# The University of Georgia

# The Economic Feasibility of Using Georgia Biomass for Electrical Energy Production

Prepared by: George A. Shumaker, Audrey Luke-Morgan, Tommie Shepherd and John C. McKissick

# The Economic Feasibility of Using Georgia Biomass for Energy Production

## Executive Summary

The purpose of this study is to re-evaluate the economic feasibility of current technology for pyrolysis and gasification as methods for producing energy from Georgia's biomass resources. The study also evaluates the feasibility of converting dairy waste into methane for electrical generation. The basic process is to convert the biomass resource into "bio-gas" and "bio-oil" or "syn-gas" and "syn-oil" that can be used as fuel to produce electricity.

Georgia has a large amount of potential biomass feedstocks available for conversion into energy. There may be in excess of 13 million tons of material that could possibly be converted each year. Estimated annual electricity use in Georgia during 2006 was about 137.2 billion kilowatt hours. If all 13 million tons of bio-mass were converted into electricity using the best technology explored in the study, it would produce about 8.6 percent of the estimated Georgia electricity use. While that is an impressive amount, the likelihood of utilizing all available bio-mass for electricity production is unlikely. The cost of delivery of the biomass to a conversion facility would require a sales price of the electricity well above the current prevailing sales prices.

The properties and characteristics of each potential bio-fuel have important implications to the feasibility of individual biomass sources. In order to optimize feasibility, feedstocks must provide generators with an abundant supply at the lowest cost of delivery possible. In addition, the heat content (BTU) of feedstocks varies depending upon the type of biomass, so a high energy fuel is critical. Biomass sources also differ in ash and moisture content. This affects the energy value of biofuels, since the chemical make-up of ash generally has no energy value and the amount of water in bio-fuel affects, in a decisive manner, the available energy within every bio-fuel.

Gasification and pyrolysis are similar technologies that convert carbon laden products into component products that can be used as fuel. There are three main products produced from the processes: hydrocarbon gas or "syn-gas", hydrocarbon oils "syn-oils" that can be further processed and char and ash, the solids residual. The gasification system will produce a greater volume of syn-gas while the pyrolysis system will produce a greater volume of the oil product.

The cost of producing electricity with both the gasification and pyrolysis systems modeled in this study are above the current rates for electricity sold in Georgia. For that reason it appears that neither gasification nor pyrolysis technology, similar to that modeled here, are viable sources of electricity at the present time. The reasons for the relative high cost of electricity production with these technologies are many but a few of them include the high capital cost of the technology relative to electrical power

generated.   The high capital cost raises the fixed costs of operation and places a large financial burden of the venture.  It is possible that larger scale operations or different technologies than those modeled in this study can drive unit costs of production down enough to be competitive.

The basic findings are that while it is technologically feasible to accomplish the task, it is not economically feasible to convert biomass into electricity in Georgia at the present time.  The exception is that large dairies or smaller dairies that pool their manure may be able to produce electricity at competitive rates.

# The Economic Feasibility of Using Georgia Biomass for Energy Production

## Introduction

In 2003, the Center for Agribusiness and Economic Development (CAED) completed a study of the feasibility of generating electricity from biomass fuel sources in Georgia.  The study results indicated that it was not economically feasible to produce electricity with the technologies available at that time without significant subsidies.

Since 2003, the overall cost of energy has risen and improvements in the technologies of biomass conversion have improved.  The gasification technology modeled in the 2003 study was based upon a plant under construction in New Hampshire. That plant operated for some time and was capable of completing the conversion process. However, modifications to the technique were required.  The end result was that output was not as great as predicted.  The technology modeled in the current study is based upon the most recent types of methods under adoption within the industry.  The purpose of this study is to re-evaluate the economic feasibility of current technology for pyrolysis and gasification as methods for producing energy from Georgia's biomass resources.  The basic process is to convert the biomass resource into "bio-gas" and "bio-oil" or "syn-gas" and "syn-oil" that can be used as fuel to produce electricity.

## Methodology

The CAED contracted with Frazier, Barnes and Associates of Memphis, TN to provide research into the technologies of pyrolysis and gasification as methods for producing electricity.  Their report forms the base upon which the feasibility of the two technologies is built.   Other technical information was provided by faculty in the Department of Agricultural Engineering Outreach and industry sources.  The CAED amassed data concerning the sources and costs of providing biomass for the process and evaluated the economics costs involved in the processes.

## BioMass Feedstock Issues

Georgia has a large amount of potential biomass feedstocks available for conversion into energy.  There may be in excess of 13 million tons of material that could

possibly be converted each year.  Different potential feedstocks will have vastly different delivered costs per ton due to both the current market price of the product and its relative cost of transportation per unit.  In addition, some of the potential feedstocks are only available on a seasonal basis.  Since generation of electricity in a minute-to-minute operation, assurance of a continuous supply of feedstocks is of utmost importance.

Other factors to consider when evaluating potential feedstocks are things such as the moisture content and ash content.  High moisture content implies high drying costs that can add to the total cost of electricity production, perhaps making a given feedstock not economically viable.  The other major factor concerns the ash content of the feedstock.  High ash content feedstocks require added boiler design considerations that raise capital costs.  Ash disposal costs are also a consideration.

The quantity, location, price, transportation cost, and heat content of Georgia's current available supply of biomass was updated and determined utilizing prior feasibility analysis and secondary production data sources, such as the *2005 Georgia Farm Gate Value Report*, which lists the total amount of agricultural and forest products produced each year.  To determine the amount of residuals left after harvest, various experts in the field were consulted.  The field experts provided estimates from the residual quantity to production information.  Market prices were used for any marketable biomass feedstock.  Cost of producing selected biomass feedstocks were calculated where market prices did not exist.

The total amount of agricultural by-products was evaluated based on the annual production of total yield mass and the percent of residues left over after harvest for each potential source.  Quantities for closed-loop sources, those which are grown specifically for power generation, were determined by multiplying the annual yield per acre by the total acres in production.  The following section describes Georgia's biomass feedstock in greater detail.

**Alternative Crops**—Kenaf and Switchgrass were identified as alternative possibilities for increasing farm income and biomass.  Neither crop has been planted in large acreage in Georgia.  Research indicates each crop yields around 6 to 10 tons per acre.

Applying inflation factors to the budgeted costs derived in 2003 results in a total cost per ton of $57.50 to $72.50 for kenaf.  The average cost of $65 per ton is utilized in this study for kenaf.  Budgeted costs and expected yields for areas throughout the southeastern US were considered for switchgrass.  Switchgrass estimated cost range from $70 to $90 per ton, with the average of $80 per ton utilized for analysis in this study.

Since neither crop currently has significant acreage in Georgia acreage projections were considered.  It was estimated that 13,000 acres of kenaf and 1,000 acres of switchgrass may be planted in the near future to meet potential market demands.  The expected yields were assumed to be 6.98 tons per acre for kenaf and 6 tons per acre for switchgrass.  Thus, the total tons of biomass are estimated to be 90,750 from kenaf and 6,000 from switchgrass.

**Traditional Row and Forage Crops -** Southern agriculture is very diverse.  Production of various row and forage crops is common in Georgia.  Many of these crops have residues that could provide a source of biomass for the state.  In this section various crops that are considered "traditional" row crops and forage crops are analyzed.  Production data from the *2005 Farmgate Value Report* and expert opinions are used as the basis for tonnage estimates.

**Corn Stalks**—After grain is harvested, corn stalks remain in the field—a little bent and broken but still a good source for biomass.  It is estimated that 1,200 pounds of stalk per acre remain after grain is harvested.  The estimated production of corn stalks in Georgia based on 2005 Farmgate data is 164,570 tons.  Cost associated with corn stalks would be that necessary to remove the stalks and get them into a readily transportable form.  It is assumed that a hay rake (windrower) and hay baler will be used to accomplish this.  Utilizing a machine cost calculator to estimate the total cost for these operations, the estimated cost is $36 to $60 per ton.  Given current grain prices, the total tons of biomass available from corn stalks could significantly increase.

**Cotton Stalks**—Many cotton producers cut and till cotton stalks back into the field.  These stalks are a potential biomass product.  To estimate cotton stalk production the total 2005 Farmgate acreage was multiplied by the estimated pounds of stalk available per acre.  Based on prior research, it was assumed that irrigated cotton stalks yield 4,900 lbs per acre and non-irrigated yield 4,200 pounds per acre.  It was estimated that 35% of Georgia's cotton acreage is irrigated.  Therefore, a weighted average 4,445 pounds of stalks per acre was used.  The total estimated cottons stalks produced are 2.72 million tons.  The cost to harvest cotton stalks using a forage harvester and nutrient replacement ranges from $35 to $55 per ton depending on the machinery used and irrigated versus non.

**Gin Trash**—Gin trash is another potential biomass source produced in Georgia.  Based on conversations with local ginners and researchers at the University of Georgia, it is estimated that every bale of cotton ginned produces 185 pounds of gin trash.  Assuming and average weight of 500 pounds per bale and that all cotton bales produced in the state are ginned in the state, the total estimated gin trash produced is 205,226 tons.  Calculating the economic cost requires further assumptions be made.  Most gins give the gin trash away if someone will come and get it.  Gin trash is a light material and to be handled efficiently, it was assumed the gin trash would be placed in a module.  The cost of packing the gin trash into a module is estimated to be $0.005 to $0.007 per pound or $10 to $14 per ton.  One of the most common uses of gin trash is as supplemental cattle feed.

**Peanut Hay**—It is estimated that each acre of peanuts produces between 3 and 4 bales of peanut hay weighing 1,200 pounds per bale.  Using the total acreage, as reported in the *2005 Farmgate Report*, it is estimated that Georgia produces 1.6 million tons of peanut hay.  Baling the hay is a relatively inexpensive venture and a market exists for the hay.  Current market prices range from $20 to $30 per bale or $33 to $50 per ton.  The market price covers the harvest and baling cost of the hay and provides a small return to the

producer.  Caution must be used in the sale and transfer of peanut hay.  According to label recommendations, certain pesticides used in peanuts do not allow for the use of hay as a feedstock for livestock.  There is also a concern with Alfa toxins associated with peanuts, especially in non-irrigated production.

**Peanut Hulls**—The total tons of peanut hulls available was estimated by taking 25% of the total production.  Hulls comprise approximately 25% of the weight of peanuts.  Using the 2005 Farmgate production data, the estimated tons of peanut hulls is 289,000.  Shellers pointed out three major uses of peanut hulls including cattle feed, "filler or floor-liner" in poultry houses, and chemical carriers.  Depending on the intended use and market, the hulls may be used directly after shelling or ground through a hammer mill.  Given their low density, peanut hulls may also be pelletized for more efficient transport.  Prices ranged from $15 per ton for bulk loads to $65 per ton for pelletized peanut hulls.  The average cost per ton of $40 per ton was utilized in this study.

**Pecan Hulls**—To estimate the tons of pecan hulls available, the total production was multiplied by the typical shelling rate (33%) and the average percentage of hulls (51%).  The total estimated tons available based on 2005 Farmgate data is 7,976.  Shellers contacted stated that they usually allow hulls to be loaded from their operation free of charge.  The best way to load pecan hulls would be mechanically.  The rental price for a front-end loader is about $300 per day.  It is estimated that 4 to 5 tons per hour can be handled by one person.  Assuming an 8 hour day and a labor cost of $10 per hour, the total cost per hour would be about $47.50 or $10.55 per ton.

**Excess Hay**—In certain years hay production in Georgia is in excess of consumption.  Given recent droughts, strong cattle prices, and growing equine industry in the state, hay may not be a consistent form of biomass.  However, years with timely rainfalls may produce excess quantities of forage.  Often farmers are willing to dispose of excess hay.  A cost per ton of $40 to $60 was assumed.  It was assumed that 25% of the hay produced was in excess of the demand.  Based on 2005 Farmgate data, the estimated tons of hay available would be 674,811.  This figure will change more frequently due to overall changes in demand and variations in weather conditions and its impact on supply.

**Wheat and Rye Straw**—Each of these commodities produces between 110 to 120 square bales per acre weighing around 30 pounds per bale.  Straw has a relatively strong market in the landscape sector with market prices between $2.00 to $2.50 per bale.  Using the 2005 Farmgate production data, if the straw from every acre of wheat and rye was baled, Georgia would produce 366,834 tons of wheat straw and 139,993 tons of rye straw.  The cost per ton of straw would be from $133 to $167.  The average, $150 per ton, was utilized in this study.

**Poultry Products**
**Poultry Litter**—The poultry and egg industry is Georgia's most valuable agricultural sector and leads the nation in poultry production.  Thus, a significant amount of poultry litter is produced in Georgia.  To arrive at the total tons of poultry litter produced in the state the number of head for breeder pullets, broilers, and layers was used in respect to

their annual pounds of litter produced per head—8 pounds for breeder pullets, 44 pounds for hatching egg layers, 40 pounds for table egg layers, and 0.50 pounds per pound of bird produced for broilers.  Using the 2005 Farmgate production data the total tons of poultry litter available was estimated at 2.65 million tons.

Farmers use poultry litter as fertilizer but experience criticism in urban areas and encounter issues with compliance of the Environmental Protection Agency regulations.  Overuse of poultry litter raises the phosphorus level in soil to unacceptable amounts.  Spreading of poultry litter will continue to be popular in areas of high crop production because the crops reduce the phosphorus.  It is also seen as a less expensive source of nutrients given the rising cost of traditional fertilizer.  In Northeast Georgia limited acreage of crops exist and alternatives to spreading the litter are continuously being researched.  The average cost per ton of litter was estimated to be $12 to $25 based on market conditions for litter as fertilizer.

**Forest Related Products -** Current information for forest related products was derived from communications and data supplied by the Georgia Forestry Commission.  Analysis utilized the estimated annual harvest acreage for timber products in Georgia.  The three primary sources of forest residue to be considered in this study are bark, wood chips, and wood (harvesting) residues.

For consistency, tonnage available was calculated utilizing similar assumptions as prior analysis.  However, it is important to point out that given recent emphasis on renewable fuel sources and interest in biomass forest resources, the Georgia Forestry Commission has extensive research considering forest biomass sources in much greater detail than will be covered in this report.

Analysis in this report will base availability on the estimated annual harvested acreage in Georgia.  The Georgia Forestry Commission estimates this acreage to be about 500,000 acres.  The total forestland in the state is estimated to be 24.2 million acres with roughly 11 million being softwood (pine) forests.

**Bark**—Foresters estimate that 322 cubic feet of bark is produced per acre.  An estimated weight per cubic foot is 20 pounds. Foresters at the Warnell School of Forestry and timber companies indicated that 85% of the bark produced in the state is retained for fuel by the timber companies.  Using the total number of harvested acres multiplied by the total bark per acre and 15% for the portion not utilized within the timber companies, results in 241,500 tons of available bark. Two main outlets exist for bark—power and landscaping.  Many lumber and pulp mills use the bark to heat and fuel the machinery.  Higher quality bark is sold to the landscaping industry.  Bark prices range from $16 to $20 per ton depending on the quality and size of the final material.  This is a market price where landscapers and large firms can purchase the bark form the timber companies.

**Wood Chips**—Based on assumptions defined in prior analysis, potential biomass from wood chips was estimated. Research (Koch, 1976) suggests that 1.5 tons of wood chip residuals are produced per thousand board feet (mbf) of timber products produced. Considering the estimated annual harvested acreage of 500,000 acres, the average harvest in Georgia is 4,196.2 mbf. The total wood chips available would be 6,294.3 tons. Wood chip prices range from $18 to $22 per ton with uses ranging from a base in poultry houses to industrial applications for particle board.

**Wood (Harvesting) Residue**—Wood residues are the remains (branches, bark, and needles) from harvested acreage. It is estimated that 15% of the tree remains after harvest. The average yield per acre is 2,254 cubic feet. Thus, approximately 338 cubic feet per acre of harvest residue is left for every harvested acre. A cubic foot of residue is estimated to weigh 49.9 pounds. Considering these estimates and the state average of harvested acreage, 500,000 acres, approximately 4.2 million tons of wood residues are created annually.

One problem with efficient utilization of harvesting residue is transportation. Stacking branches on the bed of a trailer and/or truck is not efficient. The branches need to be processed through a wood chipper for the most efficient means of transportation of the waste material. This adds cost to an almost free product. The estimated operating and ownership cost for an industrial chipper was estimated by Morbark, Inc. The total estimated cost for owning and operating the chipper is $130 to $150 per hour with a throughput of 50 tons per hour. Throughput will vary considering the volume of and distance between residue piles.

Another cost to be considered is nutrient replacement. Foresters estimate that 85% of the nitrogen in the soil comes from the remains left after harvest. To replace this amount of nitrogen would cost about $115 per acre with the current price of fertilizer. Considering the cost for chipping and the opportunity for fertilizer, the total cost per ton of wood residue is $18 to $23.

**Pine Straw**—Using the total acreage of all pines in the state and a yield factor of 25 bales per acre at 20 pounds per bale results in 2.75 million tons of pine straw. Prices for pine straw range from $250 to $300 per ton. Most trading of pine straw occurs as bales with prices ranging from $2.50 to $3.00. These are the average wholesale sales price in the landscaping industry. Given the relatively high cost per ton, pine straw does not seem to be a feasible source of biomass.

**Biomass Wood Resource Assessment on a County-by-County Basis for the State of GA -** Recent reports prepared for the Georgia Forestry Commission estimate total harvesting residues at 5.314 million dry tons with only 5% currently utilized. Thus, approximately 5.05 million dry tons of harvesting residues are estimated to be available for use in Georgia. Mill residues, which would include bark and wood chips, are estimated between 6.99 and 7.97 million dry tons. However, it is estimated that only 1% of those residues are currently not utilized, resulting in only 69,930 to 79,703 dry tons available. The county-by-county biomass wood resource assessment completed by

General Bioenergy for the Georgia Forestry Commission also included other wood resources including unmerchantable timber, urban wood waste, pecan shells, paper mill sludge, and black liquor production. The total estimate of available resources in Georgia based on this study is 18.87 million dry tons.

**Biomass Properties**

The properties and characteristics of each potential biofuel have important implications to the feasibility of individual biomass sources. In order to optimize feasibility, feedstocks must provide generators with an abundant supply at the lowest cost of delivery possible. In addition, the heat content (BTU) of feedstocks varies depending upon the type of biomass, so a high energy fuel is critical. Biomass sources also differ in ash and moisture content. This affects the energy value of biofuels, since the chemical make-up of ash generally has no energy value and the amount of water in biofuel affects, in a decisive manner, the available energy within every biofuel.

Biomass sources also vary in weight and size. The altering weight, size, structure, and dimensions of varying biomass sources results in different processing and equipment use, which ultimately influences the transportation costs. Types of biomass that are most dense, or can be processed to use less space per ton, will have the lowest cost of transport and storage. A summary of Georgia's farm produced biomass resources is shown in Table 1, which shows the total tons of biomass produced, price per ton, average price per ton, delivered cost per ton, and the season of harvest.

Table 1.  Biomass Supply and Delivered Prices

| BioMass | Tons Available | Price/Ton | Avg Price/Ton | Freight cost per ton (50 Miles) | Cost Per Ton Delivered @ (2.25)/Mile | Season |
|---|---|---|---|---|---|---|
| Pecan Hulls | 7,976 | $9.50 - 11.50 | $ 10.50 | $ 7.28 | $ 17.78 | Fall |
| Poultry Litter | 2,651,372 | $12 -25 | $ 18.50 | $ 5.96 | $ 24.46 | Year Round |
| Gin Trash | 205,226 | $10 -14 | $ 12.00 | $ 7.94 | $ 19.94 | Late Summer - Early Fall |
| Wood Chips | 6,294 | $18 -22 | $ 20.00 | $ 7.28 | $ 27.28 | Year Round |
| Bark | 241,500 | $16 -20 | $ 18.00 | $ 6.62 | $ 24.62 | Year Round |
| Wood Residue | 4,217,798 | $18 -23 | $ 20.50 | $ 5.96 | $ 26.46 | Year Round |
| Peanut Hulls | 289,000 | $15 - 65 | $ 40.00 | $ 4.63 | $ 44.63 | Late Summer - Early Fall |
| Cotton Stalks | 2,717,505 | $35 - 55 | $ 45.00 | $ 5.96 | $ 50.96 | Late Summer - Early Fall |
| Hay* (Includes Peanut Hay) | 2,290,914 | $40 - 60 | $ 50.00 | $ 11.25 | $ 61.25 | Late Summer - Early Fall |
| Corn Stalks | 164,570 | $36 - 60 | $ 48.00 | $ 11.25 | $ 59.25 | Mid Summer - Early Fall |
| Kenaf | 90,750 | $57.50 - 72.50 | $ 65.00 | $ 11.25 | $ 76.25 | Fall |
| Switchgrass | 6,000 | $70 - 90 | $ 80.00 | $ 11.25 | $ 91.25 | Fall |
| Wheat Straw | 366,834 | $133 -167 | $ 150.00 | $ 14.56 | $ 164.56 | Late Spring - Early Summer |
| Rye Straw | 139,993 | $133 -167 | $ 150.00 | $ 14.56 | $ 164.56 | Late Spring - Early Summer |

Table 2 shows a summary of historical energy data for Georgia from the Energy Information Administration. The delivered fuel cost and quantity for electricity generation for coal, petroleum and natural gas for 1999 through September 2006 is shown.

Table 3 shows the biomass feedstock quality and delivered cost for some common agricultural biomass sources in Georgia. Research suggests that the fuels with the least delivered cost per million BTU (mmBTU) will be the most likely fuel sources for a biomass power generation facility.

The conversion facilities considered in this update has the capability to utilize a variety of feedstocks. The practicality of any particular feedstock is limited by season of the year, quality, delivered cost and handling and storage issues. Modeling the outcomes of each individual feedstock in each technology would create a huge task with little added benefit. Therefore, some basic assumptions concerning feedstocks were made;

1. The biomass could be a combination of various types but that it is assumed the ash content would be 8 percent or less, moisture content on delivery is not greater than 25 percent and the average BTU content would be 13 million BTU per ton. Existing biomass conversion facilities generally use some blend or combination of feedstocks and the above quality measures are consistent with current industry standards.

2. The receiving and handling system must be capable of handling the delivered biomass and must be capable of blending to provide a uniform heat content feedstock. A five day supply is assumed and assists in assuring a blend to provide uniformity.

3. The plant is assumed to operate for 350 days per year, 24 hours per day. 15 days of down time for maintenance is assumed.

**Table 2.  Delivered Fuel Costs and BTU Yield for Coal, Petroleum and Natural Gas**

| Fuel | 2006 | 2005 | 2004 | 2003 | 2002 | 2001 | 2000 | 1999 |
|---|---|---|---|---|---|---|---|---|
| Coal (dollars per million Btu) | $2.39 | $2.14 | $1.79 | $1.72 | $1.68 | $1.66 | $1.54 | $1.55 |
| Average heat value (Btu per Pound) | 9,994 | 9,994 | 9,990 | 10,041 | 10,119 | 10,169 | 10,256 | 10,245 |
| Petroleum (dollars per million Btu) | $12.05 | $9.48 | $7.60 | $6.37 | $5.10 | $5.95 | $5.89 | $3.48 |
| Average heat value (Btu per gallon) | 147,357 | 147,357 | 147,429 | 147,190 | 146,976 | 147,595 | 147,357 | 147,738 |
| Natural Gas (dollars per million Btu) | $7.14 | $9.77 | $6.38 | $5.73 | $3.65 | $3.28 | $4.18 | $2.49 |
| Average heat value (Btu per cubic foot) | 1,028 | 1,028 | 1,027 | 1,025 | 1,020 | 1,026 | 1,021 | 1,022 |

# Table 3. Characteristics of Potential Georgia Biomass Feedstocks and Delivered Costs

| Biomass | Ash Content Dry Basis | mmBTU/Ton | Price/Ton (low) | Price/Ton (high) | Average Price/Ton | Calculated Average $/mmBTU | Conversion Factor | Freight Cost per Ton Mile | 50 Mile Frt/Ton | 50 Mile Frt/mm BTU | Delivered F/S $/mmBTU |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pecan Hulls | 5.80% | 16.35 | $9.50 | $11.50 | $10.50 | $0.64 | 129.4 | $0.15 | $7.28 | $0.45 | $1.09 |
| Gin Trash | 17.60% | 13.10 | $10.00 | $14.00 | $12.00 | $0.92 | 141.2 | $0.16 | $7.94 | $0.61 | $1.52 |
| Bark, Pine | 3.30% | 14.08 | $16.00 | $20.00 | $18.00 | $1.28 | 117.6 | $0.13 | $6.62 | $0.47 | $1.75 |
| Coal (2006 US$) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | $2.39 |
| Poultry Litter | 26.68% | 8.89 | $12.00 | $25.00 | $18.50 | $2.08 | 105.9 | $0.12 | $5.96 | $0.67 | $2.75 |
| Peanut Hulls | 5.90% | 16.03 | $15.00 | $65.00 | $40.00 | $2.50 | 82.4 | $0.09 | $4.63 | $0.29 | $2.78 |
| Wood Residue | 3.20% | 8.86 | $18.00 | $23.00 | $20.50 | $2.31 | 105.9 | $0.12 | $5.96 | $0.67 | $2.99 |
| Wood Chips | 1.30% | 9.09 | $18.00 | $22.00 | $20.00 | $2.20 | 129.4 | $0.15 | $7.28 | $0.80 | $3.00 |
| Corn Stalks | 6.40% | 14.62 | $36.00 | $60.00 | $48.00 | $3.28 | 200.0 | $0.23 | $11.25 | $0.77 | $4.05 |
| Cotton Stalks | 17.20% | 12.37 | $35.00 | $55.00 | $45.00 | $3.64 | 105.9 | $0.12 | $5.96 | $0.48 | $4.12 |
| Hay | 5.70% | 14.00 | $40.00 | $60.00 | $50.00 | $3.57 | 200.0 | $0.23 | $11.25 | $0.80 | $4.38 |
| Kenaf | 3.60% | 14.78 | $57.50 | $72.50 | $65.00 | $4.40 | 200.0 | $0.23 | $11.25 | $0.76 | $5.16 |
| Switchgrass | 5.40% | 14.01 | $70.00 | $90.00 | $80.00 | $5.71 | 200.0 | $0.23 | $11.25 | $0.80 | $6.51 |
| Natural Gas (2006 US$) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | $7.14 |
| Wheat Straw | 3.50% | 14.57 | $133.33 | $166.67 | $150.00 | $10.30 | 258.8 | $0.29 | $14.56 | $1.00 | $11.29 |
| Petroleum (2006 US$) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | $12.05 |
| Rye Straw | 3.00% | 12.70 | $133.33 | $166.67 | $150.00 | $11.81 | 258.8 | $0.29 | $14.56 | $1.15 | $12.96 |

**Potential Sales Rates for Electricity Produced**

Once the electricity produced a market must be found to sell the product. The market could be divided into two major components; sale to a specific user such as a co-located business or sale into the existing power grid. The price obtained from the two potential markets may well be different. According to the Georgia Public Service Commission, Georgia Power and Savannah Electric Company must purchase power from feed-in producers within their service areas at set rates. The current rate for 2007 is $0.05058 per kilowatt hour. If the generation facility is located in the service area of other electric companies such as municipal systems of one of the Rural EMCs, then the price is negotiable between the two parties. It should be noted, these other entities are not required to purchase the electricity from feed-in producers, although it is doubtful they would refuse to buy given an acceptable price.

The second market sector would be direct sales to a business, preferably co-located to minimize delivery costs. According to the Department of Energy, the following table shows the various average retail prices for electricity in Georgia over the past few years. The industrial rate in 2005 was $0.0528 per kilowatt hour.

**Georgia Average Retail Prices (2005 cents per KWhr) by Sector**

|             | 1990  | 1995  | 2000 | 2005 |
|-------------|-------|-------|------|------|
| Residential | 9.90  | 9.22  | 8.23 | 8.64 |
| Commercial  | 9.73  | 8.60  | 7.03 | 7.67 |
| Industrial  | 6.41  | 5.31  | 4.44 | 5.28 |
| Other       | 10.76 | 10.10 | 9.22 | 6.90 |
| All Sectors | 8.70  | 7.77  | 6.72 | 7.43 |

Source: http://www.eia.doe.gov/cneaf/electricity/st_profiles/georgia.html

**Additional Possible Revenue Enhancements**

There are at least two potential added sources of revenue available to producers of electricity from biomass conversion. The first is the Renewable Energy Production Incentive from the Federal Government. This incentive is provided for renewable energy production from methods such as biomass conversion. The incentive is adjusted annually for inflation and is currently set at 1.8 cent per kilowatt hour. There is a payment for a maximum of ten years of operation.

The second possible source of added revenue is from the sale of the electricity into certain green power markets. Georgia has a Green Power program which sells green power in blocks of 150 kilo watt hours to consumers who wish to purchase energy from renewable sources. Curently Georgia Power and Savannah Electric Power participate in the program purchasing electricity produced from captured landfill gas. Any green

power could potentially take advantage of this green power market in Georgia. The Green Power rate premium is currently set at 4.5 cents per kilowatt hour but individual Electric Membership Cooperatives are allowed to negotiate rates. The recent range of rates are from a low of 2 to a high of 4.5 cents per kilowatt hour. That means that purchasers must pay that amount in addition to the going market rate for the green power. It is assumed that the green power producer would capture one-half of the green power premium (2.75 cents per kilowatt hour) charged to the consumer since they must market the power through existing distribution lines. The remainder of the premium would go to the distributor.

Thus it is assumed that added revenues of 1.8 cents per kilowatt hour from the Renewable Energy Program and 2.75 cents per kilowatt hour from the Green Power Program are obtainable for a total of 4.55 cents per kilowatt hour are obtainable.

**Feasibility Benchmark**

The bench mark for feasibility that will be used in evaluating electrical power generation using biomass feedstocks is the ability to produce electricity at a total cost less than the combined sales rate plus any added revenues from other sources such as production incentives or sales premiums. It is assumed that the sales price will be the avoided cost rate of 5.058 cents per kilowatt hour set by the Public Service Commission and that added revenues 1.8 cents from the Renewable Energy Program and 2.75 cents from the Green Power Program for a total of 9.61 cents per kilowatt hour. A method would be considered feasible if total production costs are less than 9.61 cents per kilowatt hour of electricity produced.

**Capital Cost Assistance**

There are both Federal and State programs potentially available that provide grants and guaranteed loan assistance to firms seeking to enter into the electricity from biomass industry. This study will not seek to detail these programs but does note that firms that are successful in obtaining government assistance may be able to reduce operating costs by reducing total capital outlay. As will be pointed out later in the study, these technologies are capital intensive and the fixed cost of debt service and capital re-capture (depreciation) place a heavy burden on the firm.

**Gasification and Pyrolysis Technology**

Gasification and pyrolysis are similar technologies that convert carbon laden products into component products that can be used as fuel. There are three main products produced from the processes: hydrocarbon gas or "syn-gas", hydrocarbon oils "syn-oils" that can be further processed and char and ash, the solids residual. The gasification system will produce a greater volume of syn-gas while the pyrolysis system will produce a greater volume of the oil product.

The processes for biomass conversion are built upon the basic technology used for years to convert coal into liquid fuels.  The Germans refined the technology early in the 1900s and used it extensively during World War II to provide diesel fuels to power their war efforts.  South Africa also adopted the technology during the 1980s to derive fuels from their coal resources when they were subjected to economic sanctions to force them to stop the apartheid policies.

These processes involve the chemical conversion of the biomass in a heated atmosphere of pressurized steam or air.  The gasification process is conducted in an atmosphere of limited oxygen while in pyrolysis, oxygen is excluded to avoid any combustion.   The processes drive the volatile compounds from the biomass to produce a low-to-medium calorific gas termed "syn-gas" or "bio-gas".   The syn-gas can be combusted immediately to produce power or it can be condensed, cooled, filtered and cleaned for use in combustion engines, gas turbines and fuel cells.  The syn-gas contains 70-80 percent of the energy originally present in the feedstock.  Syn-oil is the cooled and condensed form of the volatiles from the feedstock.  It is a stable transportable oil that has about one-half the heat content of conventional fuel oil.  The syn-gas and syn-oil can be refined and used as a fuel to power a generator to produce electricity.  The power plant could be a syn-gas or oil powered turbine and a steam powered turbine driven by waste heat that is converted into steam.  Since the refining process is costly, a more practical approach is to fire the syn-fuels directly in a boiler and generate steam that can then be used to generate electricity.

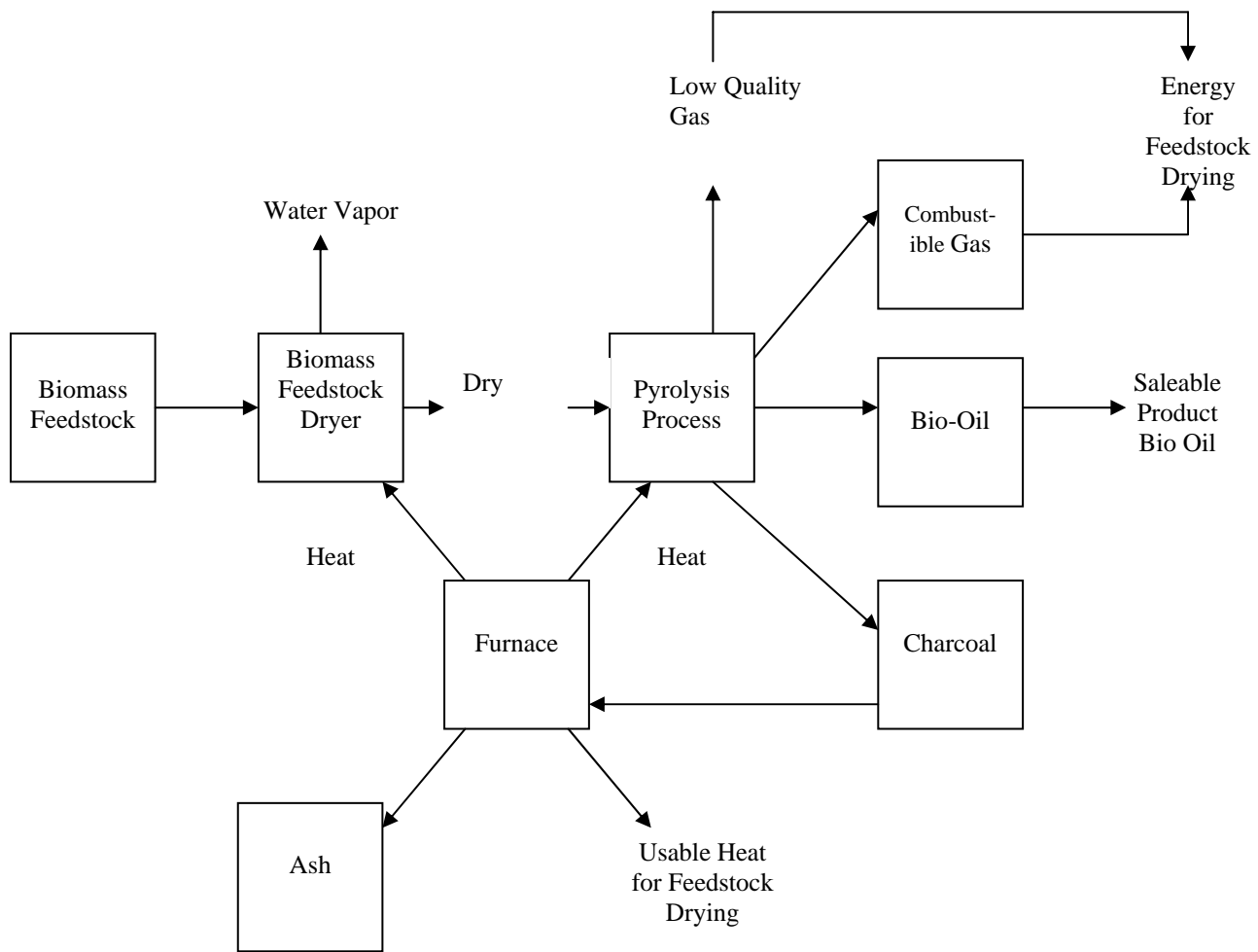The following schematic illustrates the basic process of converting biomass into electricity.
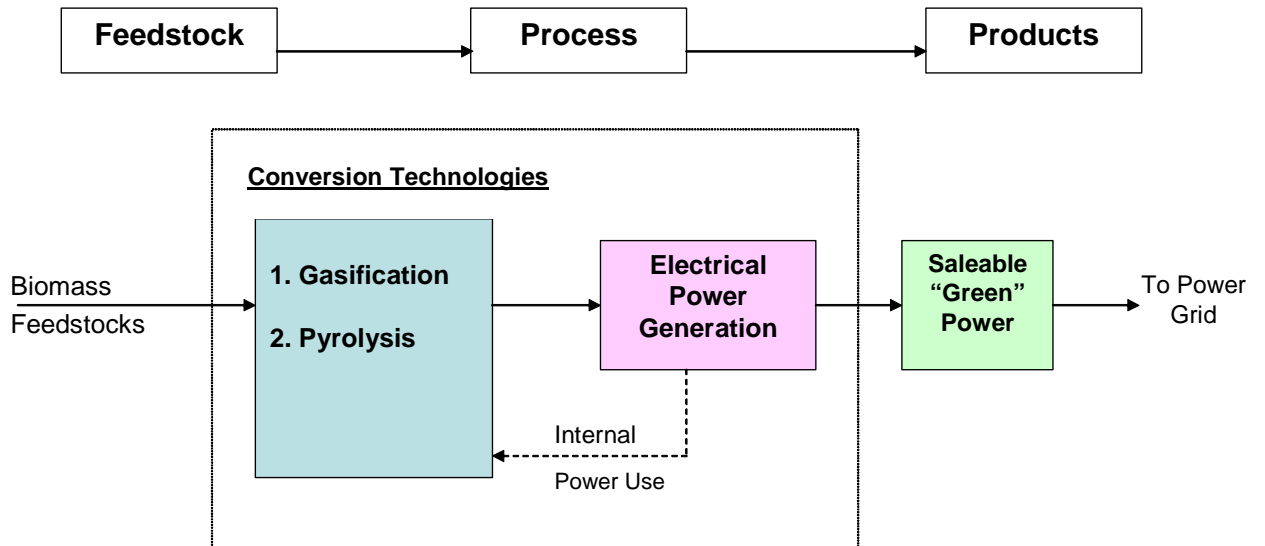


Source:  Frazier, Barnes and Associates, Memphis, TN

The following is a simplified process flow diagram of the pyrolysis method.
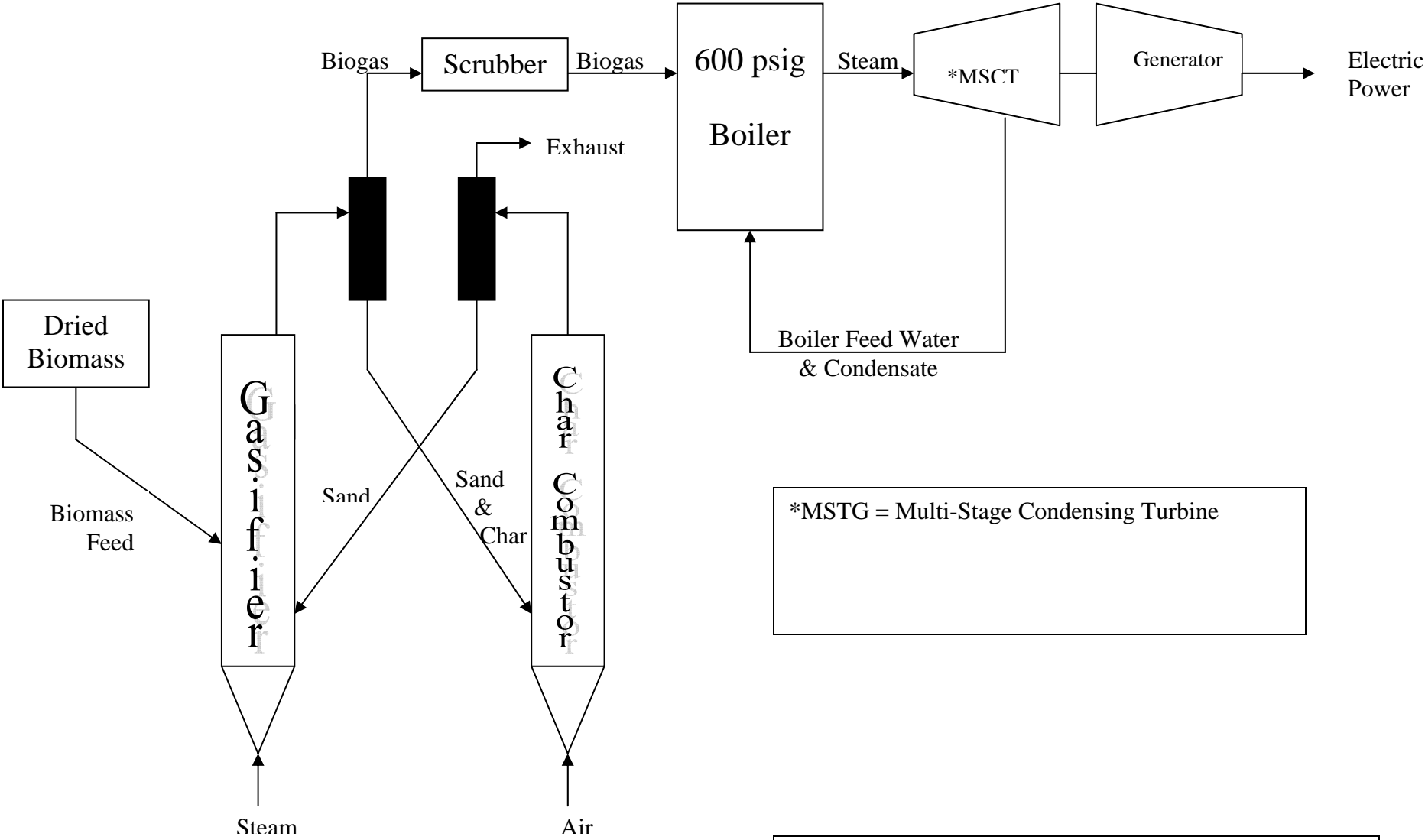
# Pyrolysis Process Flow Diagram



Biomass Feedstock

Biomass Feedstock Dryer

Water Vapor

Dry

Pyrolysis Process

Low Quality Gas

Combust-ible Gas

Energy for Feedstock Drying

Bio-Oil

Saleable Product Bio Oil

Furnace

Heat

Heat

Charcoal

Ash

Usable Heat for Feedstock Drying

It should be noted that the commercialization of these technologies is still in the developmental stages. There has been a great deal of theoretical work done to prove the practicality of the processes but there are currently no large scale facilities operating at the present time. A pyrolysis process developed by Renewable Oil International, LLC is being contemplated for construction. The concept is to build small scale plants near the feedstock source to reduce feedstock costs. The syn-fuel produced from the ROI process is heavier than water and when heated above 90 degrees F, can be transported. It is a high viscosity oil that requires a surfactant before blending with fuel oil prior to firing.

The following a simplified process flow diagram of the gasification method.

# Gasifier Flow Diagram

Biogas → Scrubber → Biogas → 600 psig Boiler

Exhaust

Steam → *MSCT → Generator → Electric Power

Dried Biomass

Biomass Feed

Gasifier

Sand

Sand & Char

Char Combustor

Boiler Feed Water & Condensate

Steam

Air

*MSTG = Multi-Stage Condensing Turbine

**Gasifier System**

18

The syn-gas produced from the gasification process is cleaned of most impurities and then burned in a boiler to create steam. The steam powers a turbine generator that produces electricity for sale. The direct gas fired turbine design has not been proven to be practical at this point in time due to impurities inherent in the biogas for smaller than 50 MW gasification plants. It may be practical for large size plants.
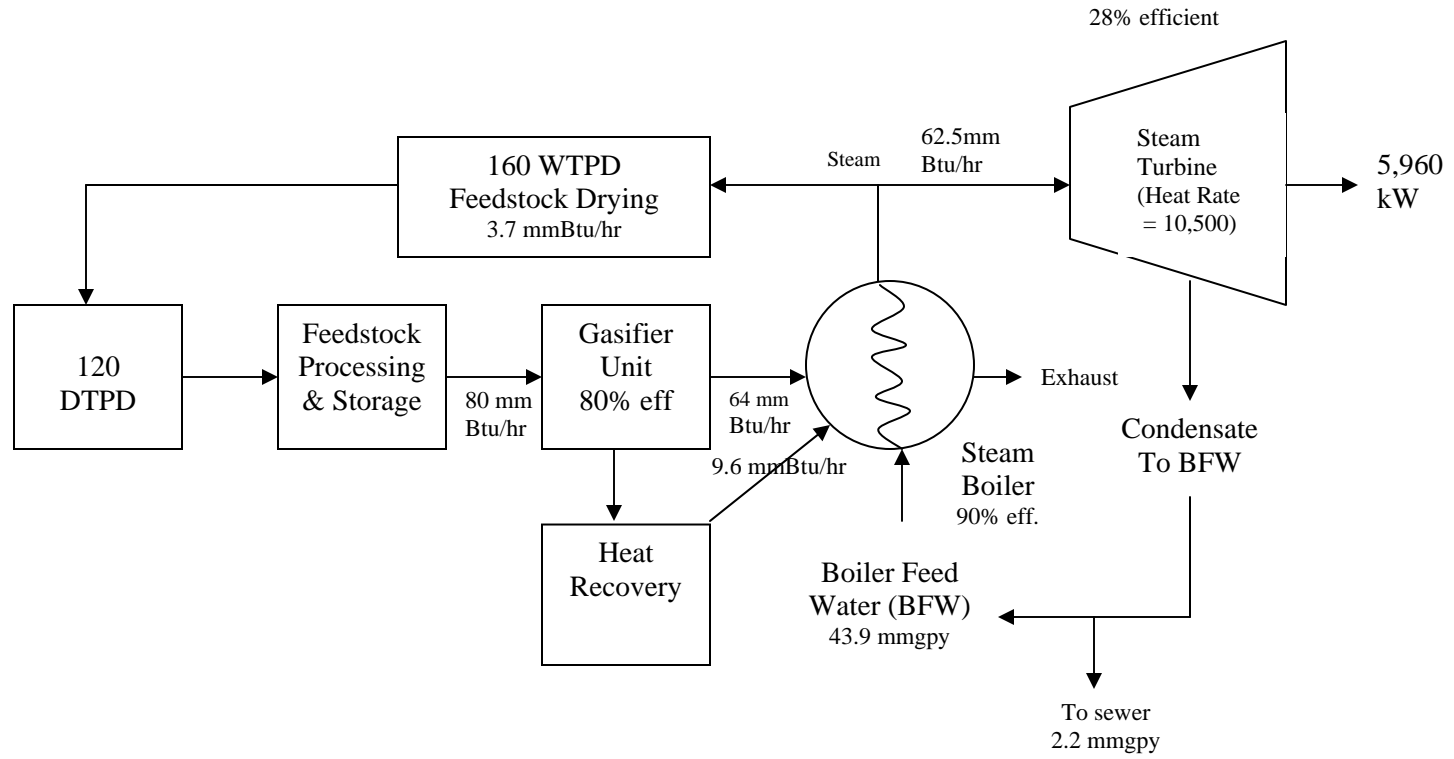
Several firms have researched the possibility of using the biogas as a fuel and burning it directly in a turbine to drive a generator to produce electricity. After extensive testing and economic evaluation, Frazier, Barnes and Associates has determined that the type of gasification process selected will determine the need for cleaning the syn-gas before introducing it into the gas turbine. If the steam reformed gasification process is used, the need for cleaning the syn-gas will be greatly reduced. The use of the air reformed gasification process will, in all likelihood, increase the need for cleaning of the syn-gas. Regardless of the manufacturer of the gasification process and equipment, one point appears to be pre-eminent in all of them. The equipment for each one requires daily inspection and maintenance.
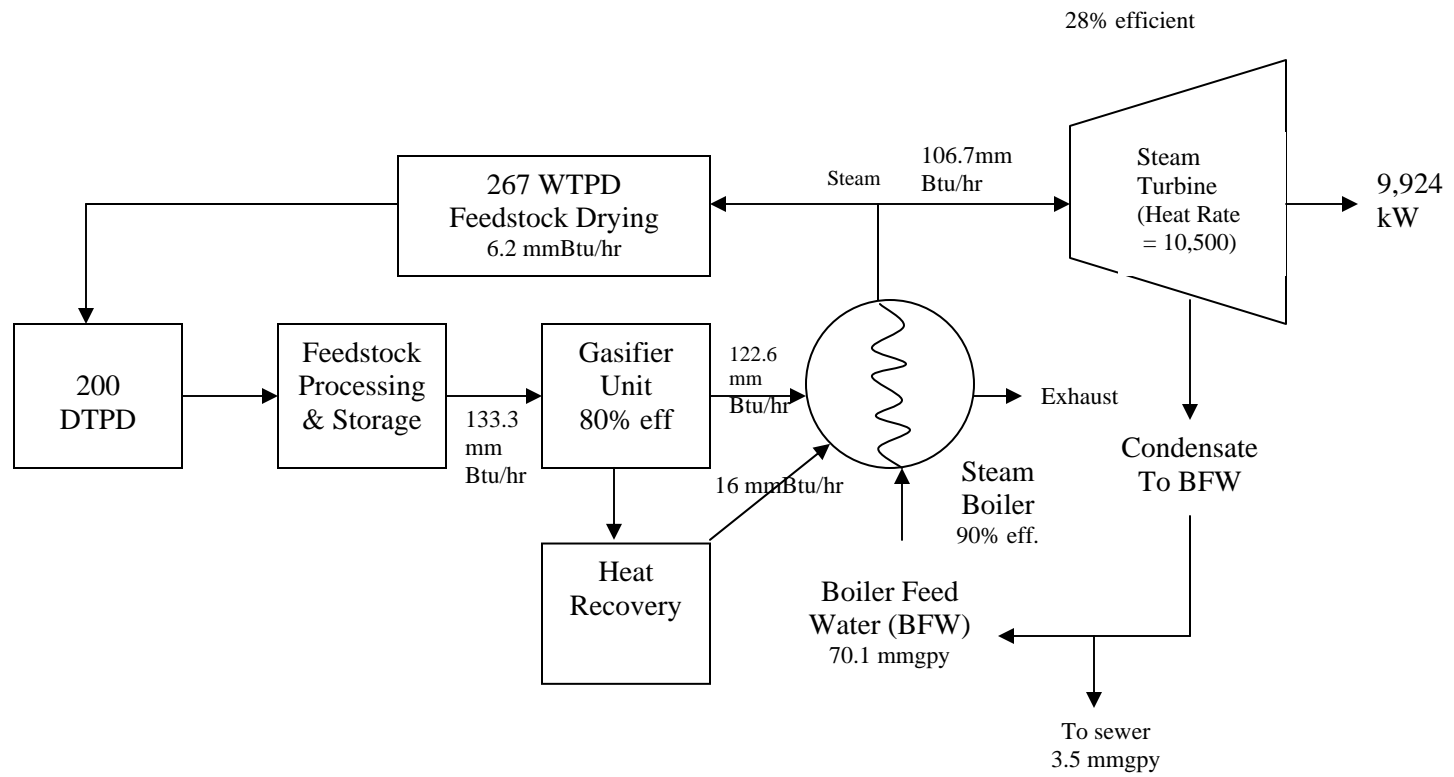
**Model Schematics**

The basic concept of biomass conversion is to use the energy available from the biomass (except for feedstock drying) to produce to steam, which is then used to generate electric power with a steam turbine/generator set. The electricity can either be used at a nearby facility in need of electric power or the electricity could be sold into the grid system.

In this study we evaluated three different sized biomass conversion models for both gasification and pyrolysis. The following pages contain schematic diagrams illustrating the process. Note the volume of biomass needed for each plant size, the amount of electricity produced and the relative efficiency of each system.
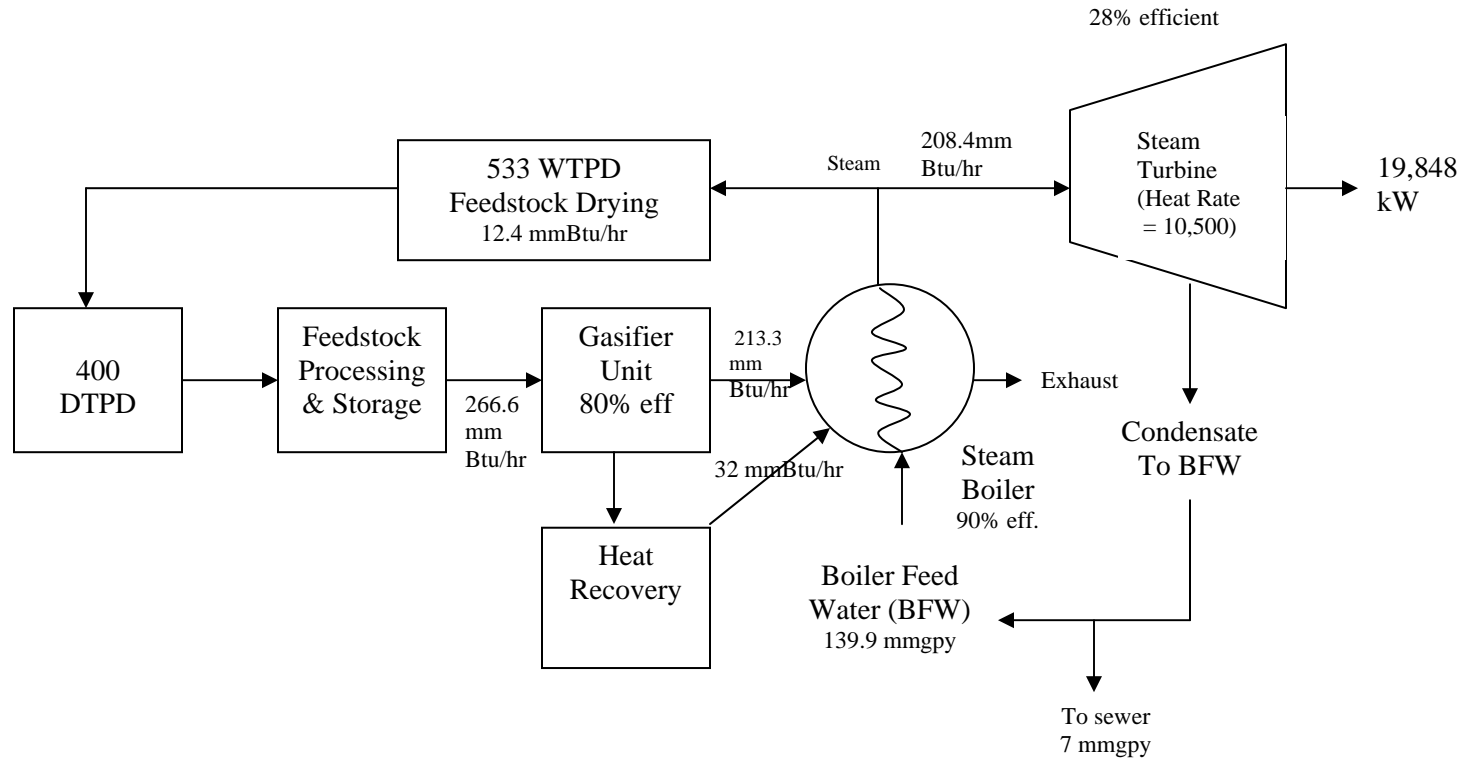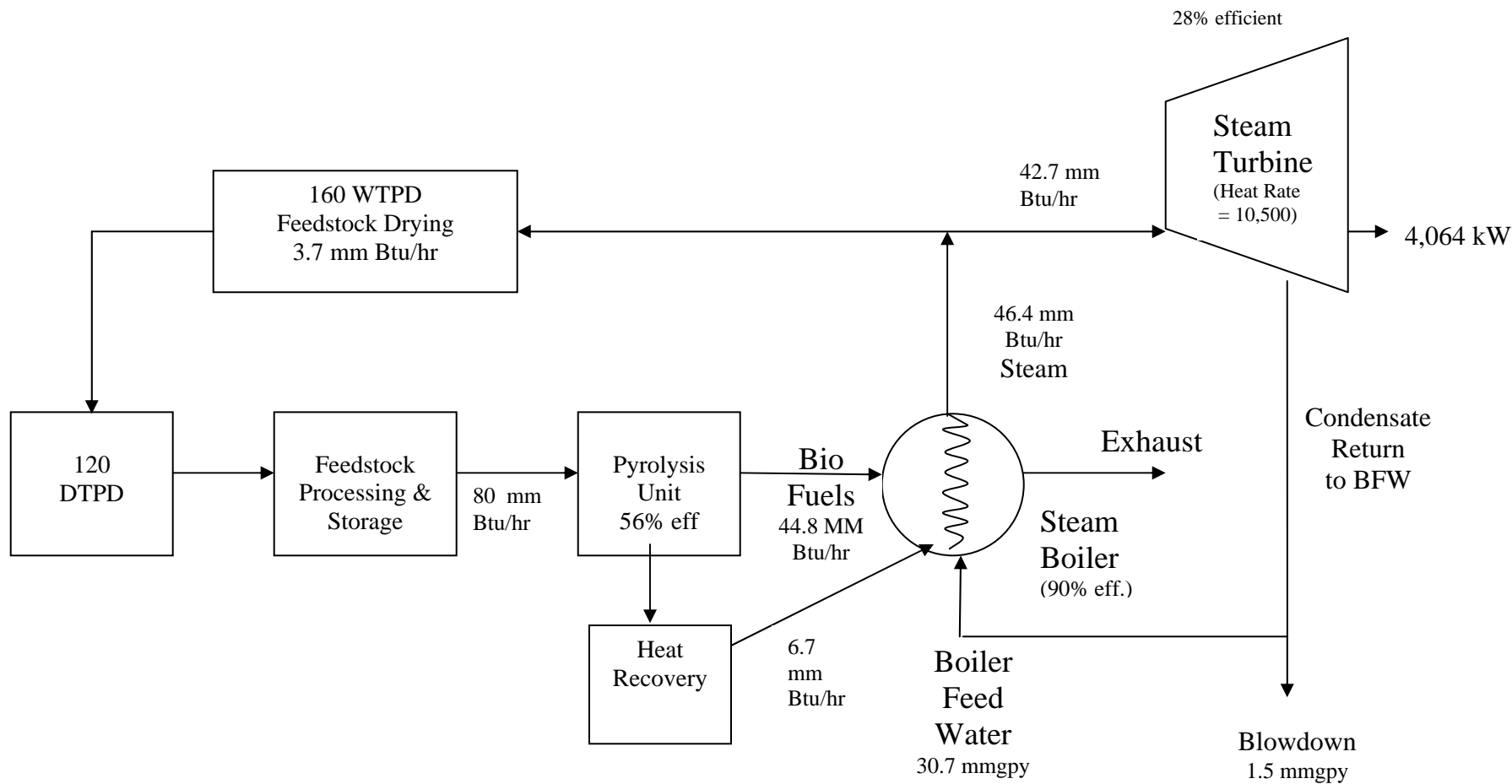
# Gasifier Process Flow Diagram
## Case #1 160 WTPD

28% efficient

| 160 WTPD Feedstock Drying 3.7 mmBtu/hr | Steam | 62.5mm Btu/hr | Steam Turbine (Heat Rate = 10,500) | 5,960 kW |

120 DTPD

Feedstock Processing & Storage

80 mm Btu/hr

Gasifier Unit 80% eff

64 mm Btu/hr

9.6 mmBtu/hr

Exhaust

Steam Boiler 90% eff.

Condensate To BFW

Heat Recovery

Boiler Feed Water (BFW) 43.9 mmgpy

To sewer 2.2 mmgpy

# Gasifier Process Flow Diagram
## Case #2 267 WTPD



28% efficient

| 267 WTPD Feedstock Drying 6.2 mmBtu/hr | | Steam | 106.7mm Btu/hr | Steam Turbine (Heat Rate = 10,500) | 9,924 kW |

200 DTPD

Feedstock Processing & Storage

133.3 mm Btu/hr

Gasifier Unit 80% eff

122.6 mm Btu/hr

Exhaust

16 mmBtu/hr

Steam Boiler 90% eff.

Condensate To BFW

Heat Recovery

Boiler Feed Water (BFW) 70.1 mmgpy

To sewer 3.5 mmgpy

# Gasifier Process Flow Diagram
## Case #3  533 WTPD

# Pyrolysis Process Flow Diagram
## Case #1 160 WTPD



28% efficient

Steam
Turbine
(Heat Rate
= 10,500)

4,064 kW

42.7 mm
Btu/hr

160 WTPD
Feedstock Drying
3.7 mm Btu/hr

46.4 mm
Btu/hr
Steam

Condensate
Return
to BFW

120
DTPD

Feedstock
Processing &
Storage

80 mm
Btu/hr

Pyrolysis
Unit
56% eff

Bio
Fuels
44.8 MM
Btu/hr

Exhaust

Steam
Boiler
(90% eff.)

Heat
Recovery

6.7
mm
Btu/hr

Boiler
Feed
Water
30.7 mmgpy

Blowdown
1.5 mmgpy

# Cogeneration Pyrolysis
# Process Flow Diagram
# Case #2 320 WTP

| Label | Value |
|-------|-------|
| 160 WTPD | 3.7 mm Btu/hr |
| Steam | |

120 DTPD

Feedstock Processing & Storage

80 mm Btu/hr

Remote Pyrolysis Unit

Bio Fuels

Heat Recovery 11.2 mm Btu

28% efficient

160 WTPD 3.7 mm Btu/hr

Steam

120 DTPD

Feedstock Processing & Storage

80 mm Btu/hr

Main Pyrolysis Unit

Bio Fuels 74.7 MM BTU/hr

7.4 mm Btu/hr Steam

69.9 mm Btu/hr Steam

Steam Boiler (90% eff.)

Steam Turbine (Heat Rate = 10,500)

6,655 kW

Condensate Return to BFW

Boiler Feed Water 61.5 mmgpy

Blowdown 3.1 mmgpy

# Cogeneration Pyrolysis
## Process Flow Diagram
## Case #3 480 WTPD

| 160 WTPD 3.7 mm Btu/hr | | Steam |
|---|---|---|

| 120 DTPD | Feedstock Processing & Storage | Remote Pyrolysis Unit | Bio Fuels | Heat Recovery 22.4 mm Btu |
|---|---|---|---|---|

28% efficient

| 160 WTPD 3.7 mm Btu/hr | | Steam |
|---|---|---|

| 120 DTPD | Feedstock Processing & Storage | Main Pyrolysis Unit |
|---|---|---|

Steam Turbine (Heat Rate = 10,500)

Bio Fuels 149.3 MM Btu/hr

3143.5 mm Btu/hr Steam

13,663 kW

| 160 WTPD 3.7 mm Btu/hr | | Steam |
|---|---|---|

Steam Boiler (90% eff.)

Condensate Return to BFW

| 120 DTPD | Feedstock Processing & Storage | Remote Pyrolysis Unit |
|---|---|---|

Boiler Feed Water

92.2 mmgpy

Blowdown 4.6 mmgpy

Bio Fuels

## Scope of Financial Analysis

The study evaluates both gasification and pyrolysis technologies to produce electricity using various feedstocks. It is assumed that:

1) The feedstock will be dried using heat generated through the gasification and pyrolysis processes.
2) Electricity will be produced from the bio-fuels, and
3) The energy from the bio-fuels can be sold locally at competitive prices.
4) The plant size should be limited in size to keep feedstock transportation cost at a minimum. Larger plant sizes may be contracted but capital costs rise steeply with increased scale.
5) By-products such as char and ash will be treated as waste products. Although there may be emerging markets for these materials as soil amendments, market values have not been established at this time.

The study also evaluates potential scale economies by analyzing three different plant sizes based on wet tons of feedstock. The three plant sizes for the gasification technology are 160 wet tons per day that would produce about 5,956 kilowatts (KW), 267 wet tons per day that would produce about 9,924 KW and 533 wet tons per day that would produce about 19,848 KW. The three plant sizes for the pyrolysis technology are based on a160 wet tons per day plant that would produce 4,064 KW scaled up by replicating the same plant two and three times that would produce 6,655 and 13,663 KW, respectively.

## Capital Costs for Gasification and Pyrolysis Facilities

The following tables list the capital cost estimates for different sized facilities that will produce electricity using biomass feedstocks.

**Gasification Capital Costs**

| | Plant Size | | |
|---|---|---|---|
| **Components** | **160 WTPD** | **267 WTPD** | **533 WTPD** |
| Capacity - KiloWatts of Electricity | 3,370 | 5,627 | 11,232 |
| Buildings | $596,700 | $716,040 | $947,700 |
| Feedstock Receiving & Processing | $1,638,750 | $2,338,750 | $3,637,750 |
| Truck Dump | $117,000 | $117,000 | $117,000 |
| Front End Loader | $140,000 | $140,000 | $140,000 |
| Fuel Processing Building | $820,000 | $1,350,000 | $2,339,000 |
| Metal Removal Equipment | $18,000 | $18,000 | $18,000 |
| Grinding/Sizing Equipment | $193,000 | $216,500 | $263,250 |
| Blending Equipment | $87,500 | $117,000 | $146,250 |
| Fuel Storage Bins | $117,000 | $234,000 | $468,000 |
| Conveyors | $146,250 | $146,250 | $146,250 |
| Gasification Process Equipment | $6,880,000 | $10,000,000 | $15,560,000 |

| Components | | | |
|---|---|---|---|
| Interconnections | $1,053,000 | $1,521,000 | $2,340,000 |
| Steam Boiler | $3,500,000 | $6,000,000 | $8,000,000 |
| Power Generation Equipment | $1,500,000 | $2,000,000 | $3,300,000 |
| Heat Recovery | $600,000 | $1,040,000 | $1,560,000 |
| Engineering/Permitting | $296,400 | $510,000 | $702,000 |
| Land/Site Preparation | $238,700 | $325,000 | $434,000 |
| Sub Total | $16,303,550 | $24,450,790 | $36,481,450 |
| Contingency (20%) | $3,260,710 | $4,890,158 | $7,296,290 |
| Total Estimated Cost | $19,564,260 | $29,340,948 | $43,777,740 |

WTPD = Wet tons per day of feedstock.

**Pyrolysis Capital Costs**

| Components | Plant Size | | |
|---|---|---|---|
| | **160 WTPD** | **320 WTPD** | **480 WTPD** |
| Capacity - KiloWatts of Electricity | 2,266 | 4,534 | 6,801 |
| Buildings | $596,700 | $1,193,400 | $1,790,100 |
| Feedstock Receiving & Processing | $1,638,750 | $2,338,750 | $3,637,750 |
| Truck Dump | $117,000 | $117,000 | $117,000 |
| Front End Loader | $140,000 | $140,000 | $140,000 |
| Fuel Processing Building | $820,000 | $1,350,000 | $2,339,000 |
| Metal Removal Equipment | $18,000 | $18,000 | $18,000 |
| Grinding/Sizing Equipment | $193,000 | $216,500 | $263,250 |
| Blending Equipment | $87,500 | $117,000 | $146,250 |
| Fuel Storage Bins | $117,000 | $234,000 | $468,000 |
| Conveyors | $146,250 | $146,250 | $146,250 |
| Pyrolysis Process Equipment | $1,300,000 | $2,600,000 | $3,900,000 |
| Interconnections | $600,000 | $1,200,000 | $1,800,000 |
| 600 PSIG Steam Boiler | $3,000,000 | $6,000,000 | $9,000,000 |
| Demineralizer System | $175,000 | $350,000 | $525,000 |
| Power generation Equipment | $875,000 | $1,750,000 | $2,250,000 |
| Heat Recovery System | $702,000 | $1,404,000 | $2,106,000 |
| Engineering/Permitting | $351,000 | $620,000 | $940,000 |
| Land/Site Preparation | $120,000 | $240,000 | $360,000 |
| Sub Total | $9,358,450 | $17,696,150 | $26,308,850 |
| Contingency (20%) | $1,871,690 | $3,539,230 | $5,261,770 |
| Total Estimated Cost | $11,230,140 | $21,235,380 | $31,570,620 |

WTPD = Wet tons per day of feedstock.

Source: Frazier, Barnes and Associates, Memphis, TN

## Operating Costs

The following two tables summarize the operating costs of three different sized plants for both the gasification and pyrolysis technologies. Basic assumptions include operating 24 hours per day for 350 days per year, annual average delivered feedstock costs of $25.00 per ton, and other details indicated in the left hand column of the tables.

### Gasification Operating Cost

| | Plant Size | | |
|---|---|---|---|
| **Components** | **160 WTPD** | **267 WTPD** | **533 WTPD** |
| **Electricity Produced - KW** | 5,956 | 9,924 | 19,848 |
| Annual Production - kWh | 50,032,000 | 83,360,000 | 166,720,000 |
| Sales Price = $0.0743/kWh | $0.074 | $0.074 | $0.074 |
| Daily Sales | $10,621 | $17,696 | $35,392 |
| Annual Sales | $3,717,378 | $6,193,648 | $12,387,296 |
| | | | |
| **Variable Costs** | | | |
| Feedstock @ $25.00/ton | $1,400,000 | $2,336,250 | $4,663,750 |
| Electricity @ $0.055/kwh | $169,000 | $290,400 | $532,400 |
| Water & Water Treatment | $25,740 | $66,690 | $186,000 |
| Ash Disposal @ $20/ton | $13,650 | $27,300 | $54,600 |
| Inert Gas | $12,000 | $20,025 | $39,975 |
| Labor | $720,000 | $720,000 | $800,000 |
| | | | |
| Total Variable Costs | $2,340,390 | $3,460,665 | $6,276,725 |
| | | | |
| **Fixed Costs** | | | |
| Maintenance 3% of invest. | $586,928 | $880,228 | $1,313,332 |
| Taxes & Insurance @ 1.5% of invest. | $293,464 | $440,114 | $656,666 |
| Interest on capital @ 8% of ave. invest. | $782,570 | $1,173,638 | $1,751,110 |
| Depreciation (SL 13.5 yrs) | $1,449,204 | $2,173,404 | $3,242,796 |
| | | | |
| Total Fixed Costs | $3,112,167 | $4,667,384 | $6,963,903 |
| | | | |
| **Total Costs** | **$5,452,557** | **$8,128,049** | **$13,240,628** |
| | | | |
| **Net Revenues** | **-$1,735,179** | **-$1,934,401** | **-$853,332** |
| | | | |
| **Cost of Generation per kWh** | $0.109 | $0.098 | $0.079 |

**Pyrolysis Operating Cost**

| Components | 160 WTPD | Plant Size 320 WTPD | 480 WTPD |
|---|---|---|---|
| **Electricity Produced - kW** | 4,064 | 8,127 | 12,191 |
| Annual Production - kWh | 34,134,400 | 68,268,800 | 102,403,200 |
| Sales Price = $0.0743/kWh | $0.074 | $0.074 | $0.074 |
| Daily Sales | $7,246 | $14,492 | $21,739 |
| Annual Sales | $2,536,186 | $5,072,372 | $7,608,558 |
| | | | |
| **Variable Costs** | | | |
| Feedstock @ $25.00/ton | $1,400,000 | $2,800,000 | $4,200,000 |
| Electricity @ $0.055/kwh | $146,000 | $262,000 | $386,000 |
| Water & Water Treatment | $12,000 | $24,000 | $36,000 |
| Ash Disposal @ $20/ton | $18,375 | $36,750 | $54,600 |
| Labor | $561,000 | $924,000 | $800,000 |
| | | | |
| Total Variable Costs | $2,137,375 | $4,046,750 | $5,476,600 |
| | | | |
| **Fixed Costs** | | | |
| Maintenance 3% of invest. | $336,904 | $637,061 | $947,119 |
| Taxes & Insurance @ 1.5% of invest. | $168,452 | $318,531 | $473,559 |
| Interest on capital @ 8% of ave. invest. | $449,206 | $849,415 | $1,262,825 |
| Depreciation (SL 13.5 yrs) | $831,862 | $1,572,991 | $2,338,564 |
| | | | |
| Total Fixed Costs | $1,786,424 | $3,377,998 | $5,022,067 |
| | | | |
| **Total Costs** | **$3,923,799** | **$7,424,748** | **$10,498,667** |
| | | | |
| **Net Revenues** | **-$1,387,613** | **-$2,352,377** | **-$2,890,109** |
| | | | |
| Cost of Generation per kWh | $0.115 | $0.109 | $0.103 |

The cost of producing electricity with both the gasification and pyrolysis systems modeled in this study are above the current rates for electricity sold in Georgia. For that reason it appears that neither gasification nor pyrolysis technology, similar to that modeled here, are viable sources of electricity at the present time. The reasons for the relative high cost of electricity production with these technologies are many but a few of them include the high capital cost of the technology relative to electrical power

generated.   The high capital cost raises the fixed costs of operation and places a large financial burden of the venture.  It is possible that larger scale operations than those modeled in this study can drive unit costs of production down enough to be competitive.

Another observation on the relative efficiency of the two processes may offer insight into the potential for using these technologies to produce electricity or other energy.  The term "efficiency" in the biomass energy conversion area should be viewed with a great deal of caution. It can be influenced by the type of feedstock, the variables that affect the boiler operation and above all the feedstock moisture and percent ash that will remain after conversion. We have assumed that the moisture content will not exceed 25% and that the ash will be in the 4% - 8% range. The boiler should be designed for dual firing (both solid fuel and natural gas) and with sufficient excess air to minimize emissions.  The following table illustrates the percent of total feedstock energy that is ultimately available in the form of electricity.  These system losses represent a considerable inefficiency.

### Biomass Cogeneration
### Energy Efficiency Summary

| Technology | Biomass Conversion Efficiency (%) | Energy Conversion System Efficiency (%) | | | Total System Energy Efficiency (%) | | |
|---|---|---|---|---|---|---|---|
| | | Case #1 | Case #2 | Case #3 | Case #1 | Case #2 | Case #3 |
| Gasification* | 80 | 20 | 20 | 20 | 16 | 16 | 16 |
| Pyrolysis** | 56 | 20 | 20 | 20 | 11 | 11 | 11 |

*Gasification efficiency courtesy of PRIMENERGY, Inc.
**Pyrolysis efficiency courtesy of ROI, Inc.
Source:  Frazier, Barnes and Associates, Memphis, TN

An important point of difference between the two technologies concerns the biomass conversion efficiency percent.  The gasification technology is able to capture about 80 percent of the available energy from the biomass while the pyrolysis method yields only about 56 percent of the available energy from the biomass.  The main factor is that the bio-fuel from the pyrolysis method has a lower Btu content than the syn-gas from gasification.  This difference is substantial and results in the lower unit costs of electricity production from gasification versus pyrolysis.

**Economic Comparison of the Two Technologies**

The following table is a summary comparison of the three plant sizes for the two technologies.  It is based on the same assumptions used in determining the operating costs for the two technologies.  There appears to be significant scale economies in both the gasification and pyrolysis technologies.

**Economic Comparison of Gasification and Pyrolysis Facilities**

|  | **Plant Size** | | |
| --- | --- | --- | --- |
| **Gasification** | **160 WTPD** | **267 WTPD** | **533 WTPD** |
| Production Capacity (kW) | 5,956 | 9,924 | 19,848 |
| KiloWatt Hours Per Year | 50,032,000 | 83,360,000 | 166,720,000 |
| Total Estimated Capital Cost | $19,564,260 | $29,340,948 | $43,777,740 |
| Capital Cost per kW | $3,284.69 | $2,956.62 | $2,205.69 |
| Estimated Operating Costs | $5,452,557 | $8,128,049 | $13,240,628 |
| **Operating Cost per kWhr** | **$0.109** | **$0.098** | **$0.079** |

| **Pyrolysis** | **160 WTPD** | **320 WTPD** | **480 WTPD** |
| --- | --- | --- | --- |
| Production Capacity (kW) | 4,064 | 8,127 | 12,191 |
| KiloWatt Hours Per Year | 34,134,400 | 68,268,800 | 102,403,200 |
| Total Estimated Capital Cost | $11,230,140 | $21,235,380 | $31,570,620 |
| Capital Cost per kW | $2,763.58 | $2,612.87 | $2,589.70 |
| Estimated Operating Costs | $3,923,799 | $7,424,748 | $10,498,667 |
| **Operating Cost per kWhr** | **$0.115** | **$0.109** | **$0.103** |

**Summary of Gasification and Pyrolysis**

In summary, it does not appear that it is feasible to produce electricity at a competitive cost to current commercial operations from biomass using pyrolysis and gasification technologies under the current economic environment without subsidies in the form of Renewable Energy Production Incentive from the Federal Government and Green Energy Premiums. The operating costs of producing electricity using these technologies are well above the current cost of electricity producing using atomic, coal and gas fired plants. Production costs of electricity from coal, nuclear and gas powered plants range from 2.5-3.5 cents per kilowatt hour. Improvements in system efficiency and reductions in capital costs will be needed before these technologies can be competitive.

Given the existence of subsidies, the largest scale gasification plant in this study is feasible and the largest scale pyrolysis plant comes quite close to being feasible missing the benchmark by 0.6 cent per kilowatt hour. While not explored in this study, it is possible than a larger scale pyrolysis plant could be feasible if the observed trend of lower unit costs at larger scale were to continue with increased plant size.

**Comparison of Results with 2003 CAED Study**

In 2003 CAED published a study of which the current paper is an update ("The Feasibility of Generating Electricity from Biomass Fuel Sources in Georgia", Wayne Curtis, et al, FR-0306, August, 2003, CAED, UGA). The basic finding was that the cost of producing electricity using biomass fuels in Georgia was only slightly above the prevailing commercial sales rates for electricity in Georgia at that time. It appeared that the outlook for electrical generation using biomass had a promising future. It should be noted that the 2003 study used a slightly different technology than evaluated in the current study.

The results of the current report paint a different picture. The cost of converting biomass into electricity using the current technologies is well above current commercial electrical production cost and above current electrical retail prices. The root cause of the different findings involves technology changes in the current report compared to the 2003 report.

In the 2003 report, it was reported that the then cutting edge theory for biomass conversion into electricity involved generating a bio-fuel, either via gasification or pyrolysis, and burning that fuel directly in a turbine engine that would power a generator to produce electricity. Heat generated by the turbine would be captured to create steam that would power a second steam powered turbine that would also generate electricity. Experience has shown that this theory will not work in practice. It seems that the crude syn-fuel has highly corrosive properties (10-20% corrosive gases and solids) that will quickly destroy the turbine engine. Refining of the crude syn-fuel prior to burning in the turbine proved to problematic as the heating value of the syn-fuel is depleted up to 75 percent rendering it almost useless as a fuel.

The current report is based on technology that is proven in practice. The basic gasification and pyrolysis methods are used to produce a syn-fuel. The syn-fuel is then burned directly in a boiler specifically designed to operate on syn-fuels. The boiler creates steam that is then used to produce electricity. The system does work from a technological point of view. The problem is that much less electricity can be produced using this method than theoretically could have been produce by the 2003 method – had it worked.

The following table is a comparison of the 2003 and current study findings. The generating capacity of all the cases studied is reduced by the change in the technology from the 2003 study to the current situation. And there lies the source of the differences between the 2003 study and the current findings. The technology posited in 2003 did not work as predicted.

A second minor source of difference in the cost of producing electricity between the two reports concerns the assumed cost of securing feedstock at the plant. The 2003 study assumed average delivered feedstock cost of $20 per ton while the current study assumed average delivered feedstock costs of $25 per ton. The cost rise was due to both increased costs of the raw materials in some cases but also due to a considerable increase in transport costs. The average difference the higher feedstock cost means to the cost of generating electricity is about 0.6 cent per kilo Watt hour.

**Economic Comparison of Gasification and Pyrolysis Facilities**

| | 2007 Study Plant Size | | | 2003 Study Plant Size | | |
|---|---|---|---|---|---|---|
| **Gasification** | **160 WTPD** | **267 WTPD** | **533 WTPD** | **160 WTPD** | **267 WTPD** | **533 WTPD** |
| Production Capacity (kW) | 5,956 | 9,924 | 19,848 | 6,294 | 10,061 | 20,227 |
| KiloWatt Hours Per Year | 50,032,000 | 83,360,000 | 166,720,000 | 55,135,440 | 88,134,360 | 177,188,520 |
| Total Estimated Capital Cost | $19,564,260 | $29,340,948 | $43,777,740 | $19,122,000 | $28,626,000 | $45,462,000 |
| Capital Cost per kW | $3,284.69 | $2,956.62 | $2,205.69 | $3,038.13 | $2,845.24 | $2,247.59 |
| Estimated Operating Costs | $5,452,557 | $8,128,049 | $13,240,628 | $4,569,378 | $6,530,229 | $11,180,780 |
| **Operating Cost per kWhr** | **$0.109** | **$0.098** | **$0.079** | **$0.083** | **$0.074** | **$0.063** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Pyrolysis** | **160 WTPD** | **320 WTPD** | **480 WTPD** | **160 WTPD** | **320 WTPD** | **480 WTPD** |
| Production Capacity (kW) | 4,064 | 8,127 | 12,191 | 4,652 | 9,570 | 14,370 |
| KiloWatt Hours Per Year | 34,134,400 | 68,268,800 | 102,403,200 | 41,627,520 | 83,833,200 | 125,881,200 |
| Total Estimated Capital Cost | $11,230,140 | $21,235,380 | $31,570,620 | $13,950,000 | $23,020,800 | $31,758,000 |
| Capital Cost per kW | $2,763.58 | $2,612.87 | $2,589.70 | $2,998.71 | $2,405.52 | $2,210.02 |
| Estimated Operating Costs | $3,923,799 | $7,424,748 | $10,498,667 | $3,848,568 | $6,891,721 | $9,931,939 |
| **Operating Cost per kWhr** | **$0.115** | **$0.109** | **$0.103** | **$0.092** | **$0.082** | **$0.079** |

**Firms are building gasification plants in Georgia.  Are We Missing Something?**

A reviewer of a draft posed the above question and it is a good one.  Why would firms enter into the business if the economics appear so bleak?  There are several potential answers to the question.

In analyzing the cost structure of producing electricity with the gasification process, one can see that feedstock costs and fixed costs, primarily debt service and capital recovery dominate while variable production costs are relatively low.  Fixed costs account for 53 percent, feedstock costs account for 35 percent while variable costs are only 12 percent of total production costs.  The following chart illustrates the situation.  If a firm can secure feedstock at a price below those used in the study, $25 per delivered ton, then production costs can be reduced directly.  A $5 per ton reduction in the price of feedstock will result in a one-half cent ($0.0054) reduction in production costs.  So, a firm that secures very low priced feedstock, say $5 per ton, could reduce costs 2.2 cents per kilowatt hour.  One industry source contacted indicated their anticipated feedstock cost would be near $5 per ton.

Another means for costs reduction is to lower that capital outlay from the firm by securing grants or other forms of assistance from government agencies.  Gasification and pyrolysis are very capital intensive operations and thus have high fixed costs of operation.  By reducing the costs of debt service and capital recovery, the firm can reduce production costs.  Let's assume that a firm was able to secure 25 percent of the capital requirement from grants, thus reducing its capital outlay for the largest gasification plant from $43.8 million to $32.85 million.  Fixed costs would be reduced by over $3 million per year resulting in a 1.8 cent per kilowatt hour reduction in production costs.  One firm that has announced plans to build a plant in Georgia has secured significant grant and loan guarantee support.

A third possibility is that firms entering the industry possess technologies that are more efficient that those modeled in this study.  Better technology usually implies lower unit costs of production.

In summary, it is possible that firms may be able to take a combination of the above advantages and produce electricity profitably or believe they can do so.  Reducing feedstock costs to $5 per ton and receiving 25 percent of capital in the form of grants could lower production costs from 7.9 to 3.9 cents per kilowatt hour making the firm quite competitive with existing technologies.



Gasification Costs
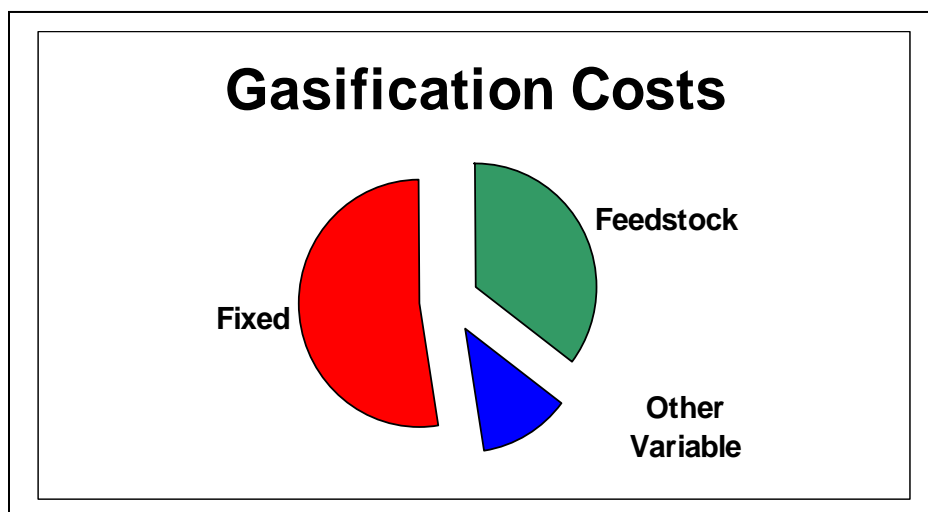
**An Assessment of the Potential for Electricity Generation Using Manure Digesters on Georgia Dairy Farms**

The technology for producing electricity from animal waste on commercial farms has existed for more than a decade. Advances in this technology have accelerated at a rapid rate over the past several years. A number of factors have lead to this advancement, including improved reliability of the anaerobic digesters used to capture methane gas from manure, an increased emphasis on environmental quality, the development of more state and federal programs to share in the cost of developing these systems, and the emergence of new state energy policies aimed at encouraging reliable renewable energy production.

One area of agriculture that has seen successful implementation of a number of manure digesters nationwide is the dairy industry. Large to mid-sized dairy farms generally tend to be well positioned to benefit from on-farm electricity production from manure for several reasons. The most important is the concentration of available manure associated with the typical confined animal feeding operation model employed by many dairy farms. This model generally requires that the farm have a waste management plan in place. Since most such waste management plans in Georgia center around the use of a lagoon of some type, manure collection and concentration is a function that is already performed on the farm. Geisy, Wilkie, De Vries, and Nordstedt recently conducted a study of the feasibility of using anaerobic digesters to produce electricity on Florida diary farms. Results of the study found the feasibility of the systems studied to be sensitive to capital investment, interest rates, and the wholesale price of electricity.

This brief study is intended to assess the potential for electricity production from dairy waste in Georgia. Based on a feasibility analysis spreadsheet developed by the University of Florida Extension Service, as well as discussions with individual producers, the minimum farm size necessary for a digester to be economically feasible is in a 500-600 cow range. Based on annual milk production data obtained from the USDA's Agricultural Marketing Service/Dairy Programs Division there were 344 dairy farms in the state in 2005. Of these 344 farms, only about 25 had 500 or more cows. Although these 25 farms account for less than 8% of dairy farms in the state, they represent approximately 45% of its total milk production and thus about 45% of the state's dairy waste (Figure 1).

Figure 1.

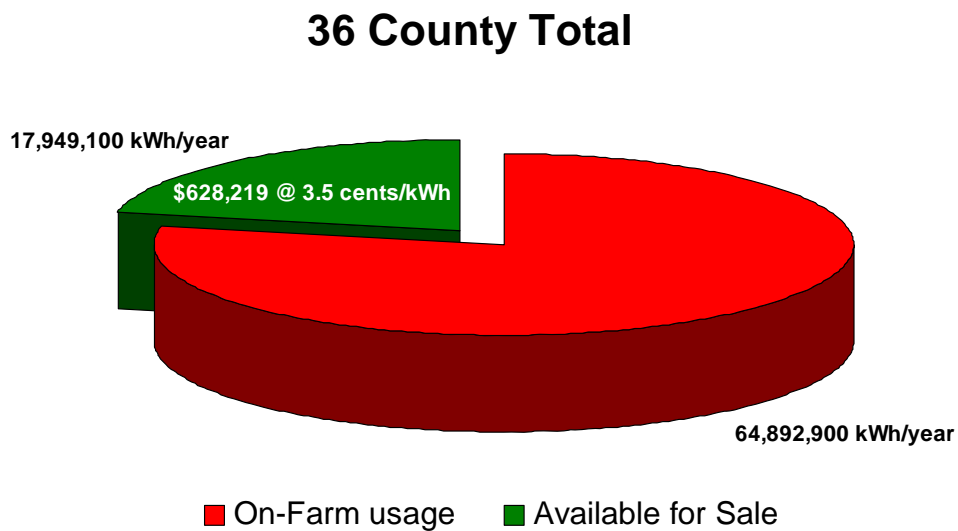**2005 Georgia Dairy Farms By Size**
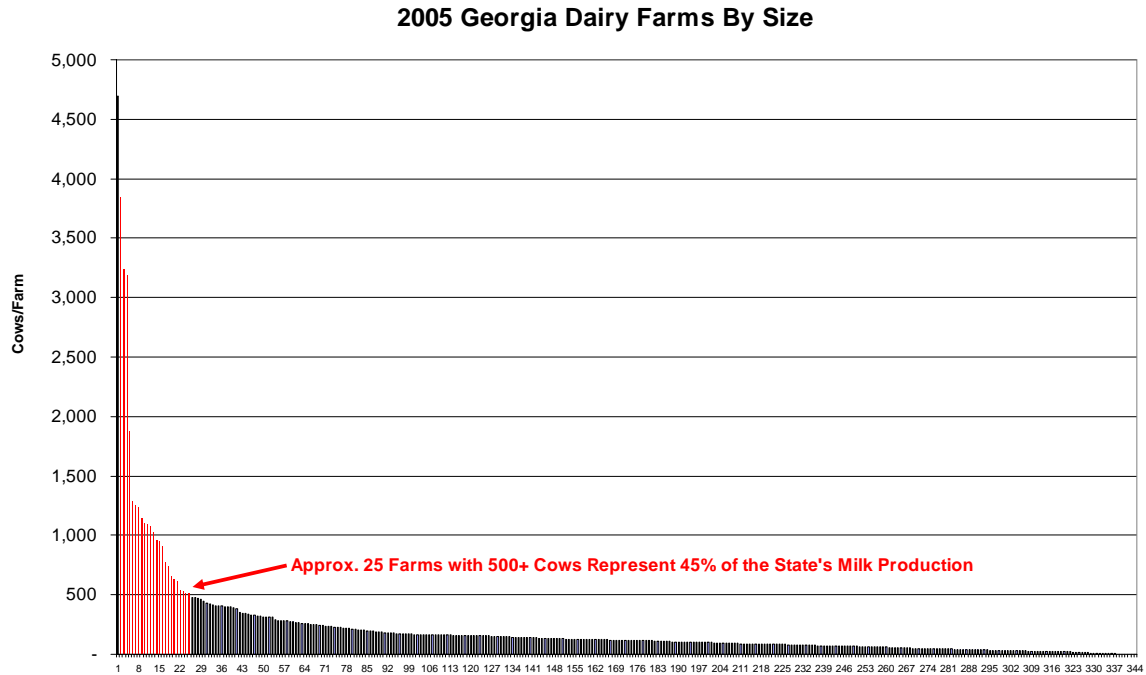


The possibility exists for groups of small, centrally located dairy farmers to form a cooperative type structure that could pool a sufficient amount of manure to feasibly operate a manure digester. The feasibility of such an arrangement was studied by Mehta (2002) for small to mid-sized dairy farms in Wisconsin.  Economic feasibility would obviously be limited by the cost associated with collecting and transporting manure to a central location for electricity generation. Assuming that manure could be cost effectively hauled within an individual county, the 36 counties shown in Figure 2. represent potential digester locations based on having at least 500 cows each. Collectively, these 36 counties represent approximately 89% of the state's total milk cows, and hence about the same percentage of its total dairy waste production. Aggregating small dairy farms to a county level significantly increases the portion of the state's dairy waste that is available for electricity production over that which is produced only by 500 cow or greater herds.
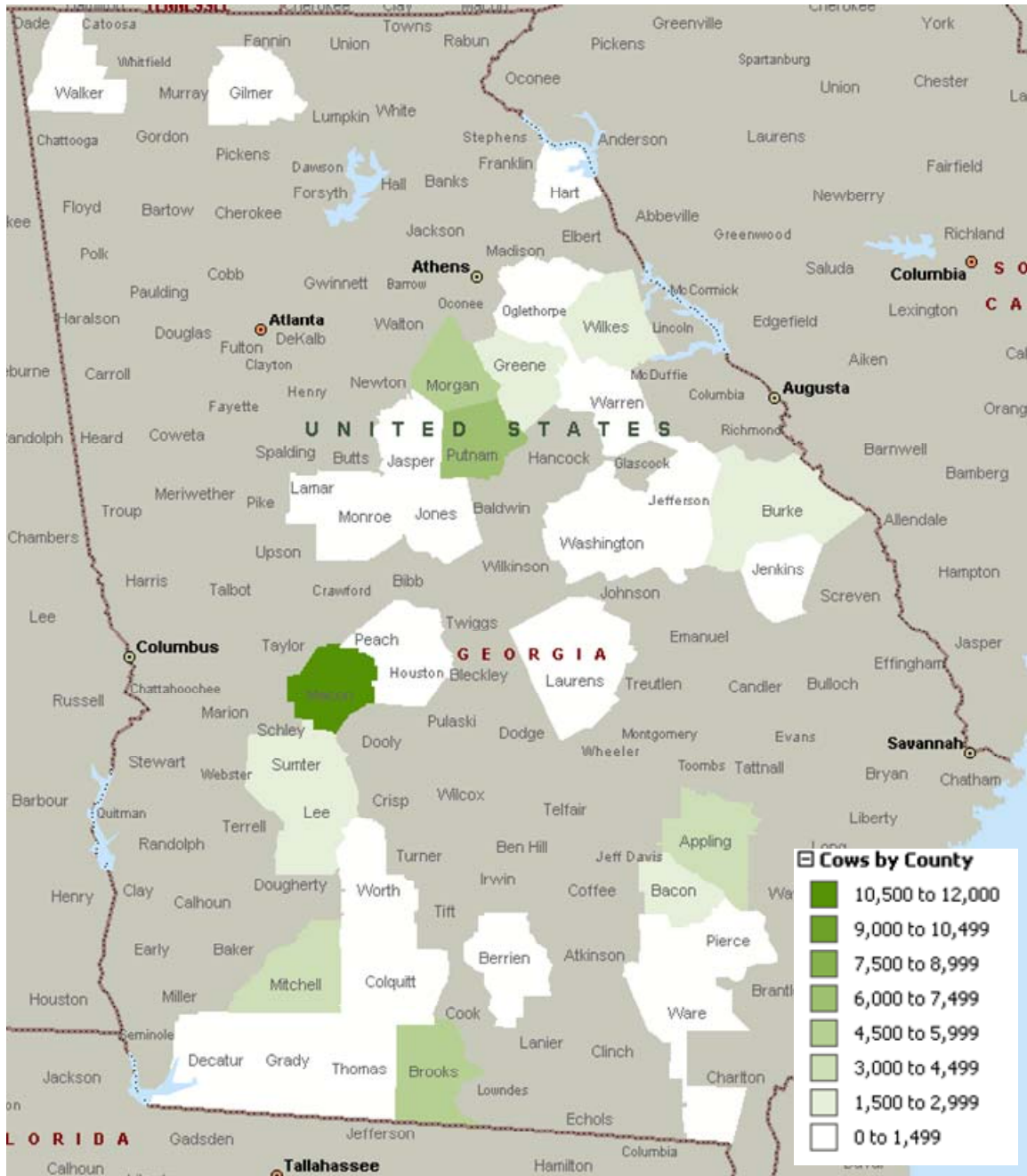
Based on a review of existing literature and conversations with digester operators, the following simplifying assumptions are made. A complete digester system for a model 1,000 cow dairy will cost approximately $1 million to construct and will produce about 1.2 million kWh/year of electricity. A farm of this size will consume about 940,000 kWh/year internally and will be left with an additional 260,000 kWh/year to sell to an outside source at a wholesale rate of 3.5 cents per kWh. It is further assumed that these cost, production, usage, and sales figures may be scaled up or down in a linear fashion to accommodate larger or smaller herd sizes.

Applying these simplifying assumptions to the 36 Georgia counties that had 500 or more head of dairy cattle in 2005, the production, usage, and sales availability estimates shown in Figure 3 were calculated.  For these 36 counties as a whole, total waste from all 69,000 dairy cows is estimated to have the potential for generating 82.8 million kWh of electricity annually. Of this amount, about 64.9 million kWh would be consumed internally by the farms and an additional 17.9 million kWh would be available for sale. At a wholesale rate of 3.5 cents/kWh, this would generate approximately $630,000 in revenue Figure 4.

Figure 4.



## 36 County Total

17,949,100 kWh/year

$628,219 @ 3.5 cents/kWh

64,892,900 kWh/year

■ On-Farm usage    ■ Available for Sale

This simple analysis does not consider the costs associated with transporting manure within a county to a central digester location, or any transaction costs that may be involved in working with a local electricity supplier. The digester owner's capital investment, interest rates, and fluctuation in retail and wholesale electricity prices could significantly impact the validity of these assumptions used in these calculations.
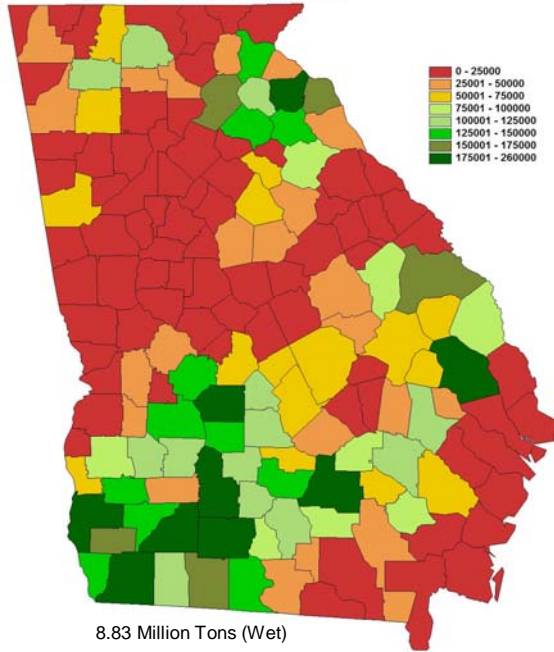
**kWh/Year Production Capability**
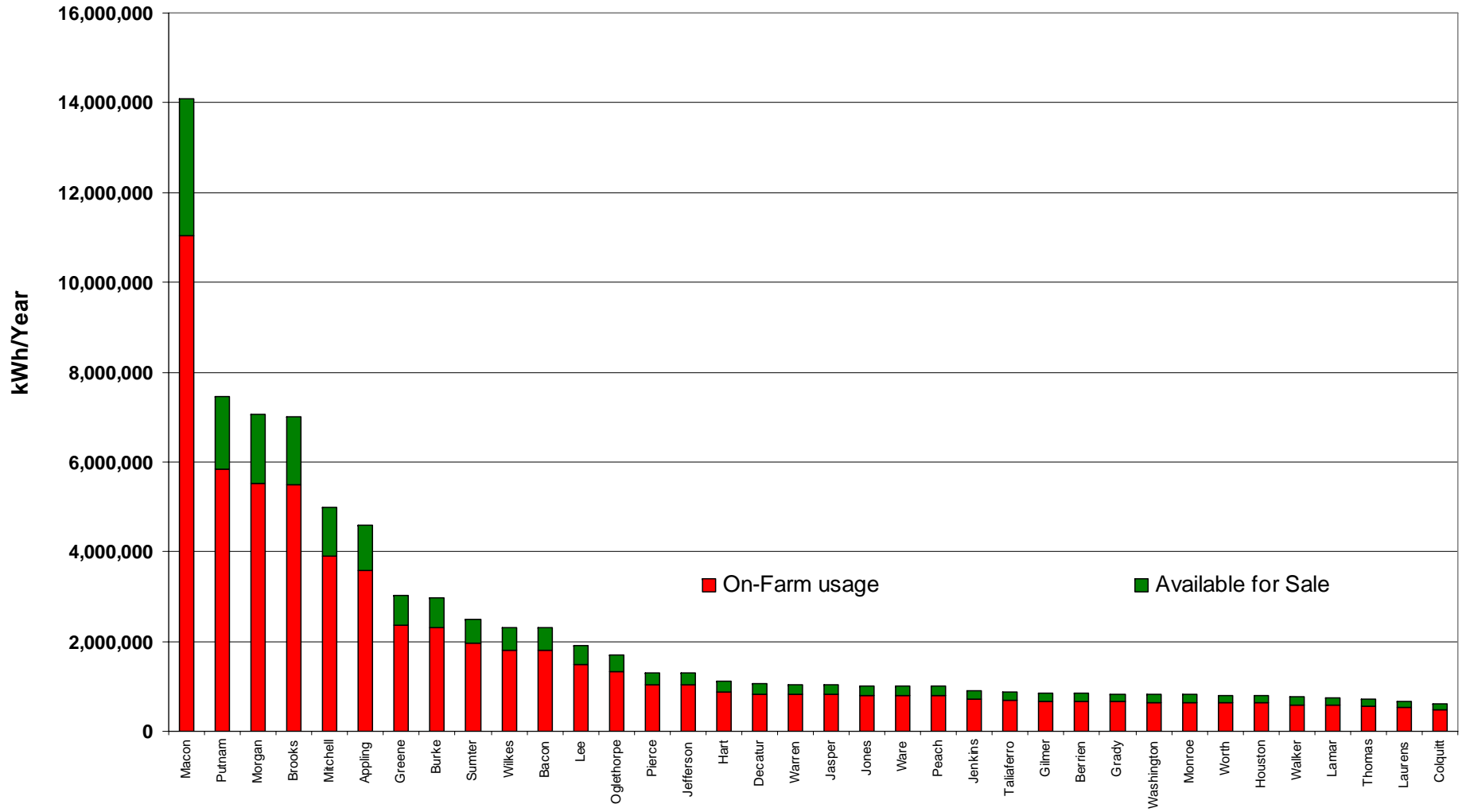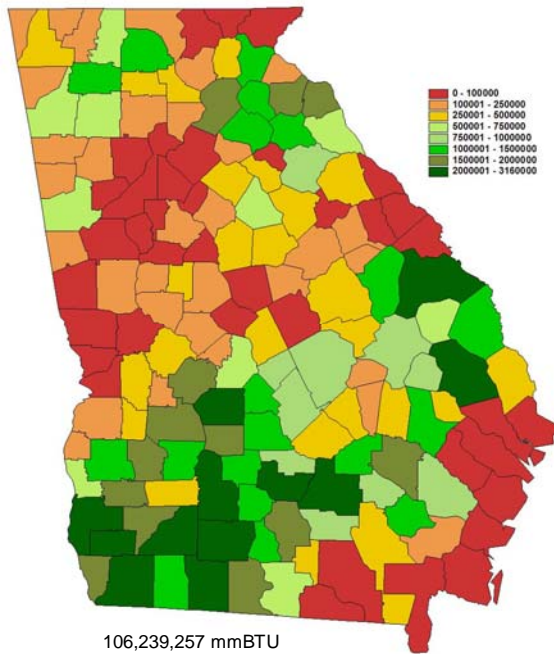
## Biomass Study Summary

This study evaluated the use of biomass for the purpose of generating electricity using current technologies to determine whether or not it is economically feasible in the current economic environment.  Three different plant sizes for two different but related technologies were studied.  Gasification of biomass shows promise as technologies for utilizing the syn-gas improve but as yet the cost of generating electricity is above current retail rates in Georgia.  Pyroysis was also evaluated but showed less promise as it appears to be a less efficient means of gathering the available energy from the biomass.  The resulting bio-fuel has a lower Btu content than that from gasification and thus a lower electricity yield and resultant higher cost per unit of production.  The basic findings are that while it is technologically feasible to accomplish the task, it is not economically feasible to convert biomass into electricity in Georgia at the present time.  The exception is that large dairies or smaller dairies that pool their manure may be able to produce electricity at competitive rates.
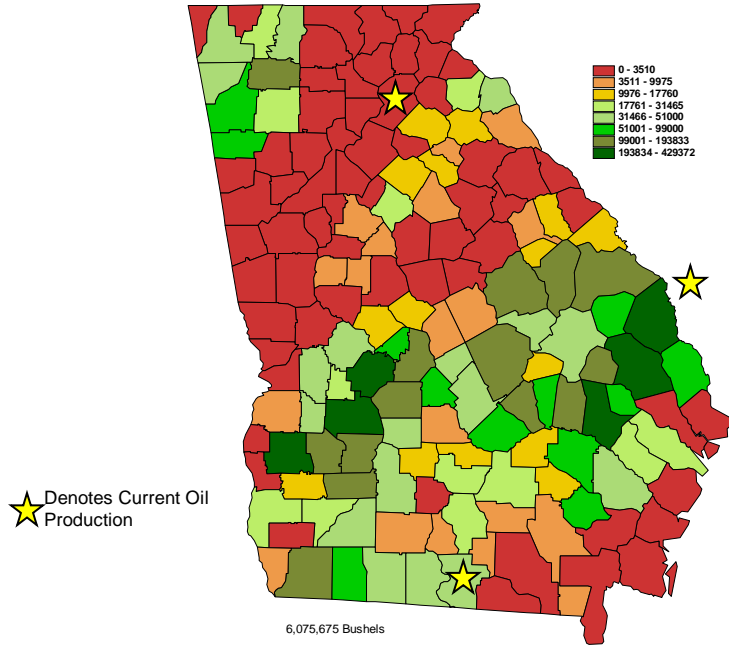
APPENDIX
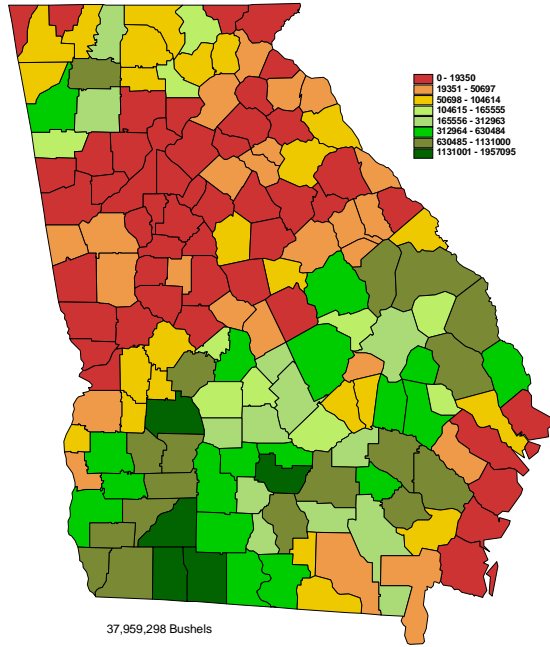
Estimated Biomass Available from
Ag-Related Sources (Tons)



| | |
|---|---|
| ▮ | 0 - 25000 |
| ▮ | 25001 - 50000 |
| ▮ | 50001 - 75000 |
| ▮ | 75001 - 100000 |
| ▮ | 100001 - 125000 |
| ▮ | 125001 - 150000 |
| ▮ | 150001 - 175000 |
| ▮ | 175001 - 260000 |

8.83 Million Tons (Wet)

Estimated Biomass available from Ag-Related Sources, (mmBTU)



| | |
|---|---|
| ▮ | 0 - 100000 |
| ▮ | 100001 - 250000 |
| ▮ | 250001 - 500000 |
| ▮ | 500001 - 750000 |
| ▮ | 750001 - 1000000 |
| ▮ | 1000001 - 1500000 |
| ▮ | 1500001 - 2000000 |
| ▮ | 2000001 - 3160000 |

106,239,257 mmBTU

41

Soybean Production, Total Bushels
(2006 Farm Gate Value Report)



0 - 3510
3511 - 9975
9976 - 17760
17761 - 31465
31466 - 51000
51001 - 99000
99001 - 193833
193834 - 429372

Denotes Current Oil
Production

6,075,675 Bushels

Corn Production, Total Bushels
(2006 Farm Gate Value Report)



0 - 19350
19351 - 50697
50698 - 104614
104615 - 165555
165556 - 312963
312964 - 630484
630485 - 1131000
1131001 - 1957095

37,959,298 Bushels

Poultry & Eggs, Total Farm Gate Value
(2006 Farm Gate Value Report)



0 - $4,694,679
$4,694,679 - $12,908,160
$12,908,160 - $22,831,066
$22,831,066 - $36,877,896
$36,877,896 - $53,268,850
$53,268,850 - $103,972,654
$103,972,654 - $196,151,376
$196,151,376 - $280,632,537

$4,393,640,206
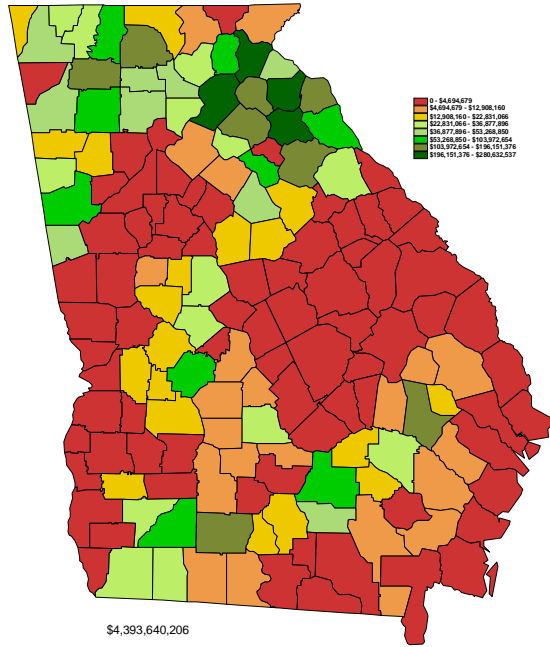
Broiler Grower, Total Farm Gate Value
(2006 Farm Gate Value Report)



0 - $173,556
$173,557 - $631,536
$631,537 - $1,297,613
$1,297,614 - $2,203,407
$2,203,408 - $3,666,364
$3,666,365 - $6,595,117
$6,595,118 - $12,249,170
$12,249,171 - $27,768,914

$409,315,065

43
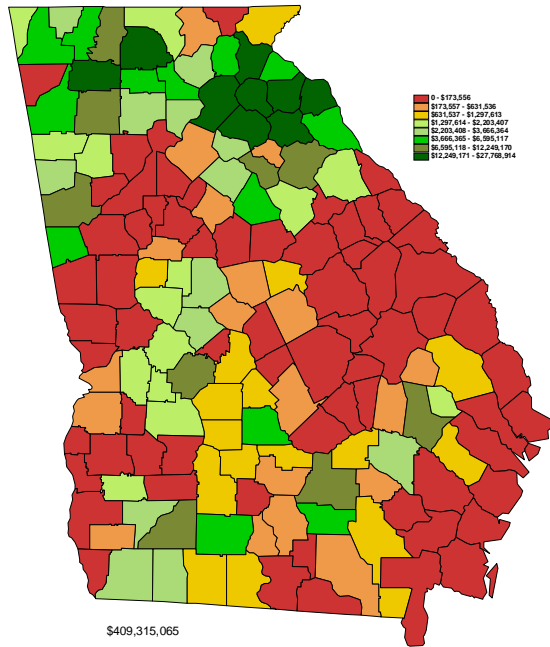
# The Center for Agribusiness & Economic Development

The Center for Agribusiness and Economic Development is a unit of the College of Agricultural and Environmental Sciences of the University of Georgia, combining the missions of research and extension. The Center has among its objectives:

> To provide feasibility and other short term studies for current or potential Georgia agribusiness firms and/or emerging food and fiber industries.

> To provide agricultural, natural resource, and demographic data for private and public decision makers.

To find out more, visit our Web site at: http://www.caed.uga.edu

**Or contact:**

**John McKissick, Director**
**Center for Agribusiness and Economic Development**
**Lumpkin House**
**The University of Georgia**
**Athens, Georgia 30602-7509**
**Phone (706)542-0760**
**caed@agecon.uga.edu**

**Report Number: CR-07-16**                                          **March 2007**

J. Scott Angle, Dean and Director