Micro Auto Gasification System: Lid Proposal

Terragon Environmental Technologies Inc.

November 28th, 2011

SUBMITTED BY:

Marc Gaulier

Samir Kassam

Lori Miller

Andrew Partheniou

Atiq Qasim

Anthony Stante

COMPANY REPRESENTATIVE:

Steve Lavigne

Acknowledgement

The contribution of the following individuals greatly attributed to the completion and success of this proposal.

Terragon Environmental Technologies Inc.

Mr. Steve Lavigne

Martin Keighan

Samuel Leung

McGill University

Prof. Paul Zsombor-Murray

Prof. Vince Thomson

Lucie Parrot

Tony Pattinson

Executive Summary

Terragon Environmental Technologies is a company focused on making a difference in waste management. Their MAGS system is designed to gasify waste and minimize the amount of greenhouse gases released into the atmosphere.

The scope of the Value Engineering project was to optimize the value of the original lid design. The main function of the lid is to transfer the waste into the gasifier in a safe and environmentally-friendly manner.

In order to complete the task, a series of six steps were taken as per the value engineering method. The process involved a brainstorming session, a cost analysis, and a development phase to evaluate the feasibility of the ideas.

The final proposed concept is a simple truncated drum design with an off-centered axis of rotation. At the manway, a retracting seal mechanism lifts on and off the drum to isolate the environment from the gasifier. This new mechanism will increase the reliability of the system as well as its ease of maintenance. The outer structure of the lid would be very similar to the original design. The new design would cost approximately $300 more than the original lid. However, due its improvement in quality and "satisfaction of needs", this increase is justifiable.

The following report describes the overall process used to develop the new design for the MAGS lid as well as provides details and drawings of the proposed design.

Table of Contents

Introduction

Terragon Environmental Technologies Inc.

Founded in 2004, Terragon Environmental Technologies was established for communities and habitats in which the conventional approach to waste management—exporting waste to another location—is not practical. Habitats and environments such as ships, military operations, isolated communities, resorts, and hospitals are Terragon's target markets.

Product Description

The Micro Auto Gasification System (MAGS) is a small scale solid waste disposal system that uses gasification to break down organic waste and transform it into combustible 'syngas'.

The syngas is produced in the gasifier, similar in size to a 45 gallon drum, which is kept at vacuum pressure and elevated temperatures (600-750˚C). The unsorted waste is introduced into the gasifier through the lid, which acts as a transfer point from the atmosphere (operator's environment) to the gasifier. The vacuum pressure serves two purposes: 1) to dramatically reduce the heat transfer from the gasifier to the environment, and 2) to inhibit the introduction of oxygen into the gasifying environment. Oxygen present in the gasifier would cause combustion to take place, effectively nullifying the gasifying process, and causing the machine to fail.

Diesel fuel is used to start-up the MAGS when waste is first introduced. Once the machine is heated to the desired temperature, the syngas produced from the gasified waste is combusted in a combustion chamber and is recirculated to heat the machine. The diesel fuel input, at this point, ceases and the system becomes self-sustaining.

The syngas combustion product goes through a water spray for instant cooling before passing through a scrubber. These processes prevent the emission of noxious fumes into the atmosphere. The end result is emissions that meet the strictest of regulations and are invisible, odorless, and safe.

Additional advantages include the production of a solid by-product of gasified waste known as bio-char, useful in fertilizer applications, as well as additional heat in the form of hot water that can be used on-site.

Current Design

The current lid has a few significant issues that need modifying. Primarily, seal damage is a problem contributing to inefficienciesand high cost in the system. The load of the drum and high heat environment damages the two seals, silicone and Teflon, therefore increasing the need for maintenance. However, this problem can be solved by changing the location of the seals. The current seals are located at the bottom of the drum. Changing them therefore requires the dismantlingof the lid,a time consuming and expensive job that suspends use of the system.

Furthermore, as the syngas escapes from the gasifier and condenses on cooler surfaces, it solidifies and therefore causes tar build-up on all surfaces. Tar build-up causes obstruction of moving parts and damage to the system. Additionally, as the gas is purged, it can solidify in the vacuum pipes, therefore causing the flow to choke and inefficient purging.

The lid functioning involves two main mechanisms: a lifting mechanism and a rotating mechanism. Once waste is loaded into the drum, the manway is closed. The drum, at this loading position, sits in the sealed position relative to the gasifier thus preventing syngas release to the atmosphere. The drum is then purged of air and lifted off the seals by a rack and pinion, therefore opening the passage to the gasifier. The drum is then rotated 180˚C and, once the hole of the drum is aligned with the gasifier entrance, the waste is discharged into the gasifier. The drum is rotated back to its original position and lowered back onto the seals. Air is drawn into the drum to equalize the drum pressure with the atmosphere. The process is then repeated.The two mechanisms involved in this process greatly contribute to the high cost of the lid. The simplification of this process would ensure that the value of the final product would increase.

Team Members

Marc Gaulier

Samir Kassam

Lori Miller

Andrew Partheniou

Atiq Qasim

Anthony Stante

Terragon Representative

Mr. Steve Lavigne

Value Engineering Job Plan

A structured format for optimizing a product or process is the key to any project's success. The Value Engineering Job Plan provides a step by step process used to breakdown the most complicated problems into simplified phases. As such, engineers are able to fully understand the problem at hand and improve the value of the final product by increasing the satisfaction of needs while minimizing cost. The following seven phases outline the value engineering process used to optimize the MAGS lid:

1. **Organization Phase:** The precise scope of the project was identified, as well as goals and constraints.
2. **Information Phase:** After a visit to the Terragon facilities, the team's knowledge of the MAGS reached a greater depth. Having seen the MAGS first hand and having consulted with Terragon engineers, the technical and non-technical aspects of the lid were better understood.
3. **Functional and Cost Analysis Phase:** Each component of the lid was analyzed to uncover its specific function. These functions were divided into the main function and sub-functions. A cost analysis was then performed to better illustrate the cost associated to each function.
4. **Creativity Phase:** A brainstorming session was performed in which many ideas and concepts were generated.
5. **Evaluation Phase:** Each concept from the creativity phase was evaluated using a gut feel index. This scoring system allowed for several scenarios to stand out while inferior ones were eliminated from further consideration.
6. **Development:** The remaining concepts were examined in further detail and refined. Through the use of a Cost-Merit graph, the best concept was chosen as the final proposal to Terragon Environmental Technologies.
7. **Implementation Phase:** This phase is not included in the project, however it is considered as the final step in the Value Engineering Job Plan. This phase involves the implementation of the proposal and a follow-up from the team to examine the progress of the new design.

1.Organizational Phase

Scope

The scope of this project is focused solely on the lid of the MAGS. The lid encompasses the entire top section of the MAGS responsible for accepting and discharging waste safely and efficiently into the gasifier. Specifically, the main focus is on the manway, the drum, the seal, as well as the lifting and rotating mechanisms. The air valves as well as the cooling system are of secondary importance. The emphasis is on improving the reliability, safety, performance and cost of this part of the MAGS.

Goals

In response to the client's needs, clear goals have been established in order to improve the overall value of the MAGS lid. These goals can be broken down as follows:

1. **The Seal**

   The purpose of the seal is to minimize heat transfer into the drum, inhibit the introduction of oxygen to the gasifier and reduce tar formation in the lid. It is currently placed in ahigh temperature location and subjected to abrasion.The goal specific to the seal is to search for alternative materials and/or explore alternative placement of the seal in order to increase its value.

2. **Lifting and Rotating Mechanisms**

   The lifting and rotating mechanisms, used to transfer the waste from inside the drum to the gasifier, are the main reason for the lid's high cost. The goal in terms of the mechanisms involved is to combine them, remove them, or replace them with a simpler mechanism. Accomplishing this goal will ultimately improve lid's efficiency and overall value.

3. **Tar Build-Up**

   Tar formation in the lid and in the air purging system is a problem deserving of recognition.A reduction in the amount of tar build-up will increase usability and reliability of the system.

Constraints

Several constraints were imposed by the client to ensure proper operation and safe use.

1. **Cool Drum Temperatures**

   Despite the high temperatures (600-750°C) inside the gasifier, the temperature inside drum must not exceed 40°C. This low temperature must be kept for two reasons: 1) to ensure operator safety while waste is loaded into the drum, and 2) to ensure that the waste does not melt before being dropped into the gasifier. The latter prevents the waste from sticking to the drum, and therefore not dropping into the gasifier. In such a case, the operator would have to shut down the system in order to clean the drum and re-establish cooler temperatures.

2. **Vacuum Pressure**

   During the operation cycle, the lid must maintain a gage pressure of -20kPa. Working at vacuum pressure ensures that no combustion takes place within the gasifier.

3. **Ceiling Height Restriction**

   The MAGS is found in a variety of locations (ex: ships), and must abide by the strict space limitations. In order for the MAGS to be serviceable in its environment, its height must not be increased.

4. **Sub-Assembly Required**

   In order for the MAGS to be installed, it must be transported to its service location. Sub-assembly is therefore required.

2. Information Phase

Technical

The following is a process overview of the MAGS machine from the point of receiving the waste to the point of releasing it into the gasifier where it is then gasified.

1. The manway of the machine is opened, and a medium sized garbage bag is inserted into the drum. It is important to note that the temperature in the drum must not exceed 40°C in an effort to ensure operator safety and to avoid the melting of the waste.
2. The manway lid is closed, and the air inside the drum is purged to ensure that the drum is in a vacuum state, and the pressures in the drum and gasification chamber are equalized.
3. The drum is lifted from its cradle using a rack and pinion mechanism. This lifting is done so as to prevent damage to the seals while the drum is rotating (following step). The purpose of the seals on the cradle is to restrict gases, particularly syngas, from entering the drum and to minimize heat transfer into the lid.
4. The drum is rotated manually (180˚) until the opening, originally at the top of the drum, is aligned with the entrance to the gasifier at the bottom. The wastethen falls straight through the opening into the gasifier where it is heated at temperatures of up to 750°C and vaporized into syngas, which, in turn, is used to fuel the machine. The drum returns to its original position. The sides of the drum are not spherical but are steeply curved to ensure the waste is discharged properly. Manual operation of the rotating mechanism is advantageous due to the operator's capability to unjam a stuck garbage bag.
5. The drum is then lowered back onto the seals to prevent syngas from entering the area. Air is added into the drum to restore drum pressure to atmospheric.

Once this process is completed, and the waste has entered the gasifier, the drum can be reloaded with another garbage bag. The goal of the MAGS is to run uninterrupted for as long as needed, during which it should be able to handle multiple loads of waste. Additionally, the MAGS, ideally, should be able to process between 5 to 10 kg of waste in 10 minutes.

The MAGS can only operate with such consistency if it is highly reliable.The machine must also be easy to maintain and use. In other words, the MAGS must be easy to clean, contain durable seals, and allow for sub-assembly. Reliability and maintenance are of high priority since MAGS machines are usually operated in remote or isolated environments such as ships and resort hotels.

Materials

The current machine is made of 3/8 stainless steel. The drum of the machine itself weighs approximately 100 lbs. The seals placed on the cradle of the drum are of two different materials: Teflon and silicone. Two different seals were originally used as a means to experimentally test the effectiveness and reliability of each material. The Teflon seal was revealed to be the more efficient and durable choice. The next generation of MAGS machines will therefore only use Teflon to seal the drum and gasifier.

Economic Aspect

The lid for the current MAGS machine costs approximately $10,000. Since the machine has not yet been released commercially, its costs are usually covered through contracts and partnerships with various enterprises. Currently, the machine is in an experimental phase and is being used on military vessels and in hotels, where its performance is being reviewed. The MAGS is suitable for small to medium consumption locations.

Environmental Aspects

Since the MAGS mainly operates in isolated locations, it must be self-sustaining. By using recirculating the syngas through the machine to generate power and heat, pollution, to a certain extent, is minimized. The MAGS has a number of environmental benefits:

- Prevents CO_2 produced through the combustion process from entering the atmosphere due to the filtration process.
- Reduces volume of waste by 95%.
- Uses surplus thermal energy to heat water, thereby saving energy.
- Syngas produced in the gasification chamber is recycled and used as fuel to heat the gasifier, thereby replacing the need for diesel during its entire running period.
- The by-product of the waste, known as bio-char, can also be used as a soil additive, thus ensuring nothing is wasted.

Usage

The manual aspects of the machine include the loading of the waste as well as the lifting and rotatingof the drum. These simple tasks ensure easy use.

Legal – Safety

To ensure operator safety, temperatures inside the drum must be kept low. The operator will therefore not be at risk of burns while loading the garbage bag into the drum. Additionally, blowback of syngas must be prevented when the manway is opened.

3. Function and Cost Analysis

Functional Analysis

The functional analysis phase is used to express the functions a product must fulfill in order to satisfy a client's need. Each component of the MAGS has its own function, which can then be broken down into sub-functions. A complete functional analysis creates a better understanding of the product and its components.

Identifying functions can be approached in different ways to ensure that no important function is forgotten. In the case of the MAGS lid, three different methods were used: 1) Intuitive Research, 2) Sequential Analysis, and 3) Environmental Analysis.The details of these methods and the functions identified can be found in Appendix I.

Following the identification stage, these functions must be organized, characterized and quantified (if possible). The organization of these functions can be accomplished using a FAST diagram. The characterization of functions can be found in the Appendix.

FAST Diagram

From the list of functions created, the duplicated and irrelevant ones were removed. The remaining functions were categorized (basic, secondary, or constraint function) and then prioritized based on importance.

In the FAST diagram below, the functions are organized according a basic or secondary functionality. On the left side of the chart, the main mission of the lid is stated as such: "*To input waste into the gasifier in a safe and environmentally friendly manner*".

The four main secondary functions, found to the right of the basic function, are the following:

1. Transfer Waste
    a. Accept Waste
    b. Discharge Waste
2. Ensure Operator Safety
3. Ensure Reliability
4. Prevent Syngas Release to the Atmosphere

The following diagram in Figure 1 shows the four main functional groups as well as their sub-functions.

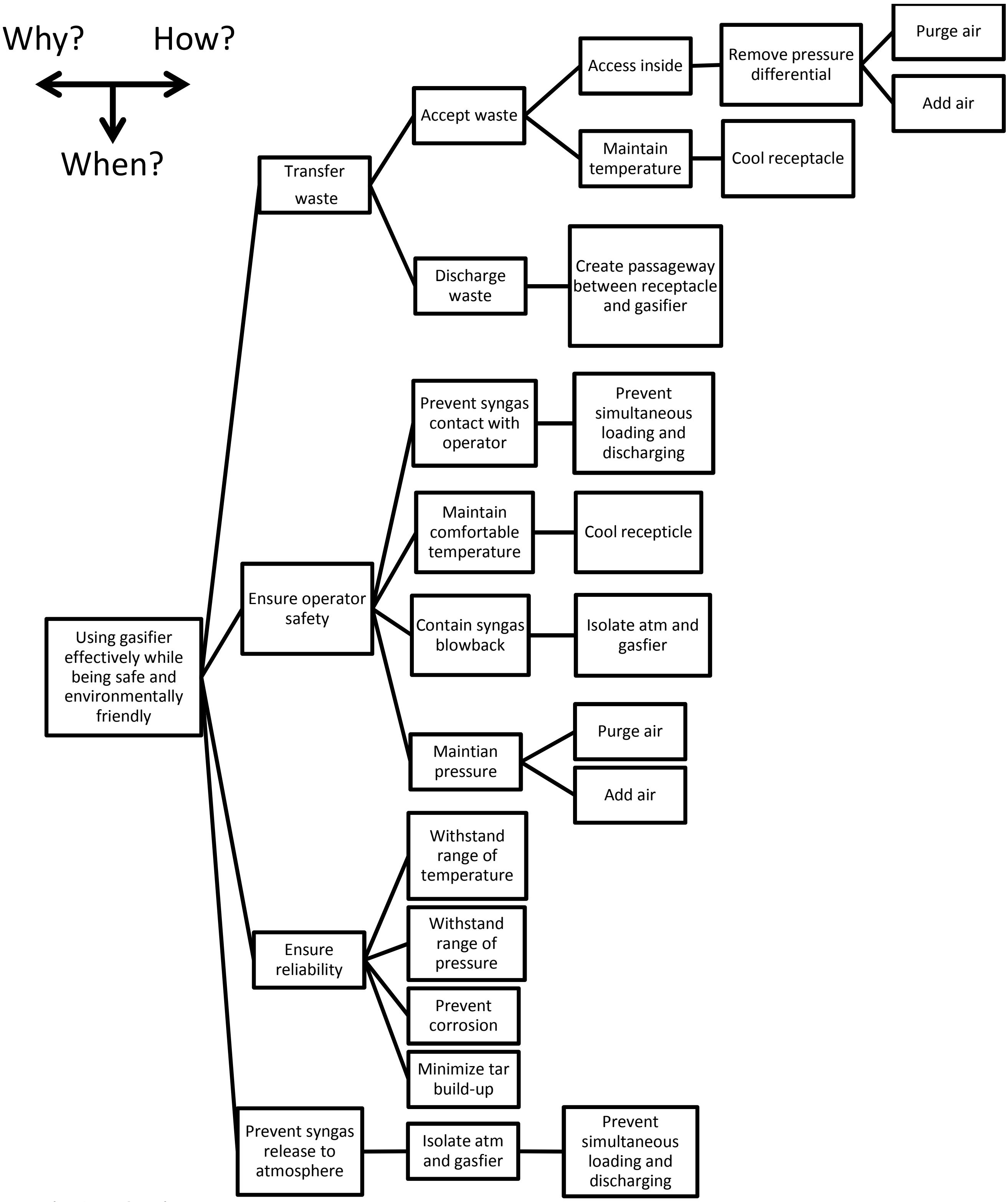


Fig. 1 -FAST Diagram

Cost Analysis

The cost analysis is a continuation of the functional analysis. With the FAST diagram, the four secondary functions can be assigned an estimated cost. As such, the total cost of the lid can be broken down into the amount spent per function in order to understand where most of the money is being spent.

The steps taken to break down cost according to function were as follows:

1. Identify the components of the lid.
2. Break down the original bill of materials (as given by Terragon) into the different tasks performed by the lid.
3. Determine the function performed by each component.
4. Assign the weight (or importance) of each function for each component.

Table 1 lists the components of the lid, the secondary functions and what proportion of each component serves a specific function.

Table 1 – Function Weight by Component

	Accept Waste	Discharge Waste	Ensure Operator Safety	Ensure Reliability	Prevent Syngas Release to Atmosphere
Drum	25%	25%	-	25%	25%
Manway	40%	-	40%	-	20%
Lifting Mechanism	-	80%	-	20%	-
Cooling Mechanism	-	-	60%	40%	-
Rotating Mechanism	-	100%	-	-	-
Seals	-	-	15%	5%	80%
Lid Cover	-	-	70%	-	30%
Lid to Gasifier Passage	-	40%	30%	30%	-

Note: The secondary function "Transfer Waste" was broken into two sub-functions: *Accepting Waste* and *Discharging Waste*. These two functions are quite distinct in terms of assigning components to that function.

Table 2 demonstrates the functional cost analysis table for the current lid design. The cost of each component is calculated and distributed across the relevant functions based on the proportions assigned above.

Table 2 – Cost Analysis

	Accept Waste	Discharge Waste	Ensure Operator Safety	Ensure Reliability	Prevent syngas relase to atmosphere	Cost of Components	Percentage of Total Cost
Drum	$ 299.10	$ 299.10	-	$ 299.10	$ 299.10	$ 1,196.40	14.77%
Manway	$ 318.78	-	$ 318.78	-	$ 159.39	$ 796.94	9.84%
Lifting mechanism	-	$ 1,513.38	-	$ 378.35	-	$ 1,891.73	23.36%
Cooling Mechanism	-	-	$ 438.60	$ 292.40	-	$ 731.00	9.03%
Rotating mechanism	-	$ 645.70	-	-	-	$ 645.70	7.97%
Seals	-	-	$ 7.86	$ 2.62	$ 41.94	$ 52.42	0.65%
Lid cover	-	-	$ 445.74	-	$ 191.03	$ 636.77	7.86%
Lid to Gasifier Passage		$ 859.10	$ 644.33	$ 644.33	-	$ 2,147.75	26.52%
Function cost	$ 617.88	$ 3,317.28	$ 1855.30	$ 1616.79	$ 691.46	$ 8,098.71	
Percent	**7.63%**	**40.96%**	**22.91%**	**19.96%**	**8.54%**	**100%**	
Increase or Decrease Cost	Increase	**DECREASE**	Increase	Increase	Neutral		

A few points to note from the above table:

1. The Discharge Waste function is too large. In other words, the lifting and rotating mechanism greatly contribute to the high cost of the design. The percentages in cost need to be spread more evenly across the rest of the functions.
2. The first secondary function (accepting and discharging waste) accounts for 48% of the total cost on the current lid design.
3. The percentage spent on the safety and reliability must be increased.

In the third step of the Value Engineering Job Plan, the main functions of the MAGS lid were identified, organized, and characterized. A simple yet effective cost analysis was then performed to highlight the key inconsistencies in the amount spent on a function versus that function’s importance.Now that the goals in terms of cost have been identified, the next phase, the creativity phase, will have more direction.

4. Creativity Phase

The creativity phase involves proposing numerous concepts in an effort to solve the problem at hand. During this phase, brainstorming was the creativity tool used to generate ideas. The goal of the brainstorming session, as discussed with Mr. Lavigne, was to develop a string of concepts that could be classified under either Plan A, completely new concepts, or Plan B, a modification on the original design.

The session lasted almost two hours, and the following was generated:

Plan A	12 concepts
Plan B	23 concepts
TOTAL	**35**

"Plan A" concepts focused on simplifying the original design. The rotating and lifting mechanisms, which greatly contribute to the high cost of the lid, were either removed or replaced with, in most cases, simpler mechanisms.

"Plan B" concepts involved modifying the original design with the intent of increasing the efficiency of the MAGS and/or decreasing the cost. Ideas ranged from changing the seal material to creating a double-loading system where one lid fed to two gasifiers. Ideas were generated to solve specific problems such as tarbuild-up and high stress on the drum.

A detailed description of each of the 35 concepts can be found in Appendix II.

5. Evaluation Phase

The goal of the evaluation phase is to eliminate the concepts that are infeasible, expensive or over-complicated. At the end of this phase, only a few concepts should remain that can then be analyzed in greater depth before a final solution is chosen.

The evaluation phase occurred in two steps:

1. Elimination of concepts with no potential.
2. Rating the remaining concepts using the “Gut Feel Index”.

In the elimination step, 17 out of 35 ideas were eliminated on the basis of infeasibility, implementation difficulty or high cost. Additionally, two concepts were labeled as BSP (Beyond the Scope of the Project).

The Gut Feel Index involves rating each concept based on intuition, or a “gut feel”. The ranking of this index is as follows:

1	No way, nonsense
2	I don’t like it
3	Many risks but some hope
4	Maybe, let’s try
5	Possibly
6	Not great but some potential
7	Interesting, possible benefits foreseen
8	No risk, very much doable
9	Many benefits
10	Champion idea

Table 3 illustrates the distribution of the scores for the remaining 16 concepts.

Table 3 – Concept Scores

Score	1	2	3	4	5	6	7	8	9	10
	-	-	-	**1**	**1**	**3**	**5**	**5**	-	**1**

Based on this scoring, 5 scenarios were chosen, and further analyzed in the following sectionsin order to determine the final design.

Proposals

Scenario 1

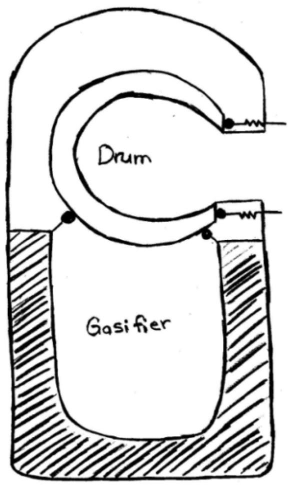


Fig. 2 – Scenario 1

The following scenario, as illustrated in Figure 2, differs from the original design with respect to the drum shape, the mechanisms responsible for the drum motion, and the location of the primary seal.

The waste is inserted into the side of the cylindrical drum instead of the end. The primary seal is relocated from the entrance of the gasifier to the drum entry point, therefore ensuring ease of maintenance due to the seal's increased accessibility. Abrasive seals are located at the entrance of the gasifier, and serve as secondary seals and tar scrapers.

The sealing mechanism here involves circular bellows activated by pushrods. Before opening the manway and loading the waste, the pushrods are extended such that they force the seal symmetrically onto the face of the drum and are then locked in place. The manway is then opened and the waste is inserted into the drum. After the manway is closed, the pushrods are unlocked and the seal is removed from the face of the drum. This step is important because, as the drum rotates, it must not contact the seal and cause abrasion. The waste is then dropped into the gasifier when the drum reaches its 90° rotation. The drum returns to its original position and the cycle starts again.

The drum rotating and lifting mechanisms were combinedinto one by moving the center of rotation off the symmetrical axis of the drum. This off-centre rotation effectively combines two motions into one, saving space and cost.

Despite the modification of the sealing method, the altered drum shape, and the off-centre rotation, the cost of the entire lid assembly would nevertheless resemble that of the original design. Since this new scenario is an improved version of the original for approximately the same cost, it is a favorable choice to consider in more detail.

Scenario 2

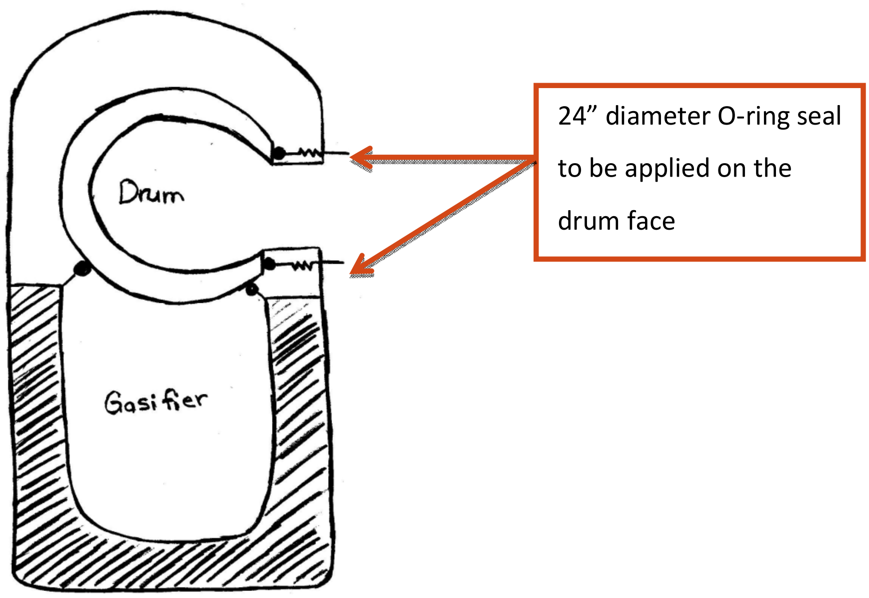


Fig. 3 – Scenario 2

This scenario, as illustrated in Figure 3, shares essentially all of the characteristics with Scenario 1 discussed above, except that the seal is actuated with a lead screw mechanism rather than bellows. This idea provides a direct method to apply the seal to the drum entrance. By using a lead screw, the seal would be applied evenly to the surface, while the cams would not necessarily apply the force uniformly.

However, on further analysis of this design, it was determined that the cost for machining a precisely threaded piece of steel approximately 24 inches in diameter would be too great. Furthermore, the action of screwing in the gasket until it comes in contact with the drum and then further rotating to create a seal implies the necessity of an abrasive seal. Such a seal would have to be frequently replaced, and would increase the risk of failure if not constantly maintained.

Scenario 3

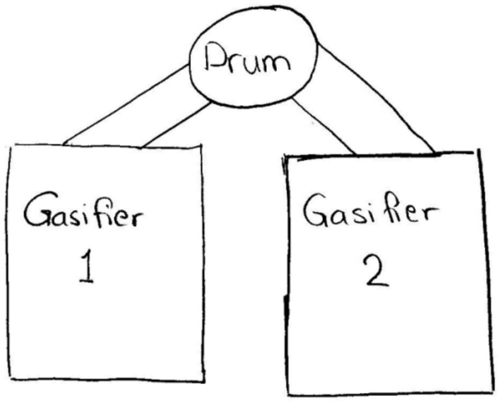


Fig. 4 – Scenario 3

Figure 4 shows the third scenario involving a single loader for two gasifiers. The drum would resemble that of the original design. However, the lifting motion is different since the drum must be lifted vertically since it cannot be in contact with either seal located at the entrance of the inclined chute. The drum can then be rotated toward either entrance.

The main advantage of this idea relates to cost. Cost is essentially cut in half due to the elimination of an entire lid. However, there are many disadvantages associated with this design. The introduction of an inclined chute to transfer the waste from the drum into the gasifier is much less reliable than the simple dropping of the waste. The waste must slide down the chute into the gasifier. However, this motion may be rendered difficult due to factors such as tar build-up or the consistency of the waste. These factors can be ignored in the original design since they do not interfere in the transfer. Furthermore, this design does not solve the original problem of the seal's location. Both seal are still located under the drum, and are therefore not easily accessible for maintenance purposes.

Scenario 4

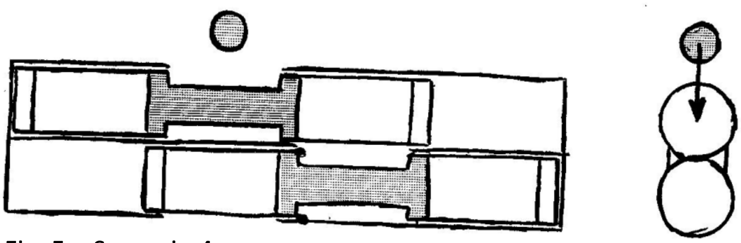


Fig. 5 – Scenario 4

Scenario 4, as portrayed in Figure 5, involves a system of two pistons working in unison. The top piston accepts the garbage. The piston would then slide across to drop the garbage into the lower piston. The lower piston then slides across to drop the waste into the gasifier.

This idea would replace the lifting or rotating motions on the original design with one-dimensional sliding. The double-piston system would also be very safe, since the operator would only be in contact with the top piston.

There are, however, a few foreseeable problems with this design. First, the piston mechanism is much larger than the current design. Second, abrasive seals are required and are quite expensive, especially for a 24" diameter piston. Third,the pistons and the seal are subjected to a lot of abrasion and tar build-up, which may prevent piston motion.

This new concept is drastically different from the current design, and therefore the initial cost of building this design will be very high.

Scenario 5

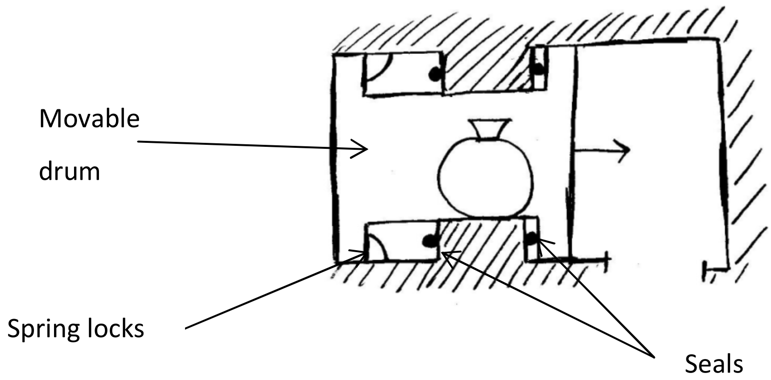


Fig. 6 – Scenario 5

The drawer scenario, as illustrated in Figure 6, allows the elimination of the two mechanisms used in the original design of the MAGS to dispose of the waste. A simple manual push-pull mechanism makes this design easy to use.

A garbage bag is placed into a drum, which is not fixed in the horizontal direction. Once the lid is closed, the entire drum can be pushed inward. When the drum is aligned with the cavity connecting it to the gasification chamber, a gap at the bottom of the drum allows the garbage bag to fall straight through, into the chamber. Seals are placed strategically to block access of the syngas to the entrance of the drum while the drum is in its initial position and during the garbage bag disposal position.

A major disadvantage of this mechanism however, is that during the transition stage of the drum, between the initial and the disposal position, the syngas is allowed to escape through the entrance of the machine, thereby compromising safety and reliability. The drum would also be expensive to manufacture due to its irregular shape and the addition of a second seal. The lack of weight on the seals would also compromise the safety of the machine. Additionally, since the waste is displaced as a result of the horizontal movement of the drum, there is a possibility of the garbage bag getting stuck in the chamber, or getting jammed between the drum and the chamber. This issue adds to the unreliability of the proposed design.

6. Development Phase

Having slimmed down the proposals to the five most viable candidates, the team endeavored to enact a final evaluation phase to arrive at the best solution. Considering that these designs are comparable in functionality, evaluation of these concepts must be quantitative, careful, and decisive. Thus, the team decided to utilize a cost-merit analysis to determine the final design.

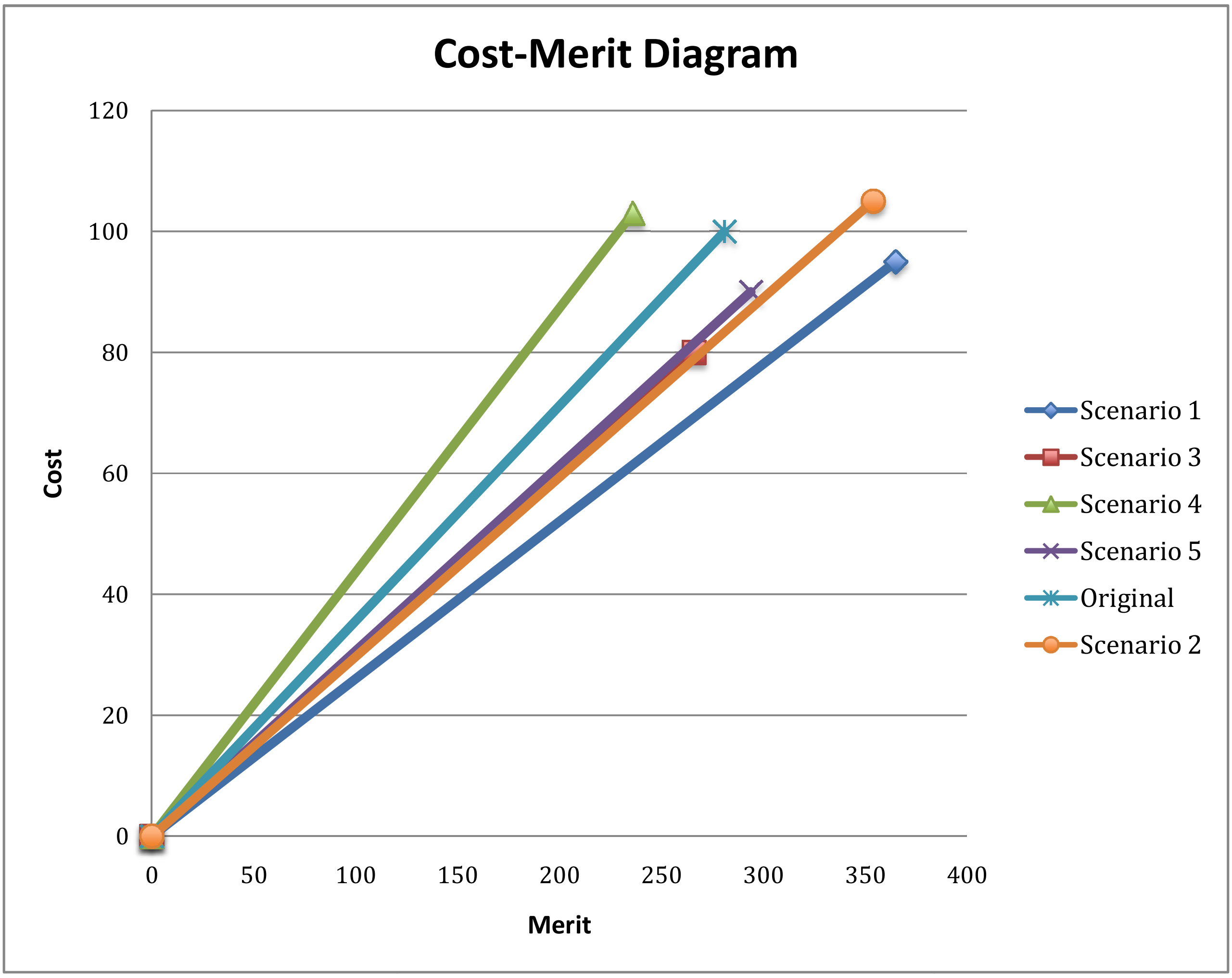
Cost-Merit Analysis

This evaluation method, as the name implies, compares the costs and benefits of each given proposal, and the one with the highest benefit-to-cost ratio is the winning choice. This evaluation method was chosen because it clearly and simply lays out the best choice, and is appropriate given the scope of the project. Considering Terragon has no revenue stream to date, there is no baseline or expectation as to the return on investment, so it is of greater importance to achieve a design for the long term with greater utility and lower cost.

Table 4 and Graph 1 show the scenarios that were ultimately decided upon, and their respective costs and merits.

Table 4 – Cost-Merit Table

Criteria	**Weight**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Original**
Aesthetics	1	6	6	6	5	6	6
Safety	10	9	9	6	8	7	7
Ease of Maintenance	8	9	8	4	4	4	4
Manufacturability	6	6	7	9	2	8	7
Reliability (Long Life)	9	9	8	6	6	6	6
Ease of use	7	8	8	6	5	9	8
Space taken	3	8	8	6	6	7	7
TOTAL		365	354	266	236	294	281
Cost		95	105	80	103	90	100
Slope		3.84	3.37	3.33	2.29	3.27	2.81



Graph 1 – Cost-Merit Graph

Discussion

As can be seen in the table and chart, Scenario 1 offers the greatest merit for the lowest cost, and is thus the option that will be pursued moving forth. Although this is not an exhaustive quantitative analysis of the options, the group felt this was the best option because it had certain qualities that were not necessarily reflected in this diagram. Furthermore, considering many of the component costs are relative approximations, the result bears further discussion and analysis. The benefits of Scenario 1 will be explained moving forward, and it will become overwhelmingly apparent that this is indeed the best option.

FINAL SOLUTION: Scenario 1

Overview

The new design solution borrows many of the same components as the original design; however there have been several significant changes that need to be outlined. Functionally, the largest changes arise in the way the waste is loaded into the loader, and how the waste is then deposited in the gasifier.

The following schematics illustrate the new procedure and functionality, and how it varies from the original.

Bellows and Seal

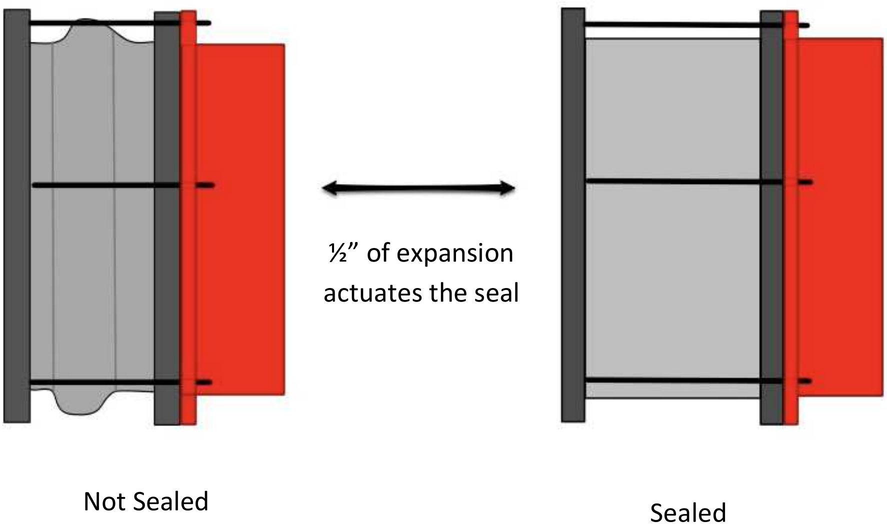


Fig. 7 – Bellows and Seal

The bellows are deformed by actuating the push rods with a cam lever, which applies and retracts the seal from the surface of the drum, as illustrated in Figure 7. This new design differs from the original in the placement of the seal (at the entranceway as opposed to the opening to the gasifier) and the way the seal is applied. One of the distinct advantages this new placement of the seal gives is that now, the seals can be easily reached and maintained where before the entire drum assembly had to be removed to access the seals.

Loading Mechanism Procedure

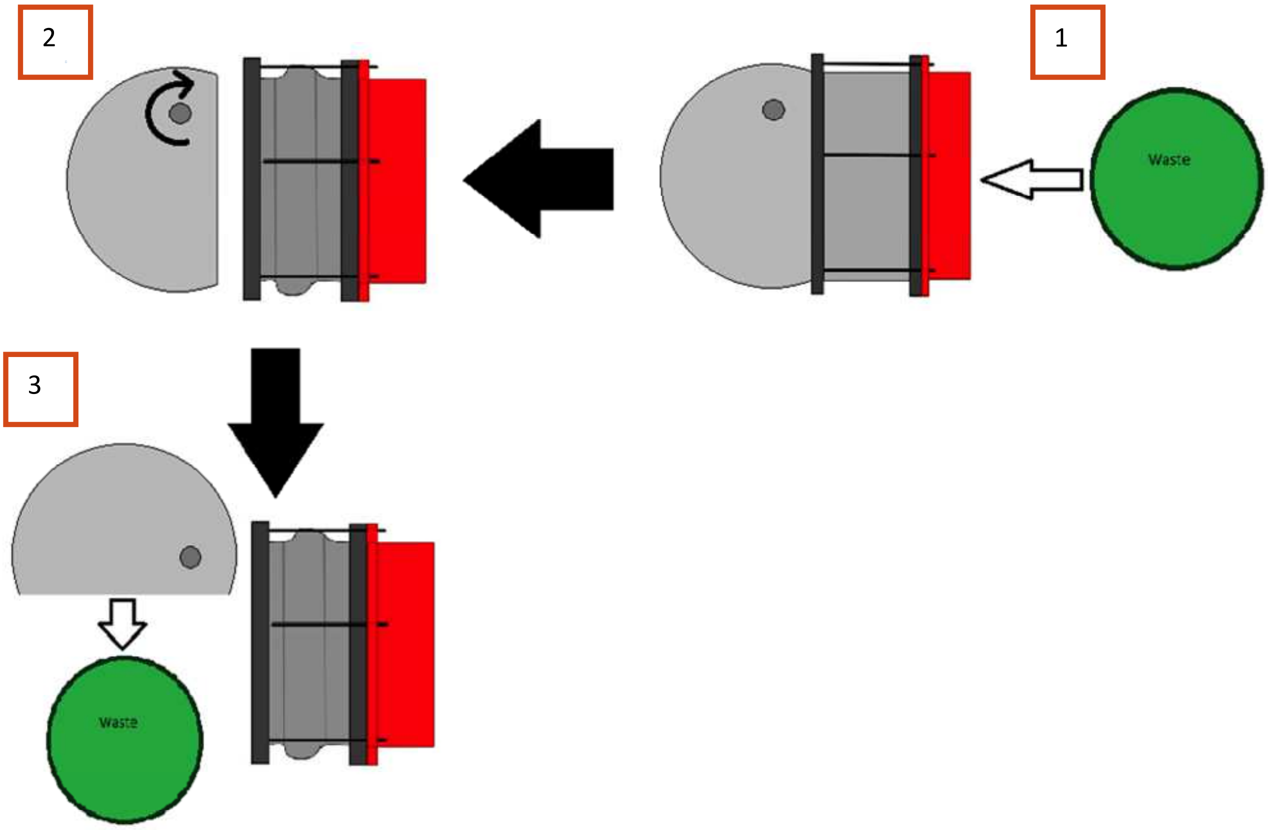


Fig. 8 – Loading Mechanism

As shown in Figure 8, the actual loading mechanism differs remarkably from the original; the drum axis of rotation has been rotated through by 90° relative to the operator so the drum now rotates perpendicular to the entrance.

Detailed Drawings

Concentric Gasket at Loader with Rubber Bellows

The main sealing gasket has been completely relocated to be concentric with the manway entrance. Note here that to seal the gasket, the cams are in their fully extended position, which means there must be a set of springs on each of the rods that supply the necessary axial force. In Figure 9 below, the parts have been colored merely to highlight the differences between them, and do not reflect any desired color scheme.

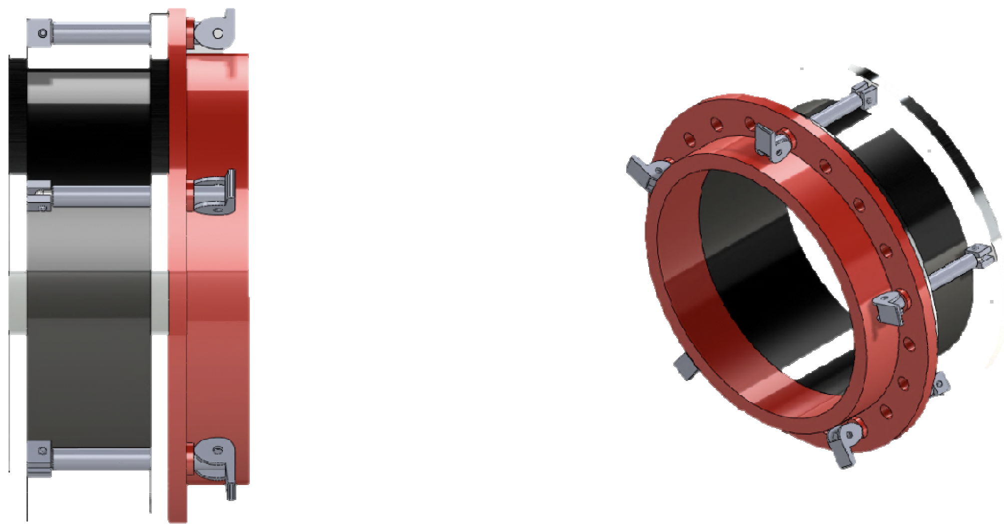


Fig. 9 – Concentric Gasket at Loader with Rubber Bellows

The next task was to determine the material that the bellows should be made of. The temperature present in the lid is significantly lower than in the gasifier (40°C compared with 400°), however the bellows material must necessarily withstand it. Furthermore, while the bellows is attached to the face of the drum, there is a -20 kPa pressure differential across the bellows wall. Upon conducting some research, it became clear that the main types of bellows available are steel, aluminum, and rubber. After pursuing some quotes, the material chosen for the bellows was rubber; the high heat and pressure properties of rubber bellows is comparable with costlier steel models.

Truncated Drum Face with Off-center Axis of Rotation

The current design of the drum, as shown in Figure 10, has changed from the original in a few significant ways. Primarily, the drum has only one single opening located on its lateral side. The reason for this is that unlike the original system, this drum uses the same opening as an entrance and exit and rotates to either accept or discharge the waste. Also, the drum has been designed so as to be able to accept and discharge a larger twenty-four inch bag.

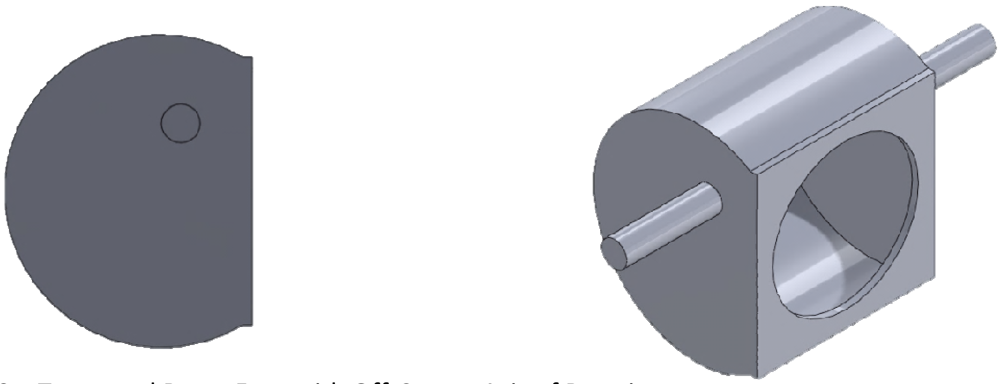


Fig. 10 – Truncated Drum Face with Off-Center Axis of Rotation

Another key feature of the design is the location of its axis of rotation. Unlike the original system where the axis passed through the center of the drum, this design has its axis placed off-centre. This is to eliminate the need to lift the drum off the seal prior to rotation so as to not damage the seal. Instead, the off center axis allows the circular drum to rotate in a cam-like motion, both rotating and translating the body of the drum. This feature is a key component in what makes the new design a success. This system provides both the lifting and rotating motion required to minimize seal damage while lowering costs of the discharging waste function.

Moreover, this design eliminates the need for a cradle to support the drum as the axle supports the entire load. This further reduces costs and simplifies the overall mechanism.

Lastly, since the axle can be hollow and still support the drum, coolant tubes can be passed directly through the axle and into the drum, eliminating the need for costly malleable metal coolant hoses. This is extremely important, as keeping the drum cool is key for machine and operator safety.

Bill of Materials

As part of the development phase, the team went about analyzing the old design of the MAGS and comparing it to the new one. By using the bill of materials provided by Terragon, the team was able to identify the mechanisms and materials that were not necessary for the new design. See Appendix III for a table of all the parts and materials that were removed from the original design.

Removing the lifting and rotating mechanisms from the design and replacing them with one single mechanism to dispose of the waste into the gasifier can save a total amount of **$2537**.

Next, a list of the parts for the new design was made, and the sum of the cost of each part was taken to give a total cost that would have to be added to incorporate the new design. Table 5 lists of all added parts.

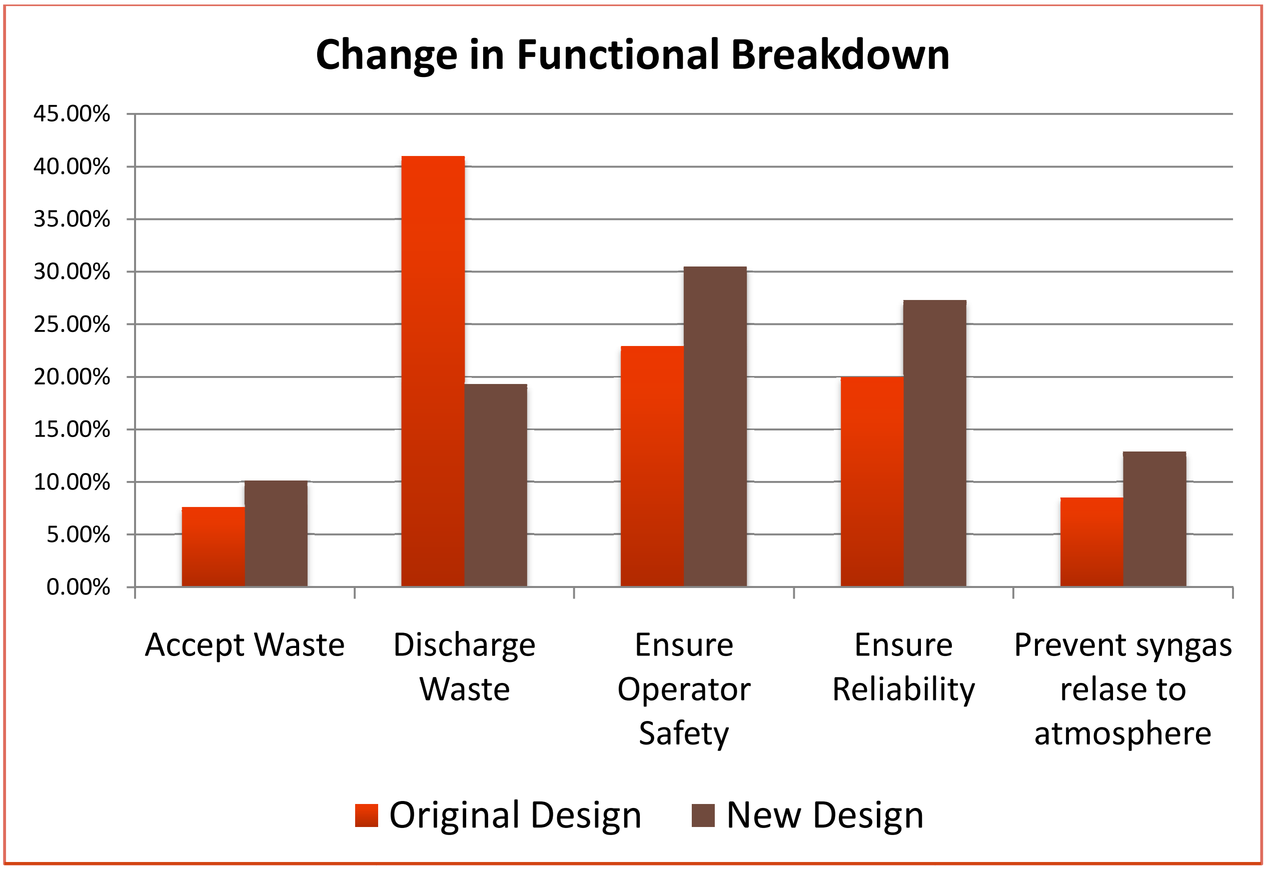
Table 5 – Details of Added Parts

	Part	Material	Supplier	Part Number	Qty (unit or inch)	Unit Cost ($)	Cost/Lid ($)
Door and Sealing Mechanism	Rubber Expansion Joints 24" Dia	Rubber	Mercer	NA	1	1900	1900
	Shaft 10" machined on one end, wlded on other, 1/2" diamter	Stainless Steel	McMaster	1144K28	5	23	115
	Zinc plated grade 4 steel Screws - 1/4" Hex Head (bag of 100)	Stainless Steel	McMaster	92865A537	1	5.75	5.75
	Zinc plated grade 5 steel Hex Nuts 1/4"	Stainless Steel	McMaster	95462A029	84	0.03	2.52
	Cam Lever with spring and seal mechanism	NA	McMaster	5720K52	5	38.75	193.75
	Bushings Dia 1/2"	NA	McMaster	8491A214	5	4.68	23.40
	Pump Shaft Seals - 1/2"	Flouroelastomer	McMaster	9281K66	5	17	85.00
	Silicone coated fiberglass seal	Silicone	McMaster	8858K12	2	29.9	59.8
Rotational Mechanism	Two shafts 2" - Length 10"	Steel	McMaster	6061K653	1	49.65	49.65
	Die Cast Zinc Hand Wheel Revolving 6" Wheel Dia, 1" Hole Dia	Steel	McMaster	6033K77	1	$27.23	27.23
	Standard roller and ball bearing 1"	NA	McMaster	6656K11	2	195.26	390.52
					Total Sum ($)		**2853**

The total added cost of **$2853** results in an overall increase in the cost of the machine of **$315.** The minor increase in the cost, however, is outweighed by the increased reliability and durability of the new design.

Comparison

Upon completing the final new design, a new functional cost analysis was performed. Graph 2 represents the overall changes in functionality from the original to the new design.



Graph 2 – Functional Comparison

When comparing the original MAGS system to the new re-engineered model, it is easy to see how the design changes affect the cost of the machine. Originally, 3,317.28$ was spent on discharging the waste. This was the most expensive function occupying 40.96% of the total cost. The re-engineered design entirely eliminates the lifting mechanism by replacing it with a cam motion drum that incorporates both the lifting and rotating motions. The cost of the original lifting and rotating mechanism could then be redistributed among the other functions.

The second and third largest change in function cost came from *Ensuring Operator Safety* and *Ensuring Reliability* respectively. *Ensuring Reliability* increased from 22.91% to 30.46% due mostly in part to the new bellow sealing mechanism. The addition of a second set of seals on the drum further increased the cost. Meanwhile, *Ensuring Reliability* also increased in large part to the sealing mechanism increasing from 19.96% to 27.27%.

Lastly, *Preventing Syngas Release to the atmosphere* also increased due to the new sealing mechanism adding seals, as did the *Accepting Waste Function*. These functions increased from 8.54% to 12.88% and 7.63% to 10.12% respectively.

In conclusion, the overall cost of the system is more evenly distributed among the different functions while keeping the most heavily weighted function of importance with the greatest cost percentage. *Accepting and Discharging the Waste* and *Ensuring Operator Safety* are now very closely weighted in terms of cost. As previously mentioned the largest change came in the *Discharging Waste* function, which has been decreased by half. This solution provided a more even and value-centricdistribution of costs.

Additional Recommendations

The following two recommendations are ideas that have not been analyzed but nevertheless provide interesting ideas that could be incorporated into the proposed final design.

Casting

Many of the larger pieces can be iron casted out of a mold in order to save cutting costs.

Pros

- Would save costs over a period of time
- Quicker to manufacture

Cons

- Larger initial cost to create the mold
- Less precision

Ultimately the costs will decrease and the ease manufacturability will increase. This recommendation would be the most valuable when the MAGS system is in production since the savings are over a period of time. Only the parts that do not require precise tolerances would be cast.

Removable pipe corner with air flow sensor

In the air purging system it could be valuable to place a removable piece at the corners, where syngas tar builds up the most. This will ensure the syngas will condense on the filter, which can be removed every so often.

Pros

- Pipe can be removed cleaned very easily
- Will prevent full blockages
- Sensor will recognize when pipe is partial blocked to prevent unknown
- Cheaper form of maintenance

Cons

- Will require regular changes by the operator when machine is off
- Operator would need an extra training session

With the addition of a removable 90-degree corner the maintenance costs are significantly decreased and prevent pipe choking without the operator's awareness.

Conclusion

In conclusion, the newly designed lid system has changed in a few significant ways. Primarily, the drum rotates in a cam motion thus eliminating the need for a lifting mechanism. Secondly, since the drum now only has one opening, one seal is required to prevent syngas exposure to the atmosphere. However it is important to note that a second seal is included on opening to the gasifier to minimize syngas release to the rest of the lid and to try and contain it to the gasifier. The newly designed cam-push sealing system allows for quick and secure access to drum. Overall, the new drum and push-cam seals are an elegant solution to a complex problem. Although the cost of the entire lid increased slightly, the redistribution of function costs makes this machine a more valuable system.

Appendices

I.Identifying Functions

To identify the main functions of the lid, three methods were used. These methods are similar, resulting in repetition. However, using several methods ensures that no function is overlooked. Once these functions were identified, they were then characterized based on criteria, level and flexibility.

Intuitive Research

This phase allows the team to be creative as well as to list the most obvious functions. The functions that were identified in this phase were:

- Ensure operator safety
- Discharge waste into gasifier
- Prevent heat loss from gasifier
- Minimize air intake into drum

Sequential Analysis

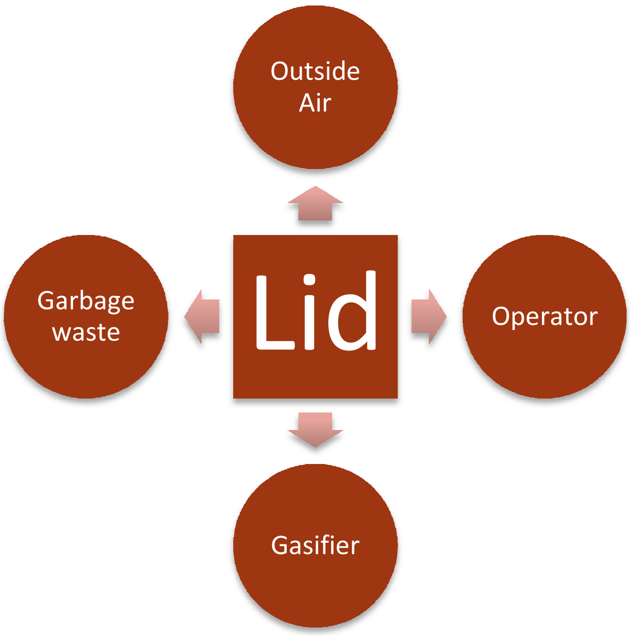
The overall process of the MAGS lid was reviewed and functions were identified according to each step, as shown in Table 6.

Table 6 – Sequential Analysis

Step	Description	Functions
1	Opening Lid	• Purge air (bring pressure to atmospheric) • Maintain low temperature • Accept Waste • Cool Drum • Prevent blowback • Bring pressure to atmosphere
2	Lift Drum	• Lift Drum
3	Rotate Drum	• Align with hole • Lift above seals • Rotate back into place • Resist high temperature • Drop garbage

Environmental Analysis

The third brainstorming session was the Environmental Analysis in which functions were identified by their interactions with the surrounding. A physical flow chart, shown in Figure 11, was used to distinguish the different parts.



Environment	Functions
Outside Air	• Prevent syngas release to atmosphere • Input air

Operator	• Ensure safety
	  o Prevent blowback
	  o Maintain low temperature
	  o Separate drum and gasifier

Garbage	• Discharge into gasifier • Accept garbage
Gasifier	• Isolate gasifier from user • Minimize tar build-up

Fig. 11 – Environmental Analysis

Characterizing Functions

Characterizing functions involve how functions are measured, the criteria needed, and the allowed flexibility. Table 7 below shows the function, its position on the FAST diagram, the criteria, the recommended level and the flexibility.

Table 7 – Function Characterization

Function Number	Function	Criteria	Level	Flexibility
1	Transfer Waste	Frequency	3 mins	F2
1.1	Accept Waste	Dimension	18"	F1
1.1.1	Access Inside	-	-	-
1.1.1.1	Remove pressure differential	kPa	-20 - 0 kPag	F0
1.1.1.1.1	Purge Air	kPa	-20 - 0 kPag	F1
1.1.1.1.2	Add Air	kPa	-20 - 0 kPag	F2
1.1.2	Maintain temperature	Celsius	40-60°C	F0
1.1.1.2	Cool receptacle	Heat flow rate	-	F1
1.2	Discharge Waste	Time	5sec	F2
1.2.1	Create passageway between receptacle and gasifier	Dimension	18"	F1
2	Ensure Operator Safety	-	-	-
2.1	Prevent Syngas contact with operator	Concentration	<1500ppm	F0
2.1.1	Prevent simultaneous loading and discharging	-	-	-
2.2	Maintain comfortable temp	Celsius	40-60°C	F0
2.2.1	Cool receptacle	Q.	-	F0
2.3	Contain Syngas Blowback	Quantity	Never	F0
2.3.1	Isolate atm and gasifier	-	-	-
2.4	Maintain Pressure	kPa	-20 - 0 kPag	F0
2.4.1	Purge Air	kPa	-20 - 0 kPag	F0
2.4.2	Add Air	kPa	-20 - 0 kPag	F0
3	Ensure reliability	Frequency of repair	5 years	F2
3.1	Withstand range of temp	Temperature	Atm. - 1000°C	F1
3.2	Withstand range of pressure	Pressure	Atm. – -20 kPag	F1
3.3	Prevent Corrosion	Time	>10 years	F1
3.4	Minimize tar build-up	Thickness	<2 mm	F2
4	Prevent syngas release to atmosphere	Concentration	<1500 ppm	F1
4.1	Isolate atm and gasifier	-	-	-
4.1.1	Prevent simultaneous loading and discharging	-	-	-

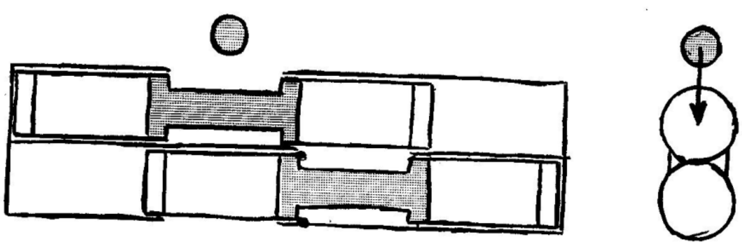
II. Brainstorming and Evaluation

The following concepts, sub-divided into Part A and Part B, were generated during the brainstorming session and evaluated based on the following legend:

1	No way, nonsense
2	I don't like it
3	Many risks but some hope
4	Maybe, let's try
5	Possibly
6	Not great but some potential
7	Interesting, possible benefits foreseen
8	No risk, very much doable
9	Many benefits
10	Champion idea
XXXX	Infeasible, expensive or over-complicated
BSP	Beyond Scope of Project

PART A

1.	Double Piston	SCORE 7



Description: The double piston involves two sealed pistons, one above the other. The waste is dropped into the upper piston and slid to align with the entrance to the bottom piston. This bottom piston then slides the waste in the other direction to align with the entrance of the gasifier. Both pistons are sealed along the edges to limit heat convection and conduction.

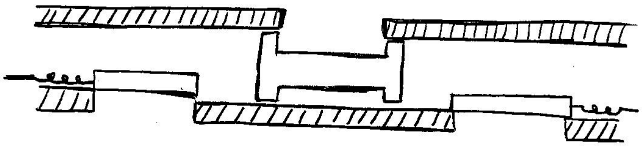
PROS

- Easy to purge.
- Maintains low temperature due to double seal.

CONS

- Too large.
- Involves abrasive seals.
- Subjected to leaks.

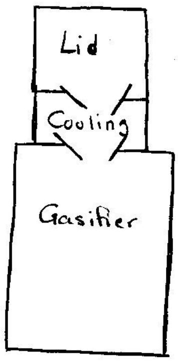
2.	Single Piston	SCORE 6



Description: The single piston is a double loading system. In other words, there is a single lid for two gasifiers. The waste is inputted into the piston, which slides the waste toward the gasifier in question. Both entrances to the gasifiers are covered using spring loaded doors. These doors are slid to the side when the piston comes into contact with them. The waste is then dropped into the gasifier.

PROS	CONS
• Easy to purge.	• Involves abrasive seals.
• Double loading system.	• Subjected to leaks.

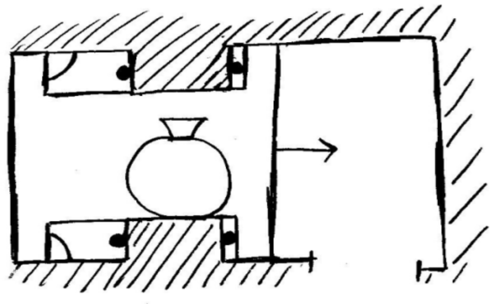
3.	Two Simultaneous Trapdoors	SCORE XXXX



Description: Two simultaneous trapdoors would replace the lifting and rotating mechanisms of the original lid. The waste is placed in the loading area. Once the manway is closed, the air is purged. Both doors are then opened allowing the waste to drop into the gasifier. The two trapdoors would enclose a “cooling zone” such that the loading area would not need extra cooling.

PROS	CONS
• Cooling zone.	• Too high.
	• Too complicated to implement simultaneous trap doors.
	• Seal placement becomes difficult.

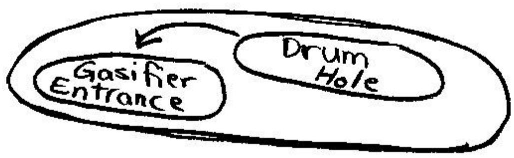
4.	Drawer	SCORE 7



Description: The drawer is a simplified way to dispose of the waste into the gasifier. The waste is placed in the loading area, and the manway is then shut. The drawer is then pushed backward (from the outside), until the hole of the drawer aligns with the entrance to the gasifier. The drawer is sealed both in the initial and the final drawer positions.

PROS	CONS
• Simple and easy.	• No seal during drawer movement, only for initial and final position. • Must move drawer from outside.

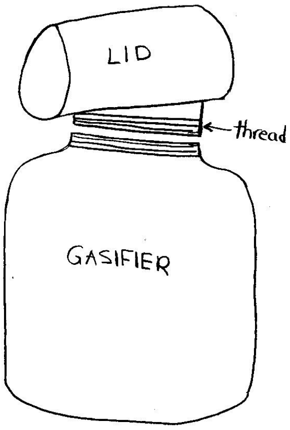
5.	Side Alignment	SCORE XXXX



Description: Rather than the entrances be aligned one above the other, they can be side by side, and aligned through rotating the drum.

PROS	CONS
• Rotating and lifting mechanisms eliminated.	• Infeasible.

6.	Twist Top	SCORE XXXX



Description: The twist top involves a very large thread to replace a required seal. The waste would be placed inside a loading area. This loading area would be twisted such that the hole of the loading area would align with the entrance to the gasifier.

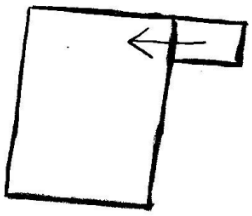
PROS	CONS
• Thread replaces seals, and lifting and rotating mechanisms eliminated.	• Infeasible.

7.	Rotating Side-Loading	SCORE XXXX

Description: The twist side-loading concept focuses on the decrease in heat conduction if the loading area was not located directly above the gasifier, but to the side. The loading area would then be rotated to align with the entrance of the gasifier. Both entrances would require doors that would give way once in alignment.

PROS	CONS
• Rotating and lifting mechanisms eliminated. • Minimized heat transfer into loading area.	• Infeasible.

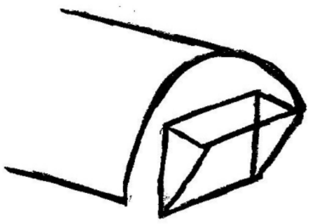
8.	Drawer Side-Loading	SCORE XXXX



Description: The drawer-side loading also uses the concept of the loading area to the side of the gasifier. The loading area would consist of a drawer that would be pushed inward so that it aligns with the gasifier entrance.

PROS	CONS
• Rotating and lifting mechanisms eliminated. • Minimized heat transfer into loading area.	• Infeasible.

9.	Mailbox Loading	SCORE XXXX



Description: The mailbox loading concept involves opening the door, disposing of the waste, and then closing the door.

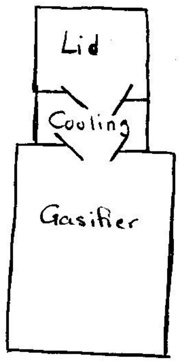
PROS	CONS
• Rotating and lifting mechanisms eliminated.	• Infeasible. • Unsafe.

10.	Pressure Valves (for cases with trapdoors)	SCORE XXXX

Description: Pressure valves can be used as a means of activating the trapdoors (if trapdoors are used in the new design).

PROS	CONS
• Automated rather than manual.	• Unreliable.

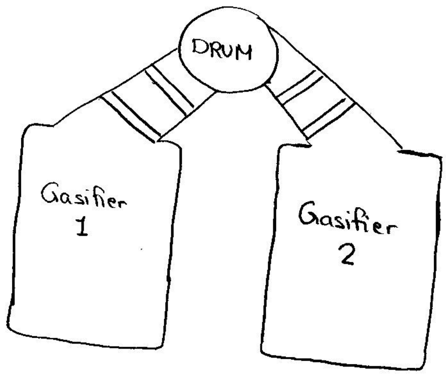
11.	Two Trapdoors (not simultaneous)	SCORE 4



Description: This concept is very similar to concept 3 without the simultaneous aspect, therefore rendering the idea more realistic.These two doors would also enclose a "cooling area." However, since the doors would not be simultaneous, the waste could rest within the cooling zone. Only the cooling zone (and not the loading area) would need purging.

PROS	CONS
• Easy to purge.	• Too high.
• Cooling zone.	• Difficult seal placement.
	• Too complicated.

12.	Double-loading, Double Trapdoor	SCORE 5



Description: A double-loading, double trapdoor system consists of a rotating drum and an inclined chute each containing two trapdoors. The drum would rotate to either entrance of the chute. The trapdoors would open, allowing the waste to pass through to the gasifier. These trapdoors would enclose a “cooling zone”.

PROS

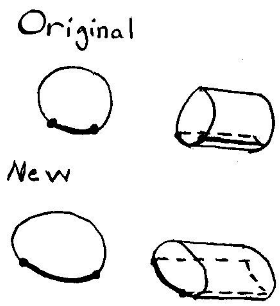
- Cooling zone.
- Double loading system.

CONS

- Waste may get stuck in inclined chute.
- Trapdoors difficult to implement.

PART B

13.	Drum Shape	SCORE 8



Description: The drum shape can be changed so that the pressure exerted on the drum is spread over a larger area, therefore reducing the pressure (i.e. an oval-shaped drum).

PROS

- Feasible.
- Decrease in pressure.
- Reliability of seals.

CONS

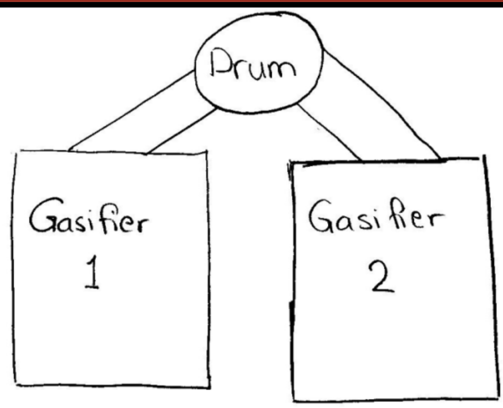
- More difficult / expensive to manufacturer.

14.	Refrigeration	SCORE 7

Description: The cooling water could be replaced by a refrigerant, such as R134.

PROS	CONS
• More efficient cooling.	• More expensive. • Not as convenient as water (since water is more accessible).

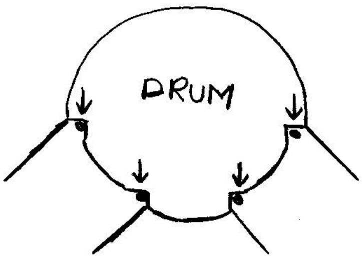
15.	Double-Loading System	SCORE 7



Description: The double-loading system involves a similar lifting and rotating mechanism. However, this concept would dispose waste into two gasifiers through a single lid. Each inclined chute, leading to the gasifier, has a seal at its entrance, similar to the current design. The drum is then lifted and rotated in the direction of the gasifier in question.

PROS	CONS
• Double-Loading System.	• Waste may get stuck in inclined chute. • Too high.

16.	Notches	SCORE XXXX



Description: Notches would create a horizontal platform on which the drum would sit. The seals would be located between the drum and the platform.

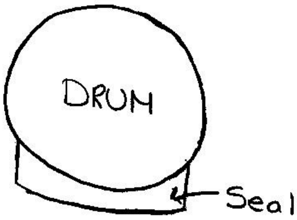
PROS

- Allow the seals to work more effectively.
- Increase reliability as seals will be pushed down evenly.

CONS

- If alignment is off, the drum will not sit on seals.
- Expensive to manufacture.

17.	Thicker Seal	SCORE 8



Description: A thicker seal would, like concept 13, create equal pressure across the seal.

PROS

- Feasible.
- Decrease the pressure per unit area.

CONS

- More expensive seal.
- May be excessive.

18.	Seal Material - Grafoil	SCORE XXXX

Description: Replace current Teflon seal with grafoil seal.

PROS

- Excellent strength and handling characteristics.

CONS

- Difficult to implement.

19.	Seal Material - Peek	SCORE XXXX

Description: Replace current Teflon seal with peek seal.

PROS	CONS
• Excellent wear. • High durability.	• High cost.

20.	Seal Material – Silicate Aerogel	SCORE XXXX

Description: Replace current Teflon seal with silicate aerogel seal.

PROS	CONS
• Excellent thermal insulation properties.	• Not proven to be a good sealant.

21.	Seal Material – Calcium Silicate	SCORE XXXX

Description: Replace current Teflon seal with calcium silicate seal.

PROS	CONS
• Excellent thermal insulation.	• Difficult to implement.

22.	Abrasive Seals	SCORE XXXX

Description: Replace current Teflon seal with abrasive seals.

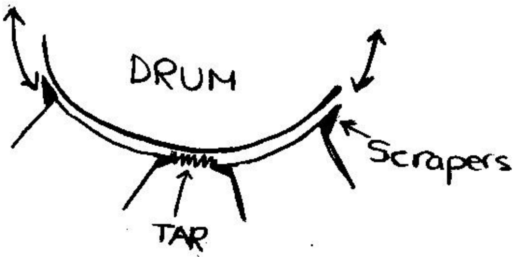
PROS	CONS
• Lifting mechanism eliminated.	• Tend to deteriorate. • More brittle, less elastic compared to rubber seals. • May not seal effectively.

23.	Moveable Seal	SCORE 6

Description: The moveable seal involves displacing the seal such that the drum no longer needs a lifting mechanism.

PROS	CONS
• Lifting mechanism eliminated.	• Drum is no longer resting on seal, therefore seal must be pushed onto drum.

24.	Tar Scrapers	SCORE 6



Description: In any concept, whether that concept is a rotating drum or a sliding piston, a scraper can be attached such that tar can be removed automatically.

PROS	CONS
• Automatic tar removal.	• May not be necessary. • Mechanism may not be reliable

25.	Tar Filter	SCORE 8

Description: A tar filter can be placed in the air purging pipe in order to prevent tar build-up at the corner. The filter would be removable and easy to clean.

PROS	CONS
• Removable and easily replaceable. • Allows air to be purged effectively.	• Filter must be changed on occasion.

26.	Pressure Valve Insulation	SCORE 8

Description: An insulation sleeve may be placed on the corner of the air purging pipe to prevent tar build-up and eventual blockage of the pipe.

PROS	**CONS**
• Allows free air flow.	• May not work over a long period of time as tar buildup is inevitable.

27.	Gear Ratio Increase	SCORE XXXX

Description: The gear ratio of the rotating and lifting wheel may be increased for operator convenience.

PROS	**CONS**
• Wheel is easier to turn.	• Size of gears would increase.

28.	Wheel Size Increase	SCORE 10

Description: This concept involves simply increasing the size of the wheel used by the operator to rotate the drum. The wheel is currently quite small and therefore awkward to turn.

PROS	CONS
• More ergonomic.	• May interfere with entrance to lid.

29.	Upside-Down	SCORE 7

Description: This concept is the current design turned upside down. The seal is now lifted instead of the drum. The drum, here, only requires a rotating mechanism. The seal would be lifted, the drum would rotate until its hole aligned with the entrance of the gasifier, and the waste would then drop into the gasifier.

PROS	CONS
• Lifting mechanism simplified since only lifting a small seal.	• Drum no longer rests on seal (seal must now apply enough pressure onto drum). • Greater surface area of drum exposed to high temperatures.

30.	Drum Material	SCORE XXXX

Description: Drum of material can be changed from steel to another material that is less conductive and less expensive, such as ceramic.

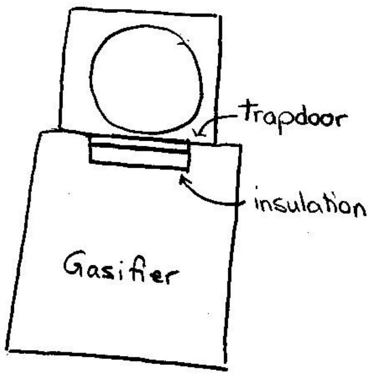
PROS	CONS
• Less conductive (i.e. less heat transfer) • Less expensive.	• More brittle. • Difficult to manufacture.

31.	Automation of Lifting and Rotating Mechanisms	SCORE BSP

Description: The current design involves an operator manually lifting and rotating the drum. However, these mechanisms can be automated.

PROS	CONS
• More autonomous and continuous.	• If waste jams, machine must be stopped (when manual, drum can be rotated back and forth to solve problem).

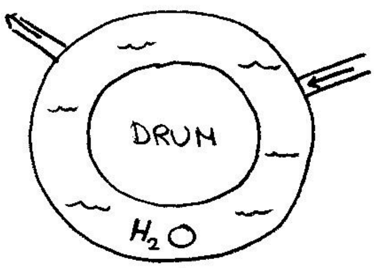
32.	Insulation Trapdoor	SCORE XXXX



Description: This concept involves a trap door that is heavily insulated so that heat conduction from the gasifier into the drum is minimized.

PROS	CONS
• Rotating and lifting mechanisms eliminated.	• Trapdoors are difficult to implement. • Unsafe.

33.	Cooling Water	SCORE XXXX



Description: This concept involves water inside the hollow drum used as a heat exchanger instead of copper pipes of running cool water. The water would sit at the bottom of the drum, in between the inside of the drum and the gasifier. When the drum rotates, the water would always remain in the same place due to gravity.

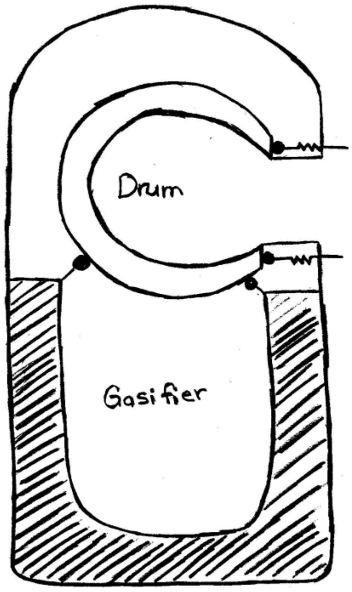
PROS	CONS
• None.	• Infeasible.

34.	Water Jet	SCORE BSP

Description: Water jet could replace laser jet for cutting and shaping of materials.

PROS	CONS
• Less expensive.	• Less precise than laser jet.

35.	Moveable Seal and Rotating Drum	SCORE 8



Description: This concept combines several ideas and involves a moveable seal and a rotating drum. The waste would be inserted into the drum and the manway would then be closed. The seal, pushing against the opening of the drum, would be moved off the drum using either bellows or a large screw. The drum would then rotate 90 degrees and drop the waste into the gasifier. Tar scrapers or abrasive seals could be used to scrape tar off the drum as it rotates.

PROS	CONS
• Automatic tar removal.	• Addition of a seal mechanism.
• Elimination of lifting mechanism.	

III. Removed Parts

Table 8 below lists the parts removed from the original Bill of Materials if the new design is implemented.

Table 8 – Removed Parts from Original MAGS Lid

PART	COST ($)
Spoked Die Cast Zinc Dished Hand Wheel Revolving Handle, 6" Wheel Dia, 1" Hole Dia	$27.23
Hardened Precision Shafts with Machined Ends Annealed Both Ends, 1" Dia, 36" Length	$79.88
Cast Iron Flange-Mounted Steel Ball Bearing, 4-Bolt Square-Flange, for 1" Shaft Diameter	$40.95
Black-oxide Alloy Steel Socket Head Cap Screw7/16"-14 Thread, 1-3/4" Length	$2.68
Zinc-plated Steel Type A Sae Flat Washer 7/16" Screw Size, 59/64" Od, .05"-.08" Thick	$0.32
Pressure-sealing Washer For Nuts & Washers 7/16" Screw Size, .91" Od, .07"-.09" Thick	$10.38
Zinc-Plated Grade 5 Steel Hex Nut, 7/16"-14 Thread Size, 11/16" Width, 3/8" Height, Packs of 100	$0.38
Sealed Precision Steel Needle-roller Bearing For 1" Shaft Diameter, 1-1/2" Outside Diameter	$43.72
High-temp Cast Iron Mounted Ball Bearing Base Mount, Set Screw Lock, For 2"shaft Diameter	$167.16
Grade 5 Zinc-plated Steel Hex Head Cap Screw 3/4"-10 Thread, 2-3/4" Length	$5.74
Zinc-plated Steel Type A Sae Flat Washer 3/4" Screw Size, 1-15/32" Od, .1"-.16" Thick	$1.12
Pressure-sealing Washer For Nuts & Washers 3/4" Screw Size, 1.38" Od, .1"-.12" Thick	$13.36
Steel Shim .125" Thick, 3/4" Id, 1-1/8" Od	$5.58
Steel Shim .015" Thick, 3/4" Id, 1-1/8" Od	$3.52
Steel Shim .062" Thick, 3/4" Id, 1-1/8" Od	$5.37
Zinc-Plated Grade 5 Steel Hex Nut, 3/4"-10 Thread Size, 1-1/8" Width, 41/64" Height, Packs of 25	$1.47
Steel Finished-bore Roller Chain Sprocket For #50 Chain, 5/8" Pitch, 12 Teeth, 1" Bore	$14.90
Standard Ansi Roller Chain #50, Single Strand, 5/8" Pitch, .400" Dia, 6'l	$27.48
Add-and-Connect Link for #50 Standard ANSI Roller Chain	$0.97
#50 Connecting Link For Standard Ansi Roller Chain	$0.97
Two-piece Clamp-on Shaft Collar Steel, 1" Bore, 1-3/4" Outside Diameter, 1/2"width	$4.09
Fully Keyed 1045 Steel Drive Shaft 3/8" OD, 3/32" Keyway Width, 18" L	$19.85
Miniature Alum Base-Mnt SS Ball Bearing--ABEC-3 for 3/8" Shaft Diameter	$19.00
One-Piece Clamp-on Shaft Coupling Steel, with Keyway, 3/8" X 3/8" Bore, 7/8" OD	$29.58
Spoked Thermoplastic Dished Hand Wheel Revolving Handle, 3-29/32" Wheel Dia, 3/8" Hole Dia	$23.87
Compact ACME Screw Jack Threaded Inverted Style, 500# Load Cap, 6" L Travel	$274.46
Alloy Steel Tube-End Weld Nut Fits 1" Tube OD, .095" Wall Thickness, 1/2"-20 RH Thread	$10.80
Silicone Gel Gasket Foam Backed, .060" Thick, 1" Width, 20' Length	$31.47
18-8 Stainless Steel Dowel Pin 3/8" Diameter, 2"	$2.41
Steel Finished-bore Roller Chain Sprocket For #50 Chain, 5/8" Pitch, 72 Teeth, 1-1/2" Bore	$93.27
Fully Keyed 1045 Steel Drive Shaft 1-1/2" Od, 3/8" Keyway Width, 9" Length	$36.55
Mounting Flange One-piece Shaft Collars 1-1/2" Bore, 2-1/2" Collar Od, 1" Overall Width	$46.22
Face-mount One-piece Shaft Collars 1-1/2" Bore, 2-3/8" Outside Diameter, .553" Width	$9.87
Black-oxide Alloy Steel Socket Head Cap Screw1/4"-20 Thread, 5/8" Length	$0.06
Heat-treatable Alloy Steel Oversize Key Stock3/8" X 3/8", 12" Length	$2.46
DDD_front_flange	$466.00

DDD_brace	$10.80
DDD_push_bar	$27.00
DDD_brace_arm	$0.00
DDD_push_bar_angle	$0.00
Unhardened Precision Tubular Shaft With Finished Id, 2" Od, 1-1/2" Id, 36" Length	$286.11
DDD_shield	$76.67
DDD_alignment_angle	$0.00
DDD_lower_side_jack_support	$0.00
DDD_upper_side_jack_support	$0.00
DDD_Back_side_jack_support	$0.00
DDD_Shield_support	$0.00
Face-mount One-piece Shaft Collars 2" Bore, 3" Outside Diameter, .678" Width	$24.88
Black-oxide Alloy Steel Socket Head Cap Screw1/4"-20 Thread, 1-1/2" Length	$1.27
Zinc-plated Steel Type A Sae Flat Washer 1/4" Screw Size, 5/8" Od, .05"-.08" Thick	$0.30
Zinc-plated Grade 5 Steel Hex Nut 1/4"-20 Thread Size, 7/16" Width, 7/32" Height	$0.12
Crowned Long-life Stud-mnt Track Roller Sealed, Hex Head, 1-3/8" Roller Dia, 3/4" Width	$478.08
Steel Shim .125" Thick, 1/2" Id, 3/4" Od	$6.78
Zinc-plated Steel Type A Sae Flat Washer 1/2" Screw Size, 1-1/16" Od, .07"-.13" Thick	$1.07
Grade F Nylon-insert Hex Flange Locknut Znc-pltd Steel, 1/2"-20 Thread Sz, 3/4"w, 9/16"h	$96.64
Black-Oxide Alloy Steel Socket Head Cap Screw, 3/8"-16 Thread, 1-1/4" Length, Packs of 25	$2.20
Zinc-plated Steel Type A Sae Flat Washer 3/8" Screw Size, 13/16" Od, .05"-.08" Thick	$0.43
Zinc-plated Grade 5 Steel Hex Nut 3/8"-16 Thread Size, 9/16" Width, 21/64" Height	$0.55
Black-oxide Alloy Steel Socket Head Cap Screw1/2"-13 Thread, 1-1/2" Length	$1.15
Zinc-plated Grade 5 Steel Hex Nut 1/2"-13 Thread Size, 3/4" Width, 7/16" Height	$0.24
Black-Oxide Alloy Steel Socket Head Cap Screw 3/8"-16 Thread, 1-1/2" Length	$0.00

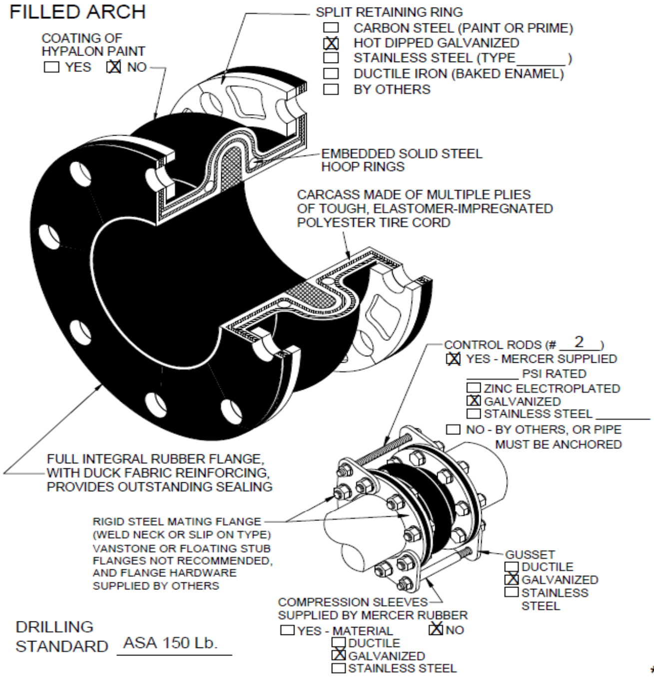
IV. Rubber Expansion Joint and Bellows

Quotation for Rubber Expansion Joint

MERCER RUBBER Co. 350 Rabro Drive, Hauppauge, NY 11788, Tel 631-582-1524, FAX 631-348-0279, Info@Mercer-Rubber.com	JOB NAME: CUSTOMER: MCGILL UNIVERSITY CUSTOMER P.O.: MERCER NO.: Q-ROP11711-2 DATE: 11-7-11 DWG. NO. ROP11711-2

INVINCIBLE 501-FA - HEAVY DUTY EXPANSION JOINT

FILLED ARCH



Tube	Cover		Temperature Rating
☐	☐	Natural Rubber	180°F
☐	☐	Pure Gum	180°F
☐	☐	Chlorobutyl	250°F
☐	☐	Neoprene	225°F
☐	☐	Food Grade Neoprene	225°F
☐	☐	Self Extinguishing Neoprene	225°F
☐	☐	Hypalon	225°F
☐	☐	Nitrile (Buna N)	210°F
☒	☒	EPDM	250°F
☐	☐	Viton	250°F
☐	☐	EPDM w/Kevlar	350°F
☐	☐	Viton w/Kevlar	400°F

Expansion joints installed in piping systems must be anchored on both sides of the joint. In this case no control rods are necessary providing piping movements are within allowables. If control rods are installed as a safety measure, the locking nuts must be backed off with a clearance equal to the specified axial movement. The expansion joint will exert a thrust force on the anchors. To calculate pressure thrust on anchors use the following equation:

Pressure Thrust = (Pressure Thrust Area) x (Rated Working Pressure)

Expansion joints installed in unanchored piping or connected to isolated equipment must have control rods. Once control rods are installed the joint will no longer act as an expansion joint, since the pressure will extend the joint into the nuts of the control rods. The joint will no longer take up axial motion. It will make up for misalignment, transverse and possibly angular motion. In this case the nuts of the control rods should be threaded tight to control rod gussets, thereby locking out control rods.

Initial misalignment should be kept to a maximum of 1/8".

Expansion joint flanges must be in contact with a continuous surface, or a maximum of 1/16" standard raised face. Depressions or protrusions typical of vitaulic or similar type flanges must be covered with a steel spacer flange first. Rubber flanges will not retain loose elements in valve bodies that rely on contact with a steel flange. In these applications, a steel spacer flange must be inserted between the rubber expansion joint and the valve body.

*** RUBBER EXPANSION JOINTS ARE NOT TO BE INSTALLED IN OCCUPIED SPACE ***

STYLE 501-FA DIMENSIONS, ALLOWABLE MOVEMENTS and OPERATING PRESSURES

QUANTITY	SIZE (in)	FACE TO FACE F.F. (in)	FLANGE OD (in)	DIA. BOLT CIRCLE (in)	NO. OF BOLT HOLES	DIA. OF BOLT HOLES (in)	AXIAL COMPRESSION (in)	AXIAL EXTENSION (in)	LATERAL DEFLECTION (in)	RATED WORKING PRESSURE (psi)	VACUUM RATING (IN Hg.)	PRESSURE THRUST AREA (in^2)
	14		21	18 3/4	12	1 1/8	1/2	5/16	5/16	250	30	153
	16		23 1/2	21 1/4	16	1 1/8	1/2	5/16	5/16	250	30	201
	18		25	22 3/4	16	1 1/4	1/2	5/16	5/16	250	30	254
	20		27 1/2	25	20	1 1/4	1/2	5/16	5/16	250	30	314
	22		29 1/2	27 1/4	20	1 3/8	5/8	3/8	5/16	250	30	380
1	24	10	32	29 1/2	20	1 3/8	5/8	3/8	5/16	250	30	452
	28		36 1/2	34	28	1 3/8	5/8	3/8	5/16	250	30	615
	30		38 3/4	36	28	1 3/8	5/8	3/8	5/16	250	30	706
	32		41 3/4	38 1/2	28	1 5/8	5/8	3/8	5/16	250	30	804
	34		43 3/4	40 1/2	32	1 5/8	5/8	3/8	5/16	250	30	907
	36		46	42 3/4	32	1 5/8	5/8	3/8	5/16	250	30	1017

NOTES:

DWN	CHKD ROP	DATE 11-7-11	DWG No. ROP11711-2

FORM NO. MS-1183.DWG

Quotation for Metal Expansion Bellows

EagleBurgmann EJS
expansion joint solutions

Quote Number: 38116

QUOTATION

Page 1 of 1

CUSTOMER

McGill University
3480 Rue University
Montreal QC H3A 2A7
CANADA

Date: 11/16/2011
Expires: 12/16/2011
Reference:

Sales Person: Sudbury International

Phone: 514-961-0901

Attention: Marc Gaulier

Revision 1- Revised Design, To 1/2" Thick Flanges

Line	Part Number	Description	Revision	Extended Price
1	38116-1	SNG24FFUT-P1T2-NLNCNCD-M5M5M5	A	

Lead Time: (4) Weeks

24" Dia. Flanged Expansion Joint Unit Per Sketch 38116-1A.

Quantity	UM	Unit Price		
2.00	EA	2,114.00	$	4,228.00

Expires: 12/16/2011

Please note that unless specified, freight charges are not included in the total

TOTAL USD	$	4,228.00
TOTAL MISC CHARGES	$	-
GRAND TOTAL (USD)	$	4,228.00

UNLESS APPROVAL IS GIVEN BY SELLER, THE ABOVE EXPIRATION DATE WILL BE THE LAST DAY QUOTATION PRICES WILL BE VALID. PRICES QUOTED ARE BASED ON ALL QUANTITY OF EACH LINE ITEM BEING ORDERED AT THE SAME TIME. PLEASE READ KE-BURGMANN EJS TERMS AND CONDITIONS CAREFULLY. IF BUYERS TERMS AND CONDITIONS ARE TO BE USED THEN WRITTEN ACCEPTANCE BY EJS IS REQUIRED.

"The Quality Remains Long After the Price is Forgotten"

PRICING BASED ON ALL ITEMS PURCHASED

PAYMENT TERMS: 30 DAYS NET
FREIGHT TERMS: EXW
EST. FREIGHT: Unless otherwise specified, freight is prepay & add, PLUS 10% - Not included in above pricing
EST. SHIP DATE: Lead time is based on time after receipt of order or receipt of "Approved" drawings, if requested by customer

AUTHORIZED SIGNATURE

Rich Eichhorn

* Price includes (12) month standard warranty. For an additional (12) month extended warranty, add 15%. 2

** Sales to CA, KY and TX are subject to Sales Tax-Not included in above pricing.

FORM-316

EagleBurgmann EJS
Expansion Joint Solutions
A Division of EagleBurgmann KE, Inc.
10035 Prospect Avenue
Santee, CA 92071 USA

Tax ID# 61-1382416
Tel: +1 (619) 562 6083
Fax: +1 (619) 562 0636
E-mail: info@keb-ejs.com
Web: www.keb-ejs.com

Remit Payment to:
EagleBurgmann EJS
24807 Network Place
Chicago, IL 60673-1248
USA

EFT/ACH Remittance:
Receiving Bank
JP Morgan Chase
Chicago, IL
USA

ABA Transit Routing No.
071000013
Acct Name: EagleBurgmann EJS
Acct No.: 838723732
Swift Code: CHASUS33

EagleBurgmann EJS
expansion joint solutions

10035 PROSPECT AVE STE 202
SANTEE, CA/ 92071-4320
P.O. BOX 711288
SANTEE, CA 92072-1288
email: SALES@KEB-EJS.COM
PHONE: (619) 562-6083 FAX: (619) 562-0636

DESIGN DATA SHEET

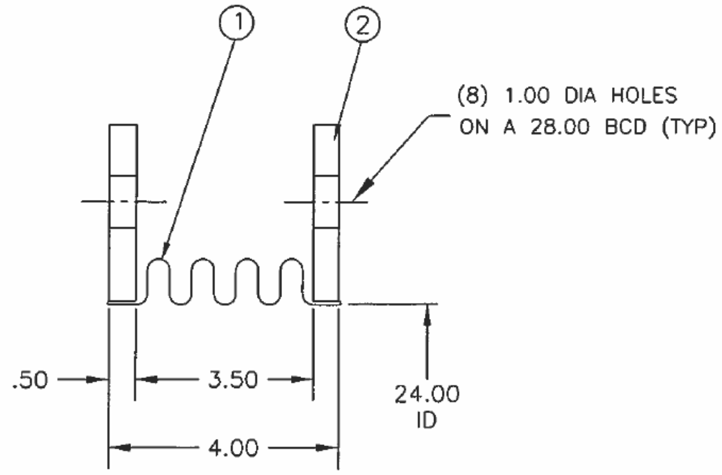
DESCRIPTION: 24 ND FLANGED SINGLE EXPANSION JOINT	WT.: 100 LBS.	38116-1A
CODE: EJMA	DATE: 10-31-11 KA	SHT 1 OF 1

MEDIA	ADVISE	NDE'S & TESTS: QTY: 2
DES. PRESS.	-4.35 PSIG [-30 kPag]	100 % PT BELLOWS SEAM WELDS AND CIRCUMF. ATTACH. WELDS.
DES. TEMP.	572 F [300 C]	
AXIAL COMP.	0.0 IN	
AXIAL EXT.	1.00 IN	
LATERAL	0.00 IN	SPECIALS:
ANGULAR	0.00 DEG	NO PAINT REQUIRED.
CYCLE LIFE	1000 (EJMA) MIN	
PRESS. THRUST	-2114 LBS	
FLOW VELOCITY	ADVISE F/SEC	

AXIAL S/R: 958 LBS/IN	LAT. S/R: N/A LBS/IN	ANG. S/R: N/A IN LBS/DEG

PC#	QTY	DESCRIPTION	MATERIAL SPEC.
1	1	BELLOWS- .018 THK X 24.00 ID X 25.75 OD X 1 PLY X 4 CONS X 3.50 Lb	A240-304
2	2	PLATE FLANGE - .50 THK X 24.188 ID X 31.00 OD	A240-304
3			
4			
5			
6			
7			
8			

REV A: ITEM 2 REVISED PER CUST. (WAS .75 THK.) 11-15-11 KA



EJS P/N REF: SNG24FFUT-P1T2-NLNCNCD-M5M5M5