BIO GAS LAWNMOWER

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ABSTRACT

The genesis of this project was to explore another possible alternative fuel for a small engine. We have all heard about using ethanol and bio diesel for engines however, I wanted to do something different and in hindsight more challenging. I set out to make a standard lawn mower run on the lawn clippings that it produced during a mowing operation. What I learned is that while it is possible to; in fact, make a small engine run on bio gas it is probably not an option the main stream will embrace as a replacement to gasoline anytime soon.

After evaluating customer needs my first concept resulted in a lower pressure version that ran on duel fuel with limited results. The primary issue was that the mower did not a sufficient usable run time. Wanting to correct some of the problems I made a second version that ran entirely on biogas. The second version does require the gas to be highly pressurized but solved the low pressure issues and produced a result with higher functionality. In conclusion I can make two statements; the first, I believe that biogas is a viable solution for those willing to deal with the weaknesses of the technology. Secondly, I think that if one were to continue experimentation a third version with a medium pressure tank would be a relatively reasonable compromise of the two versions I produced in this project.

PROBLEM DEFINITION AND RESEARCH

INTRODUCTION & BIOGAS BACKGROUND

The basic concept of this project is to develop a kit to convert a standard push mower to be able to run on Biogas produced from lawn waste. Biogas has been used by humans for thousands of years however with the ever increasing cost of using fossil fuels many are beginning to consider alternatives. A kit like this also has a great "feel good" feature in that it allows you to treat lawn care as a system to greatly reduce the environmental impact.

Biogas is something that is a common topic in renewable energy circles, but most do not know about its history. Humans have used biogas for a long time in fact, ancient civilizations used biogas to heat their baths because it was consider more efficient than the use of wood fire almost 5,000 years ago. Our industrious ancestors in Victorian England converted sewer gas (a biogas) to light the famous gas lamps. The use of biogas only fell off because of the readily available and inexpensive fossil fuels.

Interestingly, the natural process that produces biogas actually predates the production of fossil fuels in nature. Biogas can be produced by microorganisms in an anaerobic environment that naturally decompose organic matter. Fossil Fuels were produced from the accumulation of organic matter over millions of years. The nice thing about biogas production is we do not need to wait millions and millions of years to product a fuel source. Biogas can pre generated in many cased in 2 – 3 days. Biogas could in many applications easily replace the now common fossil fuel.

Methane (CH4) is the primary flammable gas in biogas the same fuel found in natural gas, a common household fossil fuel. Biogas can also go by other names such as; sewer gas, swamp gas, or bio off gas. These slang names mostly come from the method of production but, even though the name sounds to the contrary the truth is bio gas is clean-burning.

Maybe the best part is that biogas is not very difficult to manufacture on the small scale. Something as simple as organic waste, such as table scraps, and a trash bag could be used to make a crude bio digester. Another common organic matter is lawn waste and what a better use for it than to power your lawn care equipment with it. The lawn waste used can consist of the actual clipping, pet waste, leaves, weeds, etc. The best thing about it is that you can simply rake or bag up the mix and toss it in the digester. If you have pets or a garden all of the waste from that can be added to the mix.

The experts referred to the use of biogas as indirect solar energy, this is a great analogy. In simplified terms, we follow the flow of energy starting with solar energy (sunshine) hitting the plants. The plants will convert the solar radiation and nutrients from the soil in to organic material. This organic material is then converted in to biogas (stored energy) and fertilizer in the digester. The biogas is used to harvest the organic matter and the fertilizer is used to replace the nutrition the plants took up during growth.

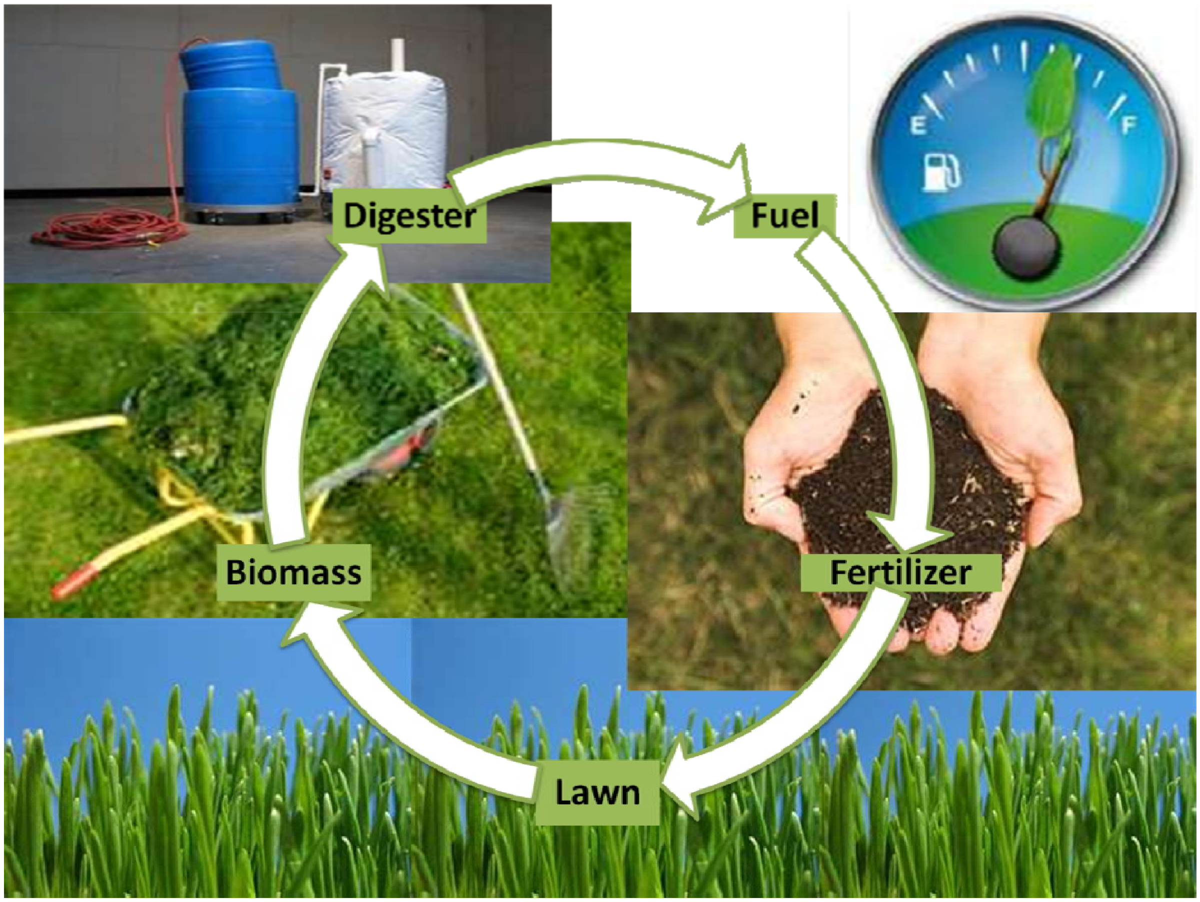


Figure 1 Lawn care system

The illustration above (Figure 1) shows how considering lawn care as a system rather than individual components allow us to derive greater efficiency. This is why biogas can create 2-5 times the amount of useable fuel as a comparable liquid bio fuel such as biodiesel or ethanol. In addition biogas will run cooler, quieter, and cleaner in a comparable engine. (1)

The process provides the backbone for this project. The biogas kit for a homeowner's lawnmower will allow them to work within a closed system rather than working against a system requiring many additional inputs.

Biogas is not used extensively in the USA as much as it is internationally. In China they have the most biogas plants in the world mostly from smaller household size production facilities servicing a village. Compared to the 50 million plants in China, India also has a large number with almost 4 million facilities. In fact the Beijing 2008 Olympic torch was powered by methane from biogas. In the European Union many countries, especially the Nordic countries, use bio fuel feed into the natural gas supply as well as for fueling vehicles.

In the west many of the infrastructure systems such as waste management, water purification, agriculture, and others are run by different agencies or private companies making the logistics of difficult. This may explain why large scale biogas production facilities are not as popular in the US as in more socialized nations such as the EU or in China where the government controls most nearly the entire infrastructure. The spirit of independent west makes it a perfect place for decentralized small scale production of biogas. A small scale local production facility is better since transporting waste and compressing fuel to ship can be expensive.

Another side benefit of biogas productions is to remove many pathogens and parasites from waste. Most municipalities use anaerobic digestion as an aggressive and inexpensive way to treat wastewater to minimize the use of many harsh chemicals. The biogas in some cases has been burnt off as a waste gas but, is beginning to be used in generator to produce some of the electricity needed to run the facility. In the third world one of the major killers is dysentery from contaminated water, a properly set up anaerobic digester can kill the pathogen in 30 hours.

One of the other important byproducts of producing biogas is the slurry that remains after the digestion process can be used as a high grade fertilizer and soil amendment. Most agricultures extension offices recommend that homeowner leave their grass clippings on the lawn to promote growth. The digestion process actually makes the clippings better by keeping the nitrogen but also converting some matter in to ammonia another amendment utilized by plants. With the concerns that people have about releasing carbon dioxide in to the atmosphere, bio gas also excels. Biogas will release the same amount of CO_2 when burnt in combustion as it would if it remained organic matter decomposing naturally. It actually just releases about the same about of CO_2 that it absorbed while growing.

APPLICATION BACKGROUND (PROBLEM DEFINITION)

The problem is that currently there are not many options for a homeowner who would like to run their mower on biogas. This solves the question; "how can I make lawn care sustainable?" In Appendix A several possible alternatives are shown however, the only real solutions is to convert the mower to run on propane or a do it yourself project with scattered information. Both of these options have significant drawbacks. The conversion to propane is expensive and is not truly running on biogas. The do it yourself projects require extensive reading, a large time commitment, and mechanical skill to build the kit.

The potential market for these kits is any homeowner that needs to cut grass. The focus would be on an environmentally concerned person so; the market would likely be a niche market rather than something for the masses. The kit could be adapted to be used for other applications such as a tiller, wood splitter, or other small engine application. Most of the costumers surveyed, see Appendix B, wanted to see an improvements in fuel efficiency and to reduce the impact on the environment. People are becoming more accepting of ideas that will provide multiple benefits. For marketing most customers will fall into buying something they need or something they want. If the kit is sold as something to help a homeowner feel better about what they are doing it will add to the marketability of the product.

The US Environmental Protection Agency says that a typical four-horsepower gasoline lawn mower engine generates as much pollution in one hour of use as driving your car for four hours. In a biogas lawn care system the CO2 produced while burning the fuel approximately the same as the CO2 captured while the lawn is growing. (2) Therefore, treating lawn care as a system it is possible to protect the environment while being able to get the work completed.

RESEARCH, TECHNOLOGY, & EXISTING DESIGNS

The focus of this design project will be on the kit to make an existing lawnmower able to run on biogas (methane). In the following sections there several current types of lawnmowers and conversion products. The good and bad points of each design are discussed and were used to frame the customer feedback survey and product objectives. The digester is not discussed in great detail as there are several kits that are ready made or do it yourself commercially available. Research indicates there are not any commercially available kits to convert existing small engine lawnmowers to run on biogas. This plan could be used for future designs that could work with any small gasoline powered engines commonly used by a homeowner. Some examples might be a garden tiller, chipper / shredder, generator, and many more.

EXISTING TECHNOLOGY

The following section is a discussion of various alternatives for the homeowner wanting to maintain their lawn. There is a short description along with the benefits and drawbacks of various designs that are commonly used for cutting a lawn. None of the existing technologies are able to fulfill all of the requirements expressed in the customer feedback section.

The reel mower (Figure 2) is one of the most basic types of lawnmowers available. Some of the advantages are: It is definitely a green option since it requires zero fuel to operate. The cost is rather low since you do not have a motor, and also it very quiet. Storage of this mower is very minimal and you do not have to worry about fluids leaking since it does not use any. A lawn mower like this is great for a physical fit hard core environmentalist. (3)

Figure 2 Reel Mower

The major disadvantages to this type of design are that it is not powered, thus maximum physical effort is needed to operate the mower. This may make the mower unsuitable for homeowners that have a large yard or have limited physical ability. The time to cut a lawn may also increase because of the physical effort and minimal cutting power. The comparable cut is rather small (cutting width) and often requires multiple passes to complete cut the grass. Since this mower is human powered is will be limited to far less than one horse power.

The mower's inability to bag grass and need for frequent adjustments does not make this an ideal solution for lawn care for many people.

An electric push mower (Figure3) has the primary advantages of this type of lawnmower are the relatively low cost and minimal maintenance. What sticks out most about this lawnmower is that it is in the middle on many categories. It can perform many of the tasks that a homeowner would need from a mower however it does not do many of them very well. For example it has a bagger and reasonable noise levels and some models have a self-propelled option for additional cost. (4)

Figure 3 electric mower

The deal breaker for most people will be that it is limited by the length of the power cord. An extremely long power cord could be used however; the voltage drop will cause premature damage to the electric motor. The cord limits both maneuverability as well as the range of the device, two items that customers found to be desirable for a lawnmower. For environmental impact this lawnmower may or may not be an advantage. If the power is generated from a renewable source such as hydroelectric or solar it is a good environmental option however, most electricity in the Midwest is produced from coal poor environmental choice. There are also some safety concerns with cutting the power cord and using this type of mower in a wet environment.

The battery powered electric lawn mower (Figure4) solves many of the issues with the standard corded electric lawnmower by, removing the leash (cord). This will increase the maneuverability while still maintaining the ability to run on electric. As with the other electric option it requires not gas, oil, or extensive maintenance. One really nice feature of an electric mower is that it can start and stop on demand. (5)

Figure 4 Battery powered electric mower

The downside to this mower is the limited cutting power and tall or wet grass might stop the cutting blades. Also the green option of charging with solar panel will add a significant cost to the product, in this case $600 for the mower and an additional $250 for each panel. Storage is also a little bit of a concern since battery life is adversely affected by temperature extremes and you will need the additional room for the solar panels and / or wall charging unit. There are also some environmental issues with the use of batteries especially ones that contain toxins such as; lead, mercury, and lithium.

The benchmark product and most widely used mower in this category are the gasoline powered mowers (Figure 5). There are many companies and hundreds of models to choose from so a customer can select a mower that would best suit their needs. For example in a small suburban lawn a smaller low power mulching mower may be the optimal choice. Whereas, for someone who owns a large rural property with heavy grass where a high powered, wide cutting mower with a bagger is a better option. Since there are multiple models people tend to be happy with the one they selected and the price is reflective in the features and size of lawnmower they selected. (6)

Figure 5 Standard gasoline mower

Some of the disadvantages to an unmodified gasoline powered mower are the reliance on an ever increasing fuel. Also a standard mower is somewhat noisy and one of the least environmentally friendly options on the list. We see this when almost every year new legislation increasingly restricts the emissions on small engines.

Propane conversion lawnmowers

Figure 6 propane kit

To make a more environmental friendly standard lawn mower one commercially available option is a propane conversion (Figure 6). The primary drawback to this is that it can be cost prohibitive. The cost for a push mower can be about $4000 and a riding mower can be $7000, there some kits that are slightly less expensive that will run on small propane cylinders such as the ones for lanterns and torches. Another disadvantage is that you may not be able to find this product locally this becomes a concern if you ever need maintenance preformed. (7)

The big advantages are that you maintain good cutting power and have an even longer range when compared to the standard gasoline powered mowers. A propane mower is also quieter than gasoline and has many options for a customer to select an option that would suit their application the best.

Possible Solutions

Potentially the most cost effective solution might be for a home owner to build their own kit using the available instruction online or in various books (Figure 7). The price for information on the internet is essentially free and a good book on the subject will range from about $20-30. This would give the customer the maximum flexibility to make a system that matches their application. (8)

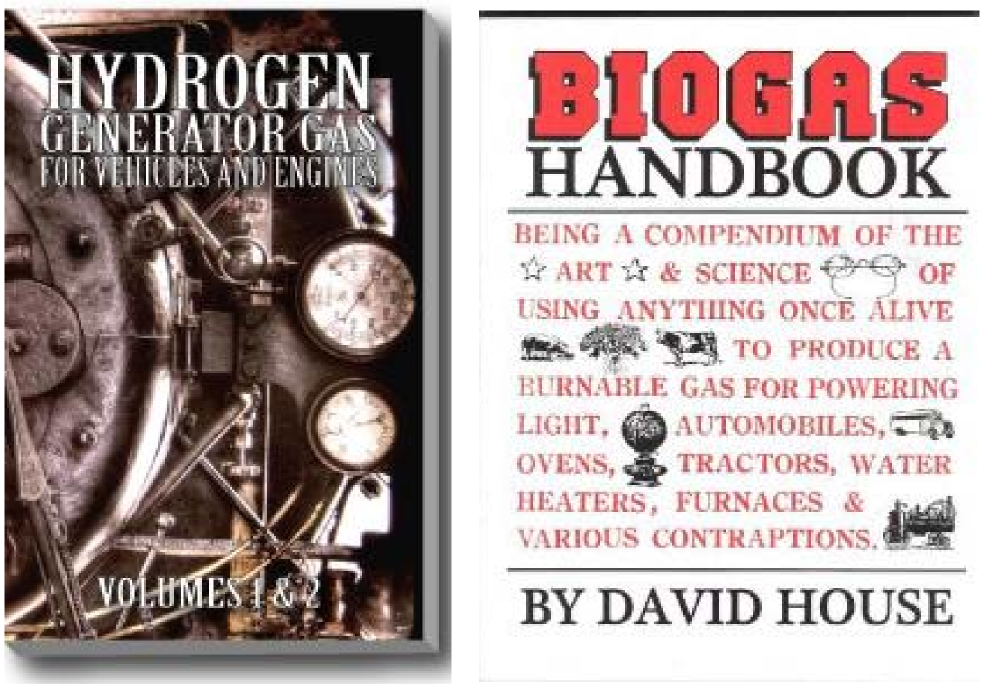


Figure 7 DIY books

The problem with this potential solution is that not everyone has the skill or time to design, construct, and implement a do it yourself (DIY) kit. Most of the books tend to be mostly theoretical and converting the information into practical application may be an issue. Parts used in most of the internet project are random, scrounged up by the builder. Many of the parts must be purchased and sized. This leaves a lot of room for fitment issues in the final product. Also with any home DIY project there is an element of danger from not considering all of the potential safety concerns working with flammable gases.

SOLUTION

Using the existing standard gasoline powered mower as the platform and then adding a kit to convert it to run on bio gas proved to be the optimal solution and will be explored with this project. The customer will be able to use their current mower and makes it a more environmentally friendly device. The survey results in the following section and in appendix B confirm that most people are happy with their current mowers. Using a kit approach the homeowners do not have to compromise on what they want in a mower they can just to it better. Since they are already familiar with the function of the mower the goal is to add a kit that allows them to do exactly what they have always done just with a more environmentally conscious result. This kit will provide the energy efficiency, durability, and environmental impact the customer desires and an affordable product cost.

The focus of this project is the conversion kit for the motor itself. The biogas digesters are available through multiples sources, or could be manufactured with commonly available items. If this product were to be commercialized an optimized digester would be provided so the homeowner would have a complete off the shelf solution. For the scope of this project a properly sized biogas digester will be selected, manufactured, and utilized to product the fuel needed for testing the prototype kit.

CUSTOMER FEEDBACK, FEATURES, & OBJECTIVES

The focus of this design project has been on the kit to make an existing lawnmower operate on Biogas. A survey was given to home owners with instructions on how to fill out the form. Twenty completed surveys were received in time to compile the results in the following discussion, also see appendix B for exact results. The product features and project objectives were also derived based on analysis of the customer feedback and feasibility with meeting the goals of the project.

SURVEY ANALYSIS

The results of the 24 returned surveys from various homeowners were compiled and analyzed to determine the costumer's satisfaction and needs for a lawnmower. The survey contained ten features that were rated on importance and satisfaction with their current lawn mowing devices. The results from the survey indicate that all except one participating was male, all owned a home, and no one used a lawn service. The homeowners were ask to rank various features on a 1-5 scale for importance and how satisfied they were with their current mowers. A standard QFD was used to rank importance of features and satisfaction, see Appendix C. The QFD also allow the designer to effectively analysis the results to determine what items to focus the most time and resources on during the project.

The most important features of the design were determined by analyzing the average importance score, average satisfaction score, a designer multiplier, the planned satisfaction, and improvement ratios, and the relative weight. From the voice of the customer it can be determined that the top features that the design will need to consider will be; Energy Efficiency (14%), Durability (12%), Initial Product Cost (11%), Environmental Impact (11%).

Most of the other features fall just below the percentages of the top features so in conclusion the product will need to have a holistic design accounting for all of the features in some respect. Thus, all of the features that were ranked with at least 10% relative weight should be considered in the design. See table #1 survey results.

Some of the features from the survey ranked lower in relative weight and will be given less scrutiny in the design. This is important when detailing the design when a design tradeoff is needed. The designer will need to make a determination to optimize one of the features with a high percentage weight while compromising a feature that was lower in customer importance. Even though a feature has a lower ranking it will still be considered in the final design as the features are still important. The features that did not have a high ranking are also listed in table #1 survey results

Table 1 Survey Results

Survey Criteria	Average Importance Score	Designer's Multiplier	Average Satisfaction Score	Planned Satisfaction	Improvement Ratio	Relative Weight (%)
Energy Efficiency	3.7	1.3	3.2	5.0	1.6	**14%**
Durability	4.6	1.1	3.6	4.5	1.3	**12%**
Environmental Impact	3.2	1.3	3.4	5.0	1.5	**11%**
Initial Product Cost	4.1	1.2	3.4	4.0	1.2	**11%**
Cost to Operate	3.7	1.3	3.8	4.0	1.1	**10%**
Cutting Power	4.5	1.0	3.7	4.5	1.2	**10%**
Ease of Operation	4.1	1.2	4.2	4.5	1.1	**10%**
Time of Operation	3.5	1.1	3.6	4.0	1.1	**8%**
Safety	3.9	1.0	4.1	4.0	1.0	**7%**
Ease of Storage	3.2	1.0	3.5	4.0	1.1	**7%**

In the table above the relative weight of the customer features is shown. The average importance column of the table is the average that the potential customers' scored for each of the features that could be found on a new mower. The next column in the table shows the customers feedback of satisfaction with their current mower. After that a designer's multiplier is applied to some of the features. This multiplier is used to weight features over other that as a designer we believe to answer the customer needs better. Since only the designer envisions the final design it might be difficult for the designer to fully convey their ideas to the customer. The two most important engineering characteristics were the environmental impact and energy efficiency so they were given a higher designer multiplier. The other high multiplier went to the cost to operate as cost is almost always a factor in any commercial design. The initial product cost and ease of operation will directly affect a customer's satisfaction of the product so they were given a slight improvement. Finial the durability and time of operation were given a minimal improvement since it will improve the customers' general sense of satisfaction. The planned satisfaction it the improvement planned by this designing the project comparing to the current designs. The improvement ration is calculated to show the ration of improvement over the current design. Finally the relative weight was calculated and shown in order from the greatest to the least in the far right column.

PRODUCT FEATURES & OBJECTIVES

The following is a list of product objectives and how they will be obtained or measured to ensure that the goal of the project was met. The product objectives will focus on a kit attached to a standard push mower. The lawnmower that was selected is intended for use by a home owner for a small yard or to trim a larger lawn. The system consists of two major parts the "kit" that attached to an existing lawnmower and the "digester" that is stationary and will produce the biogas.

Cost to Operate / Energy Efficiency / Environmental Impact: (10% / 14%/ 11%)

- Must use less than 50% of petroleum fuel, as compared to the gasoline powered mower prior to kit installation.
- Recycles multiple fuel sources of lawn waste as a raw material for the digester
- Power to run digester will be less than the fuel savings, (system must have net gain)
- Other than the initial kit, lawn waste, and power for the warmer, the digester will not require any other inputs.

Durability (12%)

- Kit must be able to withstand forces generated from mowing a yard
- Kit will be capable of withstanding vibration expected throughout operation.
- Digester will be designed with components having a minimum service life of one cutting season (approximately 8 months).

Initial Product Cost (11%)

- The lawnmower upgrade kit and digester will cost less than $200 (to mass produce)
- The kit will attach to an existing lawnmower saving the cost of a new unit.

Cutting Power (10%)

- Upgraded lawnmower will have the same cutting power as a standard mower that has not been upgraded.
- The kit will allow for a "boost" mode that allows the user to switch back to petroleum fuel when lawnmower is under heavy load.

Ease of Operation (10%)

- The kit will use controls and adjustments that are no more difficult than a standard push lawnmower
- Instructions for use will explain operation
- Force to operate controls will not be greater than existing push lawnmowers

Time of Operation (8%)

- Time required to load digester will not be more than 1hr per week.
- Time to start mower for each operation will not add more than 10 min of setup

Safety (7%)

- Lawnmower must have all originally equipped safety features
- The kit will provide single fault protection against a fire related to duel fuel system
- Pressure vessels are designed with adequate safety factors based on pressure

Ease of Storage / Resistance to outdoor conditions: (7%)

- The kit will attach to standard gasoline powered put lawnmower and will be maintained within the perimeter of the lawnmower
- Kit will use components suitable for use outdoors use to prevent excessive corrosion
- The biogas fuel production unit will be stored outside. The optimal location is alongside a garage or shed. The foot print of the bio digester will be less than 4 ft by 8 ft.

One Person Operation

- The kit and digester must be able to be operated by a single user

Compatibility w/Existing mower

- The kit will attached to a standard small gasoline engine powered lawnmower

Remote operation

- The kit will not restrict the ability of the lawnmower to be used away from a power source

Range of operation

- The kit will provide enough fuel to extend the range of the existing mower by 50%.

Maneuverability

- The kit will not restrict the mower's maneuverability around object, for example a flag pole or tree in the yard.

ENGINEERING CHARACTERISTICS

Several engineering characteristics were considered for these analyses that are used to define how the project will accomplish the customer's desired features. The increase of energy efficiency is the core of this project and will address environmental impact and the cost to operate the mower two key customer features. Increasing the energy efficiency of the mower is measured by how much fossil fuel is needed the largest cost to operate and a major contribution to the pollution affecting the environmental impact. To further increase the mowers energy efficiency, reduce the environmental impact, and lower the cost to operate the kit will have the ability to use the fuel produced from lawn waste. Currently for most potential customers lawn waste is not used so being able to create a fuel greatly improves efficiency.

The table below shows the engineering characteristics discussed above in order of importance from greatest to least:

Table 2 Engineering Characteristics

Engineering Characteristics	Relative Importance
Increase of Energy efficiency	12%
Uses lawn waste for fuel	12%
simplified controls	9%
designed for outdoor use	8%
one person operation	8%
Maneuverability	8%
Time to load digester minimized	7%
boost mode / cutting power	6%
ergonomic controls	6%
Attaching to existing mower	6%
Product cost of kit	5%
service life	5%
Single fault protection	4%
Remote operation	4%
vibration resistance	1%

Most of the engineering characteristics fell in to the middle of relative importance. These items remain important to deliver a good product however are not going to give as many results as a characteristic of higher importance. The simplified controls will give moderate benefit to the operator on many features such as the safety of operation, how easy it is to control, and the time to complete the necessary operational steps. Simplifying the controls will also allow the costumer to save frustration and should also keep initial product cost down. The mower and kit will need to be used outside so it will be an essential engineering characteristic that it be used for outdoor use. Similarly a mower must be able to be operated by a single user; customers would likely reject any option that required multiple operators since their current mowers do not require a second operator. Considering the complexity of some lawns maneuverability and navigating around obstacles, such as trees, houses, flagpoles, etc. will be important.

By minimizing the time it takes to load the digester we can keep the time to mow the yard reasonable and since it takes less time also increases the perceived ease of operation. Some homeowners expressed a need to power through tall grass and needed maximized cutting power. A slight reduction in power is one of the draw backs to using biogas, so to minimize the impact the user can use a boost mode. The boost mode will restore the mower to running on gasoline and its original full cutting power. To increase the ease of operation at the controls will be designed in an ergonomic way. Ergonomic controls also have some impact on the products safety, time to operate, and the efficiency. One of the fundamental goals of the project is for the biogas kit to attach to an existing lawn mower. The primary reason to attach to the existing mower is to keep total cost to a minimum however it will have a minor impact on many of the other costumer requested features.

Some of the characteristics ended up lower on the relative importance scale. This features will still need to be included in the design of the kit however, if an engineering tradeoff is needed they will not be prioritized. The product cost is one of the lower importance engineering characteristic and would normally be used as the primary factor is favorable sales, however since there are no other commercially available kits it becomes less of a factor in the design. With a green and newer application of this technology it is important for the device to function more so that be optimized for cost effectiveness. With the kit being an application of a new technology the service life might suffer. Ideally the service life will be much longer than stated to increase customer satisfaction. The single fault protection of the device is not something a customer would every think about is the device is designed properly. The safety of the kit will not compromise the safety of the mower and should be a fundamental of any good design. Another characteristic that ranked lower on importance however in practice would be unacceptable by a customer is remote operation. Most of the customers would not accept a mower that needed to be connected to a power source that prevents them from mowing any location.

DESIGN

In the following section alternative designs are explored and reason is given for the design selected that meets the potential customers needs the best. This section will also include a few drawings illustrating key elements of the design along with approximate visualizations of the finial assemblies. The design is then evaluated by considering the loading conditions that we will see during the expect use cases during the project service life. There is design analysis for some of the elements of the product discussed in the following pages. The factor of safety was considered when selection components for the product. The list of major components is found in the bill of materials attached in this section.

DESIGN ALTERNATIVES AND SELECTION

When trying to determine the best way to create a sustainably fueled mower several possible design alternatives were considered. One method was to use a wood gasification process that would produce hydrogen, a flammable gas that can be used for fueling a small engine. A couple of concepts were derived from the use of anaerobic digestion to product a bio gas (methane) for fuel. The other design alternative that was explored was the use of solar panels (photovoltaic) to produce electricity that would be used to power an electric mower.

Wood Gasification

The wood gasification concept consisted a reactor mounted to the front of the mower and will be responsible for converting the wood chips (or other fuel source) in to fuel. After reading Hydrogen Generator Gas for Vehicles and Engines (9) I found that a constant down draft system need to also include a blower to product the down draft. As seen in figure 8 below you can see a sketch of the concept along with major component s marked.

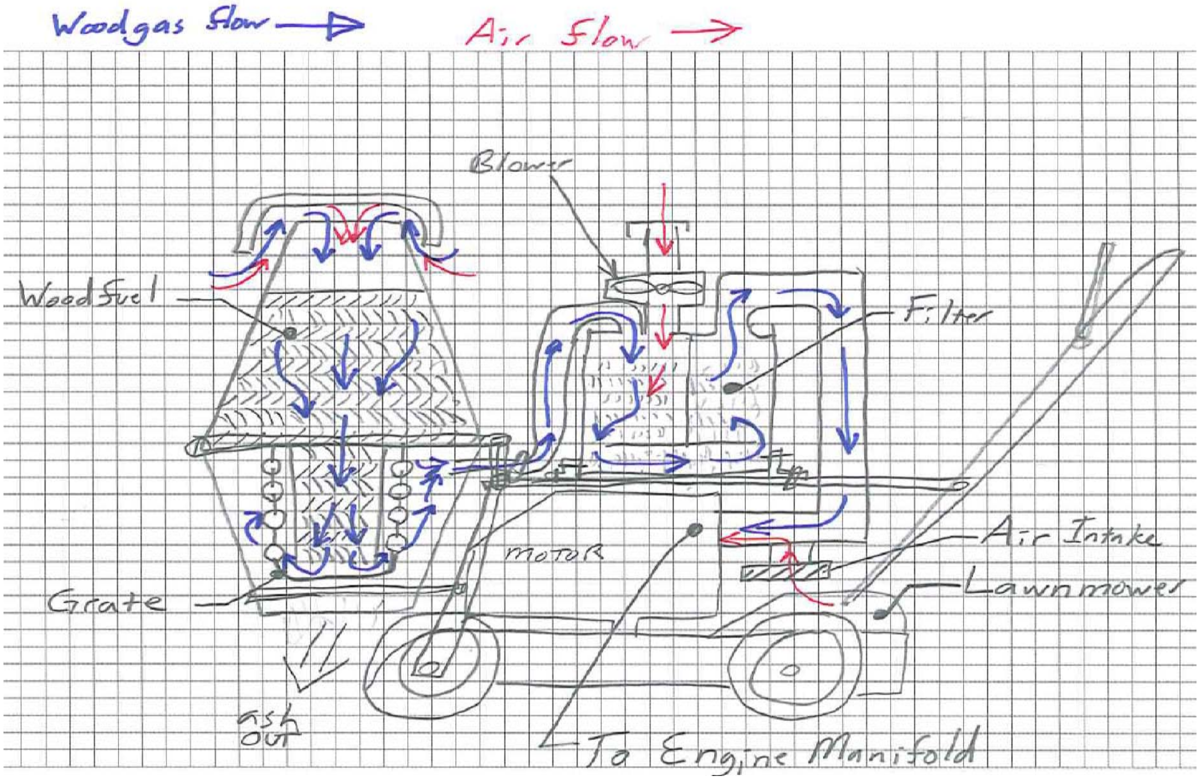


Figure 8 Wood Gasification Concept

The major advantages of using wood gasification are the fuel is produced directly so there is no issue with storage of fuel. In addition the fuel source is inexpensive (or free) wood chips are used for fuel. The waste from biogas production is distributed on the lawn and acts as a low grade fertilizer and can be seen in the above sketch (figure 8) as “ash out”.

This concept was not used for several reasons. Mounting the "reactor" to the mower is complicated and bulky. In addition in Hydrogen Generator Gas for Vehicles and Engines (9) the book stated that the reactor did not scale down to smaller versions easily due to clogging. The reactor requires an additional heat source to produce biogas. This could come from excess engine heat however would further complicate the design. Finial the additional controls are complicated and require multiple adjustments during operation

Bio Gas Digestion

Bio gas produced through anaerobic digestion was also considered for this project. I first read a book that explained the process called Biogas Volumes 1 & 2 (10). The major components can be seen in the following sketch (figure 9). The basic idea is that a homeowner can put the lawn waste (leaves, grass, and pet waste) in to a digester. The digester is sealed and the methane gas produced during the anaerobic process is used for fueling the engine. The mower will have a "kit" to hold the fuel during use. Another slight variation to the bio gas concept includes replacing the low pressure bladder with a higher pressure bladder to increase fuel capacity.

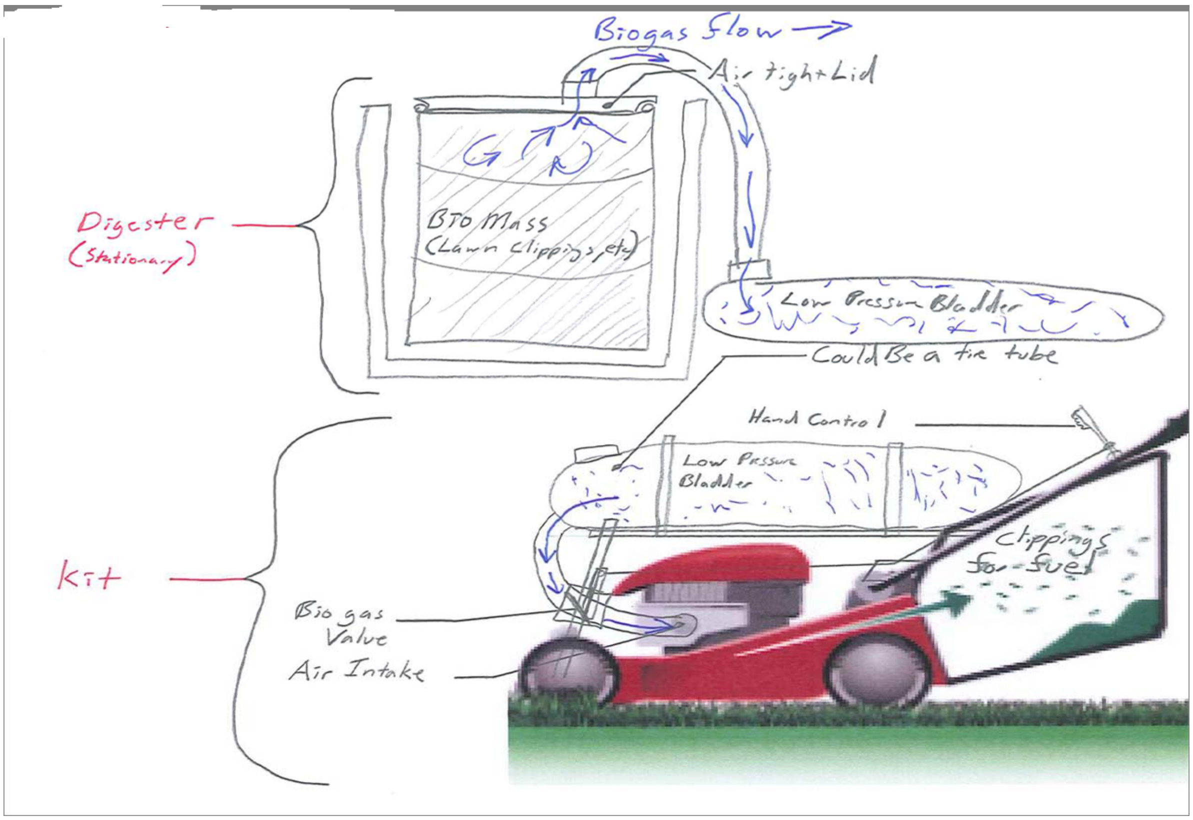


Figure 9 Bio Gas Digestion

The disadvantages of using biogas include the fact that the fuel must be stored until ready for use. As with any fuel source there is a slight risk from stored fuel and transferring biogas from collector to bladder on lawnmower. Anaerobic digesters work best above 15^{o}C and may need additional heat in colder climates based on information from Biogas Volumes 1 & 2 (10).

Biogas has several major advantages for example the fuel is produced from lawn waste in digester. The digester itself requires minimal effort to maintain and produce biogas. The biogas fuel bladder and mounting kit adds minimal weight to lawn mower. The conservative estimate for weight of the kit is about 20 lbs and will be used in the calculation section. Digestion of biogas produces fuel and fertilizer with minimal waste when considered as a system. The fertilizer that is produced is very high in nitrogen and many other key nutrients that are beneficial to lawn.

Solar Power (PV Panels)

Using solar panels (photovoltaic technology) to produce enough electrical energy to power a lawn mower is shown in the sketch below (figure 10). The key features of the design are the solar panels used to charge batteries through an inverter. The solar power concept requires an electric mower and the ability to add batteries to the mower. The mower must be a DC motor or the use of an additional inverter to convert the power back to AC.

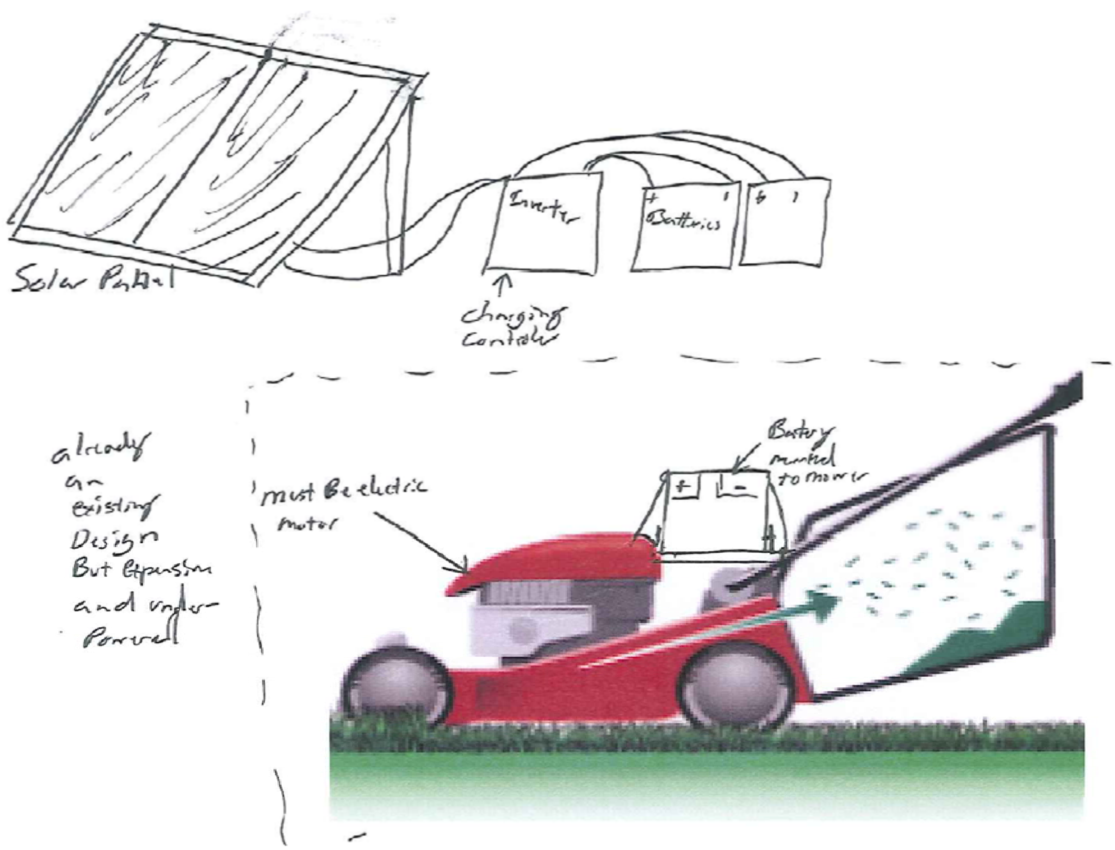


Figure 10 Solar Powered Mower

The major advantages to using solar over the other ideas are that it is less messy than other methods. The user would only have to provide minimal input for operation. Generally speaking electric mowers can be quieter than a standard internal combustion mower.

Photovoltaic charging systems and batteries can be expensive are just one of the disadvantages of this potential solution. The batteries add a significant amount of weight to the mower and can hurt the maneuverability of the mower. Solar panels require an area with good sun exposure and can be greatly affected by weather conditions such as clouds, temperatures, etc.

Each of the solution ideas were evaluated against the customer criteria and engineering characteristics. The information is provided in the following table (Table 3). As you can see from the table the concept with the highest rating was the bio gas concept. This was a change from my original plan to make a modified wood gasification design to power the mower. In concept development a combination of two similar ideas both based on production of biogas will give the optimal solution for this project.

Table 3 Concept Evaluation

		Wood (Gasification)		Bio Gas (Digestion)		Solar (Photovoltaic)	
Criteria	Importance Weight (%)	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Energy Efficiency	0.14	7	0.98	7	0.98	6	0.84
Durability	0.12	5	0.60	9	1.08	5	0.60
Environmental Impact	0.11	8	0.88	9	0.99	4	0.44
Initial Product Cost	0.11	8	0.88	9	0.99	2	0.22
Cost to Operate	0.10	8	0.80	8	0.80	6	0.60
Cutting Power	0.10	5	0.50	5	0.50	7	0.70
Ease of Operation	0.10	3	0.30	5	0.50	9	0.90
Time of Operation	0.08	3	0.24	5	0.40	6	0.48
Safety	0.07	6	0.42	6	0.42	7	0.49
Ease of Storage	0.07	6	0.42	7	0.49	7	0.49
Totals	**1**	**6.02**		**7.15**		**5.76**	

MAJOR COMPONENT

The major component that needed to be designed for this project was the “kit” that will be mounted to the mower and will hold the fuel during use. The assembly drawling below (figure 11) shows a representative illustration of the finial product. It is basically a easily mounted shelf and a large fuel tank mounted over the lawnmower’s engine. Individual drawings are found in the appendix for the sub components.

The large green box show below (figure 11) is the mower bio gas fuel tank. It will be used to store the fuel with enough capacity to provide a useful amount of work. It will also have plumbing connecting the tank to the engines air intake where the auxiliary (methane) fuel will be supplied.

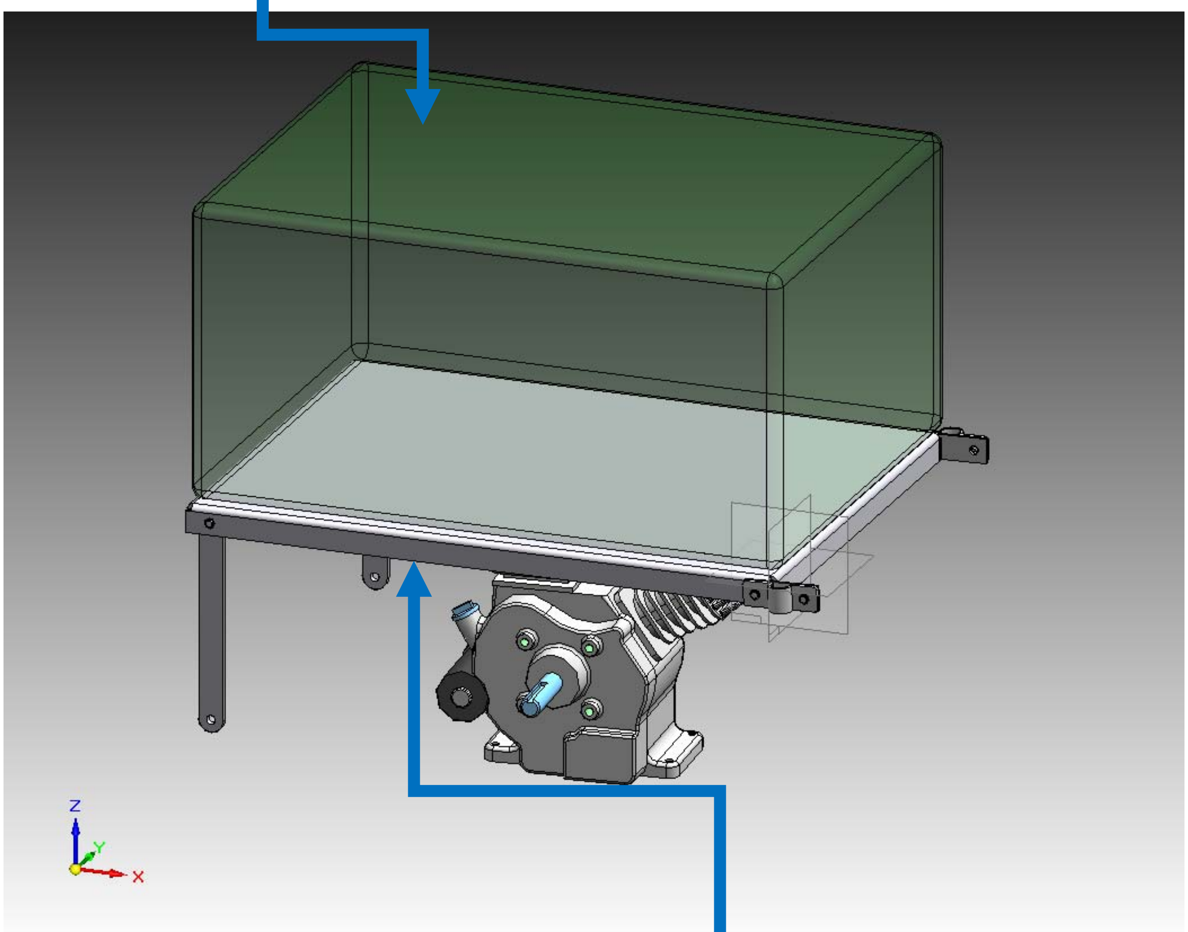


Figure 11 Mower "Kit" Assembly

The shelf of the “kit” is used to support the fuel tank. It features several brackets that will mount to almost any standard lawn mower. The front straps have a hole to mount to the bracket that holds the front wheels on the mower deck. The brackets at the right of the above illustration (figure 11) will clamp around a ¾ to 1 inch diameter tube that is commonly used as a handle for most lawn mowers.

LOADING CONDITIONS

The use case for this design consists of the activity of mowing a yard and the forces related to this activity. The shelf of the mower “kit” will need to support the approximately 20 lbs of the tank and hardware used to mount the kit. Typically the greatest forces are from impact loads on a device that is going to be moved during use. The largest impact a mower typically will see is falling off of a garage step. To simulate this step the final product will be dropped off of a 4 inch step.

The other condition that needs to be considered for this project was the amount of fuel needed. This correlates to the size and pressure needed in the fuel tank and will be discussed in the design analysis section where the calculations are shown.

DESIGN ANALYSIS

Power Calculations

The power calculation was used to answer what size of tank is needed for the project. Several iterations were conducted using pressure and size as a variable. The calculations shown below are the finial sizes determined for use and are intended to serve as an example of the calculations used in determining what was needed.

Given (published values): 1 horsepower hr = 2540 BTU
Fuel value of methane = 950 BTU/ft^3

Variables: TV (tank vol.) = 24” x 18” x 12” cylinder = 5184 in^3 = 3 ft^3
TP (tank pressure) = 100 psi = 6.8 atm
EV (effective vol.) = (TP) (TV) = 20.4 ft^3 = 19380 BTU
hp = horsepower of engine hr = hours of running
x = heat value of gas (BTU/ft^3) y = efficiency of engine (25%)

Methane Gas Consumption (G) (ft^3) of general heat engine:

$$G = \frac{(hp)*(2540BTU)*(hr)}{(x\, BTU/ft^3)*(y\%)}$$

Gasoline engine on methane:

$$G = \frac{(hp)*(2540BTU)*(hr)}{(950\, BTU/ft^3)*(.25)} = 10.7\, ft^3/hp-hr$$

For 3.5 hp mower
G = (hp)(hr)(10.7 units) = (37.45 ft^3/hr)(hr)

Operating Time (OT)

$$OT = \frac{(EV)}{(G)} = 10.7\, ft^3/hp-hr = .54hr$$

Conclusion: The design will have a little over a half hour of run time if pressurized to 100 psi. This pressure is easily achievable with a standard home air compressor (most are rated to 120psi).

In practice the fuel bladders used on the version one kit could not hold the 120 psi pressure as initial planned. So when corrected for the lower pressure the mower would only run for about 5 minutes on the biogas. This was key in driving the version two kit as seen on the next page.

Below the version 2 kit was calculated for run time.

Given: 1 horsepower hr = 2540 BTU
Fuel value of methane = 950 BTU/ft^3
Variables: TV (tank vol.) = 4" x 18" cylinder = 226 in^3 = .13 ft^3
TP (tank pressure) = 2000 psi = 136atm
EV (effective vol.) = (TP) (TV) = 17.7 ft^3 = 16796 BTU
hp = horsepower of engine hr = hours of running
x = heat value of gas (BTU/ft^3) y = efficiency of engine (25%)

Methane Gas Consumption (G) (ft^3)
of general heat engine:

$$G = \frac{(hp)*(2540BTU)*(hr)}{(x\, BTU/ft^3)*(y\%)}$$

Gasoline engine on methane:

$$G = \frac{(hp)*(2540BTU)*(hr)}{(950\, BTU/ft^3)*(.25)} = 10.7\, ft^3/hp-hr$$

3.5 hp mower

G = (hp)(hr)(10.7 units) = (37.45 ft^3/hr)(hr)

Operating Time (OT)

$$OT = \frac{(EV)}{(G)} = ft^3/hp-hr = .47hr$$

In conclusion the version 2 kit should be able to run for about a half of an hour.

Stoichiometric (Air-Fuel) Ratio

Calculating the air-fuel ratio is necessary to determine what adjustment will need to be made to the carburetor of the engine on the lawn mower. Since methane fuel as a slightly different ratio than gasoline an adjustment will need to be made. As seen in the calculation below I will need to allow more air in to the combustion chamber to allow the engine to work properly.

Reaction of methane (natural gas) as a fuel
$CH_4 + 2(O_2) \rightarrow CO2 + 2(H_20)$
The atomic weights of the atoms in the reaction are as follows:
Carbon (C) = 12.01
Hydrogen (H) = 1.008
Oxygen (O) = 16

1 molecule of methane has a molecular weight of:
1 * 12.01 + 4 * 1.008 = **16.042**
One oxygen molecule weighs: 2 * 16 = **32**

The oxygen-fuel mass ratio is then:
2 * 32 / 1 * 16.042 = **64 / 16.042** reduced to **3.99kg/1 kg**

Since 23.2 mass-percent of air is actually oxygen, we need :
3.99 * 100/23.2 = **17.2 kg /1 kg** of methane.

So the air-fuel ratio of methane is 17.2 as a Reference Gasoline is 14.7. So this tells me that the combustion will work as long as more air is allowed to enter the combustion chamber. This is well within the adjustable range of the carburetor.

Digester Bench Testing

Digester performance was a major concern for the project's success so to mitigate a potential failure a bench test was conducted to find the best method for producing bio gas. This experiment consisted of several one liter bottles filled with various combinations of organic matter commonly found in lawn waste. Some were filled with lawn clippings and water only. Others had a mix of green (grass clippings) and brown (leaf, wood) organic matter. The finial combination was a mix of green organic matter, brown organic matter, and pet waste. Two of each mix were made and subject to different temperatures. In the illustration below you can see some of the bottles at the beginning of the experiment. (Figure 12)

Figure 12 Bio Gas bench test start

In the picture to the right you can see that the balloons are used to keep the air out of the mini digester to insure that anaerobic digestion would take place. Only some of the samples are shown to give a representation of the experiment.

Figure 13 Bio Gas bench test at 3 weeks

In this figure you can see that the balloons are partly inflated for most of the samples. Sample number 2 is not inflated because the balloon had a small cut in it and thus failed to product any gas. This showed that it is critical to have an air tight digester

This bench testing proved that a critical factor for proper and efficient digestion is maintaining a good temperature. The mixture also played a role in how much gas was produced and when the production started. The mixture with green, brown, and pet waste was the first to produce and seemed to product the greatest volume. My hypothesis is that this is because of the increased amount of initial bacteria from the pet waste that could quickly begin breaking down the organic matter. When the samples were subjected to outside temperatures (approximately 50-deg F) the production slowed to almost noting. The gas produced during this bench testing was combustible with an open flame.

FACTORS OF SAFETY OF CONCERN

The factor of safety was not a major concern on this project because the relatively light weight of the components do not create forces great enough to push components near there yield strength. To illustrate this sheer calculation on bolts was conducted as seen below. The bolts were selected because they would logically be the weakest link in the design given the relative strength of the other components.

The formula for shear is as follows:

$$\tau = \frac{F}{A} = \frac{F}{\pi r_{bolt}^2} = \frac{4F}{\pi d_{bolt}^2}$$

In this application we get: Given: a 20lb load and ¼ inch bolts

$$\tau = \frac{(4)(20lb)}{(\pi)(.25in)^2} = 407PSI$$

In the table below you can see the published strength of various size bolts.

Table 4 bolt working loads

Bolt Safe Working Loads (lbs) (Safe tensile load at 6,000 psi load) (Safe shear strength at 7500 psi load)			
Bolt Diameter(in)	NF Thread Grade 2 Iron Bolt		
	Shear (at thread root)	Shear (Full Bolt)	Tensile (at thread root)
1/4	200	370	160
5/16	340	575	270
3/8	510	830	410

To get the safety factor we compare the published value to the actual load needed in the analysis and we get the following. A safety factor of over 18 is greatly over any design guideline and confirms that further analysis is not needed for this design.
(7500PSI) / (407PSI) = **18.4**

COMPONENT SELECTION

To comply with the customer requirement that the product be designed for outdoor use only components with good weather resistance were selected. The "kit" is constructed out of mild steel because it will optimize keeping the cost down, has great strength properties, and is readily available. The mild steel was primed and painted to protect it from an outdoor environment. The bolts used to hold the brackets together will have a zinc coating to protect it from the outside environment. Since strength is not a major concern due to the loading calculation a grade 2 bolt will have a lower cost and still have good strength properties. The fuel tanks used on the mower kit were collapsible plastic water containers designed for camping use. They are made out of number 2 plastic that is ideally suited for the application; in fact it is commonly used for the standard gasoline fuel containers. The second version of the mower kit used a high pressure propane cylinder. The small cylinders are designed for outdoor camping use and were well suited for this application.

The digester is the other major component of the design. The primary component is the large barrel used as the digester container. For this project a common 55 gallon metal drum was used. The steel barrel was selected over the initial plan to use a plastic container because the steel container had a removable top. The removable top made loading and unloading the barrel much easier. Since the barrel was steel it needed to be painted to protect it from the environments both inside and outside the container. Black paint was used to increase the day time heat gain for the digester. Thermal properties are important since the anaerobic digestion can be effected by temperature fluctuations. Based on bench test experimentation temperature is critical and for the project the digester will be insulated depending on the weather. The large volume of the tank serves as a thermal mass protecting the bacteria from temperature fluctuations that will adversely affect biogas production. A pool inter tube was used to hold the collected biogas until it could be transferred to the fuel bladders for the version one kit or be compressed for the version two kit.

In addition to the major components of the project there are several smaller but still important properties. To meet the safety customer requirement a backfire preventer was used to prevent the chance of the kit's fuel tank from becoming ignited during use. The back flow preventer was incorporated in the torch head I used that also served as the on / off switch for fuel in to the motor. They are used for cutting torch applications and are excellent at allowing fuel flow in one direction but provide a check valve in the event of a backfire. Another item for the project is the plumbing needed to connect the tank to the engine and the digester to the inner tube (fuel storage). This tubing will be commonly used PVC. The PCV offers good resistance to environmental factors and has a wide range of sized, fittings, and adapters making installation and simplifying the finial construction. I also used rubber gaskets in the air intake modification to prevent addition air from entering the combustion chamber potentially displacing fuel.

BILL OF MATERIAL

In table 5 (shown below) you can find the bill of materials for the project. The list gives the major components and a short description of what each component entails. The exact part numbers are not critical and many parts were salvaged during this project. A person wanting to duplicate this design is encouraged to make use of the materials available to them. In appendix E the budget contains information about the price and quantity of parts needed to construction of the project. In the budget section I also discuss the costs and parts that would be needed to product the kits on a larger scale.

Table 5 Bill of Materials

Component	Description
Digester	Includes a main tank, several valves, piping, and a heater/insulation. Instructions for building were available. Consisting of a steel tank and PVC plumbing
Biogas storage	A large inner tube and valve will withstand some low pressure (5-6 psi) and store a large quantity of gas. For project a pool float tube was used and constructed out of PVC. A garden hose was used to connect the plumbing of the digester to the pool tube
Mounting Shelf	The shelf to hold the on mower fuel bladder safely and securely above the motor. The material used was painted mild steel. Mounting hardware was standard coated ¼ inch bolts
Fuel Bladder	Water storage containers used for camping held the low pressure fuel on the version one kit. The fuel bladder was replaced in the version two kit with a reused propane cylinder to hold the higher pressure and increase the fuel capacity.
Air intake	Air intake of the mower is modified to accept gas from the fuel bladder or the compressed gas cylinder
hose assemble	The hoses are used to allow the gas to enter the engine at the correct ratio (17.2 to 1)
Backfire preventer	Torch head provided a flash back arrestor is used for a critical safety feature in the design and to turn the gas fuel on and off to the motor
Lever & Cables	Control Lever and cable was used on the version one kit to provide a easy way to adjust the air entering the carburetor and allows the user the make minor adjustments to the air fuel ratio during operation.
Lawnmower	The homeowner could modify their existing lawnmower or other small engine for this project. I purchased a new mower for the version two kit to experiment with running the mower on 100% biogas

CONSTRUCTION AND MANUFACTURING

The project consisted of two major components the biogas digester and the kit mounted to the lawn mower. The kit has two versions; the first was designed to support low pressure fuel bladders above the lawnmowers engine, and the second used a high pressure cylinder mounted to the handle of the mower.

Figure 15 Manufacturing Programming Water Jet

Figure 14 Water Jet

The lawnmower kit had several components that needed to be designed and fabricated. In figure 14 the model maker is programming the water jet that I used to cut out the deck of the mower kit. This machine cuts the steel with an extremely high velocity stream of water and an abrasive media called garnet. This machine was able to accept my drawing and convert it to a program to operate the saw. I was able to have finished parts in the same day that I submitted the parts to the model shop. Working with a local machine shop was an expedient way to quickly have high quality parts made for my project. If this kit were to ever be made for mass production I would most likely look at using a die stamp or a laser cutter to drive down cost of a larger production run.

The water jet (figure 14) and a large bender was all that was needed to make the shelf for the mower kit. The ready to paint version is seen the (figure 15) below.

The mounting brackets and clamps were also constructed out of mild steel so they could be easily bent in to place. Holes were drilled for clearance of the ¼ inch standard hard ware with a small drill press. I then removed the sharp edges with a bench grinder and cleaned the part. All of the metal parts were then painted to protect them from the elements.

Figure 16 Kit Shelf

Figure 17 Digester

The other major component that was constructed for this project is the bio gas digester. As you can see (figure 17) the digester primarily consists of a 55 gallon drum and a set of valves. To construct the kit I used the book (also pictured) as a reference on construction of the system.

The barrel was first sanded down using a wire wheel on an angle grinder. It is very important that the digester make a good seal for proper anaerobic digestion to take place so, the barrel was filled with water and inspected for leaks. I was able to weld shut few areas that had small leaks using my MIG welder. The barrel was then primed and painted to protect against the elements and to maximize solar gain.

To make the barrel air tight the bung openings were closed up and the gasket around the removable top was replaced. I also used a silicon calk to insure a good pressure tight seal and prevent loss of biogas during production. Despite all of my preparation the final product did develop a small leak around on one of the bung openings and had to be repaired with a two part epoxy resin.

The plumbing used is ½ inch PVC schedule 40 pipe and can be found at any hardware store. Each part was glued in to place using the primer and glue for PVC. I installed two valves on the digester one is used to turn on and off the flow of fuel to the storage tank and the other is used to transfer the gas to the on mower fuel bladders or compressor.

Figure 18 Digester: what is inside?

The digester is filled with three components; water, grass clippings and manure. This mixture was thoroughly mixed to create a homogeneous mixture. The starter (from the bench test) mix is added as a bacterial starter colony. Once it is full the digester was sealed with the band. The Collection bladder was attached and valve opened to allow the biogas to collect. The digester was placed on the south (sunny side) in an outdoor location for production.

The bio gas digester began to product gas in about 2 weeks. According to research I did reading “Bio gas Volumes 1 & 2” (10) production would have continued for about 8-10 weeks. I had to stop the digester’s production to transport the project to Tech Expo. When I stopped the digester it was filling the storage tube in about 3-4 days. The complete biogas digester can be seen to the right in figure 19.

Figure 19 Digester

The carburetor was modified to accept the bio gas on both versions of the kit. The bio gas is already a gas so it can be pushed straight in to the combustion chamber. Gasoline in contrast is a liquid fuel and must be vaporized in order to burn properly. To allow the bio gas to enter the engine I cut a hole in the air intake cover and ran a hose in to the existing air filter. This allows for a large volume of fuel to enter since the bio gas is less dense then gasoline. By keeping the air filter in place the air filter will also remove the particulate in the bio fuel.

On the version one kit a fuel cut off valve was added to the gasoline supply line to control the amount of gasoline entering the engine. Each of the on mower storage fuel bladders have a valve to control how much biogas enters the engine. By using the three valves an operator can start the engine on gasoline and then switch over to bio fuel. When the bio fuel runs out it can be switched back to gasoline operation.

Figure 20 The completed Lawnmower kits

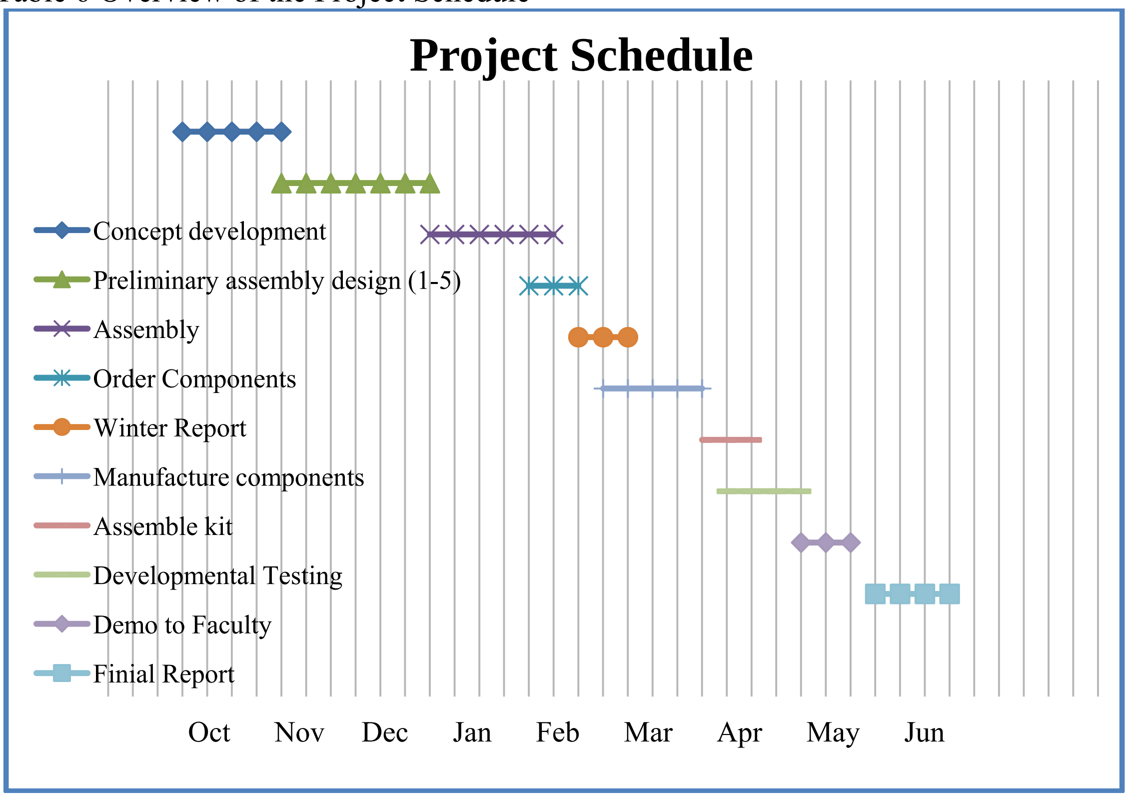
The version two kit used a torch head to control the compressed biogas. I used 3/8 inch high pressure air hose to supply the engine with bio fuel. I also added an addition control for the throttle plate so the operator is able to adjust the air entering the engine. Between the two controls the operator is able to quickly adjust the air fuel ratio as outside parameters change. Both of the kits are shown assembled in figure 20 to the left.

PROJECT MANAGEMENT

SCHEDULE

The project schedule begins November, 2011 with the completion of a weighted objective method and proof of design statement. The project timeline covers the seven months of development ending in June, 2012 with the presentation of the final report. The detailed project schedule is found in appendix D. The project schedule is shown in two tables outlining the two major components. The project ran slightly behind the originally planned schedule throughout the project however was completed on time and all of the key deadlines were met. The technical expo featured a fully functional product. Testing was completed and the results are included in the testing section of this report. The findings were presented to the faculty along with this report.

Table 6 Overview of the Project Schedule



BUDGET

The overall budget for this project reflects the cost to build the prototype developmental model. If this product were to be mass produced components would be selected to drive down cost. There is an obvious economy of scales as producing a custom one of a kind bracket will, for example will cost significantly more than a mass produced off the shelf bracket. Another example is buying a single component will cost more than the price per part if a large productions (1000 plus) order is placed. The design will incorporate as many off the shelf solutions as possible in the design to meet one of the primary customer goals of keeping initial product cost to a minimum.

The detailed expect cost break down can be found in Appendix E. Table 7 shows each of the major components and the proposed vendor for each. It is expected that the actual cost should be less than the proposed cost. Also if this project were converted to a mass produced kit the finial cost would be significantly reduced because of economies of scale. The table also shows an approximate value for items that a homeowner may already have available. . The digester is expected to cost $265 and the “kit” installed on the mower will be about $850 for the prototype. In summary, the planed cost to build the prototype is approximately $1115.

The actual cost are also presented in Appendix E of this report. The cost to build the digester prototype was about $90 and the kits were about $175 for the version one and $225 for the second version. This cost was less than the $1115 estimate for the prototyping budget as expected. I also calculated my construction time for 30 hours of work with an estimated value of $1500. This did not include any time spent engineering, drawing, analyzing, or reporting. So the total for the prototype effort is about $2000 with time included.

If this kit were to be further designed for mass production I included estimates for time in Appendix E. The cost could also be driven down. The productions cost includes the estimated assembly time, biogas digester and one of the two versions of the lawnmower kit. The version one kit featuring a low pressure fuel bladder and deck is estimated to cost $314. Version tow with a high pressure cylinder is estimated to cost $245. The actual kit for the high pressure version is only about $25 in raw materials if a do it yourself handyman wanted to duplicate this project.

The break even as compared with the standard gasoline mower is almost even at current fuel prices. A gallon of gas is currently about $4 and the cost to compress the biogas into the cylinder is also about $4. If gas were to rise to $8 is would take a little over a year of operation or about tow mowing seasons for the kit to pay for itself.

This intended market for this product is not the overly budget concuss consumer as it will likely not be cost effective. The targeted customer would be someone interested in creating a sustainable system. Part of a good marketing strategy would be using sustainability and environmental concerns rather than price as distinguishing features.

TESTING

The design of the project was successfully verified through the use of testing based on the critical criteria described in the proof of design statement (see Appendix G). Each of the bullet pointed items will have an associated test or inspection related to it. Testing and inspection was conducted where appropriate.

The engine is required to run on 50% biogas as a fuel. This will be tested by observing the amount of fuel used based on running the engine for a specific amount of time and recording the amount of gasoline used. Various trials were conducted as seen in the table below. I was able to produce a limited amount of biogas so I was only able to run single trials in testing. The remaining biofuel was used for prototype demonstrations.

Table 7 Run Time Testing

Condition	Run Time (min)
Running on Gasoline (Version 1 old mower)	31.57
Running on Gasoline (Version 2 new mower)	Note 1
Running on mixed gasoline and biogas (V1)	33.01
Improvement by adding biogas	**1.44**
Running on low pressure biogas (V1) Trial1	2.34
Running on low pressure biogas (V1) Trial2	1.15
Running on low pressure biogas (V1) Trial3	1.57
Running on low pressure biogas (V1) Average	**1.69**
Running on compressed biogas (V2)	19.76
Motor running on gasoline 50% goal	15.79
Percentage of goal reached (Note 2)	**125.18**

Note 1: The second version kit did not require gasoline and there for was not tested.
Note 2: With the second version of the kit I was able to reach 125% of my goal to match 50% of the gasoline equivalent run time.

To test the strength of the components of the product the mower with the kit installed will be dropped off of a 4 inch step. The mower kit met this pass criterion and was inspected to insure that the kit did not become loose or fail to remain on the mower. By inspection one can observe that the nuts used are all locking. Common aircraft nuts were used because of the combination of weatherproofing and locking ability.

By inspection the kit will be mounted to a standard push mower. The kit will also comply with the CPSC guideline for mower safety (11). The lawnmower with the version one kit installed maintained the stock mowers built in safety features. The engine cutoff and blade brake were not modified during the insulation of this kit. The CPSC guideline also recommended guidance for stability when mowing on hills. I measured the tip angle of the mower with and without the kit. In both the lateral and longitudinal directions the mower was within 1-deg inclination compared to the un-modified mower.

The mower can be operated by a single user and I was able to complete the testing without assistance from an additional operator. The mower was able to maneuver around objects with the kit installed since the kit was within the wheel base of the stock mower. This kit is able to be installed with common hand tools. Both versions of the kit were installed on the mowers with common hand tools found in most homeowner's garages.

All of the above testing was conducted consideration as to what the worst case version would be for each test or inspection. In general the version one kit was the worst case considering the addition of the support deck and larger onboard low pressure fuel bladders. The inspection criteria were verified on both versions of the kit.

The bio gas digester has several design criteria that was verified by inspection. The first criterion was that the only materials used to produce the fuel (methane) will be common yard waste. To fill the digester the only materials I used was grass clippings, water, and horse manure. The bench testing demonstrated that well or rain water would work better than the chlorinated tap water. I used well (no-chlorinated) water in this project to help support the bacteria that are working to convert the organic waste in to a usable fuel.

The components of the system were inspected for use as a piece of equipment able to be used in an outdoor environment (also see component selection section of this report). The plastic parts in the digester were UV resistance plastic components based on the materials properties from the manufacture. Weather resistance was addressed by coating all of the metal components with both primer and paint. A black paint was used to add a thermal gain since the production was in the spring and digestion was most efficient at a slightly warmer temperature.

The digester set up within the 4 by 8 foot size requirement. The final foot print of the bio gas digester is approximately 4 by 7 feet in and irregularly shaped area. This area could be reduced by setting the storage tube vertically but was not necessary for this project. The homeowner should be advised that the filled bio gas digester will weigh 350-450 pounds. This will make it difficult to move after it is filled. The location in relation to the sun is also somewhat important. In a northern area, such as Cincinnati, a south facing area with good solar exposure it ideal to locate the digester, with a north facing area being lease favorable.

CONCLUSION

In general the project was successful in that is met the design criteria established based on customer requirements. The problem this project solves is mowing the lawn as a system with minimal waste produced. Early in the project I did a lot of research in to biogas production and its potential uses. I used this information to guide a problem definition. Other existing technology was explored and analysis for viability. Ultimately, using bacteria produced bio gas was the best concept and was selected for design.

In the second phase of the project the device was designed to meet the criteria. This was accomplished by doing engineering analysis and calculation to understand what was needed to be completed. I did this by documenting any questions I had about the design and then going back and answering the questions. I used a solid modeling to create the parts needed for the project.

Figure 21 Tech Expo

The bio gas digester was constructed and was operational for testing. Having the digester air tight is critical to operation. Several small leaks developed as the bio gas came up to pressure and were repaired. The amount of work to load the digester was significantly greater than I initially anticipated. The digester also has a significant loaded weigh making it difficult to move. Despite its imperfections the digester worked very well and was able to product an acceptable amount of fuel to complete demonstrations and testing.

The mower kit was first constructed as planned using the low pressure fuel bladders and a steel deck. Because of a limited run time I designed and constructed a better second version that used a compressed high pressure tank to deliver the biogas to the engine. The second version met the criteria for the design. The second version kit was place on a new mower that has never been run on gasoline.

In conclusion the project was a valuable learning tool. If I were to continue extermination with this design I believe that a third version of the kit would be optimal. This version would have a 120 psi compressor so that a standard air compressor could be modified to compress the gas. I also would make the digester easier to move around by adding casters. I feel that biogas, while not for everyone is a viable alternative fuel source. When the fuel is no longer being produced you can use the remainder to fertilize and start the process all over again.

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APPENDIX A - RESEARCH

Interview with customer, Sep. 25, 2011 (11)
Ken Rudolf, land owner, 13685 N. County RD 50 W., Batesville, IN, 47006.

- Owns a small 23 acre farm with about 2 acres of grass that needs to be cut.
- Need to account for cutting multiple types of grass; thick prairie grass and fine lawn grass.
- Would like to save on ever increasing fuel costs
- Bags grass clippings most of the season
- Interested in being green as long as it is not hard
- Stored in an un-insulated barn
- Collects and composts other yard waste such as apples, sticks, and dog droppings
- Areas that are mowed can be away from buildings

http://www.lehmans.com/store/Outdoors___Lawn_Care_and_Equipment___RazorCut_Premium_38_Reel_Lawn_Mower___12500700?Args= 9/26/11 **RazorCut Premium 38 Reel Lawn Mower** lehmans.com (3)

The RazorCut Premium 38, manufactured by Brill, is for people who love quiet, peaceful gardens, bird watching, and taking care of our environment.

- Lighter and more maneuverable than other brands - weighs just 17 lb!
- Almost completely silent and friction-free
- 5 flame-hardened, welded steel blades for even cutting
- Overall 21½"W
- Plastic wheels 8"OD
- Mows a 15"W swath
- Handle 49"L
- German engineering; built in Europe

Green option
Requires maximum physical effort from the user
Small cutting swath
Not capable of thicker tall grass
Quiet
Small storage area
Not powered
Does not collect yard waste

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http://www.walmart.com/ip/Remington-19-3-1-Side-Discharge-Mulch-Rear-Bag-12Amp-Electric-Push-Mower-electric-start/13373919
9/26/11 Remington 19" Side-Discharge/Mulch/Rear Bag Electric Push Mower
Walmart.com (4)

The Remington 19" Side-Discharge/Mulch/Rear Bag Electric Push Mower has a high-quality motor with superior cutting performance that you'll appreciate.

19" cutting deck
Side discharge/mulch/rear bag
12-amp engine
Electric start
Single-lever height adjustment
7" front wheels/8" rear wheels
2-year manufacturer's warranty

Great mower for a smaller yard. Met expectations. Used a 100ft. extension cord for ease. Price was great--higher at other stores as well as the Remington site.(Customer review)
</td>
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Medium size cutting width
Reasonable noise level
Powered
Some models are self-propelled additional cost
Fair cost $150-$200 (not self-propelled)
Safety concerns with wet weather
Cord limits range
Difficult to maneuver around objects
Requires electrical input that may or may not be green depending on source
Low maintenance
Has a bagger
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http://www.peoplepoweredmachines.com/epic/index.htm#
9/26/11 **Epic Cordless Electric Solar Mower,**
peoplepoweredmachines.com (5)

The only high-performance cordless electric mower with features typically found on high-end gas models:

mulching
push-button start
self-propelled rear wheel drive
cuts the average lawn in one charge
21" inch extra wide cut
battery powers mower for 45 minutes on one charge
24 volt system powered by two 12 volt batteries
requires no gas, oil, maintenance or annoying cords
low maintenance costs, hassles, and pollution
solar panel option

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Limited battery life
Maneuverable around objects
Not limited by power cord
Green option if using solar or other green electrical source
Batteries could be toxic
Tall grass may be difficult
Few self-propelled options
Electrical input required for charging
Cost is high $600 plus $250 solar panel
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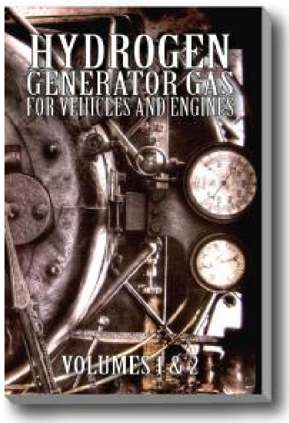
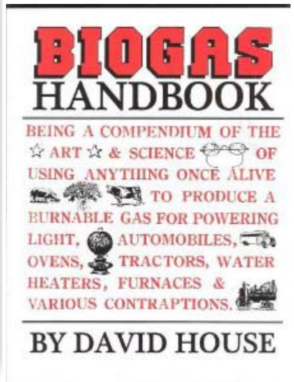
 http://www.cubcadet.com/webapp/wcs/stores/servlet/gallery_10051_14101_33831_33830_600000_-1_image 9/26/11 Self-propelled lawn mower. cubcadet.com, (6) ▪ SureStart™ Guarantee certifies that your self-propelled lawn mower will start in 1-2 pulls (available on select models) ▪ Cyclocut™ System discharges grass evenly ▪ Easy, single-lever cutting height adjuster ▪ Rugged steel deck ▪ Ball-bearing wheels ensure that your walk behind mower will move smoothly ▪ 3-year limited residential warranty (see your local retailer or independent dealer for warranty details)	Home owner may already own Noisy Fuel cost continue to rise Good power Many options for exact application Reasonable price $270-$330 Has a self-propelled option Almost unlimited range Range limited only but fuel capacity

http://www.livingthecountrylife.com/machinery/mowers /choosing-a-propane-lawn-mower-/ 9/26/11 www.livingthecountrylife.com "Choosing a propane lawn mower" By Betsy Freese from the Living the Country Life Radio Program interviewing *Mark Leitman, director of agriculture programs,* (6) Just like the auto industry, makers of powered outdoor equipment are looking at alternative energy to comply with tougher environmental rules. The US Environmental Protection Agency says that a typical four-horsepower gasoline lawn mower engine generates as much pollution in one hour of use as driving your car for four hours Push mowers run on propane will cost about $4,000, and riding mowers start around $7,000. You can also buy conversion kits to retrofit your gas mower over to propane. Some will even run on the small propane cylinders used for camping lanterns and small utility torches.	Uses fossil fuel Cost prohibitive at $4000 Good power Many options for exact application Very good range Difficult to find a locally Quieter than gasoline





http://www.amazon.com/Biogas-Handbook-David-House/dp/0915238470
9/26/11 www.amazon.com Book for sale on the subject of using biogas in small engines (8)

The first book in our Hydrogen Generator Gases for Vehicles and Engines series contains two great, complimentary works on the subject of Producer Gas. The first volume in this book is entitled Producer Gas: Another Fuel for Motor Transport. This volume will guide you through everything you need to know about Producer Gas from its history to its economics. The second volume, Producer Gas Vehicles is for anyone who wishes to have a complete understanding of the true potential of Producer Gas
Product Description

The first edition of the book quickly established itself as the book on biogas generation. Now in a newly revised edition, David House brings together all the information, from the most theoretical scientific research to grass roots home scale trial and error.
Here are the detailed designs for generators and the knowledge, encouragement, imagination, and humor you will need to build a generator of your own. While biogas may not yet be a household word, you should consider it seriously if you believe in the future of alternative energy.
Use biogas for illumination, cooking, water heating, refrigeration, space heating, and to fuel vehicles.
*Over 100 figures and tables *All the necessary formulas *6 model generators and a design flow chart *Complete list of resources *Extensive bibliography

Good price $20-$30 for a book
Requires skill to build
Requires time top build
Parts must be purchased
Inexpensive to build most plans
Plans give general ideas only
Converting theoretical in to practical may be an issue

APPENDIX B – SURVEY RESULTS

Biogas Powered Lawnmower
CUSTOMER SURVEY

The purpose of this survey is to help determine your thoughts on using an alternate fuel source for your lawnmower or other small engine application. The results will help determine what product features are most significant and explore a viable business plan.

How important is each feature when considering a new lawnmower?
Please circle the appropriate answer. 1 = low importance 5 = high importance

Cost to Operate	1	2(2)	3(5)	4(10)	5(3)	N/A
Environmental Impact	1	2(6)	3(6)	4(3)	5(4)	N/A
Safety	1	2	3(7)	4(8)	5(5)	N/A
Cutting Power	1	2	3(1)	4(8)	5(9)	N/A(1)
Ease of Operation	1	2	3(2)	4(15)	5(3)	N/A
Ease of Storage	1(1)	2(5)	3(7)	4(4)	5(3)	N/A
Initial Product Cost	1	2	3(6)	4(6)	5(7)	N/A(1)
Time of Operation	1	2(3)	3(7)	4(5)	5(4)	N/A(1)
Durability	1	2	3	4(8)	5(12)	N/A
Energy Efficiency	1	2(4)	3(4)	4(6)	5(6)	N/A

How satisfied are you with the current lawnmower?
Please circle the appropriate answer. 1 = very UNsatisfied 5 = very satisfied

Cost to Operate	1	2(3)	3(6)	4(3)	5(6)	N/A
Environmental Impact	1	2(2)	3(10)	4(3)	5(3)	N/A
Safety	1	2	3(4)	4(11)	5(5)	N/A
Cutting power	1	2(4)	3(4)	4(6)	5(6)	N/A
Ease of Operation	1	2	3(5)	4(7)	5(8)	N/A
Ease of Storage	1(1)	2(3)	3(4)	4(8)	5(3)	N/A
Initial Product Cost	1	2(1)	3(9)	4(7)	5(1)	N/A(2)
Time of Operation	1	2(3)	3(4)	4(10)	5(2)	N/A(1)
Durability	1(1)	2(1)	3(6)	4(9)	5(3)	N/A
Energy Efficiency	1	2(3)	3(12)	4(3)	5(1)	N/A

How much would you likely spend on a lawnmower?

$100-200(3) $200-500(9) $500-$1000(6) $1000-$2000(2)

Thank you for your time.

Table 8 Survey Results

	Survey #																				
Customer Importance	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**AVERAGE**
Cost to Operate	4	5	4	4	5	4	4	2	3	4	4	3	4	5	3	3	2	3	4	4	3.70
Environmental Impact	3	4	4	3	3	5	3	3	2	3	1	2	5	5	2	2	2	2	5	4	3.15
Safety	4	5	5	3	5	5	4	4	5	3	3	3	4	4	4	3	3	4	3	4	3.90
Cutting Power	4	4	4	5	5	5	3	5	5	5	5	4		4	5	4	4	5	4	5	4.47
Ease of Operation	3	4	4	4	4	4	4	4	5	4	4	4	4	5	4	4	4	5	4	3	4.05
Ease of Storage	3	3	3	5	4	2	2	3	1	5	2	3	4	5	2	4	3	3	4	2	3.15
Initial Product Cost	4	5	3	4	3	5	3	4	5	4	5	5		5	3	4	5	4	3	3	4.05
Time of Operation	4	3	4	4	5	3	3	3	3	4	2	4	5	5	3		3	5	2	2	3.53
Durability	4	5	4	5	5	5	4	5	5	5	5	4	4	5	4	4	4	5	5	5	4.60
Energy Efficiency	5	3	5	4	5	3	3	4	5	4	2	2	5	5	2	3	2	4	4	4	3.70
Customer Satisfaction																					
Cost to Operate	3	5	2	5	2	5	3	3	3	5	5	3	4	2	5	4	3	5	4	4	3.75
Environmental Impact	3	2	2	3	3	4	3	2	3	3	5	3	5	3	4	4	3	5	5	3	3.40
Safety	4	4	5	3	4	5	4	4	5	3	4	4	4	4	3	4	3	5	5	4	4.05
Cutting Power	5	4	5	2	3	5	4	5	5	2	3	4	4	4	5	4	3	3	2	2	3.70
Ease of Operation	5	3	5	4	5	5	3	5	5	4	4	5	4	4	4	4	3	5	3	3	4.15
Ease of Storage	4	2	3	4	2	3	2	3	4	4	4	4	5	4	5	4	3	5	1	4	3.50
Initial Product Cost	3	3	3	4	5	3	4	3	3	4	4	4		3	2	4	3	4	3		3.44
Time of Operation	4	4	4	2	5	3	3	4	5	2	4	3	4	4	4		3	4	2	4	3.58
Durability	5	4	4	3	4	5	3	4	5	3	4	3	4	3	4	3	1	4	2	4	3.60
Energy Efficiency	3	3	2	3	3	3	2	2	3	3	4	3	5	3	5	4	3	4	3	3	3.20
Total	77	75	75	74	80	82	64	72	80	74	74	70	74	82	73	66	60	84	68	67	
Cost in Dollars	500	500	2000	1000	200	500	500	500	2000	1000	500	1000	1000	200	1000	500	500	1000	200	500	755.00

APPENDIX C – QUALITY FUNCTION DEPLOYMENT

Table 9 Quality Function Deployment

Sam Rudolf Biogas Powered Lawnmower 9 = Strong 3 = Moderate 1 = Weak	Energy efficiency	Uses waste for fuel	Single fault protection	boost mode	simplified controls	ergonomic controls	designed for outdoor use	Product cost of kit	Attaching to existing mower	Time to load gasifier minimized	service life	vibration resistance	one person operation	Remote operation	Maneuverability	Customer importance	Designer's Multiplier	Current Satisfaction	Planned Satisfaction	Improvement ratio	Modified Importance	Relative weight	Relative weight %
Cost to Operate	9	9		1				3	1		1					3.7	1.3	3.8	4	1.1	5.1	0.10	10%
Environmental Impact	9	9		1			1		1		1				1	3.2	1.3	3.4	5	1.5	6.0	0.11	11%
Safety			9		3	3	1		1	1		1	1		3	3.9	1.0	4.1	4	1.0	3.9	0.07	7%
Cutting Power	1			9											2	4.5	1.0	3.7	4.5	1.2	5.4	0.10	10%
Ease of Operation		1			9	9	3		1	9			9	9	9	4.1	1.2	4.2	4.5	1.1	5.3	0.10	10%
Ease of Storage							9		3				3	1		3.2	1.0	3.5	4	1.1	3.6	0.07	7%
Initial Product Cost		1			9	1		9	9	1						4.1	1.2	3.4	4	1.2	5.6	0.11	11%
Time of Operation					3	3			1	9			9	1	1	3.5	1.1	3.6	4	1.1	4.3	0.08	8%
Durability			3				9				9	1			1	4.6	1.1	3.6	4.5	1.3	6.3	0.12	12%
Energy Efficiency	9	9		3	1	1				1			1	1	3	3.7	1.3	3.2	5	1.6	7.5	0.14	14%
Abs. importance	3.26	3.37	1.01	1.56	2.45	1.60	2.16	1.25	1.62	1.95	1.28	0.19	2.04	1.18	2.05	27.0					53.1	1.00	100
Rel. importance	0.12	0.12	0.04	0.06	0.09	0.06	0.08	0.05	0.06	0.07	0.05	0.01	0.08	0.04	0.08	1.0							

APPENDIX D – PROJECT SCHEDULE

Table 10 Project Schedule Part 1 Mower kit

Bio-Fuel lawn mower Kit **Tasks**	Week of	24-Oct-11	31-Oct-11	7-Nov-11	14-Nov-11	21-Nov-11	28-Nov-11	5-Dec-11	12-Dec-11	19-Dec-11	26-Dec-11	2-Jan-12	9-Jan-12	16-Jan-12	23-Jan-12	30-Jan-12	6-Feb-12	13-Feb-12	20-Feb-12	27-Feb-12	5-Mar-12	12-Mar-12	19-Mar-12	26-Mar-12	2-Apr-12	9-Apr-12	16-Apr-12	23-Apr-12	30-Apr-12	7-May-12	14-May-12	21-May-12	28-May-12	4-Jun-12
Proof of design to advisor						23																												
Concept development						23																												
Concept sketches to advisor						23																												
Best concept selection							27																											
Preliminary assembly design (1-5)																																		
(1) Mounting bracket, platform													15																					
(2) bladder, fuel storage												8																						
(3) air intake mounting														22																				
(4) hose / hose schematic															29																			
(5) safety protection																5																		
(6) User interface controls																5																		
Assembly BOM																	12																	
Assembly Instruction																		19																
Design Report																		19																
Oral Report																			26															
Order Components																				4														
Winter Report																				4														
Manufacture components																								1										
Assemble kit																										8								
Developmental Testing																											22							
Modification to the design																												29						
Demo to Advisor																													6					
Demo to Faculty																														13				
Oral Report																																20		
Finial Report																																		27

Table 11 Project Schedule Part2 Digester kit

Bio-Fuel lawn mower digester **Tasks**	Week of	24-Oct-11	31-Oct-11	7-Nov-11	14-Nov-11	21-Nov-11	28-Nov-11	5-Dec-11	12-Dec-11	19-Dec-11	26-Dec-11	2-Jan-12	9-Jan-12	16-Jan-12	23-Jan-12	30-Jan-12	6-Feb-12	13-Feb-12	20-Feb-12	27-Feb-12	5-Mar-12	12-Mar-12	19-Mar-12	26-Mar-12	2-Apr-12	9-Apr-12	16-Apr-12	23-Apr-12	30-Apr-12	7-May-12	14-May-12	21-May-12	28-May-12	4-Jun-12
Proof of design to advisor						23																												
Concept development						23																												
Concept sketches to advisor						23																												
Best concept selection							27																											
Preliminary assembly design (1-5)																																		
(1) Size system													8																					
(2) Select components														22																				
(3) Purchase components															29																			
(4) Assemble components																5																		
Assembly BOM																	12																	
Assembly Instruction																		19																
Design Report																		19																
Oral Report																			26															
Order Components																				4														
Winter Report																				4														
Manufacture components																								1										
Assemble digester																									8									
Developmental Testing																											22							
Modification to the design																												29						
Demo to Advisor																													6					
Demo to Faculty																														13				
Oral Report																																20		
Finial Report																																		27

APPENDIX E- BUDGET

Table 12 Budget (plan)

Component	Description	Vendor	Unit Cost	Quantity	Expected cost	Actual Cost
digester	Available kits (needs to be sized)	online	100	1	100	
Biogas storage	Inter tube	ebay	20	1	20	
misc for digester	Various screws, nuts, fasteners	McMaster Car	25	1	25	
Labor	to assemble digester, based on shop rate	NA	40	3	120	
Sub total					**265**	
Mounting Shelf	Custom shelf to hold assembly above motor	NA	100	1	100	
Fuel Bladder	Inter tube	ebay	20	1	20	
air intake	Air intake cover (to be modified)	Lawnmower parts	30	1	30	
hose assemble	Hose sold by the foot, exact sizes will be part of design	Home depot	20	1	20	
back fire preventer	Torch flash back arrestor	harbor freight	20	1	20	
Cables	Cable and accessories sold by the foot, exact sizes will be part of design	TSC	10	1	10	
Miscellaneous	Various screws, nuts, fasteners	NA	50	1	50	
Labor	to assemble and manufacture kit	NA	40	15	600	
Sub total					**850**	
Total					**1115**	

Table 13 Budget Actual

What	Cost	Note	Task	Time (hrs)
Barrel	20	Salvage	Paint	2
Plumbing	12.45	Home Depot	Fill	1
Paint	7.9	Rural King	Seal	0.5
Seal	5.15	Rural King		3.5
Hose	19.95	True Value		
Bladder	24.5	Inter tube		
Sub total	**89.95**			
Shelf	125	From model shop	Assemble	0.5
Hardware	8	TSC	Fill bladder	0.25
Hose/plumbing	10	salvage / Home depot	Plumb	0.25
Fuel Valve	5	TSC	mod carb	0.5
Bladders	26	(2) water jugs		1.5
Sub total	**174**			
Mower	206	Wal-Mart	Mod carb	0.5
Hose	2	Home depot	install air cont	0.25
Air control	6	throttle control (rural king)	install kit	0.25
Tank / torch head	10	Old propane tank		1
Fill	2	each fill		
Sub total	**226**			
Total	**489.95**	For prototype an labor		**1989.95**
My Labor (30 hr)	1500			

Production cost (estimates)

Version 1 production	Version 2 production
314	245

APPENDIX F- DRAWINGS

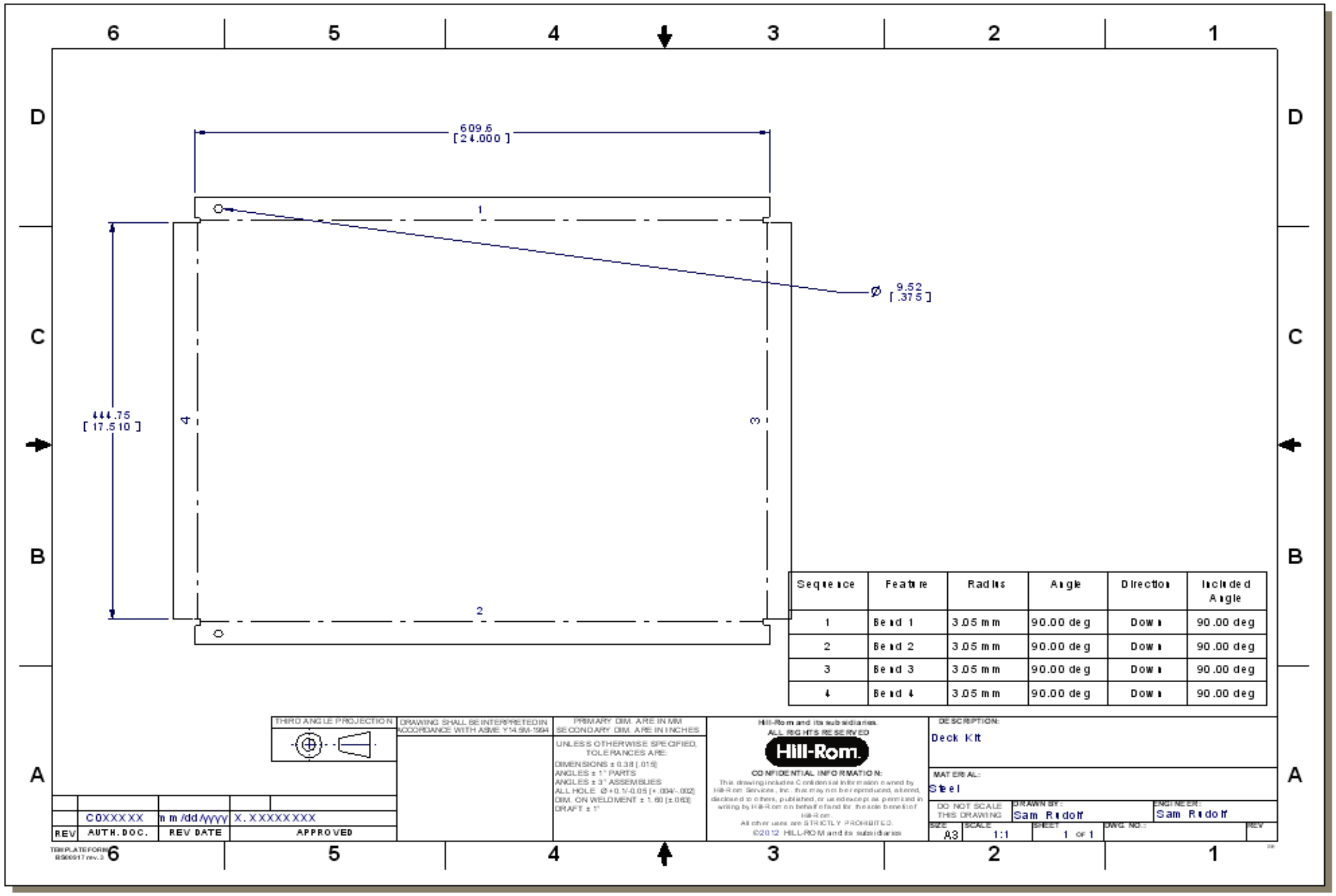


Figure 22 Sheet metal deck

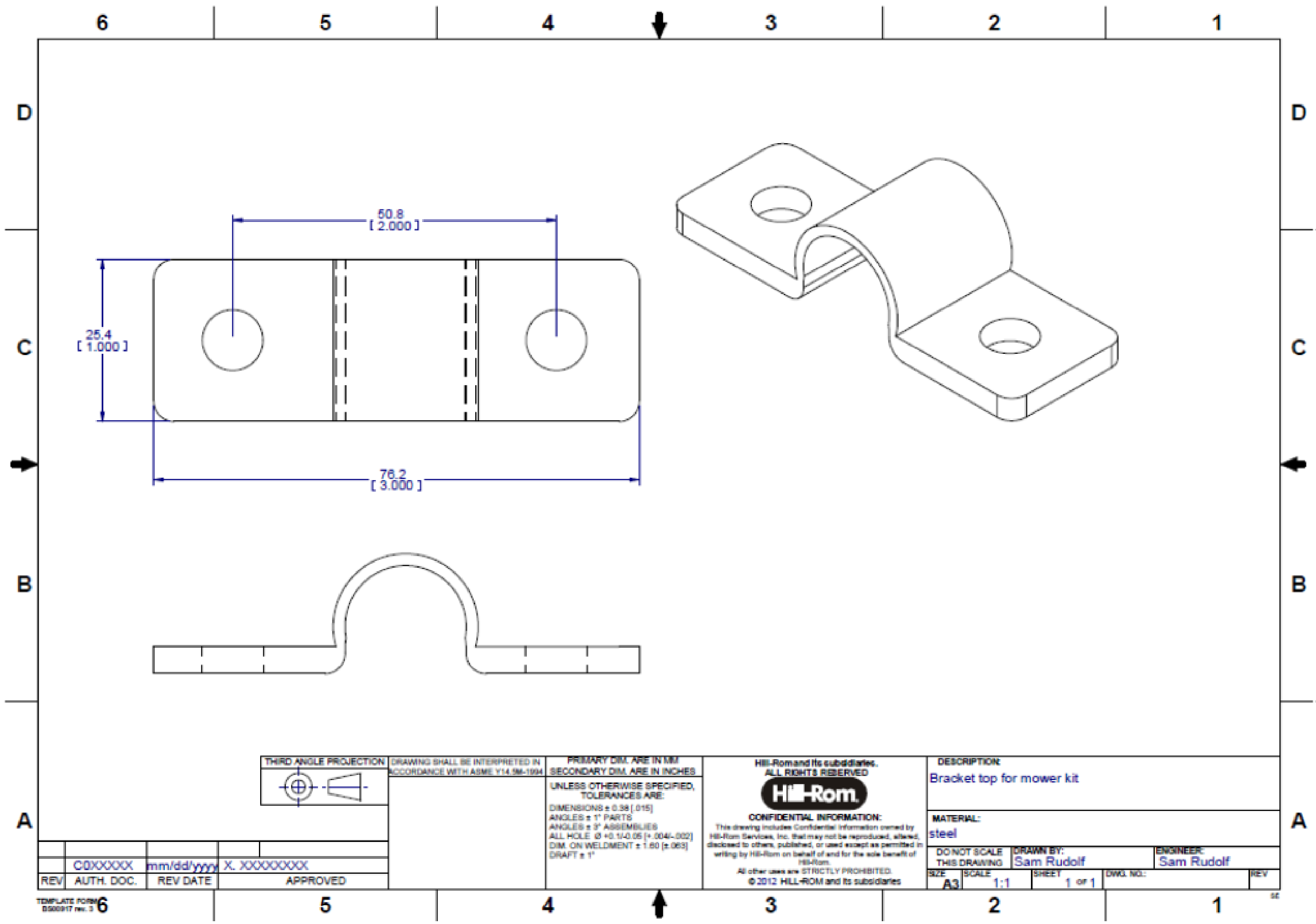


Figure 23 Clamp Bracket

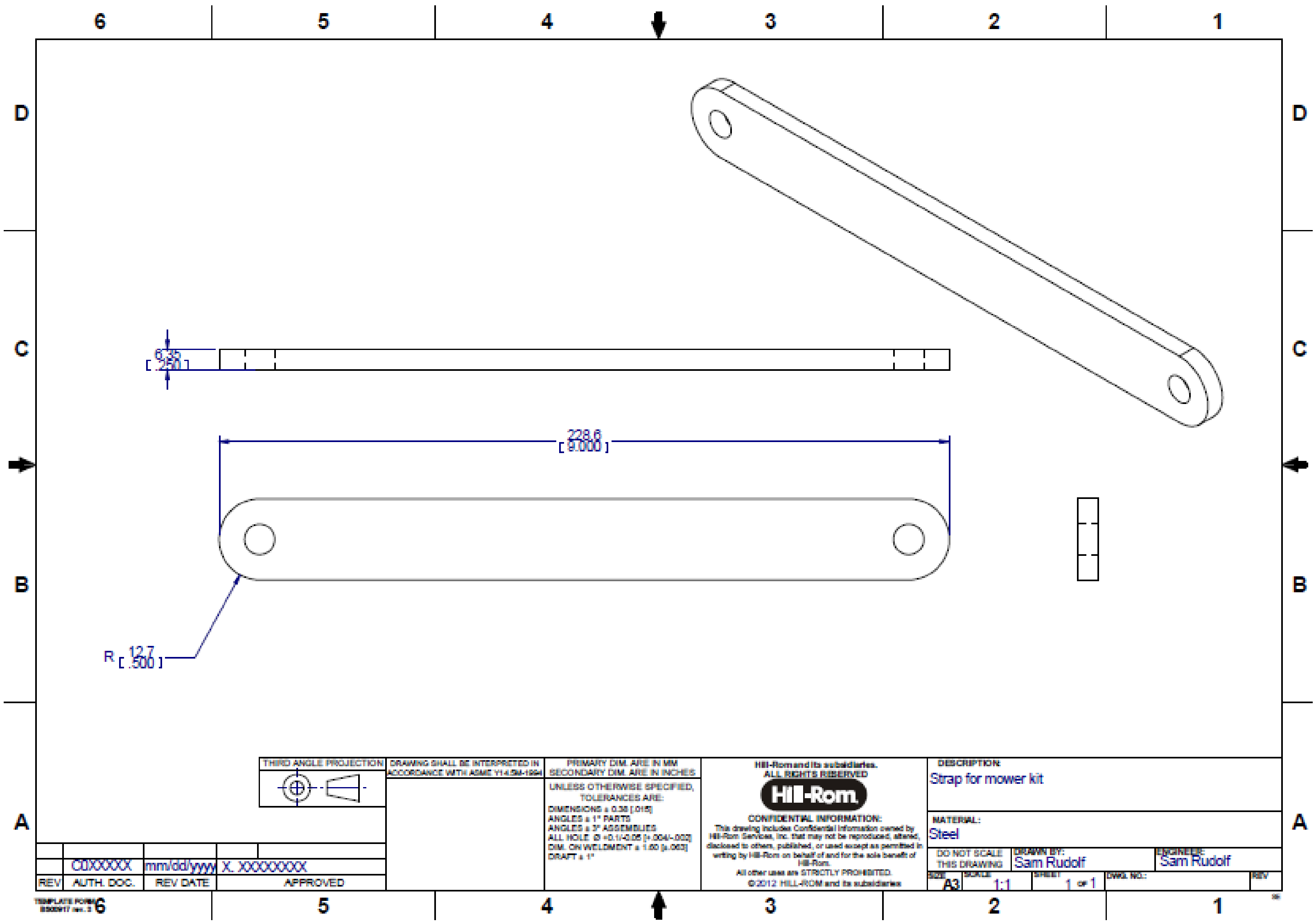


Figure 24 Lawn mower Kit Strap

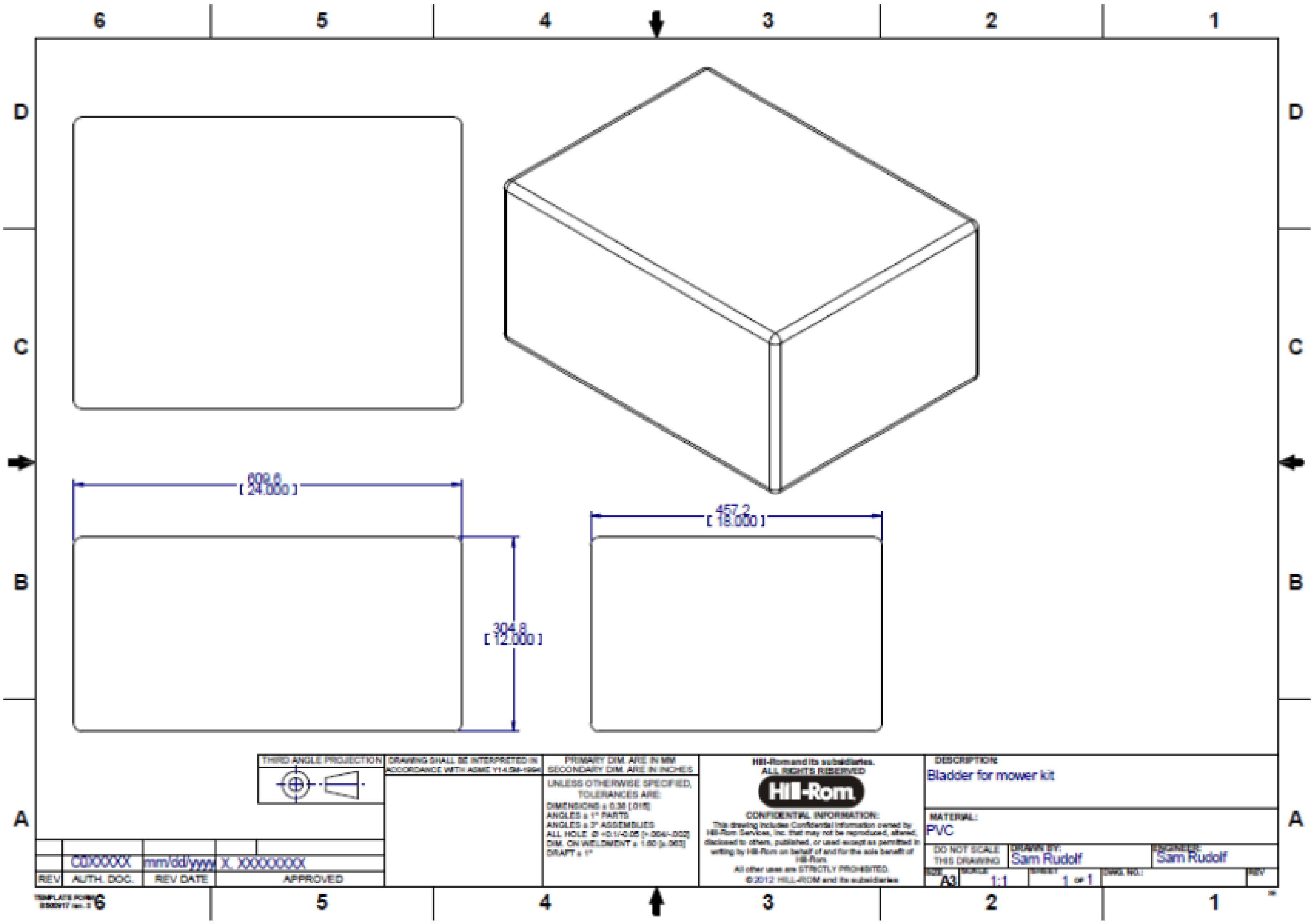


Figure 25 Bladder for Mower Kit

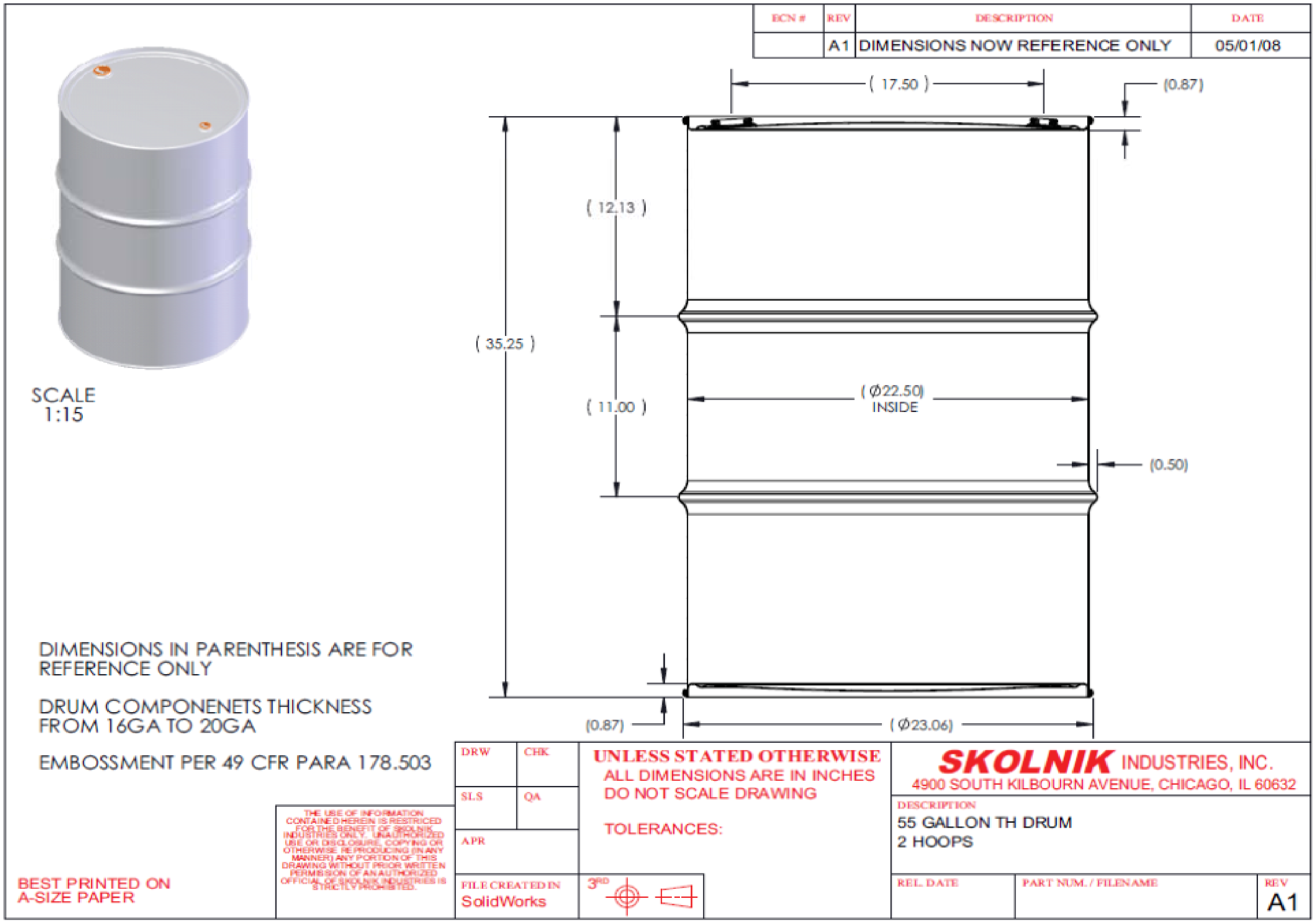


Figure 26 Barrel (purchased)

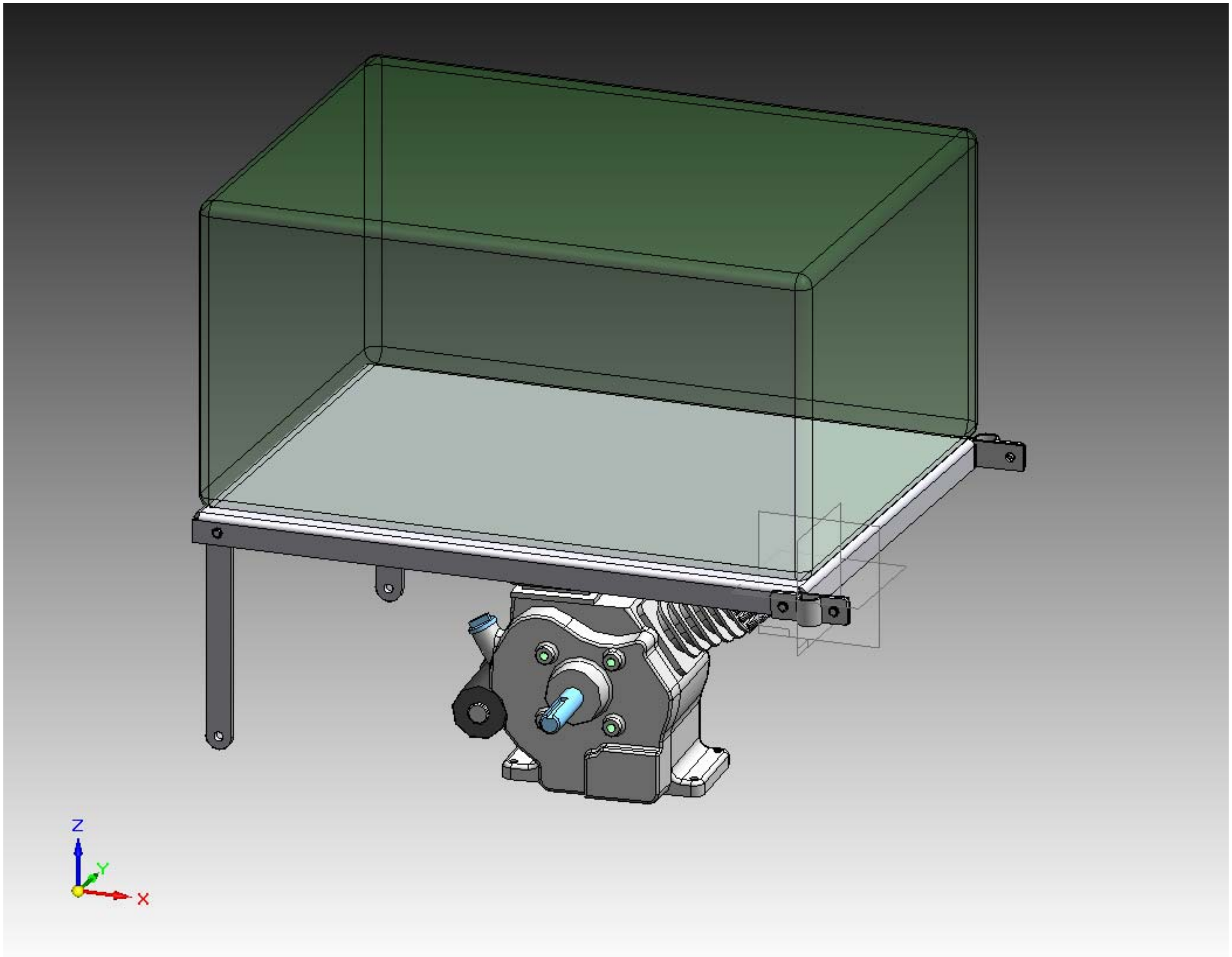


Figure 27 3D Model of Version 1 kit

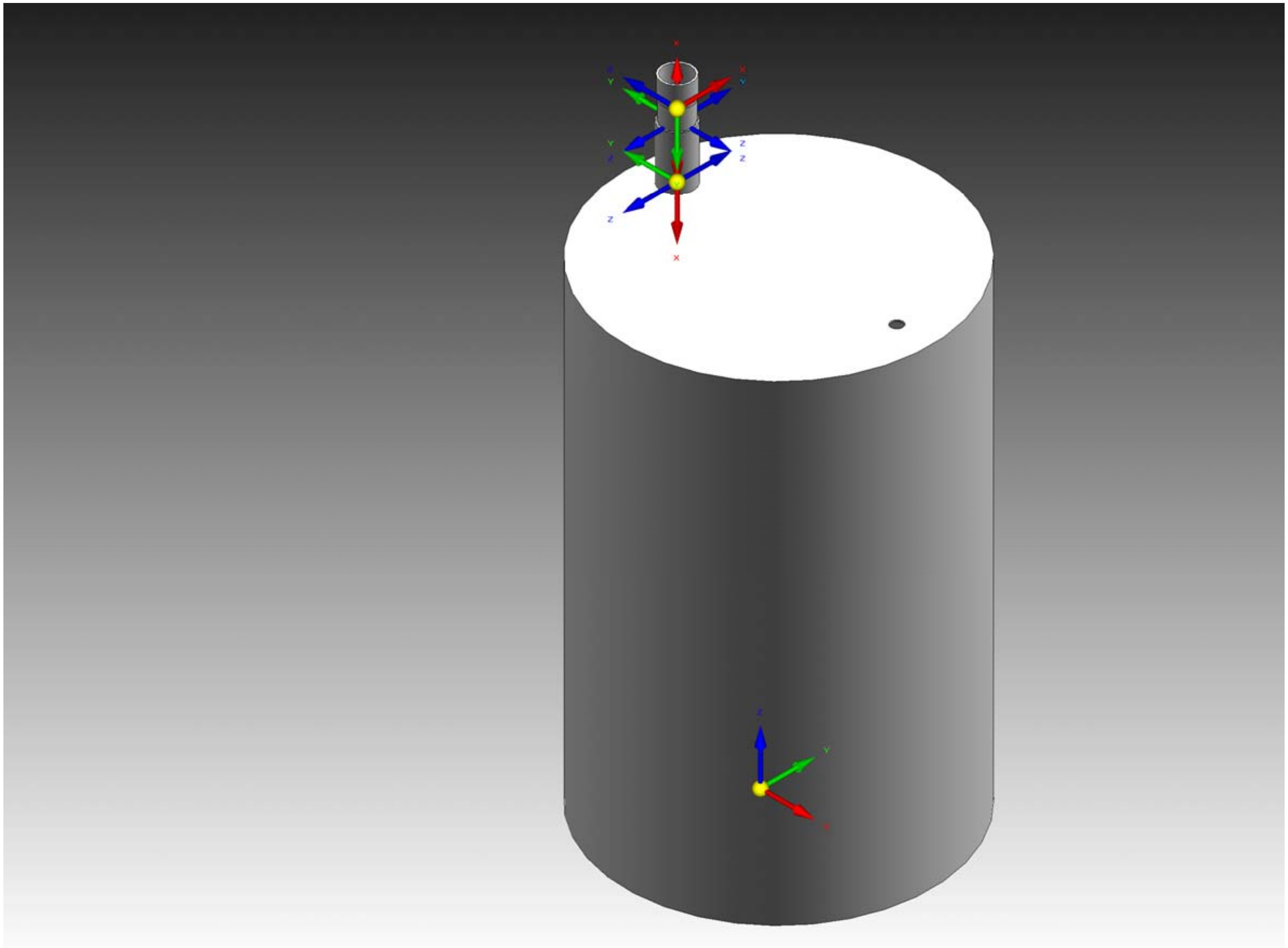


Figure 28 3D model of Digester

APPENDIX G- PROOF OF DESIGN STATEMENT

Bio Gas Powered Lawn Mower

The basic design of the project will have two major components consisting of the bio digester and lawn mower kit. The bio digester will be used to produce the bio gas used in the system. The lawnmower kit is used to convert a standard push mower to use the bio gas.

Lawn mower kit

- Engine will run on 50% biogas
- The installed kit must be able to withstand a drop off of a 4 inch step to simulate impact forces generated from mowing a yard. The assembly will be checked for loose hardware after impact.
- Kit will contain hardware capable of withstanding vibration expected throughout operation. For example lock nuts, torque specifications, and keeper rings.
- Kit will mount to a standard lawn mower (defined once purchased)
- Kit will comply with Consumer Product Safety Council Guideline 5126 for push behind lawn mowers.
- The system will require only one operator
- Kit will not impede maneuverability around object by keeping with in the wheel base of the mower.
- Kit will install with common hand tools.

Bio digester

- Lawn waste (such as leaves, grass clippings, etc.) is used as a raw material for the digester
- Other than the initial kit and lawn waste the digester will not require any other inputs.
- Digester will use components rated for outdoor use.
- Plastic components will have UV resistance
- Metal components will have a weather resistant coating
- Foot print of Digester will be less than 4 X 8 ft.

Sam Rudolf; Student	Janak Dave, PhD; Advisor
Date	Date