IPRO 349: Solid Biofuel from Corn Stover for Cogeneration

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Instructor: Dr. *Donatas Tijunelis*

Serena Chacko
Anna Dlugosk
Joseph Hefferman
Joshua James
Jonathan Mikesell
Terrance Stanfield
Anna Vassi
Ying Bing Yap
Xin Yi Yeap

0.1 Introduction

IPRO 349 of the 2008 Spring Semester is comprised of a diverse group of IIT students hoping to solve one of today’s most pressing global issues. The worldwide energy shortage is a major problem for our generation and will only continue to escalate in scope and consequence in upcoming years. IPRO 349 has taken a great leap forward in proposing and analyzing a possible solution to this problem. Specifically, our solution combines many of the positive aspects of several current alternatives to the fuel crisis while avoiding the negative, and provides for a very exciting path towards sustainability. Our proposed solution would be an environmentally friendly, renewable resource, which does not compete with the global food market or require vast amounts of energy for pre-processing. Thus, we provide the basis for a highly efficient process, which recovers energy that would otherwise be completely untapped and wasted.

0.2 Background

Renewable energy is one of the most important and widely researched topics today. It is classically defined as any form of energy coming from any naturally replenish-able source. This may include everything from solar to wind power, as well as biomass or biofuels. When considering biomass, or any (living or recently-dead) biological material, the chemical energy of the molecules is generally collected through combustion.

The area of liquid fuels from biomass has especially gained much notoriety and support in recent years. This is due to the lower emissions and clean-burning nature of these fuels when compared to more traditional approaches, as well as the obvious renewable nature of the starting material. While vegetable oils or animal fats can be used as a replacement for diesel fuels, corn, switchgrass, or other grains are more widely used to produce ethanol for use in common combustion engines. Today’s E85 fuel is sold to customers with a chemical makeup of 85% ethanol and 15% gasoline.

Often, the country of Brazil is cited as a leader in the switch to an ethanol based fuel economy. Brazil has made tremendous progress in this area, converting 40% of their motor vehicle fleet to run on ethanol. So, why then cannot a country like the United States, with its vast resources and cutting-edge technology, do the same? The answer to this question can be found by delving a little deeper into where this ethanol must come from.

Ethanol is derived from the fermentation of simple sugars. Plants that contain a lot of free sugars are good candidates to produce ethanol. The tropical climates in Brazil render it ideal for the production of sugarcane, a plant that is obviously rich in simple sugars. The ease with which sugarcane can be grown in Brazil allows for the efficient production of ethanol. This is not the case for the US. Here, corn is the cash crop of choice and convenience. While corn is used for the production of ethanol, it is extremely important to note that the only component of corn that contains simple sugars is the kernel itself. Even so, it contains very little sugar when compared to sugarcane, and the rest of the waste (leaves, stalk, etc…collectively known as stover) that is produced from growing one ear of corn ultimately causes the process to be very inefficient.

In fact, some studies suggest that the energy acquired from burning ethanol is up to 67% lower than is contained in the plant from which it is derived. The use of *solid* biomass as a direct supplier of energy, however, is an area still left relatively unexplored in this growing field. In theory, and as preliminary research suggests, harvesting energy directly from solid biomass may be considerably more efficient than gathering it from its processed liquid counterpart.

Additionally, the use of corn kernels for fuels creates another important and immediate issue. By using corn kernels as the basis for fuel production, the process competes with the global food market by diverting corn which would normal be consumed by people (and livestock) into a commodity that would be consumed by engines. This competition will only perpetuate the current problems of energy expense and availability. Instead, a more sustainable solution must be pursued, and that is what IPRO 349 sought to do.

Our solution for long-term energy sustainability avoids many of the problems with current solutions. Specifically, we hope to use corn stover (waste from corn production) as a solid fuel in cogeneration systems. Stover was chosen as the basis for the study because it is a “2nd generation” fuel. This means that it will not compete for resources because it is really a “waste” product. Stover is already produced in vast amount during the harvesting of corn for food, yet it has no use beyond that. With this solution, we avoid the problem of competing with the food market, as well as help rid farms of a waste product.

Unlike corn kernels, however, stover does not contain much free sugars. Instead, it contains much of its energy in the form of cellulose, the chemical backbone of plants that makes them stiff and stand upright. The best way to extract energy from cellulose is simply to burn it directly in its solid form. The use of this stover as a solid fuel for direct burning creates a much more efficient process than in ethanol production. By coupling the burning with a cogeneration system, or the simultaneous recovery of heat and electricity, even more useful energy can be extracted

There are, however, several other factors besides energy projections to consider when looking at the economic and market viability of any approach. For example, one of the main advantages of liquid fuels over solid is the ease of transportation and storage. Additionally, the feasibility of developing a whole new process of biomass collection and processing must be balanced with economic and logistical constraints. These constraints require not only careful analysis of energy and cost balances, but also in-depth examination of all equipment, manpower and environmental limitations. These considerations are the basis of IPRO 349. We have spent the semester considering the viability of corn stover as a solid biofuel in cogeneration, and have concluded that our process may be one possible solution to the word’s energy crisis.

0.3 Purpose

IPRO 349 was established to examine an alternative solution to the current energy crisis. Specifically, we will consider the viability of sold fuel from biomass. We have narrowed the scope of our research to biomass derived from corn stover within the state of Illinois. Illinois was chosen because it is currently the largest producer of corn in the nation. Corn stover was chosen because it is the natural waste product of our current corn industry, but has been shown to have a large yet untapped energy content. With our approach, it may be possible to utilize what would otherwise be considered “waste” to produce useable, renewable energy. For the purposes of this project, cogeneration, or the simultaneous generation of both electricity and useful heat was examined for its high efficiency.

Our specific objectives for the Spring 2008 semester were:

- Examine the logistics for the collection of corn waste stover within the state of Illinois.
- Conceptualize the technology that would be required in the form of a process flow sheet and equipment considerations.
- Deliver a final report that evaluates the overall energy and economic potentials of such an approach.

0.4 Research Methodology

IPRO 349 was established conduct an exploratory, first-past study into the viability of using corn stover as a solid fuel for cogeneration. Our overarching goal was to consolidate and analyze publicly available information to arrive at some sort of conclusion regarding the viability of our topic. Because our project was primarily research based, all members were expected to gain a thorough background and understanding of the topics at hand. Initially, the team was left somewhat unstructured with only research and business subteams. This was done, because the exploratory nature of the project would require delegation and reassignments of tasks as more information became available. A subteam for business purposes was created to manage and delegate paperwork and deliverables, while the research subteam would do the same for all research topics. Members from both teams, however, were expected to participate with tasks for the other teams. In addition, as many members as possible were asked to attend all IPRO workshops and tutorials regardless of what team they were on. This is to ensure that all members gain as much as possible from the IPRO experience across all discipline, not just the one relating to his/her subteam.

In general, subteam members were assigned individual tasks by their team leader throughout the semester and then expected to complete their tasks outside of class time. iGroups was organized so that each member could upload relevant files to their relevant categorical folders. Members were expected to keep updated on the findings of fellow team members via iGroups. Classroom hours were also a time for members to interact and update one another on progress and goals. Class time was spent discussing findings and decisions that may affect the overall project. For example, though a variety of options or paths may exist for one particular aspect of the process design, the team would collectively decide the best and most efficient path to take in the scheme of the overall project. In general, the team leaders would delegate tasks to the members, and individual members would conduct research on his/her topics outside of class. This research was then discussed and analyzed as a group at the next class meeting for decision-making. The ultimate outcome of the project was a comprehensive study of all possible methods of cogeneration from stover, followed by a narrowing of this to the most viable and efficient process. At that point, the proposed process was analyzed in detail for logistical and economic considerations.

In general, research and task delegations were decided based on the interest and background of individual members. In the initial research phase, each team member was assigned one specific role or topic in which they were expected to become an expert (see Table 1). This information could then be utilized by the rest of the team as needed for the overall project. However, as the team moved out of the research phase and into the viability and decision-making phases, several new subteams had to be created based upon the previous research, as expected (see Table 2). Again, members and roles were decided based upon expressed interest and background. Here, it is important to note, that cross communication between teams was considered to be of utmost importance. While the subteams overlapped and individual members worked on several subteams, the reason for creating the subteams was to create a sense of ownership and responsibility for each task. Thus, while an individual or small group of members was ultimately held responsible for completion of his/her/their specific tasks, they were expected and encouraged to acquire help from other members.

0.5 Assignments

Table 1: Team Members and Breakdown of Tasks During Initial Research Phase

Member	Year	Major	Task/Research Topic
Business Team			
Serena Chacko	4th	BME	Team Leader: Direct research and administrative teams to focus ideas in deadlines and products
Terrance Stanfield	4th	CPE	Using Microsoft Project to determine and monitor team timeline for task completion
Ryan Ruidera	3rd	MMAE	Recording of minutes, organization of iGroups for cross communication
Research Team			
Jonathan Mikesell	3rd	ECE	Research Team Leader, Processing
Anna Dlugosk	4th	AE	Filtering
Anna Vassi	3rd	ChE	Emissions Laws and Guidelines
Joseph Hefferman	4th	BME	Transportation
Joshua James	1st	BME	Collection
Ying Bing Yap	3rd	ECE	Turbines/Cogeneration
Xin Yi Yeap	3rd	BIOL	Charcoal

Table 2: Subteams and Members

Research Team	Anna D., Jon, Josh, Joe, Xin Yi, Bing, Anna V.
Business Team	Serena, Ryan, Terrance
Code of Ethics Team	Xin Yi, Bing, Serena, Anna V.
Visuals Team	Anne D., Anna V., Xin Yi, Bing, Joe, Terrance
Report Team	Xin Yi, Jon
Flowchart Team	Ryan, Xin Yi, Bing
Deliverables Team	Serena, Ryan
Presentation Team	Josh, Terrance, Ryan

0.6 Obstacles

While no major obstacles were encountered in completing our proposed objectives, one issue was presented during our efforts to meet a proposed stretch objective. As part of the economic viability component of our project, we hoped to have detailed cost information on the equipment necessary for the process. This includes both start-up and operating costs. However, after email and phone communication, many companies were reluctant to give this information to anyone that is not a serious or potential client. Thus, while much of the information is collected, several components are still needed. We leave this research to the continuing IPRO for further consideration.

Additionally, a code of ethics detailing the major problems we were likely to encounter was written. The code included such topics as adherence to EPA laws and obligations to the global and local communities. Of particular importance and relevance to IPRO 349 was adherence to intellectual property laws and rights. Because one of our overarching themes of our IPRO was the consolidation of publicly available information, a particular effort was made to acknowledge all information sources appropriately. In addition, these references will serve as a good starting point for future IPRO teams to continue our work.

0.7 Results

IPRO 340 began by identifying the problem and constrains of our topic. The scope of the project was narrowed to corn stover within the state of Illinois due to the availability and nature of the material and its abundance within the state. Next, the main backbone of steps needed to take corn stover and turn it into heat and electricity were identified. They are listed as follows:

1.) Growth in Field

2.) Harvesting
3.) Bunching
4.) Transportation
5.) Storage
6.) Processing
7.) Cogeneration

At this point, the research was divided among team members (see Table 2), and the specific logistical and equipment consideration of each step was collected. Then, the scope of the process itself was defined. The team considered two options, small and large scale. The small-scale option entails an individual farmer collecting his own stover and using it in an onsite process to convert energy for his own farm and/or farmhouse. The large-scale entails a large central facility were framers combine their stover in order to supply a large-scale power plant where the energy could be bought and sold. Theoretical numbers (for such parameters as average farm size/production, energy content of stover, etc…) collected during the research phase were analyzed for the theoretical potential of the process on both scales. It was found that the small-scale process would allow an individual farmer to be energetically self-sufficient according to the first-pass analysis. Additionally, the large-scale process was optimized to operate on a county basis. This was decided upon because it allowed for enough energy conversion to power an average sized plant, while still maintaining a reasonable distance for transport of large amounts of stover from local farms.

Next, the options for each of the seven backbone steps were considered for the two options. The best option for each step was chosen, and further analysis was conducted looking at the specific considerations of each step for each scale. With this, IPRO 349 created a detailed, recommended process from start to finish for generating energy from corn stover on both a small and large scale. A more detailed analysis, specifically including losses and efficiencies (loss in energy due to transportation, efficiency of turbines, etc…), was conducted to provide a more real-world potentiality. The energy loses in the real-world analysis was negligible compared to the theoretical analysis, and the processes proved to again be viable on both scales. The details of all gathered information was consolidated and compiled into a technical report, which will serve as the basis for the continuing IPRO. Additionally, the information was conceptualized in a flow chart for presentation to the public on IPRO day.

Additionally, several stretch objectives were perused, reaching various levels of completion. Initially, the development of briquettes similar to charcoal was proposed and researched but eventually rejected due to time and information constraints. Also, a detailed start-up cost analysis was initiated, but has been left to future IPRO teams for reasons mentioned in section 6.0. Finally, all tasks and deliverables for the IPRO office were completed on time, by their respective subteams.

In conclusion, our analysis provides an exciting basis for continued investigation into the use of corn stover for cogeneration. While several areas of research remain to be explored, our first-pass, exploratory analysis indicates the proposed solution to be a viable option on small and large scales. With continued research by future IPRO teams, this approach may be one possible solution to the world’s energy crisis and another exciting step towards sustainability.

0.8 Recommendations

IPRO 349 recommends that this project be continued for further study before implementation. Specifically, we have identified the follow areas where more research is needed.

Future work should further explore the storage step, possibly determining construction and real estate costs but more importantly researching the costs associated with the containers or shelves for bales and briquettes and the lifting machines that carry the material from step to step. In addition, the degradation of stover over time, especially within the storage conditions should be explored. Initial findings suggest that as long as microbial degradation of the stover can be avoided, energy losses over time should be negligible. However, the next IPRO team must optimize the conditions for such an environment.

Not all of the equipment proposed was necessarily optimal, and even in cases where it was, it is not guaranteed to remain so. A future project should re-evaluate the equipment and replace any lacking devices. A factor not considered in our calculations is the explosive hazard presented by the dry powder. Spontaneous or equipment-induced combustion should be a very rare occurrence, but nonetheless a contingency system for this event should be explored.

Based upon our initial research, the specific outcomes for these recommended areas of study will not negate the viability of the solution process. However, more detailed analysis in these areas is needed to refine the process before implementation.

Eventually, after all data collection and processes have been finalized, this IPRO could possible become and ENPRO during the final implementation phases. At this point, the start-up costs for developing the process in industry as well as the market considerations in buying and selling stover must be analyzed.

0.9 References

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0.10 Acknowledgements

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