Crop Wastes to Bright Lights:
Applications of producer gas technology in developing countries

Team Members:
Isaac Hulvey ______________________
Thomas Pugh ______________________
Faculty Advisor:
Paul Goodall ______________________
External Sponsor:
Least of These, International

April 29, 2011

Abstract

Producer gas is a relatively untouched potential source of renewable energy that is made by gasification of plant material. Through gasification, hydrogen, carbon monoxide, and other gasses are produced and this mixture combusts similarly to natural gas. Producer gas can then be used to provide power and heat to buildings through its combustion. This project's purpose is to prototype a device that can make producer gas from crop wastes and other local organic material. The purpose of this system is to provide an underdeveloped small village with electrical power for lights, irrigation, and cooking. The project will also analyze alternatives to the producer gas device for areas where it would be more practical to pursue the use of a different energy source.

Table of Contents

1. Introduction

The process of gasification is rather complex in that it involves burning organic material in an absence of oxygen. Instead of combustion, which includes oxygen, the process is called gasification, which excludes oxygen. Gasification is defined as the process of converting biomass to synthesis gas (syngas), which can be used as a fuel (McKenzie, 2010). The basic chemical process behind gasification is shown in Equation 1 below.

$$Biomass + Insufficient\ O_2 \rightarrow (H_2 + CO) + Tars + Particulates \qquad \text{Equation 1}$$

The gasses released, hydrogen and carbon monoxide, released during the gasification reaction is the main piece of interest here. This mixture of gas is known as producer gas. When gasification is used for the generation of electricity by burning the producer gas, the gas must be filtered to remove tar and other impurities such as particulates. Failure to remove these impurities from the gas can cause damage to the engine. However, the amount of tar present in the producer gas can be limited by ensuring that the temperature at which the gasification process is running is high enough to “crack” the tars. Cracking tars means that they are burned when the temperature of the reaction becomes high enough to break the bonds of the molecules. Tar that is not cracked can be removed from the gas by filtering the gas before sending into the engine manifold.

To understand the process of gasification further, it is helpful to see a schematic of how a gasifier works. In Figure 1 below, a downdraft gasifier schematic is shown.

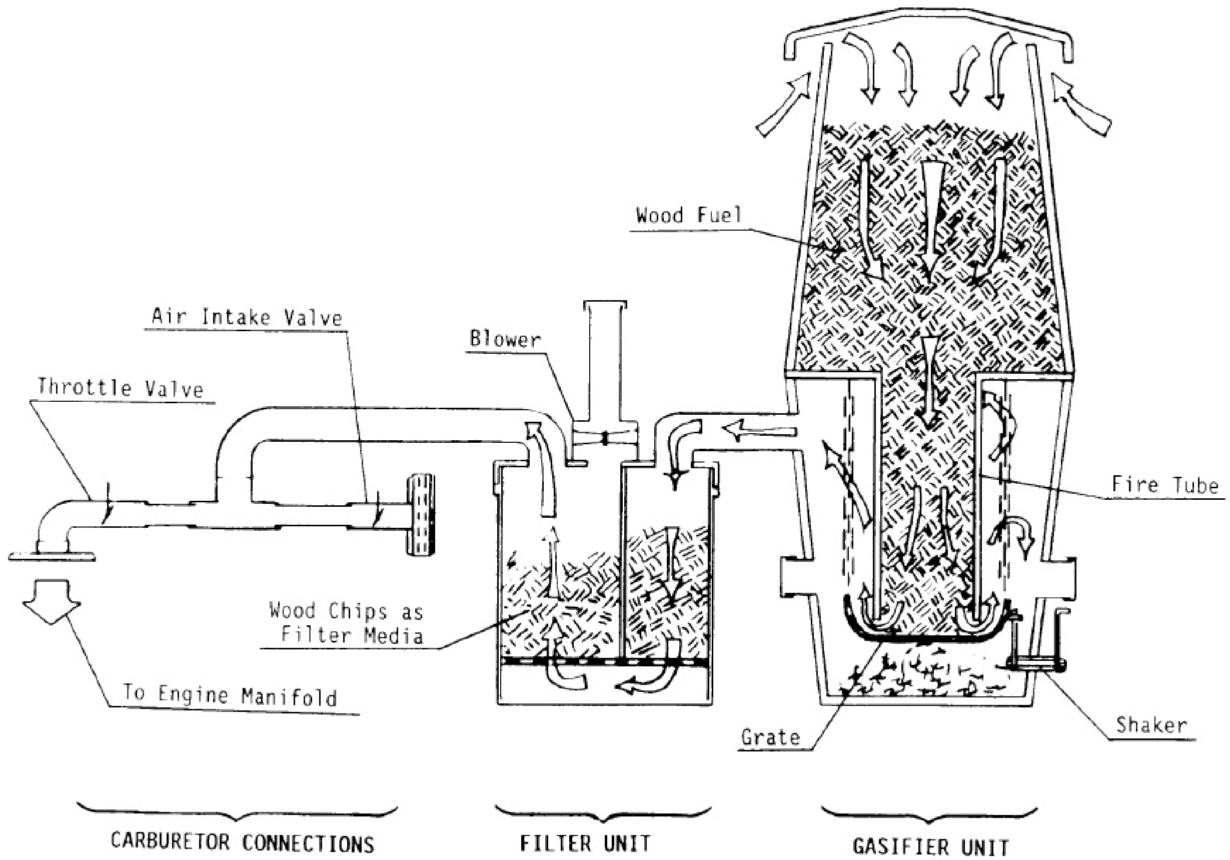


Figure 1 - Schematic for FEMA downdraft gasifier (LaFontaine, & Zimmerman, 1989).

As seen in Figure 1, air is drawn down--hence the term downdraft-- through the wood fuel, through the pyrolysis zone where it reacts and forms hydrogen gas and carbon monoxide. The producer gas is then drawn through the filter unit by a blower. The filtered gas then passes into the carburetor where it would then enter the engine and be burned as fuel.

It is when the producer gas is burned in the engine that useful work is done. The shaft work produced can be used to power a vehicle, to pump water, or in the case of this research, to power a generator for electricity production. The electricity generated from the work of this engine can be used for lighting, to power well pumps to provide drinking water, to power irrigation pumps, or for any number of uses. In use in a developing region of the world, a biomass gasifier could be used to convert crop refuse into usable energy. This availability of energy can enable the developing region to begin the path of development in a sustainable and environmentally friendly way.

To conceptualize how a system will not only work in practice, but how it will work as part of a larger system is to examine its technological lifecycle. The easiest way of doing this involves stepping back from just the technology and examining how it effects the surrounding environment, economy, and culture. Fully understanding the technology lifecycle of a biomass gasifier, particularly one in a developing region of the world, is vital to ensure the success of the project. A technology may be well suited for the environment but could have negative cultural or economical impacts. A biomass gasifier provides a use for leftover crop wastes, but if these waste products are used for something else, the gasifier could throw off the balance. Likewise, the leftover ash from the gasification process can be used to boost carbon in soils but there are certain techniques to doing this effectively. This report will go into further detail on the technological lifecycle of a biomass gasifier as an electricity source in a developing region of the world in order to determine whether or not it is the best solution available.

While a gasifier may be able to provide access to clean and efficient fuel, if the system cannot operate safely, it won't be of much use. The gasification process has been around for over 100 years and though it has been refined and perfected, there are always safety concerns when dealing with the combustion of a flammable fuel. There are several safety concerns that will be addressed in more detail within this report. Primarily these concerns deal with the production of the gas, that is the gasification process, and the combustion of the gas, that is the electricity generation process.

Along the same lines, there are maintenance issues that must be addressed when generating electricity through the gasification of a biomass. While the gasifier itself has few moving parts, the electricity generation system has many moving parts and it is imperative that these pieces all be well maintained to ensure efficient electricity production and a reliable system. The primary maintenance concern is the protection of the internal combustion engine. Engines are not inexpensive and can easily become the reason a project falls through. Generating clean producer gas is the key objective of the gasifier. To do this, the mechanisms that remove particulates and tars must be functioning at their highest levels. The various maintenance protocols will be discussed in further detail later in this report.

2. Objectives

The objectives of this project are to examine producer gas as a technology solution for electricity generation in a developing region of the world. This technology would be compared to existing solutions to determine its effectiveness compared to alternatives. The societal, economic, and environmental impacts of producer gas generation are also discussed in order to ensure that any and all potential impacts of the technology are taken into account so a thorough recommendation can be made.

3. Background

In reading through this document there are several definitions and meanings that need to be defined in order to fully understand the technology being used. These include a more concise breakdown of the varying types of gasifiers, why they make more sense in different situations, and a better understanding of some of the more important aspects of gasification.

3.1 Definitions

-*Pyrolysis* is the process by which biochar is formed and producer gas. It's essentially combustion of material without oxygen. With the application of heat these organic products are "burned" and converted to a gaseous form as well as a solid remainder product containing ash and carbon. It's essentially the most important aspect of gasification. With chemicals, heat, pressure, and a lack of oxygen (it's impossible to have zero oxygen, so a severely reduced is optimum) any organic material can be put through pyrolysis to make combustible gases, including carbon monoxide and methane, which can then be used in the producer gas process.

-*Gasifiers* are the devices in which the gasification process occurs, and they come in several different styles, shapes, and sizes. They have been and are increasingly seen all over the world, performing actions from cleaning up goal to converting waste into energy. There are 4 main types: downdraft, updraft, fluidized bed reactors, and entrained flow.

-*Updraft (or counter current fixed bed) gasifiers* have a bed of coal, or whatever material is used, through which the gasification agent involved (air, steam, etc) flows in the opposite direction of the materials moving. Pictured in Figure 2, this allows for a much dryer removal of ash from the system and a much higher thermal efficiency in the gases output. However the amount of tar and methane is also significantly higher than ideal.

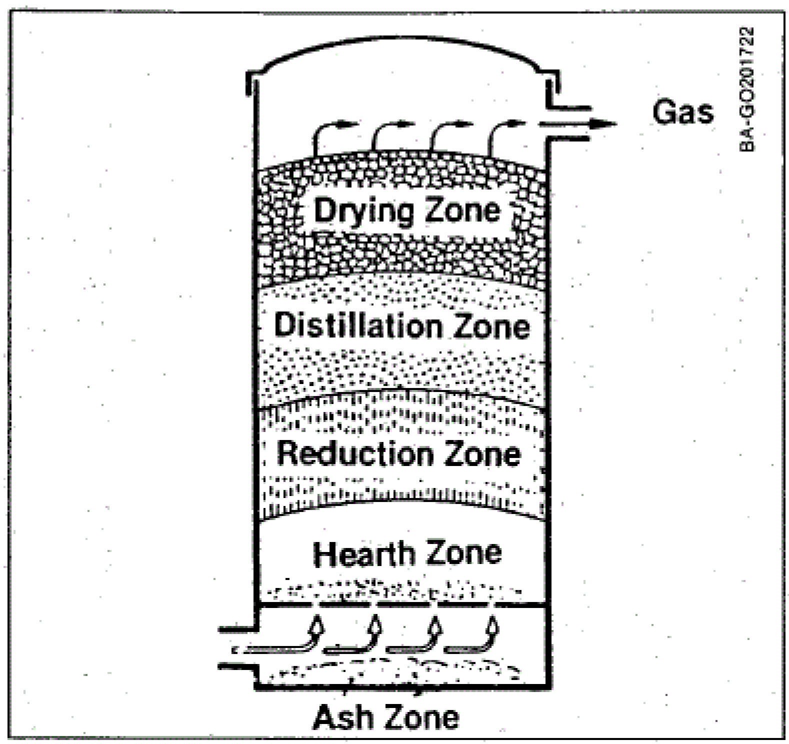


Figure 2 - Basic updraft gasifier schematic (LaFontaine & Zimmerman, 1989).

-*Downdraft (or co-current fixed bed) gasifiers*, pictured in Figure 3, are much like the updraft gasifiers except that the agent flows with the material. Granted this does require a higher initial heat at the beginning but the exiting gas can usually be recycled to provide that extra needed heat. The tar involved is also forced through the cycle a view times, resulting in much lower emissions than the updraft.

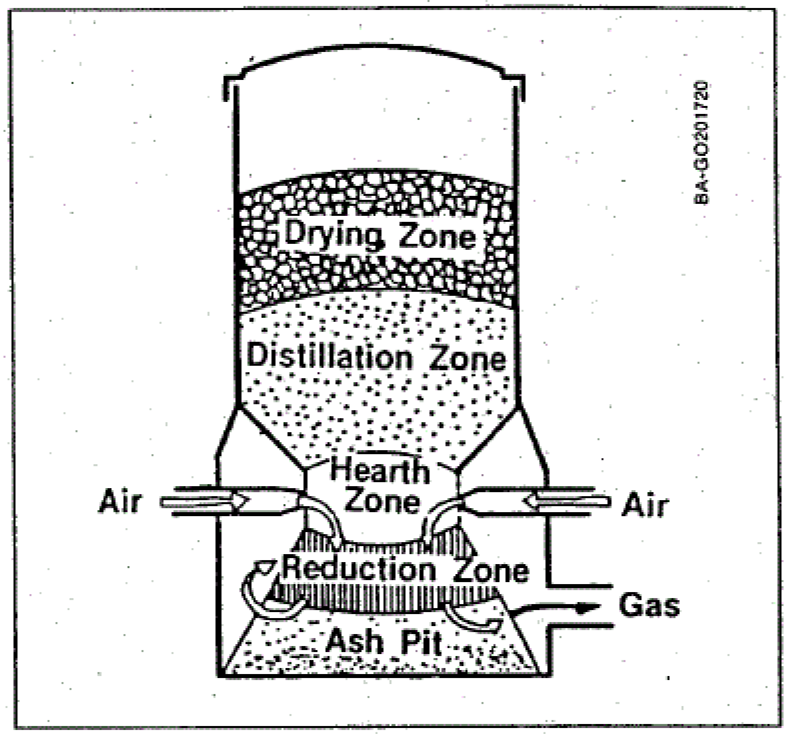


Figure 3 - Basic downdraft gasifier schematic (Lafontaine & Zimmerman, 1989).

-*Fluidized Bed Reactors* are exactly what their names imply, reactors that fluidize the incoming material to a liquid fuel. This helps to reduce ash but is used primarily for larger scale systems due to a low efficiency.
-*Entrained Flow Gasifiers* are much more suitable for large scale usage and for coal. It uses much higher temperatures and much more oxygen than the other three types to condense the traveling material to a very fine cloud. The resulting product gas has very little tar or methane but often has particles too large to be usable. It also has the least efficient conversion process.
-*Producer Gas* is simply the gas produced by the gasification of certain organic materials, primarily wood, coal, and charcoal. However other organic material can be used, like crops, plants, and in some cases even waste. The result is always a mixture of combustible and incombustible gases that can then be used as one gas and provide fuel to engines. The compounds always involved include carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4), water vapor (H_2O) and nitrogen (N_2), all of which contribute to the gas's energy capabilities.
-*Bridging* is a common problem in any sort of gasification procedure in which the particles in the fuel are too large to leave through the devices exits or to be used as a viable fuel source.

Gasifiers hold a fair amount of potential for developing nations in a number of different applications. There are specific views we aim to fulfill with the use of a gasifier in the regions.

3.2 Applications

Gasification has been around for quite a while and has proven itself useful in several different situations. Described below are several of the different applications producer gas has benefited and what areas they could be used for.

-*Cooking*

The primary uses of producer gas in developing areas around the world are for cooking fuel and for off-the-grid electricity generation. As a cooking fuel, the use of producer gas greatly decreases the amount of indoor emissions that would normally come from a wood-fueled fire. Since producer gas (when properly cleaned) has no particulates, it burns extremely clean compared to wood, as seen in Figure 4.

Figure 4 – Producer gas used as a cooking fuel.

Likewise, since producer gas is primarily made up of H_2 and CO, the emissions are H_2O and CO_2. The major danger to using producer gas as a cooking fuel, when indoors, is that producer gas contains a substantial percentage of CO which can be harmful or fatal at the right concentrations. Often times, a lethal dose of CO can be inhaled before the producer gas leak has even been identified. Therefore, it is imperative that leaks be identified quickly or some sort of a tracer gas be added to the producer gas so that it has an odor and can be identified when leaking.

-*Electricity Generation*

The use of producer gas for electricity generation works much like using producer gas for cooking fuel, but instead, the gas is burned in an internal combustion engine (or a microturbine) to generate shaft work which turns a generator. While producer gas burns much differently than gasoline or even natural gas, it can be burned in an internal combustion engine. This requires that the engine be timed differently and that the air-to-gas ratio be properly established. Along the same lines, any tar that makes its way into the engine will cause pistons and intake valves to stick which could damage the engine. Therefore, it is very important that the gas be altered to ensure its cleanliness. Along the same lines, producer gas can be used in conjunction with a microturbine to generate electricity. However, because microturbines are a newer technology, there is not as much research into using them with producer gas.

-*Transportation*

Using producer gas in an internal combustion engine has been around since World War II when it was used as the primary fuel source for transportation vehicles. Oil had become scarce and hard to obtain and an alternative source was needed. Because of this, there was substantial work done in this field. Producer gas can be used in diesel engines as well as spark-ignition engines. In a diesel engine a mixture of approximately 80% producer gas 20% diesel is necessary. A spark-ignition engine can run on 100% producer gas, however. There are few applications of producer gas for transportation at the present time. However, much of the same technology can be used in producing electricity. Instead of powering a drive-train, as seen in Figure 5, a generator can be powered to produce electricity.

Figure 5 – Example of producer gas technology used as a transportation fuel ("240 wood burning," 2010).

- *Combined Heat and Power*

While there are few industrial installations that use biomass gasification, the ones that do exist are typically combined heat and power systems. Since the process that creates the producer gas is very hot and the gas is typically hot when it comes out of the gasifier, a combined heat and power system is able to recover some of that heat and use it to further increase the efficiency of the system. Thermal efficiency is optimized when the temperature difference in a thermodynamic system is maximized. By decreasing the temperature of the gas as it leaves the gasifier, the overall thermal efficiency of the system is increased. This "left-over" heat can be used for space heating, or to create steam which can drive other mechanical processes. Also, this extra heat can be used to further heat the incoming air into the gasifier which also raises the thermal efficiency

4. Literature Review

The topic of creating producer gas from the thermochemical biomass gasification has been around for more than a century. J. Emerson Dowson pioneered some of the founding research on producer gas in the early twentieth century. In his book Producer Gas published in 1907, Dowson outlines the theory behind creating producer gas as well as the practical means of producing it for use. Also, in Chapter 12 of his book, he outlines the different fuels that can be used to create producer gas, particularly wood and wood-charcoal which is what this proposal is interested in studying (Dowson, 1907). The use of producer gas in more modern times has diminished with the availability of natural gas. However, not all regions of the world, particularly developing regions, have access to natural gas. These areas rely heavily on biomass fuels like wood and animal feces. A study by Schei, et al., determines if there is an association between the use of open wood res for cooking and asthmatic symptoms in children. The conclusion of this research being that asthma was more prevalent in children in homes with open res than in children in homes with stoves and chimneys (Vosecky, 2009). By substituting producer gas for wood in use for cooking fuel, this could reduce the presence of asthma in children in these developing areas. Producer gas has more or less made its way into the hobby or research sector of science (Fung, n.d.). It is not a widely used technology in the developed world for energy, but because of the relative ease and simplicity of the technology, it seems well suited for a developing area. A case study in India by Ravindranath and Hall seeks to find and promote an alternative energy option for developing countries. They discuss the benefits and drawbacks of producer gas as well as discuss the processes behind its creation (Ravindranath, 1995). Producer gas also holds a lot of potential due to its ability to use any kind of plant material for its production. Another case study in Ireland found that a variety of different wood and crop products all provided a significant amount of energy through gasification and were applicable as an alternative energy (Bhaird, 2009). One big drawback to producer gas is that, as with any sort of biomass energy system, it has potentially harmful emissions. Granted, they are lower than most other types of biomass energy production, they still have are large enough to warrant concern and cleaning. One of the most prevalent pollutants released in the production of producer gas is tar. Attempts to reduce this tar output have risen greatly in the past few years, and now the cleaning of the producer gas during the gasification process instead of filtering the gas itself is where many scholars and engineers have put their focus according to a variety of journals (Vosecky, 2009). Producer gas holds a lot of potential for alternative energy in developing nations primarily due to the variety of different materials that can be used in its production. Almost all and any plant materials can be used, anything from crop wastes freshly cut wood. As various studies, conducted by groups such as the Japan Institute of Energy, have shown any sort of plant product that can go through gasification can be used for producer gas. Studies have also shows that different plants have different efficiencies and different emissions or size of emissions (Hanaoka, 2004). However this very wide variety of sources highly encourages the application of producer gas in nations that cant a afford coal or oil or simply don’t have the resources to provide power.

5. Alternatives Analysis

A producer gas technology may not be the best option for a developing community. There are numerous factors to take into account when determining whether a technology is well-suited for the community and whether the community is well-suited for the technology. The factors that will be used to determine the “fit” of a technology with a community are: institutional, human resources, technical, economic/financial, environmental/natural resources, energy, social/cultural, and service. These eight factors are taken from the Capacity Factor Analysis developed by Justin Henriques at Least of These International. Figure 6 below shows these eight factors and their definitions.

FACTOR	DEFINITION
INSTITUTIONAL	Laws, Regulations, Administration, Processes
HUMAN RESOURCES	Professional, Skilled Labor, Unskilled Labor: Literate, Illiterate
TECHNICAL	Supply chain: Spare parts, Supplies, Services
ECONOMIC/FINANCIAL	Markets, Mechanisms, Taxes, Fees, Financial options
ENVIRONMENTAL/ NATURAL RESOURCES	Carrying capacity of media; Stock of resources: land, water, soil type, precipitation
ENERGY	Sources, access, utilization, opportunity cost
SOCIAL/CULTURAL	Housing type, transience rate, caste/class equity, female participation, community organization
SERVICE	Supply, delivery, growth

Figure 6 - Capacity Factor Analysis (CFA) definitions used by LOTI (Saavedra, 2010).

Solar (Photovoltaic)

Solar Power, also called photovoltaic cells, is panels made of silicon and other semi-conductor materials that take in sunlight and convert it to electrical power. They vary in size and scale and have many different efficiencies based on the material used. Also, the different types of materials used in constructing PV cells allows for different types of use--whether on rooftops, in a ground-based array, or some other placement.

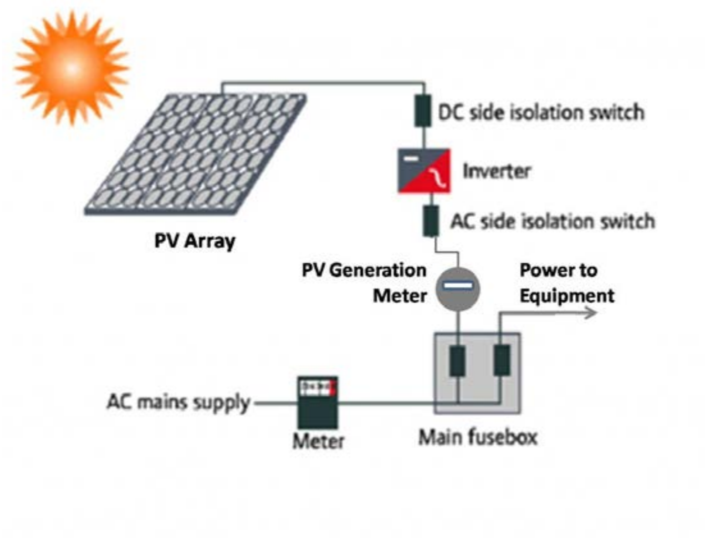


Figure 7 - Basic diagram of a photovoltaic array ("Solar pv diagram," 2009).

Institutional - The use of photovoltaics has very few institutional drawbacks. However, there may not be government incentives or tax breaks towards the purchase of photovoltaic panels in all countries.

Human resources - Installing photovoltaic panels requires a low level of technical expertise mainly limited to the knowledge of electrical wiring and the optimal positioning and angling of panels. Compared to other technologies, photovoltaics are generally very low maintenance and often only require cleaning as the primary maintenance to ensure their performance is not limited. Likewise, with no mechanical components, photovoltaics are typically a low-maintenance solution.

Technical - Obtaining all the necessary components for a photovoltaic solution can be difficult. Panels are not manufactured in most developing areas around the world and thus they must be shipped to the area. Likewise, the wiring and other components are not likely to be found in proximity to the area and also must be shipped. This makes repairing photovoltaics difficult. Should a wire short out or a panel malfunction, it could be weeks or months until the problem is solved due to shipping and transportation.

Economic/Financial - The biggest limiting factor to photovoltaics is their cost. While the cost of panels has dropped substantially over the past few decades, they are still quite expensive. An entire village may not be capable of fronting the entire cost of the panel array and necessary wiring components. A 15 kWh-daily array with all necessary “off-grid” components will run in the order of $30,000 ("Battery based systems," n.d.). This is a very substantially investment for a community and may often be far out of their price range.

Environmental/Natural Resources - The exceeding benefit of a photovoltaic system is that they run on an inexhaustible resource--the sun. As long as the area where the system is being implemented has a good solar resource, the system will always produce energy. With a battery attached to the system, the array can still produce electricity at night or on cloudy days. Realistically, the only limiting environmental factor of photovoltaics is whether the area has a good solar resource. As most of the developing areas around the world are found within the tropics, it is unlikely that any area would have poor access to solar.

Energy - The primary energy input to implementing a photovoltaic solution is human labor. The arrays come pre-manufactured and simply must be installed on roofs or in ground systems. A village of any size could easily provide the man-power needed to install one of these systems as long as someone with the technical background necessary could provide the guidance needed to ensure the system is setup correctly.

Social/Cultural - A photovoltaic solution has few social/cultural limitations. The biggest hurdle could be if the system is designed to be installed on rooftops. Thatched roofs would likely be unable to support the weight of a photovoltaic array. Also, there could be issues in getting the home-owner's approval to install the array on their roof. People could demand lower energy prices if the array is installed in part on their roof leading to divisions within the village. It is hard to speculate how an area would accept photovoltaics as a solution.

Service - A photovoltaic solution is usually an easy system to expand and further develop. While these systems are often very expensive, once the initial infrastructure is installed, more and more panels can be added as needed to meet demand. Also, as mentioned before, these systems are low-maintenance and don’t require a lot of technical knowledge to maintain. The largest hurdle is getting the necessary components the area where they are being installed.

Wind Turbines

Wind turbines are tall metal pillars ranging from 20 to 100 feet with spinning blades much like a fan. These blades spin in the wind, allowing components inside to turn and provide kinetic energy to a turbine which then powers a generator to produce electricity.

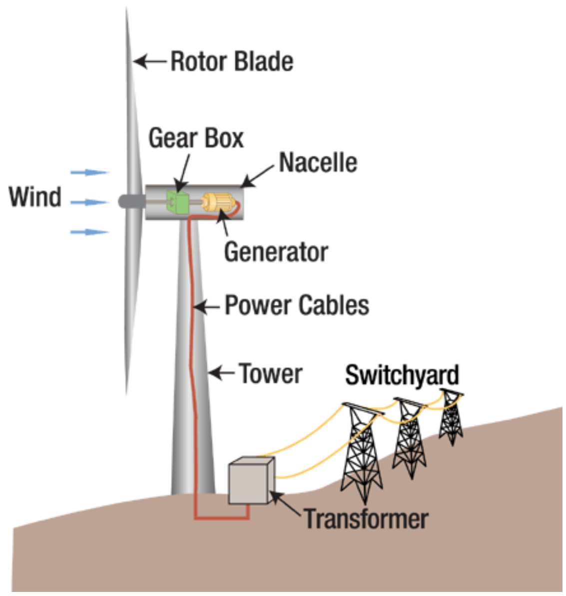


Figure 8 - A basic diagram showing the components of a wind turbine ("Tva: wind turbine," n.d.)

Institutional - Much like solar power there are no federal or state laws throughout the world prohibiting the use of wind turbines. However there may also be no tax incentives or discounts for their use. One issue that may arise in certain localities is institutional problems with the aesthetics of the turbines. Several neighborhoods in the US have banned turbines, and there may be regions across the globe that would want to do the same, passing policies against their implementation.

Human Resources - Wind turbines are a reliable technology that can last for a long time but do require some maintenance. Given their height, moving parts, and connection to an electric circuit wind turbines do require a fair amount of maintenance and expertise. Usually this requires the knowledge of a mechanical engineer, and depending on the weather may only rarely be needed. Installation and maintenance also requires the use of workers that know how to operate a crane or other large equipment to reach the height needed.

Technical - Wind turbines are almost exactly like solar panels in this sense, in that almost none of the components are found locally, and often require expensive and timely shipping in from nations creating all the parts. It can create some huge problems, should a blade get damaged in a storm. It would take weeks to months for it to arrive in some of the more remote areas.

Markets/Financial - The biggest problem with wind turbines is how expensive they can be. Generally without tax incentives even the average working person in the US can't afford one, let alone a village in a developing nation. Generally when a turbine is 100 kWh or less the cost will run anywhere between \$3000 to \$5000 per kWh. So even the smallest turbines producing 10 kWh can cost \$40,000 (Drupal and Advantage Labs, Inc). Without any sort of tax incentives it would be virtually impossible for a small town or village in a developing nation to afford even one.

Environmental/Natural Resources - Wind and solar are both very similar in another way, in the fact that they basically get their energy from the sun, with wind being a much more indirect method. Wind has no pollutants, minus those involved in the actual creation of the turbines. The majority of the resources involved come from developed nations, so as mentioned before the most of the target developing nations will not have the natural resources to build.

Energy - Wind turbines require a certain amount of energy to produce, but it mostly comes from forging the steel components and putting them together. Depending on the size, however, extra energy may be required as well for installation. If it's a smaller turbine then human laborers can do it with ropes and pulleys. Minus the transportation and production energy input, the turbines would require no other outside or synthetic energy sources since it's powered by the wind. Unfortunately some areas have more wind than others, and wind itself is never constant, so it's impossible to guarantee a steady, constant supply of electricity. However, after the initial construction and installation, all the energy needed is generated by the turbine itself.

Social/Cultural - A wind turbine holds a couple social and cultural considerations that are not to bet taken too lightly. Due to its size, obtrusiveness, and design wind turbines could conflict with the small, earthly design with some of the smaller villages, as well as disrupt standard cultural practices such as rites of passage and festivals, as several of these require open spaces and interaction with local wildlife. The latter interaction is also another huge concern. Wildlife, such as birds, bats, and insects, is usually impacted in some way by wind turbines. Studies have shown them to kill a fair amount of animals and disrupt natural processes. These creatures and processes are parts of many cultures, and a problem with them can likely lead to problems within the regions using the turbines in terms of cultural identity. It could also be beneficial, however, in that bird hunting would decrease as the bird bodies could simply be picked up. Outside of the effects of the wildlife on the village's or town's culture, the social impacts would ideally be very little.

Service - Wind turbines are not always the easiest system to expand. After the initial installation of both a turbine and the electronic system you can't really "grow" a wind turbine. Their built to a certain height, and then stopped. The only way to expand a wind turbine system, at least to produce more energy is to add more turbines. This is however very expensive, and given some locations could take many months to do. To expand the electronic portion does take significantly less work, as all that's needed are the pieces and a man or woman who knows how to install electrical systems in homes and buildings.

Micro-hydro

Micro-hydro involves the use of diverting stream water into pipes that flow down a steep gradient with turbines inside that are propelled by the movement of water. These turbines are then connected to a generator that produces electricity.

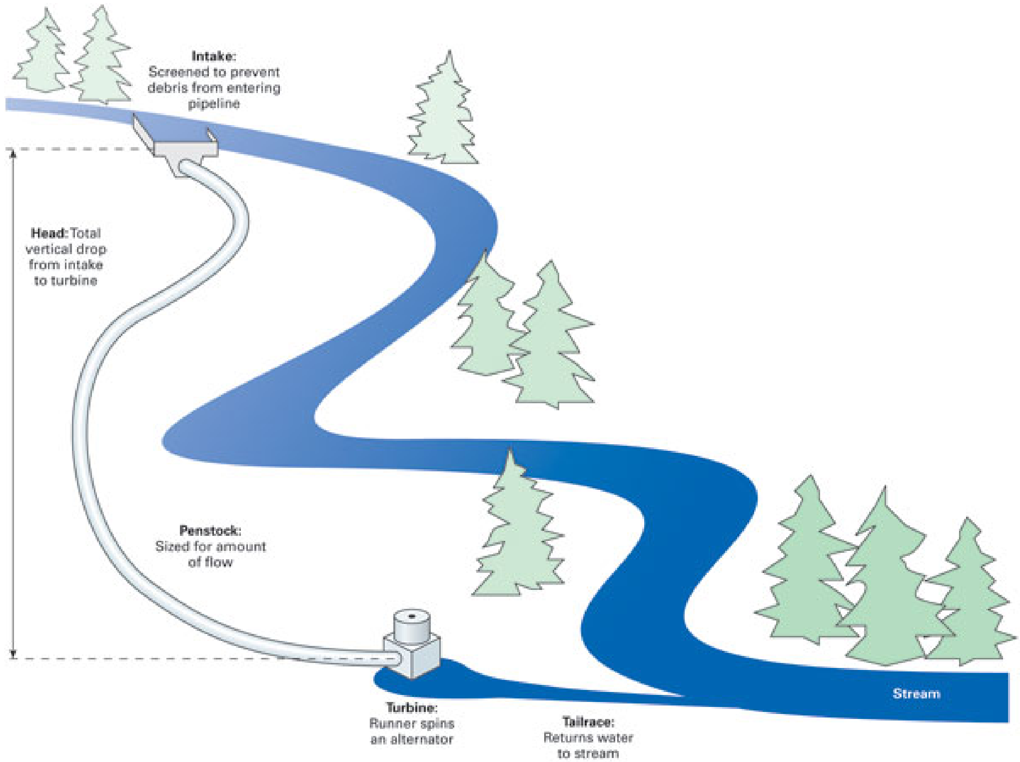


Figure 9 - Basic diagram showing the layout of a micro-hydro system ("Micro hydro power," 2010).

Institutional - The use of micro-hydro runs the risk of encountering a lot of laws, regulations, and government restriction surrounding the use of streams for power generation. The specific laws that may limit the use of micro-hydro is completely determined by the country where the technology is being implemented. It should be noted the potential of limiting laws and regulations make micro-hydro a riskier solution to attempt to implement.

Human Resources - As with any sort of mechanical power generation, there is the need for a person or team of people who have the necessary technical knowledge to design the system, install the system, and maintain the system safely. In a smaller-scale setting, such as what would be used to provide electricity to a village, there wouldn't be a need for a large team to maintain the system. However, there would be a need for knowledgeable operators to ensure that the dam is well managed and the turbines are generating efficiently.

Technical - The availability of spare parts and the necessary supplies to maintain a micro-hydro solution could pose a problem. As far as maintaining the dam goes, most localities should have the necessary materials to make cement to repair the dam. However, to maintain the turbines and generator, localities may not have access to the mechanical parts needed. Should a turbine break or a generator stop working, it could be weeks or months until the system is repaired. This potential unreliability should be taken into account when looking at micro-hydro as a solution.

Economic/Financial - The costs of a micro-hydro solution are typically lower than most other forms of alternative energy. Like any other system, a micro-hydro turbine can be used to charge batteries which allow the electricity to be used whenever it is needed. “A complete hydropower system with hydro generator, charge control, batteries and inverter costs about $4000 - $6500 plus the pipeline and installation” ("Micro-hydro power," n.d.).

Environmental/Natural Resources - Obviously, for micro-hydro to be a solution there must be a nearby water resource. This is the most limiting factor of micro-hydro as a solution. There must be substantial flow to meet the electricity needs and the flow must be consistent enough to meet needs throughout the year. An inconsistent water supply would leave the village with an inconsistent supply of electricity.

Energy - Any sized village could provide the necessary labor needed to install a micro-hydro solution. If a dam is needed to channel the water to maximize power output, then the majority of human labor input would be needed the dam construction. Also, as stated above, it is vital that the village have access to a stream.

Social/Cultural - Unlike solar or wind power, the nearby stream may be a resource used. Implementing a micro-hydro solution may limit how much water can be drawn out for irrigation or for drinking. Thus, the social/cultural implications of installing a micro-hydro solution would vary from location to location. If by installing a micro-hydro solution, the stream can no longer be used for sufficient irrigation, the people of the village may not be able to maintain an adequate agriculture production and the advantages of the system may be outweighed by the disadvantages.

Service - Expanding a micro-hydro system is usually not an easy option. Typically there is a maximum amount of energy that can be withdrawn from a stream. Once the stream output has been maximized a village would have to look to other solutions to meet a growing need for electricity. Also, getting necessary maintenance that cannot be performed by a local could be difficult to find.

Geothermal

Geothermal works in much the same way as solar, in that fluid is heated, forcing its speed to increase and evaporate quickly enough to produce pressurized steam which then powers a turbine to produce electricity. The difference here is that the fluid is heated by pockets hot rock and a gas hidden within the Earth’s crust.

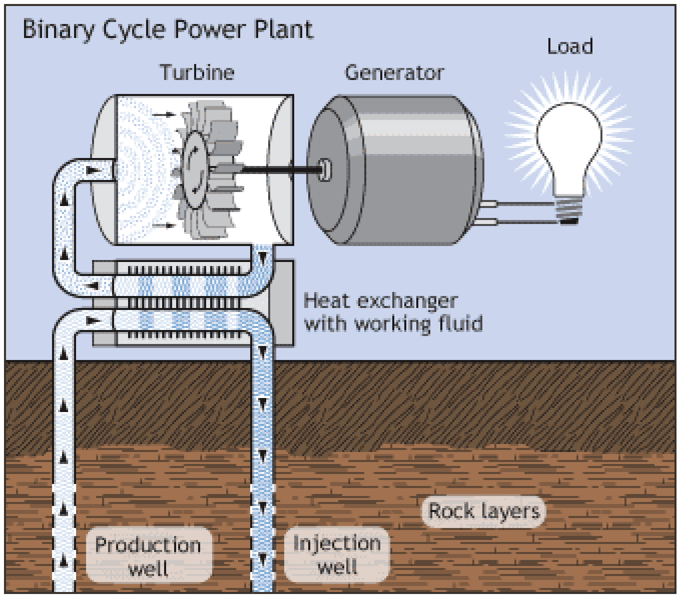


Figure 10 - Diagram showing the basic function of a geothermal system ("How geothermal energy," 2009).

Institutional - Geothermal electricity generation has very few institutional obstacles to go through, but the largest one throughout the world is restrictions on drilling. All geothermal devices require drilling past certain levels to reach the sources of heat and pressure deep beneath the earth. Some regions have restrictions based on unstable seismic activity. Others, in slightly more developed areas, prevent drilling to protect underground wires or tubes housing, electricity, water, or natural gas. Other than that geothermal has little to no official restrictions preventing its development.

Human Resources - Much like micro-hydro geothermal is a mechanical electrical energy generator, and there is the need for a person or team of people who have the necessary technical knowledge to design the system, install the system, and maintain the system safely. In a smaller-scale setting, such as what would be used to provide electricity to a village, there wouldn’t be a need for a large team to maintain the system. Generally a few people will be sufficient. The most human resource that will be needed is during installation, as nearly the entire initial process requires special equipment and the knowledge to use it properly and safely.

Technical - The biggest problem facing the technical aspects come in the form of spare parts. Much like all three of the previously mentioned technologies require components not locally made, and usually created in much larger nation. Maintaining the geothermal generator poses quite a challenge. Ideally the only maintenance would be on the generator above ground or any connections to the underwater portion or electrical systems. Those typically require the knowledge of an engineer or at least an individual with understanding to repair these. If something were to break underground or more likely sediment just needs to be cleaned, however, much more technical knowledge and equipment would be necessary, as cement will not repair or be effective with the high levels of heat, and much of the repairs there can be anywhere from a few hundred feet to a few miles below ground. Not to mention, should some portion stop working due to a broken part, it could be weeks or months until the system is repaired. On the plus side geothermal plants use very strong material, and constant maintenance is uncommon. Generally they're put together well enough to last a long time with little to no repairs, and only the occasional cleaning.

Economic/Financial - Possibly the largest hindrance to geothermal technology is its high cost. Everything from installation is expensive minus the parts themselves. Generally it require a lot of money to hire a team to drill and install, rent out the equipment they need (primarily drills), do the research to make sure geothermal is even possible in an area, and install the generator to some sort of electrical system. The installation cost alone will range between $3000 to $5000 for a smaller scale geothermal plant. (Department of Energy, 2006). This means, much like wind turbines, the initial installation cost, not including pipes and generator, for a 10 kWh geothermal plant will be around $40,000. This is an absurd amount that many areas would struggle greatly just to reach the lowest price. With no real tax incentives or government discounts it makes geothermal a very unattractive option.

Environmental/Natural Resources - Geothermal requires the earth itself to be an effective electricity source. Generally an area with low to mild seismic activity, a fair amount of hot springs or underground heat activity will provide all the natural resources necessary for geothermal to work. That's really all it takes, and supplies a constant stream of energy, providing there are no underground movements. However, in areas that are from the Earth's crusts' edges or are cold deep underground geothermal power plants would not be useful.

Energy - Any sized village could provide the necessary labor needed to install geothermal plant. The problem is that they would also need specialized equipment and any fuel needed to run those (usually diesel). Much of the energy that would go into the construction and maintenance of a geothermal plant would be all those involved in the creation of the parts and installation. Pipeline and generators are built in factories, requiring fossil fuels for the production. However, once the plant is installed almost the other energy required would come from the earth itself, and no other outside sources would be necessary.

Social/Cultural - Generally geothermal would have little to no impact on social and cultural aspects of life in these villages and towns. Electricity is usually generated from geothermal power plants, separate buildings with no emissions and an electrical system connected to the rest of the town. For the most part it's simply another building since almost all the work is done underground. There would be some employment for people to maintain the plant, and that would really be about the extent of the cultural influence.

Service - The expansion of a geothermal power plant is not an easy feat. It requires extra active heat sources underground and a lot of money to essentially install another geothermal plant, minus the above ground building. It's extremely expensive and in certain areas could take even years to complete, depending on how remote it is and deep the heat sources are.

Diesel Generators

Diesel generators operate much like diesel engines in that they convert diesel fuel, using heat and pressure, to kinetic energy. This kinetic energy is then used to power an electrical generator which produces electricity.

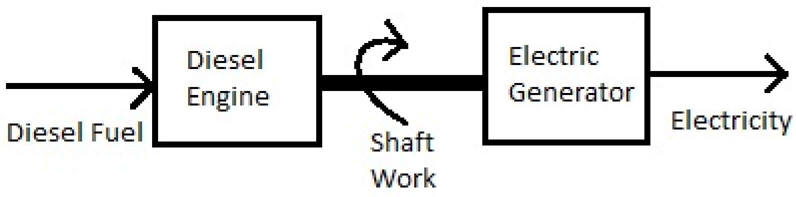


Figure 11 - Basic diagram showing the function of a diesel generator.

Institutional - Diesel generators are very similar to our biomass gasifier in terms of using a fuel to power an engine to power a generator. Generally, unless a region has rules or standards on emissions, the only institutional obstacles are going to be any that are already in place for both diesel and diesel engines. In many developing nations, there aren't very many regulations because there's not really a reason to have any.

Human Resources - In terms of human resources the diesel generator is the lightest one on this list. The generator needs a small team to set it up, but after that only one person to check on it. Then the manpower will also be needed to ensure that diesel is available for the generator. Otherwise it doesn't really require much human attention.

Technical - The diesel generator has the same amount of mechanical processes as any of the other technologies listed, but its design is one that has been used for almost a century now. Generally any car mechanic or person knowledgeable in a combustion engine already possesses the basic understanding to work and maintain a diesel engine. Since many areas already have a couple mechanics then it only takes a little bit more education to run the generator. To maintain and provide the fuel takes even less technical knowledge. Generally diesel engines don't break down and repairs are needed every couple of years, depending on local weather and climate. From that perspective the diesel generator is very easy to maintain.

Economic/Financial - If a village has enough money to afford a large car or truck then they will more than likely be able to afford the diesel generator. The different components put together consist of a lot of parts found in trucks, with the addition of a generator. The average cost of a diesel generator is between $1,000 and $2,000 and can usually provide 6 to 10 kWh. This is substantially lower than almost all of the listed technologies, and slightly lower than a complete gasifier. The only other cost, besides the generator itself, is the diesel needed to run it. That can be expensive, depending on how much is needed and the how well the oil market is doing. However, even with the rising cost of fuel the diesel generator remains the least expensive option.

Environmental/Natural Resources - The environment and resources would be the diesel generators' biggest flaw. Diesel is a petroleum based fossil fuel, meaning that it comes from a finite resource and will run out. Some projections have it running within the next 50 years, so it would not run off a worthwhile natural resource. On an environmental level diesel combustion has a lot of emissions that are very harmful to the environment. To some more undeveloped nations that still have a lot of wildlife this could be very damaging to the local ecosystems, and naturally contributes to carbon emissions. The diesel generator overall has very negative effects on the environment.

Energy - Diesel generators require the most amount of energy after installation and construction than all the other technologies being compared. This is primarily from the fact that they constantly require diesel. Without it the generator is simply useless. Because of this the diesel generator requires a yearly intake of energy from external sources. In some developing nations that means importing oil at high rates. Due to this constant attention these generators require much more human energy than the other alternatives.

Social/Cultural - Diesel generators would have very little cultural impact on a region that has at the very least a truck or car. It’s essentially the same type of device, just providing energy to homes instead of cars. One possibility that could arise is independence between families, as it is possible, yet unlikely for each home to have their very own generator. That could potentially alter the usual family style in several countries, causing them to have less or more children, or putting multiple families in one home. With the small size and accessibility of the generator it is possible to a shift in family structure in some of these developing areas.

Service - The diesel generator is not too difficult to expand, but it is possible. Multiple tanks for one generator can be installed, as well as multiple generators to one building or area. The expansions are relatively inexpensive, and with a mechanic or electrician around they can be added to a system already in place. The parts for possible expansion can really be salvaged from a junkyard or truck; however a safe and efficient generator would require parts from companies that actually produce generators. Again the largest factor to take into consideration with these is location, but because the pieces are relatively small it may not be as hard as some of the larger technologies.

Summary

Biomass gasification is just one possible solution to energy problems in developing nations, and as this analysis just showed there are a few alternatives that can be applied with the same or better results. However, the majority of these are simply too expensive for a developing region, with a yearly salary, in some areas, less than a monthly minimum wage in the United States. The best alternative to the gasifier, should it be too costly or not applicable for a region would be the diesel generator. While it does use a finite resource and pollutes the environment, on a small scale its impact is low. The other options cost easily 30 times the cost of the generator, and for many of the areas the cost will be the ultimate deciding factor. Wind, hydro, and geothermal all also require specialized landscapes that cater to electricity generation. Solar, diesel, and even the gasifier to a degree can be used almost anywhere with special steps taken to ensure safety and efficiency. Diesel generators are a tested and widely used technology, and for a developing area have a lot of potential should the biomass gasifier not be applicable for various reasons.

6. Methodology

6.1. Refine Topic and Scope of Project

The initial step of this research after completing the proposal was to refine the topic through input from sponsoring organization, Least of These International (LOTI). Through meeting and discussing various directions this project could take, it was agreed upon that the goal of this project would be to provide LOTI with the information needed to assess a producer gas technology as a potential solution for a community in the developing world. LOTI uses a Capacity Factor Analysis model to score communities based on different resources they have. This score is then used to determine which technologies are best suited for the community being assessed. Because of this, LOTI was very interested in having all the necessary information to begin using producer gas as a technology for implementation in developing communities.

6.2. Background Research

With the scope and topic specifically defined, the project could move forward by beginning research of the producer gas technology and its applications. Since little was known about this topic after the proposal writing stage, it was very important that thorough background research be completed. This would ensure that the project could provide LOTI with the information needed to assess producer gas accurately. The goals of background research were to obtain a working knowledge of a producer gas system--how it operates, how it is generated, and issues--and begin to refine the gathered information into a usable form.

6.2.1 Identify Applications and Case Studies

By performing a literature review, different case studies and applications of producer gas in developing communities were studied and researched. The goal of obtaining case studies was to learn whether or not this technology could be implemented successfully and if so, how to best go about doing so. Likewise, using case studies allowed for assumptions on which style of gasifier would be best to be made. Examining case studies also provided ideas about how an entire community could function around a gasifier system and the various advantages and disadvantages of implementing a system. These case studies also shed some light on different applications of producer gas in various regions and helped us identify exactly how versatile the gasifiers could be.

6.2.2 Evaluate Producer Gas Advantages and Perform an Options Analysis

While the overall goal of this project was to develop a producer gas technology that could be applied to a developing community in the world for cooking and electricity here was no guarantee that it would be the best solution in all situations. Research was conducted to include an options analysis on other applicable solutions and to weigh the strengths and weaknesses of the gasifier in terms of its environmental and social impacts. In addition to these particular factors it was also important to look at other possible alternatives to the gasifier and see if they may fair better in different region, calling for the need of an alternatives analysis. This was performed using the analysis standards from Least of These, International they require when looking at different technologies for a certain area. Using those requirements we compared the factors of 5 different technologies with the producer gas gasifier.

6.3 Design the Prototype

Initially there was a plan to design and build a small, working prototype of the gasification process, and have it generate some power. Unfortunately, given findings from our initial research we determined that it would be too costly and timely, with no location and no working knowledge, to physically build the gasifier. The decision was then made to design the device, with schematics, and create a plan that would involve the proper funding. The prototype would be planned based on known materials, safety standards, efficiency, possible applications, cost effectiveness, and past case studies. With initial research completed on some of the organic material necessary and some of the feats that producer gas gasifiers have accomplished we could create the initial plan for a prototype in a developing nation. Through careful consideration the downdraft style gasifier was chosen. From there a plan was made to use an already existing device and apply that to a developing nation. In order to build a cheap gasifier the expensive one must be built first. Looking at various styles and designs it was decided to base our model off of the GEK downdraft gasifier. Using that design, and ideally that exact product, we could plan a device using more inexpensive and regional parts, such as 50 gallon drums and plumbing pipes. With that mindset a gasifier could then be planned for a developing area. Another aspect considered in this design phase was the fuel being used. The organic material going into the gasifier would be crop wastes more than anything else, so the design had to take that into account and lend itself to giving back to the creation of the crops via ash. Further device planning, as it was determined through this initial design phase, must include safety, cost, construction, and maintenance analyses. All four of these must be considered for the implementation of the gasifier to any region unfamiliar with its technology. The continued performance of the gasifier was one of the biggest aspects of the planning considerations, seeing as an area won't get the use thy need out of the gasifier unless it is easy to use the fuel will benefit the community. The initial design is aimed to achieve these goals.

6.4 P3 Grant Proposal Application

After the realization that the construction of the gasifier the initial design of the prototype would be much more expensive than we expected LOTI recommended applying for a grant, specifically the EPA P3 Grant (People, Prosperity and the Planet Student Design Competition for Sustainability). The grant is awarded to 65 presentations for $15,000 each. The grants application process involved getting the support of both the ISAT department and James Madison University. It also required a carefully written submission detailing the aspects of the gasifier, the possible applications, beneficial impacts to the environment and local people, and a budget. The Application was then sent in to the EPA, along with letters of support from the ISAT department and LOTI. Grant success is currently pending.

6.5 Preparation for the Next Phase

With the grant applied for and the design completed for the most part the next step was to prepare for the future. This included developing potential plans for the construction of the gasifier in two different scenarios, one in which we get the EPA grant and one in which we don't We determined that if we do receive the grant the best route to take would be to purchase a gasifier kit to better understand exactly how the device works. From there a group of students can use that technology and combine it with local parts to create a "homemade" gasifier. The other option, if we do not receive the grant, is to carefully study the design of the downdraft gasifier and then attempt to build the homemade device from that secondary research. Ideally both routes are possible. The next step in our preparation was to find a student or students to continue on with the construction of the gasifier. This required recruitment of rising seniors who would need their own senior project and hopefully passing on this one. We were successful in our recruitment and found Daniel Ferrante to carry on the project.

7. Results

As noted, there are numerous designs and styles of gasifiers. Choosing the design that is best suited for this particular use involved studying the advantages and disadvantages of each design as well as examining case studies to determine which designs have been used in similar settings. Two different gasifier designs were studied thoroughly. The entrained flow gasifier and fluidized bed gasifier designs were omitted from consideration because of their very complex and technical nature. This left the updraft and downdraft gasifiers as the designs to be considered for use in an electricity generation system. The initial advantage to an updraft gasifier is that, by drawing the incoming air up through the already hot ash, the air is heated, thus increasing the thermal efficiency of the system. However, because the gas then does not flow through the ash, many of the tars found in the gas are not cracked and make their way to the engine. A downdraft gasifier draws the air in through the cooler fuel, but the gas leaves by flowing through the hot ash where many of the tars are cracked resulting in a much cleaner fuel. For the purposes of this system, that is, a clean gas to be burned in an internal combustion engine, it became clear that a downdraft gasifier was best suited for the needs of the system. Also, through examining case studies, it became apparent that the most widely used style of gasifier was the downdraft design.

In order to ensure a fair and thorough evaluation of producer gas as a technology solution for a developing region, the eight factors of LOTI's CFA model will be applied. These eight factors are: institutional, human resources, technical, economic/financial, environmental/natural resources, energy, social/cultural, and service.

Institutional - The protection of forests in legislation can make producer gas a tougher technology to implement. For example, in some countries, because of widespread deforestation, forests are protected and special permits must be obtained in order for harvesting of trees. Even in a setting where an energy forest had been planted, it could be difficult to harvest and use these trees. Using crop wastes helps avoid this issue; however, using crop waste carries with it its own negative impacts such as taking away from animal feed, composting material, and other various uses.

Human Resources - One of the biggest draws that a producer gas solution brings with it is the opportunity to provide economic activity within a community. Workers are needed to process the organic material--that is, ensure that it is in a burnable state. If an energy forest is planted, workers are needed to maintain the forest and harvest the trees. Also, at least one operator is needed to ensure that the system is functioning and operating correctly and safely. Likewise, by providing power to the surrounding people, a producer gas solution stimulates the already existing economy. The major drawback to a producer gas solution from a human resources standpoint is that the technology is rather complex and requires that a well-trained operator be present at all times while the system is in operation. Likewise, there are numerous moving parts and it is very important that a knowledgeable engineer be involved in the maintenance and repair of the system.

Technical - The technical aspects of a producer gas solution are interesting. While the various technologies that go into a producer gas system are well documented and widely used, their use together in an integrated system is less widely practiced and thus can make for a technically complex system. An internal combustion gasoline engine has been in use and development for over a century. This engine requires a few simple modifications to run on producer gas. Likewise, a shaft-powered generator has been around for even longer and can be powered by anything that produces shaft-work--in this case, an internal combustion engine. The process of gasifying biomass has also been well documented and studied. However, the combination of these three technologies and processes can make for a complex and potentially hard to maintain system. Given the time to tune the system and prepare it adequately for the type of fuel that will be burned, many of the technical problems that can hinder a producer gas solution can be avoided. Likewise, with sufficient maintenance on the system, many gasifier systems can run for decades.

Economic/Financial - As noted above, there can be numerous economic and financial benefits from a successful producer gas system. It would be part of its own economic cycle that could greatly benefit any community it’s placed into. The gasifier would be powered by a communities own organic wastes, saving money on bring in fuel from an outside source. So the men and women of these communities would already be better off financially because their own agricultural practices would be providing their energy. This would in turn benefit their agricultural practices as more power means better farming practices. With better farming an area can have a much bigger output and then make more money, allowing for a better standard of living. Depending on the region the only initial costs of this device are the actual purchasing of the gasifier itself, which ideally won't be any more than $10,000 and barely $1000 at the lowest cost. After that first expense a region would pretty much supply all the fuel needed to run the gasifier through their own daily activities. So ideally it would ultimately pay for itself.

Environmental/Natural Resources - As mentioned before the gasifier would run on semi natural resources, as in the wastes from crop production, and should the need arise wood chips can be used. In most regions this would have little impact on the local ecosystems because it would just be using local practices. Since combustion is part of the process being used then naturally there will be some emissions in the form of carbon, but also as tar and ash. However all of these byproducts, minus ash, would be significantly lower than they would in petroleum based fuels. One big advantage with using biomass is that the resulting ash can be used to help fertilize the soil to grow more crops. There are several factors that go into the nutritional value of the ash, such as the soil type, the heat at which the biomass is burned, and more importantly what was actually in the biomass. The biggest advantage a gasifier system has is that it is effectively a carbon neutral solution. The only carbon emitted is that that was contained in the organic material. Newly planted crops will take up the carbon that was released; thus, keeping the system at a net release of zero.

Energy - The sources of energy available for use in a gasifier system are limited to organic fuel inputs. In a region where agriculture is not widely practiced, such as an urban area or in a climate that does not support agriculture, a gasifier system would not be a good solution. A key requirement of a community being able to support a gasifier system is that the community must be able to supply the adequate biomass needed for gasification. An area could have all the other necessary requirements, but the key limiting factor to this technology is the fuel inputs. Another potentially limiting factor to a gasifier system is that the use of organic material for fuel could take away from another use. For example, if corn waste is already ground up to use as feed for animals and a gasifier system is designed to use that corn waste; there could quickly become a situation where neither can be adequately supported.

Social/Cultural - An effective and long-lasting gasifier system would need the support and approval of the surrounding community. Without the necessary labor required for operating and maintaining, the system will never be successful. People in the community must be willing to not only supply the man-power needed for construction and implementation of the system, but they must also be willing to support the operation of the system through providing the needed technical expertise and labor to ensure that the system operates regularly and efficiently. It would even be idea to have a few trained system operators living within the community so that they can work in shifts to ensure that the system is running when power is needed. Likewise, in the event one of these people are not available--sickness, travel, etc.--it would be in the community's best interest to have at least another person available who can safely operate the system. Also, the community must be willing to give its crop waste to be used for fuel. As previously stated, if this crop waste is currently used for other uses, it may be difficult to persuade people to surrender it for use as fuel. Providing an economic incentive such as a discounted electricity rate for providing crop waste to be used as fuel could make it easier for people to want to adopt a gasifier system.

Service - A potentially major drawback to a gasifier system is the service and maintenance aspect. There is a substantial number of moving parts compared with other technologies and every moving part is an opportunity for something to break or malfunction. Likewise, the gasifier itself needs to be operating within certain temperature and pressure parameters that, if not met, could cause the production of low-quality gas which could cause the engine to misfire and be damaged. The filter systems on the gasifier must be monitored and changed when needed in order to ensure the gas is being cleaned. Unclean gas burning in the engine will quickly cause tar and particulates to build up in the cylinders. Thus, it is imperative that the system be closely monitored by a knowledgeable individual who is capable of performing the tasks necessary to prolong the life of the gasifier and combustion engine. Should components break or need to be replaced, the supply chain surrounding the gasifier system could become a limiting factor. Not only may there not be an individual capable of repairing the system, there may not be the parts needed for fixing the system. While the internal combustion engine is a resilient piece of technology, it needs to be carefully maintained to ensure that it continues to operate properly.

To summarize the alternatives analysis using the CFA model produced by LOTI, Figure 12 shows a matrix displaying the differences in technologies as well as their advantages and disadvantages. A rating of -2 shows a strong negative impact or strain that the technology puts on that particular factor. A rating of 2 shows a strong positive impact or benefit that the technology gives that particular factor. A rating of 0 shows a neutral impact.

	Factors							
Technology	Institutional	Human Resources	Technical	Economic/ Financial	Environmental/ Natural Resources	Energy	Social/ Cultural	Service
Solar (PV)	1	1	-2	-2	2	1	0	1
Wind	0	0	-1	-1	2	1	-1	0
Micro-hydro	-1	-1	-1	1	-1	1	-1	-1
Geothermal	1	1	-2	-2	-1	-1	1	-2
Diesel	1	2	2	2	-2	-2	0	1
Producer Gas	0	2	1	2	1	1	1	0

Figure 12 - Matrix rating advantages and disadvantages of technologies.

8. Discussion

The implementation of the gasifier has a lot of benefits and a fair amount of problems associated with it, but given the right circumstances it could really change lives and increase standards of living. Producer won't be the best solution for every village, but for those in which it works the results will greatly benefit the community as a whole. As mentioned previously, since the producer gas is made from organic material, in this case primarily crop wastes, it creates a system that generates growth, gets rid of wastes, and allows a village or town to flourish if proper preparations are taken. The whole process of the gasifier creates a cycle of growth and generation that can be maintained and sustained. After the gasifier is built it requires fuel, crop waste and other organic material, to generate electricity. It then can give back to the growth of that organic material in a few ways. The ash that's produced can be spread over the area's growing vegetation to return some nutrients to the earth and help the crops grow a little better for a higher yield. Along those same lines the electricity and producer gas that the gasifier would generate would allow for better farming techniques, such as better irrigation and cheaper tractor fuel. All of this would also contribute to a higher yield of crops, which would also mean more crop waste and more fuel. With better agricultural practices and higher crop yields a village could potentially start making more money, which would allow them to afford better farm equipment, medicine and better food. Again, with better equipment comes a higher yield. And with better health care, like basic medicine and cleaner food, the local people will be healthier and stronger, allowing them to be better at producing their own crop yield. Which again means more crop waste and more fuel for the gasifier. If things were to work as perfectly as this then it would be a completely sustainable system. Some areas will fare much better with this cycle than others, depending on their soil quality, rain fall, and other factors. But just the potential for a cycle to work this well makes the producer gas gasifier a very attractive option.

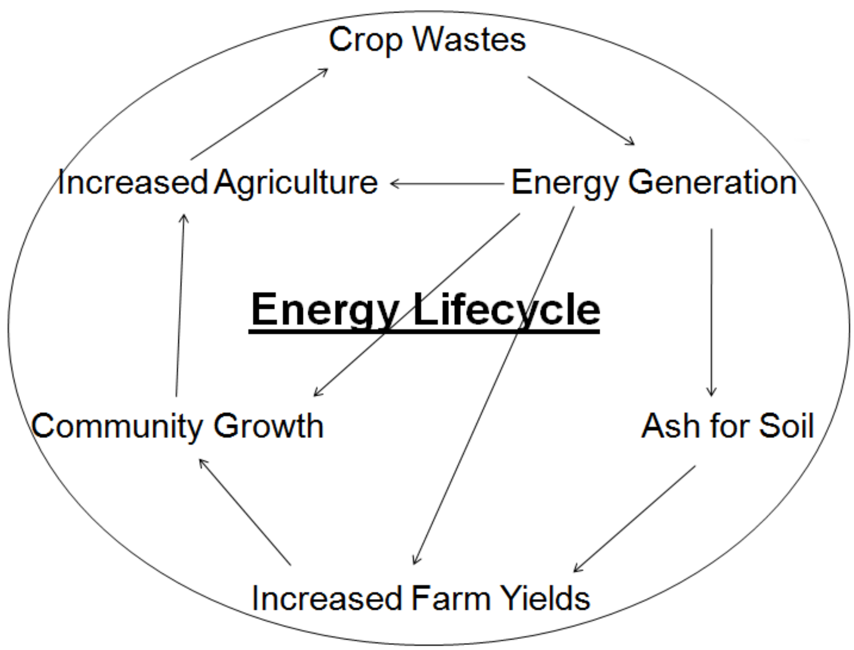


Figure 13 - Potential energy lifecycle when using a producer gas system.

When looking at the potential of this energy lifecycle a huge consideration is exactly how much land will be needed. Since the focus, in this situation, is on the crop wastes the amount of energy that can be retrieved from an area of land extends well beyond just the grains. Using a few base assumptions on how much energy would be needed it's possible to provide power to a gasifier for one whole year. It's assumed that the base load for an entire community would be around 144 kWh per day. When compared to the average American college household running about 14 kWh per day it's not a far leap. Ideally most of this energy usage would come from irrigation systems, water or well pumps, some lighting, and more than likely a few other devices. Another big assumption is exactly how much energy you could get from crop wastes. On average, using the efficiency of the GEK downdraft gasifier, a single kilogram of biomass would produce roughly 0.75 kW of energy. With these assumptions in mind we can then figure out how much crop land will be needed to provide the waste for each year. Most likely not all of that waste will be retrieved, since a large portion will go back into plowing the ground. For this project we looked at corn, sugar cane, and switchgrass, which would most likely be the crops that would be used. For corn we assumed that the average farm in a developing nation could produce about 70 bushels per acre. Using some base calculations on how much of that was waste and that only 50 percent of the waste would actually be used for gasification then we can determine how many acres would be needed for one year using the calculations below, which would be around 46.6 acres. Much like corn, sugarcane and switchgrass would also only produce about half of their total wastes to gasification. In order to figure out how much would be produced in a developing nation we took the average American yield and cut that in half, and then used the following equation to figure out acres needed. After corn we looked at sugarcane. Assuming that the average production would be around 4000 lbs per acre we found that it takes roughly 38.5 acres per year. Switchgrass worked in much the same way, assuming an average production of 3000 lbs and switchgrass for one whole year would require 51.4 acres to provide energy to a community for one whole year. While these totals may seem like a large number for the average farm in areas like Kenya is 13 acres per family, when you look at the bigger picture it makes more sense. In any given community there are going to be many families, a lot of times in excess of 60. When providing energy to an entire community for one whole year that becomes a much more feasible possibility when the entire group is involved.

Unfortunately, as with any type of technology, there are always unintended consequences. Many of these consequences involve environmental impacts and social considerations. Some consequences would occur in the off chance that an area would run out of crop wastes to generate the gas, so they would have to look to other organic plant matter for fuel, if they so wanted. This would mean further encroachment, in some areas, on lands that had been allowed to grow wildly for generations. Another consequence is one that comes with any device that relies on heat to work, and that would be the possibility of a fire. Some areas are very dry during certain times of the air, and given the right conditions one incomplete combustion could result in some deadly forest and house fires. There's also the slight increase in emissions if a region had none or very little to begin. There's no way to know exactly what the impacts would be of some tar and carbon being released into an area. It could have severe effects on the atmosphere, on the local wildlife, and even on the health of the villagers. Ideally it is a lot cleaner than a simple brush fire, but with multiple gasifiers in one area the results would be hard to completely predict. Not all the consequences are necessarily negative. The added ash to an area could contribute extra growth not planned on by the locals. In many situations more growth is a good thing.

A huge unintended consequence that could likely happen would be very much a social one, dependence on the electricity from the generator for a community's entire livelihood. While the electricity is a wonderful thing that can definitely increase health care, productivity, and incomes, it is not meant to be the sole source of energy and growth in an area. If a village starts relying solely on the generator, one that is powered by crop harvests, to keep water clean or provide life support to an injured villager then the outcomes could be disastrous. Since the gasifier is run on crops it requires some type of harvest all year round to provide energy. Farming is a seasonal practice, and one that is heavily dictated by the weather. If a community is forced to suffer through a drought one year than it is unlikely that they will have the electricity they desire, unless they use other sources. While electricity generation from crop wastes is amazing it is not a technology that should be taken lightly, and there should always be a backup plan for some of the more important aspects of a village's life support.

9. Conclusion

The producer gas generator is a device that uses a century old technology to turn organic material into electricity. While it is not widely used in developed regions of the world it holds a lot of potential in developing nations. It's relatively inexpensive to buy and build, requires minimal technical knowledge, and can run on the byproducts of an area's own agricultural processes. This report looked at the technology behind gasification, some other alternatives to them, and what it would take to build one, financially and technologically. It also looked at the possible impact the gasifier could have on a community, ultimately empowering local people. The gasifier creates a cycle of growth, power generation, more growth, and ultimately gain. It grants a community power over the whole process of electricity generation because it lets them control how much they produce, how much they're willing to pay, and gives the power they need. The whole cycle works together to grant communities strength, independence, and growth. That cycle is what we feel sets the gasifier apart from other renewable technologies, and given the right climate conditions is the ideal technology for electricity generation in developing nations. It is vital that a community be empowered to take their future into their own hands and grab hold of a vision of what could be. Simply giving a community all they need to better their situation is never enough. The individuals of the community, the community leaders, and the organizations involved, need to have a uniform and defined vision of their goals. By sharing a common goal and vision for a better community, the individuals are being empowered to change their own situation. The keys are to discuss the past, the present, and the future. This applied to a gasifier solution would involve communities examining their energy sources of the past, their current energy resources, and helping them learn what the future could hold. This could involve community leaders visiting areas where this technology has been successfully implemented. When individuals have internalized their own capability to make a change, they have become empowered, and they are able to make change happen.

10. Future Work

A major component of this project was researching and applying for the Environmental Protection Agency's P3: People, Prosperity, and the Planet Student Design Competition for Sustainability. The Tier 1 grant awards up to $15,000 for designs that address the three "P's" of the competition. There are five different subcategories within this competition: Energy, Built Environment, Materials and Chemicals, Water, and Agriculture. This project applied within the Energy subcategory.

If this project wins the grant and is awarded the $15,000 requested, then the future work of this project will be to construct a gasifier system from a kit sold by All Power Labs. Using the grant money to purchase the Gasifier Experimenters Kit (GEK), the kit would be constructed and then real-world testing of the system could be performed. Ideally, it would be important to know what effect different fuels have on the output gas. Likewise, it would be important to know how the system operates in various weather conditions.

Figure 14 - The GEK gasifier as built by All Power Labs ("About - gasifier," n.d.)

On a longer-term scale, it would be best to begin re-designing the kit for construction in a developing area of the world using locally procured materials. It is neither economical to transport the entire kit overseas, nor is it ideal because the replacement parts cannot be easily obtained. Thus, it would be important to study the kit and determine what components can be swapped out for locally found parts. This would greatly reduce the cost burden the system would have on a community. It would also increase the collaboration between the community and the outside project developers hopefully leading to a more successful project.

In the event that the grant is not won, it would still be important to begin designing a gasifier that could be constructed entirely out of locally procured materials. While this would be more difficult without a tangible gasifier to test and examine, this could still be completed through research and some small-scale testing.

Whatever the next action will be it is not one the current authors can take up due to circumstances of the world. It is required that a new team of researchers and practitioners begin working on the next phase of this project. As of right now, Daniel Ferrante will be continuing the project and we feel confident that he will take the project forward in its next phases.

Regardless of whether the grant is won or not, the primary goal of any future work would be developing a set of technical schematics that would allow Least of These International, or any organization to construct and operate a gasifier system in a developing region of the world.

References

240 wood burning producer gas powered2. (2010). [Web]. Retrieved from http://www.flickr.com/photos/12663308@N06/5075676994/in/photostream/

¨McKenzie, M. (2010). *Biotechnology terms*. Unpublished manuscript, College of Agricultural Sciences, Oregon State University, Corvallis, Oregon. Retrieved from http://agsci.oregonstate.edu/orb/sites/default/files/orb_biotech_terms_2010.pdf

¨LaFontaine, H., & Zimmerman, F. P. United States Department of Energy, Federal Emergency Management Agency. (1989). *Construction of a simplified wood gas generator for fueling internal combustion engines in a petroleum emergency* Oak Ridge, TN: Oak Ridge National Laboratory.

¨Pitman, R. (2005). Wood ash use in forestry – a review of the environmental impacts. *Forestry,79*(5), Retrieved from http://forestry.oxfordjournals.org/content/79/5/563.full

¨*Battery based systems*. (n.d.). Retrieved from http://www.pvpower.com/battery-based-systems-4080w-system-w-outback-inverter.aspx

¨*Micro-hydro power*. (n.d.). Retrieved from http://www.backwoodssolar.com/catalog/hydropower.htm

¨Saavedra, C. (2010, May 25). Building a sustainable biogas system in kenya. *Environmental Protection*, Retrieved from http://eponline.com/articles/2010/05/25/building-a-sustainable-biogas-system-in-kenya.aspx

¨Drupal and Advantage Labs, inc. (n.d.) How much do wind turbines cost? *Windustry.org*. Retrieved from http://www.windustry.org/how-much-do-wind-turbines-cost

¨Department of Energy. (2006, January 13).*Geothermal faq's*. Retrieved from http://www1.eere.energy.gov/geothermal/faqs.html

¨(not used) Balat, Mu., Balat, Me., Kirtay, E., & Balat, H. (2009). Main routes for the thermo-conversion of biomass into fuels and chemicals. part 1: pyrolysis systems . *Energy Conversion and Management*, *50*(12), Retrieved from http://www.sciencedirect.com/science/article/B6V2P-4X6M98W-3/2/10bc9e69dee2799b3f4914568d41bb01 doi: 10.1016/j.enconman.2009.08.014.

¨Sears. (2011). *Etq diesel portable generator 6000 watt continuous*. Retrieved from http://www.sears.com/shc/s/p_10153_12605_07139462000P?srccode=cii_17588969&cpncode=24-134729507-2&i_cntr=1302812006667&sid=IDx01192011x000001

¨*About - gasifier experimenters kit*. (n.d.). Retrieved from http://www.gekgasifier.com/

¨*Tva: wind turbine energy*. (n.d.). Retrieved from http://www.tva.gov/greenpowerswitch/wind.htm

¨*Solar pv diagram*. (2009, April 24). Retrieved from http://blog.mapawatt.com/2009/04/24/solar-pv-diagram/

¨*Micro hydro power*. (2010, September 30). Retrieved from http://blog.mapawatt.com/2010/09/30/micro-hydro-power-2/

¨*Geothermal*. (n.d.). Retrieved from http://www.mightyriverpower.co.nz/Generation/PowerStations/Geothermal/

¨FRTR, Initials. (2004). *Typical pyrolysis process*. Retrieved from http://www.frtr.gov/matrix2/section4/4-25.html

¨Vagts, T. (2005). *Nutrient content and value of corn stover.*. Unpublished manuscript, Iowa State University, Carrol, IA. Retrieved from http://www.extension.iastate.edu/nwcrops/corn_stover.htm

¨Soil Quality technology Development Team, Initials. U.S. Department of Agriculture, National Resources Conservation Service. (2006). *crop residue removal for biomass energy production: effects on soils and recommendation* Greensboro, NC: Retrieved from http://soils.usda.gov/sqi/management/files/sq_atn_19.pdf

¨Judice, W, & Griffin, J. (2008). *To burn or not to burn – sugarcane crop residue management*. Unpublished manuscript, Louisiana State University, Baton-Rouge, LA. Retrieved from http://www.lsuagcenter.com/en/communications/publications/agmag/Archive/2008/Spring/To+burn+or+not+to+burn++sugarcane+crop+residue+management.htm

¨Hessen J. Smith K. Bruce N. McCracken J. Schei, M. and V. Lopez. Childhood asthma and indoor woodsmoke from cooking in guatemala. Journal of Exposure Analysis & Environmental Epidemiology, 14:S110{S117, 2004

¨Biomass gasication for agricultural energy sources and soil enrichment, 2009. http://cfpub.epa.gov/ncerabstracts/index.cfm/fuseaction/display.abstractDetail/abstract/8997/report/0.

¨ Alfagy. Wood biomass gasication chp.
http://www.alfagy.com/index.php?option=com_content&view=article&id=5&Itemid=6

¨ S. M. A. Bhaird, G. Devlin, K. McDonnell, P. Owende, C. Unger, and T. Schulzke. Quality of producer gas from the gasification of different feedstocks pertinent to the Irish climate. American Society of Agricultural and Biological Engineers Annual International Meeting 2009, 2009

¨ P. Caton, M. Carr, S. Kim, and M. Beautyman. Energy recovery from waste food by combustion or gasification with the potential for regenerative dehydration: A case study. Energy Conversion & Management, 51(6):1157{1169, 2010

¨ R Datta and G. Dutt. Producer gas engines in villages of less-developed countries. Science Magazine, 213(4509):731{736, 1981

¨ R. Dorf. Technology, Humans, and Society: Towards a Sustainable World. Academic Press, San Diego, 2001

¨ Miskam M.A. Hassan S., Zainal Z.A. A preliminary investigation of compressed producer gas from downdraft biomass gasifier. Journal of Applied Sciences, 10(5):406{412, 2010
¨ J. Jones. Producer gas from biomass. Fuel, 89(5):1181, 2010

¨ A. Milbrandt. Gek wiki/FrontPage, 2010. http://gekgasier.pbworks.com/

¨ D. Peterson and S. Haase. Market assessment of biomass gasication and combustion technology for small- and medium-scale applications. National Renewable Energy Laboratory, Golden, CO, 2009

¨ N. Ravindranath and David Hall. Biomass, energy, and environment. Oxford University Press, USA, 1995

¨ Paul P.J. Sridhar, G and H.S. Mukunda. Biomass derived producer gas as a reciprocating engine fuel{an experimental analysis. Biomass and Bioenergy, 21(2):61{72, 2001

¨ J. Swinnen. Global supply chains, standards and the poor: how the globalization of food systems and standards asects rural development and poverty. CABI, Wallingford, UK and Cambridge, MA, 2007

¨ M. Vosecky, P. Kamenikova, M. Pohorely, S. Skoblja, and M. Puncochar. Novel approach to tar removal from biomass producer gas by means of a nickel-based catalyst. Proceedings of the 20th International Conference on Fluidized Bed Combustion, 2009

Appendix A: Calculations

- Base Assumptions:
  - An electrical demand of 144 kWh/day
  - 0.75 kW produced per 1 kg biomass

144 kWh/day *1 kg/h/0.75 kW = 192 kg/day*2.2lb/kg = 422.2 lb/day

- Corn
  - 3920 lbs of corn stover per acre
  - 100% retrieval
  - 0.845 is a corn stover constant

422.4 lb/day/0.845 = 499.9 lb/day*1 bushel/56lbs*1 acre/ 70 bushels*365 days/year = 46.6 Acres/year

- Sugarcane
  - 4000 lbs of sugarcane residue per acre
  - 100% Retrieval

422.4 lb/day*1 Acre/40000 lbs *365 days/yr = 38.5 acres/year

- Switchgrass
  - 3000 lbs of bailed switch grass per acre
  - 100% Retrieval

422.4 lb/day*1 Acre/3000 lbs *365 days/ye = 51.4 acres/year

Appendix B: EPA P3 Grant Application

Thermodynamic Biomass Gasifier for Electricity Generation in Small to Medium Villages and Towns in Developing Nations

Table of Contents

Abstract
a. Research Category and Funding Opportunity Number - P3 Awards: A National Student Design Competition Focusing on People, Prosperity and the Planet.
Funding Opportunity Number: EPA-G2011-P3-Q1 – Energy
b. Title - Thermodynamic Biomass Gasifier for Electricity Generation in Small to Medium Villages and Towns in Developing Nations
c. Principal Investigator - Paul Goodall, Associate Professor of Integrated Science and Technology at James Madison University (goodalpb@jmu.edu);
d. Student Investigators - A team of 3 student investigators will be created in the spring of 2011.
e. Institution - James Madison University, Harrisonburg, VA
f. Student Represented Departments and Institutions - James Madison University - Department of Integrated Science and Technology; Non-Profit Organization - Least of These International
g. Project Period - The Phase I project will begin on or about August 15, 2011 and end on or about August 14, 2012.
h. Project Amount: $15,000.00
i. Total Project Amount: $15,000.00
j. Project Summary:
Objective - The goal of this project is to complete the design of a thermochemical biomass gasifier to provide electricity for a small to medium sized village in a developing region of the world. With the concept design completed, the first step in this project is to build a prototype using a commercially available kit and operate it to gain experience. This system will be evaluated for efficiency, safety, and environmental impact. The information gained, combined with past case studies, will inform the design of a prototype for third world application which will utilize known local materials and expertise. Design goals include cost effective, safe, and environmentally sound maintenance, repair, and operation in a third world application. By using renewable fuel sources such as wood chips or crop wastes, the system will not only provide electricity from a renewable source, but will also put the developing town or village in a position to grow and develop in a sustainable manner.
Description - This project relates to people by providing those in a developing area the opportunity to have access to electricity. The system will be able to power well pumps, irrigation pumps, as well as light bulbs and other electric devices helping to increase crop production and improving public health through access to clean water. By using a renewable and sustainable source of energy, these developing communities will be in a position to develop in an environmentally friendly manner.
Results – This project will yield a biomass gasifier design appropriate for use in a third world application. Construction, operating, and maintenance guides will also be developed. The system will be evaluated based on cost, ease of operation, safety, and environmental impact.
k. Contribution to Pollution Prevention or Control: This project will contribute to pollution control by replacing fossil fuel electricity generation systems with sustainable and renewable sources. By using renewable sources such as trees and crop wastes, we are providing electricity to developing areas without the use of fossil fuels. This approach not only limits pollution, but also reduces contribution to atmospheric carbon.
l. Supplemental Keywords: alternative energy source, renewable energy, biomass, waste to energy

Research Plan

Proposed Project/Design

The ultimate goal of this project is to provide a complete electricity generation system for developing communities around the world. The biomass gasifier will be built on-site using either prefabricated pieces or recycled parts. The phase I of this project will involve designing a prototype of our electricity generation system and developing operating, maintenance and safety protocols. Once the system is determined to be safe, affordable, efficient, and environmentally sound, phase II of the project will be to find a town or village in a developing area--through help with our supporting NGO, Least of These International--to construct and operate our designed electricity generation system.

By partnering with a developing town or village, we aim to provide an electricity generation system that can be maintained and operated by the local population. Therefore, this system must not be overly technical. It will be imperative that the system have clear and understandable documentation that explains maintenance protocol and operation protocol. It will not be acceptable to design a system that requires us our or supporting NGO to make regular trips to the system to perform maintenance or testing.

This project relates to pollution prevention and control through the replacement of a fossil fuel electricity generation system with our biomass gasifier system. Electricity could be generated for a town in a developing area by simply using a diesel generator. This system would be simpler to use and cost less, but it is neither sustainable nor renewable. Likewise, a diesel generator would be polluting the air. The biomass gasifier system provides a carbon neutral solution and since the gas generated by this system is hydrogen and carbon monoxide, the products are water vapor and carbon dioxide.

The innovative aspects of our proposed project are using biomass gasification as a fuel source for electricity generation. This technology has been around since the early 1900s but, its use as a fuel source for electricity generation is relatively new. The inventive aspects of our proposed project involve modifying a gasoline engine to run on the gas created by the biomass gasifier. This producer gas is made up primarily of hydrogen gas and carbon monoxide. In order for this gas to power an engine, a new carburetor will need to be designed.

The technology behind biomass gasification has been known for over 100 years and its feasibility as a power generation technology is well proven. In fact, this technology was used extensively during World War II in Europe because of petroleum rationing. Instead of using this technology for transportation, it will be used for electricity generation. This all revolves around the same principle of using the gas generated by the gasifier to power an engine that produces shaft work. Instead of using this shaft work to turn wheels, it will be used to turn a generator. There is no technology involved that hasn’t been thoroughly tested; however, the combination of these technologies is the key innovative aspect of this project.

Biomass gasification works by incompletely burning organic material in a depleted oxygen environment. Since there is insufficient oxygen to complete the combustion process, pyrolysis occurs instead. The products of the pyrolysis reaction are hydrogen gas, carbon monoxide, and trace amounts of other gasses. This mixture of gas, primarily hydrogen gas and carbon monoxide, is often referred to as producer gas. This gas is then filtered to remove particulates and tars and is then fed into an engine through a carburetor where it is combusted and useful work is produced by the engine.

Challenge Definition

The design challenge of this project was to create a system that can be constructed out of pre-existing materials and that requires as little maintenance as possible. It would not be feasible to design a system that requires numerous, customized parts. If something were to fail, it could be weeks or even months to replace a custom part. By designing a system that uses pre-existing parts and materials, the system will be easy to maintain, and thus, it will be used. Likewise, this system must not be overly costly. It is just as important to develop a system that is easy to maintain as it is important to develop a system that is relatively low cost. Communities will not be able to afford a system that is too costly. Along the same lines, communities will not be able to maintain a system that is high in cost. However, the most important challenge will be to design a system that is safe. By using pre-existing parts, we will not have the luxury of knowing exactly what the parts have been through or how much wear and tear they have already been subjected to. These are the three challenges that we will address in this project: 1) how do we develop a system that is constructed out of pre-existing parts 2) how do we develop a system that is easy to maintain and 3) how do we develop a system that is safe for use.

The topic of creating producer gas from thermochemical biomass gasification has been around for more than a century. J. Emerson Dowson pioneered some of the founding research on producer gas in the the early twentieth century. In his book Producer Gas published in 1907, Dowson outlines the theory behind creating producer gas as well as the practical means of producing it for use. Also, in Chapter 12 of his book, he outlines the different fuels that can be used to create producer gas, particularly wood and wood-charcoal which is what this project is interested in studying (Dowson, 1907). The use of producer gas in more modern times has diminished with the availability of natural gas. However, not all regions of the world, particularly developing regions, have access to natural gas. These areas rely heavily on biomass fuels like wood and animal feces. A study by Schei, et al., determines if there is an association between the use of open wood fires for cooking and asthmatic symptoms in children. The conclusion of this research is that asthma was more prevalent in children in house with open fires than in children in homes with stoves or chimneys (Schei, 2004). By using producer gas for electricity generation for cooking instead of open wood fires, the presence of asthma in children in these developing areas could be reduced.

Producer gas is not a widely used technology in the developed world, but because of the relative ease and simplicity of the technology, it seems well suited for a developing area. A case study in India by Ravindranath and Hall seeks to find and promote an alternative energy option for developing countries. They discuss the benefits and drawbacks of producer gas as well as discuss the process behind its creation (Ravindranath, 1995). Producer gas also holds a lot of potential due to its ability to use any kind of plant material for its production. Another case study in Ireland found that a variety of different wood and crop products all provided a significant amount of energy through gasification and were applicable as an alternative energy source (Bhaird, 2009).

Producer gas holds a lot of potential for alternative energy in developing nations primarily due to the variety of different materials that can be used in its production. Almost all and any plant materials can be used, anything from crop wastes to freshly cut wood. As various studies, conducted by groups such as the Japan Institute of Energy, have show any sort of plant product that can go through gasification can be used for producer gas generation. Studies have also shown that different plants have different efficiencies and different emissions or size of emissions (Hanaoka, 2004). However, this very wide variety of sources highly encourages the application of producer gas in nations that cannot afford coal or oil or simply do not have the resources to provide power.

Relationship of Challenge to Sustainability

Our project offers some major benefits in many different fields, including the protection of the local environment in the towns and villages where it would be implemented, economic prosperity for the people living in the newly powered communities, and social and standard of living changes that come with the best parts of development. Through the gasifier's nearly carbon neutral production of electricity and the use of local waste from usual agricultural practices, very little damage is dealt to the environment; significantly less than from the use of fossil fuels. With the production of their own electricity for certain projects, money can be taken from current electrical applications and put into a communities own economic development. The gasifier, as a replacement for charcoal heating in some instances, allows for an increase in the health of the locals as there is a lot less smoke forced into their homes and with the amount of money people could make then lives could be changed for the better.

People

The end result of this project, which will be implemented through our sponsor, LOTI, would ideally be projects for small to medium villages or towns most likely in developing nations like Guatemala and Kenya. The gasifier design will be given to locations that have a beginning or building relationship with LOTI along with instruction on how to build, use, and maintain the device. Materials would be paid for by the village itself, but located by the sponsor company to provide the most affordable and safe components for the gasifier. The village and town will then have all the knowledge and ability needed to keep the gasifier running and providing energy to the homes and the entire community. This way not only will the community have the experience of creating and using the gasifier from the beginning from the LOTI representatives they will also have the ability to repair their own source of energy generation should problems arise, increasing their independence.

This increased independence is just one of many of the ways that the people of these regions could improve their lives. There are also some great health benefits these villages stand to gain. When wood is burned, substantial amounts of particulate matter are given off, which in a closed environment, can be bad for health. There is research studying the association between using wood for cooking fuel and asthma in children in these areas of the world. According to research conducted by Schei, "The prevalence of all the symptoms of asthma was higher in children from households that used open fires compared to improved stoves with chimneys" (Schei, 2004). One application the gasifer could be used for is providing energy to ovens and stoves, decreasing the need for wood fires within the homes.

One way in which the whole society could benefit would be an overall increase in their standard of living. In addition to the increased health the target area would also see an increase in the amount of money they have from what they aren't spending on outside energy sources. With this money they could then make purchases that would increase their overall welfare, such as being able to afford good health care, better irrigation systems, and possibly even some luxuries like a community computer. The gasifier, even for the bit of energy that it can produce could go a long way towards providing better lives for the people of these areas.

Prosperity

There are initial costs for the gasifier that, depending on the area, could be very expensive. These costs would come primarily from the materials used. The end result should require relatively inexpensive components from local sources, such as 50 gallon drums, but in order to ensure safety the prices may be somewhat larger for a few different items. The components needed would be the only initial costs, with the most expensive of these being the engine where the gas is used. Implantation would be our sponsor, LOTI, teaching the people how to put all the parts together and how to use the gasifier. In the long term there would much smaller expenses, ideally, associated with maintenance and upkeep of the gasifier over the community's lifetime and, should the need arise, the purchase of more plant products for fuel for the device. In these situations the costs primarily come from buying new parts, or tools used to repair old parts. Overall the only real expenses to the entire community would be in buying parts for the initial construction and repair parts over its lifetime.

This supports economic growth for the target village. With the relatively low costs of installation and upkeep money can be allocated to increasing the components of the village that gasifier would help with, such as heating homes, cooking, lighting, and even agricultural activity. Money that these towns spend on energy, or out of date farm equipment, would be suddenly available for other uses, and ultimately these towns would be able to afford better technology to increase their yield in their individual practices, especially agriculture. With better farming machines the potential for economic growth greatly increases as these societies would have much larger yields, and overtime make more money. The money allocated from energy production and waste removal with the implementation of the gasifier would allow economic growth for the target communities.

Planet

The developing regions where the gasifier is implemented will have a large step up on many of their more developed counterparts in terms of creating a society that is much more sustainable from the start of their energy development. Some of these villages do use wood, and in some occasions fossil fuels to provide some sort of energy to their town, and these fuels release carbon dioxide to the atmosphere. The gasifer, while having some emissions itself, maintains a low rate of the release of any sort of gases, and a switch to using the gasifer could greatly reduce the overall emissions of a community, thereby increasing the atmospheric health of the area. Another huge benefit the gasifer would have for the local environment of these villages would be a solution to waste products. Ideally, the waste products from agricultural practices could be used to power the gasifier, and ultimately certain devices in the village. Pieces of wood too small for lumber, failed crops, and essentially anything organic that wouldn't have a practical use in the village could be used. So that would provide an outlet for the waste products in which they aren't taking up space in the environment or filling up landfills, if any are used, and instead providing a source of energy. The gasifier would reduce a town's emissions, reduce the need to pull an outside source of energy as everything used would simply be a by-product of some other activity, and provide space that would normally be used for waste for wildlife to develop. Since all the aspects of the procedure, from the material used for fuel to outgoing gas are all organic and natural, very little damage would be done to the surrounding environment. The gasifier does produce some emissions, but they are much less harmful to the atmosphere than that comes from coal plants, or any sort of fossil fuel. Because there are no liquids involved there are no impacts it could have on local water sources, under or above ground, other than by products in the rain. The only threat this process could pose to the local wildlife and landscape would be, under very rare and unlikely conditions, catching fire to the nearby plants, which could have some large consequences. However this could only happen under the rarest conditions and almost all of the components of the gasifer that could start a fire would be safely contained within the machine itself.

Results, Evaluation and Demonstration

The ultimate results of phase I will be to develop an effective design for the biomass gasifier which can be used for its intended purpose in developing nations. The first step will be to create a prototype. An operating prototype will be built from a commercially available kit and operated to gain experience. This system will be evaluated for efficiency, safety, and environmental impact. The information gained, combined with past case studies, will inform design of the prototype for third world application which will utilize known local materials and expertise. Cost analysis of the various materials required to create the prototype will be included to make this device more applicable globally. An understanding of the various plant matter and wastes found in different developing nations must also be taken into consideration so that the device itself can be designed to utilize a large variety of size and shape of plant material. Other analyses that will be conducted include safety, construction, maintenance, and environmental impact. Even if the project is inexpensive and the materials are affordable safety and environmental threats to the target communities must be minimal.

Phase II of the project will work with LOTI to construct the final gasifier prototype and install it in a third world village. If successful this design may be used in small towns and villages around the world in developing nations. The anticipated success of the machine can be determined by several factors, such as better technology in these communities, higher standards of living, and an increased communal income from various trades. As these communities use the gasifiers they stand to gain a new level of sustainability for themselves using their waste to safely provide power to their homes. In some situations it would allow for whole new technologies to be introduced, such as a group computer, or even light bulbs. Better farming technology can also be introduced, allowing for increased crop yield and an increase in a regions agricultural and economical prosperity. Water pumps can also be powered to give a village clean water. The energy the gasifier could generate, while only being enough to power a car engine, stands to provide enough energy to regions that have never had their own sources of electricity. Due to it's relatively small size (about the size of an average height man) it would be a very unobtrusive design that by using local parts will fit right into any community. Due to these factors, the size and availability of components, the gasifier can be used almost anywhere as long as a village is willing to make the initial investment and to learn how to construct and maintain the device.

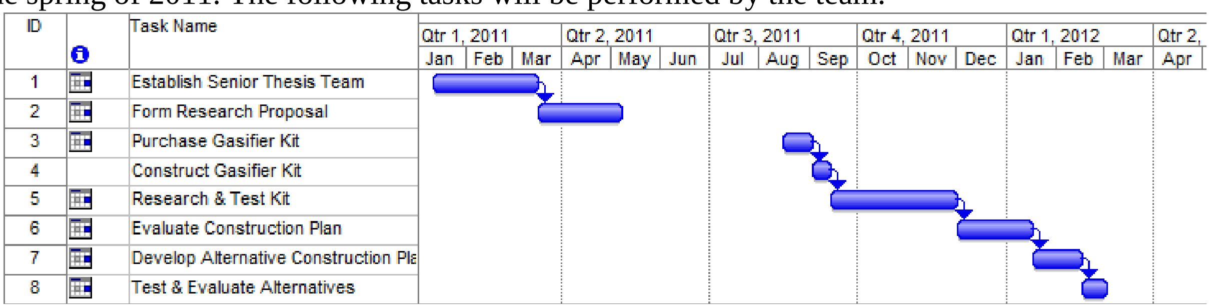
Integration of P3 Concepts as an Educational Tool

This project requires expertise from many different fields and provides an example of how energy, the environment, human health, and quality of life, are all interconnected. Developing countries are seeking to develop in a way that matches the quality of life found in the developed world. However, if they attempt--and succeed--by following the example set by the developed world, they will find themselves developed, but in an unsustainable way. The future of fossil fuels as an energy source is uncertain at best and the more and more countries that develop economies based on fossil fuels, the quicker they are going to be used up. By promoting sustainable development, the world can become a place where a high quality of life is found globally and is certain for the future. If one community can successfully implement a biomass gasifier, other communities will want to follow suit. This viral expansion of technology--one community becoming two, two becoming four, and so on--will soon lead to a sustainably developing country.

More and more technological problems the world faces today are interconnected problems. We cannot simply approach the energy side of an issue and neglect the environmental impacts, social impacts, or economical impacts. A proposed solution may look great in terms of engineering, but socially, it could be detrimental to a culture or society. Without approaching a problem from the perspective that each discipline is strongly related and connected, the risk of providing a less than adequate solution is dramatically raised. This project seeks to examine the problem from every perspective. By taking into account the environmental, social, economic, and energy impacts of this project, the overall goal of providing an effective solution becomes attainable. Having a reliable source of electricity provides a community with energy. This energy can be used for economic gain as well as social gain. Irrigation pumps can be run effectively, boosting crop yields. Lights can be used, allowing people to work later than sundown. Through increased economic gain comes the opportunity for increased welfare and social gain. People now have income with which they can better their lifestyle.

Project Schedule

The project began in spring of 2010. Thomas Pugh and Isaac Hulvey began by performing preliminary research on biomass gasification and the applications of this technology in developing regions of the world. This research will be completed to meet the undergraduate research requirements for a degree in Integrated Science and Technology at James Madison University. This research will be continued by a team of three students that will be determined in the spring of 2011. The following tasks will be performed by the team.



With the gasifier kit purchased and constructed, research and testing on this kit can be performed. This research will enable the team to develop a construction plan to build the gasifier out of materials found in a developing region of the world. With the alternative construction plan completed, the plan can be tested and evaluated.

Partnerships

Least of These International (LOTI) - LOTI's mission is to meet the basic needs of the poor in developing countries through "the use of appropriate and sustainable technologies, partnering with grassroots organizations, and research and development into innovative solutions" (Least of These International, 2008). They effectively work as an engineering consulting firm for local, often indigenous, organizations who need technical expertise to meet a community need. They provided the topic of biomass gasification which is the basis of this project.

James Madison University - This project is being pursued as a capstone design project and thesis for two Integrated Science and Technology students in their final undergraduate year at James Madison University. The team of Isaac Hulvey and Thomas Pugh is being advised by Paul

Goodall, Associate Professor and Director of the Integrated Science and Technology Program. The team of three students to be determined in the spring of 2011 will also pursue the topic of biomass gasification as their senior thesis research project.

References

Dowson, J. E., & Larter, A. T., *Producer gas.* London: Longmans, Green, & Co., 1907.

Schei, M., Hessen, J., Smith, K., Bruce, N., McCracken, J., & Lopez, V., *Childhood asthma and indoor woodsmoke from cooking in Guatemala.* Journal of Exposure Analysis & Environmental Epidemiology, 14S110-S117. doi:10.1038/sj.jea.7500365.

Ravindranath, N., & Hall, David, *Biomass, energy, and environment.* USA: Oxford University Press, USA, 1995.

Bhaird S.M.A., Devlin G., McDonnell K., Owende P., Unger C., Schulzke T., *Quality of producer gas from the gasification of different feedstocks pertinent to the Irish climate*. American Society of Agricultural and Biological Engineers Annual International Meeting 2009, 6, pp. 3796-3811.

Hanaoka, T., Sakanishi, K., Minowa, T., *Hot gas cleaning of producer gas from biomass gasification using carbonaceous materials as a bed additive.* Nihon Enerugi Gakkaishi/Journal of the Japan Institute of Energy, 83 (10), pp. 828-831 2004.

Budget

SECTION B - BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY (1) 8th Annual P3 Awards: A National Student Design Competition for Sustainability Focusing on People, Prosperity and the P1	(2)	(3)	(4)	Total (5)
a. Personnel	$	$	$	$	$
b. Fringe Benefits					
c. Travel	2,726.00				2,726.00
d. Equipment	10,932.00				10,932.00
e. Supplies					
f. Contractual					
g. Construction					
h. Other	41.00				41.00
i. Total Direct Charges (sum of 6a-6h)	13,699.00				$ 13,699.00
j. Indirect Charges	1,301.00				$ 1,301.00
k. TOTALS (sum of 6i and 6j)	$ 15,000.00	$	$	$	$ 15,000.00
7. Program Income	$	$	$	$	$

Authorized for Local Reproduction

Budget Justification

The budget includes funds to purchase a biomass to electricity conversion “GEK Power Pallet 10kw” kit (budget item d. Equipment). The kit will be assembled and tested by Integrated Science and Technology (ISAT) students as part of their Senior Project. Funds are also included for three students and faculty advisor to attend an EPA conference in Washington D.C. as required by the granting agency(budget item c. Travel).

The goal of this project is to complete the prototype design of a thermochemical biomass gasifier which can provide electricity for a small to medium sized village in a developing region of the world. By using fuel sources such as wood chips or crop wastes, the system will provide electricity from a renewable source thereby improving a village’s quality of life in a sustainable manner. The design work for the system has been completed. This project will prototype and test the system to study its environmental impact and assure that it can be constructed, maintained, and safely operated in a third world setting.

The project and grant proposal are being developed by two ISAT students as part of their Senior Project with sponsorship by Least of These International (LOTI). LOTI was created by two ISAT graduates with a mission to meet the basic needs of the poor in developing countries through application of appropriate, sustainable technologies in partnership with grassroots organizations. LOTI has an impressive track record and has sponsored several other ISAT Senior Projects over recent years.

Once funded, project deliverables will be completed by three ISAT Senior Project students during the 2011-2012 academic year. In addition to confirming design for third world application, the completed prototype system has the potential to support ISAT education initiatives in other laboratories and Senior Projects within the Energy and Environment Concentrations.

Resumes

Paul B. Goodall
James Madison University
College of Integrated Science & Technology
Harrisonburg, VA 22807
Phone (540) 568-2711

SUMMARY

Associate Professor and Director Integrated Science and Technology Program
Assistant Department Head – Integrated Science and Technology Department
Director, External Relations- Integrated Science and Technology Program at James Madison University
Developing real world learning experiences to serve as a capstone for student education

Operations Executive - 18 years Merck & Co., Inc.
Established new worldwide site services function generating $30 million savings in first year
Led environmental and safety operations which are recognized among the strongest in the industry
Led worldwide process design for fine chemical manufacture
Extensive manufacturing experience involving Good Manufacturing Practices

JAMES MADISON UNIVERSITY
COLLEGE OF INTEGRATED SCIENCE AND TECHNOLOGY

Associate Professor and Director BSISAT ***2010 - Present***

Serve as Director and teaching faculty for the Integrated Science and Technology undergraduate program. This innovative Bachelor of Science degree program numbers approximately 400 students.

Assistant Department Head ***2008- 2010***
Fulfilled teaching and administrative duties for the Integrated Science and Technology Department including development of new courses in math and energy business/technology, management of personnel development and capital equipment funds, and facilities planning.

Director, External Relations ***1996 - 2007***
Developed liaison with private and government sectors to strengthen the Integrated Science and Technology Program with special emphasis on senior thesis projects within industry, curriculum development, internships and professional opportunities for students. Participating in curriculum development and classroom instruction in areas pertinent to my expertise and industrial experience.

MERCK & CO., INC.

Vice President Worldwide Site Services ***1993 to 1995***
Established new functional responsibility covering over $500 million of site services including maintenance, energy management, facility management, and travel services. Operating responsibility for corporate headquarters at Whitehouse Station, NJ and Brussels office buildings with total budget of $60 million and 300 staff - full time and contract employees.

- Achieved $30 million savings during first year and created a plan to reduce annual expenditures by $100 million over five years (20% reduction from current level).
- Reduced annual office lease expense by $4.2 million (25% reduction) through an integrated space planning program and aggressive lease negotiation. Strategy identified a further $8 million reduction potential.
- Operated one million square feet world headquarters facility with a total of nine Merck employees through innovative outsourcing with eight service firms. Reduced controllable operating budget by 12% while maintaining excellent service levels as measured by a comprehensive customer feedback system.

Vice President Safety and The Environment ***1992 to 1993***
Executive Director Safety and Industrial Hygiene ***1989 to 1992***
Built an integrated safety and environment function which achieved industry leading performance throughout all operating divisions around the globe.

- Led company efforts to reduce emissions of SARA toxic chemicals by 90%, successfully implementing one of the most aggressive reduction programs within the chemical/pharmaceutical industry.
- Achieved safety performance in the top quartile of pharmaceutical companies. Established “best in class” programs for process safety, potent compound handling, biosafety, contractor safety and fleet safety. Implemented coordinated safety program in European Operations. These programs have been enthusiastically received in presentations through American Institute of Chemical Engineers, American Industrial Hygiene Association, Pharmaceutical Safety Group, American Society of Safety Engineers and The Business Roundtable.
- Recognized company through numerous awards including: National Safety Council Award of Merit, British Safety Council Sword of Honor, Chemical Manufacturing Association Lamont DuPont Safety Award, the National Wildlife Federation Award for Environmental Achievement, and the National Environmental Development Association International Environment Achievement Award.

Senior Director Process Engineering ***1988 to 1989***
Led cost effective, worldwide process design for $400 million of new bulk chemical manufacturing capacity.

Manufacturing Manager ***1985 to 1988***
Led manufacturing at the Stonewall, VA plant with $100 million budget and 250 employees. Operations included chemical synthesis, fermentation, natural product isolation, and bulk sterile isolation supporting $3 billion annual human health, animal health and vitamin sales.

EDUCATION

Bachelor of Science in Chemical Engineering: University of Virginia, 1972
Master of Business Administration; College of William and Mary , Williamsburg, VA, 1978.

Thomas Pugh

WORK EXPERIENCE

Madison Union

January 2010 to Present

Operations Assistant

Responsibilities include filing, working with Microsoft Excel, setting up rooms, answering phone calls, working with the scheduling office, working with customers, and answering various questions from students and faculty.

Home Garden and Design

June 2008 to August 2008

Landscaper

Responsibilities included mulching, weeding, pruning, hedge clipping, leaf blowing, planting, and digging irrigation systems.

Main Street Lenders

June 2006 to August 2006

Intern

Worked in an office setting, responsibilities included scanning files, working with small business lending software, helping with office filing, and ensuring all recent sales and past sales were on file and accounted for.

EDUCATION

James Madison University

Integrated Science and Technology Major, Concentrations in Energy and Biotechnology

Religion Minor

Expected Graduation date: May 2011

Stafford Senior High School

Graduated Sum Cum Laude

Key Club President, NHS member, SGA council, Student Mentor, Track & Field, Cross Country, Tennis

CURRENT EXTRACURRICULAR ACTIVITIES

Sigma Phi Epsilon Social Fraternity

Junior Marshall for 2010

Responsibilities include hearing cases of misconduct and standards infractions within the fraternity and making decisions on punishment

Canterbury Episcopal Campus Ministry

Senior Warden for 2010

Responsibilities include calling meetings, leading students, contacting the Diocese, connecting with the community, scheduling with the rest of the vestry, and leading various activites

Study Abroad in Malta

May 12 2010 to June 12 2010

Time spent included working on a project in energy development within the island nation.

Mission Trips to Honduras, Jamaica, West Virginia, Mississippi, and Florida.

Working with people from destitute situations, playing with children and building structures. Working on repairs for various buildings in regions that have suffered damage from disasters

SKILLS

-Basic computer skills -Microsoft Excel skills -Experience with people of different cultures
-Basic garden and landscaping skills (mulching, pruning, digging) -Biotech Lab Skills (PCR, cloning) -Energy lab skills (DMM usage, circuit construction) -Office skills (Filing, answering phone calls) -Various building construction and repair techniques (painting, dry wall, insulation, wood work)

Isaac Tyler Hulvey

242 Cantrell Ave, Harrisonburg, VA 22801 | 540.560.3636 | hulveyit@dukes.jmu.edu

EDUCATION:

James Madison University, Harrisonburg, VA

13. August 2007 to Present
14. Major: Integrated Science and Technology
15. Dual-concentration: Environment & Information/Knowledge Management
16. Minor: Environmental Information Systems
17. Cumulative GPA: 3.692 | In-Major GPA: 3.736
18. CISAT Dean's List - Fall 2007, Spring 2009, Fall 2009, Spring 2010

EXPERIENCE:

Research Intern | June 2010 to July 2010 | Least of These International, Charlottesville, VA

- Researched technologies to meet needs of developing communities

- Wrote briefing reports on various environmental and energy topics
- Provided research support to team in the field

Web Design Contractor | August 2008 to August 2009 | Immerge Technologies, Inc., Harrisonburg, VA
- Worked one-on-one with clients designing website solutions
- Designed sites and tailored applications to meet clients needs
- Performed general website maintenance for clients

Summer Web Design Intern | May 2008 to August 2008 | Immerge Technologies, Inc., Harrisonburg, VA
- Researched content management systems (CMS)
- Developed website solutions for clients
- Performed general website maintenance for clients

Computer Sales Associate | June 2007 to May 2008 | James Madison University Bookstore, Harrisonburg, VA
- Sold computers to incoming freshman
- Worked on sales floor answering questions with customers
- Returned phone calls
- Packed and shipped accessories with FileMaker Pro database

SKILLS/INTERESTS:

Microsoft Office 2003 and 2007
- In-depth knowledge of Word, Excel, PowerPoint, and Access

Website design
- In-depth knowledge of Dreamweaver
- Some experience with ASP.Net and PHP

Graphic Design
- In-depth knowledge of Adobe Photoshop

Computer Programming
- In-depth knowledge of Visual Basic
- Brief experience with Python, C++, and Java

3-D Modeling
- In-depth experience with Google SketchUp

Video Editing
- Some experience with Adobe Premier Pro and Final Cut Pro

Current and Pending Support

OMB Approval No. 2030-0020
Approval Expires 4/30/09

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Dr. Paul B. Goodall

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal: Thermodynamic Biomass Gasifier for Electricity Generation in Small to Medium Villages and Towns in Developing Nations

Source of Support: U.S. Environmental Protection Agency

Total Award Amount: 15,000.00 Total Award Period Covered: 08/15/2011 to 08/14/2011

Location of Project: Harrisonburg, Virginia

Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 0.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal:

Source of Support:

Total Award Amount: Total Award Period Covered: to

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Letter of Support from Least of These International

LOTI

Least of These International
P.O. Box 7966
Charlottesville, VA 22907

ph. 434.295.7881
www.lotint.org

December 21, 2010

Dear Sir or Madam,

LOTI will provide support for the project team “Thermodynamic Biomass Gasifier for Electricity Generation in Small to Medium Villages and Towns in Developing Nations” if funding is awarded the EPA P3 grant. We are a nonprofit organization whose mission is to meet basic needs in small rural communities in developing countries through the use of appropriate and sustainable technologies.

The focus area of the proposal is part of our ongoing efforts to bring sustainable energy access to developing communities. LOTI will provide the logistical support and professional input for the success of this project.

Sincerely,

Justin Henriques
Executive Director, LOTI