



# Developing a Bioenergy Fuel from Manure and Other Agricultural Byproducts

**Final Report**

for

**Colorado  
Department  
of Agriculture**

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## Introduction

This research project explores opportunities to develop biomass fuel briquettes from the extensive agricultural residues and waste materials found in Colorado, particularly manure and crop residues such as wheat straw (straw). Blending and compressing these two materials into a suitable fuel briquette could provide a renewable fuel that can be burned to generate energy or be co-fired with coal in power plants, while converting financially and environmentally burdensome wastes into a potential new source of revenue for agricultural producers. This research project strives to find an answer to the question of viability, both technical and financial, of converting manure and straw into a briquette fuel.

## Project Overview

The purpose of this project is to identify a method to cost-effectively utilize manure and other abundant agricultural wastes to produce useful energy. A fuel made from this resource has the potential to reduce farmers' waste disposal and energy expenses, mitigate negative environmental impacts caused by excessive and inappropriately stored manure, and improve the economic viability of farm operations.

Drawing from iCAST's previous experience and successes with similar projects, this research project designed, produced and tested several samples of a "straw-pooh" fuel briquettes that could be co-fired with coal in utility-scale power plants, burned on site to produce heat and power for agricultural operations, or used in a medium-scale application, such as district heating (to provide heat to one or more large buildings or structures). This project also studied processes and equipment for producing optimized fuel briquettes in or near the area where agricultural wastes are produced so that product transportation costs can be reduced and any byproducts can be recycled into local farm operations. Ideally, such a process would amount to an isolated system with inputs of solar radiation, air, water, and CO<sub>2</sub>, and one output, the fuel briquettes.

In conducting this project, iCAST collaborated with experts, faculty and student engineering teams at Colorado School of Mines (CSM), Colorado State University in Fort Collins (CSU), and University of Colorado – Boulder (CU), as well as farmers and members of the bio-energy industry around the region.

The engineering teams from CSM evaluated several commercial processes for farm-scale production of engineered fuel briquettes, designed and built a bench-scale prototype of the production process, and used the prototype to produce eighteen briquette samples of varying proportions of straw and manure for testing. The briquette samples produced by the CSM

team consisted of manure provided by '4M Feeders', a cattle feedlot south of Stratton, CO, with about 30,000 head of cattle, blended with wheat straw provided by Chuck Clapper, an independent farmer in Stratton. Laboratory analyses of two of the briquette samples are provided in Appendix B. Three consecutive reports written by the CSM teams are provided in Appendix C.

Based on the testing of the prototype briquettes conducted by iCAST at 'SGS Laboratory' and the market analysis for using the product in Colorado, it became clear that too many technical and economic barriers remain for the straw-pooh briquettes to be adopted by today's markets. iCAST expanded the scope of the research to include novel approaches to optimizing the briquette production process and making the straw-pooh briquette product compatible for utilities to co-fire alongside coal in their existing power-plants. This was necessary because iCAST learned, during the course of this research project, that the performance of the straw-pooh briquettes needs to match not only other conventional biomass fuels and conversion processes but more importantly, needs to match the performance of coal for the power plants to accept it as a compatible fuel.

So iCAST changed directions for the research project. The engineering team from CSU evaluated alternative biomass fuels and conversion processes, including torrefaction, bio-char, pyrolysis, thermal gasification and anaerobic digestion. The report from the CSU team is provided in Appendix D. Based on the research by the CSU engineering team, iCAST concluded that the torrefaction process would be a better solution to utilizing animal waste and wheat straw (and other agricultural residues) for producing a marketable fuel briquette for Colorado.

### **Key Findings, Analysis and Recommendations**

Manure and other agricultural wastes have been used as a source of heat and power by many cultures around the world for centuries, and even today, this technology is finding modern applications around the U.S. In Vermont, for example, the Energy Biomass Resource Center has also studied the feasibility of manure-based bio-fuels, while the construction of a biomass briquetting plant using crop residues is underway in Maine. But straw-pooh briquettes are a novel product with no existing market.

Estimates drawn from Colorado agricultural data indicate that about 7 million tons of wheat straw and about 10 million tons of feedlot manure were generated in Colorado in 2009. Technically, it is feasible to convert about half of these waste materials into 2.6 million tons of biomass fuel briquettes annually. The heating value of these briquettes is equivalent to 1.3 million tons of coal and could generate about 320 MW of electric power (see calculations in

Appendix A). To put this into perspective, Xcel Energy's 806 MW Cherokee power plant in northeast Denver consumed 2.4 million tons of coal in 2005.<sup>1</sup>

Through its research, iCAST learned that the production process for making straw-pooh briquettes was similar to the process for making wood pellets using dryers to dry the biomass (manure and straw) and extruders to compress at high temperatures the mixture of straw and manure. But iCAST also learned that this technical feasibility does not translate into a viable product; a biomass fuel briquette made from straw and manure does not have established markets in Colorado. There is no district heating market in Colorado. Less than a handful of projects using biomass (forestry residue) are running in Colorado and even with the abundant 'beetle-kill' fuel there is no new project on the horizon.

The utility power market (coal-fired power plants) represents the most important potential market for engineered fuel briquettes as a renewable fuel to be co-fired in coal-burning power plants. At this time, it appears that biomass briquettes will not gain access to this market locally without stronger support from public policy. Biomass fuels face staunch competition in Colorado, even with relatively abundant biomass resources, amidst mature markets in Colorado's other abundant energy resources of coal, oil, natural gas, solar, wind, and hydropower. Moreover, bio-energy has not benefitted from Colorado's policy-based incentives that have primarily stimulated renewable energy investments in wind and solar.

In the absence of policies to account for externalities such as impacts on public health and the environment, the cost of fuel largely determines wholesale cost of power (along with capital costs and other operating costs), particularly in the case of coal and biomass. Factors that affect fuel costs include:

- Raw material costs
- Cost of conversion to usable fuel
- Delivery costs to the conversion plant and the power plant
- Fuel efficiency (heating value, in energy per unit mass)
- Costs of environmental mitigation

Biomass reduces pollutants emitted in power production. Burning biomass is considered carbon neutral: net carbon emissions are zero, thus helping utilities to reduce their carbon footprints. Since there is no carbon reduction policy and no monetary value to reducing their carbon footprints, utilities currently have no reason to use biomass-based fuels. Perhaps in the future, if US policy will provide a monetary value for carbon reductions, utilities will adopt bio-power.

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<sup>1</sup> EPA, eGRIDweb: Plant: Colorado: Cherokee: Characteristics. <http://cfpub.epa.gov/egridweb/>. Accessed 3/18/11.

As compared to coal, burning biomass can reduce SO<sub>x</sub>, NO<sub>x</sub>, Mercury and other pollutant emissions. A 50% blend of biomass in a coal-fired power plant can reduce its pollution by 40%. Also, manure and agricultural residue left to decompose on-site will release methane (which is 23 times more harmful as a greenhouse gas than CO<sub>2</sub>). But again, without policy drivers and incentives, utilities are unlikely to adopt biomass fuel.

Since coal sets the benchmark, a prerequisite to adoption of straw-pooh briquettes by utility companies lies in developing an optimized biomass briquette that emulates the technical performance of coal more closely than can be achieved with conventional straw-pooh briquettes. The straw-pooh briquettes produced by iCAST had numerous properties that make them a problem for a coal-fired power plant to accept them as a bio-fuel. The straw-pooh briquettes have an energy density that is half that of coal so burning biomass briquettes would result in de-rating of the coal boiler and loss of efficiency, making it more expensive for the coal power plant to accept straw-pooh briquettes as a fuel. Also, the straw-pooh briquettes are not hydrophobic: unlike coal, they will absorb moisture when exposed to the environs and have to be stored in a covered space, further increasing the cost of our briquettes. Finally, the fibrous straw-pooh briquettes do not grind as well as coal so they cannot be mixed into the coal bin and run through a pulverizer alongside coal. The straw-pooh briquettes require special biomass grinders and this increases the cost to a coal-fired power plant even more.

Two other criteria also determine the viability of biomass briquettes as a fuel in the utility marketplace: the wholesale cost of power, and the logistics of long-term accessibility. Since the industrial revolution, coal has set the benchmark for these criteria in the U.S. (with the exception of large hydropower during the three decades following the great depression). Long-term accessibility to adequate supplies of raw materials presents one of the greatest challenges faced by biomass fuel production. From a technical perspective, the abundance of manure and straw in northeastern Colorado is very promising, but retrieval costs pose challenges. These costs, along with the poor technical performance of conventional straw-pooh briquettes and the capital and operating costs of making and using them, present too many barriers at this time.

Through its research iCAST discovered a new process, called torrefaction, which promises to resolve some of these issues, making pellets or briquettes made from manure and straw, and other biomass resources, more viable.

***Torrefaction***

Torrefied biomass can provide a variety of benefits including: health, community, environmental and economic benefits. The superior fuel quality of torrefied biomass makes it very attractive for combustion and gasification applications in general.

- Torrefied biomass can be pulverized, since the torrefaction process breaks down the fibers in the biomass, making the torrefied bio-coal product cheaper for the coal-fired power plant to process than any other biomass.
- Torrefied biomass is hydrophobic, meaning it can be stored in the open for long periods without absorbing water, similar to coal and can be blended and processed with coal from the gate.
- Torrefied biomass can contain the same energy density as coal so that there is no de-rating or loss of boiler efficiency in burning torrefied biomass fuel for a coal-fired power plant.

The higher energy density makes transportation costs more affordable. Torrefaction also eliminates the need for expensive storage and handling at the power station. All of these advantages could make biopower a viable option to augment coal power, giving utility companies a new alternative to meet Colorado's renewable energy portfolio standard, while providing economic, environmental and social benefits to Colorado communities in the form of new jobs and businesses, converting biomass waste streams into a value-added commodity, and reducing pollution from burning coal.

With additional research, iCAST hopes to show that a small-scale, mobile torrefaction unit can produce a fully optimized biomass fuel that meets the criteria of the utility power market.

**Problems Encountered/Mitigating Circumstances**

While engineered fuel briquettes made from biomass promise to make bio-energy more viable, they face several limitations that make them unappealing to utility companies as an alternative to coal. Biomass fuel briquettes made from manure and straw face several technical and economic barriers, including:

- The briquetting process does not sufficiently diminish the odor of the manure
- Briquettes disintegrate easily when they become moist or wet; unlike coal, they are not hydrophobic and require special storage
- Lower heating value (compared to coal) means utility generating stations have to be de-rated proportional to the ratio of biomass used and since boilers have been optimized for a certain fuel density and capacity, the lower energy density of the bio-fuel actually causes loss of efficiency of the boilers and higher costs for the power plant

- Fibrous material and poor grindability of straw-pooh briquettes require special processing rather than adding them to the coal in pulverized coal plants, thus adding to the process changes and costs
- High ash content increases plant maintenance costs and down-time, and may cause slagging and coking problems
- High sulfur and other chemical constituents increase the costs of air pollution abatement and compliance
- Storage and handling requirements arising from structural integrity problems and potential decomposition add to higher processing costs

The torrefaction process offers to resolve these limitations by producing bio-coal, a more practical, high-performance product that may be readily adopted by utility companies.

### **Next Steps**

The results of this project will be used as the basis of continued research to develop a design for a small-scale, mobile torrefied biomass production unit that can produce bio-coal at or near the source of feedstocks. In addition to agricultural wastes such as manure and straw, the feedstock conversion process will be expanded to include forestry residues such as beetle kill, slash, and lumber mill residue; energy crops such as switch grass and miscanthus; and invasive species such as tamarisk and Russian olive.

iCAST will begin with a review of the state-of-the-art in torrefaction technology. iCAST will also identify and contact project stakeholders, including supply side and demand side customers, to evaluate customer needs, market requirements and opportunities. Stakeholders and customers include natural resource management agencies, forestry and agricultural producers on the supply side, and electric utility representatives on the demand side. Through its contacts, iCAST will strive to develop collaborative relationships with stakeholders and other torrefaction researchers. These relationships will be used to refine and guide development of the torrefaction system.

The information gained from the technology review and stakeholder participation will be combined with the current design parameters to develop an appropriate, low-cost torrefaction process to make bio-coal from a variety of waste biomass resources. Based on our research to-date and the lessons learned from this current research, the design parameters for the torrefied biomass process and product include:

- A small-scale, skid-mounted system that can be deployed in the field close to raw biomass materials.

- A versatile process capable of processing multiple biomass materials, including forestry residues, agricultural residues and waste materials, invasive species and energy crops.
- A self-powered system that can operate in the field under its own power.
- A production scale appropriate to the typical availability of local biomass feedstocks.

iCAST will work with university and industry partners to develop a process design for the torrefaction system based on the feedback received from the stakeholders who are potential end-users and beneficiaries from this project. This will help to ensure that the design is appropriate, functional, affordable, and efficient.

### **Notable Successes and Accomplishments**

This research project designed, produced and tested several samples of “straw-pooh” fuel briquettes. This section summarizes the successes and accomplishments of this research project as they relate to the straw-pooh briquette production process, identifying the fuel characteristics, and the economics and logistics of bio-fuel supply into Colorado markets.

Through its research, iCAST learned that the production process for making straw-pooh briquettes was similar to the process for making any other sort of biomass briquettes or pellets such as wood pellets. The key processes for making straw-pooh briquettes requires a drum dryer to dry the manure and straw, both of which have moisture content (MC) over the desired amount. Manure in its wet form has over 70% moisture while straw can have over 40% moisture. The straw-pooh briquettes require under 10% MC. The other key process to making straw-pooh briquettes is the extrusion process that compresses the materials at high pressure and temperatures into a condensed form.

iCAST successfully tested the prototype briquettes at ‘SGS Laboratory’ to determine the properties and characteristics of the straw-pooh briquettes. Next it compared the results to pellets and other data on torrefied biomass. The results of these analyses are provided below.

**Fuel Characteristics and Testing**

		Units	Wood	Wood Pellets		Straw-pooh Briq Sample 1	Straw-pooh Briq Sample 2
				low	high		
Manure:Straw		--	--	--	--	55:45	45:55
Moisture Content		%	35	10	7	8.2	7.5
Heating Value	as received	Btu/lb	4,514	6,706	6,964	6,805	6,731
	dry	Btu/lb	7,609	7,609	7,609	7,416	7,279
Energy Density (as received)		Btu/ft <sup>3</sup>	155,000	209,000	283,000	212,000	210,000
Bulk Density		lb/ft <sup>3</sup>	34	31	41	31	31
Pellet strength			--	good		good	
Dust formation			moderate	limited		moderate	
Hygroscopy			water uptake	swelling / water uptake		swelling / water uptake	
Bio-degradation			possible	possible		possible	
Seasonal influences			high	moderate		moderate	
Handling properties			normal	good		good	

		Units	Torrefied Wood	TOP Pellets		Bit. Coal (PRB)
				low	high	
Moisture Content		%	3	5	1	8
Heating Value	as received	Btu/lb	8,555	8,555	9,286	11,723
	dry	Btu/lb	8,770	8,770	9,759	12,170
Energy Density (as received)		Btu/ft <sup>3</sup>	123,000	401,000	493,000	610,000
Bulk Density		lb/ft <sup>3</sup>	14	47	53	52
Pellet strength			--	very good		--
Dust formation			high	limited		limited
Hygroscopy			hydrophobic	low swelling / hydrophobic		hydrophobic
Bio-degradation			none	none		none
Seasonal influences			low	low		low
Handling properties			normal	good		excellent

The key findings and recommendation to change the focus of research to the torrefaction process is based on the analysis conducted as part of this research project. That is the key accomplishment of this project. It helped iCAST understand the limitations of the straw-pooh briquettes it had been researching and realize that bio-fuel briquettes made from manure and straw face several technical and economic barriers, including:

- There is no established market for straw-pooh briquettes currently in Colorado. The residential market does not exist, the small scale commercial market for heating is very small (less than a handful of systems are in existence currently and they have their own forestry waste fuel source), the small scale electricity production market does not exist and the large scale utility market is tied to existing coal-fired power plants.

- The briquetting process does not sufficiently diminish the odor of the manure and can cause ‘NIMBY’ issues when used in large amounts
- Briquettes disintegrate easily when they become moist or wet i.e. they are not hydrophobic and require special storage unlike coal that adds to the cost of the fuel.
- Lower heating value (compared to coal) means utility generating stations have to be de-rated proportional to the ratio of biomass used and since boilers have been optimized for a certain fuel density and capacity, the lower energy density of the bio-fuel actually causes loss of efficiency of the boilers and higher costs for the power plant
- Fibrous matter and poor grindability of straw-pooh briquettes require special processing rather than adding them to the coal in pulverized coal plants, thus adding to the process changes and costs

**Final Accounting of Expenses**

iCAST ACRE Research Grant Straw-Pooh Briquettes	
<b>Grant Amount</b>	
iCAST Personnel	40,780
Consultants	6,783
Project Materials	2,073
Printing	87
Travel	277
<b>Total CDA Grant</b>	<b>50,000</b>
<b>Cash Match/Inkind</b>	
Student teams & volunteers	41,497
iCAST cash match	3,114
<b>TOTAL MATCH</b>	<b>44,611</b>

## Appendix A

**Estimates of wheat straw and feedlot manure production in Colorado; technically feasible capacity of straw-pooh briquette production; potential electric power generating capacity and equivalent amount of displaced coal.**

## Estimates of wheat straw and feedlot manure production in Colorado

<b>Winter wheat, Colorado, 2009 statistics</b>		
Total production	98,000,000 Bu	
	2,940,000 tons	
Dry weight	72 %	
Residue Factor	2.50	
Availability Factor	0.40	
Moisture content (as received)	28 %	
<b>Collectible straw (as received)</b>	<b>2,940,000 tons</b>	
<b>Feedlot manure, Colorado, 2009 statistics</b>		
Cattle on feed	1,020,000 head	
Manure production rate	53 lb/head/day	
Total feedlot manure production	9,865,950 tons	
Dry weight	12 %	
Residue Factor	1.00	
Availability Factor	0.65	
Moisture content (as received)	30 %	
<b>Collectible manure (as received)</b>	<b>2,693,404 tons</b>	

## Technically feasible capacity of straw-pooh briquette production

Total collectible straw (at 8% m.c.)	2,352,000 tons	
Total collectible manure (at 8% m.c.)	1,282,574 tons	
<b>Total straw-pooh briquette production (50/50 blend at 8% m.c.)</b>	<b>2,565,147 tons</b>	

## Potential electric power generating capacity

<b>Straw-pooh briquettes (50/50 blend at 8% m.c.)</b>		
Annual consumption	2,565,147	tons/yr
Heating value (as received)	6,768	Btu/lb
Energy content	34,721,830	mmBtu/yr
Conversion rate	12,500	Btu/kWh
Electric generation	2,777,746,383	kWh/yr
Operating hours	8,760	hours
Capacity	317	MW
Capacity factor	75	%
<b>Nameplate capacity</b>	<b>396</b>	<b>MW</b>

## Equivalent coal displacement

<b>Bituminous coal (Powder River Basin, 8% m.c.)</b>		
Conversion rate	11,218	Btu/kWh
Heat input	31,160,849	mmBtu/yr
Heating value (as received)	11,723	Btu/lb
<b>Displaced coal consumption</b>	<b>1,329,048</b>	<b>tons/yr</b>

## **Appendix B**

### **Part 1: Laboratory analyses of straw-pooh briquette samples**

### **Part 2: Brochure on briquetting features and advantages from BriquettingSystems.com**



Analysis Report

September 24, 2010

Page 1 of 1

Clean Coal Briquette, Inc.  
8745 W. 14th Ave.  
Suite 240  
Lakewood, CO 80215  
USA

Client Sample ID: Straw 45/55  
Date Received: 09/10/2010  
Matrix: Unknown

Kind of Sample : Straw/pooh  
Sample Type : -2"

SGS Minerals Sample ID: 072-48051-001

		<u>As Received</u>	<u>Dry</u>
% Moisture, Total	[ASTM D 3302]	8.23	
Gross Calorific Value (Btu/lb)	[ASTM D 5865]	6805	7416
% Sulfur	[ASTM D 4239]	0.23	0.25
% Carbon	[ASTM D 5373]	40.58	44.22
% Nitrogen	[ASTM D 5373]	1.07	1.17
<u>Tests</u>		<u>Result</u> <u>Unit</u>	<u>Method</u>
Pounds of Sulfur/mm Btu		0.34 lb	
Pounds of SO2/mm Btu		0.67 lb	
Chlorine, Dry		0.40 %	ASTM D 6721
Mercury, Dry		<0.02 ug/g	ASTM D 6722
AA Basis		Ignited	ASTM D 4326
Silicon		27.87	ASTM D 4326

SGS North America Inc. Minerals Services Division  
4665 Paris St Suite B-200 Denver CO 80239

Somer Rodriguez, Denver Laboratory

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Analysis Report

September 24, 2010

Page 1 of 1

Clean Coal Briquette, Inc.  
8745 W. 14th Ave.  
Suite 240  
Lakewood, CO 80215  
USA

Client Sample ID: Straw 55/45  
Date Received: 09/10/2010  
Matrix: Unknown

Kind of Sample : Straw/pooh  
Sample Type : -2"

SGS Minerals Sample ID: 072-48051-002

		<u>As Received</u>	<u>Dry</u>
% Moisture, Total	[ASTM D 3302]	7.54	
Gross Calorific Value (Btu/lb)	[ASTM D 5865]	6731	7279
% Sulfur	[ASTM D 4239]	0.24	0.26
% Carbon	[ASTM D 5373]	39.27	42.47
% Nitrogen	[ASTM D 5373]	1.48	1.60
<u>Tests</u>		<u>Result</u> <u>Unit</u>	<u>Method</u>
Pounds of Sulfur/mm Btu		0.36 lb	
Pounds of SO2/mm Btu		0.72 lb	
Chlorine, Dry		0.40 %	ASTM D 6721
Mercury, Dry		<0.02 ug/g	ASTM D 6722
AA Basis		Ignited	ASTM D 4326
Silicon		26.01	ASTM D 4326

Somer Rodriguez, Denver Laboratory

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# BRIQUETTING

## FEATURES AND ADVANTAGES

- **Capital and Operational costs are less than pelleting**
- **Produce fuels for several applications** including power generation, district heating, CHP, institutional, greenhouse heating etc as well as consumer heat products
- **Modular design** allows for outputs from a thousand pounds per hour to tens of thousands of tons per year plants similar to pelleting operations.
- **More flexible** plant sizes which can be localized closer to feedstocks and markets
- **Faster startup , less complex and more tolerable to feedstocks** than pelleting.
- **Horsepower per ton consumption and wearable costs less than pelleting.**
- **Available in 3 formats**-in house, containerized and large silo format where feedstock on upper level is sweep augered to presses on main floor. See pictures of the three below.
- **Utilize similar pellet plant feedstocks** thus complimenting a pellet operation as well as diversifying it at the same time.
- **Process a wide array of feedstocks**, some that are not pelletable
- **Modern PLC touch screen controls** with remote interface and modems with CSA / UL electrics for 460 and 600 volt 3 phase operation.
- **Simple heavy duty constant output** mechanical design for 24/7 operation
- **Does not have the complexities** of hydraulic cycling briquetters
- **Available in several model sizes** and capacities exceeding hydraulic models.
- **CF Nielsen briquetters are made in Denmark for the past 60 years. CFN is the leading supplier of briquetters to Europe and now have them on six continents.**



**INHOUSE**

**CONTAINERIZED**

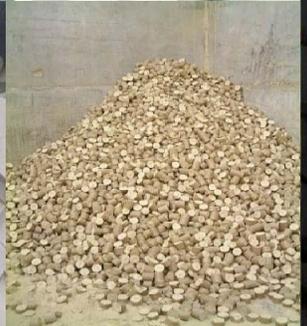
**LARGE SILO FORMAT**

## FEEDSTOCKS

**Briquetters can process wood, agriculture, paper and a mixture of feedstocks.**

**Moisture content** can range up to 15% and particulate size can be larger than pellet mill feedstock-up to 15mm size thus requiring less pre-grinding energy. Using larger particulate size can reduce the fines generated.

In the case of **co-firing** the necessary fines feedstock typically 2 mm minus size can be briquetted. For example we have the machines in dust situations compacting plywood sander and MDF dust in mills as well as paper dust in tissue mills and printing plants.



**WOOD**

**AGRICULTURE**

**PAPER DUST**

**SANDER DUST**

## APPLICATIONS AND MARKETS

**The presses** with applicable options can produce fuel pucks which are 12 mm long x 60—90 mm diameter (most common 75mm diameter), as well as random length fuel briquets in these diameters and consumer firelogs the latter in square and round cross section shapes.

Other **consumer applications** are for firing barbecues, pizza ovens and meat and fish smokers to name a few. A puck **"quartering system"** will be implemented. This will bridge the size between pellets and pucks and open up even more markets.

**Torrefied fibers** have been briquetted. **Torrefied fuel pucks can be stored outside, have higher heat values and can be pulverized with the same ball mills used for coal.** Most torrefaction processes are in the pilot plant mode. Therefore CF Nielsen is working with the Danish institute of standards to establish processes related to torrefaction and briquetting.



**FUEL PUCKS**

**TORREFIED**

**FIRELOGS**

## WHY FUEL PUCKS ??

Fuel pucks can be the solution to the “**pellet myth**” which some subscribe to as the only game in town.

**Fuel pucks** are used for coal co-firing and 100% biomass firing of power stations in Europe and have been for many years. In regard to co-fire applications, providing they are made from fines, pucks can be ground up and sprayed into the burners with the coal fines.

Many European power plants can operate on chips, pellets and briquets. They do this in order to even out their fuel costs as fuel pucks can sell for less than pellets. The main reason for this is pucks cost less to produce than pellets. **Heat values** per ton are the same as pellets providing moisture contents are similar.

**Pucks are now exported** from North America for the same applications as pellets. Any fossil fired heat or power plant in North America planning to use biomass will be wise to allow for a multitude of bio-feed types thus not tying themselves to one format and one price structure.

Power plants should also look at installing onsite dedicated grinders located before combustion thus reducing dust issues in transportation and handling of bio-fuel formats. Larger initial feedstock particulate could then be used. For example pellets have **dust handling issues** because they are made from dust/fines.

The **potential markets** for biomass in North America is significant with over 600 large coal fired plants as well as a myriad of other fossil users such as cement plants.

Fuel pucks and random length briquets are also used for **district heat plants, greenhouse heating, institutional heating as well as CHP, combined heat and power**. In some cases pellet fuel systems have been replaced with fuel pucks due to lower fuel costs.

**See a North American installation** in video section in [www.briquettingsystems.com](http://www.briquettingsystems.com) -see “fuel puck manufacturing for boiler use.” Here you will see fuel pucks made, transported and used to heat a large 30 acre greenhouse.



**COAL PLANT**



**DISTRICT HEAT  
& CHP**



**GREENHOUSE**

## TRANSPORTATION AND LOGISTICS

Logistics can make or break an operation. This not only applies to moving out the finished product but also the feedstock coming to the plant.

In some cases due to feedstock challenges as in whole log collection and grinding very large operations are becoming limited. Sawdust is at a premium and will stay that way.

Using **smaller plant sizes located near feedstocks and markets** maybe beneficial. This is one of the advantages of briquetting vz pelleting, the latter usually on the large size due to ROI constraints.

Larger plants can be constructed. However in the range of 25,000- 75,000 tons per year briquetting has definite advantages.

As for shipping product the **briquetters can discharge direct** to warehouses, ship containers, truck loaders, roll off bins or supersacs on a carosel. See pictures below for examples.

This is done by configuring the presses discharge cooling lines to carry the finished product to its desired collection point. The force of the press pushes the briquets/pucks through its heated forming die and down these lines up to 200 feet.

Fuel pucks are made in a uniform way by the simple reciprocating force of the press. Unlike pellet mills, **die exit cutters and knives are not used** to control the output format. One less wearable to be concerned about.

No exit conveyors are required-see following pictures for some variations of this method. In addition no motorized after-coolers are required as is the case with pelleting. One less piece of machinery required. Belt exit conveyors may not be required. **Less handling also relates to less fines/dust produced.**

**A special drive through tipping container** device quickly allows pucks to be bulk loaded into ship containers. The alternative is loading the containers with supersacs.

Providing shipping costs work, **containers can eliminate** the need for expensive bulk loading and unloading facilities, labour savings and negating the costs in storing thousands of tons of finished inventory ( typically 3000-6000 ) for an arriving ship, as well as keeping the pucks safe and dry and allowing them **direct access to more markets.**

Pucks can be made and loaded into containers as they come out of the presses reducing inventory. **Fuel pucks weigh in the range of 30-40 pounds per cubic foot** depending on machine settings and feedstocks. Trucks, ship containers and railcars can be maxed out.



Containers



Roll-off Bins



Super-Sacs



Truck dump



Warehouse

### “Automated Loading Examples”

In conclusion this gives you an idea of the many cost effective advantages of briquetters. For further information visit our website [www.briquettingsystems.com](http://www.briquettingsystems.com) ph 604-818-0287

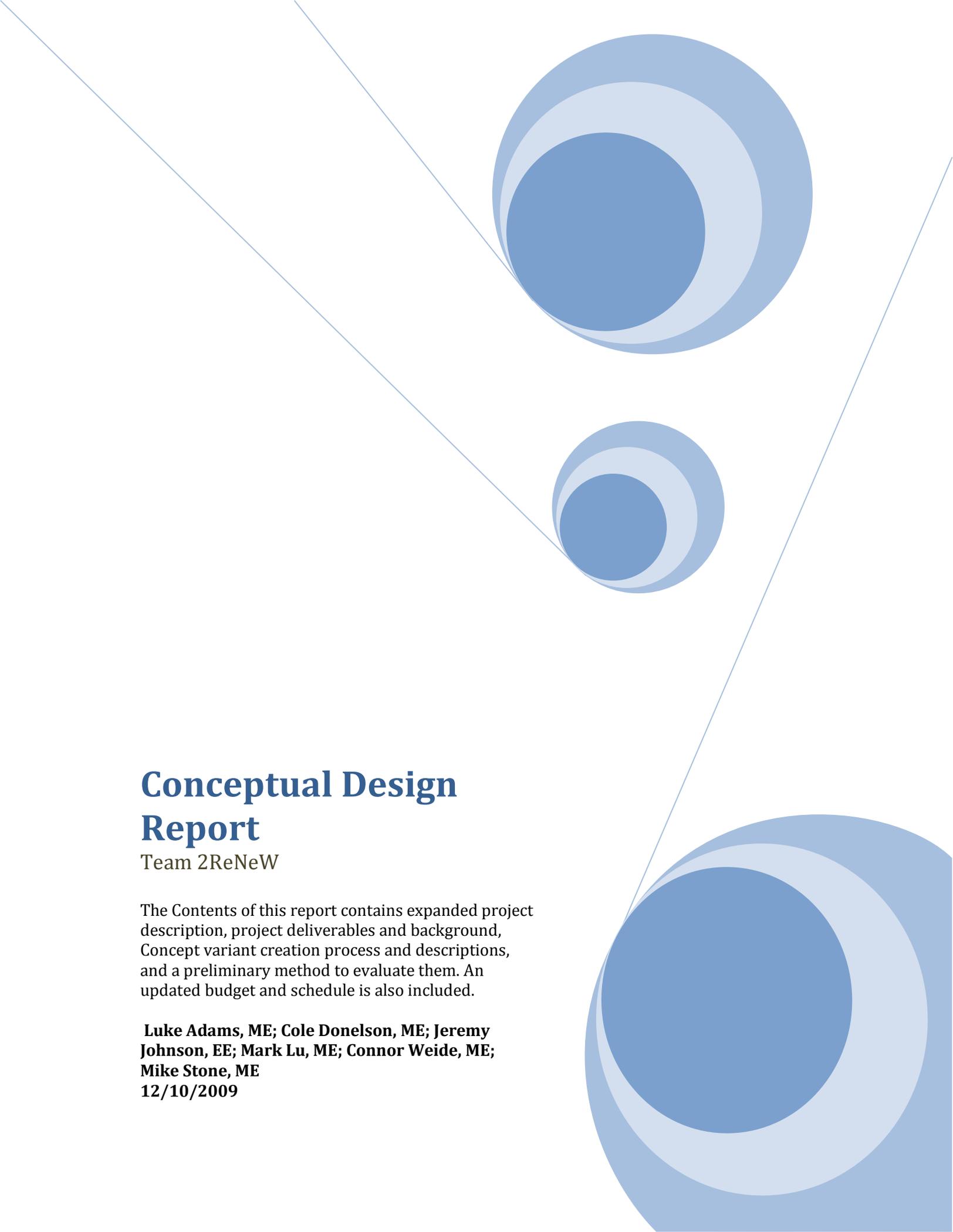
## **Appendix C**

### **Reports from Colorado School of Mines**

#### **Part 1: Concept Design Report**

#### **Part 2: Design, Analysis and Validation Report**

#### **Part 3: Final Design Review**



# Conceptual Design Report

Team 2ReNeW

The Contents of this report contains expanded project description, project deliverables and background, Concept variant creation process and descriptions, and a preliminary method to evaluate them. An updated budget and schedule is also included.

**Luke Adams, ME; Cole Donelson, ME; Jeremy Johnson, EE; Mark Lu, ME; Connor Weide, ME; Mike Stone, ME**  
**12/10/2009**

December 11, 2009

Luke Ilderton  
8745 West 14<sup>th</sup> Avenue, Suite 220  
Lakewood, CO 80215

Dear Luke,

Please find enclosed our Concept Design Report. This document is the second report deliverable for the Senior Design I Course at the Colorado School of Mines.

Despite a few initial setbacks and a late start, team 2ReNeW is well on the way to designing a sustainable and feasible agricultural waste briquetting machine. The team started off with several client meetings, and with the help of the technical consultant, was able to decide upon a concise and appropriate list of deliverables. From there, the team has done extensive research into the subject. With this research the team has gathered much of the empirical data necessary to determine the best design. Team 2ReNeW has also come up with several design variants and several methods for evaluating the different designs. The team has also developed a presentation to display their progress thus far.

This paper will cover the work that has been done so far, as well as what needs to be done in the future. First the problem the team has been assigned is discussed. This covers the new scope of the project as well as some general background information on briquetting. The project requirements, goals, and constraints are also covered. The design methodology the team used to determine its concept variants is also explained, including descriptions and drawings of the three concept variants the team has chosen. The paper also includes the team's plans for the future, which are concept variant selection, plans for testing and prototype building, and other deliverables. Finally the team's project schedule and budget are explained.

We look forward to any feedback which you may have on the report. Also enclosed is an evaluation form of our progress and performance as a team. This form should be returned directly to Dr. Cameron Turner. We respectfully request that this form be returned by December 18, 2009 as it constitutes a portion of our grade. The winter break at CSM runs through Wednesday, January 13, 2009. As a result, we will have a little more than four months to finish the project when the spring semester begins. We would like to schedule a meeting/teleconference with you at your convenience for early in the new semester to discuss our progress and plans for the spring semester. Lucas Adams will be in contact with you to schedule the meeting. In the meantime, if we can be of any assistance, please contact us at your discretion.

Sincerely,

Lucas Adams

Jeremy Johnson

Mike Stone

Cole Donelson

Mark Lu

Connor Weide

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## 1.0 INTRODUCTION

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Team 2ReNeW is a Senior Design Project team at the Colorado School of Mines and consists of the following six members: Lucas Adams, Cole Donelson, Connor Weide, Mark Lu, Mike Stone, and Jeremy Johnson. Our client is iCAST, represented by Luke Ilderton. Our faculty advisor is Michele Zeles-Hahn and the team technical advisor is Neal Sullivan. Our group was initially charged with the task of designing an agricultural briquetting machine to be used by farmers and ranchers in Colorado. After meeting with the client, it was mutually decided that since there were several briquetters commercially available, the scope of the project should be changed. The new scope involves developing a start to finish system concept for producing briquettes using a commercially available briquetter. The team has also been charged with the task of creating an alpha prototype, or table top model, to showcase the technology to farmers. The contents of this report include project background as well as the goals and constraints. The design process and explanations of potential solutions (concept variants) to the project are also detailed. In addition, a Gantt chart and budget are included.

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## 2.0 PROBLEM REVIEW

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In the South Eastern plains of Colorado, ranchers face a problem. The cattle they own produce a large amount of waste each year and must be removed. It is our goal to explore and expand on current research to turn this waste stream, along with its wheat straw counterpart, into biomass briquettes to produce energy for stoker power plants.

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### 2.1 CURRENT SYSTEM

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The ranchers and farmers of South Eastern Colorado have two massive waste streams, manure and wheat straw, that prove to be cumbersome and costly. The current methods used to remove them are satisfactory, but they cost plenty of money and waste plenty of potential chemical energy.

Cows can produce anywhere from 100 to 150 lbs of manure each day. This results in roughly 36,000 to 55,000 lbs of waste each year. Through natural anaerobic digestion, bacteria can reduce those numbers by about a third, but with anywhere from 1,000 to 2,500 cattle on a ranch, the waste stream is simply too big for a farmer to handle. Very little manure is used or sold back as fertilizer. This results in the farmer having to hire a company to come and dispose of the waste via a truck.

These visiting companies can charge anywhere from \$3,000-4,000 each visit and the waste ends up taking up landfill space for years to come.

Another waste stream present for the farmer in South Eastern Colorado is non-irrigated wheat straw. After the wheat has been cultivated the agricultural by-product of removing the wheat grains is the straw. While clearing land for planting crops, a farmer may remove the wheat straw or simply plow it back into the ground to return its nutrients into the soil. When the farmer does remove it, it may be used as filler for stock feed. However, due to its abundance there is simply too much of it to stock pile. The wheat straw is therefore another available waste stream that may be utilized by this project.

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## 2.2 POTENTIAL BENEFITS FOR FARMERS AND UTILITY

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When the two available waste streams are ground, mixed, and compressed into brick-form, we create a biomass briquette. This briquette can be burned in a furnace and the potential energy stored within it is released to produce electrical energy. Taking these waste streams and turning them into this energy can prove to be substantially beneficial for everyone involved.

The rancher/farmer can turn a material that he once had to pay others to dispose of into a viable product that a utility company will now pay him to receive. Thus, waste products can now become a marketable product with an initial investment in a briquetting process. Currently, some utilities in Colorado are slowly moving towards implementing biomass in their combustion process. Ultimately the utilities will be the main purchaser of the biomass briquettes.

The Black Hills stoker power plant is a pioneer in biomass energy exploration and use. Black Hills has had a working relationship with iCAST over the past few years on different bio-fuel projects and has been open to any and all suggestions. Black Hills is one such plant that will be able to buy the biomass briquettes from the South Eastern Colorado farmer for energy production.

Biomass energy production has several biomass credits in the state of Colorado as well as surrounding states. It is therefore economically beneficial for stoker power plants to implement biomass co-firing, which is the process of firing the briquettes with coal at the same time. Similarly, Colorado has a few stoker plant requirements as well in order to reduce emissions into the environment.

While co-firing may reduce carbon emissions, burning the briquette by itself is considered to have a net-zero carbon output. According to a 2007 EPA study, due to the wheat straw and cow's intake of CO<sub>2</sub> throughout their life cycles, a briquette adds no "additional" carbon to the atmosphere that was existent before the straw and cow. While some might consider burning only briquettes by themselves, it has been found that co-firing is the most beneficial. Briquettes alone would not yield the necessary energy output compared to coal. However, the biomass process would help the farmer, the power plant, and ultimately the environment.

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## 2.4 STOKER POWER PLANTS

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A stoker power plant is a coal burning facility that uses the released thermal energy from coal to boil water into steam and in turn uses the steam to turn generators and produce power. It is like any other coal burning plant, but the term "stoker" simply refers to the way in which coal is input into the furnace.

Figure 1 shows the cutaway view of a stoker plant below. One of many designs includes large stockpiles of coal that are allowed to fall onto a continually moving conveyor belt. As the coal on the belt enters the furnace, it heats up and eventually combusts with the surrounding coal and releases energy to boil the water. Some different stoker plants include different ways of supplying the coal with oxygen. Exposing it to oxygen from below and from above are called underfeed and overfeed plants, respectively. When the coal reaches the end of the conveyor belt, it expels 99% of its energy and the remaining ash falls into an ash hopper to be cleaned out on a regular basis.

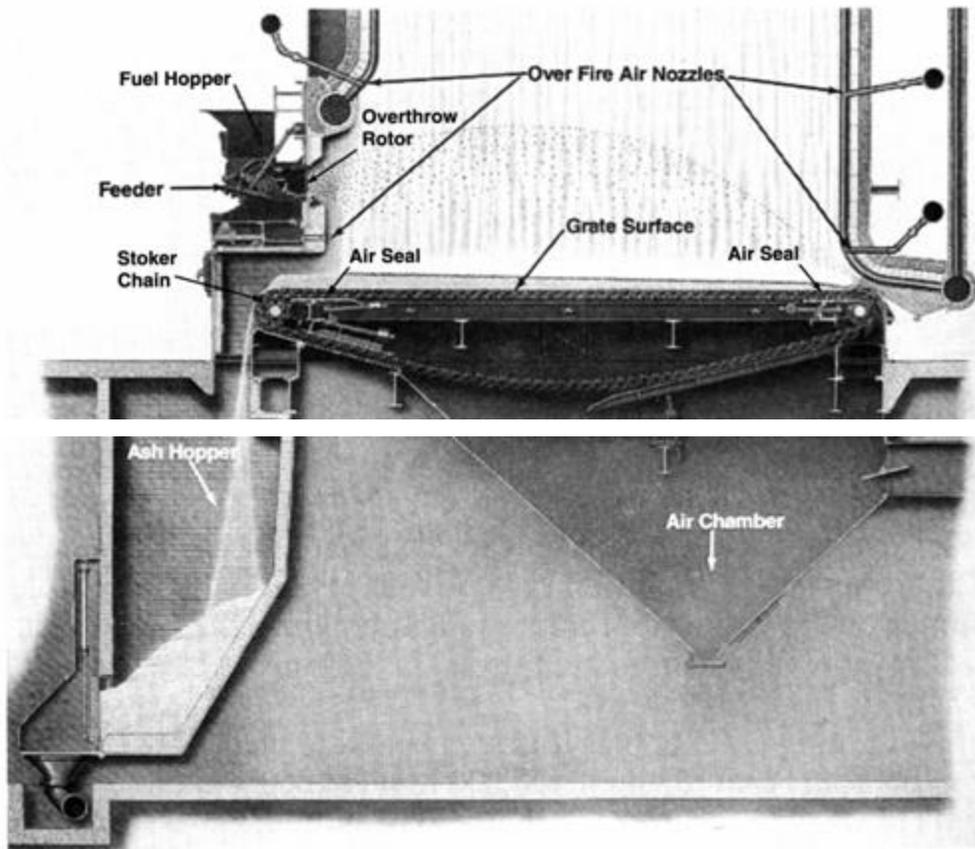


Figure 1. Cut-Away View of a Traveling Grate Stoker Boiler

### 2.3 WHY THE ENGINEERING COMMUNITY SHOULD BE CONCERNED

Biomass briquetting is beneficial to not only those involved, but the greater engineering community. Briquettes displace the amount of carbon that would otherwise be burned, curbing emissions. In reference to global warming, the process of producing and co-firing biomass briquettes is not a solution, but rather a temporary reduction mechanism as it merely reduces our carbon output. Regardless, it is an important intermediary step that allows us to slow our output while we search for other viable solutions to save the environment.

Additionally, since 2008, the USA and the rest of the world have been experiencing one of the harshest economic crises since the Great Depression. Many small-town rural farmers have been greatly affected. By introducing biomass briquetting as a part of their farm output, they reduce disposal costs while increasing pay from a source other than livestock and crop sales. As engineers,

it is in our best interests to help in any and all humanitarian efforts both local and abroad. By helping a small-town farmer, we can produce a better humanitarian effort all over the world.

Finally, biomass briquetting transforms something that was once in a landfill into viable energy. Biomass is a renewable energy source in a world struggling to meet a high energy demand. Any alternative and renewable energy sources should be of the utmost importance to responsible engineers over the world.

Biomass briquetting is not a new field, and there have already been many patents made in relation to this subject. As far back as 1977, and as recent as 2009, people have been procuring patents related to biomass briquetting. Three examples of patents related to briquetters is one for a briquetting machine, a briquetting process, and a component of a briquetting machine. One patent from 1991 describes a briquetter that used rollers and molds to create bricks [1]. This technique could be implemented in our alpha prototype design. Another patent from 1985 describes an ideal process for making briquettes out of coal fly ash and organic combusting material. It describes ideal conditions such as moisture content and mass flow rate [2]. The process to achieve those two conditions may be borrowed and implemented into our final design. Patent 4017241 is a patent that describes a notched-flight screw for a briquetting machine. It is referring to the screw feed mechanism in some briquetters, which can be optimized by putting notches in the shaft to allow for some backwards flow of waste materials [3]. Our search for patents will continue as the project progresses.

### 3.0 PROJECT REQUIREMENTS, GOALS AND CONSTRAINTS

---

The goal of this project is to design an economically beneficial process to produce biomass briquettes for SE Colorado cattle farmers to sell or burn for energy. In addition, we must construct an alpha physical prototype of the system to show to farmers to illustrate the briquetting process. We must then create a pilot plant design of a large scale system to present to iCAST. An energy and economic analysis will also be included in the large scale design plan. The table below lists the deliverables needed and the main team members responsible for each.

TABLE 1. LIST OF DELIVERABLE AND DESCRIPTIONS

Deliverable	Description	Team Members Responsible
<b>Alpha Prototype</b>	Discussed in Depth Below	Mark, Luke, Mike, Cole, Connor
<b>Pilot Plant Design</b>	Solid works of the large scale process, Description of retrofitting stoker plants	Connor, Mike, Luke
<b>Process Energy Balance</b>	Analysis of the energy input and Energy output	Jeremy
<b>Economic Analysis</b>	Determine whether the process is economically feasible	Cole
<b>Testing Procedure</b>	A creation of steps to be conducted for testing the briquette properties from alpha prototype	Mark, Connor, Jeremy
<b>Documentation</b>	Documenting an analysis of entire process to benefit iCAST progression	All

### 3.1 ASSUMPTIONS

Requirements and assumptions for this project also exist. One design requirement is that we are only concerned with cow manure and non-irrigated wheat straw as the waste streams, given their abundance in rural Colorado. Also, it is assumed that ranchers produce ample amounts of waste, and as such we do not need to be concerned with the quantity, but rather how to manipulate the two. We are also instructed to exclude collection process of manure on their farms. The design assumes that the two waste streams are already collected in one spot, compiled and ready to be processed. Cost of collection is also excluded. On site power generation is also to be excluded from the project, given the complicated scope and the potential for selling the waste. As such, we are to assume that a market exists for briquettes, and the farmers can sell them once they are produced.

### 3.2 CONSTRAINTS

Various constraints in the project must be addressed. Since it is considered a humanitarian engineering project, we must develop our design within the limitations of the community's ranchers. We must make sure that our design is as simple and untechnical as possible such that the

farmers feel confident in their knowledge to briquette on their own. Issues with a complicated design not only contain a steep learning curve to operate, but will also require extensive outside help in the event the machine breaks.

Budgetary limitations exist. In developing the pilot plant design, we must make sure the process includes a financially feasible design that will tempt farmers to invest in the process. Budget limitations also exist in the alpha prototype construction and testing. We must construct a demonstrable process that depicts briquetting while still being under our \$1500 budget provided by the client.

Another constraint is that we must design our pilot plant with commercially available briquetting machines and equipment. This will introduce more feasibility for iCAST to further the project. Moreover, it is unnecessary to design custom machines when there are many already on the market. In using only commercially available machines, there is the further constraint of integrating two machines in the overall process. This will be a major factor in our design process and an area that will be explored through more product research.

Constraints for the waste also exist. It has been determined that a 1:1 ratio of wheat straw and manure provides the best energy content in briquettes. Using this ratio, an energy content of 3,599 kcal/kg can be extracted. In comparison, coal has a rating of 6000 kcal/kg. Our process must be able to take the two waste streams and mix them evenly. This poses problems since straw is much lighter than manure, so differences in their physical properties must be addressed. Also, many briquetters require a size limit on the materials entered into the machine. Thus, crushing the two waste streams to fulfill the machine requirement must also be incorporated in the design. Lastly, many briquette machines contain a maximum allowable moisture content (generally ranging from 12-15%) the input material must have to be properly briquetted. Heating the briquettes is a factor that must be introduced in the process, as it also helps increase the energy content and allows the materials to be formed easier by the machine.

### 3.3 ALPHA PROTOTYPE

---

Team 2Renew will be determining the most efficient biowaste briquetting process; doing so will allow the team to make a proposal of how to implement this process on a larger scale for farm use. Furthermore, a visual demonstration of the briquetting process will be greatly beneficial to farmers

in clarifying the benefits and requirements of briquetting technology. Much of the design and construction requirements for the course will be through the design and implementation of this device. Thus, Team 2Renew will be developing an alpha prototype to help achieve the project goal.

The alpha prototype will be a simplistic, scaled-down model that will assist in demonstrating how the briquetting process would be completed on a full-scale. For example, coffee cans can be utilized to represent the hopper mechanisms, a hand-turned grinder can represent the crushing/mixing mechanism, a hand-press can represent the briquette machine, and so forth. However, data collected from future experiments can be used to alter our prototype in order to yield the best possible design. As such, the design of our alpha prototype is still pending.

Team 2Renew will be conducting a series of experiments in the near future to determine several key parameters for our alpha prototype. These experiments will also serve to give us a better understanding of certain quantifiable values that are pertinent to our proposed full-scale briquetting process.

First, the team will determine the desired composition of the briquettes. Although it has already been determined that a 50-50 ratio of straw to cow manure is best for real world applications, such a ratio may not be ideal for the prototype. Thus, through experimentation, we will conclude what ratio of straw to manure is ideal for the alpha prototype. Also, the team will investigate the effects of grinding straw and manure before briquetting. This will allow the team to determine if the overall efficiency of the briquette is improved, or if doing so will yield negative or negligible effects.

Next, the team will analyze the durability of a briquette consisting of the correct straw and manure mixture. The briquette will be made using a hand-press supplied by the client. The team will need to examine how many briquettes remain intact over time versus the amount of briquettes that decompose. Therefore, this experiment will indicate whether using a hand-press can serve as a suitable briquetter for our prototype.

Also, the shelf-life of the sample briquettes will need to be determined. After the biowaste has been compressed into a briquette, the team will dry the briquettes in a microwave; the amount of time spent in the microwave will simulate the amount of time the briquettes have been in storage. Once this is done, the team will verify if the briquettes are still intact; this will allow the team to decide if the briquettes have an acceptable shelf-life, or if changes need to be made in order to prolong their shelf-life.

Another key experiment that must be performed is to analyze the energy content of our sample briquettes. Once the biowaste briquettes are prepared, we can analyze their efficiency by comparing them to coal briquettes. This can be achieved by using both types of briquettes to heat a given amount of water, and comparing the time required for the water to reach the boiling point. Actual energy content of the biowaste briquettes will be obtained by sending the briquettes to a lab for further analysis.

Finally, Team 2Renew will explore the briquetting process of the alpha prototype. The team will investigate how certain components interact with each other. This will allow the team to determine where each component must go within the process to ensure that the setup is the most efficient.

The data gathered from these experiments will be vital in yielding the best prototype design; this will help the team offer the best proposal for full-scale implementation of the entire briquetting process, as well as to help convince farmers to embrace briquetting technology. However, while the data from these experiments are the key focal points, much more data will likely need to be acquired as the project progresses. Therefore, additional experiments may need to be conducted in order to address any areas of concern that may arise as the project continues to move forward.

## 4.0 DESIGN METHODOLOGY

---

The design process for creating the concept variants melded research and ideation techniques. A main focus for the pilot plant design is to implement a design based on commercially available parts. The briquetting process includes different manipulations of the waste before the final briquette. Appendix A shows various orders the process can include to briquette. From this process, a list of subsystems was compiled. Table 1 below lists and describes each (note that in implementation some can be combined).

TABLE 2. LIST OF SUBSYSTEMS

Subsystem	Description
Storage	Allows for acceptance of waste
Feeder	Feeds waste into briquetting machine
Mass Transfer	Transfers the waste from one subsystem to another
Crusher	Crushes the briquettes to a finer material
Mixer	Mixes the two waste streams. Must mix the two streams to 1:1 ratio
Heating	Heats the waste before briquetting
Receiver	Receives the finished briquettes

Our first step was to research existing briquetting machines, since our designs for feeding, mixing, storage, and/or heating need to be integrated with the machine parameters. Characteristics of the machines we focused on were mass output, power consumption, and whether it already integrated a solution to one of the subsystems listed above (storage, heating, etc.). In accordance to our constraints, we eliminated briquette machines that were too expensive and were designed for industrial purposes (usually ones with mass output rates well beyond 160 kg/hr). Since this process will be managed by farmers who only want to rid their waste, large industrial machines designed to run all day were beyond the scope of what was necessary. Another issue with briquetters with larger outputs was the output is proportional to the power consumption. Machines that consumed more power than what is harnessed from briquettes is neither energy nor economically efficient. To verify that there was a correlation between the output rate and power consumption, we compiled data from different briquetters and graphed the two. This proportional relationship was correct, and allowed us to gain an understanding of the engineering metrics involved, as well as a basis for elimination based on mass output and power consumption. We concluded we did not want to exceed over 20kW and an output mass rate of 120 kg/hr. Additional factors for elimination included machines that were complicated and required an abundant knowledge of machine operation. Our goal is to create a design that works within the means of consumers' strengths and weaknesses. An over engineered and complicated process will not entice farmers to invest in the technology.

There are two major types of briquette machines, mechanical and hydraulic. Mechanical machines generally include the crushing subsystem, and provide a more involved briquetting process. Hydraulic machines are generally simpler and compress the briquettes via hydraulic pumps. Each has their benefits. The table below illustrates the numerous features mechanical machines have, where a plus sign indicates it incorporates said feature. Generally, the trade off is while most mechanical briquetters include numerous features, they also tend to be the most complicated.

TABLE 3. HYDRAULIC AND MECHANICAL BRIQUETTER COMPARISON

	Mechanical	Hydraulic
<b>Pre Heater</b>	+	
<b>Crusher</b>	+	
<b>Industrial Use</b>	+	
<b>Automated</b>	+	+

After our research and elimination, we chose two mechanical and one hydraulic design to base our process designs off of. Appendix B shows the pictures of each. These three machines all have varied features and physical builds, yet are the most common designs on the market. They also provide a mass output rate appropriate for small scale use. From this data, we compiled a table listing our subsystem features such as mixing, heating and crushing to see whether some designs already included them. For designs missing features, we used the ideation technique brainball to develop ways to incorporate the said features in the process. Appendix C shows the table compiled from this exercise. The top row lists the subsystems/process features integral to briquetting, and the leftmost row is the list of the three briquetting machines by their model number. The last row contains the brainball ideas for each subsystem. As an example, from the table hydraulic briquetters do not involve a preheating subsystem. A brainball suggestion is to involve a “space heater” device before the load is input into the machine. The more viable suggestion was then filled in the heater-BP-100 block.

After the table was compiled, we then performed 6-3-5. The justification for this was to have a visual representation of the briquetting process, and to graphically incorporate some of the

brainball suggestions. Appendix A shows the proposed process orders the briquettes would be subjected to. Some differences included potentially introducing moisture before mixing and then heating, or immediately heating the two waste streams before any other process. Ultimately the team agreed upon order one, as it is the basic briquetting process and can be easily designed. Each member drew their ideas, and we compared our results. For the most part, the process basis was fairly similar, although a few unique solutions were created and combined with others (described more in the concept variant section). Appendix C shows the table results that spawned our concept variants. The options column is the compilation of our brainball ideas.

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## 5.0 CONCEPT VARIANTS

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The three briquetting machines the team decided to use are the Biomass Briquette Systems BP-100, the Anyang GemCo BZBJ-1, and the DiPiu MB-50. These three machines were chosen because of their mass output rates, power requirements, costs, and efficiencies. All matched the needs and available resources a typical farmer of 2000 head of cattle might have. These machines are the most feasible options, and the following concept variants show how they could be used in conjunction with other equipment to complete an economically reasonable and energy efficient briquetting process.

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### 5.1 CONCEPT VARIANT 1

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Figure 1 in Appendix D illustrates the first concept variant, which features a rotary drum mixing component, similar to a cement mixer. The briquetting machine is the BP-100. Transport between components is carried out by gravity. Manure and straw are stored in separate silos above the briquetter. Valves restrict the flow of each downward. As each material leaves the silo, it passes through a grinder or crusher to cut or break the particulate into appropriate size. The two materials then fall into the rotary drum, where they are mixed together thoroughly. A space heater and fan pump hot air into the mixer to dry the matter before the briquetting process. After mixing, the manure and straw composite falls of its own accord into the briquetter. There it is compressed into briquette form and falls into a collection bin for transport.

The BP-100, while an effective briquetter, does not mix input materials before the briquetting process, nor does it heat them. Both these processes help to produce more durable and homogeneous bricks. This variant feasibly provides both processes. The rotary drum mixer is very

similar to a concrete mixer, and is illustrated in Figure 1-A in Appendix D. The grinders could be as simple as a set of rotary blades like that of a paper shredder. The cost of the silos, if the farmer does not already own two, is important to note in the budget. Electrical costs from running the heated fan, grinders, and rotary drum must also be considered. Possible complication could arise from rigging the rotary drum above the briquetter and below the silos.

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## 5.2 CONCEPT VARIANT 2

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Figure 2 in Appendix E shows the BZBJ-1 working with two silos and a vertical blender. The two silos would be arranged similarly to the first variant, except that each would have attached its own grinder—one to cut the straw into very small pieces, and one to pulverize the manure into particulate matter. This ensures better briquette durability. After passing through the grinders, the two materials enter into the vertical blender, which uses large spinning blades to mix the components together thoroughly before allowing them to exit via a valve on the bottom. After exiting the blender, the material falls into the briquetter. It then exits for transportation.

The BZBJ-1 preheats materials before compressing them into briquette form, so any heating element outside the machine is superfluous. The vertical blender is similar to those used in any large manufacturing plant, shown in Figure 2-A in Appendix E, and ensures more homogeneous bricks, which in turn produce more reliable energy flow. However, the mixer might not work as efficiently if it is nearly empty. Price concerns are similar to the first variant, considering the two silos and the electrical costs of the grinders and blender. Again, as in the first variant, gravity transports all materials within the process, cutting costs. Difficulties could occur lifting raw materials up into the silos. This could be achieved with a conveyor system or a screw feed.

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## 5.3 CONCEPT VARIANT 3

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The third concept variant, illustrated in Figure 3 in Appendix F, is a more lateral process, and features a trough-like storage device in conjunction with the MB-50 briquetting machine. The sloped, triangular troughs store straw and hay lower to the ground, eliminating the costs of silos and those of raising the materials into the silos. This trough, shown in Figure 3-A, houses a screw feed along the sloped bottom ridge. During operation, the screw feed automatically lifts raw materials into the vertical blender. After mixing in the blender, the materials exit through another screw feed and into the briquetter. As the briquettes exit, they pass along a long tube, which can be

opened to expose the fully-formed briquettes. If needed, a heating element could be placed directly above the tube to flash dry them before burning.

This variant addresses the need to raise large amounts of materials much higher than the briquetting machine. By placing the storage trough much lower, and possibly even in the ground, a farmer need only dump the manure and straw in from truck-bed height. However, screw feeds must still transport materials between components, thus increasing cost. Screw feeds also complicate the flow measurement process, and in order to maintain a 50/50 mixture, would need to be calibrated and kept at a very specific speed. The presence of the vertical blender compensates for the MB-50s lack of any device which reduces the materials to particulate size, but would require electrical power.

In order to decide which of these variants best suits the needs of the team, client, and farmers, the team must consider economic feasibility, energy efficiency, and compatibility of each component with the others, as well as the farmers' available space and equipment. If a process costs too much to assemble or maintain, or if it consumes more energy than it offers, it will be discarded. Likewise, if a setup demands too much space or is too difficult for the farmers to use and repair, then it will not be considered. One very likely possibility is that a certain process might yield briquettes that are not consistently of the proper energy content, mixture ratio, size, weight, etc. for the stoker power plants. If these variances are too drastic, the process could be discarded. Ultimately, it is very probable that the team will combine variants to produce the best possible system. If a certain aspect of one variant is desirable while the rest is not, it could replace components from another variant.

Evaluating the concept variants will include using a Pugh chart to rank each. Preliminary attributes the team is considering are how well the machines can be integrated with other equipment, cost, and complexity of the process to be performed by the farmer. The testing of the alpha prototype will also give insights into process variability. Our goal is to maintain a level of consistency in the briquettes, where each one will yield the same energy content. If the production varies too much, the plants would not accept them. Thus, including and retracting subsystems during the alpha prototype will allow us to determine which has the most importance in the briquetting process. This subsystem hierarchy can then be applied to the Pugh chart evaluation metrics. A QFD will also be used to evaluate the machines after testing, since testing will provide us with a basis on various engineering metrics (energy content, durability, heating capacity of the heater, length of time for heating, smallest size of input materials, etc). With these metrics, we can utilize the advantages of a

QFD to specify quantitatively constraints we would like in our design. Other evaluation factors will arise as the project continues.

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## 6.0 PROJECT SCHEDULE AND BUDGET

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### 6.1 PROJECT SCHEDULE-GANTT CHART

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In order to reduce clutter and confusion, last semester's Gantt chart has been kept separate from next semester's. Changes to the first chart include the addition of an activity titled 'Define Scope.' The team discovered that this was a critical and lengthy process, and a lack to do so pushed other events back considerably, most notably 'Concept Design Methods,' and 'Compile Designs and C.V's.' Other events tied to deliverables with set deadlines were not pushed back, but the team struggled to complete them on time.

The second Gantt chart is much more linear and stretched out than past charts. The difference between the upcoming semester and this last one is the proximity of events and deliverables. For the first half of the fall semester, teams had six weeks to complete a project. Because of this, deliverables were close together, and processes moved very quickly. Now, the team has eighteen weeks to complete what, in the first semester, took only two. Some deliverables, according to the class schedule, are more than a month apart. The team has made the best estimate it can for the future timeline. The chart describes the initial design for the pilot plant and alpha prototype, procurement of materials for the alpha prototype, and the building and testing of the alpha prototype. As the next semester progresses, we will be keeping a close eye not just on how we complete activities, but how other activities are changing. This way, we hope to avoid time crunches. Possible traps could include serious malfunctions of the prototype, difficulties in acquiring supplies or materials, difficulty finding and paying for adequate testing of the briquettes. Also, most of the team will be taking the EIT next semester; team members will need to focus on and plan around it.

Regarding specific activities within the new Gantt chart, the team has allotted itself ample time for both 'Analyze Design' due to the number of deliverables due within that time—specifically the Internal D.A.V., Internal D.A.V. Report, and D.A.V. Report. All these will focus on the team's analyses of its designs. 'Design Prototype' was also given extensive time. Although it may not take nearly as

long as the free float allows, the team will undoubtedly need to make subtle changes throughout later processes. If new methods of illustrating the process or new ideas arise, it will effectively change the self imposed deadline to incorporate those changes. 'Re-design/Re-construct prototype,' is present only in the event that testing reveals major flaws.

---

## 6.2 BUDGET

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In order to ensure that sufficient funding is available when the alpha prototype begins development, Team 2 Renew is proposing a budget shown in Appendix G. The total estimated cost is currently \$1375. The justification for each part is also displayed in the table. Note that due to the excessive cost, lab testing will only be performed given the client's consent. Therefore, an exact value for briquette energy content may or may not be determined for the alpha prototype.

Also, the client has allocated a budget of \$1500 that can be used towards accomplishing the goals of this project. Our client iCAST will be the main source of the funding, and will be handling all procurements as well. As it stands, the proposed budget is sufficient to cover the team's estimated cost for completion of this project. However, if unforeseen future costs arise that can improve the design and quality of the project, adjustments to the budget will be necessary. The client has stated that in such a scenario, a request to increase project funding will be acceptable, and will be easily dealt with.

---

## 7.0 CONCLUSION

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After some initial setbacks, Team 2ReNeW is well committed to developing a system for agricultural waste briquetting. Having completed the vast majority of research and brainstorming, the team is prepared to progress with the project in January 2010. The team will choose a design using QFD and Pugh charts. The team will also construct an alpha prototype and create Solidworks drawings of the full scale agricultural waste briquetting systems. The team will then do both economic and energy analysis of the chosen system. The team will perform a series of tests using the alpha prototype in order to gather relevant information. Naturally the team will document the entire process, and will complete class deliverables as they are due. In order to accomplish all of this the team will follow our schedule created this semester. The team would like to thank its client, technical advisor, and faculty consultant, and would also like to request permission to continue on the project.

## PATENT REFERENCES

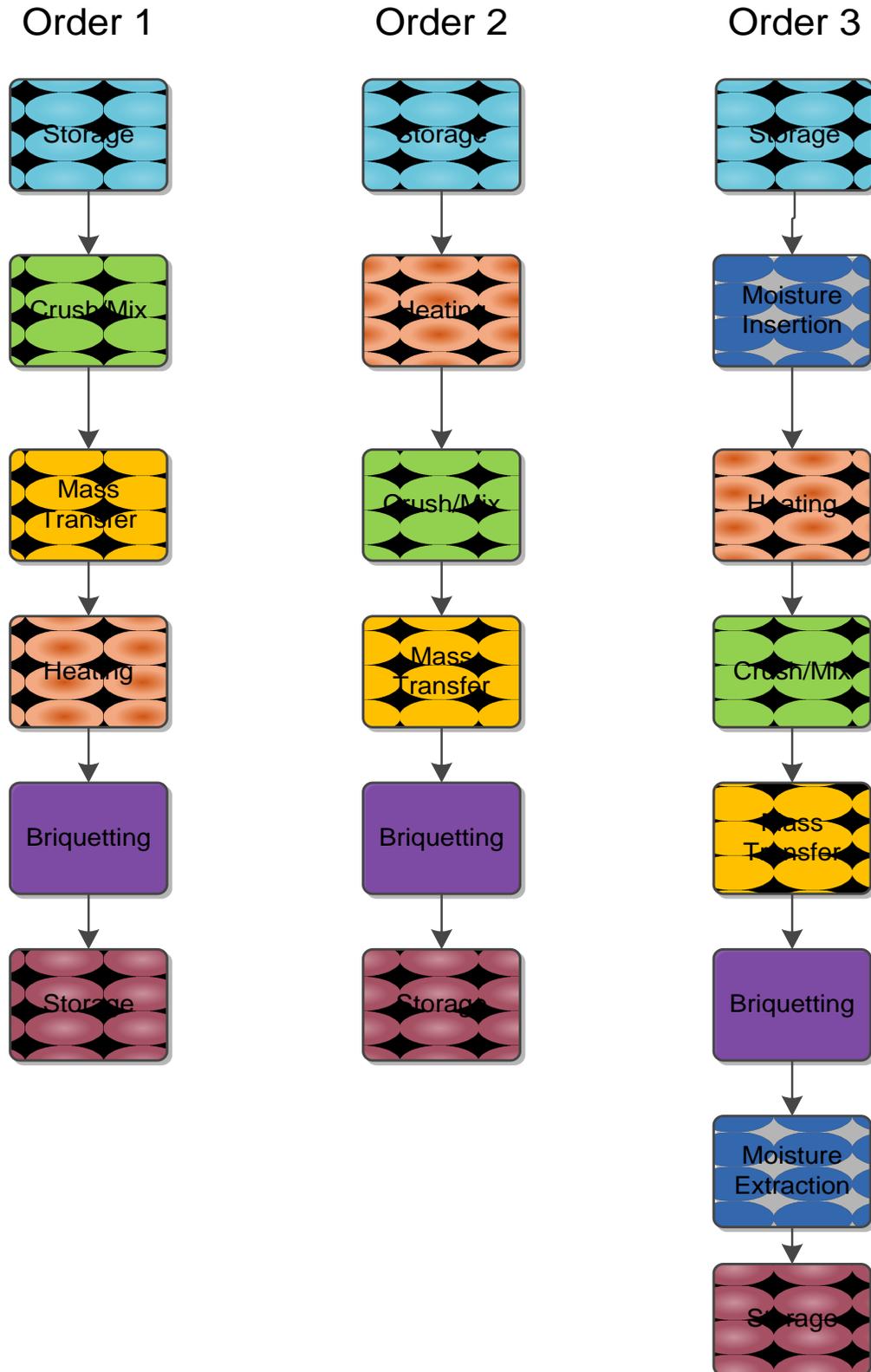
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[1] Holley, Carl A.. Patent 5017124. Freepatentonly.com. 05/21/1991. Accessed 12/01/09.

[2] Aunsholt, Knude E. Patent 4589887. Freepatentonline.com 04/30/2986. Accessed 11/25/09.

[3] Papinchak, Michael J. Patent 4017241. Freepatentonline.com. 04/12/1977. Accessed 11/25/09.

## APPENDIX A: PROCESS ORDER



## APPENDIX B: BRIQUETTER PICTURES

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BP-100: Hydraulic



MB 50: Mechanical



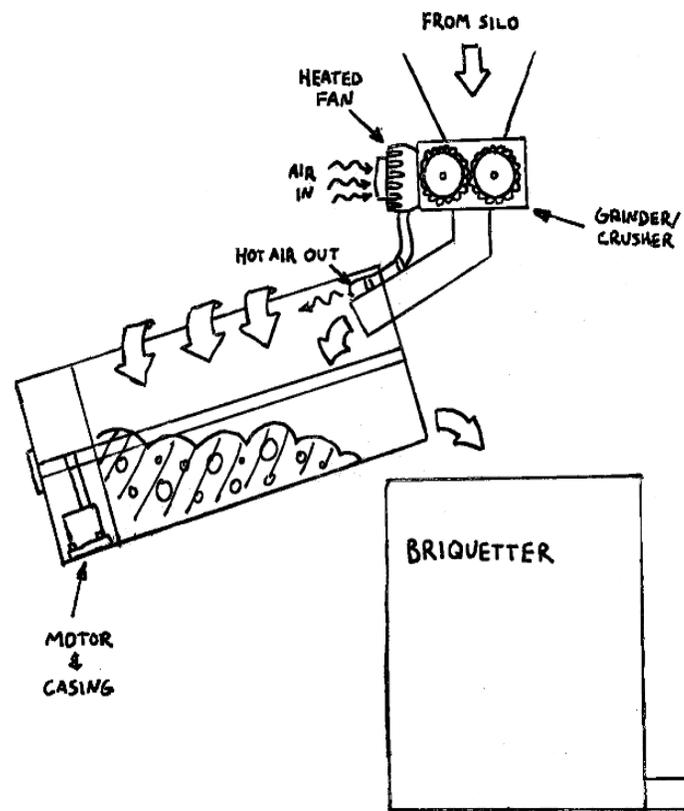
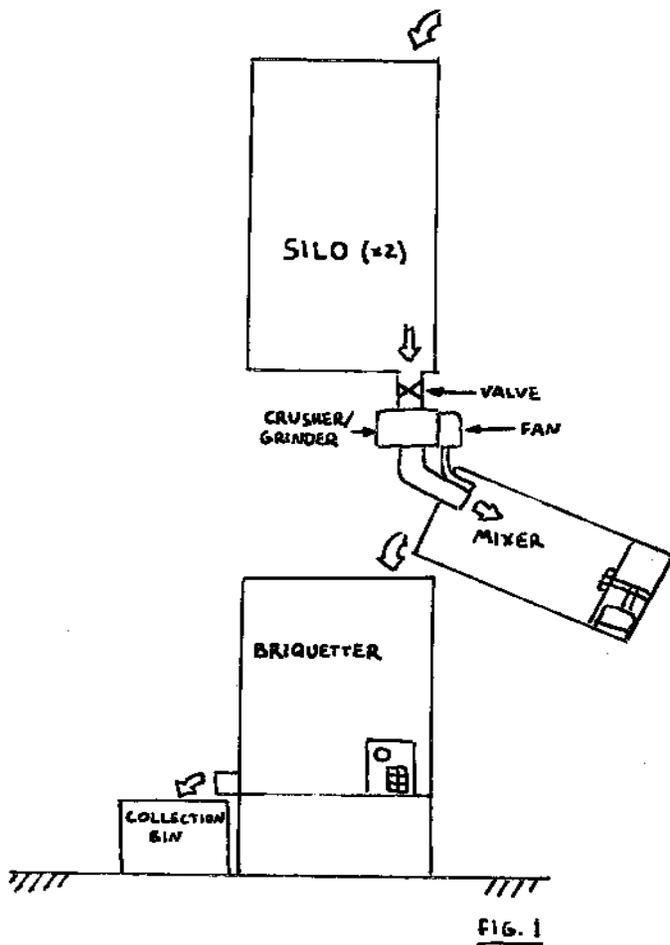
BZBJ-1: Mechanical



## APPENDIX C: DECISION TABLE

Briquetter	Heating	Mass Transfer	Storage/Vibration	Crush/Mix	Receiving
<b>BP 100</b> <b>(Hydraulic)</b> <b>Concept Variant 1</b>	Heating Elements (Space Heater)	Screw Feed	Gravity Hopper	Rotating Drum	Conveyor to bin with Flash drying
<b>BZBJ-1</b> <b>(mechanical)</b> <b>Concept Variant 2</b>	+	Conveyor Belts	Bin w/ screw feed	+ (Helical Mixer)	Wood Bin
<b>MB-500</b> <b>(Mechanical)</b> <b>Concept Variant 3</b>	+	screw feed	Bin w/ screw feed	+ (Helical Mixer)	Conveyor to Swiss bin w/ flash drying
<b>Options</b>	Lamps Heating Element Convection	Screw Feed  Conveyor Belt Shovel Gravity	Large Bin w/ Screw feed  vibration motor gravity Silos	Rotating Drum  Helical Mixer Grinding element	Wood Box  Conveyor to Large bin Flash Drying Swiss-Cheese Bin

APPENDIX D: CONCEPT VARIANT #1



APPENDIX E: CONEPT VARIANT #2

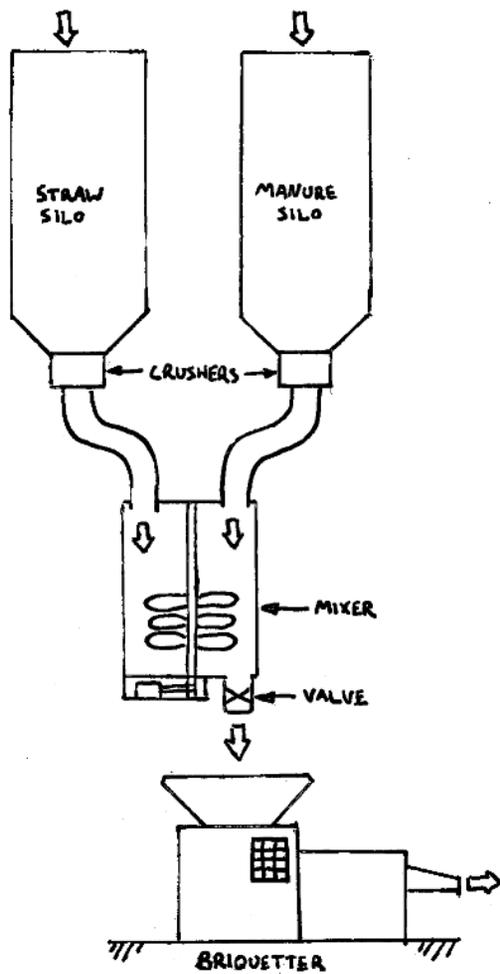


FIG. 2

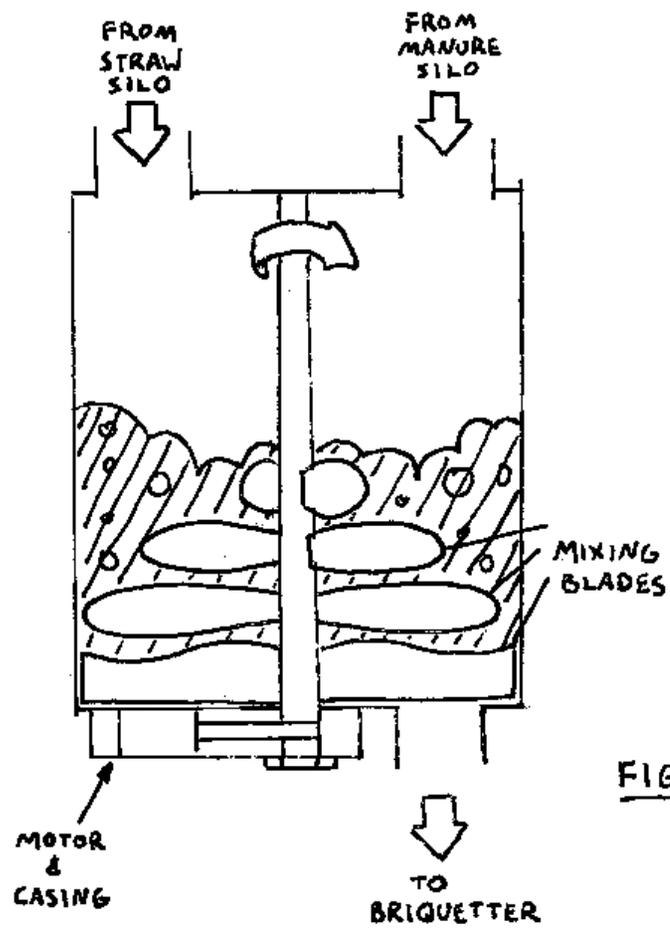


FIG. 2-A

APPENDIX F: CONCEPT VARIANT #3

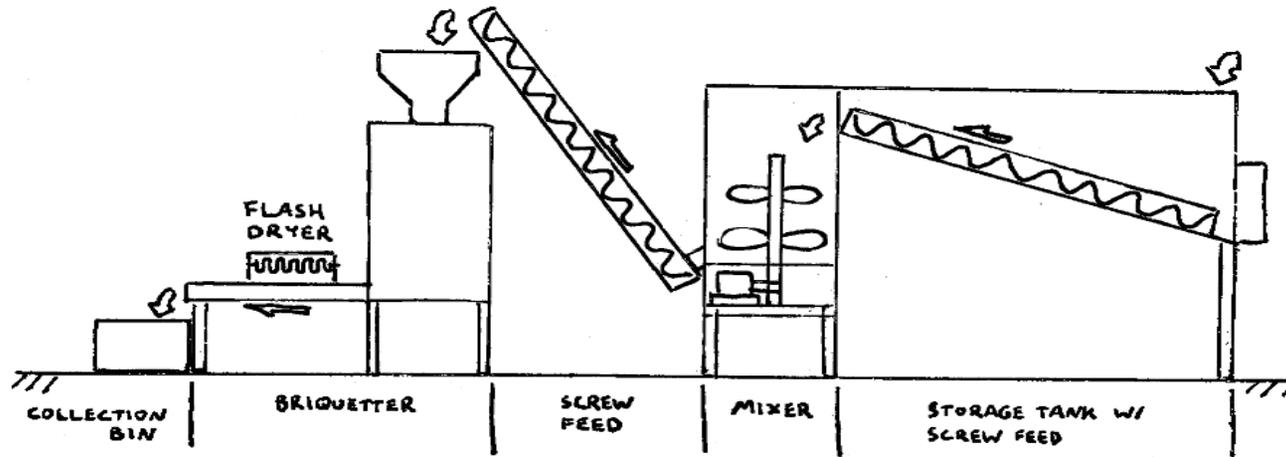
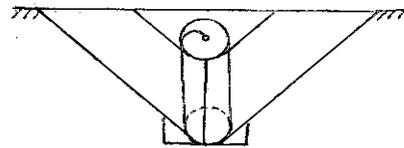
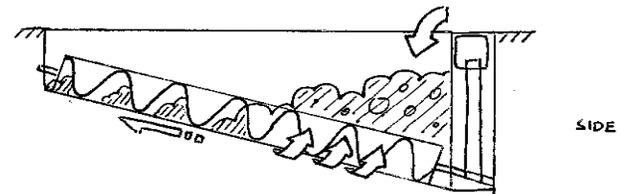
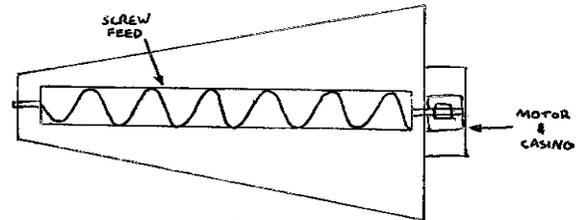


FIG. 3

FIG. 3-A



FRONT

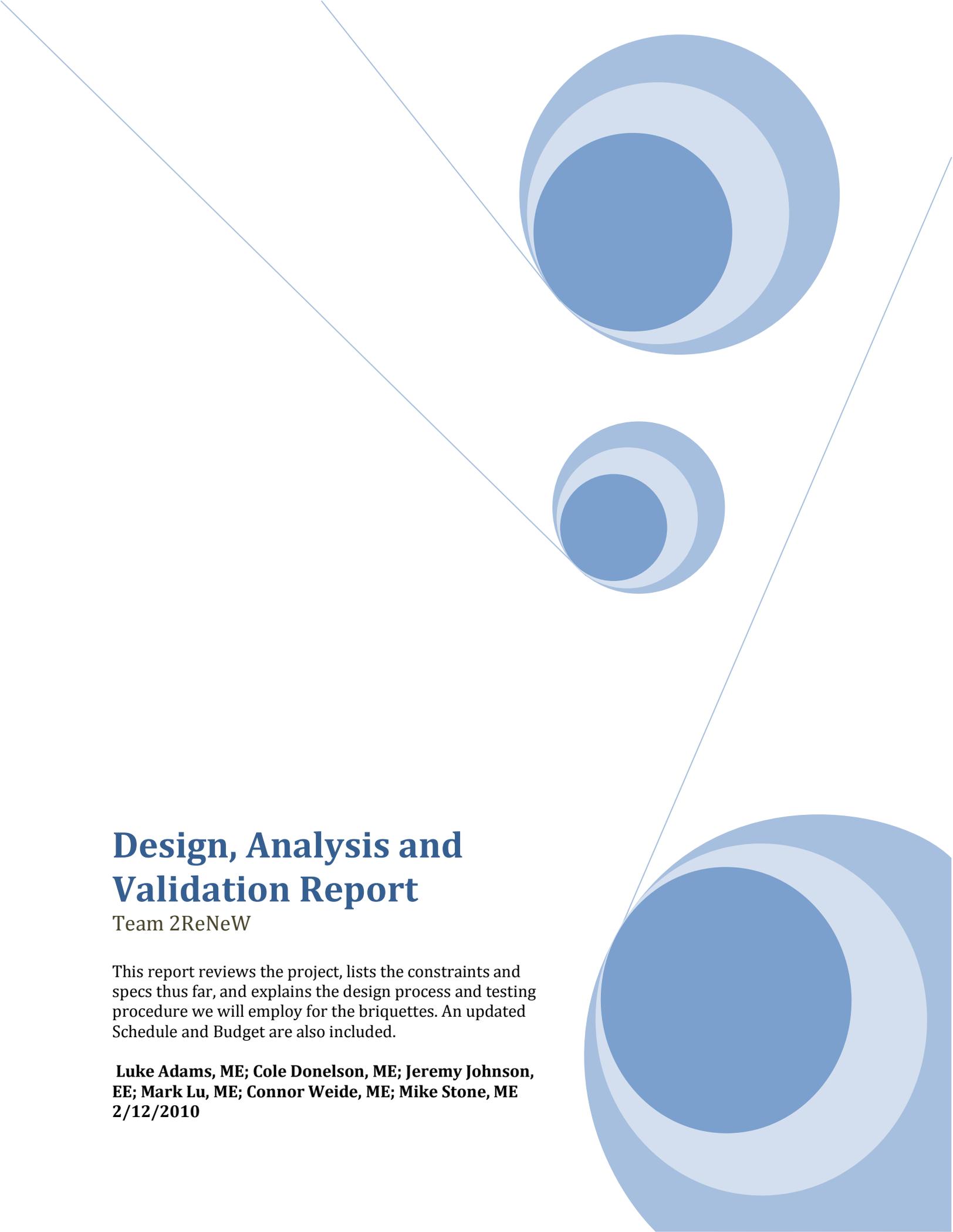


TOP

## APPENDIX G: BUDGET TABLE

<b>Component</b>	<b>Purpose</b>	<b>Quantity</b>	<b>Estimated Total Cost</b>	<b>Justification of Cost</b>
Conveyor Belt System	Used to transport biowaste before and after the briquetting process	~5	\$150	This includes the price of motors, gears, drive shafts, belts, and any other necessary materials for a small-scale application
Screw Feed Mechanism	Used to transport biowaste before and after the briquetting process	~5	\$150	This includes the price of the screw, motor, and all other necessary materials for a small-scale application
Scrap Metal	Used to construct a small scale-model hopper/bin to simulate the input mechanisms, as well as other various components	Varies depending on size	\$30	Scrap metal is fairly inexpensive, and can oftentimes be found for free
Mixer/Grinder	Used to mix/grind the biowaste	1	\$15	Such a setup can be taken from a blender
Space Heater	Used to dry the biowaste briquettes before briquetting	1	\$30	This is the price for space heaters currently on the market that are applicable to the prototype
Hand Press	Used to simulate briquetting process; will serve as our "briquetting machine"	1	Free	Will be supplied by the client
Microwave	Used to dry briquettes once they are completed; this will simulate drying of the briquettes during real-time storage	1	Free	Microwaves can be obtained from a team-member's household
Lab Testing	Necessary to determine exact energy content of biowaste briquettes	10 Hours (minimum lab time requirement)	\$1000	Lab fees include briquette testing of our biowaste materials, drying, grinding, cleaning, and burn testing
<b>Total Estimated Cost:</b> \$1375				

\*NOTE: As described in the report, lab testing is optional and dependent upon client demand.

A decorative graphic on the right side of the page features three overlapping circles of varying sizes, each composed of concentric blue rings. Two thin blue lines intersect at the top left and extend diagonally across the page, framing the circles.

# Design, Analysis and Validation Report

Team 2ReNeW

This report reviews the project, lists the constraints and specs thus far, and explains the design process and testing procedure we will employ for the briquettes. An updated Schedule and Budget are also included.

**Luke Adams, ME; Cole Donelson, ME; Jeremy Johnson, EE; Mark Lu, ME; Connor Weide, ME; Mike Stone, ME**  
**2/12/2010**

February 12, 2010

Sam Anderson  
iCAST (International Center for Appropriate and Sustainable Technologies)  
8745 W. 14th Ave. Suite 220  
Lakewood, CO 80215

Dear Sam,

Enclosed is our design analysis and validation report. This document is the first report deliverable for the Senior Design II Course at the Colorado School of Mines. The purpose of this report is to document the team's selection of a conceptual solution, the engineering analysis to support the design selection, and the planned engineering analysis/experimentation to prove that the final design will meet the specifications and requirements of the project.

We ask that you carefully review our report which will be sent to you electronically for errors in our proposed technical direction, particularly any errors that will affect the project requirements, goals or constraints. If there are concerns, they must be communicated both to the design team and to our Faculty Advisor Michelle Zeles-Hahn.

We look forward to receiving any feedback you may have on our report, as well as obtaining authorization to begin assembling the parts needed for constructing the alpha prototype. Additionally, please keep in mind that our final design project review will be conducted during the week of 4/19/2010. More information will be communicated as to the location and time of the review once we determine all associated parties' schedules for that week. If we can be of any assistance, please contact us at your discretion.

Sincerely,  
Team 2ReNeW



A collection of handwritten signatures in black ink, arranged vertically. From top to bottom, the signatures appear to be: a stylized signature, a signature that looks like 'Alex A.', a signature that looks like 'Curtis', a signature that looks like 'Michelle Zeles-Hahn', a signature that looks like 'Cole V.', and a signature that looks like 'Megan'.

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## 1.0 INTRODUCTION

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Team 2ReNeW is a Senior Design Project team at the Colorado School of Mines and consists of the following six members: Lucas Adams, Cole Donelson, Connor Weide, Mark Lu, Mike Stone, and Jeremy Johnson. Our client is iCAST, represented by Sam Anderson. Our faculty advisor is Michelle Zeles-Hahn and the team technical advisor is Neal Sullivan. The purpose of this project involves developing a start to finish system concept for producing briquettes using a commercially available briquetter. The team has also been charged with the task of creating an alpha prototype, or table top model, to showcase the technology to farmers. The contents of this report include project review, design requirements and specifications, and design methodology. A prototype design for testing procedures design validation is discussed in detail. In addition, a Gantt chart and budget are included.

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## 2.0 PROJECT REVIEW

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The ranchers and farmers of South Eastern Colorado have two massive waste streams, manure and wheat straw, that prove to be cumbersome and costly. The current methods used to remove them are satisfactory, but they are costly and waste potential chemical energy. When the two available waste streams are ground, mixed, and compressed into brick-form, a biomass briquette is formed. This briquette can be burned in a furnace and the potential energy stored within it can be released to produce electrical energy. Taking these waste streams and turning them into this energy can prove to be substantially beneficial. Farmers briquetting their waste can sell these briquettes to utilities, making money where they otherwise would be spending \$3000 to \$4000 to have their waste removed. Utilities also benefit by burning the briquettes. Biomass energy production has several biomass credits in the state of Colorado as well as surrounding states. It is therefore economically beneficial for stoker power plants to implement biomass co-firing, which is the process of firing the briquettes with coal at the same time.

Biomass briquetting is beneficial to not only those involved, but the greater engineering community. Briquettes displace the amount of carbon that would otherwise be burned from coal, curbing emissions. Although briquettes release CO<sub>2</sub> emissions, they are considered 'carbon neutral' since they are composed of carbon taken from the atmosphere; thus by burning them it is returning those gases back. Burning coal, however, pours carbon in the atmosphere that would otherwise be in the ground, creating a net positive input. In reference to global warming, the process of producing and co-firing biomass briquettes is not a solution, but rather a temporary reduction

mechanism as it merely reduces our carbon output. Regardless, it is an important intermediary step that allows us to slow our output while we search for other viable solutions that emit fewer emissions.

The goal of this project is to design an economically beneficial process to produce biomass briquettes for SE Colorado cattle farmers to sell or burn for energy. In addition, we must construct an alpha physical prototype of the system to show to farmers to illustrate the briquetting process, as well as create briquettes to test to gain more information on the process. We must then create a pilot plant design of a large scale system to present to iCAST. An energy and economic analysis will also be included in the large scale design plan.

### 3.0 DESIGN REQUIREMENTS AND SPECIFICATIONS

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Team 2Renew's ultimate goal is to develop a briquetting process that can be implemented on a real-world scale using commercially available parts. However, in order to gain insight into the requirements of developing this process, Team 2Renew will be developing a table-top model of the briquetting process. As such, the team has compiled a set of design requirements and specifications to aid in the prototype design; this will allow the team to conduct experiments that give insight into how the briquetting process should be assembled on a real-world scale.

The first requirement is the moisture content of the biowaste briquette prototype. Our research has shown that the biowaste must maintain a specific moisture content before briquetting in order to be briquetted correctly. Furthermore, in our selection of a real-world briquetting machine (BP-100), we discovered that the machine had a moisture content requirement of 15%. Therefore, when creating a briquette prototype, Team 2Renew will design the briquette to also maintain a 15% moisture content. An explanation on how we selected the BP-100 will be given in the Design Methodology section.

The second requirement is the energy content of the biowaste briquette. Because lab testing is not economically feasible, we cannot test for the actual energy content of our prototype briquettes. However, we can test for the relative energy content of the briquettes. We can compare the amount of time required to evaporate a given amount of water using both charcoal and biowaste briquettes. Thus, designing the biowaste briquettes to boil off the water roughly within the same timeframe as the charcoal is another specification we have. The difference between the two timeframes will allow us to determine the energy content of our biowaste material relative to charcoal. This procedure will be described in further detail in the Engineering Analysis section.

The third requirement is the durability of the briquette prototypes. In a real-world scenario, the biowaste briquettes would have to be stored and transported once made. The briquettes could end up in storage for several weeks, and would also have to survive the transportation from the briquetting site to the furnace site. Thus, the briquette prototypes must also maintain their shape for several weeks; this will be simulated through the use of a microwave. The procedure for this durability test will be described in further detail in the Engineering Analysis section.

The fourth requirement is that our briquette prototype must be able to compress the biowaste with the same force per area as the real-world model. The real-world model (BP-100) is specified to have a maximum working capacity of 15MPa (approximately 2175.56 psi). The large scale briquetter is designed to also be able to handle harder materials like wood. However, in our research, we have discovered that only 5-7MPa is required to compress manure and straw biowaste; any less pressure is not sufficient. Therefore, our prototype must be able to exert the same 5-7MPa of pressure.

To aid in easily identifying the design requirements and specifications for our prototype, a specifications list has been compiled below.

Table 1. Alpha Prototype Requirements and/or Specifications

<b>Briquettes must maintain 15% moisture content before briquetting</b>
<b>Briquettes must evaporate given amount of water within same timeframe as charcoal</b>
<b>Briquettes must be durable enough to withstand transportation as well as several weeks of storage (storage time will be simulated through use of microwave)</b>
<b>Briquetter must be able to compress biowaste with 5-7MPa of pressure</b>

## 4.0 DESIGN METHODOLOGY

### 4.1 BRIQUETTE MACHINE SELECTION

After finding commercially available briquette machines and potential large scale designs based upon their characteristics, we proceeded to evaluate each based on important criteria, which are

listed below. In addition, weights of 1-3 were given to each which was dependent upon what was the most important factor given the goals and constraints of the project.

Table 2. Machine Selection Variables

Variables	Weight
Cost	3
Accessibility	2
Features	2
Ease of Use	3
Maintenance	3
Energy Consumption	1

Cost was chosen since one of our main goal is to design and briquetting process that is economically feasible for farmers. Because our constrain is to make this economically feasible, it was given a weight of 3; the highest priority. Accessibility is used to describe how easy or difficult to get the briquette machines to Colorado. Since the BZBJ-1 and the MB-50 are fabricated and sold in China and Italy, respectively, we needed this to be factored into the evaluation process. It was given a 2 since the main concern with accessibility is the shipping costs associated with it. However, the cost variable takes this into account. Integrated features of the machines were another aspect, since some contain subsystems necessary (like heating and crushing) for adequate briquetting built in. A 2 was also given to this since although important, the machines could have features that are redundant to our briquetting process. An important constraint to our project is that the design must take into consideration the limitations of the persons using it. Obviously, farmers are not engineers and over-complicated operating procedures and equipment would not create investment from farmers, which is iCAST's goal from the project. Thus, the ease of use variable is important and given the highest priority of 3. Maintenance is also a large factor. If the machine breaks, it must not be too complicated to fix (again, designing within the consumer's limitations). This was also given a 3 since it is integral to the success of a long term investment, which this process will be. Lastly, energy consumption is another important factor. The energy consumed must be less than the energy the briquettes provide, maintaining both energy and economic efficiency. Each machine has a power rating and were ranked accordingly. Although important for an energy balance perspective, the amount of energy in a briquette is still much larger than the amount of energy used to form it. Because of this, the variable was given a weight of 1 since relative to the other priorities; this was insignificant. The decision matrix used to evaluate the machines is listed in Appendix A.

Although the BZBJ-1 and the MB-50 had many features, both were bogged down by complicated operation and the location they are sold from. If farmers could not operate the briquette machines, or if they had a large learning curve, the benefits of briquetting would be hard to convey. Even though both machines have extra subsystems necessary for proper briquetting, it also leads to slightly more complicated designs. Thus, if the briquetter broke down, maintenance would become too complicated and require external help. Specifically with the BZBJ-1, replacement parts cost just as much as the briquetter, and the company selling it only offers a 60 day warranty. Another factor is that both are made overseas, so customer service and attaining replacement parts would further complicate maintenance. In addition, machine power supply compatibility also poses a problem. The US's standard for voltage and frequency is 120V at 60Hz. The BZBJ-1 manufactured in China operates at 220V and 50 Hz, and the MB-50 manufactured in Italy operates at 230 V and 50 Hz. Frequency converters and adapters would be necessary if those briquetters were to be chosen. Overall the BP-100 had the advantage in its overall simplistic design that is more intuitive to explain (a hydraulic pump compresses the biomass). Although it lacks a heating and crushing subsystem, but since a lot of farm equipment sold locally can do these functions, it allows us to design a more intuitive process with equipment that farmers would understand.

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## 4.2 PROTOTYPE DESIGNPROCESS

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In engineering, there is not always a guarantee that engineering metrics will determine how a final product will look or function. For instance, one design may be too loud for a customer's preferences, so a different mechanism may be used for crushing, etc. Other times, the size of the product may need to be scaled down in order to fit in small spaces and therefore, different means may be necessary.

These are the types of decisions that we needed to make for the final design of our prototype. We wanted to build a small scale model that mimicked the full size final product as accurately as possible and needed a way to determine what it would look like by use of an open discussion. Appendix B contains the full description of our thought process, but it is important to note that it may not fully explain our decisions based on numbers.

For instance, when crushing the manure into manageably sized pieces, we decided to go with a rolling drum design so the manure would crumble into its smaller counterparts. If straw were used in this same crushing element, the straw would simply pass right through at the same size. This is why we need to cut and slice the straw down to size in a different subsystem.

Ultimately, there were a few decisions based on metrics. For instance, a hand press would need a very high load for mechanical advantage to mimic the final design's press, so we went with a small hydraulic press to mimic the same pressures necessary to make the briquettes.

So, by use of an open discussion of possibilities, we were able to take all the teammate's drawings and ideas and decide on one final design. Each of our subsystems mimic the same mechanical processes as the final product, which allows us to gain information from our prototype to employ in the large scale design.

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## 5.0 ENGINEERING ANALYSIS

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### 5.1 CALCULATIONS

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#### 5.1.1 ENERGY CALCULATION

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An important calculation we performed was to determine the amount of energy needed to form the briquettes. Using the known values of the power consumption; energy content of a 50/50 mix of manure and straw (our research indicates 3,599 kcal/kg), and assuming the thermodynamic process and generator efficiencies, the input and the energy of the briquettes were compared. The comparison was based on the amount of energy and mass output in one hour. The result was that the energy input is much less than the energy that could be harnessed from the briquette, making the process energy feasible. The calculation is listed in Appendix C.

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#### 5.1.2 BRIQUETTE SIZE

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The chart titled "Surface Area to Volume ratio of Cylinder, Cube, and Brick Configurations," shown in Appendix D describes the relationship between each geometric shape's surface area and volume. A briquette with a high surface area will burn quicker than one with small surface area. But a briquette with a large volume will last longer than a smaller one. So the ideal briquette is one with both qualities, resulting in a briquette that burns both hot and steadily for a long time. However, there are size limitations to the briquettes. Therefore, the geometric configuration with the most surface area relative to its volume is optimal. Given the nature of briquetting machines, either a rectangular prism or cylinder shape is feasible. The brick shape has a width:length:height ratio of 3:5:10. The cylinder shape has a radius:height ratio of 1:5.

The graph clearly shows that the cylinder configuration is optimal. The cube only surpasses the cylinder at unreasonable volumes. The brick would surpass the cylinder at high enough volumes, but these briquettes would be too large to produce or burn efficiently.

It is important to note that the brick shape's dimension ratio was arbitrary, and much more analysis would be necessary to fully determine how useful it is. However, since the cylinder configuration is easy to produce and burns much better than both other designs at appropriate volumes, it was chosen for this project.

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### 5.1.3 CURRENT ECONOMIC ANALYSIS

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In order to be certain this project is feasible, the team conducted an economic analysis. The goal of this analysis was to make sure that someone investing in the briquetting process would get some return. The team started by determining how much money it would cost the operator to run the briquetting system. This is known as the operating cost. In order to do this the team used two approaches to find out how much power was used. One way was multiplying the volts by the amps to get watts, and then converting to kilowatt hours. Kilowatt hours are what utility companies use to measure how much power people use. The alternative method was to determine the number of kilowatt hours from the maximum horse power the briquetter uses. Both of these methods yielded the same amount of energy used. It was then assumed that the heating and mixing subsystems would require power, although not as much as the briquetter. After looking at the energy requirements of some of the proposed subsystems, we made a conservative estimate that assumed that they would use approximately one third as much energy as the briquetter. This was assumed given the subsystems simplicity compared to the amount of work for the briquetter to compress the biomass. The amount of energy used by the briquetter was then multiplied by one and one third to get the total energy used by the entire system. This method was also applied to determine how much energy the briquetter used when it was producing its minimum output. It was then determined how many hours it would take to produce one ton of briquettes given the briquetter's minimum and maximum output numbers. The number of hours were multiplied by the number of kilowatt hours the machine used. This number was then multiplied by the average cost of electricity per kilowatt hour in the state of Colorado during 2009. This gave us a good number on how much money it would cost to produce one ton of briquettes from waste materials. This also gave us insight on the cheapest way to run the briquetter. According to our calculations one could save about three dollars a ton by running the machine at maximum output for less time. The team then compared the cost of producing one ton of briquettes to the 2008 prices of a ton of coal. Assuming

that all else equal, the farmer stands to make about twenty five dollars of profit per ton of coal. In addition to the economic profits that farmers stand to make, there are also economic incentives for power plants to use briquettes produced by farmers in Colorado. One incentive includes tax breaks for using renewable resources. Another incentive involves meeting quotas for reducing emissions and using less fossil fuels. These incentives are hard to quantify, but they only add to economic feasibility of this project.

After verifying that waste briquetting could cover the operating cost, the team then made some assumptions and did some rough calculations to see how long it would take to cover the investment, or capital cost. To do this the team found out how many tons the farmer would have to produce to make enough money to cover the capital cost. It was then calculated how long it would take to produce that amount of briquettes. It would take roughly 1000 days of producing briquettes at full capacity, or 3.33 years to cover the cost of the initial investment. The calculations are shown in Appendix E.

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## 5.2 PROTOTYPE DESIGN

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### 5.2.1 ENCLOSURE/HYDRAULIC PRESS

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In developing a press to mimic the BP-100 briquetting machine we selected, we designed a steel enclosure which will house the components necessary for producing briquettes. These components will include a two inch long ASTM A36 steel bushing with an inner diameter of 2.05 inches, and an outer diameter of 3.05 inches. A single acting hydraulic actuated cylinder and pump will also be utilized to obtain the optimum pressure for creating briquettes. Our enclosure will allow team 2ReNeW to wedge the cylinder against one of the flanges of the enclosure and extend the piston into the bushing. After the desired pressure has been reached, the piston will be retracted to allow for the extraction of the briquette.

A finite element analysis was performed to determine how the enclosure would withstand the pressure and reaction forces it will experience. The displacement, stress, and factor of safety plots for the housing enclosure are located in Appendix F of this report. Preliminary calculations were also performed to determine the viability of the proposed enclosure for creating briquettes. These calculations can also be found in the appendix.

Steel channel sizing standards indicate that the dimensions needed for constructing this enclosure are unavailable. In order to obtain the desired dimensions of our housing enclosure, three ASTM A36 steel .25 inch thick plates will be welded together.

The mechanical advantage of hydraulics will allow us to reach the prescribed pressure to simulate the pressure associated with the BP-100 briquetting machine. We will be able to accurately determine when this desired pressure is reached by visually inspecting the attached pressure gage on the hydraulic pump. Additional modifications will be made as the testing of our hydraulic press progresses.

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### 5.2.2 CRUSHING DRUMS

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In order to take raw manure and break it down into a manageable size for both heating and briquetting, we need a mechanical way to physically break down the solids. The best option we found was using a food processing standard element called a “seed crusher.” A seed crusher is essentially two metal drums that rotate into each other. The raw material is deposited on top by gravity and the smaller, crushed remains exit the bottom. Different seed crushers have a different distance between drums and are actuated by two simple gears of the same size. Since a commercially available seed crusher will be used in our full-scale, Beta prototype, we will recreate a smaller one for our Alpha prototype.

Using a lathe, the metal drum elements will be set to the right size. Additionally, catalog-bought gears will attach to the drum shafts via a small gear key. Finally, the enclosure that will hold the drum elements together will be made out of wood, vinyl, or any other easily available material used to make simple boxes. The drums will be powered by either a hand crank or an electric motor depending on budgetary constraints. Also, the feeding mechanism will again be gravity fed by installing a 5-gallon bucket with a cut-out bottom above the drums.

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### 5.2.3 MIXER

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In order to ensure proper mixing after the straw and manure have been reduced in size, a mixing station will create product homogeneity. This will be done by mimicking the Beta prototype’s mixing element which is a commercially available, large, rotating drum used for small civil projects and farm operations. Much like a cement mixer, the inside of the drum is lined with helical fins and the over-all drum is set at an angle to the ground. When the drum is turned one way, all the elements are brought to the bottom of the drum and continually tossed and mixed. Turned the opposite way, all the material will make its way to the top of the drum and fall out into our next element. In the Beta prototype, this drop will pour the evenly mixed manure and straw directly into the briquetter.

By making “batches” of mixed product, the mixer will turn one way for a predetermined time to mix, then the opposite way to expel the material into the briquetter. This time will be determined through our research with the Alpha prototype. Additionally, the amount of material mixed in each batch as well as the time it takes to make one batch will be accounted for in order to match the output of the Beta prototype’s briquetter.

In our Alpha prototype model, we will use hand-cut and bent sheet metal to create the helical fins in a 5-gallon bucket. They will be attached by nuts and bolts or rivets if they become available to us. Next, using basic carpentry skills, a wooden base will be constructed so that the drum will be held at a 45 degree angle and will be supported by a small bearing at the bottom as the top will rest between two wheels from a lawnmower. One of these wheel’s shaft will then be connected to a hand crank or a motor depending on budgetary constraints. This can all be seen by the photographs in appendix G.

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## 5.3 TESTING PROCEDURES

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In mimicking the large scale process, we wanted to use our prototype to test various characteristics of briquettes to gain insight that could impact our final design. The traits our team found were important were durability, relative energy content, moisture content and process variability.

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### 5.3.1 DURABILITY

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In order to test the durability of the briquettes, the team will perform the following procedure.

1. Obtain about twenty similarly-sized briquettes
2. Set up the Tinius Olson machines (available in the labs in Brown Building) to hold the briquettes and administer a compression force
3. Measure the briquettes for axial compression:
  - a. Place the briquettes vertically (flat faces up and down) into the Tinius Olson machine
  - b. Run the machine, increasing the pressure until the briquette fails
4. Measure the briquettes for lateral compression:
  - a. Set up the Tinius Olson machine so that the round faces of the briquettes will not roll away from the compression plates
  - b. Place the briquettes horizontally (round face down) into the Tinius Olson machine

- c. Run the machine, increasing the pressure until the briquette fails
5. While running each set of tests, vary the speed at which the pressure is increased.  
(As of right now, it is difficult to determine what range the pressures will fall into, and so it is also difficult to determine at what rate to increase the pressure. However, once several tests are run, this rate will be easy to distinguish)
6. Compile all of the data and, using the formula  $\sigma=P/A$  and other mechanics of materials fundamentals, determine the Young's Modulus, Ultimate Strength, and Yield Strength of the briquettes. These properties represent the brittleness, durability, and strength of the briquettes.  
Using statistics theories, determine the average values, as well as the standard deviation of these values (which will in part represent the variability of the briquettes).

The reason for varying the rates of pressure increase is to determine if the biomass is not perfectly elastic. A similar study by iCAST suggested that the point at which the briquettes fail would be difficult to determine, as the briquettes fractured slowly. A slow pressure increase might imitate these results, with the briquette fracturing at a given pressure value, whereas a very rapid pressure increase might cause the briquette to fail in a brittle manner, and possibly at a different pressure value.

These tests are necessary to prove that the briquettes will hold their shape under extreme conditions, because the shape of the briquettes is vital to optimal burning. During transport, for instance, the briquettes may not be treated very delicately. The team needs to know that they will not simply crumble back into a powder of manure and hay. Knowing the durability of the briquettes will ensure that they burn as efficiently as possible.

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### 5.3.2 RELATIVE ENERGY CONTENT

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The relative energy content experiment allows Team 2Renew to determine the amount of energy in our biowaste briquettes in comparison to briquettes of known energy content. This experiment will compare the amount of time required to evaporate 50mL of water using both charcoal briquettes and our biowaste briquette prototypes.

By evaluating the amount of time required to evaporate a set amount of water, we can see how much energy the biowaste releases relative to the charcoal. The data collected from this experiment will be vital in determining the thermal efficiency of our biowaste briquettes. If the biowaste briquettes can evaporate the water within the same timeframe as the charcoal, then we

can assume that they have roughly the same thermal energy content. They will most likely be different, but using the proportion of the times for both material burning and the energy content of charcoal, we can determine the energy content of the briquettes.

If the briquettes prove to be energy inefficient, we can test different compositions of biowaste by altering the ratio of straw to manure; this will allow Team 2Renew to determine the briquette's optimum ratio and improve its thermal energy efficiency. This data will therefore allow us to create real-world biowaste briquettes that offer optimum energy efficiency.

The procedure for this experiment is as follows:

1. Obtain 50mL of water
2. Obtain 1lb of charcoal
3. Pour the water into a heating pot
4. Place charcoal into barbecue grill
5. Place heating pot on top of barbecue grill
6. Ignite charcoal and sustain fire until charcoal can sustain its own heat
7. Record amount of time required for the water to completely evaporate
8. Repeat steps 1-7 using 1lb of biowaste briquettes (50/50 straw to manure ratio) in place of charcoal

NOTE: Once the experiment has been completed, repeat the experiment using 1lb of biowaste briquettes that do not have a 50/50 straw to manure ratio. Test different ratios until it is evident which ratio of straw to manure provides the most thermal energy.

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### 5.3.3 MOISTURE CONTENT

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The procedure for figuring moisture content of the raw materials before briquetting is as follows:

1. Obtain a plastic bin, an old oven, an old microwave, a scale sensitive down to 1/100 of a gram, and a cool dry storage area.
2. Using the plastic bin to zero out the scale, weigh out a quantity of 10, 10 gram samples of "fresh" manure.
3. Using the plastic bin again, weigh out a quantity of 10 gram samples of "fresh" straw as well.
  - a. Keep each sample of manure and straw properly labeled.
4. Exactly 24 hours (+- 1 hour) after weighing out the original samples, reweigh all the samples for both the manure and straw.

5. Repeat step 4 until the change in weight seen by the next weigh-in is less than 5%.
6. When this happens, place all the samples in an oven at 90-100 degrees Fahrenheit for 24 hours in order to completely dry out the samples.
7. Quite separately from steps 2-6, weigh out 10 10gram samples of “fresh” manure and 10 10gram samples of “fresh” straw again.
8. Using the microwave at 70% of high power, cook one of the samples for 1 minute and reweigh it after.
9. Repeat step 8 while continually increasing the cook time at appropriate increments as seen fit throughout the test for each new sample used.
10. Taking the information you obtained from steps 2-6, use the following equation to determine the moisture content of the materials at various days in the timeline.

- a. 
$$M_n = \frac{(W_w - W_d)}{W_w} \times 100$$

- b. Where Mn is the moisture content
  - c. Ww is the wet (current) weight of the sample
  - d. And Wd is the dry (final) weight of the sample
11. Repeat step 10 with the results you obtained for steps 7-9.

The previous test will prove crucial in figuring moisture content for the raw materials we will be using to make our briquettes. First, the briquetting machine we will be using has a certain tolerance for the moisture content of the materials that are put into it. This tolerance band ensures a good briquette product. Additionally, we want to guarantee to the future client (the farmer) that the product they produce will not crumble due to a variance in moisture content, which in turn effects its ability to stick together.

By manipulating the data obtained from the previous experiment, we will be able to determine a window of “days after creation” when the manure and straw will be safe to use for briquetting. In the case of the manure, the “creation” is when it is expelled from the cow, and for the straw, “creation” will be when it is cut from the ground. It is from those moments on that the moisture content will gradually decrease until it becomes in balance with the Colorado atmosphere.

By weighing the samples every 24 hours, we will find an average wet weight for each 24 hour period. When we completely dry out the samples in an oven at the end of our experiment, we will be able to tell the exact moisture content of the samples as the weight after the oven will be the official dry weight. As you can see, it will be quite beneficial to know that manure must be used 5-8

days after it is created where the straw may only need to wait two days. This will ensure us a good, consistent product.

Just to explain one further point, the use of a cool, dry storage space for the samples is supposed to mimic being on the inside of a barn or under a canopy on the farm. Hopefully, by keeping the samples covered, they will at least be free from any rainfall and in turn unreliability.

Finally, the point of the second part of the experiment (using a microwave to quickly dry the samples out) is for the benefit of our research endeavors. If we can find a strong correlation between say, drying the samples for 6 minutes and waiting 5 days, then long periods of waiting for samples to dry to appropriate moisture contents will not be necessary and will not conflict with time constraints in the semester.

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#### 5.3.4 PROCESS VARIABILITY

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The following procedure will be used to test the variability of our briquettes:

1. Create at least 30 briquettes using the table-top prototype model that the team built where the 30 briquettes must come from at least three batches.
2. Using a knife or a saw, cut a sample in half across its 2" cross-section.
3. Using a magnifying glass or simply your eyes, count the "clumps" of manure and the "clumps" of straw.
4. Repeat steps 2-3 for all of the samples.

Process variability testing will ensure that the mixing element to our prototype and ultimately, our entire design is satisfactory for use. If the resulting data proves to have a close to 50-50 mixture (our intended mixture) then, any random cross-section of the briquettes should also be 50-50. It will be assumed that any random 2D cross-section can be representative of the whole if enough samples are taken. This will ensure a homogeneous product and therefore, will guarantee both the farmer and the stoker power plant that they will be receiving a good and consistent product which will be crucial to the success of this project.

One point that needs to be stressed is that all the parts of the model mimic the full scale machinery. This way, the model will indeed produce a similar product that the end machinery will produce. If we find that the briquettes are NOT homogeneous, then we will increase the mixing time as seen appropriate. It is these tests, early on, that will guarantee a good end product.

Finally, by taking at least 30 samples from 3 different batches, we are ensuring good statistical practices and won't have any outliers without a truly good reason for them being present. From all our data, we will plot our results from many samples to get a standard deviation. This will allow us to have a quantifiable result to express the variability as well.

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## 6.0 PROJECT SCHEDULE AND BUDGET

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### 6.1 PROJECT SCHEDULE

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The Gantt chart is very similar to the last except for a few changes. Most importantly, the team realized the need to test not only the prototype, but the briquettes as well. Two processes were added: the design of the briquette testing procedures and the actual testing of the briquettes. The other major change was the repositioning of the activity, "Design Prototype." After discussing the project with faculty and technical advisors and the client, the team decided that the production of the prototype would be much more of the engineering analysis and design process than previously thought. For this reason, it was moved back so that its conclusion aligned with the completion of the 60% DAV report, and free float to allow for minor changes to the design before the final DAV report. All other changes were made to compensate to the previous changes, and are not particularly significant. The schedule is attached to the email along with this report.

### 6.2 PROJECT BUDGET

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In order to ensure that sufficient funding is available when the alpha prototype begins development, Team 2 Renew is proposing the budget shown in Appendix H. The client has allocated a budget of \$1500 that can be used towards accomplishing the goals of this project. Our client, iCAST, will be the main source of the funding, and will be handling all procurements as well. As it stands, the proposed budget is sufficient to cover the team's estimated cost for completion of this project. However, if unforeseen future costs arise that can improve the design and quality of the project, adjustments to the budget will be necessary. The client has stated that in such a scenario, a request to increase project funding will be acceptable, and will be easily dealt with.

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## 7.0 CONCLUSION

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At this stage, team 2ReNeW has created a design for the alpha prototype that will allow us to start performing tests on the briquettes. These tests will aid us in altering the final pilot plant design.

Because of this, we made certain that our prototype subsystems had a large scale analog to ensure the best results and insights. After feedback from our advisors, we will finalize the prototype design and tests and begin building. Once these tests are performed, we will move on to designing the large scale solution based on commercially available farm equipment. Our schedule reflects our course plan, and our budget illustrates the needs to build out prototype. We look forward to continue with this project and fulfill the goal of benefiting local farmers and progressing alternative energy adaptation.

## APPENDIX A: BRIQUETTER DECISION MATRIX

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	<b>Briquetting Machines</b>	BP-100	BZBJ-1	MB-50
<b>Variables</b>	Weight			
Cost	3	3	3	1
Accessibility	2	5	1	1
Features	2	2	4	4
Ease of Use	3	4	5	2
Maintenance	3	4	2	2
Energy Consumption	1	4	4	2
	<b>Weighted Totals</b>	51	44	27

## APPENDIX B: DETAILED PROTOTYPE DESIGN PROCESS

### Prototype thought process

1/27/2010 meeting notes (Upstairs CTLM group meeting)

- The hand press briquetter is no longer available to us
  - Need to design our own as a part of the prototype
  - Initial thoughts on hand presses
    - Using mechanical advantage, have a simple crushing lever
    - After basic calculations, we found that the applied force will need to be very high
      - No way to accurately duplicate it every time
    - Could us a smaller surface area ( $d=1\text{inch}$ ) to get needed force
      - Does not mimic real product
        - What if scaling has a significant effect on burning speed?
        - Will definitely have an effect on durability
      - Need to duplicate real product at  $d=2\text{inches}$  and  $0.5\text{in}<L<5.5\text{in}$
    - Also thinking about a screw-type mechanism, but again, it would be too cumbersome to produce bricks and appropriate psi would not be reached
  - Determined the use of a hydraulic/pneumatic press/piston mechanism would get correct compression
    - Have a model in mind that has a simple piston element
    - Can compress fuel mixture into a PVC/metal pipe with 2in diameter and we will compress up to the given psi
  - All mechanical means seem ineffective. Determined the hydraulic route is the way to go.
    - Additionally, the compression enclosure could be made out of an appropriate flange beam ("C" beam)
- Need a way to store the raw products
  - Determined a 5-gallon bucket is adequate for the prototype while also manageable on our scale.
- Need a way to crush the straw and manure before mixing
  - Initial thoughts on the use of a blender
    - While the blender, would chop up straw highly effectively, there is no large scale equivalent to it.
    - **We decided that we want to mimic the large scale end-product with our small scale prototype, so we must use appropriate methods of manipulation in order to problem solve if errors occur.**
    - The blender is out.
  - Crushing straw may be done by grinding
    - We want to mimic an electric shaver (and many food processing machines) by having a spinning blade and a grate at the bottom of the crushing/chopping vessel.
      - Only pieces small enough to fit through the grate will fall to the next step of the process
      - Pieces still too large will be reground until small enough.
  - Crushing the manure may be done by two rotating drums
    - Since the manure will be at the appropriate low moisture content, it will have a certain brittleness to it.

- The “crumbling” properties of the manure will be taken advantage of by feeding it through two rotating cylinders.
    - This process is also done in many food processing plants i.e., seed crushing.
      - Any manure still too big to fit through the opening will remain above the drums
  - The Reason for two different crushing machines
    - It is thought that manure in a blade-type mechanism will not be effectively degraded much like ice cubes bounce in a blender without the presence of liquid.
      - This is why we need the rotating drums.
    - It is thought that straw in a rotating drums-type mechanism will not be effectively degraded as the thin straw stalks may simply get “crunched” and not cut into smaller pieces.
      - This is why we need the blade and grate.
  - Exploration
    - It may be found that the blade may be effective for both material inputs. Additionally, it may be found that the drums may be effective for both as well.
    - The prototype will determine if these processes are redundant and modifications to the final design may be made as a result.
- Need a way to mix the two input materials
  - Since it is a table top model, we could simply mix the two materials together by hand.
  - One of the original concept variants we made had a rotating drum that mixed the materials.
    - On the inside of the drum, there are helical groves just like a cement mixing truck.
      - By turning the drum one way, the materials will be brought to the bottom and continually mixed
      - By turning the drum the opposite way, the materials will make their way out of the top of the drum (and in our case, into our hydraulic press)
  - We again need to duplicate the large scale process in order to guarantee that it works.
    - This is why we chose a rotating drum rather than mixing the ingredients together by hand.
    - Also, by having the small-scale rotating drum, we will be able to determine a “minimum mixing time” in order to guarantee proper homogeneity of the final product.
- Need a way to pre-heat the material before briquetting
  - Possible ways are still heating coils, and blowing air.
  - Since no strong evidence for or against either method can be theorized at this point, both conduction and convection heating methods will be explored in making our prototype.
- We will not include any screw-feed mechanisms in our prototype due to scaling costs.
  - There is no reason to believe that farm-capable (and commercially available already) screw feeds cannot deliver organic materials that they already handle all over the world every day.

- Using this entire thought process, we determined that our prototype would include rotating drums to crush the manure, rotating blades and a grate to cut the straw, a rotating drum to mix the two together, and a hydraulic pump in order to duplicate the actual final briquettes.
  - Any problems we encounter along the way will come as a direct result of problem solving these variations.

## APPENDIX C: ENERGY CALCULATION

### ENERGY CALCULATION

#### ASSUMPTIONS / KNOWN

- Using 50/50 Manure to straw mixture  
 $3599 \text{ kcal/kg} \Rightarrow 15.07 \text{ MJ/kg}$
- Briquetter operating at full load : Max output
  - 6 kW @ F.L , 63 kg/hr
- Thermo Efficiency @ 22%, Generator efficiency 80%  
 (Heat  $\rightarrow$  MECH WORK)      (Mech work  $\rightarrow$  Electricity)

#### ONE HOUR BASIS

#### INPUT ENERGY

$$6000 \frac{\text{J}}{\text{s}} \cdot (3600 \text{ s}) = \underline{21.6 \text{ MJ}} \text{ used by Briquetter}$$

#### Output / ENERGY FROM BRIQUETTE

$$63 \text{ kg/hr} \cdot 1 \text{ hr} = 63 \text{ kg of Briquettes made}$$

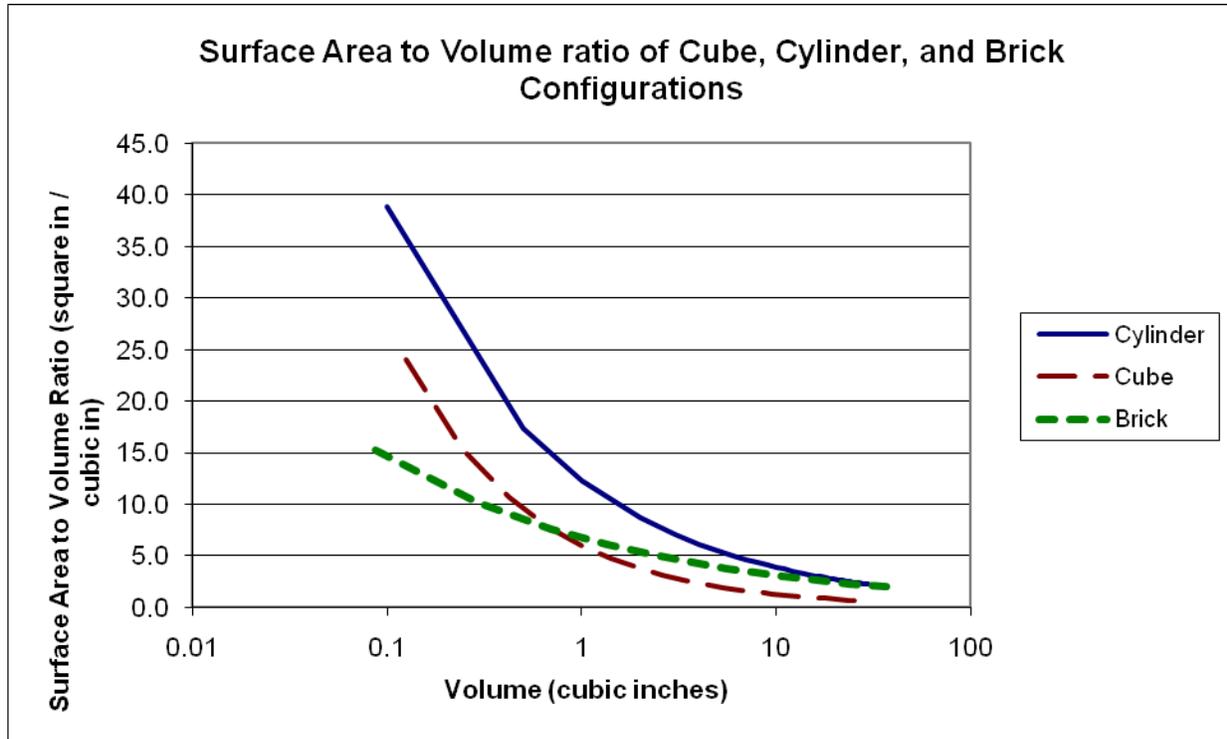
Burning briquette to produce MECH. work to Electricity

$$- 63 \text{ kg} \left( \frac{15.07}{\text{kg}} \right) = 949.4 \text{ MJ of Energy in 1 Hour Batch}$$

$$- 949.41 \text{ MJ} (0.22)(0.8) = \underline{167.09 \text{ MJ}} \text{ of Electrical Energy from Briquettes}$$

Since  $167.09 \text{ MJ} > 21.6 \text{ MJ}$ , or Electrical Energy from Briquettes  $>$  Input Energy to Briquetter, the process is Energy Feasible.

## APPENDIX D: CYLINDER VS CUBE CHART



## APPENDIX E: ECONOMIC ANALYSIS

Maximum Output:

$$V := 230V \quad I := 26A \quad \text{Power} := V \cdot I \quad \text{Power} = 5.98 \times 10^3 \text{ W}$$

Electricity used :  $\text{Power} \cdot 60 \text{ min} = 5.98 \text{ kW} \cdot \text{hr}$

$$\text{Power} := 7.5 \text{ hp} \quad \text{Power} = 5.593 \times 10^3 \text{ W}$$

$$\text{Electricity}_{\text{used}} := \text{Power} \cdot 3600s \quad \text{Electricity}_{\text{used}} = 5.593 \text{ kW} \cdot \text{hr}$$

Assumption : the other heating and mixing systems are not as electrically demanding, and therefore will use approximately 1/3 as much energy.

$$\text{Electricity}_{\text{briquetter}} := \text{Electricity}_{\text{used}}$$

$$\text{Electricity}_{\text{other}} := \frac{1}{3} \text{Electricity}_{\text{briquetter}}$$

$$\text{Electricity}_{\text{total}} := \text{Electricity}_{\text{briquetter}} + \text{Electricity}_{\text{other}} \quad \text{Electricity}_{\text{total}} = 7.457 \text{ kW} \cdot \text{hr}$$

In 2009 commercial electricity cost 8.16 cents per kW\*hr

[http://www.eia.doe.gov/cneaf/electricity/epm/table5\\_6\\_b.html](http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html)  
Maximum output is 140 lb per hour

$$\frac{1 \text{ ton}}{140 \text{ lb}} = 14.286$$

It would take 14.286 hours to produce 1 ton of briquettes at maximum output

$$14.286 \cdot 0.8167547 = 8.798$$

It would take \$8.80 to produce 1 ton of briquettes at 14.286 hours for 8.16 cents a kW\*hour using 7.457 kW\*hour.

Minimum Output

$$V := 208V \quad I := 26A \quad \text{Power} := V \cdot I \quad \text{Power} := 5.40810^3 \text{ W}$$

Electricity used :  $\text{Electricity}_{\text{used}} := \text{Power} \cdot 3600s \quad \text{Electricity}_{\text{used}} = 5.408 \text{ kW} \cdot \text{hr}$

$$\text{Electricity}_{\text{briquetter}} := \text{Electricity}_{\text{used}}$$

$$\text{Electricity}_{\text{other}} := \frac{1}{3} \text{Electricity}_{\text{briquetter}}$$

$$\text{Electricity}_{\text{total}} := \text{Electricity}_{\text{briquetter}} + \text{Electricity}_{\text{other}} \quad \text{Electricity}_{\text{total}} = 7.211 \text{ kW} \cdot \text{hr}$$

Minimum output is 100 lb per hour

$$\frac{1\text{ton}}{100\text{lb}} = 20$$

$$20 \cdot 0.08167 \cdot 211 = 11.768$$

It would cost \$11.768 to produce 1 ton of briquettes at 20 hours for 8.16 cents a kW\*hour

for electricity using 7.211 kW\*hour.

The average cost of coal per ton is \$36

[http://greenecon.net/understanding-the-cost-of-solar-energy/energy\\_economics.html](http://greenecon.net/understanding-the-cost-of-solar-energy/energy_economics.html)

$$36 - 8.789 = 27.211 \quad 36 - 11.768 = 24.232$$

$$\frac{27.211 + 24.233}{2} = 25.722$$

This number shows that all else equal, farmers stand to make around \$25/ton of waste briquettes

Assume the briquetter will cost \$16,000, and to get a round number for the project, we can assume that the other systems and labor will cost roughly \$4000, we will try to determine how long the briquetter must be run to pay back initial investment.

Assumptions : briquetter is run for 12 hours a day, 300 days a year, it takes 15 hours to produce a ton of coal, and the operator stands to make \$25 of profit per ton

$$\frac{20000}{25} = 800$$

It will take 3 and 1/3 years to cover the cost of capital  
It will take 800 tons of briquettes to cover the cost of the machine

$$800 \cdot 15 = 1.2 \times 10^4$$

It will take 12,000 hours to produce 800 tons

$$\frac{12000}{12} = 1 \times 10^3$$

It will take 1000 days at 12 hours a day to make 800 tons

$$\frac{1000}{300} = 3.333$$

## APPENDIX F: ENCLOSURE/HYDRAULIC PRESS MODELING AND CALCULATIONS

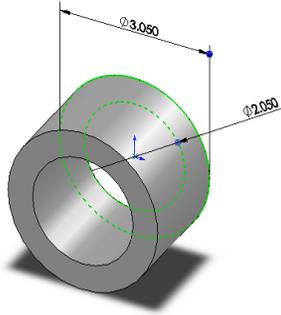


Figure 1. SolidWorks Model of Steel Bushing

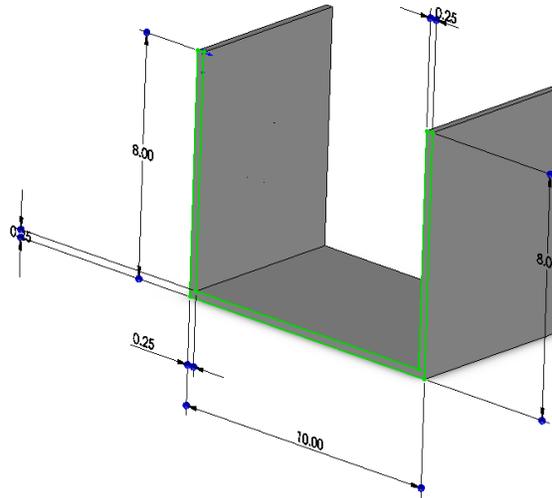


Figure 2. SolidWorks Model of Enclosure for Producing Briquettes

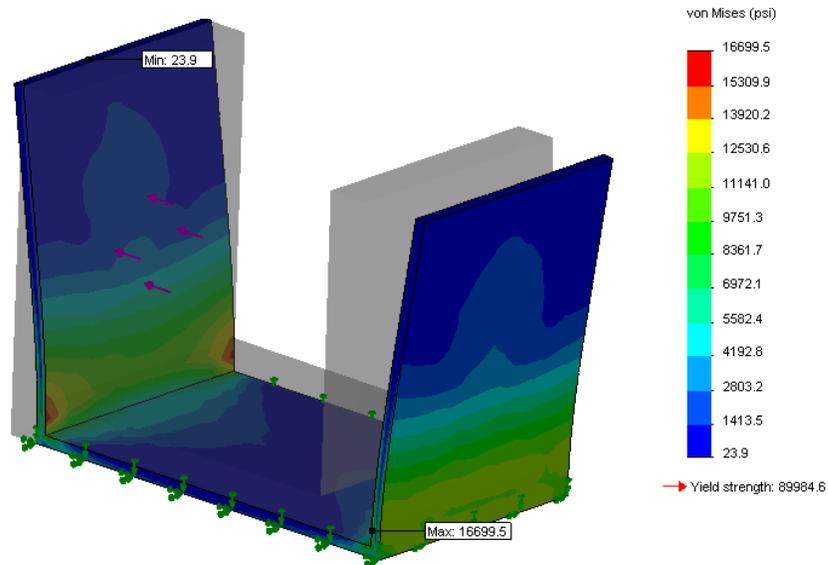


Figure 3. Finite Element Analysis of Enclosure for Producing Briquettes (Stress)

Figure 4. Finite Element Analysis of Enclosure for Producing Briquettes (Displacement)

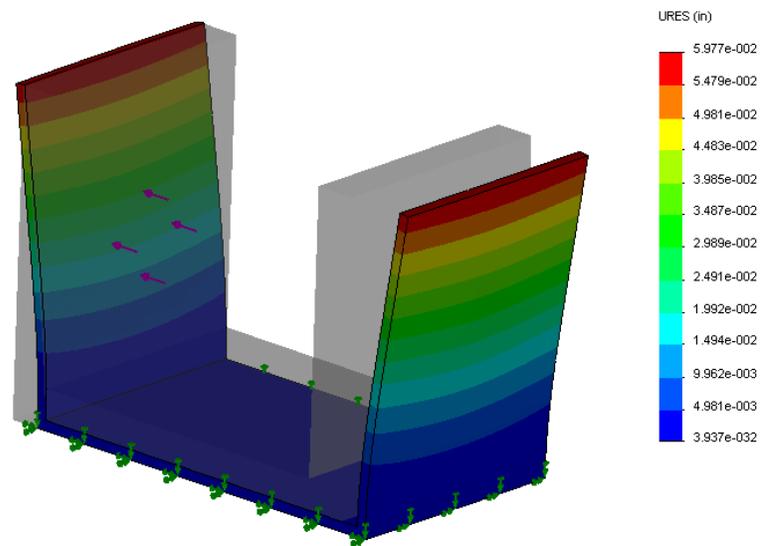


Figure 5. Finite Element Analysis of Enclosure for Producing Briquettes (Factor of Safety)

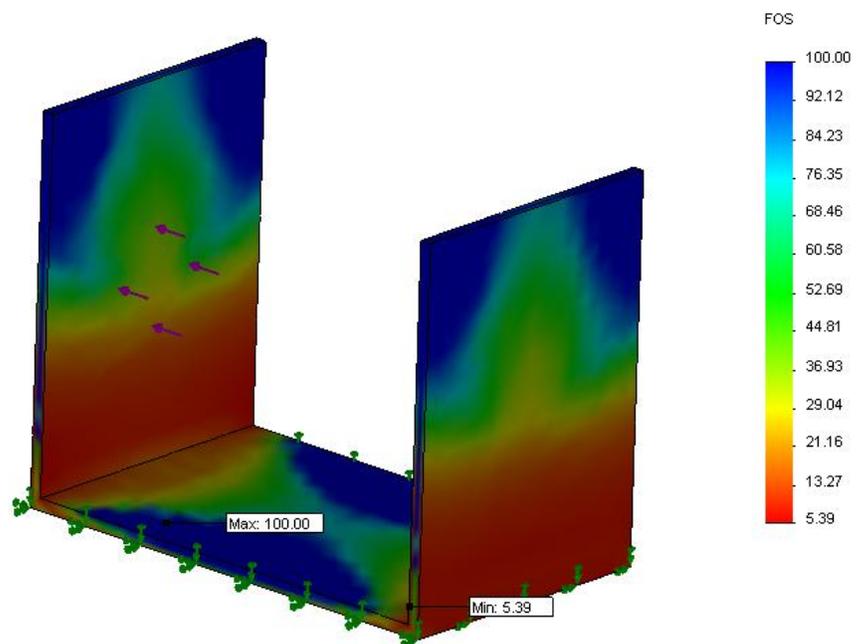
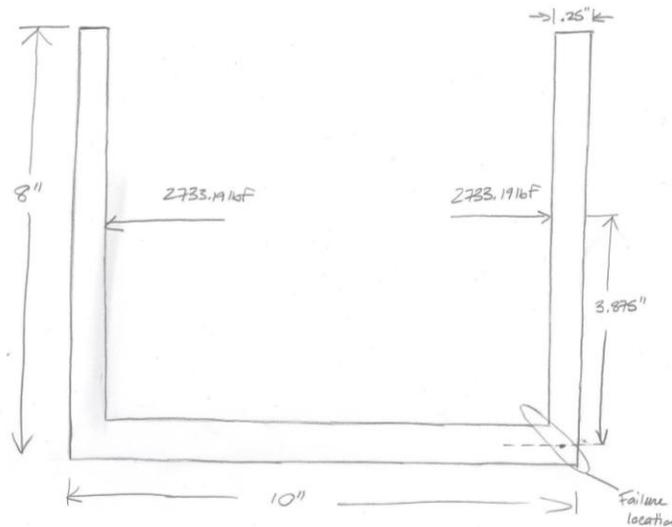


Figure 6. FBD/Dimensions of Enclosure



### Preliminary Calculations:

$$\text{Ideal}_p := 870 \frac{\text{lbf}}{\text{in}^2} \quad b := .25\text{in} \quad h := 8\text{in} \quad l_{xx} := 3.875\text{in} \quad S_y := 36300 \frac{\text{lbf}}{\text{in}^2}$$

$$F_{\text{area}} := \text{Ideal}_p \cdot \pi \text{ in}^2 = 2.733 \times 10^3 \text{ lbf} \quad c_{xx} := .125\text{in}$$

$$I := \frac{1}{12} \cdot b \cdot h^3 \quad I = 10.667 \text{ in}^4 \quad \text{Conservative stress concentration.}$$

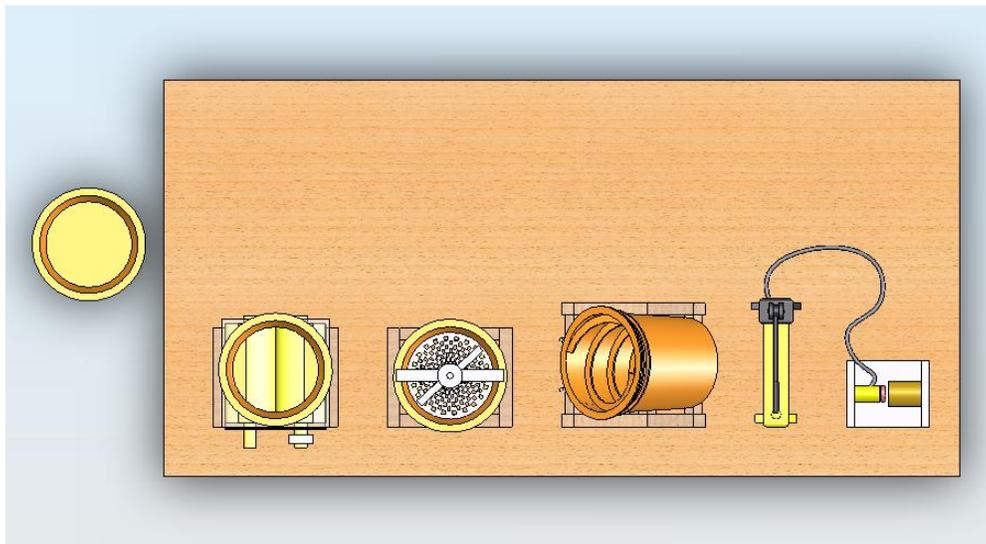
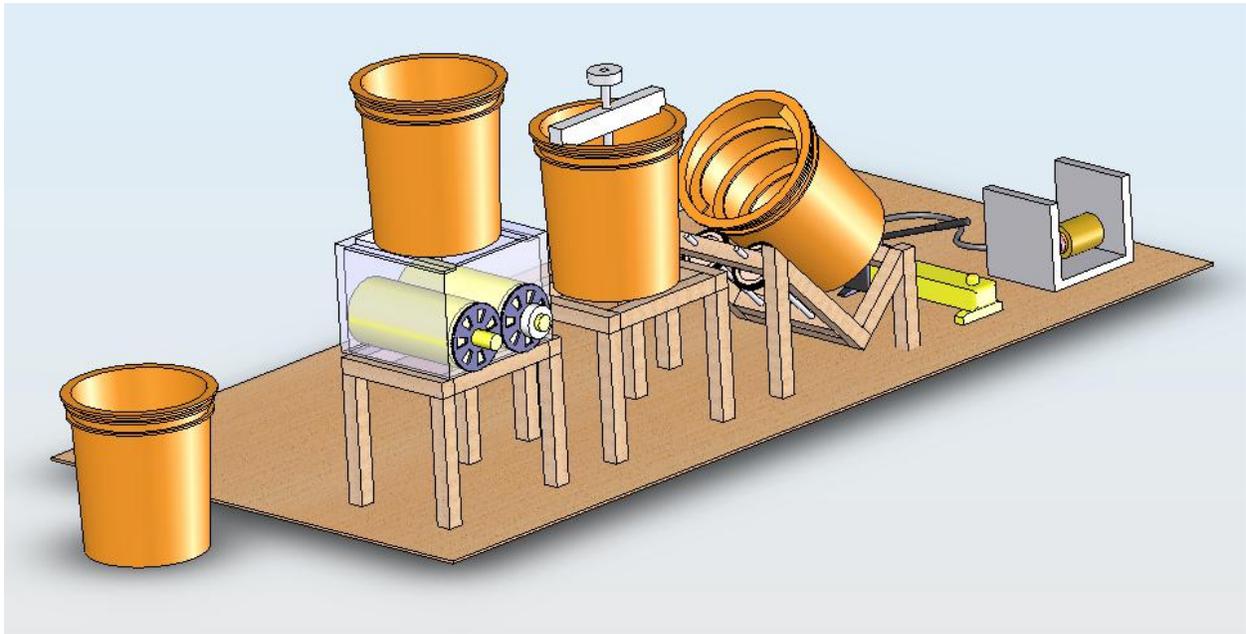
$$M := F_{\text{area}} \cdot l \quad M = 1.059 \times 10^4 \text{ lbf} \cdot \text{in} \quad k := 3$$

$$\sigma := \frac{M \cdot c}{I} \cdot k \quad \sigma = 372.343 \text{ psi}$$

$$\text{FOS} := \frac{S_y}{\sigma} \quad \text{FOS} = 97.491$$

The hand calculations don't account for stress concentrations along the edge of the weld connecting the .25 inch pieces together thus the hand calculations are very conservative. By using 60,000psi rated weld material, the enclosure can be modeled as a single part.

## APPENDIX G: SYSTEM DESIGN



## APPENDIX H: BUDGET

Component	Purpose	Quantity	Estimated Cost	Justification of Cost
Biowaste (non-irrigated wheat straw and cow manure)	These are the materials that will be briquetted	Variable	Free	Biowaste will be supplied by the client
Sheet metal	Used to construct housing for prototype	Variable	\$100	Sheet metal is fairly inexpensive, but a significant amount will be required to construct the housing
PVC piping (2" diameter, 4 feet long)	Used as a mold to create prototype briquettes	1	\$3.35 per foot	This is the cost of PVC piping as found in a catalog
Mixer/Grinder	Used to mix/grind the biowaste	1	\$150	This is the cost of a mixer/grinder setup as found in a catalog
Space heater or blow dryer	Used to dry the biowaste briquettes before briquetting	1	\$40	This is the cost for space heaters/blow dryers currently on the market that are applicable to the prototype
Enerpac Hydraulic press	Used to simulate briquetting process; will serve as our "briquetting machine"	1	Free	Can be obtained through team member. Initial cost is free; however, if desired, press can be purchased at a later time at a cost to be determined
Microwave	Used to dry briquettes once they are completed; this will simulate drying of the briquettes during real-time storage	1	\$20	This is the cost of a cheap microwave
Tinius Olsen machine	Used to conduct compression testing in order to evaluate durability of briquettes	1	Free	These machines can be supplied through CSM
Miscellaneous items for construction	Used to construct various components of the prototype	Variable	\$300	Cost will vary depending on type and quantity of items required (e.g. motors, screws, bolts, buckets, wood, etc.)
<b>Total Estimated Cost: \$623.40</b>				

A decorative graphic on the right side of the page features three blue circles of varying sizes, each composed of concentric circles in different shades of blue. Two thin blue lines intersect at the top left and extend diagonally across the page, framing the circles.

# Final Design Review

Team 2ReNeW

This report contains background of the briquetting project; what our group was tasked to design and the results. Design methodology, specifications and requirements, engineering analysis, budget and schedule are included.

**Luke Adams, ME; Cole Donelson, ME; Jeremy Johnson, EE; Mark Lu, ME; Connor Weide, ME; Mike Stone, ME**  
**5/3/2010**

May 2, 2010

Sam Anderson  
iCAST (International Center for Appropriate and Sustainable Technologies)  
8745 W. 14th Ave. Suite 220  
Lakewood, CO 80215

Dear Sam,

Enclosed is our Final Design Report. This document is the last report deliverable for the Senior Design II Course at the Colorado School of Mines. The purpose of this report is to document the team's final selection of an alpha prototype and pilot plant designs. Engineering analysis was done to support the design selection, and engineering analysis/experimentation was performed to ensure the final design met the specifications and requirements of the project.

We ask that you carefully review our report which will be sent to you both physically and electronically. Please evaluate our final proposal for any errors that will affect the project requirements, goals or constraints. We hope that the insight gained in the development of this project will assist iCAST in achieving their mission of providing sustainable technology to underserved communities.

We thank you for all the support and feedback you have given us throughout the course of this project. We hope the results we have obtained through our research will assist iCAST as they oversee the continuation of this project. The end of the Senior Design II Course is 5/14/2010. If we can be of any further assistance, please contact us at your discretion.

Sincerely,  
Team 2ReNeW

A collection of handwritten signatures in black ink, arranged vertically. The signatures are stylized and difficult to read, but appear to be the names of the team members. From top to bottom, they include: a signature that looks like 'Tony Ph', a signature that looks like 'Alex', a signature that looks like 'Curtis', a signature that looks like 'Mindy', a signature that looks like 'Cole', and a signature that looks like 'Ryan'.

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## 1.0 INTRODUCTION

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Team 2ReNeW is a Senior Design Project team at the Colorado School of Mines and consists of the following six members: Lucas Adams, Cole Donelson, Connor Weide, Mark Lu, Mike Stone, and Jeremy Johnson. Our client, the International Center for Appropriate and Sustainable Technologies (iCAST), is represented by Samuel Anderson. Our faculty advisor is Michelle Zeles-Hahn and the team technical advisor is Neal Sullivan. The purpose of this project involves developing a start to finish system concept for producing briquettes using a commercially available briquetter. The team has also been charged with the task of creating an alpha prototype, or table top model, to showcase the technology to farmers. The contents of this report include the project review, design requirements and specifications, design methodology, specific engineering techniques used, as well as engineering analysis implemented in our design selection. Additionally this report will also contain the patent search conducted for our prototype, as well as the work breakdown structure, project schedule, and budget.

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## 2.0 PROJECT REVIEW

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The ranchers and farmers of South Eastern Colorado have two massive waste streams; manure and wheat straw. The current methods used to remove them are satisfactory, but incur unnecessary costs where revenue could instead be produced. When the two available waste streams are ground, mixed, and compressed into brick-form, a biomass briquette is formed. This briquette can be burned in a furnace and the potential energy stored within it is released to produce electrical energy. Farmers briquetting their waste can sell these briquettes to utilities, making money where they otherwise would be spending \$3000 to \$4000 per year to have their animal wastes removed. Utilities also benefit by burning the briquettes. Biomass energy production has several biomass credits in the state of Colorado as well as surrounding states. Therefore, it is economically beneficial for stoker power plants to implement biomass co-firing, which is the process of firing the briquettes with coal simultaneously. Additionally, the recent changes in renewable energy tax credits in the state of Colorado would allow farmers the ability to reduce their level of operational taxes by implementing a renewable energy system such as bio-mass briquetting.

Biomass briquetting has the potential of benefiting farmers in Southeastern Colorado if the technology is implemented appropriately with all parties in agreement about the specifics. This would require some sort of agreement between the stoker power plants of the area and the regions

cattle farmers. This technology also poses to benefit the human community in addition to the farmers of this region by curbing the exponential growth of carbon dioxide in our atmosphere. In reference to global warming, the process of producing and co-firing biomass briquettes is not a solution, but rather a temporary reduction mechanism as it merely reduces our carbon output. Regardless, it is an important intermediary step that allows us to slow our output while we search for other viable solutions that emit fewer emissions. Engaging economically disadvantaged communities by providing economic, environmental, and social benefits to directly improve their well being was the primary driving force in the development of our project. This was a direct reflection of the iCAST and CSM humanitarian engineering missions.

The goal of the engineering project was to design an economically beneficial process to produce biomass briquettes for SE Colorado cattle farmers to sell or burn for energy. We were asked to make a few assumptions for the design of the project. The first assumption was the ranchers had ample amounts of waste. Thus we did not have to concern ourselves with ranchers running out of waste streams and analyzing the viability. The second assumption was there already exists a market for the briquettes, so we did not have to go in depth on some of the economic factors. We also were told not to research the collection of the manure from the farms, but rather assume the waste streams are already gathered and are centralized in one spot. These assumptions allowed us to focus strictly on the design portion of the project and to create a viable process.

Team 2Renew began our investigation of implementing a pilot plant design in southeastern Colorado by researching commercially available briquetting machines. Of these machines, we analyzed their various power usages, their ease of maintenance, location of replacement parts, and overall effectiveness of being implemented. We selected the BP-100 through decisive engineering techniques discussed within this report. Narrowing the scope of our pilot plant design, and eventually our alpha prototype design through our selection of the BP-100, team 2Renew then began developing our prototype design using specific engineering design methodology. Once a design was selected, appropriate engineering analysis was utilized to calculate the relative strength and safety of our design. Once we established a sound engineering design for our alpha prototype design, team 2Renew then began construction/assembly of the various subsystems of our alpha prototype design. During this phase, experimental testing was conducted to evaluate the relative moisture content of the wastes to produce the optimum characteristics for bio-mass briquettes. Throughout the production of the various briquettes our team created, it was discovered that the

bio-digestion of the manure was affecting the relative moisture content of our samples which resulted in our data being inconclusive. The design methodology, testing procedures, instructions for creating briquettes with our prototype, and recommendations for implementing a large scale design plan are all discussed within this report. Having assembled an alpha physical prototype demonstrating this technology; collected data on the optimum characteristics needed to produce suitable briquettes for combustion, and extensive research indicating an appropriate and feasible system that could be incorporated in this region, iCAST will be well equipped to highlight the concepts of this technology to local cattle farmers in southeastern Colorado. In addition they will be able to provide make recommendations for larger scale systems to be incorporated on local farms in the region based on our research, design and testing.

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## 3.0 DESIGN REQUIREMENTS AND SPECIFICATIONS

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### 3.1 BACKGROUND

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As was already expressed, Team 2Renew's ultimate goal was to develop a biomass briquetting process that can be implemented 1) on a real-world scale, 2) using commercially available parts, and 3) through modifications from conclusions made from a small-scale prototype. As such, a table-top model of the briquetting process was constructed that simulates what actually occurs on a large-scale through the use of a subsystem division breakdown. In our subsystems, we came across many design requirement conclusions that varied from the original design concepts. Therefore, some of the following descriptions show the reasoning behind original design concepts and final design construction differences.

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### 3.2 REQUIREMENTS

---

Our research has shown that the two biomass waste streams must have certain moisture contents before entering the briquetting process. The real-world briquetting machine (BP-100), for instance, requires 15% moisture content on all the material going in. This is due to the fact that any moisture content significantly above that causes unnecessary strain on the internal mechanics of the machine as it attempts to squeeze out all the excess moisture and doesn't produce a stable briquette. As it turns out, this same moisture content of 15% (or less than it) is ideal for our other subsystems prior to the BP-100 as well. For instance, if the cow manure has a moisture content

of 15% or less, it easily crumbles when put into the crushing subsystem. If the manure has 25% or more moisture content, then the crushing subsystem simply starts to “squeeze” the manure rather than breaking it down into smaller particle size. For this reason, the design requires input streams to maintain a 15% or less moisture content and applications were put in place to ensure it. An explanation on how the BP-100 was selected will be given in the Design Methodology section.

The second requirement that needed to be tested and planned for was the relative energy content of the biomass briquette. Any product in any industry must be able to do what it guarantees. The product, in our case, is a biomass briquette that will be sold to a stoker power plant in order to be burned for energy. As a result, we must be able to show that the briquettes will produce a certain amount of energy per mass every time they are put into the plant. Because high-end lab testing was not economically feasible for our project’s budget, we decided to do some control testing of our own. The first experiment included boiling away water from a bowl using the briquettes and comparing that time to the time it took charcoal to do the same experiment. Knowing the properties of charcoal, the values could be compared, but due to the availability of another, more accurate apparatus on the School of Mines campus, bomb calorimeters were used instead. This procedure will be described in further detail in the Engineering Analysis section, however; it is important to note that even though we needed to test for the energy content of the briquettes to ensure the feasibility of this project, there is no physical means of “producing” or “maintaining” energy content in the briquetting process. For that reason, testing for energy content was a testing requirement, but has no physical construct in the prototype design.

The third requirement we included in our project was that the briquettes must withstand a certain amount of mishandling, and therefore must exhibit some durability strengths. In a real-world scenario, the biomass briquettes will be dropped into a box or container, sit underneath a pile of briquettes for weeks in storage, and will be transported from the briquetting site to the power plant location on a truck. The briquettes must survive this all in a majority of their original shape. While some flaking or chipping are within tolerances due to the fact that they will all be burned for energy anyway, major dimensions must still be maintained as to not expedite the burning process. The more surface area, the faster fuel will burn. For this reason, durability testing was to

be done on the briquettes made. The procedure for this durability test will be described in further detail in the Engineering Analysis section.

Now that the design requirements for the briquettes have been covered, it is now important to note all the constraints that occurred in the construction of our prototype in order to meet those requirements.

---

### 3.3 CONSTRAINTS AND SPECIFICATIONS

---

The first and most important constraint for all prototyping projects was our budget. The 2Renew team was allotted \$1500 by the client, iCAST, to complete the project, so all design decisions had to be made with this in mind. While going over budget was not an option, coming in under-budget was attempted in all cases.

The second constraint implemented by 2Renew was to mimic all large-scale operations in our small-scale designs. In other words, there had to be a real-world, industrially available counterpart to any design decisions we made in our prototype. This is why the following sub-constraints had to be implemented as well.

The most important feature of the real-world briquetting machine is that it can compress material at very high pressures. For this reason, and in order to test the correct energy content and durability of the sample briquettes, the prototype briquetting subsystem needed to make briquettes at approximately 2,200psi, or 15MPa. Therefore, the briquetting subsystem was designed to withstand these pressures and resultant forces to make a structurally stable briquette.

In the real-world crushing subsystem, rollers are used to crush organic material into smaller pieces. Therefore, in the prototype crushing subsystem, two rolling elements must also be used to mimic the large-scale, industrial food crusher. If any problems should arise, solutions could have then been implemented.

In the real-world cutter, it will be assumed that blade speeds will reach as high as 5,000 rpm just like modern blender blades. The team originally shot to create a cutter that reached those high speeds, but due to time constraints, and a design change that ventured

away from a shearing mechanism and toward just a spinning blade, it was determined that we could not reach those high speeds without going outside our budgetary constraints. Motors that reach those speeds are simply too expensive. Therefore, we ventured toward a design that showed the concept instead and the only constraint set on the cutting subsystem was that it should mimic to large scale design, but not necessarily be able to complete the job.

The large-scale mixer also would have a simple motor as does the small-scale prototype. Given the vast ways one can mix a barrel of two inputs, it was decided that the mixing subsystem should travel one direction mixing the materials for a certain amount of time, then reverse direction for another amount of time. For this reason, the mixing subsystem was given the constraint that it should be automatically reversible as set by internal presets and resistor values.

The final constraints set by the client over the course of the project included that the prototype must be small enough to fit into the bed of a truck (4' x 6' x ~3'), it could be plugged into the wall (readily available 120V source), it would only use cow manure (not horse, llama, or other livestock), and it would only use non-irrigated wheat straw (not corn, barley, or other plant life).

To aid in easily identifying the design requirements and specifications for our prototype, a specifications list has been compiled below.

TABLE 1: REQUIREMENTS AND CONSTRAINTS

Requirements and Constraints
<b>Briquettes must maintain 15% or less moisture content</b>
<b>Briquettes must produce a quantifiable amount of energy from testing in a bomb calorimeter</b>
<b>Briquettes must be durable enough to withstand transportation as well as several weeks of storage</b>
<b>The prototype and testing must remain within the \$1,500 budget</b>
<b>The prototype must mimic real-world subsystem counterparts as follows:</b>
<b>The briquetting subsystem must be capable of compressing biomass at 15MPa</b>
<b>The crushing subsystem must have two rolling elements to crush the manure</b>
<b>The cutting subsystem must have a spinning element, but not necessarily be able to cut straw the same as the full-scale counterpart</b>
<b>The mixing subsystem must be change directions periodically</b>
<b>The prototype must be smaller than 4' x 6' x 3'</b>
<b>The prototype may plug into 120V source rather than depend upon batteries</b>
<b>The prototype will use only cow manure and non-irrigated wheat straw</b>

## 4.0 APPLICATION OF DESIGN METHODOLOGY

---

The steps for the design of our project are shown below

- Research and choose 3 briquetting machines
- Create concept variants from these machines
- Select one briquetting machine to base our designs on
- Create necessary subsystems
- Design subsystems
- Evaluate, Test , and Build Subsystems
- Perform briquette tests
- Use test results to alter design/provide information for future recommendations

After commercially available briquetting machines were researched, we moved on to create concept variants from them for our Concept Design Review (CDR) report and presentation.

## 4.1 CONCEPT VARIANTS

The design process for creating the concept variants melded research and ideation techniques. A main focus of the project is to implement a design based on commercially available parts. There are two primary types of briquetting machines; mechanical and hydraulic. Each has their own strengths and weaknesses. Table 2 below shows the differences between the two types.

TABLE 2: MECHANICAL AND HYDRAULIC BRIQUETTER COMPARISON

	Mechanical	Hydraulic
<b>Pre Heater</b>	+	
<b>Crusher</b>	+	
<b>Industrial Use</b>	+	+
<b>Automated</b>	+	+

After our research and elimination, we chose two mechanical and one hydraulic design to base our process designs off of. These three machines all have varied features and physical builds, yet are the most common designs on the market. They also provide a mass output rate appropriate for small scale use. From this data, we looked at subsystem features such as mixing, heating and crushing to see whether some designs already included them. For designs missing features, we used the ideation technique brainball to develop ways to incorporate the said features in the process.

After analyzing possible designs, we then performed 6-3-5. The justification for this was to have a visual representation of the briquetting process, and to graphically incorporate some of the brainball suggestions. Each member drew their ideas, and we compared our results. The process basis was fairly similar, although a few unique solutions were created and combined with others.

## 4.2 BRIQUETTER SELECTION

The concept variants allowed the team to gain insights on the strengths and weaknesses of each briquetting machine's ability to integrate external designs. From this, we then moved on to selecting the best briquetting machine by evaluating them based on some specific metrics. The table below shows the metrics used, and weights of 1-3 were given to each which was dependent upon what the goals and constraints of the project.

TABLE 3: MACHINE SELECTION VARIABLES

Variables	Weight
Cost	3
Accessibility	2
Features	2
Ease of Use	3
Maintenance	3
Energy Consumption	1

Cost was chosen since one of our main goal is to design and briquetting process that is economically feasible for farmers. Because our constraint is to make this economically feasible, it was given a weight of 3; the highest priority. Accessibility is used to describe how easy or difficult to get the briquette machines to Colorado. Since the BZBJ-1 and the MB-50 are fabricated and sold in China and Italy, respectively, we needed this to be factored into the evaluation process. It was given a 2 since the main concern with accessibility is the shipping costs associated with it. However, the cost variable takes this into account. Integrated features of the machines were another aspect, since some contain subsystems necessary (like heating and crushing) for adequate briquetting built in. A 2 was also given to this since although important, the machines could have features that are redundant to our briquetting process. An important constraint to our project is that the design must take into consideration the limitations of the persons using it. Obviously, farmers are not engineers and over-complicated operating procedures and equipment would not create investment from farmers, which is iCAST's goal from the project. Thus, the ease of use variable is important and given the highest priority of 3. Maintenance is also a large factor. If the machine breaks, it must not be too complicated to fix (again, designing within the consumer's limitations). This was also given a 3 since it is integral to the success of a long term investment, which this process will be. Lastly, energy consumption is another important factor. The energy consumed must be less than the energy the briquettes provide, maintaining both energy and economic efficiency. Each machine has a power rating and were ranked accordingly. Although important for an energy balance perspective, the amount of energy in a briquette is still much larger than the amount of energy used to form it. Because of this, the variable was given a weight of 1 since relative to the other priorities; this was insignificant. The decision matrix used to evaluate the machines is listed in Appendix A.

Although the BZBJ-1 and the MB-50 had many features, both were bogged down by complicated operation and the location they are sold from. If farmers could not operate the briquette machines, or if they had a large learning curve, the benefits of briquetting would be hard to convey. Even

though both machines have extra subsystems necessary for proper briquetting, it also leads to slightly more complicated designs. Thus, if the briquetter broke down, maintenance would become too complicated and require external help. Specifically with the BZBJ-1, replacement parts cost just as much as the briquetter, and the company selling it only offers a 60 day warranty. Another factor is that both are made overseas, so customer service and attaining replacement parts would further complicate maintenance. In addition, machine power supply compatibility also poses a problem. The US's standard for voltage and frequency is 120V at 60Hz. The BZBJ-1 manufactured in China operates at 220V and 50 Hz, and the MB-50 manufactured in Italy operates at 230 V and 50 Hz. Frequency converters and adapters would be necessary if those briquetters were to be chosen. Overall the BP-100 had the advantage in its overall simplistic design that is more intuitive to explain (a hydraulic pump compresses the biomass). Although it lacks a heating and crushing subsystem, yet since a lot of farm equipment sold locally can do these functions, it allows us to design a more intuitive process with equipment that farmers would understand.

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### 4.3 SUBSYSTEMS

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After selecting the BP-100 as our model briquetter, we then evaluated which subsystems were needed. This was based on the available features of the briquetter, and requirements for the briquetting process based upon our constraints. Once compiled, we used this list to design the necessary components for our alpha prototype. Below shows the table of necessary subsystems.

After creating a Solidworks model of the alpha prototype with each subsystem, we proceeded to order parts to build it. However, from the construction process and availability of parts, our initial design changed from our Solidworks model to the current model. This evolution and justification is described in detail in the engineering analysis section.

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### 4.4 BRIQUETTING INSIGHTS

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Once the press/briquetter subsystem was built and completed, we proceeded to make briquettes to gain insights on the process that would affect the design. One thing we determined was that it is best for the manure to be as dry as possible. When mixing the two waste streams together, wet manure did not allow for a uniform mixture. There was also an issue of briquetting wet briquettes; too much moisture creates mechanical issues in which the briquette got stuck to the die. This falls in line with the large scale requirement that manure must have a minimum of 15% moisture content. Ultimately we learned that the drier the manure, the easier to briquette.

To maintain adequate moisture content, we tested to see how much moisture would be lost by letting the manure sit and dry outside. Unfortunately, there was biological growth on the manure that skewed any analysis. Instead of letting manure sit and dry, we had to bake it in a toaster oven to dry it out. Ultimately baking it is a decent alternative to drying from open air and ambient temperature given time, and is a suggestion for a separate subsystem for a large scale model.

In addition, given the different densities of each material, mixing the two allowed us to analyze that equal masses of manure and straw create difficulties in the mixing process. Given that manure is much denser, a large scale recommendation for the straw is to cut and grind it into as little pieces as possible.

The design methodology of the project included ideation techniques, evaluation of these ideas through decision matrixes, and testing to gain experimental feedback on how to adjust the design.

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## 5.0 DESIGN SPECIFIC ENGINEERING TECHNIQUES

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During the design process, it is important to look at more than just failure modes and factors of safety. An engineer must think about more than the integrity of his designs, and the correctness of his calculations. Engineers must also consider the impact that their designs will have on society and the environment, as well as the impact that society and the environment will have on their designs. Team 2ReNeW took this to heart, and designed their prototype and made full-scale recommendations with this broader impact in mind. There were three main fields of consideration that Team 2ReNeW wanted to cover. The first area, and probably most important area is the economics of the project. This is so important because without financial feasibility no project will ever see fruition. The team also performed societal analysis to make sure the designs were well adapted to be used by people, and optimized to help the people who use them. Finally the team also considered sustainability. This was broken into longevity of parts, and the sustainability of the inputs of production once the design was built. With these three topics the team feels they have covered the more important impacts their designs will have.

The first issue to be discussed will be the economic analysis the team did for this project. The goal of this analysis was to make sure that someone investing in the briquetting process would be able to make an economic profit. The team started by determining how much money it would cost the operator to run the briquetting system. This is known as the operating cost. In order to do this the team used two approaches to find out how much power was used. One way was multiplying the

volts by the amps to get watts, and then converting to kilowatt hours. Kilowatt hours are what utility companies use to measure how much power people use. The alternative method was to determine the number of kilowatt hours from the maximum horse power the briquetter uses. Both of these methods yielded the same amount of energy used. It was then assumed that the heating and mixing systems would require power, although not as much as the briquetter. As a rough estimate it was assumed that they would use approximately one third as much energy as the briquetter. The amount of energy used by the briquetter was then multiplied by one and a third to get the total energy used by the entire system. This method was also applied to determine how much energy the briquetter used when it was producing its minimum output. It was then determined how many hours it would take to produce one ton of briquettes given the briquetter's minimum and maximum output numbers. The number of hours were multiplied by the number of kilowatt hours the machine used. This number was then multiplied by the average cost of electricity per kilowatt hour in the state of Colorado during 2009. This gave us a good number on how much money it would cost to produce one ton of briquettes from waste materials. This also gave us insight on the cheapest way to run the briquetter. According to our calculations one could save about three dollars a ton by running the machine at maximum output for less time. The team then compared the cost of producing one ton of briquettes to the 2008 prices of a ton of coal. Assuming that all else equal, the farmer stands to make about twenty five dollars of profit per ton of coal. This amount negates the incentives power plants receive to burn renewable energy, as well as several other factors that would make the briquettes even more economically attractive. After verifying that waste briquetting could cover the operating cost, the team then made some assumptions and did some rough calculations to see how long it would take to cover the investment, or capital cost. To do this the team found out how many tons the farmer would have to produce to make enough money to cover the capital cost. It was then calculated how long it would take to produce that amount of briquettes. Here is a brief summary of the results of the economic analysis: It will cost the farmer between \$11.77 and \$8.80 to produce one ton of coal. The average price of a ton of coal in 2008 is \$36. This means the operator stands to make an average profit of \$25.72 per ton of coal produced. It would take roughly 1000 days of producing briquettes at full capacity, or 3.33 years to cover the cost of the initial investment. The calculations are shown in the Appendix B. The team also did some economic analysis when considering the different briquetters for full scale operation. The team compared the cost of a new machine, the cost of replacement parts, the cost of supplemental systems that would be needed for different briquetters, and the cost of operating the different briquetters. With this analysis the team was able to pick one of three different commercially

available briquetters. Once the team had fully explored the impact of economics on design, they then considered the broader societal impact of their designs.

Because an engineer's first priority is the welfare of the public, team 2ReNeW looked carefully at the impact their design would have on society, as well as the impact that society would have on their design. This project is deemed a humanitarian project, and one of our most important goals is to help those in the agriculture industry in different parts of Colorado. With this in my mind, most of the team's designs are aimed at the end user: the small farmer or rancher. Once again team 2ReNew did an initial analysis to make sure that this project is in fact feasible. This time the focus was on whether or not there would be a net societal gain. The team found that there was in fact a pretty large societal gain. This project would allow farmers and ranchers, who often have narrow profit margins and rely heavily on nature to produce crops, to turn a liability into a potential source of revenue. Instead of paying for waste materials to be removed and landfilled, farmers can now extract income from their waste materials. This additional source of income could potentially raise the standard of living for those at lower income levels. Also, this higher profit margin could ultimately lead to less government subsidies to farmers. This would leave more tax dollars available to things that need it more. Once again the team concluded that their project was feasible and continued on. The team also had to consider how society would impact their designs. This ultimately came down to making sure all designs were aimed at the end user. The final product of our project would not be used by engineers, but rather farmers and ranchers. This meant that all components needed to be easy to operate and repair. After careful analysis, team 2ReNew feels that all of our systems could be easily operated by someone with a strong mechanical ability without much technical knowledge. After determining the impact our project would have on society, the team then considered the sustainability of this project.

Sustainability is a popular theme in the engineering world. Unfortunately this buzz word is used so often and for so many reasons, that it has lost some of its meaning. For team 2ReNeW sustainability is all about a near infinite product lifetime. This means the chances of our components failing are extremely small, if failure should occur it can be quickly and cheaply fixed, and the inputs for production are non-exhaustible. When designing the prototype, the team did a myriad of calculations to determine whether or not different parts would fail. The calculations and their results can be found in the engineering analysis section. In summary, the team found that the different factors of safety were so high that the chances of component failure were extremely unlikely. For full scale production the team chose a briquetter that is relatively simple. This means

that should something go wrong replacement parts are cheap, and the unit is easy to repair. The team had to consider more than just the lifetime of the components, but also the sustainability of the inputs the operators would be using. Because of the nature of this project, it is reasonable to assume that there will be a near infinite supply of waste streams that can be used for briquetting. Once again the team has concluded that the impact of this project will in fact be good.

Ultimately team 2ReNew had to consider quite a bit more than just factors of safety when considering the feasibility of our project. The team had to consider the impact this project would have on society, the economics of this project, and the sustainability of this project. In all three areas the team was able to confidently conclude that the designs were capable and ready for implementation.

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## 6.0 ENGINEERING ANALYSIS

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### 6.1 TESTING PROCEDURES

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In mimicking the large scale process, we wanted to use our prototype to test various characteristics of briquettes to gain insight that impacted our final design. The traits our team found important were durability, relative energy content, moisture content and process variability.

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#### 6.1.1A DURABILITY

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In order to test the durability of the briquettes, the team was to use the following procedure.

1. Obtain about twenty similarly-sized briquettes
2. Set up the Tinius Olson machines (available in the labs in Brown Building) to hold the briquettes and administer a compression force
3. Measure the briquettes for axial compression:
  - a. Place the briquettes vertically (flat faces up and down) into the Tinius Olson machine
  - b. Run the machine, increasing the pressure until the briquette fails
4. Measure the briquettes for lateral compression:
  - a. Set up the Tinius Olson machine so that the round faces of the briquettes will not roll away from the compression plates

- b. Place the briquettes horizontally (round face down) into the Tinius Olson machine
  - c. Run the machine, increasing the pressure until the briquette fails
5. While running each set of tests, vary the speed at which the pressure is increased.
  6. Compile all of the data and, using the formula  $\sigma=P/A$  and other mechanics of materials fundamentals, determine the Young's Modulus, Ultimate Strength, and Yield Strength of the briquettes. These properties represent the brittleness, durability, and strength of the briquettes.
  7. Using statistics theories, determine the average values, as well as the standard deviation of these values (which will in part represent the variability of the briquettes).

The reason for varying the rates of pressure increase is to determine if the biomass is not perfectly elastic. A similar study by iCAST suggested that the point at which the briquettes fail would be difficult to determine, as the briquettes fractured *slowly*. A slow pressure increase might imitate these results, with the briquette fracturing at a given pressure value, whereas a very rapid pressure increase might cause the briquette to fail in a brittle manner, and possibly at a different pressure value.

These tests were necessary to prove that the briquettes will hold their shape under extreme conditions. During transport, for instance, the briquettes may not be treated very delicately. The team needed to know that the briquettes will not simply crumble back into a powder of manure and hay.

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#### 6.1.1B DURABILITY TESTING RESULTS

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During the course of the semester, the Tinius Olsen machines became unavailable to the team for various logistical and miscommunication reasons. As a result, testing was never able to be completed, however; the procedure still remains intact. For future use by iCAST. Relative mishandling did occur, however; during briquette manufacturing and the briquettes proved to remain intact after minor drops.

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#### 6.1.2A MOISTURE CONTENT

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The procedure for figuring moisture content of the raw materials before briquetting is as follows:

1. Obtain a plastic bin, an old oven, a scale sensitive down to 1/100 of a gram, and a cool dry storage area.
2. Using the plastic bin to zero out the scale, weigh out 10 10gram samples of “fresh” manure.
3. Using the plastic bin again, weigh out 10 10gram samples of “fresh” straw as well.
  - a. Keep each sample of manure and straw properly labeled.
4. Exactly 24 hours (+- 1 hour) after weighing out the original samples, reweigh all the samples for both the manure and straw.
5. Repeat step 4 until the change in weight seen by the next weigh-in is less than 5%.
6. When this happens, place all the samples in an old oven at 90-100 degrees Fahrenheit for 24 hours in order to completely dry out the samples.
7. Taking the information you obtained from steps 2-6, use the following equation to determine the moisture content of the materials at various days in the timeline.
  - a.  $M_n = (W_w - W_d) \div W_w \times 100\%$
  - b. Where Mn is the moisture content
  - c. Ww is the wet (current) weight of the sample
  - d. And Wd is the dry (final) weight of the sample
11. Repeat step 10 with the results you obtained for steps 7-9.

The previous test could have proved crucial in figuring moisture content for the raw materials we used to make our briquettes. First, the real-world briquetting machine we will be using has a tolerance band for the moisture content of the materials that are put into it. This tolerance band ensures a good briquette product. Additionally, we want to guarantee to the future client (the farmer) that the product they produce will not crumble due to a variance in moisture content, which in turn effects its ability to stick together (durability).

By manipulating the data obtained from the experiment, we would have been able to determine a window of “days after creation” when the manure and straw will be safe to use for briquetting. In the case of the manure, the “creation” is when it is expelled from the cow, and for the straw, “creation” will be when it is cut from the ground. It is from those moments on that the moisture content will gradually decrease until it becomes in balance with the Colorado atmosphere.

By weighing the samples every 24 hours, we would have found an average wet weight for each 24 hour period. When we completely dried out the samples in an oven at the end of our experiment, we could have told the exact moisture content of the samples as the weight after the oven will be the official “dry weight.” As you can see, it will be quite beneficial to know that manure must be used 5-8 days after it is created where the straw may only need to wait two days. This will ensure us a good, consistent product from consistent raw materials.

Just to explain one further point, the use of a cool, dry storage space for the samples was supposed to mimic being on the inside of a barn or under a canopy on the farm. Hopefully, by keeping the samples covered, they would at least be free from any rainfall and in turn, huge unreliability.

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#### 6.1.2B MOISTURE CONTENT RESULTS

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After several days of weighing out samples, a white growth (fungus or bacteria) was discovered on both the manure samples kept indoors as well as outdoors. Upon further analysis, it was discovered that some of the samples continued to lose weight while some even gained weight as a result of the fungus. Due to this anomaly, no accurate conclusions could be made with sound statistical results.

Additionally, a Colorado snowfall occurred during our testing and covered the outdoor samples. This clearly added moisture to the samples and again, skewed our results. This occurrence also makes it clear that all raw materials intended for use in briquetting should be stored indoors, or at least under sufficient structural protection from the weather.

Due to each measurement being dependent upon the final measurement (before they can become useful), the entire experiment was therefore trashed. Instead, knowing that farmers would use a visual inspection anyway, the wait period of two weeks was determined to be sufficient to reach the required 15% moisture content.

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#### 6.1.3A PROCESS VARIABILITY

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The following procedure was used to test the variability of our briquettes:

1. Create at least 30 briquettes using the table-top prototype model that the team built where the 30 briquettes must come from at least three batches.
2. Using a knife or a saw, cut a sample in half across its 2" cross-section.
3. Using a magnifying glass or simply your eyes, count the "clumps" of manure and the "clumps" of straw.
4. Repeat steps 2-3 for all of the samples.

Process variability testing ensured that the mixing element to our prototype and ultimately, our entire design was satisfactory for use. If the resulting data proved to have a close to 50-50 mixture (our intended mixture) then, any random cross-section of the briquettes should also be 50-50. As we will see in the results, this is what occurred. It was assumed that any random 2D cross-section can be representative of the whole if enough samples are taken. This assumption ensured a homogeneous product and therefore, guarantees both the farmer and the stoker power plant that they will be receiving a good and consistent product.

One point that needs to be stressed is that all the parts of the model mimic the full scale machinery. This way, the model will indeed produce a similar product that the end machinery will produce. If we found that the briquettes were NOT homogeneous, then we would increase the mixing time as seen appropriate.

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### 6.1.3B PROCESS VARIABILITY RESULTS

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Rather than cutting cross-sections, the outside of each briquette was visually inspected. It was determined that every batch made by 2Renew had been mixed for more than ample time in order to produce product homogeneity. The mixing time was 10 minutes and the batches were all approximately 140 grams each.

Each briquette made had different percentages of manure and straw such as 60-40, 50-50, 55-45, but in each case, the visual inspection gave an almost exact mix. If a 50-50 mix was made, for instance, an almost exact 47-53 mix was found. This shows the briquettes produced will be produced consistently and evenly.

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## 6.2 MOTOR SELECTION

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In choosing the parts we would use to construct the prototype, we took the largest factor necessary to control and went with it. In choosing the motors, for instance, the largest factor was pricing as motors can be quite expensive. Due to the expensive nature, we went with an 18V DC requirement and chose different motors around that voltage (19.1v and 24v). The specific motors within that were then chosen by either high torque or high speed. Two motors were selected with a high torque of 10.94in-lbf for mixing and crushing, while one motor was selected with a high speed of 396rpm.

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### 6.3 GEARING

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Our design of both the mixing and cutting subsystems used gears to translate rotational energy, and as a result, the gears had to be checked for failure. Using mechanics of materials basics and machine design principles, the Safety Factors against stripping were determined to be 19.1 and 15.7.

Generally accepted engineering practices state that the use of a known material, such as steel, in a relatively unknown environment, such as with manure and other biomass particulate in the air, should have a safety factor of at least 3. Therefore, the safety factors of 19.1 and 15.7 are well above any possible failure due to gear stripping and was not a major concern in prototype design. The calculations for these numbers may be found in Appendix C and D.

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### 6.4 TORSION FAILURE

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Torsion failure analysis was conducted to ensure that the cutting, mixing, and crushing motors would not load their respective shafts to the point of failure. However, torsion failure calculations were only done for the cutting subsystem. This was due to the fact that the shafts were identical for each subsystem, and only the torque from each motor varied. Thus, since the cutting motor produced the most torque out of the three motors, analyzing the cutting subsystem would indicate whether the applied torque from the other motors would cause the shafts to fail or not.

The shafts were assumed to be solid cylinders having a diameter of 3/8" and a length of 14.5". Furthermore, the shafts were assumed to be made of a steel alloy, giving them a Young's modulus of 30Mpsi and modulus of rigidity of 11.7Mpsi. Knowing the cutting motor would supply a maximum applied torque of 0.6in-lbf, and assuming the shaft would be fixed at the other end, we were able to determine the shaft's maximum angle of deflection ( $3.83E-4$  radians). Such a small angular deflection indicated that the shaft would have minimal twist. Also, we were able to compute the maximum shear stress for our shaft (57.947 psi). Because the modulus of rigidity is much greater

than the maximum shear stress, we were able to conclude that the shaft would not fail due to the motor's applied torque. Finally, a safety factor was calculated for the cutting shaft. The safety factor was enormous (2.019E5), and thus gave more evidence that the shaft would not fail due to the motor's applied torque. Knowing that the motor from the cutting subsystem would not cause the shaft to fail in torsion, we concluded that the other subsystems would also not generate enough applied torque to cause torsion failure. Therefore, our shafts, and the motors we selected to be coupled with them, were safe to use. Appendix E shows the calculations.

## 6.5 ELECTRICAL ENGINEERING ANALYSIS

The initial design of the electronic subsystem contained the circuit topology below. The first branch controls the on/off state of the circuit by a switch, and when the switch is on the LED lights up to indicate the on state. One major complication with this design was the motor was not getting enough current. Initially it was planned to have a potentiometer and a voltage divider to control the voltage across the motor. Even though the voltage was in the range of the motor's operation, the amount of current to the motor was insufficient.

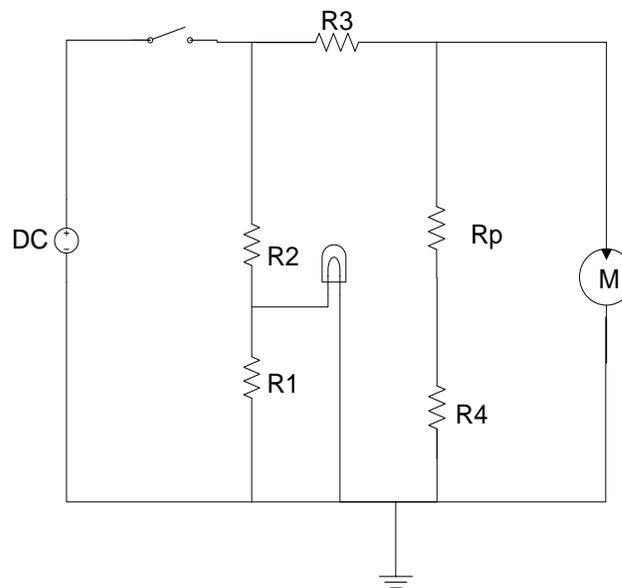


FIGURE 1: INITIAL ELECTRICAL DESIGN

As a result, a current amplifier was needed. The first choice was to use a BJT (Bipolar Junction Transistor) to boost the current, however that did not work since the amount of current necessary

for the motor (0.53 Amps at full load) was too high for the transistor to handle and as such burned out. The next option was to use a MOSFET (Metal Oxide Semiconductor Field Effect Transistor) which, when biased correctly, could operate as a voltage controlled current source. By varying a potentiometer to change the gate voltage, one can control the current going through the motor and therefore the speed. Below shows the updated and implemented electrical design.

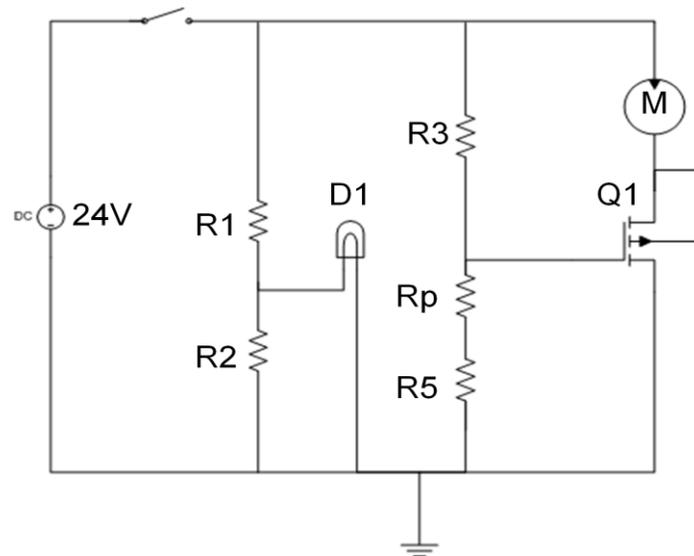


FIGURE 2: FINAL ELECTRICAL DESIGN

The values of the components are shown below, and the calculations for the design are shown in Appendix F.

TABLE 4: COMPONENT VALUES

Component Name	Value
<b>R1</b>	12.2k
<b>R2</b>	1k
<b>R3</b>	6.6k
<b>Rp</b>	500 ohm pot
<b>R5</b>	1.5 k

For the mixer, it was important that the distribution of the straw and manure was even. We decided that to get a good mixture, the motor would switch directions after a certain amount of time. To do this, we used a comparator and an RC circuit, in which the period of the mixing was determined by the external resistor and capacitor values. The diagram in Appendix G shows the initial circuit design, in which the output of the comparator went to one lead of the motor. The other lead was connected to ground. The comparator oscillates between +12V and -12V. For half the period, the

voltage across the motor is +12V, making the motor spin clockwise. For the other half of the period the motor lead has a -12V value; this reverses the direction of the current in the motor, and in turn, reverses the rotation to counter clockwise. This process repeats every period.

The issue of insufficient current arose in this circuit again. Given time and the delay of parts from McMaster, a full implementation of the direction changing feature could not be completed. However, a diagram below shows how it would be implemented; again incorporating the MOSFET amplifier to control the speed of the current.

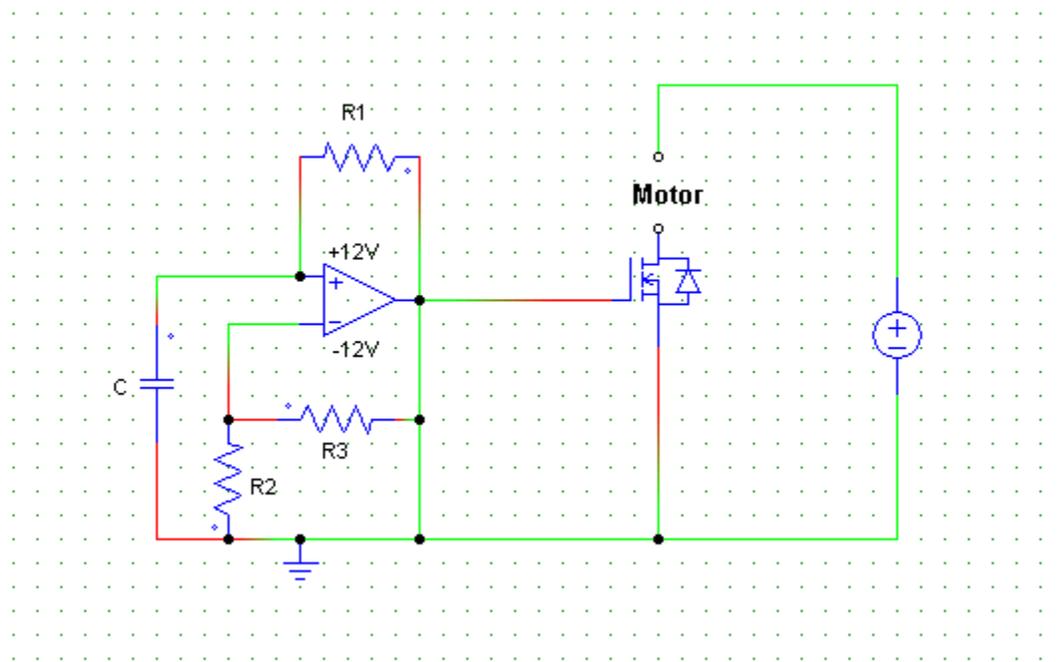


FIGURE 3: MIXER CIRCUIT DESIGN

The control panel was created from a sketch shown in Appendix H that was later sent to a plastic molding shop. Initially the panel was designed to have the solder-less breadboard underneath; however given changes and updates to the circuit the breadboard was brought to the front of the panel to allow of any immediate circuit changes and future improvements.

One recommendation for the electronic subsystem is the control of the motors via PWM (pulse width modulation). The current design involves the control of the current by a linear potentiometer. However, the current through the motor is exponentially related to the voltage created by the potentiometer. This characteristic leads to a very limited control range. After a certain voltage the current is large enough to allow the motor to run at full speed. A better way to control the motor is to incorporate a 555 timer IC connected directly to the gate. The IC creates a

pulse wave dependent upon external components (R and C), which allows the user to vary the duty cycle with a potentiometer. With the 555 timer connected to the gate of the MOSFET, the transistor will act as a switch creating instantaneous pulses of current to flow through the motor. Varying the duty cycle varies the rate at which the current flows through the motor, and in turn varies the speed. The frequency and duty cycle relationship to the speed would need to be determined experimentally. This allows for the bypassing of the exponential characteristic. PWM is normally how DC motors are controlled for more precise applications. Once the mechanical components for the alpha prototype are integrated together and revised based upon potentially different motors, the new electronic subsystem can be integrated based upon a new design.

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## 6.6 HYDRAULIC PRESS

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Several modifications to the enclosure for producing briquettes were made as the project progressed into the testing and development phase. Team 2Renew started initially with three .5 inch plates welded together to resemble steel channel. The steel channel would have had to be welded because the hydraulic pump used in creating our briquettes had dimensions unavailable for most commercially available steel channel. After meeting with our client and technical consultant, it was determined that creating an adjustable enclosure to accommodate various hydraulic pumps would be necessary since the pump used for creating our briquettes was on loan. Additionally, after performing a finite element analysis, it was deemed that the stress concentrations arising at the corners of the partially enclosed design could be eliminated if the design resembled a fully enclosed system. In approaching this problem, it was suggested using unistrut with bolts connecting the two plates together. Though the individual cut pieces could not be adjusted for varied hydraulic pumps, the new design eliminated much of the stress concentrations at the corners, and new pieces could be cut and fabricated at a fraction of the cost of welding new plates together. The final design that was selected addressed both the adjustability of the enclosure and eliminated the stress concentration that arises in our first design. By using fully threaded high strength zinc plated .5 inch diameter studs, and backing both sides of the .75 inch ASTM 36 steel plates with a pairs of nuts and washers at each corner, the fully enclosed system allowed its user the ability to adjust the plates as needed. A table highlighting the various characteristic of the components used for the enclosure and die is shown below.

TABLE 5: MATERIALS FOR ENCLOSURE

Qty	Materials
8	All-thread THREADED ROD THERMO-TORQ B7 ALLOY 1/2-13 X 3 UNC ZINC YEL DICHRIMATE
2	Steel Plates ASTM36 Steel, .75 inch thick
1	Die ASTM 36 Steel, 2.0 inch diameter, 3 inches long, two varying diameters~ 2 in, 2.25 in
2	Plugs ASTM 36 Steel, 2.0 inch diameter, .75 inch long
1	Stopper/Extractor plug ASTM 36 Steel, 2.25 inch diameter, 1.5 inch long
16	Washers FLAT WASHER TRU-TORQ 1/2 SAE 33/64 ID; 1-1/16 OD, Hardened and tempered
16	Nuts HEX NUT TRU-TORQ THICK 1/2-13 UNC PERMA PLATE, Hardened and tempered
1	Hydraulic Piston & Hand Pump General purpose cylinders (Capacity: 5-100tons, stroke:.63-14.25 inches, Max Pressure:10,000 psi)

The validation of the finite element analysis was initially conducted using basic mechanics of materials beam equations, but the final two designs for the enclosure represented three dimensional loading which could not be solved using two dimensional equations. After conducting research on how best to approach modeling the final design, it was determined that the most realistic boundary condition would arise from modeling half the enclosure because of the fact that one side would be fixed to the ground. In modeling half the enclosure, inserting the threaded stud into the plate not fully fixed, a realistic representation of the stress, and ultimately factor of safety could be determined.

In developing a press to mimic the BP-100 briquetting machine we selected, we designed a steel enclosure which will house the components necessary for producing briquettes. These components include a three inch long ASTM A36 steel bushing with an inner diameter of 2.0 inches, and an outer diameter of 3.0 inches. A single acting hydraulic actuated cylinder and pump will also be utilized to obtain the optimum pressure of 3000 psi for creating briquettes. Our enclosure will allow team 2ReNeW to wedge the cylinder against one of the flanges of the enclosure and extend the piston into the bushing. Through previous experimentation, it was concluded that we would want to heat

our die to approximately 225°F. By utilizing heat rope provided by our technical consultant, and a thermocouple capable multimeter, we were able to monitor and ensure an average temperature of 225°F was maintained within the die. After the desired pressure has been reached, the piston will be retracted to allow for the extraction of the briquette. Through the process of creating briquettes using the waste steams provided by our client, we learned that we would need an additional plug for our die. This was a result of witnessing the deflection occurring when we compressed the wastes within our die where in one instance; the piston entered the cavity of our die which resulted in considerable time being spent in removing the piston from the die. The final design for the enclosure allowed us to efficiently produce briquettes. Through experimentation we conducted, it was determined that our final design would most adequately accomplish the expectations of our client. Additional research will need to be performed for creating a more automated system, but for the purpose of demonstrating a proof of concept to cattle farmers in southeastern Colorado, the enclosure produced by team 2Renew will sufficiently allow its user to create durable and geometrically sound briquettes. Appendixes I-M show the hydraulic press and die design evolution and their analyses.

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## 6.7 ALL THREAD ANALYSIS

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After several design iterations, the team decided to use all thread to build the briquetter. Prior to construction the team wanted to test for failure using engineering analysis. In order to do this the team modeled the all thread as a bolt in tension. The material of ASTM A193 was used for the analysis. This material was chosen because it was the closest material to the one specified by the manufacturer with known properties. The plate was made from ASTM A36, and was modeled accordingly. Several assumptions were made in order to simplify the analysis. The first assumption is that the stress induced by the piston can be modeled as a point load on each of the bolts. The value of the force used in this analysis was based on a value generated by a Solid Works analysis of the briquetter. Another assumption is that the loading is static, two dimensional, and planar. The final assumption is that the materials are isotropic and homogenous. Using equations for bolts developed in Machine Design, the team was able to calculate the factors of safety relevant to the all thread. Using a force of 1555 lbf per bolt a safety factor for tension was calculated to be 9.582. Using the same force the safety factor for separation was calculated to be 12.108. The safety factor for the stripping of the threads came out to be approximately 170. From these numbers the team has determined that there is absolutely no possibility of the all threads in the briquetter failing.

These very high factors of safety would allow us to safely operate the briquetter in any environment. Appendix N shows the All thread calculations

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### 6.7 MISC. PART SELECTION

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Various other parts were selected necessary to construct the prototype, but with no direct force transfer implications associated with them.

The couplings, for instance, were chosen based upon shaft sizes. The motor output shafts have certain diameters as do the shafts that the gears will go on. The couplings were therefore chosen because they were capable of far higher torques than this project would see to ensure no loss of motion, while the bore sizes on them matched the shaft sizes.

The bearings were chosen based upon bore size and shaft size again. The type of bearings chosen were “sealed” due to them having lubrication already inside the casing and a solid barrier protecting the rotational motion ball bearings from debris in such a dirty environment. Sealed bearings were determined to be the best given the unknown environment that the prototype would be used in.

Finally, shaft collars were chosen to prevent axial slipping of the main mixing shafts and were based upon shaft diameters again. Shaft collars are meant to fit one size shaft only.

Coupling, ball bearing, and collar calculations could have been used if the bending force between the two gear faces had been known. This radial force, however; is immeasurable with our means, but assumed to be negligible anyway. This is given the slight amount of backlash between the two gear faces due to an un-tight fit in the prototype wood. Essentially, this force is so small, that all calculations gave near-infinite Safety Factors and therefore makes including the value pointless.

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### 6.8 BOMB CALORIMETER

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To test the heat content of the briquettes, small samples of each of the first three briquettes were tested in the School of Mines’ Chemical Engineering department’s bomb calorimeters. The process involved placing a small sample of briquette into a closed and insulated container pressurized with pure oxygen, then combusting the contents and measuring the temperature change of the system. The data and results can be seen in Appendix O.

The results of the calorimeter show that the heat content of the briquettes is less than expected values obtained from research. In fact, the calculations imply that a combination of manure and straw supplies less heat than manure or straw alone. However, the calculations from calibration combustion of a benzoic acid tablet returned near-perfect results. The only difference between this calibration run and the real test was the mass of the sample, the molecular weight (or molar mass) of the sample, and the temperature change. Since the temperature change was a dependent variable and the sample mass was arbitrary, it was suspected that the error stemmed from a calculation of the molecular mass values. These calculations were fairly extensive, leaving plenty of room for error. However, after checking every step, it appeared there was no error. All values were within a reasonable and expected range. Furthermore, it was discovered that a drastic change in the molar masses- changes of several orders of magnitude- changed the final heat values by only a minute fraction. Another possible source of error was the calculated number of moles of gas produced by the combustion reaction; however, these too were reasonable values and resulted in only fractional changes of the final heat value.

Therefore the error stemmed from either the empirically gathered compositional data obtained from the Phyllis database, or there was no error at all. The former seems likely; however, this data matches other available data. The latter seems unlikely, and rather impossible, however, since no member of Team 2ReNeW is proficient in chemical engineering, it is very likely there is some other cause we are not aware of. The work was reviewed by a senior in the Chemical Engineering department, but she could not locate any errors.

The heat values were close, though, and it is fairly likely that, could the team have continued testing newer briquettes as they were made, better heat values could be obtained. After all, the quality of briquettes increased significantly as more were produced. The team's recommendation to ICAST and to future senior design teams is to continue producing better and better briquettes using 2ReNeW's method, and continue testing them. A larger sample size will always yield more accurate results, and a different team could offer new insights. If better heat values simply cannot be reached, 2ReNeW recommends experimenting further with moisture content and weight ratios.

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## 7.0 PATENT SEARCH

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A patent search was conducted to give the team an indication of the originality of our biowaste briquetting process. After doing a thorough patent search for "briquettes", and filtering the results even further for any patents pertaining to "waste", we realized that no patents currently exist that

are closely related to our briquetting process. No patents existed that pertained to compressing straw and manure into briquettes so that they could be burned for energy. However, a few remotely relatable patents include:

Patent Number 7,628,839: “Method and system for producing metallic iron nuggets”

This patent pertains to producing iron metallic nuggets by thermally treating iron bearing material and forming briquettes. Natural gas-based Direct Reduced Iron (DRI) accounts for over 90% of the world's DRI production. Coal-based processes are generally used to produce the remaining amount of direct reduced iron. However, in many geographical regions, the use of coal may be more desirable because coal prices may be more stable than natural gas prices. Further, many geographical regions are far away from steel mills that use the processed product. Therefore, shipment of iron units in the form of metallized iron nuggets (i.e. briquettes) produced by a coal-based fusion reduction process may be more desirable than use of a smelting reduction process.

The patent's proposed method for producing these iron nuggets is by thermally treating the layer of reducible iron mixture; doing so would result in the formation of metallic briquettes. While this patent does not relate to Team 2Renew's proposal of forming briquettes through compaction of waste material, it shares the team's proposal of using thermal treatment in the process of forming briquettes.

Patent Number 6,698,245: “Production of vitreous fibers using high halogen mineral waste as an ingredient”

This patent relates to methods of making man-made vitreous fibers (MMVF) particularly relating to the manufacture of rock fibers. High halogen waste may be charged to the furnace in which it is to be melted in conventional granular form, and likewise the remainder of the total charge may be supplied in conventional granular form. For instance it may have a granular size above 50 mm when it is being melted in a shaft furnace and 5 to 30 mm when it is being melted in a tank furnace. The resulting granular material will be briquettes.

Again, this patent only relates to Team 2Renew's briquetting process through the utilization of thermal processes in the formation of briquettes.

Patent Number 4,304,589: “Briquetted fertilizer for forest fertilization”

This patent pertains to using briquetted fertilizer for forest fertilization comprising of the compression of molded granular isobutylidene diurea and heavy mineral oil. This patent proposes using a briquette machine to produce fertilizer briquettes. A briquette of high hardness is produced in a high yield, for example, by first spraying 0.5-3% by weight of lubricating oil into the molding zone of the briquette machine and molding a granule of isobutylene diurea together with 1 to 5% by weight of heavy oil.

This patent is most relatable to our project. Both this patent and Team 2Renew propose using a briquette machine to compact waste materials into briquettes. However, this patent does not utilize manure and straw as waste streams, nor does it specify utilizing the formed briquettes as a source of energy. While this patent intends on using biowaste briquettes as fertilizer, Team 2Renew intends on using our biowaste briquettes as energy sources by burning them in a furnace.

Upon review of all the patents in the United States Patent Office database relating to “briquettes” and “waste”, it is clear that no patents currently exist that are closely related to our project and the process we have designed for it. Thus, it is likely that our biowaste briquetting process is patentable.

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## 8.0 CONCLUSION

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### 8.1 BUDGET

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In order to ensure that sufficient funding was available to complete the alpha prototype, Team 2 Renew proposed the budget shown in Appendix P. The client allocated a budget of \$1500 that was used towards accomplishing the goals of this project. Our client, iCAST, was the main source of the funding, and handled all procurements as well. The allocated budget of \$1500 proved to be sufficient to cover the team's cost for completion of this project. \$910.05 was used of the \$1500, and \$589.95 remains.

### 8.2 PROJECT SCHEDULE

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Most alterations in the Gantt chart were adaptations to setbacks. On a few occasions, a part order received was incorrect, and the team had to order new parts in order to move forward. Most of the construction of the prototype was extended because of this. More briquettes were always

beneficial, and so this process never truly ceased, and will not until the team has produced twenty briquettes for ICAST. The testing as well was pushed back significantly. The moisture content test failed due to fungal growth and had to be stopped, and communication errors with the chemical engineering department pushed the bomb calorimeter test back to the day of the final design review. As the semester neared an end, workloads in other courses took time away from the project and slowed down the process. One set of processes, the design, testing, and test-analysis of the prototype (distinct from the briquettes) was removed entirely. These processes were added to the Gantt much earlier in the semester, and the team decided later to forgo these and focus more on engineering analysis of the prototype.

Also added to the list of activities at the bottom of the Gantt chart was a list of responsibilities. While the Gantt lists how many team members were working on an activity at any given time, the list of responsibilities shows which team members were involved, and how. Not listed, though, is the allotment of work for engineering analysis and reports. Typically, a team member worked on subjects he understood well. Michael was typically responsible for gearing analysis and construction, as well as motor selection. Luke supplied many materials from his work at NREL, and because this included the hydraulic pump and briquette die, he was in charge of the briquette press. Cole had the most experience with engineering economics, and so was responsible for economic analyses of the project. Jeremy, being the only electrical engineer on the team, was solely responsible for the electronic control panel and the engineering analyses associated with it. Connor ran the bomb calorimeter tests and the chemical thermodynamic analysis with it, and helped produce the first round of briquettes to be tested. Mark was responsible for the budget, and helped construct much of the prototype subsystems and the second round of briquettes, which were on display at the trade fair and will later be sent to ICAST. Because of formatting issues, the Excel Gantt chart is attached with an e-submission report that is going to both our FA and client.

## APPENDIX A: BRIQUETTER DECISION MATRIX

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	<b>Briquetting Machines</b>	BP-100	BZBJ-1	MB-50
<b>Variables</b>	Weight			
Cost	3	3	3	1
Accessibility	2	5	1	1
Features	2	2	4	4
Ease of Use	3	4	5	2
Maintenance	3	4	2	2
Energy Consumption	1	4	4	2
	<b>Weighted Totals</b>	51	44	27

## APPENDIX B: ECONOMIC ANALYSIS

---

Maximum Output:

$$\underline{V} := 230\text{V} \quad \underline{I} := 26\text{A} \quad \underline{\text{Power}} := \underline{V} \cdot \underline{I} \quad \underline{\text{Power}} = 5.98 \times 10^3 \text{W}$$

$$\underline{\text{Electricity used}} := \underline{\text{Power}} \cdot 60\text{min} = 5.98 \text{ kW} \cdot \text{hr}$$

$$\underline{\text{Power}} := 7.5\text{hp} \quad \underline{\text{Power}} = 5.593 \times 10^3 \text{W}$$

$$\underline{\text{Electricity used}} := \underline{\text{Power}} \cdot 3600\text{s} \quad \underline{\text{Electricity used}} = 5.593 \text{ kW} \cdot \text{hr}$$

Assumption : the other heating and mixing systems are not as electrically demanding, and therefore will use approximately 1/3 as much energy.

$$\underline{\text{Electricity}}_{\text{briquetter}} := \underline{\text{Electricity}}_{\text{used}}$$

$$\underline{\text{Electricity}}_{\text{other}} := \frac{1}{3} \underline{\text{Electricity}}_{\text{briquetter}}$$

$$\underline{\text{Electricity}}_{\text{total}} := \underline{\text{Electricity}}_{\text{briquetter}} + \underline{\text{Electricity}}_{\text{other}} \quad \underline{\text{Electricity}}_{\text{total}} = 7.457 \text{ kW} \cdot \text{hr}$$

In 2009 commercial electricity cost 8.16 cents per kW\*hr  
[http://www.eia.doe.gov/cneaf/electricity/epm/table5\\_6\\_b.html](http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html)

Maximum output is 140 lb per hour

$$\frac{1\text{ton}}{140\text{lb}} = 14.286$$

It would take 14.286 hours to produce 1 ton of briquettes at maximum output

$$14.286 \cdot 0.816 \cdot 7.457 = 8.798$$

It would take \$8.80 to produce 1 ton of briquettes at 14.286 hours for 8.16 cents a kW\*hour using 7.457 kW\*hour.

Minimum Output

$$\underline{V} := 208\text{V} \quad \underline{I} := 26\text{A} \quad \underline{\text{Power}} := \underline{V} \cdot \underline{I} \quad \underline{\text{Power}} := 5.408 \cdot 10^3 \text{W}$$

$$\underline{\text{Electricity used}} := \underline{\text{Electricity}}_{\text{used}} := \underline{\text{Power}} \cdot 3600\text{s} \quad \underline{\text{Electricity}}_{\text{used}} = 5.408 \text{ kW} \cdot \text{hr}$$

$$\underline{\text{Electricity}}_{\text{briquetter}} := \underline{\text{Electricity}}_{\text{used}}$$

$$\underline{\text{Electricity}}_{\text{other}} := \frac{1}{3} \underline{\text{Electricity}}_{\text{briquetter}}$$

$$\underline{\text{Electricity}}_{\text{total}} := \underline{\text{Electricity}}_{\text{briquetter}} + \underline{\text{Electricity}}_{\text{other}} \quad \underline{\text{Electricity}}_{\text{total}} = 7.211 \text{ kW} \cdot \text{hr}$$

Minimum output is 100 lb per hour

$$\frac{1 \text{ ton}}{100 \text{ lb}} = 20$$

$$20 \cdot .0816 \cdot 7.211 = 11.768$$

It would cost \$11.768 to produce 1 ton of briquettes at 20 hours for 8.16 cents a kW\*hour for electricity using 7.211 kW\*hour.

The average cost of coal per ton is \$36

[http://greenecon.net/understanding-the-cost-of-solar-energy/energy\\_economics.html](http://greenecon.net/understanding-the-cost-of-solar-energy/energy_economics.html)

$$36 - 8.789 = 27.211 \quad 36 - 11.768 = 24.232$$

$$\frac{27.211 + 24.232}{2} = 25.722$$

This number shows that all else equal, farmers stand to make around \$25/ton of waste briquettes

Assume the briquetter will cost \$16,000, and to get a round number for the project, we can assume that the other systems and labor will cost roughly \$4000, we will try to determine how long the briquetter must be run to pay back initial investment.

Assumptions : briquetter is run for 12 hours a day, 300 days a year, it takes 15 hours to produce a ton of coal, and the operator stands to make \$25 of profit per ton

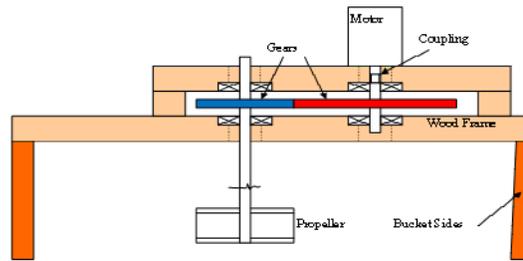
$$\frac{20000}{25} = 800 \quad \text{It will take 800 tons of briquettes to cover the cost of the machine}$$

$$800 \cdot 15 = 1.2 \times 10^4 \quad \text{It will take 12,000 hours to produce 800 tons}$$

$$\frac{12000}{12} = 1 \times 10^3 \quad \text{It will take 1000 days at 12 hours a day to make 800 tons}$$

$$\frac{1000}{300} = 3.333 \quad \text{It will take 3 and 1/3 years to cover the cost of capital}$$

## APPENDIX C: GEARING CALCULATIONS 1



**Mixing Motor: 6331K34 25rpm, 24V DC, 10.94in-lb Torque**

**Crushing Motor: 6331K34 25rpm, 24V DC, 10.94in-lb Torque**

$$T_{\text{motor}} := 10.94 \text{ in-lbf} \quad \omega := 25 \text{ rpm}$$

Through the coupling, the first gear shaft will go at the same torque and speed as the motor output shaft

$$T_{g1} := T_{\text{motor}} \quad \omega_{g1} := \omega$$

Gears are 20pitch and 14.5 pressure angle.

$$N_1 := 25 \quad N_2 := 15 \quad p := 20 \text{ in}^{-1} \quad \phi := 14.5 \text{ deg} \quad F_{\text{width}} := \frac{3}{8} \text{ in}$$

$$\text{Gear Ratio} \quad m_v := \frac{N_2}{N_1} = 0.6$$

$$\text{Mech. Adv.} \quad m_a := \frac{1}{m_v} = 1.667$$

Max operating voltage will be 18 volts for a 24 volt motor

$$V_{\text{ratio}} := \frac{18}{24} = 0.75$$

$$\omega_{g2} := \omega_{g1} \cdot (V_{\text{ratio}}) \cdot m_v = 11.25 \text{ rpm}$$

$$T_{g2} := T_{g1} \cdot m_a = 18.233 \text{ in-lbf}$$

The mixer in the bucket can produce a maximum speed of 11.25rpm with a torque of 18.233inlbf. This same speed and force will be seen in the crusher.

## APPENDIX D: GEARING CALCULATIONS 2

Computing the Tangential force on each gear:

$$W_{tg1} := \frac{2 \cdot P \cdot T_{g1}}{N_2} = 29.173 \cdot \text{lbf}$$

$$W_{tg2} := \frac{2 \cdot P \cdot T_{g2}}{N_1} = 29.173 \cdot \text{lbf}$$

Lewis Form Factors for teeth given by standards table and linear interpolation between 24 teeth and 26 teeth for a 25 tooth gear:

$$Y_{g1} := \frac{.302 + .292}{26 - 24} = 0.297$$

Lewis Form Factor for teeth given by standards table

$$Y_{g2} := .245$$

Compute the Lewis bending stress on each gear

$$\sigma_{g1} := \frac{W_{tg1} \cdot P}{F_{width} \cdot Y_{g1}} = 5.239 \times 10^3 \cdot \text{psi}$$

$$\sigma_{g2} := \frac{W_{tg2} \cdot P}{F_{width} \cdot Y_{g2}} = 6.351 \times 10^3 \cdot \text{psi}$$

Compute the safety factors for the gears

$$S_y := 100 \text{ksi} \quad \text{***Gears are 1144 steel}$$

$$SF_{g1} = \frac{S_y}{\sigma_{g1}} = 19.088$$

$$SF_{g2} = \frac{S_y}{\sigma_{g2}} = 15.746$$

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**APPENDIX E: TORSION CALCULATIONS**

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**Torsional Stress on Cutter Shaft**

$$D := \frac{3}{8} \text{ in}$$

$$L := 14.5 \text{ in}$$

$$G := 11.7 \cdot 10^6 \text{ psi}$$

$$T := 0.6 \text{ in} \cdot \text{lbf}$$

$$r := \frac{D}{2} = 0.187 \cdot \text{in}$$

$$J := \frac{\pi}{32} \cdot D^4 = 1.941 \times 10^{-3} \cdot \text{in}^4$$

$$\theta := \frac{T \cdot L}{G \cdot J} = 3.83 \times 10^{-4}$$

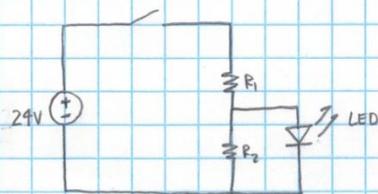
$$\tau_{\max} := \frac{T \cdot r}{J} = 57.947 \cdot \text{psi}$$

$$SF_{\text{shaft\_torsion}} := \frac{G}{\tau_{\max}} = 2.019 \times 10^5$$

## APPENDIX F: ELECTRICAL CALCULATION

### ENGINEERING ANALYSIS: ELECTRICAL CALCULATIONS

FOR SWITCH/LIGHT



$$V_s = 24V$$

$$I_{tot} < 20mA$$

$$I_{LED} = 2mA$$

$$V_D = V_s \left( \frac{R_2}{R_1 + R_2} \right)$$

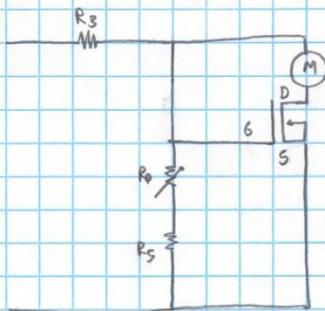
$$V_D < 2.5V, \text{ used } 1.5V$$

$$I_{LED} = \frac{V_D}{R_1 + R_2} \Rightarrow R_1 + R_2 = \frac{24}{2mA} = 12K$$

$$\therefore R_1 = 12.2K, R_2 = 1K$$

(From Availability)

FOR MOTOR/DRIVER



$$I_{DS} = K(V_{DS} - V_T)^2$$

$$K = \text{known}$$

$$V_T = 3V$$

$$V_{DS} = 5 - 6.3V \text{ from experimentation}$$

$$V_{min} = V_s \left( \frac{R_6}{R_3 + R_6} \right), V_s = 24V$$

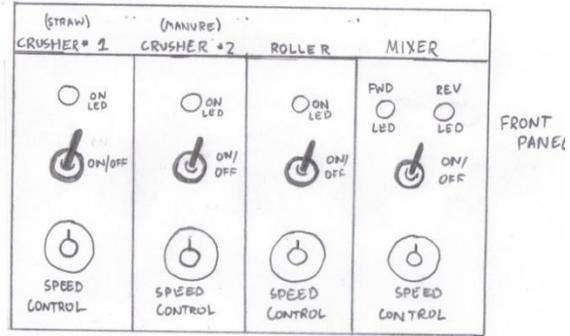
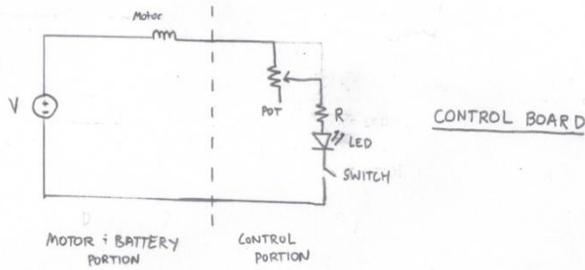
$$V_{max} = V_s \left( \frac{R_5 + R_6}{R_3 + R_5 + R_6} \right)$$

$$\therefore R_1 = 500\Omega, R_5 = 1.2K\Omega$$

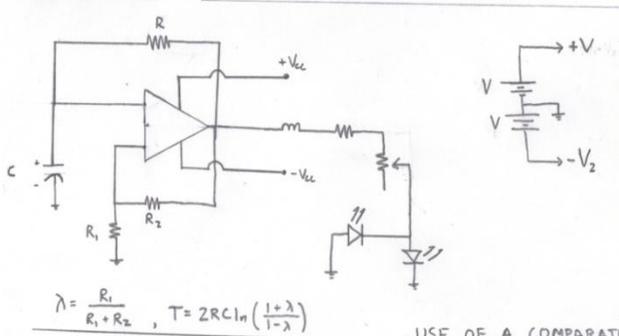
$R_3 = 6.6K\Omega$  (From Availability)

## APPENDIX G: INITIAL CIRCUIT

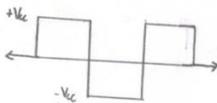
FOR THE CRUSHERS & DRUM SPINNER



FOR MIXER

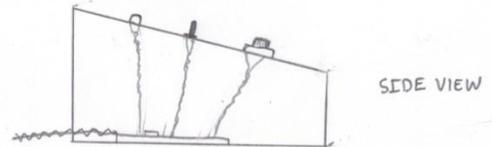


$$\lambda = \frac{R_1}{R_1 + R_2}, T = 2RC \ln\left(\frac{1+\lambda}{1-\lambda}\right)$$

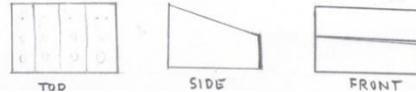


GRAPH OF VOLTAGE

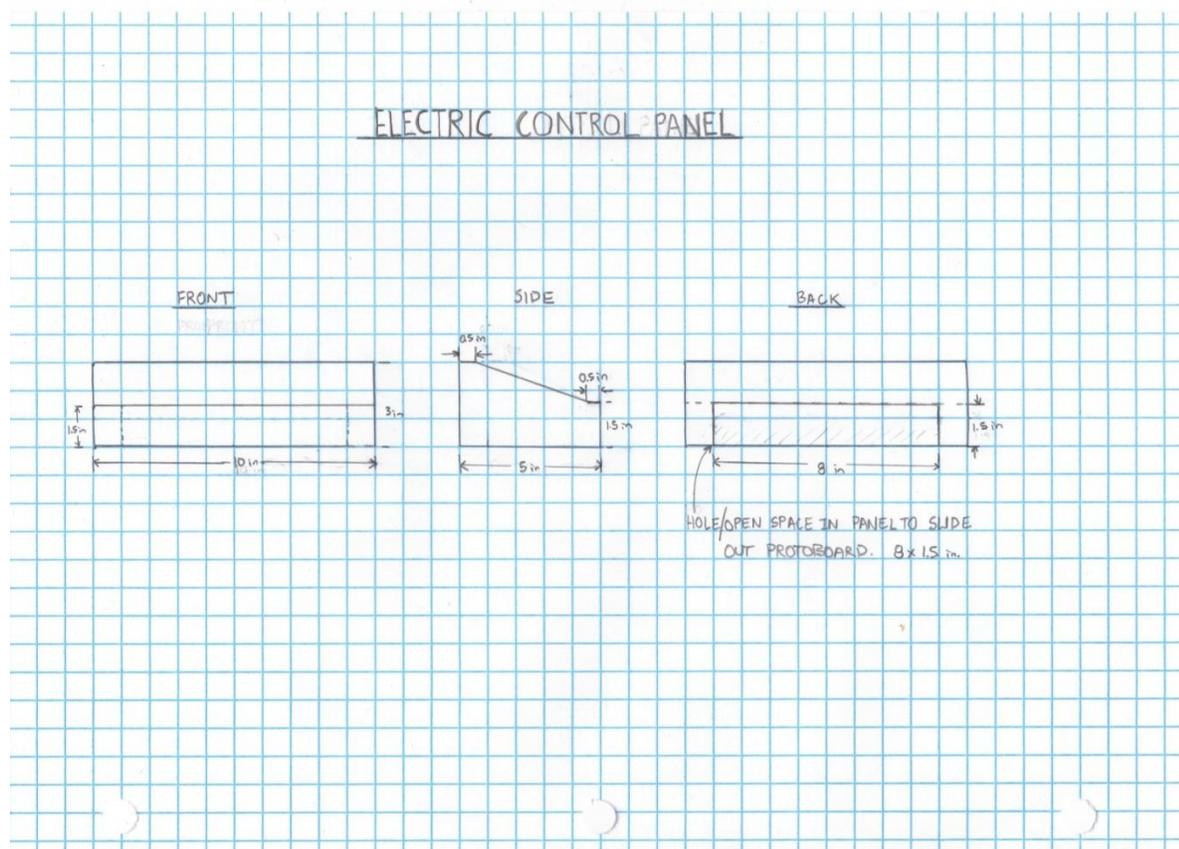
USE OF A COMPARATOR TO CHANGE POLARITY OF THE VOLTAGE  $\Rightarrow$  CHANGE OF DIRECTION OF THE MOTOR AFTER A CERTAIN TIME



\* PREFER TO BE SEE THROUGH PANEL/BOARD



## Appendix H: Control Panel



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## APPENDIX I: HYDRAULIC PRESS PREVIOUS DESIGN

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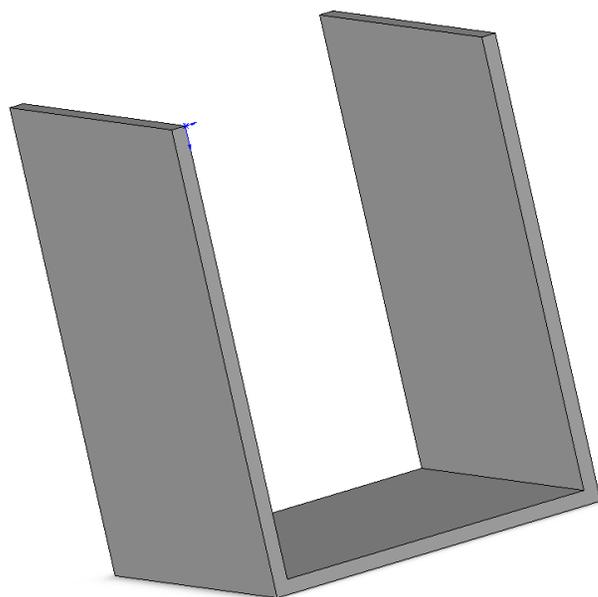


FIGURE 4: 1<sup>ST</sup> DESIGN FOR ENCLOSURE

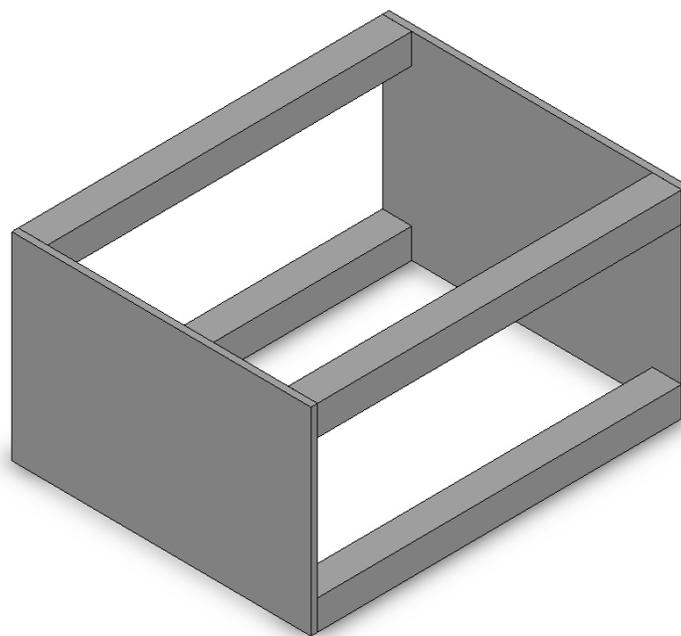


FIGURE 5: 2<sup>ND</sup> DESIGN FOR ENCLOSURE.

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## APPENDIX J: HYDRAULIC PRESS FINAL DESIGN

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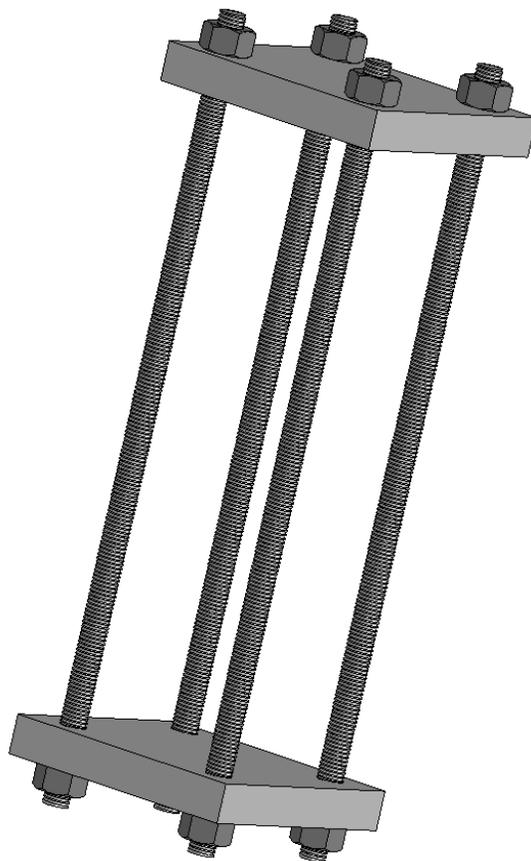


FIGURE 6: FINAL DESIGN FOR ENCLOSURE.

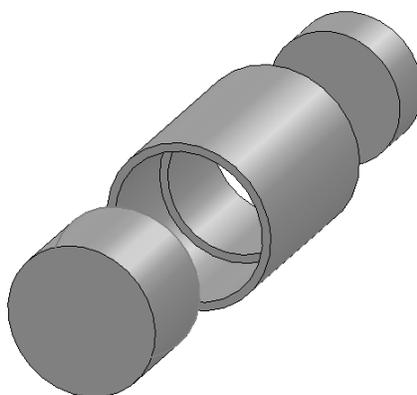


FIGURE 7: FINAL DESIGN FOR DIE CREATING BRIQUETTES.

## APPENDIX K: DIE SPECIFICATIONS

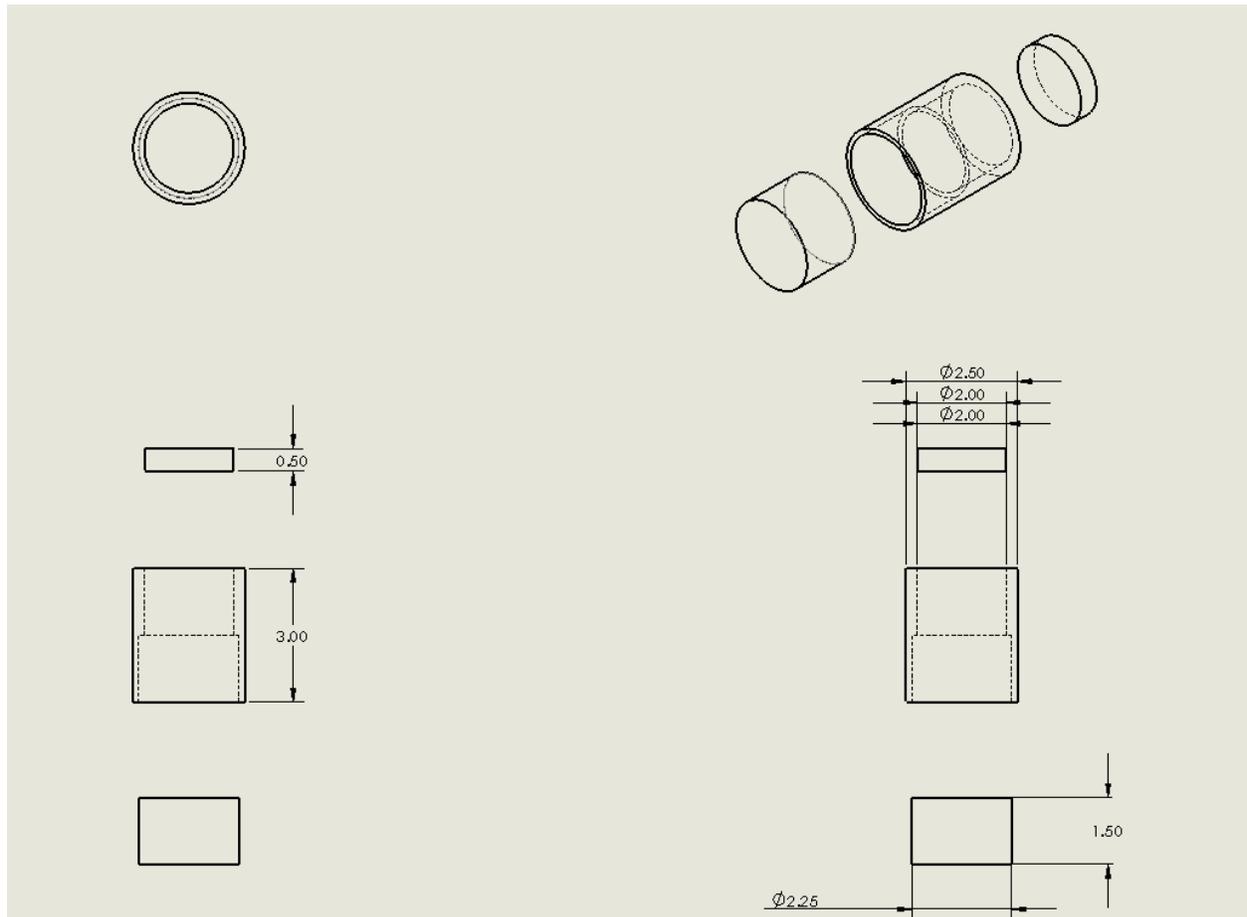
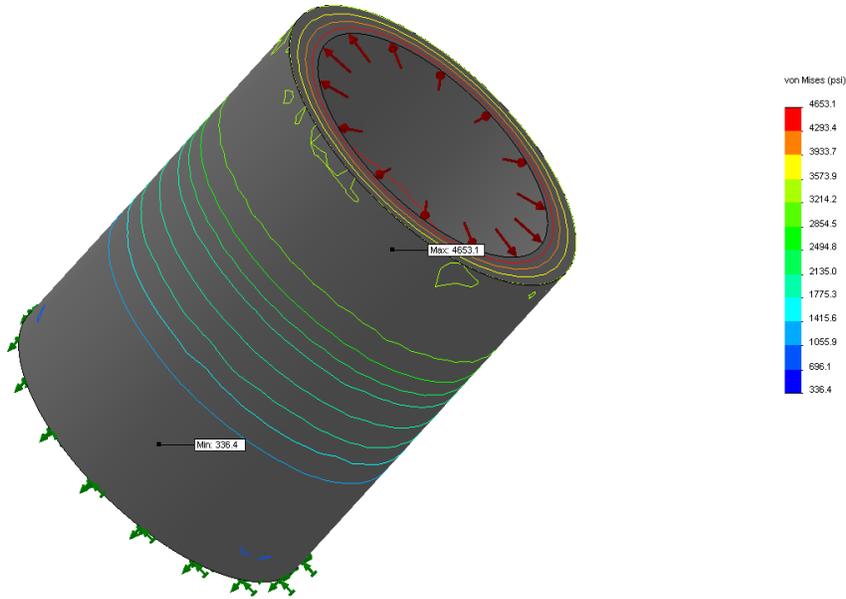


FIGURE 8: ENGINEERING DRAWING OF DIE.

## APPENDIX L: DIE ANALYSIS

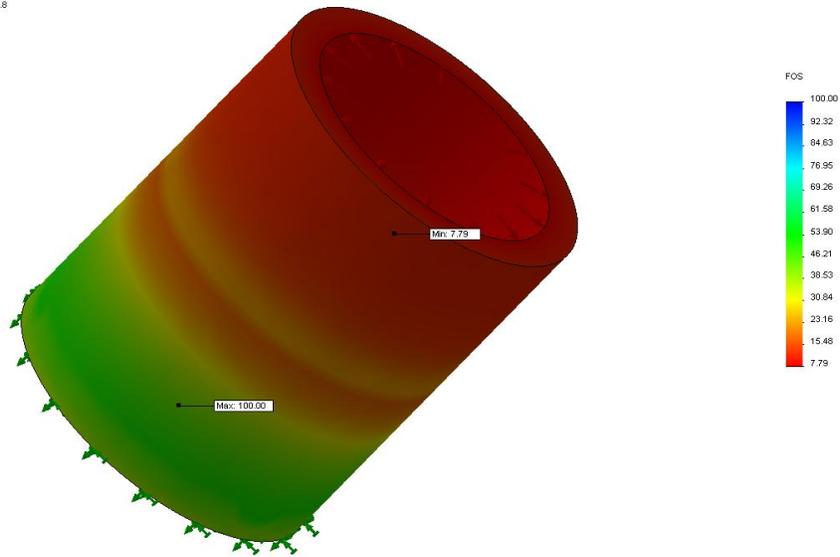
Model name: Assem1  
 Study name: Study.1  
 Plot type: Static nodal stress Stress1  
 Deformation scale: 1



Educational Version. For Instructional Use Only

FIGURE 9: STRESS PROFILE OCCURRING WITHIN DIE WITH 3000 PSI LOADING.

Model name: Assem1  
 Study name: Study.1  
 Plot type: Factor of Safety Factor of Safety1  
 Criterion: Automatic  
 Factor of safety distribution: Min FOS = 7.8



Educational Version. For Instructional Use Only

Figure 10: Factor of safety occurring within die with 3000 psi loading

## APPENDIX M: HYDRAULIC PRESS ENCLOSURE ANALYSIS

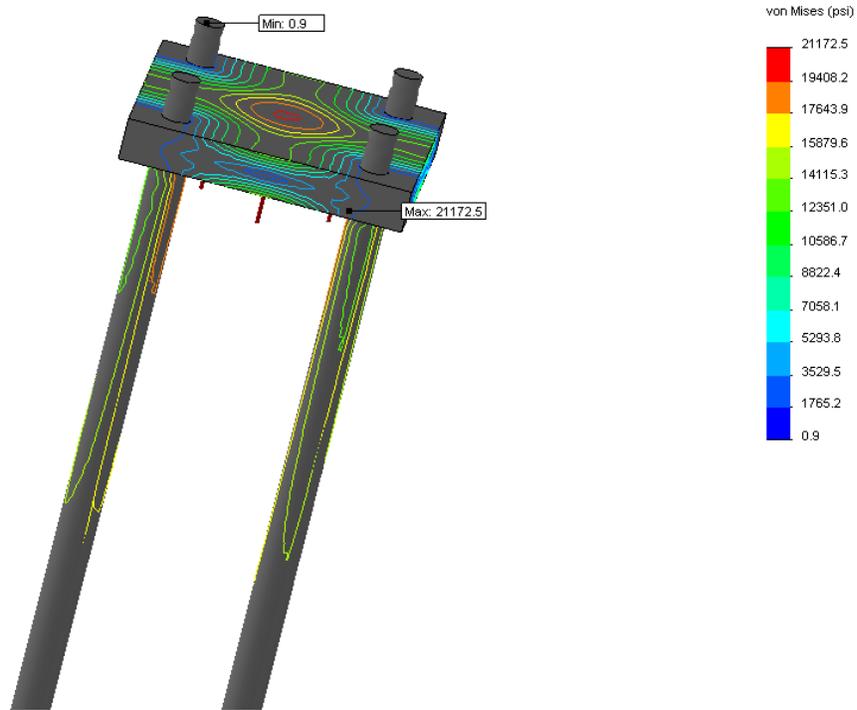


FIGURE 11: STRESS PROFILE OCCURRING IN ENCLOSURE WITH 3000 PSI LOADING.

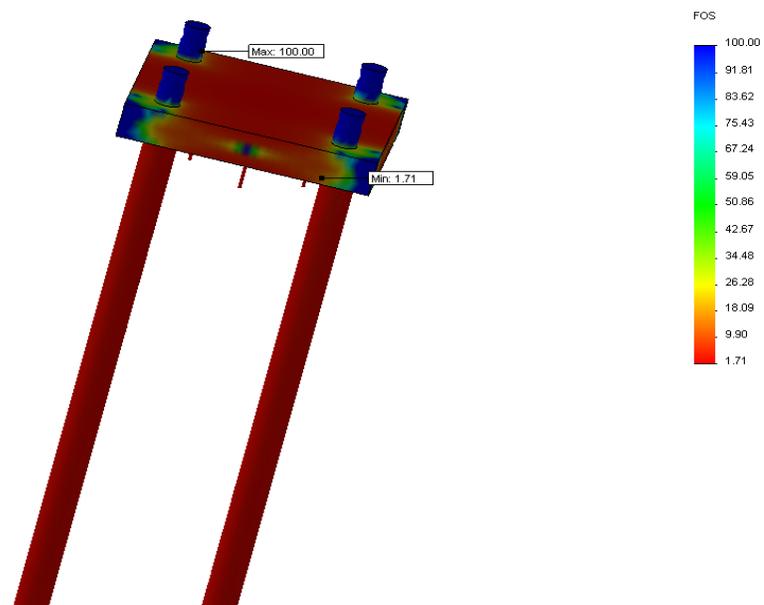


FIGURE 12: FACTOR OF OCCURRING IN ENCLOSURE WITH 3000 PSI LOADING.

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 APPENDIX N: ALL THREAD ANALYSIS
 

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ASTM A193-B7 Alloy

Bolt :

$$d := .5\text{in} \quad d_r := .4001\text{in} \quad A_t := .1419\text{in}^2 \quad p := \frac{1}{13}\text{in}$$

$$L_{\text{bolt}} = 15\text{in} \quad S_p := 175\text{ksi} \quad S_y := 105\text{ksi} \quad S_t := 125\text{ksi}$$

$$E_{\text{bolt}} = 30 \cdot 10^6\text{psi} \quad F_u := 6220\text{lbf} \quad P := \frac{F}{4} \quad P = 1.555 \times 10^3\text{lbf}$$

Plate (ASTM A36) :

$$E_{\text{plate}} := 29000\text{ksi} \quad L_{\text{plate}} := .75\text{in}$$

Analysis :

$$L_{\text{thread}} := 2d + .25\text{in} \quad L_{\text{thread}} = 1.25\text{in}$$

$$L_{\text{shank}} := L_{\text{bolt}} - L_{\text{thread}} \quad L_{\text{shank}} = 13.75\text{in}$$

$$L_{\text{thd}} := L_{\text{shank}} - L_{\text{plate}} \quad L_{\text{thd}} = 13\text{in}$$

$$A_{\text{shank}} := \frac{\pi \cdot d^2}{4} \quad A_{\text{shank}} = 0.196\text{in}^2$$

$$k_{\text{shank}} := \frac{A_{\text{shank}} E_{\text{bolt}}}{L_{\text{shank}}} \quad k_{\text{shank}} = 4.284 \times 10^5 \frac{\text{lbf}}{\text{in}}$$

$$k_{\text{thread}} := \frac{A_t E_{\text{bolt}}}{L_{\text{thd}}} \quad k_{\text{thread}} = 3.275 \times 10^5 \frac{\text{lbf}}{\text{in}}$$

$$k_{\text{bolt}} := \left( \frac{1}{k_{\text{shank}}} + \frac{1}{k_{\text{thread}}} \right)^{-1} \quad k_{\text{bolt}} = 1.856 \times 10^5 \frac{\text{lbf}}{\text{in}}$$

$$k_{\text{plate}} := d \cdot E_{\text{plate}} \cdot .77871 \cdot e^{.61616 \frac{d}{L_{\text{plate}}}} \quad k_{\text{plate}} = 1.703 \times 10^7 \frac{\text{lbf}}{\text{in}}$$

$$C = \frac{k_{\text{bolt}}}{k_{\text{plate}} + k_{\text{bolt}}} \quad C = 0.011$$

$$F_i := .75 \cdot A_t \cdot S_p \quad F_i = 1.862 \times 10^4\text{lbf}$$

$$\sigma_{\text{bolt}} = \frac{P}{A_t} \quad \sigma_{\text{bolt}} = 1.096 \times 10^4\text{psi}$$

$$SF_{\text{tension}} = \frac{S_y}{\sigma_{\text{bolt}}}$$

$$SF_{\text{tension}} = 9.582$$

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## APPENDIX O: BOMB CALORIMETER

---

### Bomb Calorimetry

#### Data:

##### Sample One: 50/50 moist

$$T_{i1} := 25.0^{\circ}\text{C} \quad T_{f1} := 25.5^{\circ}\text{C} \quad T_{\text{avg}1} := \frac{T_{i1} + T_{f1}}{2} = 298.4 \text{ K}$$

$$l_1 := 10\text{cm} - 0.7\text{cm} - 1.0\text{cm} = 0.083 \text{ m} \quad m_1 := 0.3969 \text{ gm}$$

$$\Delta T_1 := T_{f1} - T_{i1} = 0.5 \text{ K}$$

##### Sample Two: 70/30 moist

$$T_{i2} := 24.6^{\circ}\text{C} \quad T_{f2} := 25.2^{\circ}\text{C} \quad T_{\text{avg}2} := \frac{T_{i2} + T_{f2}}{2} = 298.05 \text{ K}$$

$$l_2 := 10\text{cm} - 0.6\text{cm} - 0.8\text{cm} = 0.086 \text{ m} \quad m_2 := 0.4712 \text{ gm}$$

$$\Delta T_2 := T_{f2} - T_{i2} = 0.6 \text{ K}$$

##### Sample Three: 50/50 dry

$$T_{i3} := 24.6^{\circ}\text{C} \quad T_{f3} := 25.4^{\circ}\text{C} \quad T_{\text{avg}3} := \frac{T_{i3} + T_{f3}}{2} = 298.15 \text{ K}$$

$$l_3 := 10\text{cm} - 0.7\text{cm} - 0.7\text{cm} = 0.086 \text{ m} \quad m_3 := 0.5596 \text{ gm}$$

$$\Delta T_3 := T_{f3} - T_{i3} = 0.8 \text{ K}$$

$$C_{\text{cal}} := 2485 \frac{\text{cal}}{\text{K}} \quad e := 2.3 \frac{\text{cal}}{\text{cm}} \quad R := 8.3144 \frac{\text{J}}{\text{K}\cdot\text{mol}} \quad 1 \text{ Joule} = 2.3901\text{E-}4 \text{ kcal}$$

$$\text{kJ} := 1000\text{J}$$

$$\text{MJ} := 1000\text{kJ}$$

$$M_{\text{compounds}} := \begin{pmatrix} 44.0095 \\ 80.063 \\ 67.518 \\ 283.889 \\ 60.0843 \\ 159.69 \\ 101.9613 \\ 56.077 \\ 40.3044 \\ 61.9789 \\ 94.196 \\ 79.866 \end{pmatrix} \frac{\text{gm}}{\text{mol}} \quad Wt_{\text{manureash}} := \begin{pmatrix} 1.1 \\ 2.8 \\ 3.8 \\ 3 \\ 53.5 \\ 1.7 \\ 7.8 \\ 13.9 \\ 3.7 \\ 2 \\ 6.4 \\ 0.3 \end{pmatrix} \text{gm} \quad Wt_{\text{strawash}} := \begin{pmatrix} 0 \\ 4 \\ 5.6 \\ 3.2 \\ 52 \\ 1.1 \\ 0.6 \\ 9.2 \\ 1.8 \\ 0.3 \\ 21.9 \\ 0 \end{pmatrix} \text{gm}$$

$$M_{\text{manureash}} := \frac{100\text{gm}}{\left(Wt_{\text{manureash}} \cdot M_{\text{compounds}}^{-1}\right)} = 64.599 \frac{\text{gm}}{\text{mol}}$$

$$M_{\text{strawash}} := \frac{100\text{gm}}{\left(Wt_{\text{strawash}} \cdot M_{\text{compounds}}^{-1}\right)} = 68.099 \frac{\text{gm}}{\text{mol}}$$

$$M_{\text{elements}} := \begin{pmatrix} 12.01 \\ 1.008 \\ 16.0 \\ 14.007 \\ 32.066 \\ 35.453 \end{pmatrix} \frac{\text{gm}}{\text{mol}} \quad Wt_{\text{manure}} := \begin{pmatrix} 45.4 \\ 5.35 \\ 3.1 \\ 0.96 \\ 0.29 \\ 1.16 \end{pmatrix} \text{gm} \quad Wt_{\text{straw}} := \begin{pmatrix} 45.5 \\ 6.12 \\ 40.0 \\ 0.52 \\ 0.13 \\ 0 \end{pmatrix} \text{gm}$$

$$Wt_{\text{manure\%ash}} := 15.84\text{gm} \quad Wt_{\text{straw\%ash}} := 7.73\text{gm}$$

$$M_{\text{manure}} := \frac{100\text{gm}}{\left(Wt_{\text{manure}} \cdot M_{\text{elements}}^{-1}\right)} + \frac{100\text{gm}}{\left(Wt_{\text{manure\%ash}} \cdot \frac{1}{M_{\text{manureash}}}\right)} = 418.467 \frac{\text{gm}}{\text{mol}}$$

$$M_{50,50} := (0.5 \cdot M_{\text{manure}}) + (0.5 \cdot M_{\text{straw}}) = 653.75 \frac{\text{gm}}{\text{mol}} \quad \Delta n_{g,50,50} := -4.233$$

$$M_{70,30} := (0.7 \cdot M_{\text{manure}}) + (0.3 \cdot M_{\text{straw}}) = 559.637 \frac{\text{gm}}{\text{mol}} \quad \Delta n_{g,70,30} := -4.337$$

Sample 1:

$$\Delta U_{R1} := \frac{-C_{\text{cal}} \cdot \Delta T_1 + e \cdot I_1}{m_1} \cdot M_{50,50} = -2.015 \times 10^3 \frac{\text{kcal}}{\text{mol}}$$

$$\Delta H_{R1} := \Delta U_{R1} + \left( \Delta n_{g,50,50} \cdot R \cdot T_{\text{avg}1} \cdot \frac{1}{1000} \right) = -2.015 \times 10^3 \frac{\text{kcal}}{\text{mol}}$$

$$H_1 := -\Delta H_{R1} \cdot \frac{1}{M_{50,50}} \quad \boxed{H_1 = 12.905 \frac{\text{MJ}}{\text{kg}}}$$

Sample 2:

$$\Delta U_{R2} := \frac{-C_{\text{cal}} \cdot \Delta T_2 + e \cdot I_2}{m_2} \cdot M_{70,30} = -1.747 \times 10^3 \frac{\text{kcal}}{\text{mol}}$$

$$\Delta H_{R2} := \Delta U_{R2} + \left( \Delta n_{g,70,30} \cdot R \cdot T_{\text{avg}2} \cdot \frac{1}{1000} \right) = -1.747 \times 10^3 \frac{\text{kcal}}{\text{mol}}$$

$$H_2 := -\Delta H_{R2} \cdot \frac{1}{M_{70,30}} \quad \boxed{H_2 = 13.072 \frac{\text{MJ}}{\text{kg}}}$$

Sample 3:

$$\Delta U_{R3} := \frac{-C_{\text{cal}} \cdot \Delta T_3 + e \cdot I_3}{m_3} \cdot M_{50,50} = -2.299 \times 10^3 \frac{\text{kcal}}{\text{mol}}$$

$$\Delta H_{R3} := \Delta U_{R3} + \left( \Delta n_{g,50,50} \cdot R \cdot T_{\text{avg}3} \cdot \frac{1}{1000} \right) = -2.299 \times 10^3 \frac{\text{kcal}}{\text{mol}}$$

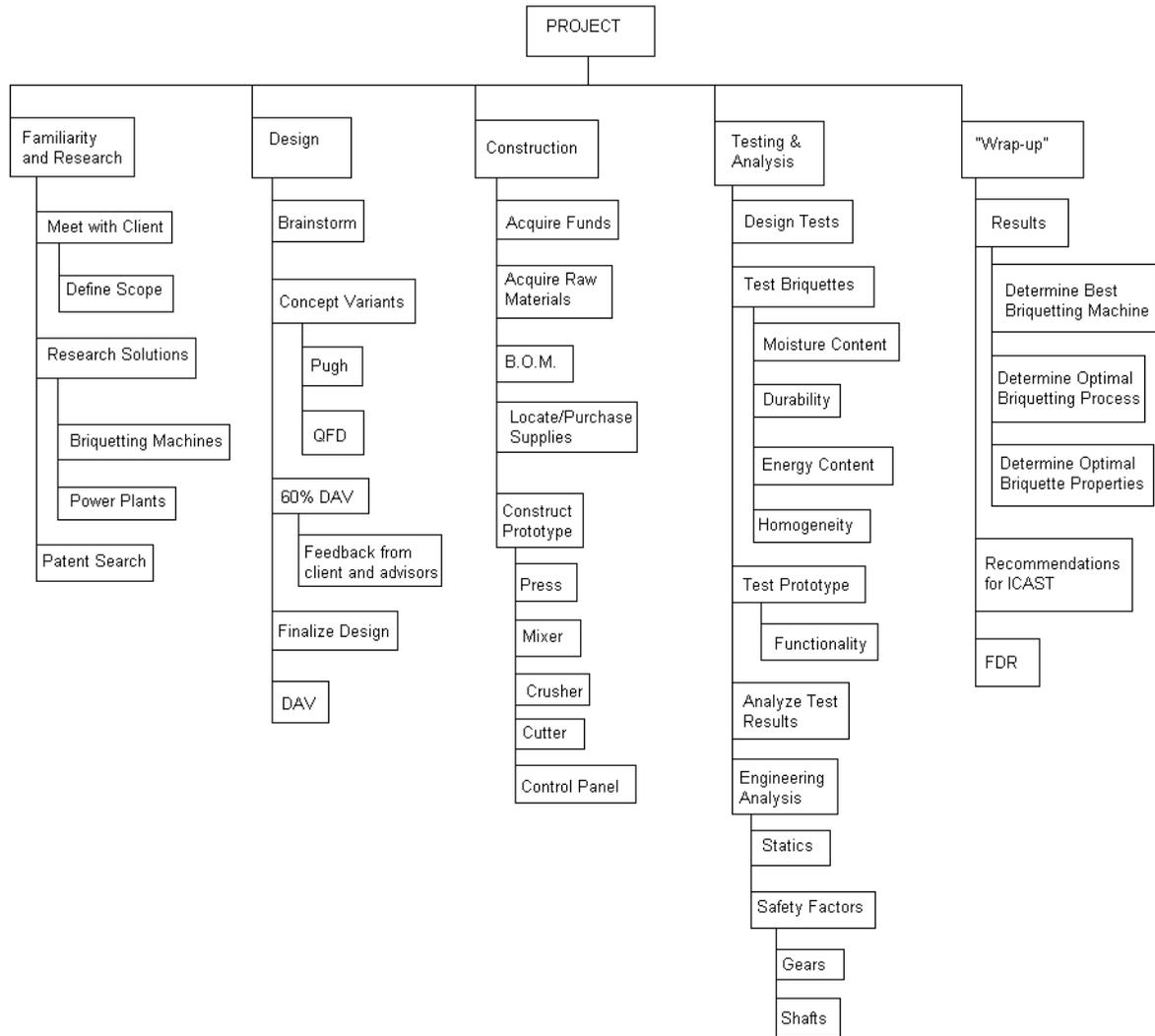
$$H_3 := -\Delta H_{R3} \cdot \frac{1}{M_{50,50}} \quad \boxed{H_3 = 14.726 \frac{\text{MJ}}{\text{kg}}}$$

~70-85% the heat capacity of what a manure/straw briquette should be and  
~53-61% of coal

## APPENDIX P: BUDGET

<b>Component</b>	<b>Purpose</b>	<b>Quantity</b>	<b>Estimated Cost</b>	<b>Justification of Cost</b>
Biowaste (non-irrigated wheat straw and cow manure)	These are the materials that will be briquetted	Variable	Free	Biowaste supplied by the client
Bearings, gears, couplings, motors	Used to construct prototype	Variable	\$396.31	Price of components in McMaster catalog
Cutting blade, shaft assembly, collars	Used to construct prototype	Variable	\$273.49	Price of components in McMaster catalog
Barley Crusher	Used to grind the biowaste	1	\$132.00	This is the cost of a Barley Crusher found in a catalog
Electrical components	Used to provide power to prototype subsystems	Variable	\$88.25	Price of components in Jameco catalog
Heat Rope	Used to dry the biowaste briquettes while briquetting	1	Free	Supplied by Technical Consultant
Enerpac Hydraulic press	Used to simulate briquetting process; will serve as our "briquetting machine"	1	Free	Obtained through team member's place of employment
Convection Oven	Used to dry manure before briquetting	1	\$20	This is the cost of a cheap oven
<b>Total Estimated Cost: \$910.05</b>				

## APPENDIX Q: WBS



## **Appendix D**

### **Report from Colorado State University**

### **Decision Matrix: Feasibility and Comparison of Five Biomass Conversion Technologies**

# Straw Poo to Gold Project

## Decision Matrix CSU iCAST team

10/15/2010

Sarah Williams  
Joe Dauner  
Austin Archer  
Justin Rogers  
Brittany Bellefeuille

	Raw Score (scale of 1-10)				Weighted Score (weight x raw score)			
	Pyrolysis	Torrefaction	Gasification	Digestion	Pyrolysis	Torrefaction	Gasification	Digestion
<b>Costs:</b>								
Capital Required	5	7	6	1	35	49	42	7
Operating Expenses	8	3	5	8	64	24	40	64
Return on Investment (ROI)	7	1	5	3	70	10	50	30
<b>Environment</b>								
Environmental Mitigation	7	7	7	7	49	49	49	49
Emissions	6	7	5	5	48	56	40	40
Noise, odor, traffic, etc.	6	7	5	9	18	21	15	27
Public Approval for facility (NIMBY issues)	4	6	5	7	28	42	35	49
Permit requirements and approval	5	5	5	5	45	45	45	45
Life Cycle Analysis	7	6	6	6	28	24	24	24
Land requirements	5	4	5	8	10	8	10	16
Water usage	10	10	10	3	20	20	20	6
<b>Technical Feasibility</b>								
Energy in V.S. Energy out (Energy Balance)	7	9	5	6	28	36	20	24
Mass Balance	7	8	8	5	28	32	32	20
Complexity of process/equipment	7	6	6	8	35	30	30	40
Reliability of process/equipment	8	6	6	8	64	48	48	64
Ease of Implementation	6	6	8	5	24	24	32	20
<b>Safety:</b>								
Safety Hazard	7	8	5	6	56	64	40	48
Hazardous By-products	8	7	3	6	40	35	15	30
<b>Social Aspect</b>								
Public Support	5	6	5	5	20	24	20	20
Political Support	9	8	7	7	36	32	28	28
<b>Total:</b>					<b>746</b>	<b>673</b>	<b>635</b>	<b>651</b>

## **Purpose**

To achieve a quantified direction tool for the Chemical and Biological design team from CSU. Topics covered were digestion, torrefaction, pyrolysis, gasification, and bio-char.

## **Current Progress**

A good sense of the varied industries progress was attained. The attached appendices provide justification for the decision matrix scores. In developing the decision matrix, it was apparent that bio-char was not going to be a central player in the final analysis.

The decision matrix shows pyrolysis as the highest scoring design project, with torrefaction a close second. Pyrolysis has the best potential for optimization. Torrefaction, pyrolysis and gasification are all related processes, the primary difference being operating temperature. The temperature ranges of torrefaction, pyrolysis and gasification are 200 to 300 °C, 300 to 800°C, and 800 to 1600 °C, respectively. As the temperature increases, the products shift from solids to gases. Pyrolysis offers the most flexibility in products and in operational conditions. Digestion, the most unique process, was a nice counterpoint to the other processes, but it focuses primarily on waste management rather than producing a product to sell.

The main problems encountered by our team were finding information regarding public opinion on processes and permit requirements. At the current time, none of these processes seem to be hot button issues.

Since our team has narrowed our focus to pyrolysis, our next step is to collaborate so that everyone has a higher familiarity with the pyrolysis process.

With the defined scale of our project at approximately 100,000 cows, our focus for next semester will be to quantify the products of pyrolysis and complete design portion of the project. The method to calculate cost shown below was used to keep estimates as uniform as possible.

## Cost Analysis method

The following is the presentation of the method in order to compare cost process method. The assumptions for all processes are as follows;

- 100,000 cows is the size operation
  - A beef cow weighing 1000-lb drops 60 lbs manure/day on a wet basis.<sup>[1][2]</sup>
  - A 90% water composition is assumed.<sup>[3]</sup>
    - Dry weight is 6 lbs/day.
    - Dry weight 2136 lbs/year
  - Our processing capability is 300 tons/day dry weight.
    - 109500 tons/year dry weight
  - Financial examples may be taken for as few as 10,000 cows and normalized
- All products (gas and/or solids) will be given a price as sold 'off farm'

The following are the equations and major values calculated for each of the processes.

1. Find a process example with financial information
  - a. Use the capitol cost
    - i.  $C_t = FOB + Installation + Start\ up$
    - ii.  $FOB = Freight\ on\ Board\ cost\ of\ Equipment$
    - iii.  $C_t = Total\ Capital\ Investment$
2. Use the Lang Factor method to estimate  $C_t$  from FOB cost.<sup>[4]</sup>
  - a.  $C_t = 1.05 * fl_{Ct} * FOB$ 
    - i.  $fl_{Ct} = Lang\ Factor = 5.03$
3. Operating costs from table 23.1.<sup>[4]</sup>
  - a.  $C_{op} = DW\&B + Utilities + Maintenance$ 
    - i. DW&B is Direct Wages and benefits
      1.  $DW\&B = \$35/Op\ hr * 8000\ Op\ hrs/year * Number\ of\ Operators$
    - ii. Utilities
      1. Varies by process
    - iii. Maintenance
      1.  $Mt = 3.5\% \text{ of } C_t$
4. Product Produced
  - a. Amount product produced per year
  - b. Market price
  - c.  $S = Gross\ Earnings$
5. ROI
  - a.  $ROI = \frac{Annual\ Net\ Earnings}{Total\ capital\ Investment} = \frac{(1-t)(Sales-C_{OP})}{C_t}$
  - b.  $t = 0.4$  for a 40% tax rate

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## Appendix 1: Pyrolysis

Pyrolysis is the process of burning material in the absence of oxygen and is usually performed between 500 and 800 degrees Celsius. It can be employed to control waste and pollution and can create valuable materials such as fuels. One potential feedstock for pyrolysis is manure biomass. To assess the possibility of using pyrolysis to obtain fuels from manure, estimates of cost, environmental benefits, technical feasibility, safety, and social aspects were researched.

### Costs

One of the most important factors to consider is the economic feasibility of pyrolysis. Most of the current research on this process is focused on production of an oil product that is used as a substitute for different fuel oils depending on the degree to which it is refined. A European market study for crude pyrolysis oil assigned it a delivered cost of \$6.8078 to \$10.9461 per GJ<sup>[7]</sup>. The biochar product was estimated at an average of \$2.6767 per GJ<sup>[7]</sup>. A typical high heating value (HHV) is 17 MJ/kg<sup>[7]</sup> for the oil and 12150 Btu/lb<sup>[9]</sup> for the char. A Canadian company called Dynamotive Energy Systems performs pyrolysis on plant biomass and their largest plant has a capacity of 200 tons of feedstock per day. Using the assumptions previously specified for plant capacity and production rate, and assuming an oil fraction of 0.65<sup>[5, 2]</sup> as well as Dynamotive's claimed efficiency of 0.8<sup>[8]</sup>, the raw oil we would produce is 0.0569 megatons per year, and the solid char yield would be 0.0175 megatons per year. With an average selling price of \$8.877 per GJ for oil this translates to sales of \$ 7.795 million per year<sup>[7]</sup>. Assuming a solid yield of 0.2<sup>[8]</sup> the total sales for biochar is \$1.2 million per year. Total capital investment was determined with an estimate from Dynamotive which reported \$30 million per megaton of installed capacity<sup>[8]</sup>. With our capacity at 0.003 megatons per day our total capital investment for the plant is \$32.85 million. Many studies and projects have determined that the remaining products can be recycled to power the pyrolysis plant. Generally these can supply at least seventy five percent of their required energy<sup>[7]</sup>, so utility costs for pyrolysis plant operation can probably be viewed as negligible. An estimate of 5 operator shifts per day gives a direct wages and benefits estimate of \$466,667. This leads to an operating cost of \$581,640 per year. The return on investment for a plant this size that is producing only biocrude oil is 0.113. If biochar is also sold the return on investment could be close to 0.134.

### Environment

Pyrolysis has significant environmental benefits because it accomplishes reduction of emissions, water pollution, and feedlot waste. Rather than being allowed to pollute water or being sent to a landfill the waste can be converted to useful products that are a source of renewable energy. Since they are considered carbon neutral, pyrolysis products can replace a portion of traditional carbon based fuel and effectively lower the output of carbon dioxide to the atmosphere. The three energy dense products are syngas, biocrude oil, and solid biochar. The ones for which conditions are not optimized are produced in lower quantities than the desired product, and they can be recycled to heat the pyrolysis process. Emissions of the process itself are negligible. However, depending on whether the desired product is gas, oil, or char, the emissions when it is

used as fuel can be significant. Biochar is expected to have significantly lower CO<sub>2</sub> and SO<sub>x</sub> emissions than traditional coal, but the NO<sub>x</sub> emissions may be equal to those of coal or slightly higher. For this reason it is desirable to co-fire the biosolid with coal. Biooil has lower CO<sub>2</sub> and SO<sub>2</sub> than traditional diesel. Specific numbers for emissions depend on the desired product, the quality of feedstock, and the method of pyrolysis. Parameters like temperature, pressure, and residence time can be optimized for the desired product. According to one study, running pyrolysis at a lower temperature tends to produce fewer undesirable compounds, namely CO, CO<sub>2</sub>, CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, NH<sub>3</sub>, HCN, tar, and oxygenated volatiles. The product gas of pyrolyzed cow manure contained 24.87% CO<sub>2</sub>, 0.49% SO<sub>2</sub>, 1.42% NO, and 15.64% CO<sup>[4]</sup>.

The pyrolysis plant is unlikely to impede or cause significant traffic. Noise should be minimal other than the vibration from the grinder. Unpleasant odor is one potential public concern. For this reason the sections on noise, odor and traffic as well as public approval for the facility were scored lower than other environmental categories. An open burning permit may be required depending on the level of control and pollution. A solid waste permit may be necessary if they system is considered an incinerator. A water permit is unlikely to be required because the process uses basically no water and there is little water pollution.

Land requirements for a large scale plant are significant. However once a product is obtained it can be used for fuel in existing facilities. This is especially true for the solid bio-coal because it could easily be co-fired in coal plants. In some cases biocrude oil would need to be further processed in a biorefinery. Water is not used unless the heat source is steam.

Manure pyrolysis is a reasonable solution for waste control, it produces a renewable source of energy, and it is a method to reduce pollution. There is no raw material production so this life cycle step is eliminated. Manufacturing is performed on site and the products can either be used on site or transported to buyers at larger scale utilities. If sold to power plants, it is necessary to account for transportation costs. Pyrolysis of biomass is desirable because it does not require food crops as feedstock. Of the three energy dense products the one with greatest fuel potential is the oil portion. However, the syngas could be used for electricity and biochar could be co-fired in coal power plants.

### **Technical Feasibility**

Pyrolysis is a proven and effective process. It was scored high in the technical feasibility category because it has consistent results and is widely researched, piloted, and demoed. There are even production plants that use the process to effectively control their industrial waste. It can be easily implemented because, once built, it is not complicated to operate and can likely be scaled up to be integrated into existing energy generating facilities. Pyrolysis plants are relatively uncomplicated and easily implemented.

When performed effectively, pyrolysis creates valuable fuels. A majority of current research focuses on utilizing the liquid portion for biocrude oil. It can be about 50-60% as efficient as traditional diesel oil<sup>[1]</sup> and can also be further refined to be even more energy efficient. The solid biochar and the combustible gas are useful as well. In a study that used swine manure as a feedstock in the interest of making biochar and combustible gas, the heating value of the solid was 19.5 MJ/kg. Another study claimed that the gas portion has a heating value of 350-550

Btu/ft<sup>3</sup> [4]. The process itself is energy intensive but it is common practice to recycle this medium Btu gas produced in order to sustain pyrolysis. It can potentially meet 75% of the fuel that is needed [2]. The process is not incredibly complex when a reliable reactor is used and it can be easily implemented and performed on site.

The mass balance of pyrolysis depends heavily on process design and feedstock quality. According to two separate studies, the bio-oil portion tends to be around 60-70% of the total product, on a mass basis, if pyrolysis is optimized for oil. [5, 2]. The Wisconsin biorefinery states that the remainder of the product is 13-25% solid that can be used for biochar, and 10-20% combustible gas. As mentioned previously the gas is typically recycled for heating the pyrolysis. The fast pyrolysis used by the biorefinery has a yield of about 72% of the mass fed to the pyrolyzer. Because multiple useful products are formed and efficiency is high, the mass balance category received a high score.

### **Safety**

There are few safety issues in performing pyrolysis. It is run at high temperatures, but lower than those of gasification. The hopper feeder is somewhat dangerous due to the moving parts but should not be considered a major threat. No hazardous byproducts are formed; in fact many of them are potentially useful. Depending on which energy source is desired (oil, gas, char), the remaining portions can possibly be made into paint fillers or ink.

### **Social Aspect**

Public support for pyrolysis in general is relatively high. The process is clean and efficient and it creates useful product. A problem could potentially arise from the concept of pyrolyzing manure, mainly because of odor associated with the controlled burning. If in close proximity to highly populated or frequently visited areas disputes could arise.

The main political benefit to pyrolysis is that it is considered a carbon neutral process. If sold to utilities, whether as liquid fuel, gas, or charcoal to be co-fired with coal, the products can be incorporated into their percentage of renewable energy (carbon credits). The federal government is clearly an advocate because NREL is currently focusing on biomass pyrolysis as a main area of their biomass research [6]. They have the capability for fast pyrolysis using a fluidized bed reactor. As they continue to research and develop liquid fuels, namely from bio-oil, they also plan to focus on stabilizing and upgrading bio-oil for transport and fuels. The reason that political support was not scored higher is because much of current government research is focused on forest biomass rather than manure waste.

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## Appendix 2: Torrefaction

Torrefaction is the heating of material to between 200 °C and 300 °C under atmospheric pressure in the absence of oxygen, distinguished by its low heating rate of less than 50 °C/min. When biomass is torrefied, approximately 70% of the mass is retained as a solid biochar while retaining 90% of the original energy content.

The only torrefaction production plant ever to exist was a demonstration plant operated by a French company called Pechiney. It was opened in 1988 and torrefied wood from the surrounding forestry near La Val de Cere, France. This plant was shut down in the early 1990's for economic reasons. Since then, a small few processes have been proposed for the torrefaction of biomass, but none have reached the commercial scale [1],[2].

To date, most of the research regarding the topic has been centered on the torrefaction of woody biomass, though there is some research into the torrefaction of several types of biomass. Examples include herbaceous crops, agricultural waste, and to a lesser extent, animal waste. Most studies have focused on the thermochemical and physical properties of torrefied biomass compared to raw biomass.

The Energy Research Center of the Netherlands (ECN) has done a significant amount of research of the torrefaction of biomass, focusing mostly on wood. Their research included data gathered from the Pechiney plant and from other studies. The information presented here is based mostly off of the research done at ECN.

### Costs

The cost of the torrefaction process depends on how the process is to be heated, whether or not it can be run autothermally (without the use of utility fuel), whether or not it will be integrated with pelletisation, and the size of the process.

Pelletised, non-torrefied, biomass has been used for biomass co-firing in coal-fired power stations [3]. Unfortunately, this material only has about half the energy density of conventional coal, and has inferior combustion characteristics. If torrefied biomass is to be considered a more viable product, its production costs must be similar to pelletisation. Also, since torrefied product is to be co-fired or gasified as a replacement for conventional coal, its price must be competitive with coal. In Colorado, the price of coal was about \$37/ton, or \$1.76/GJ [3].

Bergman et. al. have done a rough economic analysis of a stand-alone torrefaction, stand-alone pelletisation, combined torrefaction and pelletisation (TOP) processes. The analyses were done in 2005 using euros as the currency. All prices have been adjusted to 2010 dollars (\$1.20/euro in 2005, 12% inflation since then [4],[5]). These analyses took into account a process producing 60 kton/year of torrefied wood (about 100 kton/year of feedstock) for the stand-alone torrefaction and TOP processes. The stand-alone pelletisation process was taken as a 80 kton/year process. It is also important to note that the biomass being torrefied in these scenarios is wood, not wheat straw or manure, and that torrefaction temperature and residence time will effect both total capital investment and operation costs. The torrefaction of herbaceous biomass would require similar equipment as would be needed for torrefying wood [1],[6].

For stand-alone torrefaction, the total capital investment was estimated to be \$8.5-16.5 million, with production costs of \$74-\$104/ton of product. For stand-alone pelletisation, the total capital investment was \$7.9 million with production costs of \$73/ton of product. The TOP process had an estimated total capital investment of \$9.9 million with production costs of \$67/ton of product [1],[6]. If torrefaction is to be done on a commercial scale, pelletisation will have to be incorporated.

Severely torrefied wheat straw has an LHV of 20.3 M/kg [7]. The return on investment calculated by Bergman et. al. assumes an energy price of \$9.81/GJ or \$229/ton. The price that is more likely to be encountered in Colorado is \$1.75-\$2.75/GJ, or \$41-\$65/ton [3]. Given a similar size facility (60 kton/year of product annually, or about 100 kton/year feedstock), this gives significantly lower returns on investment. In fact, these prices lead to negative returns on investment for all three processes. However, due the passage of Colorado H.B. 1001, the use of renewable energies used in Colorado is mandated to go up, which could produce demand for torrefied biomass at a higher price [8]. Unless the price the product could be sold for increases, these processes are economically infeasible.

The table below summarizes the costs of the three processes. It is important to note that the numbers involved depend heavily on exact process parameters and are subject to variation. The ROI calculated from these numbers reflects the most optimistic estimate and a 40% tax rate.

Process	Pelletisation	Torrefaction	TOP
Capital Investment (millions of dollars)	7.9	8.5	9.9
Operating Costs (dollars per ton)	73	74	67
Return on Investment (%)	-3.6	-3.8	-0.7

### Environment

The chief attraction of torrefaction is its environmental benefits. Whether directly combusted, co-fired with conventional coal, or gasified, the process itself is carbon neutral. Any thermal pre-treatment of biomass would require some utility fuel, probably natural gas, though the use of this could be reduced through the combustion of some torrefaction gases to generate heat. It is possible that raw biomass could be combusted to help heat the torrefier and heater as well [1],[9].

In general, biomass for energy could provide an economical waste disposal method for beef and dairy producers. Several thousand tons of cattle manure and wheat straw are generated in eastern Colorado every year. The use of manure and wheat straw could reduce the disposal costs of feedlot owners by millions annually, as well put to use millions of pounds of waste for economic productivity.

Biomass has a diversity of chemicals associated with it. Besides the solid product and torrefaction gases, a number of condensable organics are produced as well. The gases are predominantly carbon monoxide and carbon dioxide. The organics are predominantly acetic acid, methanol, 2-furaldehyde, hydroxyacetone and a small amount of others. Some lipids also are also formed, and some reaction water from the decomposition of the biomass (predominantly hemicellulose) [1].

Some of the organics that are released can be combusted with the rest of the torrefaction gases. If, however, the composition of the gases are such that the gas is largely incombustible, this will require the use of natural gas or some other kind of utility fuel to heat the process. Combustibility of torrefaction gases is important, as it reduces the net emissions of the process. It can be considered carbon neutral or run autothermally. That is, the amount of energy required for the drying and torrefaction processes are equivalent to the energy provided by the torrefaction gases. All emissions from the process will have come from the biomass in such a scenario. If torrefaction gases can't be combusted, or the energy provided by their combustion isn't sufficient to heat the process, then alternatives will have to be considered. This would mean using either natural gas, or combusting some of the raw feedstock to heat the process (if mitigating emissions is of vital importance) [1]. Unfortunately, any torrefaction gases that aren't combusted go to flue gas.

A facility that is well located and provides low cost waste disposal would be appreciated by much of the Eastern Colorado farming community. The drying facility and the feedstock storage would likely take up several acres of space, and the large amounts may produce an odor that few will want near their homes. Most communities in the area are centered on ranching and farming, so there should be support a suitable location for a torrefaction facility.

Torrefaction demands that feedstock be dried. Water use for the process would, thus, be very low.

### **Technical Feasibility**

The purpose of torrefaction is to reduce the amount of energy in the biomass only slightly, while significantly reducing the mass. Virtually every type biomass that has been torrefied exhibits some degree of energy densification on a mass basis. Wheat straw has shown particularly dramatic improvements [7]. Much less is known about the torrefaction of manure, but the reduced hemicellulose content of cattle manure reduces the potential of torrefaction, since it is predominantly hemicellulose that is degraded during the process. Typically, 30 percent of the mass is lost during torrefaction, while only 10 percent of the energy is lost. Given the high moisture content of manure, it should be expected that manure will lose more mass, but will take more time or energy to dry. In general, the high moisture content of raw manure makes it unlikely that sufficient energy would be acquired from torrefaction gases.

It is unlikely the manure would be a useful torrefaction biomass. Its high moisture content, combined with the relatively low hemicellulose and cellulose content, makes it a poor candidate. The decomposition of hemicellulose is the primary source of mass reduction. Wheat straw has plenty of hemicellulose, cellulose, and lignin, the three chemicals that are most relevant to the process, making wheat straw a viable candidate [10],[7].

Since torrefaction has been done for so long, torrefaction equipment is available. “Torrefiers” have been built for general biomass torrefaction purposes, including Wyssmont’s Rotary Turbo Dryer, which is a popular option among those building woody biomass torrefaction facilities [Wyss11]. Several manufacturers and vendors provide size reduction equipment, briquetters and pellet mills, and all other equipment necessary for the process. The enhanced grindability of the material provided by torrefaction should make the pelletisation process easier.

A key question surrounding torrefaction involves densification. In order to effectively transport the torrefied product, it will have to be compressed by briquetting or pelletisation. Results on the success of densifying torrefied biomass have been mixed. One of the goals of torrefaction is to make grinding less demanding. It may be possible to produce strong pellets if the torrefied product is pressed while still near torrefaction temperature. Higher temperatures may keep the lignin soft and malleable enough to form strong pellets [12]. If not, addition of a binding agent may be necessary. The most important process parameter to consider here would be the torrefaction temperature. If it’s too high, the lignin could decompose. The process should be hot enough to decompose hemicellulose, while cool enough to soften, but preserve, the lignin [1].

### **Safety**

The most dangerous aspects of torrefaction are associated with the high temperatures and possible the gases released during the process. These dangers are no greater than for most chemical processing plants. At torrefaction temperatures, none of the components of the feedstock would combust. Noxious gases released would have to be carefully controlled. Another possible safety concern is the moving parts in the system. The drying process and torrefier would likely depend on the use of a moving bed of some kind. The crusher (whether it be a large hammer mill or a jaw crusher) could also present safety concerns. For the most part, the process is relatively simple, demanding only 3-5 operators for a 60 kton/year process [1],[6].

While the process does release noxious chemicals, a dangerous by-product, most of these chemicals would be released by the decomposition of the material any way. Torrefaction would speed the process along, so there may be high levels of such gases at the facility, but the total release would not likely increase. Equipment for the emergency maintenance of noxious fumes or fire would probably be necessary.

### **Social Aspect**

The concept of using biomass for energy has been around for a long time, and has had supporters for decades. The last ten years have seen a large boost in public awareness for the need for renewable energy. The specific concept of torrefaction seems to be mostly unknown to the general public. The need for a biomass thermal pre-treatment facility may not be immediately apparent to everyone, and the added step may convince some that it’s not worth it at all.

The odors of the facility may cause communities to reject the idea of having it very near their homes. It would likely need to be placed in a thoroughly rural location, where fewer people would have to tolerate any smells or traffic associated with the plant. Helping farmers eliminate

their waste cost effectively would be welcome by many farmers and ranchers, so rural areas should provide significant support for such a plant.

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## Appendix 3: Gasification

### Gasification

The process of gasification involves heating a carbon containing material to temperatures in the neighborhood of 1000 °C and exposing to low oxygen concentrations. This produces a syn-gas composed mainly of hydrogen (the desired product), carbon dioxide and carbon monoxide. The left over solids product consists mostly of metallic oxides. Gasification is often performed on the products of torrefaction or pyrolysis in order to improve gas yields.

### Costs

A local Cattle company, JBS Five Rivers, plans to install gasifiers at their Weld County site (Kroner, CO)<sup>[3]</sup>. Various values they've given for the cost and capacity of their proposed system will be analyzed with the Cost Analysis Method from above.

They are installing three, 4,200 lb/hr units that cost \$425,000 each. From this, their operation is estimated to contain 50,000 cattle units. Thus, the scale-up cost of this gasification facility is approximately \$2,550,000, as is taken as the freight on board cost. Therefore, the total capital investment is \$13,500,000. The JBS feed lot is building three separate gasifier units; therefore, if we estimate that each unit requires one, full time operator, the direct wages and benefits required for our scale-up is approximately \$840,000 per year. The operating costs can then be estimated to be \$1,000,000.

The amount of hydrogen gas produced from the process is estimated to be 3.5 MM SCF/day<sup>[5]</sup>. The delivered price of liquid hydrogen is taken at \$1.00 per pound<sup>[6]</sup>. Thus, the annual revenue from selling the hydrogen produced from this system is approximately \$3,000,000.

Thus, for the scale-up process, the ROI is calculated to be 0.089. This value does not include the cost of liquefying the hydrogen, nor the potential revenue gained from selling the residual ash.

Another example of a gasification system is provided by an economic analysis of a gasification process performed in 1974 by the Department of Chemical Engineering at Kansas State University<sup>[5]</sup>. They looked at a gasification system designed to accommodate 200,000 cattle, so their numbers will be divided in half for our analysis. In 1974 dollars, their estimated total capital investment was \$6.5 million. Normalizing for the size of the gasification capacity, this is estimated to be \$15,200,000 in today's dollars. In 1974 dollars, their estimated operation costs was \$2.2 million. Normalizing for the size of the gasification capacity, this is estimated to be \$5,200,000 in today's dollars.

They estimated their production of hydrogen gas to be 5.20 MM SCF/day. If the delivered price of liquid hydrogen is again taken to be \$1.00 per pound, the annual revenue from selling the hydrogen produced is approximately \$4,500,000.

This, unfortunately, produces an ROI value of -0.028. This value is considered to be less accurate than the one calculated above since it was produced by manipulating values from the 1970s.

## **Environment**

In many farms implementing a gasification process, the syngas produced is used for heating buildings. This reduces, by about a half, the amount of heating gases that would otherwise be used<sup>[2]</sup>.

The desired product from gasification is hydrogen gas; however, other gasses produced in large quantities include CO and CO<sub>2</sub>, both of which pose an environmental risk. Other compounds that can appear in small quantities include H<sub>2</sub>S, COS, NH<sub>3</sub> and HCN depending on the sulfur and nitrogen content of the feed<sup>[4]</sup>. These gases also pose environmental risks.

The gasification process does not require the addition of water. Generally, manure needs to be dried before it can be gasified.

Issues such as noise and odor, public support, permit requirements and life cycle analysis are a largely unknown factor at this time. Because the gasification of manure involves the transport and drying, odor is a consideration. In this preliminary analysis, no examples of public disapproval of biomass gasification plant construction were found. Similarly, no significant information regarding required permits or life cycle considerations was found.

## **Technical Feasibility**

In order to achieve gasification, the feed needs to reach temperatures of 1,000 to 1,600 °C. Often, pyrolysis is performed on the feed first before gasification to improve yields. Because of these high, long sustained temperatures, a significant amount of energy is required for gasification as compared to other techniques.

The major gasses produced from gasification are hydrogen, carbon monoxide and carbon dioxide. The ashes produced are composed of many different oxide salts (discussed below) and can be used as a fertilizer<sup>[2]</sup>. The only products with absolutely no economic value are carbon monoxide and carbon dioxide.

Many different processes exist for gasification. The most complicated are continuous processes with many moving parts needed for large operations, and the least complicated are the batch processes which require far less equipment and are generally found on individual farms. Therefore, as the size of the operation increases, the complexity of the process equipment increases.

Since gasification processes are being used on many farms, feedlots, dairies and poultry farms across the United States, and since many companies specialize in designing and installing these systems, the process equipment is reliable and easy to implement.

## **Safety**

The syngas produced contains a few harmful compounds. One that is produced in significant quantities is carbon monoxide. Other potentially dangerous compounds produced in much smaller quantities include H<sub>2</sub>S, HCN (hydrogen cyanide), COS, NH<sub>3</sub>, and others depending on the specific process and feed characteristics.

The left over ash is composed of K<sub>2</sub>O, CaO, MgO, Na<sub>2</sub>O and many other oxides<sup>[4]</sup>. Many of these compounds exothermically react with water; therefore, the ash poses a danger if exposed to large amounts of water or inhaled.

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## Appendix 4: Digestion

“From a biochemical perspective, manure is a complex mixture of carbohydrates, proteins, and fats. Each of these components can be used as a source of energy and for cell reproduction by anaerobic bacteria.”<sup>[1]</sup>

The point of this engineering project is to produce a valuable product stream. Anaerobic digestion is the most likely to produce a valuable commodity (biogas) in addition to the solids application. Aerobic digestion offers only the solids remaining as the product. Aerobic digestion also does nothing to limit the emission of methane and other greenhouse gasses. This limitation means that digestion projects are only discussed concerning Anaerobic Digestion for the following decision matrix and summary.

### Costs Summary

Cost estimates with the 100,000 cow size facility.

- Assumes that heating the digester is provided by direct burning of biogas or by heat generated from an energy generator.
- The yield of the digester is approximately 30.6 SCF of methane per cow per day

There are two ways to arrange for a large scale usage of the biogas. Allowing a three way cooperation between a energy producer, agricultural producer, and a digester operator. The agricultural producer is paid for raw biogas and then purchases energy from the utility. The second option used in this analysis is to upgrade the biogas to natural gas and direct sales to the national market. Due to the size of this project, on-farm power generation should be run by an energy utility as the energy generated would be on the order of a natural gas power generating station.

The analysis numbers are taken from a summary report of dairy manure digesters that utilize biogas. This report covered 95 anaerobic digesters and the minimum, average, and maximum capitol costs are below. All values are taken from the Dairy Digestors study.<sup>[7]</sup>

	Min	Average	Max			
Digester cost/cow	194	536	1557	\$		
Total cost/cow	299	848	1959	\$		
Digester with No energy Generation	19.4	53.6	155.7	Million \$	Total Capital Investment	
DW&B+Maintenance Estimates from Study	400,000	550,000	700,000	\$/year		4-7\$ /cow
Operating Cost	0.40	0.55	0.70	Million \$ /year		

The average cost is used for the decision matrix. The Sale price of methane was taken from the US energy Administration website average for the last year. The sale price of the methane is as below.

Assumed Production of (methane) in Biogas with Impurities	30.6	ft <sup>3</sup> /(cow*day)
Biogas	1,117	Million ft <sup>3</sup> / year
Cost to Upgrade (Scrub) to Natural Gas	3.88	\$/ (1000 ft <sup>3</sup> )
Annual Cost to Upgrade to natural gas	4,333,572	\$/year
Sales Price Average	4.0	\$/ (1000 ft <sup>3</sup> )
Net Annual Income	134,028	\$/year

The ROI for the average capitol cost case is 0.0015. The ROI calculation does not include anything about the valuing reduction in odor or in improved manure handling.

Some common traits of biogas allow it to be applied with flexibility. If a producer is a has very large heating costs this could be reduced by using biogas as a direct heating source. Digester gas produced consists of 50-70% methane with carbon dioxide and small amount of ammonia, hydrogen sulfide and volatile intermediates released from digestion.<sup>[1]</sup> Heating value of biogas ~500-550 Btu/ft<sup>3</sup>.<sup>[1]</sup> Sulfur can be removed by iron gauze. Biogas is limited to in-place use as its conversion to a liquid takes place at too high of a pressure or too low of a temperature to make use in mobile equipment practical.

## Environment

The major benefit of digestion is that greenhouse gas is retained limiting greenhouse gas emissions. This reduction in the direct methane emissions is reduced to negligible amounts.<sup>[5]</sup> Ammonia and sulfur are pollutants produced in the gas which require removal in by simple liquid stripping or adsorption processes. If the gas is flared then there is no carbon retention value. The un-quantified factor in environmental concerns is the endorsement of concentrated animal feeding. Digesters represent an endorsement of large scale concentrated agricultural practices. This leaves the small scale producers (~200 cows) at a significant disadvantage to the large scale producer.

Permits and approval for digesters were indicated to be a significant hurdle to the project implementation.<sup>[3]</sup> The public review period being difficult if large opposition to a waste processing project is coordinated. The following reasons were given the co-digestion permitting is difficult for Colorado and the “stigma associated with being labeled a ‘waste energy facility’ on permitting applications”, results in a large NIMBY effect by people not wanting to reside next to a waste processing facility.<sup>[3]</sup>

Life cycle analysis for digesters ranks above pond digestion. Digestion ranks below the heat treatment of manure in the pyrolysis due to the large amount of solids that still have to be

dealt with post digestion. While some of the solids can be sold most is trucked off to be spread on cultivated fields at very little profit. This transportation of solids is a universal across manure treatment, but digestion leaves a very low energy density solid and thus has a large expense for transportation.

Land use factor is improved compared to current pond treatment methods which require a ten times greater land impact over the digester system. Also the digester reduces the area required for large uncovered waste ponds.

Water use is high in digesters. Conditions required are that digesters be run at high water content. Approximate solids content of 10% which for some dairy operations is easily achievable. Depending on the speed of manure being placed into a digester the natural water content is usually supplemented. Also the water released generally has to be monitored for BOD and COD before general release to waterways. One more complex solution indicated is to use a two stage digestion consisting of an organic leach and then a typical digester system.<sup>[3]</sup> The organic leach removes significant organic solvents prior to moving to the digester and these volatiles are then separated as biogas from the water, and the water for the leachate is recycled.<sup>[3]</sup>

### **Technical Feasibility**

Technical feasibility for digesters is extremely high as many have been built all over the world. Energy balance on the digester indicates a positive production of energy with the combustion of biogas for energy. The heat energy is used to maintain the temperature of the digester and to provide on farm energy. European digesters indicated an energy use of 28 MJ/dry ton of cow manure to a production of 5.6-8.8 GJ/dry ton.<sup>[5]</sup> The energy input in was primarily from transportation of wastes to and from the digester.

Mass out of the digester is generally applied as a fertilizer after chemical characterization. Solids reduction in volume of 50-60%.<sup>[4]</sup> The mass balance indicates a strong reduction of mass for reduction of transportation cost. The only downside of mass reduction is the need for potential chemical levels to be monitored to prior to agricultural application. Monitoring is only for quantification of nutrient levels and not for contamination issues.<sup>[5]</sup>

Process equipment is expensive for digesters. The need for permanent flow channels and permanent facilities for sludge handling is a custom design for each facility. In addition temperature control of the digester is required by heating in the winter. The equipment and individual processes can be very simple to extremely complex depending on goals and customization. Multi-stage digestion and experimental design add expense as well as the opportunity for greater gas production. Equipment used in initial designs reviewed in the literature indicated that often cheap digester covers had to be replaced after failure in the first few years. This indicates that a trend to more reliable and expensive initial construction is generally provides a stronger return on investment. The reliability of the process and equipment depends very heavily on the operators. If equipment is maintained and evaluated regularly then operation can be simple. Operation of gas generators is considered adequate when used for 80% of the scheduled time. Digestion is a waste treatment operation, so down time is not possible as the manure keeps coming. Gas is flared during generator down time to avoid the need for large storage capabilities.

Implementation is given a low score as each project requires a long lead time and almost always more successful if initiated by the operator. The implementation requires significant farm facility modification. Startup is not considered an obstacle to operation as microbes are readily available naturally or can be seeded from a local waste treatment facility. Gas production can be optimized during the startup time while not interfering with the waste treatment aspect of the digestion.

## **Safety**

Safety elements were only considered above and beyond normal manure handling issues as producers are already adept at dealing with manure. The most significant issue for safety, is that biogas is an asphyxiate, thus anyone working around or in a digester has to be provided an adequate oxygen source. The second element of consideration is using a combustible gas. This is dealt with by proper planning and equipment evaluation during digester and generator design.

As indicated earlier gases like ammonia and sulfur have to be removed prior to energy generation or flaring. Concentration of nutrients in solids may be above levels that are directly applicable to agricultural land. Solids and waste water have to be monitored. Pathogen reduction of the solid fiber is found on 2 to 3 orders of magnitude allowing a broader scope of application.<sup>[2]</sup> The nutrient/fertilizer content of the manure is not reduced only concentrated.

## **Social Aspect**

Local support for digesters can be quite variable. Residential neighborhoods that do not already have a large agricultural presence nearby are resistant to inclusion of waste material close by. While agricultural communities generally welcome the local energy production of a digester. Transportation of large quantities of waste never appeals to residential areas. Areas that have an odor issue can be sold a digester as an odor mitigation tool. The issue of co-digestion with other waste products provides significant barriers if the additional waste products are potential hazards or perceived as potential hazards.

Mainstream support for digestion is adequate. As biogas energy generation is considered a green technology digestion can ride the wave of public support. Generation of energy on a local level is considered a good trend by the general public. Western reliance on local tools and resources plays heavily in favor of doing it yourself attitude that is required for successful digester operation.

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## Appendix 5: Bio-char

“Biochar is a charcoal carbon product derived from biomass that can enhance soils, sequester or store carbon, and provide usable energy.” Biochar starts as biomass, which is defined as organic matter available on a renewable basis<sup>[3]</sup>. Biomass is turned into biochar by means of high temperatures in an oxygen free environment. These processes are usually, but not limited to, pyrolysis, or torrefaction. Usually, low temperature pyrolysis is used to produce biochar<sup>[6]</sup>. When pyrolysis is performed on biomass at 500 degrees C in static and nitrogen atmospheric conditions, about twenty-eight weight percent of the total product is biochar<sup>[4]</sup>. Though biomass has been used directly for energy, pre-processing biomass by pelletizing, torrefaction, or condensed biomass briquettes increases the efficiency<sup>[6]</sup>.

Biochar has many benefits, as not only an energy source, but also as a soil fertility enhancer, permanent carbon sequestration, and waste mitigation. The first advantage is that the waste build up can be turned into biochar, and it is a way to deal with waste mitigation<sup>[1]</sup>. The second is that the biochar can be used to increase and maintain soil fertility while increasing crop yields. This is because biochar is high in carbon and locks it into the soil<sup>[2]</sup>. Terra Preta soils are black-earth-like anthropogenic soils with enhanced fertility, and increased crop yield. They have higher yields because they have higher levels of soil organic matter, and nutrient-holding capacity. This is caused by having biochar blended into the soil. Using biochar for a fertilizer has an advantage over inorganic fertilizers because biochar is less expensive, and the effects of biochar are longer lasting due to the high nutrient-holding capacity<sup>[7]</sup>.

The next advantage is that because biochar is high in carbon, it can be used sequester carbon. Since carbon is naturally sequestered by soil, but rapidly re-released, the need for a longer residence time in the soil is greatly beneficial for the environment. The residence time of carbon in the soil can be increased adding it as biochar<sup>[8]</sup>. The biochar used to lengthen the time that carbon is sequestered in soils by establishing a “permanent carbon sink”<sup>[1]</sup>. These carbon sinks have the benefit of being both a way to sequester the CO<sub>2</sub> in the atmosphere as well as being high producing farm land<sup>[8]</sup>.

Lastly, biochar can also be used for fossil fuel substitution<sup>[5]</sup>. It is found that when cofiring biochar with coal in a properly implemented application, the efficiency is not affected from its original coal-only operation. Cofiring does require modification of current coal-fired boilers by means of their fuel handling, storage, and feed systems. With modifications made, the benefits are usually lower overhead costs of plants, and lower emissions. However, it is best to find an existing, operational coal-fired boiler equipped with a bag-house for catching particulates that has storage space available on site<sup>[9]</sup>. The things that are desired for a cost effective cofiring plant are a high coal supply price, low biomass supply price, and a large boiler size. A negative side effect to cofiring is that it has a negative impact on the ash market. The ash from coal burning is sometimes sold to concrete manufactures. However, the current ASTM standards for concrete admixtures require that the ash is 100% coal ash. Finding a plant that does not have a large income from selling ash is a necessity for cofiring biochar. If all these requirements are met, the payback period for modifying the plant could be as low as 0.8 years<sup>[9]</sup>.

While biochar has many applications and uses, it is not a process but rather a product of processes. Production of biochar is covered in more detail in the pyrolysis and torrefaction section of this report. For the design matrix, biochar has been removed because it cannot be assessed against processes.

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