa-Barrel is to sell to major corporations that use natural gas as a main source of energy. Also, another target for this market would be farmers. Farmers have an abundant source of manure to put in the biogas digester. In addition to receiving a generous supply of natural gas from the manure, the excrements from the digesting chamber can be taken out through the bottom exit tube and used as fertilizer. Since the Renewa-Barrels will be relatively cheap, corporations and farmers can purchase multiple digesters that all feed into one holding tank to create a biogas farms and produce mass amounts of natural gas. With the recycled use of ArcelorMittal’s 55gal. drums, plastic tubs, and pallets, the Renewa-Barrel’s only costs would include roughly 10 ft. of rubber hosing, 3 shut-off valves, 1ft, 6in PVC pipe, and an 8in PVC pipe roughly cut 3ft long for the entrance of materials. All of these materials can be purchased for around $20-$25. With optimal conditions, manure will produce 4.5 L/day of methane gas. [3] With the price of natural gas at $4.79 per thousand cubic feet [4], and an average household using 62.3 thousand ft³ per winter, making their budget around $300[5], a single digester will save the owner $1.28 per winter which can be seen in figure (4). Although
this does not seem like much, with multiple digesters working simultaneously as well as using larger amounts of manure, it is possible that the owner will be able to produce significant amounts of natural gas and save them a lot of money.

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<table>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5L</td>
<td>0.0353147 ft³</td>
<td>$4.79</td>
<td>$0.007</td>
<td>182 days</td>
<td>$1.28 per Winter</td>
</tr>
<tr>
<td>1 Day</td>
<td>1L</td>
<td>1000 ft³</td>
<td>1 Day</td>
<td>1 Winter (Oct.1- March 31)</td>
<td></td>
</tr>
</tbody>
</table>

*Figure [10] Business calculations of one digester*

**Conclusion**

Through experimentation of the efficiency of our prototype, we believe that a working model made of 55 gallon and the larger cubic barrels could produce methane through anaerobic digestion. After analysis of methane output and storage capacity values shown in figure 4, we conclude that implementing one single Renewa-Barrel system would not save a significant amount of money in one winter season. The data is relative to an average cost of natural gas and methane production so real output may vary, but not by any significant variance. As stated in the business plan, a realistic approach to sale of the Renewa-Barrel systems is large scale chain which would considerably expand organic waste consumption and natural gas production.

In researching the processes of a biogas digester, we learned extensively about the chemical processes involved in the breakdown of organic material and production of natural gas. This knowledge has broadened our understanding of molecular chemistry and biofuels, two growing subfields of engineering. As intended industrial, biomedical and chemical engineers, this project was not only fascinating and exciting, but also relevant to our future career paths.

If our group were to create a third prototype, we would not make many changes to the design of our structure. However, we would aim to make a larger scale model with proper valves
and other parts that this unit could actually be tested to see if our prototype would be successful with real methane gas. Tests would be added to see if the compost breaks down and how fast. A test to see if the slurry would flow out of the digester, which could be used for fertilizer, would be performed. Tests of the environmental elements like wind and rain would also be added. We would make sure the digester would not blow over in high winds and would test to see if it was airtight so rainwater does not leak in and dilute the slurry.

Our group excelled in coming up with feasible options that would be sustainable but also economical for ArcelorMittal. Each member of the group came up with their own idea which we put into a selection matrix to decide on one prototype. After that rough sketches and SolidWorks models were created, which are shown in this report. We believe our creativity and ability to generate feasible options was one of our many strengths. Another aspect we excelled in was our prototyping and revising our prototype. We found problems in our first prototypes and worked together to revise the prototype so we could continue forward. As for weaknesses, we do not feel that any specific weakness plagued our team and overall we split the work evenly and all worked together well to achieve the goals set forth for this project.

An issue that arose from the ArcelorMittal project was that there was not much guidance given. We were unsure at first as to what the goal of the project was or what needs the customer had. When we had questions for ArcelorMittal they were not always answered in a timely fashion which did not help when making our prototypes. We feel that clearer objectives from the company along with a way to ask questions in a timely manner could greatly improve the project as a whole.
Works Cited


