IPRO 349 Solid Fuel From Biomass For Cogeneration

Final Report
May 11, 2009

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1. Abstract

In the next 30 years, energy production from traditional resources is predicted to decline while the demand for energy is predicted to increase (Matlock, Mark, 2008 NWU Presentation). This predicted gap between the supply and demand of energy will have adverse effects on everything from the health of the economy to the health of everyday people. Furthermore, traditional sources of energy, such as fossil fuels, are a major contributor to global warming.

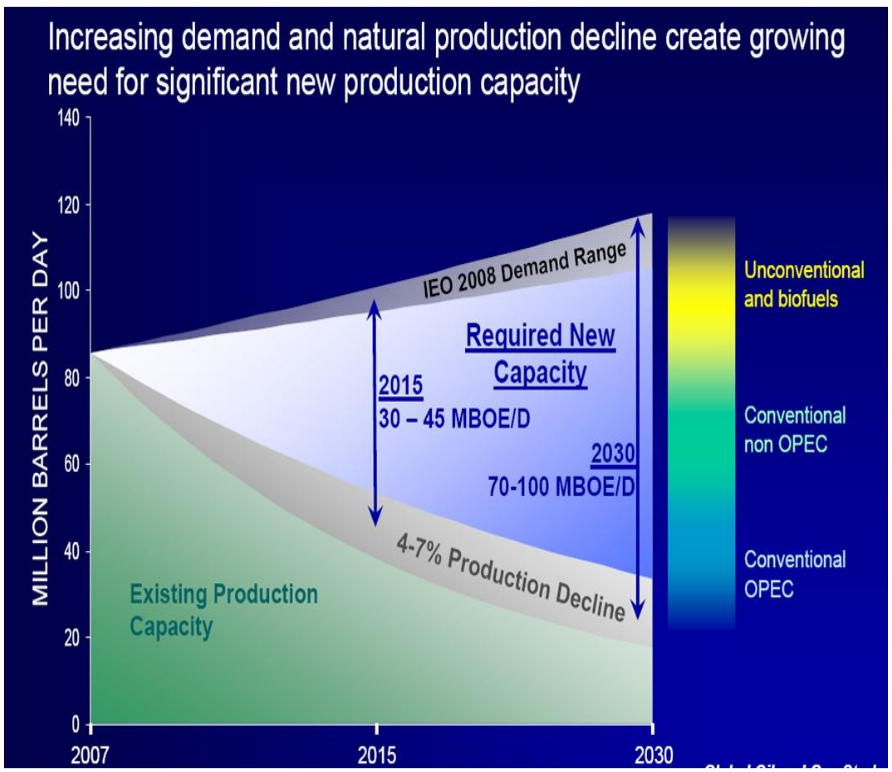


Figure 1: Matlock, Mark, 2008 NWU Presentation

Though research, development, and even implementation of sources of sustainable energy are currently underway, many of these new technologies have fallen under societal criticism. Utilizing energy sources such as wind and solar come with huge initial investments, and using biomass as an energy source has been criticized for hindering food production around the world.

IPRO 349 set out to determine the feasibility of using corn stover as a combined heat and power (CHP) source for rural community colleges. Corn stover is everything but the kernel in an ear of corn, and thus was previously considered waste. By utilizing stover, food production is not hindered, and the renewable resources of a community are taken advantage of. Additionally, because carbon is absorbed out of the atmosphere annually to produce corn, the amount of carbon produced by using corn waste as a source of power is theoretically negated. By using corn stover to power a CHP process in which electricity is produced and the waste heat from electricity generation is used to satisfy the heating demand of a facility, two major energy requirements for a facility are satisfied, and the efficiency of the entire system is dramatically increased.

In order to determine the feasibility of this process, IPRO 349 surveyed farmers and schools that would be involved in such a process, researched equipment and processes necessary to supply corn stover in a useable form, and researched equipment and processes necessary to convert stover into heat and power. From data regarding energy and heating requirements of rural community colleges and willingness/ability of farmers to participate in a CHP process using corn stover, supply and conversion subgroups researched methods and technologies for taking corn stover from farms and turning it into an energy source for rural community colleges.

2. Background

One of the main problems across the globe is the energy crisis. The main factor influencing the energy crisis is the excessive dependence on non-renewable energy sources such as coal, petroleum, nuclear, and natural gas. These sources of energy cannot be renewed and once consumed are lost forever. With increasing population, the energy demands of these sources are also increasing. This is leading to a rapid depletion of these non-renewable energy sources. We are thus facing an energy crisis too large for many to comprehend.

A solution being encouraged by the Intergovernmental Panel on Climate Change (IPCC) and the United States Environmental Protection Agency (EPA) is that we need to implement renewable energy projects and promote sustainability. The United States is finally moving towards sustainability. The various sustainable energy options come from sources like wind, solar, tides, geothermal, biomass, and biofuels. Technologies have been developed to obtain energy from most of these sources. The biomass option, though popular, is still largely unexplored. Some examples of biomass that can be used to generate energy are wheat straw, soybean straw, switch grass, and corn stover.

An additional and no less substantial benefit with the use of corn stover is the ability of photosynthesis to reduce net greenhouse gas emissions. The process of burning corn stover is seen as having a net zero greenhouse gas emission, since the same amount of carbon dioxide is absorbed into the corn plant during photosynthesis as is emitted during the combustion of the stover. If the stover were to be left in the field to decompose, the same amount of greenhouse gases would be emitted as when the stover was combusted. Overall, this maintains balance in the carbon cycle.

IPRO 349 began with the objective of looking into the various biomass options and determine feasibility for the cogeneration of heat and power, or Combined Heat and Power (CHP). IPRO 349 began in the Spring 2008 semester and determined the potential of using corn stover as a biomass fuel source in a CHP application. Spring 2008 also explored the possible mechanism for stover processing and conversion. Using this information, the Fall 2008 team determined the feasibility of a single farm CHP system powered by corn stover. Fall 2008 also created a detailed flow mechanism for stover processing and conversion. Fall '08 recommended that the next team should look into large scale applications using corn stover.

The current Spring 2009 IPRO 349 team focused on determining the feasibility of using corn stover to provide energy and heat in a larger scale application at rural community colleges. Our objective is to scale up from a single farm to multiple farm system. We also surveyed the potential for CHP applications by contacting the community colleges and created an online database for our research. Our survey was then extended to farmers, in order to determine participation, volume, harvest methods, storage, and distance for transportation, processing, and other background information. Some future CHP options for the coming IPRO's were identified.

Our main sponsor was the Kern Family Foundation. In 1998, a portion of the sale of Generac Power Systems went to establish the Kern Family Foundation, which is a private, independent grant-making organization based in Waukesha, WI. In 2006, the Kerns sold the balance of the business and directed a significant portion of the profits to grow the Foundation. The Kern Family Foundation seeks to enrich the lives of others by promoting strong pastoral leadership, educational excellence and high quality, innovative engineering talent, focusing on systemic change. They direct their funding toward broad impact, long-term programs.

3. Objectives

A. Survey the potential for CHP application

  i. Assess the feasibility of creating a process for both pelletizing and CHP conversion for two cases of a small and large community college. This was done by finding necessary equipment and assessing the flow rates and energy required.
  ii. Determine community college interest using a survey adapted from the EPA.
  iii. Determine interest of farmers using a survey.
  iv. Determine the environmental impact using analysis of transportation emissions, process emissions and crop comparison.
  v. Calculate energy balances to determine the efficiency of the process.
  vi. Determine the area required to support a small and large community college using crop yield information and results from farmer survey.
  vii. Determine number of farms needed and assess viability of collection and storage from those farms

B. Scale up from single to multiple farm system

  i. Last IPRO investigated single farm system which was not seen as economically viable at this time. Scale up to a community college being supplied by multiple farms.

C. Identify future stover CHP options

i. Examined different types of equipment, processes, and uses.

D. Investigate creation of an online database of our research

i. Database would provides information for farmers, community colleges or individuals interested in corn stover as a use of CHP.

4. Methodology

At the beginning of the semester, our team consisting of 13 students was divided into two major sub-teams: a research sub-team and an administrative sub-team. Research sub-teams were then separated into survey, supply and conversion sub-teams. There is one leader and four to five members to each of these sub-teams. On the other hand, the administrative team consists of meeting minute takers, iGROUPS maintenance person as well as a code of ethics person. Many resources were made use of to carry out our research on this project. We contacted various companies, we went through many internet articles, we had a phone conference with experienced personnel, and we also visited GTI.

Initially, the survey team had to take on most of the research responsibilities as our team needed to find out the feasibility and power usage of community colleges. Thus, the survey team started off surveying 46 Illinois and Indiana rural community colleges with modified EPA survey. After receiving the responses, follow-ups were done with colleges that replied to our survey in order to find out their power usage as well as heat demand. Later on, the survey team got in touch with a few local farmers to conduct a phone interview on one-to-one basis to find out more about farmers suggestion and opinion on this project. We also tried to find out the farmers' willingness to participate in such project in the near future.

After compiling the information received, the supply team and the conversion team became more active in research. The supply team came up with two models – 0.5MW and 2MW case study utilizing the information from the survey team. Then, both the supply and conversion teams started actively calling and contacting equipment companies. The main source used was the internet database. Equipments were chosen depending on their efficiency and our case studies' scale. The internet was also used to obtain facts and conversions to ensure accurate calculations. Freedom equipment, Somes Nick, CPM, AGICO, Andritz Sprout and Sinotech Industry are some of the companies which we contacted.

Many research articles from the internet were retrieved to aid in our project. Half of the articles utilized were mainly focused on environmental issues from burning corn stover to generate electricity and heat. One of the most used articles we looked at is an AURI report – A Feasibility Study Guide for an Agricultural Biomass Pellet Company. Besides that, we also had a phone conference with Paul DuCharme to find out more about the conversion side of the project (CHP process). Lastly, our team also visited GTI and learned more about gas cycle process in CHP machinery. Information from last semester's IPRO on farm visit was greatly utilized as well.

5. Team Structure and Assignments

Research Team:

Help in collecting important information by using internet, articles, books and contacting the rural community colleges to determine the potential of solid corn stover for the cogeneration of heat and power.

- Team Leader: Tyler Rhodes – The team leader organizes the activities of the research and deliverable teams, conducts some research and makes sure that the team meets the IPRO deadlines.
- Sub-Team Leaders: Richard Bryne, Michael Clark and Elena Dorr – The sub-team leaders make sure that their sub-team members are consistent with their research, apart from researching on their own topics. They also carry out the responsibilities of a team leader if he is unable to make it to a meeting etc.
    - Ross Brazzale – Survey
    - Richard Bryne – Survey
    - James Cheever – Supply and Conversion
    - Michael Clark – Conversion
    - Elena Dorr – Supply
    - Jeremy Gibbs – Supply and Conversion
    - Katherine Lazicki – Supply
    - Abhishek Prabha Kumar – Conversion
    - Bertha Vandegrift – Survey
    - Robert Williams – Survey
    - Terrika Worthon – Supply
    - Xin Yi Yeap – Survey and Supply

<u>Deliverables team:</u>

Assist in getting the standard documents required by the IPRO office in time as well as helping out with other administrative tasks like meeting minutes, code of ethics etc.

Everyone on the team is expected to lend a hand with a few final deliverables such as final presentation, poster, final report, etc.

- Team Leader: Tyler Rhodes – The team leader will oversee the activities of both the deliverables and the research teams besides conducting some research, compiling reports and being aware of IPRO office deadlines.
    - Terrika Worthon – minutes
    - Katherine Lazicki – minutes
    - Ross Brazzale – code of ethics

The initial Gantt Chart was provided as a rough estimate of the time would need to complete our major tasks. As the project evolved more time was a lot to specific tasks. Overall the project did not diverge from the initial project plan except that it was decided shortly before midterm that we would survey farmers for data in order to provide the project with an increased scope and more complete study of feasibility.

	Tasks	Task Lead	Start	End
1	**Survey and preliminary research/calc**		1/29/09	3/12/09
1.1	Survey colleges	Survey Team	2/09/09	2/09/09
1.2	Research large scale process and conversion	Conversion Team	1/29/09	3/12/09
1.3	Research logistics and supply	Supply Tean	1/29/09	3/12/09
2	**Collect data and calculate potential**		3/17/09	04/20/09
2.1	Compile Surveys	Survey Team	3/17/09	3/24/09
2.2	Adjust prelim process calcs to survey data	Conversion Team	3/24/09	4/07/09
2.3	Adjust prelim supply calcs to survey data	Supply Team	3/24/09	4/07/09
2.4	Develop process for connecting logistics and process	Supply/Conversion Team	4/07/09	4/20/09
3	**Administration and deliverables**		1/29/09	5/08/09
3.1	Project Plan	Tyler/Rich/Michael	1/29/09	2/06/09
3.2	Code of Ethics	Ross	2/03/09	2/05/09
3.3	Midterm Presentation		2/26/09	3/12/09
3.4	Midterm Report		1/29/09	3/12/09
3.5	Final Report		4/07/09	5/08/09
3.6	Final Presentation		4/20/09	4/29/09
3.7	Poster/Brochure		4/20/09	4/27/09
3.8	IPRO Deliverables CD		4/29/09	4/30/09
3.9	IPRO Day		5/01/09	5/01/09

Updated tasks which were integrated into our to do list as the project progressed

Task:	Assigned by:	Due:
Read Syllabus & Prepare to brainstorm project goals		01/27/2009
Supply Team develop farms/MW spreadsheet		
Conversion Team - Complete Modeling of Conversion process's	Clark, Michael	03/12/2009
All Subteams - Create Mini-presentation on findings so far		
Supply Team-Initial research on subtopics and ready to present to team	Dorr, Elena	
Supply Team-Combine powerpoints and practice for mini presentation	Dorr, Elena	02/24/2009
Supply Team-Create power points for mini presentation	Dorr, Elena	02/20/2009
Elena-Deciede on bricks vs pellets	Dorr, Elena	02/20/2009
Elena-Create flow chart for pellet/brick conversion	Dorr, Elena	02/20/2009
Supply Team - Jeremy - Round vs. Square Bales	Gibbs, Jeremy	
Supply Team - Jeremy - Best Field Collection	Gibbs, Jeremy	
Katie-slides on rail vs trucks and farmer delivery vs pickup	Lazicki, Katherine	02/20/2009
Supply Team - Wet vs dry		
Katie-flow chart for supply part of process	Lazicki, Katherine	02/22/2009
Refine midterm presenation part	Gibbs, Jeremy	
Compile/edit midterm presentation ppt	Yeap, Xin Yi	03/01/2009
Midterm Presentation		03/03/2009
Survey Team - Follow up on Community Colleges		
Supply - Pictures	Gibbs, Jeremy	
Supply - Energy in/out	Gibbs, Jeremy	
Supply - Recycle	Gibbs, Jeremy	
Supply - Environmental	Yeap, Xin Yi	
Supply - Storage	Gibbs, Jeremy	
Supply - Map	Gibbs, Jeremy	
Supply Team Hysis Drawing	Dorr, Elena	
Energy Pi Chart Analysis	Dorr, Elena	

6. Budget

Expense	Description	Amount
Mailing Material	Envelops and Stamps	$25.00
Team Dinner	Informal team-building activity	$125.00
Transportation	Gasoline for two cars to visit to GTI	$100.00
	Total:	$300.00

7. Code of Ethics

OVERARCHING STANDARD

All members of this IPRO will represent themselves honestly and respectfully to the people they interact with on behalf of this project.

CANONS

The First Layer: Law

Pressures:

Team members are asked to provide a large amount of information ranging many different topics over the course of the semester.

The citations for the researched works are not collected until the end of the semester.

Risks:

Team members may be tempted to not record all of the sources used.

Canon:

Team members shall give recognition to all of the sources referenced.

The Second Layer: Contracts

Pressures:

Team members need specific information about pieces of equipment to analyze the overall energy usage.

Vendors can be secretive about their equipment.

Risks:

Team members might be tempted to misrepresent themselves as potential buyers in order to retain information.

Canon:

Team members not shall misrepresent themselves or lead outside parties to believe that future contracts will be made.

The Third Layer: Professional Code

Pressures:

All of the work done by this project must be completed in just one semester.

Team members are pressed to find data quickly for other team members to use.

Risks:

Team members might be tempted to settle for older research rather than spending more time to determine the newest acceptable technologies.

Canon:

Team members shall use the most current accepted research and data available.

The Fourth Layer: Industry Standards

Pressures:

Team members are encouraged to find new methods for any researched processes.

Risks:

Team members might be pressured into endorsing technology that has not yet been proven to be acceptable or safe.

Team members might be pressurized into endorsing methods that do not follow EPA guidelines.

Canon:

Team members shall follow the EPA guidelines, and present research on methods and equipment that are proven and accepted forms of technology for the processes we are studying.

The Fifth Layer: Community

Pressures:

Team members are expected to have contact with outside sources.

Team members are expected to get results in a short time frame.

Risks:

Team members might be pressured to be hasty in their interaction, without taking into consideration the needs and concerns of the people they are contacting.

Canon:

Team members shall make sure that their interaction with community colleges, farmers, and companies is respectful and honest, and that the way they communicate themselves is directed towards the specific audience.

The Sixth Layer: Personal Relationship

Pressures:

Team members are asked to list the time spent on IPRO work, and expected to put in a certain amount of time per week.

Risks:

Team members might be pressured to lie about their time spent on IPRO work.

Team members might be tempted to take the credit for work accomplished by another member.

Canon:

Team members shall represent themselves and the work they accomplish honestly.

The Seventh Layer: Moral and Spiritual Values

Pressures:

The religious upbringing of each team member varies.

Risks:

Team members might be tempted to judge another member for having a different set of beliefs.

Team members might be tempted to present the information this IPRO provides with a spiritual outlook.

Canon:

Team members shall keep their personal morals and values to themselves, while respecting the morals and values of the other members.

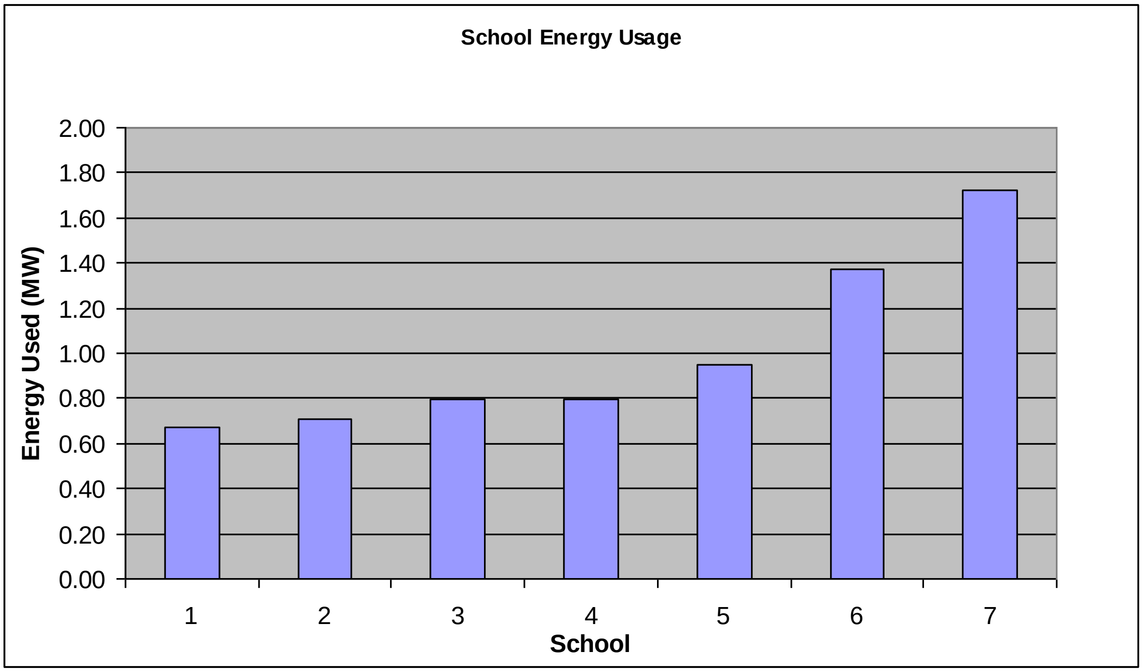
8. Results

Our team set out to develop a model to best show feasibility of implementation of the usage of corn stover, which would be a larger scale from previous teams. In order to do so, the team immediately realized the importance of 1: choosing target recipients (rural community colleges) and 2: contacting these colleges in order to determine supply and demand, which will then be used to determine storage, transporting and processing specifications. In order to accomplish these things, the team was then broken down into three (3) sub-teams: survey, supply, and conversion. Each sub-team began their research with the goal of breaking down/specifying each respective portion of the combined heat and power (CHP) process from harvest to burning of solid corn stover.

The first step in accomplishing our objective to survey the potential for CHP application, which early on the team realized was very key in determining the feasibility of the usage of corn stover, was to determine our target facilities. In doing so we decided to look into community colleges located in rural Illinois and Indiana. In order to determine this information, the survey team first developed a list of target community colleges and also determined the best way and person to contact the community colleges in order to receive appropriate answers. The final list of schools consisted of 46 community colleges located in rural Illinois and Indiana. A modified EPA CHP survey was sent to the 46 schools. The survey is listed in Appendix B.

Of the 46 school contacted, only 13 responded. According to EPA guidelines, facilities that answer yes to three or more of the above questions are good candidates for CHP system. All of the schools that replied answered yes to three or more and therefore, are considered good candidates. All of the schools stated that they were concerned about reducing the current and future energy costs. However, only 20% of the school that replied was planning to develop power facilities within the next five years.

After receiving responses from thirteen schools, a follow-up was conducted to obtain more quantified data. Seven of these thirteen schools were successfully contacted and asked questions regarding the amount of power they bought annually, the annual heating demand of their facility, whether or not they had on-campus residency, the size of their student body, and the acreage of their campus. Each school's annual power usage was converted into annual electricity usage. All of schools' annual electricity usages were plotted in a bar graph, shown below. Additionally, the average, maximum, and minimum electricity usage of all the schools was determined.



From this graph and the average electricity usage of all of the schools successfully contacted, cases of 0.5 MW and 2 MW annual electricity usage were picked as small and large models of annual electricity consumption for a rural Illinois community college. From this information, we found only a loose correlation was established between student body size and electricity usage, and no correlation was established between size of student body and the heating demand of their facility.

After conducting the surveys and obtaining follow up information from the thirteen schools that initially responded, phone interviews were done with thirteen farmers in order to determine if farmers were willing to participate, by providing stover, in implementation of CHP system. By determining the willingness of multiple farmers to participate, we were able to accomplish our objective to scale up from single farm to multiple farm system. The farmers were asked eight specific questions listed below:

- Would you be willing to participate in an agricultural waste for energy project?
- What is the approximate distance from your farm to the nearest community college?
- What is your current acreage of corn grown on your farm?
- For an estimated net profit of between $16.00 and $22.00 per ton, would you be interested in selling your corn stover? (From "Innovative Methods for Corn Stover Collection, Handling, Storage and Transportation, National Renewable Energy Lab (NREL): March, 2003; based on a trucking and handling over a 30-mile radius.)
- Would you be willing to personally harvest your stover?
- Do you own or share a storage facility or facilities for this stover?
- Would you be willing to transport this stover to your local community college or perhaps a local processing facility?

Could you offer us any additional help or advice concerning this project?

Nine of the thirteen farmers contacted were willing to participate given some conditions are met, such as the stover will be sold for a good price, $35-$42. Also five of the farmers are willing to harvest the corn stover if the necessary harvesting equipment is provided. Only one of the thirteen farmers has a storage facility for harvested storage along with some outdoor storage. However, seven farmers were willing to transport the corn stover at a good price. All of the information obtained through both the initial modified EPA- CHP survey, follow-up contact and interview of thirteen farmers was then given and used by both the supply and conversion sub-teams to calculate appropriate values to meet energy requirements of the 2 cases specified, 0.5 MW and 2 MW.

The supply team had begun their research by first determining harvesting options. It was very important to determine whether the corn stover would be harvested wet or dry because this would be used to determine storage options, transportation methods and conversion methods. The advantages and disadvantages were researched in order to arrive at the best harvesting process for implementation of the CHP system. The first harvesting option to be considered was 1 pass harvest (wet). The advantages of this process were that the combine used would control stover and the stover would be clean, which means it would contain less dirt and added particles from the field. However, a disadvantage was that it slows down harvesting time, which would increase the amount of time necessary to harvest the corn stover. Another disadvantage was that no stover would be left on the field to provide nutrients to the soil. Once further investigated it was shown that the corn stover was in fact used to fertilize the soil and complete collection would affect future crops, which puts the farmer at a great disadvantage.

The next harvesting option investigated was the 2 pass harvest (dry), which included the usage of the combine windrow. The advantages of this process were that it is easily implemented, which meant it did not increase harvesting time, and some of the stover is left on the field to provide nutrient to soil once decomposed. The disadvantage of this process is it required longer time for drying of the stover. After careful comparison of both processes, it was determined that 2 pass harvest (dry) would be best. It would allow for a longer storage life with a decreased moisture content of the stover and still benefit farm in that 100% of stover was not collected.

Next it was important, once stover is collected, to specify whether or not to bale corn stover in round bales or squares bales. Once again the advantages and disadvantages for each process were investigated. An advantage of round bales was that it had good water management in that the curvature of the bale along with its mesh wrapping helped to reduce the amount of water absorbed by the bale. Also production of round bales was found to be less expensive than that of square bales. However, a disadvantage of producing round bales was the added labor due to the removal of the mesh wrapping. Square bales had its advantages also, which included their easy transport and also the ability to efficiently stack them, whether for transport or storage. Some disadvantages were that they required more labor with them being more difficult to make, and had poor management, which would cause an increase in moisture content. An increase in moisture content would then cause a decrease in the storage life of the raw store once exposed to the outdoor elements. After investigating both options it was concluded that round bales would be best for process.

Once the corn stover has been baled, it is ready to be transported to the community college. Many different methods of transporting the corn stover have been considered in the literature for similar projects. These options include dirigibles, trains, trucks, tractors, and pipelines. Neither dirigibles nor pipelines are feasible forms of transportation for this project due to the large initial investments they would require. (Atchison, J.E.) Furthermore, pipelines would require a great amount of construction across existing roads. As this IPRO determined that the average distance between the farms and the community colleges is 16 miles, transportation by means of rail also would not be a viable means of transportation. Tom M. Schechinger has also considered trucks versus tractors in his study of corn stover harvest. Although trucks can carry a heavier load than tractors, they also require special equipment for loading and unloading the bales. According to Schechinger's detailed economic study, tractors would be more economic for transporting over a distance of less than 20 miles. Based on the calculated amount of stover needed, and the assumption that JCB tractors travel an average of 6.6 mpg (Ayala), transportation alone uses 970.51 Mwh/yr for the small scale case study, and 221.03 Mwh/yr for the large scale case study.

After the corn stover reaches the community college, it needs to be stored until it can be pelletized. Because round bales have good water shedding capabilities (Rayburn), they can be wrapped in tarp and stored outside. Pyramid stacking was chosen for this project as to reduce the storage space area. However, wet weather can cause more rotting in pyramid stacking than in end-to-end stacking, so it is important that the bales are covered (Blasi).

As mention above, the corn stover will be pelletized. After investigating pelletizing process and creating briquettes, it was concluded that the corn stover is to be pelletized. By pelletizing the corn stover, it will allow for the stover to have a higher density, longer durability, and to be smaller in size. An issue consistently presented with the usage of corn stover was storage of the raw stover and its effects on storage life. This became a major obstacle because if exposed to environmental elements for a long period of time, the stover is at risk of decomposing and being of no use. With this it seemed fit to pelletize the stover. However, pelletizing does not completely eliminate the need to store the raw stover, but it reduces the amount of time and space necessary to store the stover once reduced to pellets. The pelletizing process was then further investigated. An article produce by the Agricultural Utilization Research Institute (AURI Ag Innovations), *A feasibility Study Guide for an Agricultural Biomass pellet Company,* was then used as a vital source in guiding the team through the pelletizing process.

The needed equipment was specified for pelletizing process in the Auri Ag report. The results received from survey sub-team were then used to calculate energy from power usage, required pounds of stover, and acreage requirement for pelletizing plant and storage. For each case the following was determine:

.5 MW Case

- 12 farms with 40% pick up of stover
- 10,400,000 lb of stover/yr
- 4,800 ton pellets/yr

2.0 MW Case

- 51 farms with 40% pick up of stover
- 45,600,000 lb of stover/yr
- 21,100 ton pellets/yr

These figures were then used as specifications in equipment selection for pelletizing process. It was determined the pelletizing plant would require a primary and secondary grinder, a dryer, pellet mill and screener. In order to choose the most fitting equipment for given specifications, many manufactures were contacted including Andritz Sprout, California Pellet Mill, Rotex Pellet and many other manufactures. A major obstacle faced when contacting manufacturers was that many engineers working at the respective companies expressed because this was a school project they had no time to give any necessary answers for the specifications. However, we were fortunate to receive some feedback from companies, such as California Pellet Mill and Rotex.

The pelletizing process would go as follows; the round bale would be go through the primary grinder, CPM 15 x 44 Hammermill, to reduce the size and then dried by the dryer, (Rotary Drum Dryer), which will reduce the moisture content of chunks from 35% to ~ 10-15%. Next the dried stover would go through a secondary grinder, CPM 15x 44 Hammermill, in order to reduce the chunks to actual pellet size. The pellet are then processed in the pellet mill, CPM 1116-4 (.5MW) and CPM 7722-6 (2 MW), which is used to compress the stover into more reliable and denser form. This would allow for easier storage and combustion, which will be necessary in conversion process. The pellet mill is often used in tandem with a conditioner and cooler. Once passed through the cooler and before the pellets can be stored, the fines need to be removed from the feed and recycled back into the system. For this, a single-surface screener is needed. Many manufacturers produce screeners for large scale operations, starting at around 40 ton/hr, and those that do construct smaller scale screeners do not produce screeners that handle a feed rate of less than 5 tons/hr. Because of these limitations, the Rotex model 11A screener was chosen for both small and large case studies.

After the corn stover has been pelletized, the pellets need to be stored for later use. The usage of silos was investigated due to their large volume along with the reduced storage area they would occupy on the campus. For both case studies, the 31X89 Harvestore silo was chosen. This model is 31 ft in diameter, 89 ft tall, and has a capacity of 61,900 cubic ft (Kohlbrecher). For the small scale case study, 5 of these models would be required, while 22 silos would be required for the large scale case study. The pellets are then stored awaiting usage during conversion process.

The last stop in the CHP process is to convert the biomass into heat and power. The two options we looked at for this step were direct combustion in a boiler to produce steam for a steam turbine and gasification to produce syngas for a gas turbine. In the steam process, the pellets are feed into a biomass boiler by a screw and are combusted. The energy released through combustion is used to convert the liquid water, which passes through pipes in the upper part of the boiler, into superheated steam at 300°C and 3600 kPa. The steam moves to a turbine where it is allowed to expand, which drives the blades and produces power. This causes the pressure and temperature to drop to 25 kPa and 60°C. The exhaust from the turbine moves directly into the tube part of a shell and tube condenser which has cold water at 25°C moving countercurrent to the hot stream. Heat from the hot stream is transferred to the cold stream which causes the vapor in the hot stream to condense into liquid with zero temperature change while the cold stream temperature increases to 32°C. The hot stream exits the condenser where it undergoes a pressure increase back to its initial state of 3600 kPa. The cold stream exits the condenser and goes to the school where it can be used in a radiator system for special heating or in a heat exchanger for water heating. The cold stream returns to the plant and enters a closed cooling tower with a volume between 2,200m^3 and 9,400 m^3, which allows the excess heat to be removed from the stream without allowing for any water loss. The cooling tower also acts as the reservoir for the cold water that is pumped into the condenser.

The steam cycle has several advantages. It is a well established process with several equipment manufacturers that can provide equipment for a wide range of power requirements, including our range of 0.5 MW to 2 MW. Also, its' simplicity allows for reliable continuous operation with little monitoring which reduces the number of workers that are needed to run the process. However, a large amount of cooling water is needed which increases the size of the plant. Also, capturing heat from the liquid water stream to heat the school could prove difficult depending on the schools current heating system.

The other process we considered was a gas cycle. The first step in this process is the gasification of the biomass. This can be done with either a fixed or fluidized bed reactor. In the fixed bed case, the reactor is preheated to 540°C before the pellets are feed onto a grate that moves across the bottom of the reactor. Oxygen enters below the grate at atmospheric pressure which allows several reactions to occur with the overall reaction producing heat and a gas, otherwise known as syngas, which consists mostly of carbon monoxide and hydrogen.

$$CO2 + C \longleftrightarrow 2CO - 172.6 \text{ kJ/mol}$$

$$C + H20 \longleftrightarrow CO + H2 - 131.4 \text{kJ/mol}$$

$$CO2 + H2 \longleftrightarrow CO + H2O + 41.2 \text{ kJ/mol}$$

$$C + O2 \longleftrightarrow H20 + 406 \text{ kJ/mol}$$

$$H2 + 0.502 \longleftrightarrow H20 + 424 \text{ kJ/mol}$$

Reaction A:

$$CO2+3C+H2 \longleftrightarrow 4CO+H20+713.4 \text{ kJ/mol}$$

Note: Reaction A favors the left hand side at higher temperatures

The other reactor option is a fluidized bed. In this reactor there is a bed of silica sand that is "fluidized" by steam which means that the bed acts like a fluid. The pellets are fed into the middle of the bed by a screw and undergo the same reactions as the fixed bed to produce syngas. Ash from both reactors is collected at the bottom and can be sold as fertilizer. The syngas from both reactors contains small amounts of ash and tar that need to be removed before it can be used in the gas turbine. The larger particles are removed by two cyclones in series that spin the gas around and force the solid particles out the bottom while the gas stream exits the top. Next, the gas is cooled and passed through a filter to remove any hot tar. The clean gas enters the turbine where it is compressed and mixed with oxygen before it is combusted to produce a high pressure and velocity gas that expands across the turbine blades to produce power. The exhaust from the turbine is a high temperature gas that moves directly into a heat recovery steam generator (HRSG) which acts like a boiler to produce steam. Depending on the cold water feed rate into the HRSG, two different qualities of steam can be produced. A lower flow rate and high pressure stream will produce superheat steam that can be used in a steam cycle to produce more power. A higher flow rate and medium pressure stream will produce low quality steam that can be used from heating.

The flow rate of syngas to the gas turbine depends on the heating value of the syngas which depends on the amount of carbon monoxide and hydrogen in the gas. The average heating value for the syngas produced by the two reactors was found to be 1500 BTU/lb and 5,700 BTU/lb respectively which converts into a feed rate of pellets into the reactors of 1,360 lb/hr and 860 lb/hr respectively for the 0.5 MW case. Knowing this, we dropped the fixed bed option because it is less efficient then the steam cycle.

When compared to the steam cycle the gas cycle has several advantages. It requires less stover per year to produce the same amount of power which lowers the operating cost and it has the ability to run in combination with steam turbine to produce even more power. However, the gas turbine needed for the process is different from conventional turbines and is still being developed. Currently there are no commercial available units for the scale we are looking at.

Based on the steam cycle the total amount of energy consumed and produced for the 0.5 MW and 2MW case is 10.9x106 kWh/yr and 37.5 kWh/hr respectively. Of this energy only 3% is used for the transportation of the stover to the schools. The pelletizing process consumes 25% and 11% of the energy giving the process an efficiency of 73% and 86%. This shows that an increase in power production leads to an increase in efficiency. It should be noted we used electricity from the power company to run the pelletizing process in order to simplify the power requirement. Increasing the power requirement to meet the pelletizing needs causes an increase in the power requirement for the pelletizing process which again increases the total power requirement. This would have made it difficult to determine a set range of power requirements.

From an environmental stand point using stover for CHP is very clean with no carbon footprint. If the stover were left in the field it would decay and produce carbon dioxide. This would be equivalent to the carbon dioxide produced by the process. Also, the carbon in biomass in already in the carbon cycle, which means that the carbon dioxide produced by the process is consumed by the very plants that is used in the process, unlike coal which is a carbon reservoir outside the carbon cycle. In addition, corn stover contains very low amounts of sulfur and nitrogen, which are the other main pollutants in current coal power plants.

9. Obstacles

Far and away the largest obstacle this semester was gathering useful information from sources outside of our group. Manufacturers, farmers, and rural community college were all contacted throughout the semester with varying degrees of success. The manufacturers and community colleges often gave little information and would often take a long time to reply to e-mail or voicemail. This time delay was detrimental to the progress of our project.

Another large obstacle this semester was taking the data that was received from the community colleges and manufacturers and finding ways to effectively use this information in our project. The data received from a number of community colleges was given in units which then had to be converted to kW in order to determine the capacity of the power cycle. Furthermore, numerous reasonable estimations had to be made throughout the semester to allow the calculation of the amount of corn stover needed, and the area around the community college that would be required to harvest said amount of stover. In addition, calculating the proper feed rates and heat rates for each specific unit in the process was very time-consuming and tedious. Each unit has its own range of operating conditions that must be met to ensure efficiency as well as safety.

Lastly, the determination of the exact scale of the process was very difficult. There were myriad variables that had to be accounted for and several unexpected twists over the semester. Originally the scale-up was decided to be a 3MW and a 15MW power cycle that would power the colleges. Unfortunately, some more data was received and it was determined that the scale up should only be between 0.5MW and 2MW. This massive change in scale near the end of the semester was very difficult to recalculate.

This change of scale also rendered one of the options for producing the power to be ineffective since there is no commercially available gasifiers for scales of that size.

The aforementioned obstacles were overcome through lots of teamwork, communication, and consistent effort from everyone on the team. Most of the obstacles were not avoidable per se, but things could have been done to make them less difficult to handle when they arose. As always, a little more in team communication would have been helpful in determining problems before they arose.

Looking ahead towards the next team and their potential efforts, the biggest problems they will face will be once again dealing with manufacturers, businessmen, and others outside of the IPRO. Also a large challenge ahead for the next team is a full economic analysis.

In conclusion, this semester brought many challenges that were hard to deal with. These challenges were overcome through communication and hard work of all involved.

10. Recommendations

The Spring 2009 IPRO 349 team succeeded in determining the feasibility of using corn stover as a combined heat and power source for rural community colleges. However, many more opportunities for research exist within the same field. We would recommend that future IPROs investigate a specific case study of a community college, the feasibility of a modular stover CHP system, international humanitarian applications, and/or a more user friendly equipment database.

Throughout the Spring 2009 IPRO, we were able to analyze the general application possibilities of a corn stover CHP system on any number of community colleges. Due to the broad scope of the schools, we developed a very wide-ranging set of equipment, costs, etc. Thus, for the Fall 2009 IPRO, we recommend that a more specific case study is investigated. This may involve selecting one or two explicit community colleges and analyzing precise geographical concerns, heat and power demands, infrastructure requirements, and any other limiting factors of installing and operating a CHP system. With specific colleges being targeted, an exact cost effectiveness/payback analysis could be completed to further determine the feasibility of such a system. Based on the Spring 2009 IPRO's investigation of the technical feasibility of a corn stover CHP system, we suggest that the Fall 2009 IPRO further investigates the economic feasibility of such a system.

Another alternative for next semester's IPRO to look into is the option of creating a modular CHP system that could be used in a variety of applications. A modular system may involve having a solitary, easily transported unit that colleges/businesses could easily adapt to their current heat and power network. This would involve combining the findings from Spring 2009 and Fall 2008 teams to create a single packaged unit that the consumer would be able to purchase rather than having to individually select the dozens of pieces required to construct a modern CHP system. Possibilities for this modular setup include utilizing a Stirling engine as a power source and/or a shipping container as a chassis.

While all IPRO 349 teams to date have investigated commercial, domestic systems, a potential area of research for future IPRO teams is to pursue international humanitarian applications. If a modular system is developed, the potential for a compact, versatile system design is great. A single portable CHP system would have the potential to deliver much needed heat and electricity to impoverished neighborhoods and communities all around the globe. Most areas where these applications would be appropriate, however, do not have large quantities of corn being grown in a nearby location. To generate an accurate model for these humanitarian efforts would require the investigation of energy efficient farming, biodiversity, and other geographical limitations present in most parts of the world.

The Fall 2008 IPRO team and the Spring 2009 IPRO both developed relatively crude databases to give easy access to equipment, information about CHP, FAQs, etc. We would suggest that the next IPRO team refine our present database into a more user-friendly program. Eventually, our team would like to see an easy to use, interactive website where farmers, colleges, entrepreneurs, and the general public could go to learn more about the possibilities of corn stover as an energy source and how they can implement the technology into their lives.

IPRO 349 has accomplished a great deal during the first three semesters of its existence. We would like to encourage future teams to work hard to represent our IPRO, IIT, and Illinois as socially conscious participants in the search for environmentally friendly, sustainable energy.

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Customer Support Center.
Phone: +49 180 / 524 70 00
Fax: +49 180 / 524 24 71

12. Resources

For this IPRO, $20 was spent on stamps and envelopes for mailing the surveys to the community colleges. These surveys gave us information about the feasibility of using CHP at rural community colleges. Though our data was based only on the percentage of schools that replied, these results were much better than our unfounded estimations could have been.

We also spent $125 on a pizza party as an informal team building activity. Most of our meetings involved a quick discussion of what was accomplished and what needed to be accomplished, followed by a long review of the current main issue. Though the subteams had a few minutes for discussion, there usually was not enough time for the subteams to interact with each other. During this informal meeting, we were able to spend the entire time discussing what we required from other team members and subgroups in order to finish our respective parts.

Finally, we spent ___ on gas to visit GTI. Since the team members all had different aspects of the project to study, not everyone was familiar with the conversion process. By doing this tour, team members from the survey and supply team were able to learn about the gasification process.

Our team spent over 400 hours on this project. Most of this time was spent in subteam meetings, calling contacts at community colleges, calling vendors, and working on the deliverables. The subteam meetings allowed the teams to compile the information they had collected individually, which allowed further progress in the project to be made. Contacting rural community colleges and vendors gave us reliable information concerning the energy needs of the schools and equipment, so we could calculate the energy usage of the models accurately. Finally, the deliverables are essential in conveying the work we have accomplished this semester.

13. Acknowledgements

Our team has received much help and guidance in order to reach the completion of this project. We would like to thank our professor, Don Tijunelis, for his suggestions of topics to focus on and research further. We also thank Ray DeBoth for his insight on Stirling engines. Finally, we would like to thank Jennifer Keplinger for her assistance with the IPRO experience.

14. Appendix A: Contact List

Legend:
Company Name (# Replies/Correspondence)
Contact
Contact Info
Emails sent
Emails received

Primenergy (6)
Sean O'Grady
Associate Project Engineer
Phone (918) 835-1011
Fax (918) 835-1058

To: Sean O'Grady

Subject: Corn Stover Gasification questions

As I said on the phone I'm a student at Illinois Institute of Technology who is doing research into the gasification of corn stover. Below is a list of question I have, but any additional information regarding the process will be appreciated.

1. How much syngas is produced per kg of biomass?
2. What is the average composition of the syngas?
3. What is the required range for the inlet air temperature?

Our system uses ambient air. If waste heat was available it might be feasible to preheat the combustion air.

4. How much biomass per time can the gasifier handle?
5. What is temperature of the syngas leaving the reactor.
6. What is done in the gas clean-up process?
7. Can the ash be sold?

The ash contains the inorganics from the original fuel lots of K, some P, some Si, and some fixed carbon. It is usually good for land application as fertilizer. It is unlikely that it would be a significant source of income.

8. What is the heating value of the syngas?

Thank you for your help,
Michael Clark
612-718-4387
mclark14@iit.edu

1. How much syngas is produced per kg of biomass?

This depends on many factors (composition of biomass, moisture content, operating temperatures, etc.). The best place to start is with the biomass fuel. Dry corn stover, in our experience, has a higher heating value of 8010 Btu / lb and a lower heating value of 7497 Btu / lb. However, when processed it still has 15% moisture content. This brings the available energy to 6492 Btu / lb. When this material is fed into the gasifier at 1600 deg F and combined with enough air to maintain steady state temperature operation (for these conditions it is approximately 40% of air required for complete stoich combustion of the solid fuel), about 44.7 scf of syngas / lb of corn stover will be produced. The gas will be approximately 1500 btu / lb or 96.3 btu / scf. Keep in mind that it is at 1600 deg F so there is a lot of sensible heat. I will let you take care of the unit conversions.

2. What is the average composition of the syngas?

Syngas composition depends on fuel composition, moisture content, operating temperatures, etc. For corn stover and the conditions described above it might look like:

Formula	vol%
C	0.275%
CO	15.717%
CO2	11.314%
H2	16.809%
H2O (v)	10.832%
N2	44.940%
H2S	0.012%
HCl	0.006%
SiO2	0.095%

The high percentage of nitrogen is the result of using air as our oxygen source. This gas stream is estimated based on equilibrium calculations. Therefore, there are some unaccounted for volatile organic compounds formed.

3. What is the required range for the inlet air temperature?
Our system uses ambient air. If waste heat was available it might be feasible to preheat the combustion air.
4. How much biomass per time can the gasifier handle?
Our smallest system will handle about a ton / hr. Our largest can handle about 12 ton / hr. We can run our large systems in parallel so really it is only limited by fuel availability.
5. What is temperature of the syngas leaving the reactor.
1400-1800 deg F.
6. What is done in the gas clean-up process?
Normally we us a hot cyclone to remove particulate. The best configuration is to use the syngas immediately by firing a HRSG. We have developed some proprietary equipment that can remove the particulate and condensed organics and make the syngas suitable for use in an IC engine. This is not really feasible without some further study because the gas must be cooled to approx 100 deg F - This causes organics and water to condense making for a nasty blowdown (disposal problems). Also, when you cool the gas you waste a lot of energy in the form of sensible heat. If you fire the syngas directly (actually combustion is staged for NOx control) into a boiler the organics are destroyed and you recover most of the sensible heat. The efficiency can be 85 to 90%. The steam can be used for industrial processes, or it can be used to drive a turbine generator.
7. Can the ash be sold?
The ash contains the inorganics from the original fuel lots of K, some P, some Si, and some fixed carbon. It is usually good for land application as fertilizer. It is unlikely that it would be a significant source of income.
8. What is the heating value of the syngas?
The gas will be approximately 1500 btu / lb or 96.3 btu / scf, but keep in mind that it cannot be piped or stored because of the issues I described above. I guess I should rephrase that, it is perfectly possible to pipe it, store it, etc., however it is not very efficient, and in the current market conditions it is not economically feasible to do so.

-Sean O' Grady

Michael,

The particulate would certainly need to be removed before use in a turbine. Special design considerations would have to made for the turbine to operate on such a low heating value gas. I am not sure if this has been done. You would have to cool the gas before it could be cleaned and compressed, wasting sensible heat and producing a poisonous blowdown. By the time you finally compress it / fire it in a turbine, you have probably used more energy than was available in the fuel to begin with. There would be no net energy.

On the other hand if you fire it directly into a boiler, you can use the steam in a steam turbine with a much better result maybe 25-30% efficiency.

I am not sure if there are any commercially available fluidized bed biomass gasifiers. The do it with coal.

Sean

Michael,

Gasifier temperature is controlled automatically by an adjustable damper on the inlet of the gasifier air fan. On initial start up, a small natural gas burner (maybe 10 MMBTU release) is used to preheat the gasifier to 1000 deg F. Fuel and air are then introduced to the gasifier. It lights off, and the temperature climbs based on the gasifier air fan damper position.

Our smallest gasifier is approximately 8 ft in diameter, and it can handle about a ton / hr depending on the fuel. Our largest gasifier is 24 ft in diameter, and it can handle about 12 ton / hr depending on the fuel.

I can't really give you realistic prices because each unit is custom. Different fuels have different equipment requirements. Emissions requirements vary based on location. Also, each contract is custom. Our scope of supply changes with every project. A 10-12 MWe power production plant with our largest gasifier, not including site prep, foundations, and buildings is approximately $30 million USD +/- 20%.

Sean

Michael,

The syngas out of the gasifier is 0.02 lb / cu. ft. As I stated before, cooling the gas is not a realistic option. If you were to cool it to 100 deg F the density would be approximately 0.06 lb / cu. ft.

Sean

Michael,

That is correct; the reaction is self sustaining. Some of the fuel is oxidized to maintain the temperature setpoint. Because the gasifier is operated under reducing conditions, the rest of the fuel is converted to syngas. The high temperature causes the cellulose molecules in the fuel to disassociate to carbon monoxide and hydrogen (obviously some others, these represent the combustible majority). The CO_2 and H_2O in the syngas is the result of the partial oxidation of fuel to maintain temperature.

Sean

GE (4)

Mike Thuillez
Commercial Director - Americas
T +1 713 803 0468
F +1 713 803 0585
C +1 281 660 3378
mike.thuillez@ge.com

Subject: Re: RE: Gas Turbine Questions

I have two syngas compositions that I need flow rates for.

Formula	mol%
C	0.275%
CO	15.717%
CO2	11.314%
H2	16.809%
H2O (v)	10.832%
N2	44.940%
H2S	0.012%
HCl	0.006%
SiO2	0.095%

And

Formula	mol%
H2	24.86
CO	22.86
CO2	21.95
CH4	14.15
N2	7.48
C2H4	3.93

small percentage of other hydrocarbons

Michael Clark

Mike,

Checking to see what we can do to get a performance run. Normally have to have a project to get engineering resources and response typically takes 3-4 weeks for special fuels. The person I need to talk to is out

this week, but should be able to advise next if we can come up with an
response.

Regards,

Mike Thuillez

Michael,

1) Unfortunately, without specific fuel gas analysis I would not be > ableto calculate this value.

2) As I mentioned on the phone, the typical exhaust pressure for any gas turbine ranges from 4 to 10 inches of water depending on if there is a HRSG and/or SCR on the back end.

Regards,

Mike Thuillez

Mike,

Sorry for the delay, been traveling.

Budget price for a GE Frame 5 gas turbine generator package is $12.0 Million. Rough dimensions for the gas turbine generator skid not considering the inlet air filter is 20 Meters x 3.5 Meters x 3.5 Meters (LxWxH).

Regards,

Mike Thuillez

Bliss Industries (2)
Guy Arkin
Midwest Distributor
Cell # 630 936 9475

Subject: Questions from Jeremy Gibbs (IIT Research Team)

Illinois Institute of Technology
IPRO 349 - Solid Corn Waste Fuel for Cogeneration

Hello, my name is Jeremy Gibbs and I'm part of a University Research team investigating the possibility of using Corn Stover as an alternative energy source. I was wondering if you'd be willing to give me some details on your pelletizing equipment. We're looking at two flow rates, a 1 ton/hr machine and a 5 ton/ hr machine. Would you be able to give me estimates on price and energy needed (HP, kW, etc) for these two options? If you have the model numbers handy, those would be helpful as well.

Thanks,
Jeremy Gibbs

Subject: Bliss pelletting equipment

Hi Jeremy,
Please send me all of your contact information and I will send you all the information you need.
Regards,
Guy Arkin

AGICO (2)

Evan Wang
Project manager
E-Mail: mach@e-century.com.cn wong@agico.com.cn
M S N: aywangjf@hotmail.com
Skype: aywangjf
Tel:+86-0372-5965148 Fax: +86-0372-5951936

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Thanks,
Jeremy Gibbs

Subject: wood pellet mill

Dear Mr Jeremy Gibbs,
Thanks for your enquiry.
We have whole series biomass pellet mill that produce pellets from wood sawdust and agri wastes.To make pellets from corn waste we have enough experiences here.But the maximum output of single pellet mill is 2 ton/hour.Please read the enclosed offer.Any question please feel free to let me know.
Look forward to hearing from you soon.
Best regards,

Evan Wang

Freedom Equipment (2)
Robert Hubener
Sales Manager
815 226-9150 Main
815-505-4045 Cell
866-266-1010 Fax
robert@freedomequipment.com

Subject: Questions from Jeremy Gibbs (IIT Research Team)

Illinois Institute of Technology

IPRO 349 - Solid Corn Waste Fuel for Cogeneration

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Thanks,
Jeremy Gibbs

Subject: Re: Questions from Jeremy Gibbs (IIT Research Team)

Jeremy I would recommend a conference�call on Friday to answer all of�your questions is that a good time�for you.

Please let me know.

�Best Regards,

Robert Hubener - Sales Manager

CPM (4)
Eric McKay
CPM Applications Engineer
1-800-428-0846 Ext. 3001
mckaye@cpmroskamp.com

Subject: Questions from Jeremy Gibbs (IIT Research Team)

Eric,
I spoke with you on the phone a couple times last week about getting some rough approximations on your equipment. Here's the information about the research team I'm working with if you need to account for your time:

Illinois Institute of Technology
IPRO 349 - Solid Corn Waste Fuel for Cogeneration
(basically it's a school-organized research class about using corn stover to burn for electricity)

I tabulated some questions from my team members. The list is pretty comprehensive (aka: might take a while, I'm not sure). If it looks too long, feel free not to answer all the questions. I'm not sure if it's as easy as reading things off a chart or if you need to dig through dozens of books for each statistic. Like I said earlier, answer these at your leisure. We'd like to have most of our research done by sometime next week, but if you're too busy, take your time.

If all else fails, could you maybe send me some generic spec sheets for each group of equipment (assuming it's not confidential information or anything)? Actually, if you're just going to be reading off the spec sheets, you could just skip answering the questions and send me the sheets directly if that's easier for you.

We're looking for power requirements, cost estimates, and rough approximates of physical size for grinders (do we need a primary and secondary?), screeners, roatary drum dryers, pelletizers, and coolers all in two size ranges (5 tons/hr and 30 tons/hr). I made a handy dandy list below if it helps:

5 tons/hr
Grinder power:
Grinder cost:

Grinder size:
Screener power:
Screener cost:
Screener size:
Dryer power:
Dryer cost:
Dryer size:
Pelletizer power:
Pelletizer cost:
Pelletizer size:
Cooler power:
Cooler cost:
Cooler size:

30 tons/hr
Grinder power:
Grinder cost:
Grinder size:
Screener power:
Screener cost:
Screener size:
Dryer power:
Dryer cost:
Dryer size:
Pelletizer power:
Pelletizer cost:
Pelletizer size:
Cooler power:
Cooler cost:
Cooler size:

Eric,
I made a mistake in the calculations on my other email. I originally said that our 2 flowrates would be 5 and 30 tons per hour. Those numbers are now 5 and 1 tons per hour. Please adjust accordingly. If you don't think you'll be able to get back to me, please let me know so that I can look elsewhere for the data.

Thanks again for your help!

-Jeremy

Subject: Re: Questions from Jeremy Gibbs (IIT Research Team)

Wow Eric,Thanks so much!! Your information is greatly appreciated! We'll be sure to put in a good word for CPM during our presentation!

-Jeremy

Subject: RE: Questions from Jeremy Gibbs (IIT Research Team)

Jeremy,

Here this the budge quotation that you have requested from CPM regarding a 1 and 5 tph system to hammermill and pellet corn stover. CPM recommends that the material be dried down to 10% moisture as we would like to add liquid to the corn stover before pelleting in the form of steam or water (steam preferred). Also the percent of cobs in the stover can cause problems so if you plan on a high percentage of of cobs with your stover then production may be slower. This budget quotation is for budget purposes only, and is in no way a formal quotation fro CPM. Only a formal quotation from CPM can be used for final sale of CPM equipment.

This budget quote does not include bins, conveyors, dryers, or any other equipment that could be used in this application as CPM does not manufacture this equipment.

If you need more information please e-mail back, and I will get the information to you ASAP. Sorry for the delay as we have been very busy, and have had computer issues.

Hammermill budget quote for 1 and 5 tph of corn stover
(this hammermill will work for 1 and 5 tph)

1 - 15 x 44 Champion hammermill with 125 hp motor 1800 rpm tefc
$42,000 (#10 screen - 5/32 and need 2,250 cfm)

1 - Hammermill feeder screw (VF-drive) $11,000

1 - Air separator with magnet $5,200 (this hammermill does not include the price for the air assist)

Pellet mill budget quote for 1 tph

1 - 1116-4 pellet mill with 50 hp 1800 rpm motor $112,000

1 - 18INF6.5 conditioner with F9INF feeder and remote steam harness with water addition $56,000

1 - 14 x 14 counterflow cooler with air and dust system $60,000

Pellet mill budget quote for 5 tph

1 - 7722-6 pellet mill with 250 hp 1800 rpm motor $240,000

1 - 18INF6.5 conditioner with F9INF feeder and remote steam harness with water addition $56,000

1 - 14 x 19 counterflow cooler with air and dust system $70,000

Thank you,

Eric McKay
CPM Applications Engineer

Somes-Nick & Co. (3)
Tom Nick
Phone: 312-427-5892
Fax: 312-427-0631
somesnick@ameritech.net
Subject: Tim- Pump and Condenser Values UPDATED

Tom and Greg,

Thank you very much for your help with this. Even hypothetical/estimated/rough numbers for cost (needed for total breakdown of costs for the entire system), dimensions (needed for our theoretical layout), and power requirements (this is a project geared towards total energy efficiency, from the energy used by the trucks to ship to the stover to the actual energy created by the system) would help immensely.

New numbers from HySys model:

Condenser:
T(in)=602.9 deg C
P(in)=2.413 bar

T(out)=126.2 deg C
P(out)=2.413 bar

Pump
T(in)=126.2 deg C
P(in)=2.413 bar

T(out)= 128.2 deg C
P(out)= 129 bar

Again, thank you VERY much for your help! If you need anything else, please feel free to call me at (708) 606-8121. We're looking to have all of our information gathered by the 20th of April.

-Ross Brazzale

Item 1) Steam condenser designed to condense 6173 PPH at 13.7 kpa- budget price : $250,000.00.

Requires 800 GPM of 103F max cooling water in /15f rise

Dimensions:10 ft high x 16ft long x 4 ft wide

Item 2) Steam condenser designed to condense 25900 PPH at 34.47 kpa- budget price : $450,000.00.

Requires 3300 GPM of 135F max cooling water in /15f rise

Dimensions:12 ft high x 16ft long x 8 ft wide

Tom Nick
Somes-Nick & Co.

Subject: 10 MW Dresser-rand Steam turbine
Abhishek

Your informal request was forwarded to me.

First of all, I have no information or knowledge about the conversion of corn stover, (or any fuel for that matter) to steam.
That is something for the boiler/combustion experts.
To properly size a steam turbine, we would need mass flow rate of steam (PPH), and the steam pressure and temperature it is generated at (PSIG/DegF).
In this size it should be superheated. All of this info would have to come from the boiler vendor, or whatever process you are using to generate the steam.
Finally we need to know the exhaust pressure of the steam leaving the turbine.
this may depend on the use for the steam. If you want a true cogen system, I would assume you would send the exhaust steam to a low pressure campus distribution system.
If the system is short, you may get by using a pressure as low as 15 psig. If not you may have to use a higher pressure- 50 to 150 psig.
The higher the exhaust pressure, the more steam required to generate 10MW.
The other issue is that you have to match the exhaust flow to your steam demand. May not need much steam in the summer, unless there is a steam driven chiller.
Unfortunately, in the summer is when electrical costs and demand is greater, so it may be best to look at an extraction/condensing machine

Here is an example with estimated flow, based on an output of 10MW:

Inlet steam conditions: 600 psig/750 f
Extraction requiremnts for campus steam: 50,000 PPH at 150 PSIG.

Design exhaust pressure : 4” HgA to a water cooled steam condenser, using 85F cooling water from a cooling tower:

Inlet steam flow required at 600#/750F: 140,000 PPH
Exhaust flow at 2” HgA (140K-50K) 90,000 PPH
Power output: 10 MW
Cooling water flow required for steam condenser 8550 GPM based on 20F rise.

Budget price for turbine with generator, controls, switchgear, and condenser: $5.5 Million
Installtion not included.

During summer when campus steam requirements is low, the inlet steam flow could be reduced, with a higher % of steam flow going to condenser to still make 10MW.

I have provided short answers to your ? below in red
Hope this helps.

comments
Dear Dresser-Rand, I am Abhishek Kumar. I am an under graduate student doing Chemical Engineering in Illinois Institute of Technology. I am working on a project on co-generation of heat and power using corn stover (all parts of a corn plant except the cob) this semester. Iam doing research on the conversion of corn stover into energy. I am considering the use of steam turbines for this purpose. I came across your company while doing my research on steam turbines. For our project, my team has decided to work on the scale of 10 MW. So basically Iam looking at steam turbines with a power output of about 10 MW. I saw in your website that there are steam turbines that fit this range such as the R Model which provides up to 25 MW. I have a few questions regarding this turbine. First of all, since Iam dealing with generation of energy from corn stover, will I be able to use this turbine to generate heat and power for my project?(yes with a back pressure or extraction turbine) Also what should the feed rate of corn stover to the boiler be, in order to generate power of 10 MW? Then regarding the steam turbine, what is the usual efficiency of this turbine(60 to 70% isentropic)? Also what is the efficiency of the compressor of this turbine(no compressor in a steam turbine)? How much power would be required for the compressor if the steam turbine generates 10 MW of power? (no compressor in a steam turbine) Finally, how much heat would be removed from the condenser in a 10 MW steam turbine?(it typically works out to around 950 BTU/LB of steam condensed) Can this heat be used to heat a public institution like a community college, hospital etc?(yes if pressure leaving turbine is high enough. This requires a back pressure or extraction design) These are basically my questions at my current level of research. I will contact you further if I have more questions. I have been impressed by the level of customer service provided by Dresser-Rand. The website is so organized that it basically addresses all the concerns of its customers. Please reply to my questions as soon as possible as my project has a lot of time restrictions. I would greatly appreciate it. Thats all. Take care and have a good time. Abhishek.

Tom Nick

HRSG Group- Alstom Power (4)
Ian Lutes
Director Sales & Tendering
ian.lutes@power.alstom.com

Hello Ian,
Iam Abhishek. Iam a undergraduate student doing Chemical Engineering at the Illinois Institute of Technology. Iam currently doing a group project that deals with the cogeneration of corn stover to heat and energy. So when I did research on the gas turbines, I found that I need some important information regarding the Heat Recovery Steam Generator (HSRG). My project is dealing with a gas turbine that can produce a power output of 0.5 MW and 2 MW. We have done some modelling on the gas turbine and have come up with some rough estimates about the temperature ranges for the HSRG. We are estimating a inlet temperature range from 500 degrees celcius to 800 degrees celcius. Also we estimate a inlet gas flow rate into the HSRG of about 5 lbs/s for the 0.5 MW system and 20 lbs/s for the 2 MW system. So we are now trying to find out what would be an approximate size and cost for these two systems (HSRG for the 0.5 MW and 2 MW). Also we are not fully sure about the various inlet and outlet conditions for the HSRG for these two systems. Basically we only have some rough estimates for these conditions. So Sir, could you please give us some important inlet and outlet conditions at the HSRG, such as the temperature, pressure, the mass flow rates etc for these two systems. Thats all. Please reply soon. Thanks a lot for your support and co-operation. Take care and have a good time.
Abhishek.

Hello Ian,
Thanks for the input. So basically ALSTOM doesn't provide HRSGs for 0.5 MW and 2MW gas turbines, isn't it? Thats all right since our desired power outputs are very small. So what is the smallest HRSG that ALSTOM provides? Could you please give me some numbers for the smallest HRSG like the temperature, pressure and flow rates at the inlet and outlet? What would be the power output of the gas turbine for which this HRSG is used? You metioned in the previous reply about the GE Frame 7. Could you please tell me more about it? Thats all for now. Thanks for your help once again. I greatly appreciate it. Take care and have a good time.
Abhishek.

Subject: Re: Heat Recovery Steam Generator Inquiry

Dear Abhishek,

Thanks for your reply re HRSG product. Alstom does provide this type of equipment but for larger gas turbine frame sizes such as GE Frame 7 and larger. So unfortunately we cannot help with your request.

Good luck with the project.

Regards,

Ian Lutes

Subject: Re: Heat Recovery Steam Generator Inquiry

Abhishek:

The smallest HRSG Alstom provides is about 100 MW gas turbine capacity.

Gas turbine gas outlet temperature is about 610 C.

Pressure drop across HRSG would be about 55 millibar.

Regards,

Ian Lutes

Graham Corporation (4)
Keith Grinnel
Application Engineer
Phone: 585-343-2216
Fax: 585-343-1097
KGrinnell@graham-mfg.com

Hello again, this is James Cheever the student at Illinois Institute of Technology doing research on a power cycle for cogeneration. There have been a few changes in the design on the two cycles. The new cycles produce .5MW and 2MW respectively. Below are some of the conditions for each of units involved.
Hear are the conditions for the steam cycle.

The Temperature and Pressure are the same for both the .5 MW and the 2 MW plant.

Coming out of the boiler and going into the turbine
T1=1204 C
P1=129 bar

Coming out of the turbine and going into the condenser

T2=602.9 C
P2=2.413 bar=71.2559 inHg
Flow= .5 MW: 2900 lb/hr
    2 MW: 11500 lb/hr
Unfortunately at this time we have been unable to correctly calculate the cooling water inlet temperature so any baseline you could give us would be great. Any further information you could give would be appreciated especially concerning the dimensions, and estimated cost for these two condensers.

Sincerely,
James Cheever

Coming out of the condenser and going into the pump
T3=126.2 C
P3=2.413 bar=71.2559 inHg

Coming out of the pump and going into the boiler
T4=128.2 C (Temperature into the boiler)
P4=129 bar

Mass flow rates of steam through the cycle are:
.5 MW: 2900 lb/hr
2 MW: 11500 lb/hr

Hello, I am James Cheever and I am a student at Illinois Institute of
> Technology. I am currently doing research for a project I am working
> on. The project entails using corn stover as a means to power a steam
> cycle which would be used to produce power. After talking to Edward
> Stoermer from Steam Power LLC's I was directed to talk to you about
> thesurface condensers that could be used for this cycle. The power
> outputfrom the two cycles we are looking at would be 3MW and 15MW
> respectively. For these cycles any information regarding the
> condensersinvolved and operating conditions of those condensers
> would be greatly
> appreciated.
>
> Sincerely,
>
> James H. Cheever
>

Friday, April 17, 2009 2:36 pm
Fred & James

I really don't have anything for you. Graham really specializes in vacuum equipment that condenses saturated steam. At 2.413 bara (71.229 " HgA) you're really above our pressure range. The other thing is the 0.5 MW steam flow rate is below what we normally quote on. Even the 11,500 lb/hr (2 MW) is pretty small for us when the equipment is operating under vacuum in our normal range of 2 - 4 "HgA. I think your really looking at a shell & tube manufacturer for these applications.

Is T2 really 602.9 C? This is hotter than I'm used to seeing coming out the back end of the turbine but I'm used to condensing steam turbines not non-condensing ones. The heat exchanger you're looking at would have to do a lot of desuperheating before reaching the condensing saturation temperature of 126.2 C. The gas cooling area might exceed the condensing area requirement.

I guess the good news is that the non-condensable venting equipment you would need for the vacuum condenser we proposed initially is no longer needed for the current system.

Keith

Frederick Amey
Famey@graham-mfg.com

Subject: Fw: Surface Condensers.
To: jcheever@iit.edu

> James,
>
> Please find attached file with information as requested. Please
> keep in
> mind that based on the very limited information we were given,
> these specs
> are based solely on speculation and assumption. The first
> document in
> the file, "Budget Surface Condenser request for Quote" contains
> several
> grayed out sections that would need to be filled out by you to
> generate a
> more accurate design. We took the liberty to make some
> generalizations in
> order to get you some information. We assume it takes approx. 8000
> lbs/Hr
> of steam to generate 1MW of energy.
>
> The rough estimated cost for each unit is as follows:
> 3MW Condenser=$@**,000

> 15MW Condenser=$^**,000
>
> I hope you find this information useful. Good luck with your project.
>
>
> Sincerely,
>
>
> Fred Amey

MPR Power Solutions (2)

Joel Wilson
Operations Cheif
Phone:559-266-6248
Fax:559-266-6249

> Message:
> Hello I am James Cheever and I am a student at Illinois Institute of
> Technology doing a research project on CHP using corn stover as a fuel. I
> am interested in knowing if MMR Power Solutions has any equipment that
> could be used for this purpose. Any further information about MMR Power
> Solutions equipment that could be used for CHP would be greatly
> appreciated.
>
> Sincerely,
>
> James H. Cheever

Tuesday, April 7, 2009 11:52 am
James,

MMR Power Solutions has several CHP facilities, but nothing in the biomass-fueled area. We are developing a biomass/solar thermal hybrid plant (50 MW), but engineering and permitting are still in progress, and we have not purchased any equipment for burning biomass fuels.

All of our facilities use natural gas fueled engines (Cummins, Caterpillar and Waukesha) driving generators (from 560 kW to 2.2 MW). The engine exhaust (about 1100F) is then used to generate steam, and both the steam and electricity are used by our customers.

In the case of our Waukesha engine, hot engine coolant is put through two heat exchangers in the engine's exhaust path before going into a plate and frame heat exchanger, then going to a radiator (fan speed controlled by temperature) before returning to the engine. The secondary side of the p/f HX is used to transfer the heat from the engine coolant to a thermal storage tank of 200,000 gallons of water, which in turn is used to supply shell and tube HXs to warm liquid ammonia for transfer from a storage facility into trucks for interstate transport.

Other information and photos are on our website.

Joel Wilson

Caterpillar Power Generation Systems (1)
Clive Nickolay
Manager Global Sales & Marketing

Emails sent
Thank you for your interest in Caterpillar Power Generation Systems (CPGS).

CPGS offers a wide range of power plant solutions that include engineered equipment, turnkey power plants, financing, operation and maintenance services, and contract power arrangements. Our broad portfolio of products, including a full line of CM long-stroke, medium-speed, reciprocating engines, make us a leading provider of power from 2.8 to over 100 MW. We also provide a wide range of choices in generating technologies, fuels and configurations to maximize plant efficiency while delivering low-cost energy.

CPGS and the worldwide Cat dealer network are ready to stand behind you and your power plant project every step of the way.

For more information, visit www.catpowerplants.com or contact:

CPGS Regional Manager: Dean Powell
Title: Regional Sales Manager
Phone: 713-329-2243
E-mail: Powell_Dean@cat.com

Thank you again for your time and interest.

Sincerely,
Clive Nickolay

15. Appendix B: Edited EPA CHP Survey

CHP
EPA COMBINED HEAT AND POWER PARTNERSHIP

Is My Facility a Good Candidate for CHP?

STEP 1: Please check the boxes that apply to you:	
☐	Do you pay more than $.07/kWh on average for electricity (including generation, transmission and distribution)?
☐	Are you concerned about the impact of current or future energy costs on your business?
☐	Is your facility located in a deregulated electricity market?
☐	Are you concerned about power reliability? Is there a substantial financial impact to your business if the power goes out for 1 hour? For 5 minutes?
☐	Does your facility operate for more than 5,000 hours/year?
☐	Do you have thermal loads throughout the year (including steam, hot water, chilled water, hot air, etc.)?
☐	Does your facility have an existing central plant?
☐	Do you expect to replace, upgrade, or retrofit central plant equipment within the next 3-5 years?
☐	Do you anticipate a facility expansion or new construction project within the next 3-5 years?
☐	Have you already implemented energy efficiency measures and still have high energy costs?
☐	Are you interested in reducing your facility's impact on the environment?