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Fluidized Bed Gasification and Pyrolysis of Cotton Gin Trash for Liquid Fuel Production

Sergio Capareda, Assistant Professor

Calvin B. Parnell, Jr., Professor

Biological and Agricultural Engineering Department, Texas A&M University, College Station,
Texas 77843, E-mail: scapareda@tamu.edu

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Abstract. A biomass fueled fluidized bed gasifier was developed in the late 1980's. A patent was issued to Parnell and Lepori in 1988 at Texas A&M University for a system based upon fluidized bed gasification (FBG). Cotton gin trash and other biomass feedstock were used as fuel to generate heat energy for power production. These biomass fuels have low melting points and thus, gasification rather than combustion was deemed necessary. The relatively low price of conventional fuels in the 1990's resulted in limited progress in advancing gasification studies. The TAMU FBG can be operated on pyrolysis mode to produce liquid fuels such as bio-oils. With the price of conventional fuels steadily rising in recent years, attention has been focused on the use of the TAMU FBG for the production of valuable liquid fuels from biomass and particularly from cotton gin trash.

The goal of this study was to evaluate the feasibility of producing high value liquid fuels such as kerosene (JP-8), diesel, and gasoline-like fuels from fluidized bed gasification of cotton gin trash. A 305 mm (1') diameter laboratory scale fluidized bed gasifier was used to produce the syngas for liquid fuel production. Novel zeolite catalysts will be used for the reforming process of the low calorific value gas in addition to using steam under high temperature and pressure. The liquid fuels produced will be analyzed using a gas chromatograph.

Keywords. *Fluidized bed gasifier, low calorific value gas, char, liquid fuels.*

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Introduction

There is renewed interest in the thermal conversion of biomass waste for energy recovery purposes. Cotton gin trash (CGT) is produced in abundance in cotton gins and usually left unutilized. Piles of gin trash accumulate in gin yards every ginning season and are sometimes the cause for environmental concerns. Electrical and drying energy usage in a cotton gin is on the average about 50 kWh/bale and 200,000 Btu/bale, respectively (TCGA, 2006). Several hundred thousands of dollars are spent for utilities alone. A 40 bale per hour facility would need at least 2 MW of power to run the operation. The energy content of trash generated in a gin far exceeds this energy requirement (Figure 1). A typical stripper gin will handle 500 lbs of trash per bale while a picker gin averages 200 lbs/bale. The energy content of cotton gin trash is roughly 7000 Btu/lb. If the material is converted into heat and electricity during the ginning season, the electrical output far exceeds the electrical power requirement of the gin (Figure 3, higher yellow bars). If the gin trash is used as fuel for producing electrical energy for the grid using a 2 MW power plant for an entire year, large amounts of gin trash will need to be accumulated and stored for when the gin is not processing cotton.

An alternate scenario is to use the 2 MW power plant during the ginning season to generate electricity and use the same system to produce liquid fuels from gin trash in the off-season. In this scenario, a smaller electrical power generation unit may be installed. This scheme may be practical in a cotton gin because of minimal initial capital investment for a thermal conversion facility. Clearly, there is excess energy when gin trash is converted thermally. Each operating gin could be self sufficient in its overall energy requirements if part of the trash is converted into electrical power and heat during the ginning season. The excess trash could be further used to produce valuable liquid fuels for transport.

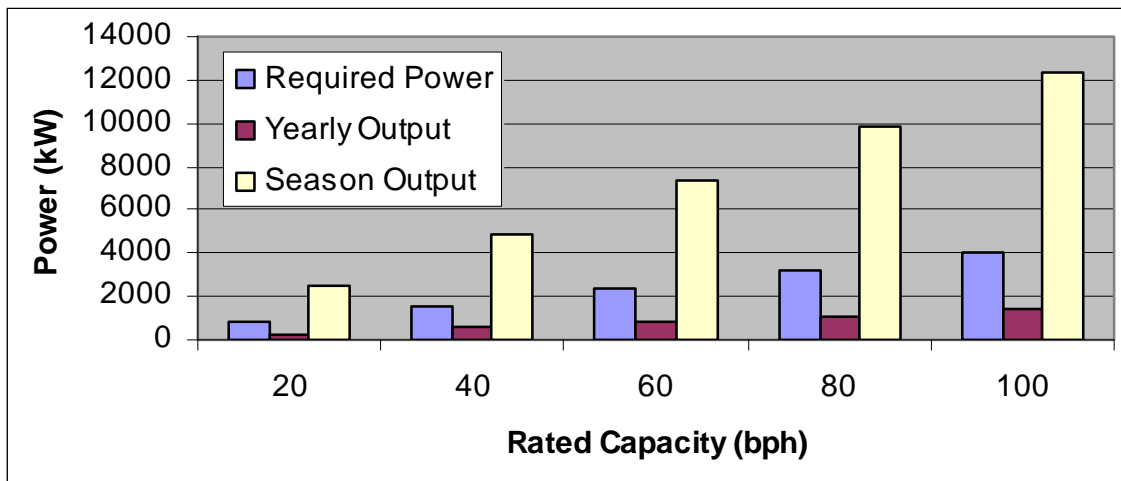


Figure 1. Required and potential power that could be generated in a typical cotton gin.

History

Texas A&M University has held the patent for a biomass fueled fluidized bed gasifier (FBG) since 1988 (Parnell and LePori, 1988). The biomass conversion unit has high throughput and can convert a variety of biomass residues. Gasification is an ideal thermal conversion process to use since many biomass fuels are characterized as having ash with low melting points. In a fluidized combustion system in contrast to gasification, the gas temperatures above the bed

increase as a consequence of burning gasses resulting in melted biomass ash and corresponding slagging and fouling problems. FBG results in decreasing gas temperatures leaving the bed which eliminates the slagging and fouling problems. Low calorific value (LCV) gas (150 Btu/ft³) is produced. The end product of the fuel leaving the fluidized bed was referred to as “char”. This char consisted of small particles comprised of ash and un-reacted carbon. The TAMU patent includes a two-stage cyclone system that is used to remove the char. Capareda (1990) reported that the char from fluidized bed gasification of cotton gin trash was in fact activated carbon with significant benefits as a potential waste water treatment control. Another unique aspect of the TAMU FBG patent was the staged combustion process. Cotton gin trash contains nitrogen. This fuel nitrogen was converted to NO_x in the process. A staged combustion process was incorporated to reduce the NO_x emissions (Cabrera et al., 1999).

The gasifier produces a gas that could readily produce steam in a fire tube or water tube boiler and can to be used in a turbine to generate electricity. Heat energy could also be recovered from the system for drying purposes. Different biomass residues (cotton gin trash, wood chips, rice hulls and manure) have been tested using the unit. Production of electricity from gasification of biomass is a proven technology and the cost effectiveness is becoming attractive. Figure 2 shows the schematic of the TAMU fluidized bed gasifier. The refractory bed material in the reactor is heated and fluidized before biomass residues are thermally converted in deficient oxygen to produce LCV gases. The LCV gases are then combusted in a two-stage process to reduce NO_x generation. About 10-20% of the material could be converted into char (>1.5% carbon content) which is a potential material for charcoal or activated carbon production. Raw CGT char has an iodine number (an indication of adsorptive ability) of about 300, while mild steam activation of the CGT char will bring this number to 600, equivalent to the iodine number of lignite-based activated carbon being sold in the commercial market (Capareda, 1990).

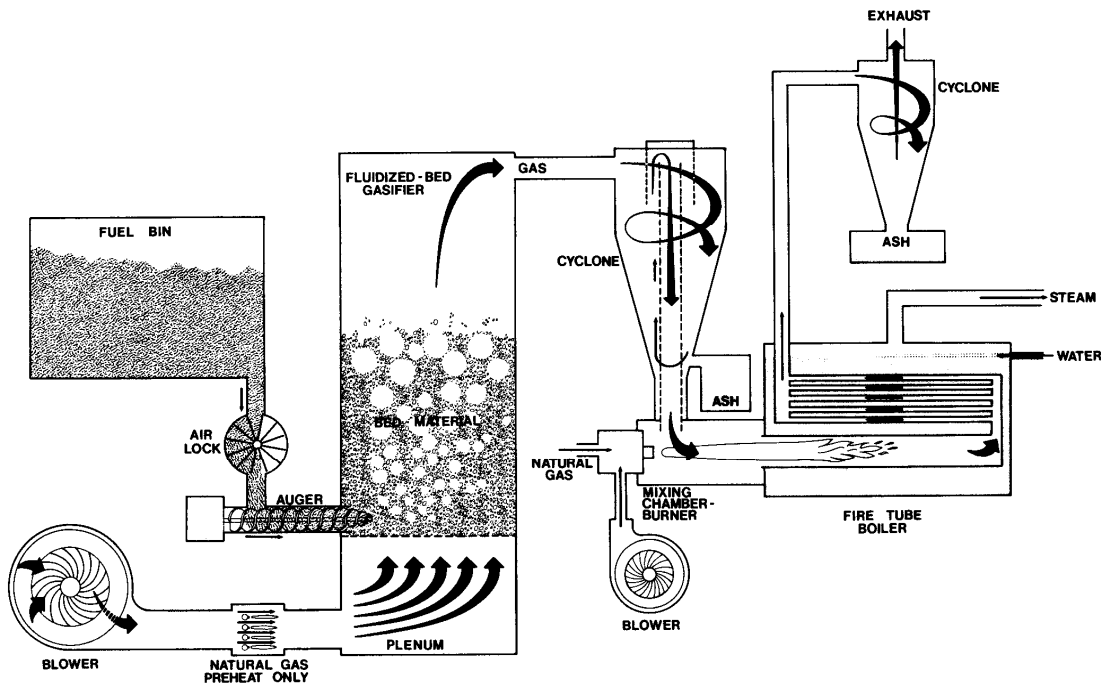


Figure 2. Schematic of the TAMU fluidized bed gasifier (Hiler and Stout, 1985).

Alternative to Electrical Power Generation

The TAMU FBG may also be configured to produce electrical power via conventional gas engines by installing an effective gas clean-up system as shown in Figure 3. A conventional gas engine may be used for this purpose. This set-up would eliminate the need for the more expensive steam generation and turbine option. The small 305 mm diameter fluidized bed facility at Texas A&M University could handle more than 2 tonnes of cotton gin waste per day. Electrical power output of approximately 50 kW could be readily produced and excess heat in the order of about 1 MMBtu/hr day may be used for drying. Thus, it was envisioned that a small fluidized bed facility installed in each cotton gin would be able to generate enough electrical power to handle part of the gin's electrical energy needs. In addition, the LCV gas may also be be used as an input for liquid fuel production via steam or catalytic processes using excess CGT. Studies were initiated in the late 1980's at Texas A&M to generate liquid fuels via the TAMU FBG. The gasifier may also be operated in a pyrolysis mode (complete absence of oxygen) with the use of an inert gas (nitrogen) as fluidizing medium. Pyrolysis, also called destructive distillation, is a thermal conversion in the complete absence of oxygen. The gaseous, liquid, and solid products are of better quality than gasification products. As conventional fuel prices increase in the near future, the production of synthetic petroleum from biomass wastes may become economical.

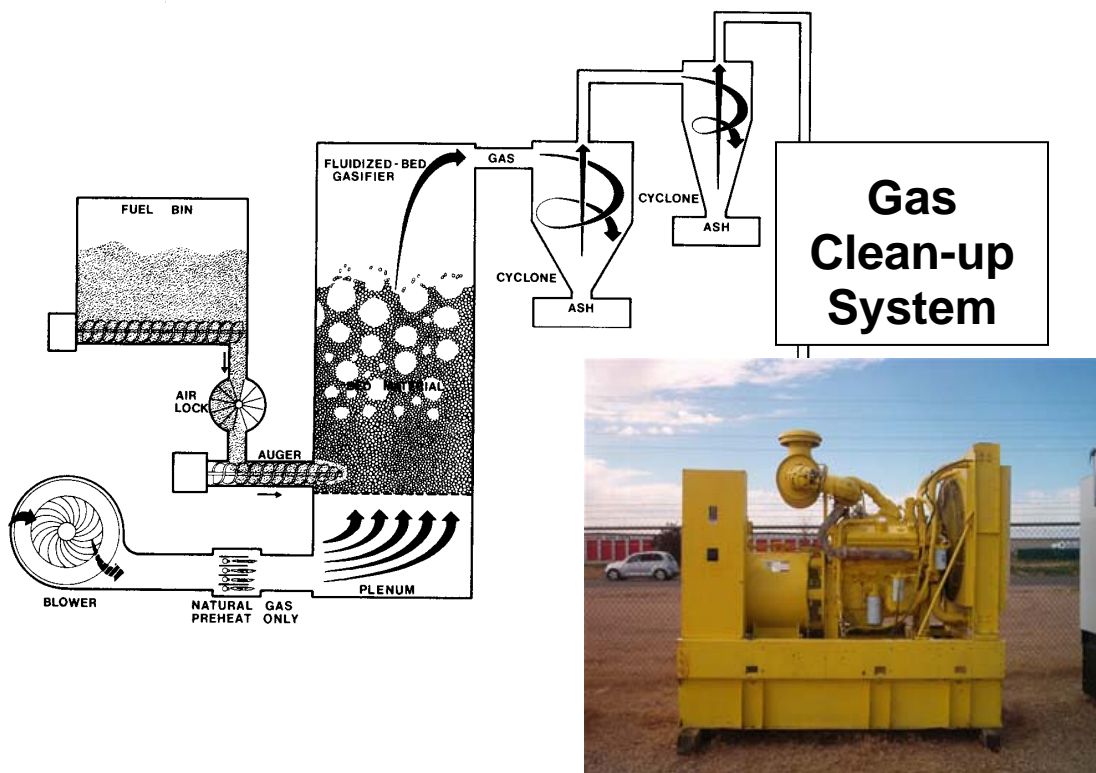


Figure 3. Schematic of the TAMU fluidized bed gasifier for engine-generator use.

Objectives

The current goal of the Biological and Agricultural Engineering Department at TAMU is to revive the gasification program initiated in the late 1980's and address the sustainable energy needs of the agricultural industry. A lot of high energy biomass wastes and residues accumulate in many agricultural facilities. The cost associated with harvesting and transporting these potential biomass fuels such as cotton gin trash are minimal in that the material is delivered to the gin with the seed cotton. Our goal is to utilize these valuable agricultural resources and reduce dependence upon fossil fuels. In the process we will seek to generate highly valuable chemical products and by-products.

The specific objectives include the following:

- a. To develop the TAMU FBG for modular-scale applications (power and heat)
- b. To operate the FBG on gasification or pyrolysis mode to optimize LCV gas production as input for liquid fuel production, and
- c. To conduct advanced liquid fuel production and conversion processes

Materials and Methods

The pilot scale TAMU FBG is still in place at TAMU (Figure 4). The unit has a diameter of 305 mm with a throughput of about 80-100 kg/hr. The unit can handle more than two tonnes of biomass residues if operated continuously. The unit will be upgraded using currently available control systems and a gas clean-up system. Provisions will be put in place to operate the gasifier on a pyrolysis mode to improve the quality of gases produced which will be used as input for liquid fuel production. Baseline pyrolysis studies are underway (Aquino et al., 2007) to prepare process design parameters for the operation of the TAMU FBG. In addition, other baseline studies are being conducted to prepare the TAMU FBG for char and activated carbon production (Hernandez et al., 2007).



Figure 4. The pilot scale fluidized bed gasifier at TAMU.

Results and Discussion

Table 1 shows the results of initial studies on the thermal conversion of cotton gin trash into bio-oil (Hiler and Stout, 1985). Data for fuel oil (No. 6) is also provided. The heating value of bio-oil is 40% less by weight and 20% less by volume as compared to No. 6 fuel oil. The density of bio-oil is higher due primarily to the presence of tar and other heavier fractions. Both pour point and flash point are higher for bio-oil. The viscosity of bio-oil is four times higher than that of fuel oil.

Extensive studies were conducted at Texas A&M University in the 1980's on the hydro-processing of biomass thermo-chemical products (see Chapter 2, Reference 2, Hiler and Stout, 1985, pp 58-66). The research was extended to processing a wide range of biomass residues such as corncobs, sugarcane bagasse, cotton gin trash, rice hulls and nut shells. Several types of catalysts were screened for this purpose. Initial work with 0.5% palladium and platinum catalysts on alumina with hydrogen-donor solvents such as tetralin and decalin resulted in some hydrocracking and hydrotreating. Research studies were later expanded to include higher concentrations of noble metals on various supports as catalysts (Soltes, 1983). The hydrocarbons that were produced included branched- and straight-chain hydrocarbons in the C₅ to C₃₀ range. The use of feedstock such as cotton gin trash could provide a new breadth of products that may resemble light ends of the hydro-treated products with properties very similar to JP-8 (aviation fuel), diesel or gasoline.

Table 1. Comparative data between fuel oil and biomass pyrolytic tar.

	No. 6 Fuel Oil	Biomass Pyrolytic Tar
Components (wt%)		
Carbon	85.7	59
Hydrogen	10.5	7
Oxygen	2.0	32
Sulfur	0.7-3.5	0.1
Nitrogen	---	1
Properties		
Density, g/mL	0.98	1.3
kJ/kg	<u>42,333</u>	<u>24,656 (40% less)</u>
kJ/L	<u>41,473</u>	<u>33,167 (20% less)</u>
Pour Point, °C	18-29	32*
Flash Point, °C	66	111*
Viscosity, SSU, 88°C	340	1150*
Pumping temp, °C	46	71*
Atomization temp, °C	105	116*

Source: Hiler and Stout, 1985.

Sequential Use of Gasification and Pyrolysis

Pyrolysis is an energy intensive process. External energy is required to maintain the high temperature of the reactor for the operation to proceed. In the gasification mode, part of the biomass is thermally converted into low calorific value gas that is partially combusted to generate an endothermic reaction. However, gasification products are inferior in quality to pyrolyzed biomass. To address the high energy input required for pyrolysis processes, the sequential use of a gasifier and a pyrolyzer may be used. This is shown in Figure 5. The fluidized bed gasifier may be operated on the front end of the system to generate heat needed for the pyrolyzer while producing electricity to run the motors and blowers. Excess heat energy from the pyrolyzer may also be used to dry wet biomass. In addition, the pyrolysis reactor also produces high quality combustible gas which may be re-used together with the FBG gas to heat up the reactor, produce electricity, or dry wet biomass. The gas produced passes through a condenser to recover liquid products in the form of bio-oil. This bio-oil, together with the tar produced may be hydrogenated to generate other liquid fuels. Figure 6 shows the wide range of products that could be produced from pyrolysis and hydro-processing of cotton gin trash wastes. Phenols and activated carbon could be readily produced.

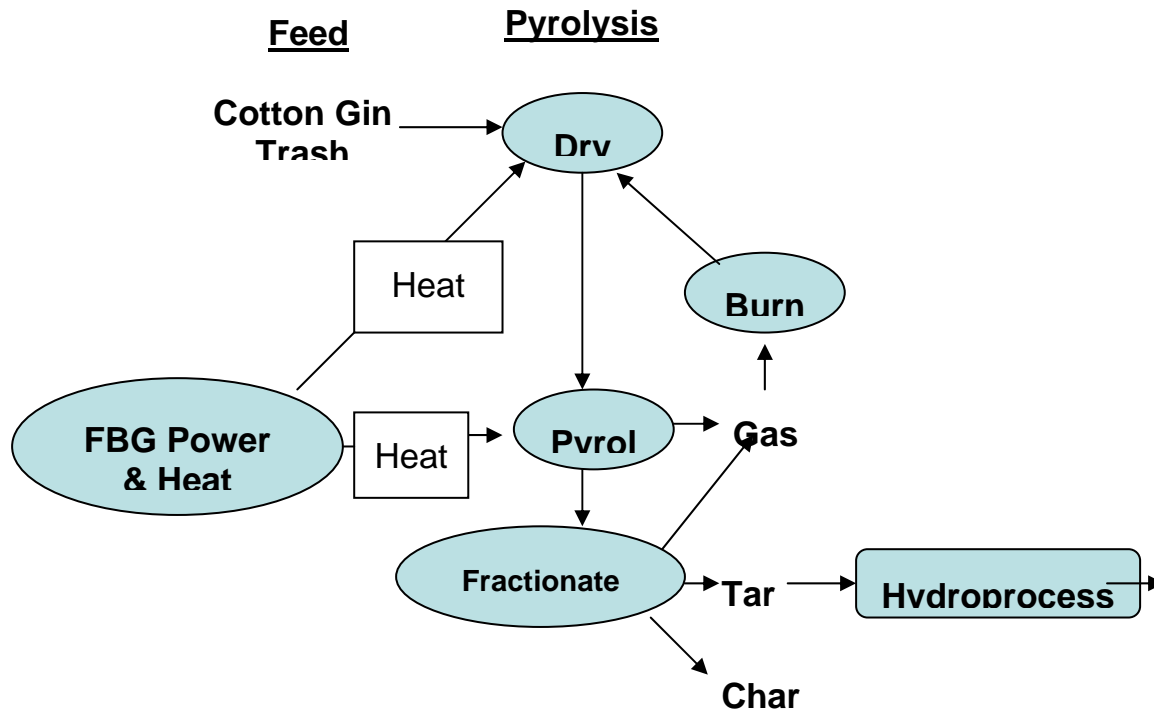


Figure 5. Schematic of sequential use of gasification and pyrolysis process (Modified from Hiler and Stout, 1985)

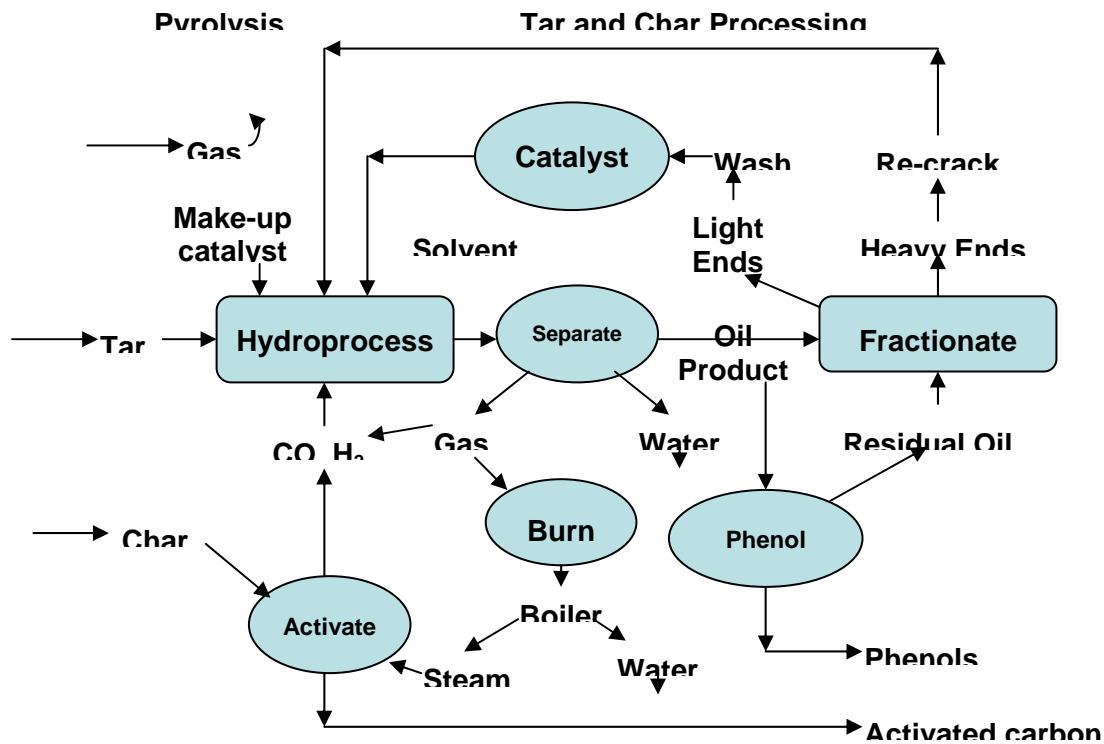


Figure 6. Schematic of products from pyrolysis and hydroprocessing of gin trash wastes (Hiler and Stout, 1985).

Hydrogenation of Biomass Wastes for Advanced Liquid Fuel Production.

The bio-oil product could be hydrogenated to generate various fuel feedstock. With the use of catalysts such as size selective zeolites, more fuel products could be produced. These include diesel-like compounds, dimethylether (DME), and aviation fuel (JP-8), among others. Gasoline-like products may also be fractionated depending upon the type of catalyst used. The schematic for tar processing is shown in Figure 7. Final blending using numerous additives is required to produce a product that would resemble gasoline or diesel.

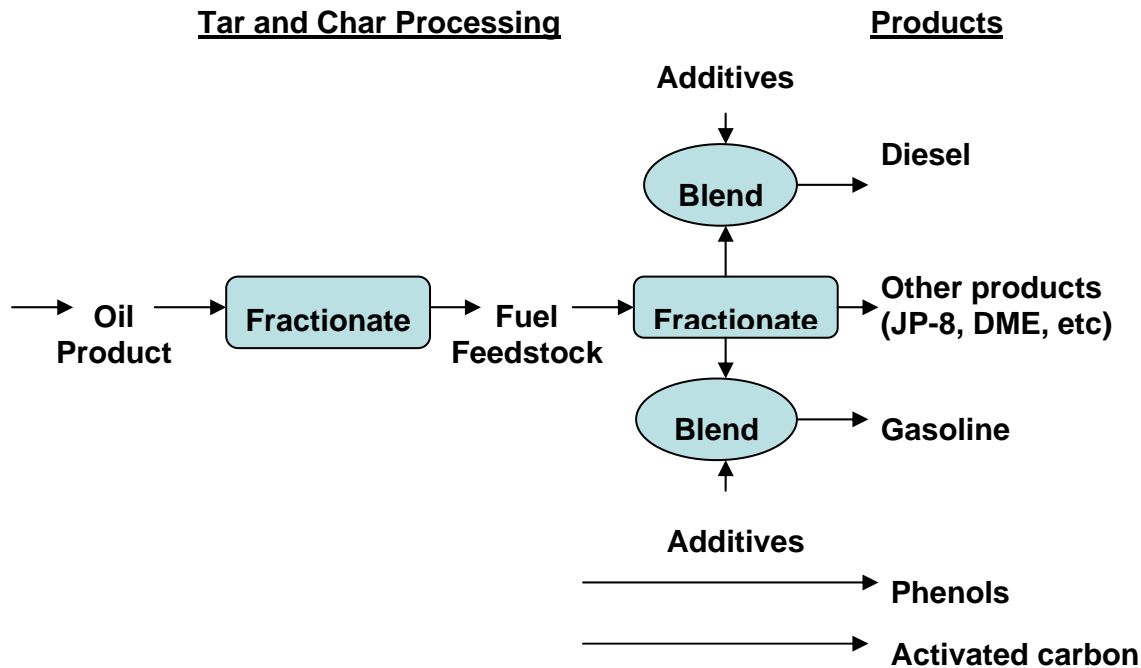


Figure 7. Liquid fuel production from gasification and pyrolysis of cotton gin trash (Hiler and Stout, 1985).

Conclusion and Recommendations

Electrical power and heat energy production from cotton gin trash via gasification is already a proven technology. Texas A&M has a patented a fluidized bed gasifier that may be used to generate heat and electricity. Because of current interest in the production of liquid fuels to slowly replace fossil fuels, gasification technology may become a ubiquitous conversion system in agricultural industries that generate large volume of wastes. Pyrolysis on the other hand is becoming an important thermal conversion process due to the high quality of gas, condensibles and char products produced. The only disadvantage of the pyrolysis process is the high energy requirement. Thus, the sequential use of gasification and pyrolysis could be a novel operative combination for the production of liquid fuels. Excess energy from gaseous and liquid products of the system could be used to produce liquid fuels for transport. The high quality char could be used to produce high value activated carbon.

The current research goal at Texas A&M is to bring the patented fluidized bed gasification technology to a number of agricultural facilities that generate volumes of waste to produce not only heat and electricity but liquid fuels for transport. Initial studies initiated in the 1980's showed that various liquid fuels could be produced via hydro-processing of bio-oil and tar product. The bio-oil produced has 40% heating value by weight and 20% less by volume compared with fuel oil No. 6. The use of catalysts could improve the fuel product and generate high value liquid

fuels such as gasoline and diesel-like fuels. Aviation fuels (JP-8) and other valuable chemicals such as dimethyl ether (DME) could be produced together with phenols and other alcohols.

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