Size matters: small distributed biomass energy production systems for economic viability

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Abstract: Current large scale biomass energy production systems including cellulosic ethanol, gasification, and pyrolysis facilities face significant technical and economic hurdles. Compared with these large scale systems, small distributed biomass energy production systems (DBEPS) are believed to offer advantages including lower capital costs, lower feedstock costs, simplified transportation and logistics and higher returns for biomass producers. DBEPS compliant technologies are expected to make utilization of regional biomass supplies practical and economically viable in the near-term. This paper presents arguments on the need and importance of DBEPS, available DBEPS options, and an economic scenario of DBEPS implementation on an average size farm in the US.

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Introduction

Renewable energy is one of the most feasible long-term strategic solutions to energy security and sustainable development. Wind power, solar energy, hydraulic power, geothermal energy, biomass power and fuels, and ocean power are the popular forms of renewable energy. In recent years, tremendous interest and investment have been directed towards production of energy from biomass, which accounts for 47% of all renewable energy or 4% of the total energy in the US. A 2005 United States Department of Energy (DOE) and United States Department of Agriculture (USDA) report projected that 1.366 billion dry tons of forest and agricultural biomass is available per year[1]. The notable rationale underlying this trend is the possibility of providing renewable liquid fuels for transportation and other uses where liquid fuels offer advantages, particularly in emissions control. Liquid fuels, which account for more than 45% of the total energy use in the US, have high energy densities, are easy to transport, store and handle, and are distributed through established infrastructure. Therefore liquid fuels made from biomass have the potential to replace petroleum-based liquid fuels. The same DOE and USDA report predicted significant increase in transportation fuels from biomass from 0.5% in 2001 to 4% in 2010, 10% in 2020, and 20% in 2030[1].

Biofuel boom competing with feed and food supply

Currently, ethanol from corn and biodiesel from soybeans are the most successful biofuels in the U.S. Increasing demand for biofuels is putting tremendous pressure on corn and soybean production. There are concerns about the corn ethanol and soybean biodiesel industries competing with feed and food supplies. For example, the price of corn rose by 70% between September 2006 and January 2007 to reach its highest level in a decade[2]. The feed and food industries and consumers are already feeling the pinch of increased corn prices due to the explosive growth in ethanol production encouraged by high petroleum prices, government support, and the promise of new technology[3].

Cellulosic biomass: A solution with many challenges

Increasing interest is being turned to the utilization of lignocellulosic agricultural crop and forest residues for

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biofuels and bioproducts because these cellulosic feedstocks are abundant and outside the human food chain. The federal government has invested heavily in the development of technologies for converting cellulosic biomass to ethanol. Earlier this year, DOE awarded $23 million federal funding for research[4] and $385 million federal funding for building six new cellulosic ethanol plants[5]. However, the cellulosic ethanol alternative faces difficult technical and economic barriers. The high capital costs coupled with high costs of enzymes and feedstock present very high risks to investors, blocking commercialization of the technology. One challenging issue is enzyme cost, so Federal agencies contracted with two major enzyme companies to develop low cost enzymes. In October 2004, Genencor was able to reduce the enzyme cost by 30 fold to $0.10–0.20 per gallon of ethanol, and Novozymes Biotech reduced enzyme cost from $5 to $0.30 per gallon of ethanol [6]. However, the overall cost for cellulose ethanol is still much higher than for corn ethanol. Nevertheless, the largest cost contributor is feedstock. Although cellulosic residues in the field are rather inexpensive[7], getting the residues to the processing plants and converting them to fermentable sugars is very costly[8]. A study funded by the DOE shows that the delivered costs for corn stover range from $43.1 per dry ton for a 500 dry ton/day facility (1,800 square miles collection area, 22 miles average one-way hauling distance) to about $51.6 per dry ton for a 4000 dry ton/day facility (14,000 square miles collection area, 62 miles average one-way hauling distance)[7]. The difference in delivered costs between facility sizes reflects transport costs, which account for 33% of total delivered costs for a 500 dry ton/day facility and 40% for a 4000 dry ton/day facility. Research has found that the financial advantage provided by large processing capacity may be offset by high delivered costs of feedstock, and suggests that biomass industry development should include smaller-scale facilities to be economically viable[9]. Furthermore, compared with corn ethanol production, additional processing costs are needed to convert cellulosic feedstock to fermentable sugars, which would raise feedstock-associated costs to as high as 70%～80% of the final product cost[10]. Thus, cellulosic ethanol faces challenges to reduce costs in feedstock transport and processing.

Distributed biomass energy production systems: A "smaller" solution

The above analysis leads us to believe that future economically viable alternative biomass processing systems must significantly cut down feedstock-related costs by reducing transport costs and developing more efficient processing technologies. Biomass has a very low bulk density (173 kg/m³ 2.98×10^6 kJ/m^3 for baled hay)) as compared with bio-oils (1473 kg/m^3 and 2.09×10^7 kJ/m^3) (Figure 1). This 7.5-fold improvement in BTU density is a key benefit of producing bio-oils from biomass. If biomass feedstock can be processed into bio-oils on the farm and the bio-oils can be used directly as a boiler fuel or transported to a central biorefinery for further processing, significant cost savings can be realized (Figure 2). To achieve this, alternative biomass energy production systems must be developed.

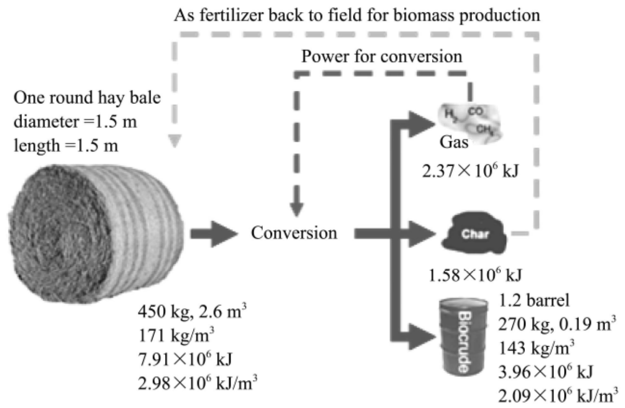

Figure 1 "Bale to Barrel" – on-farm biomass conversion approach

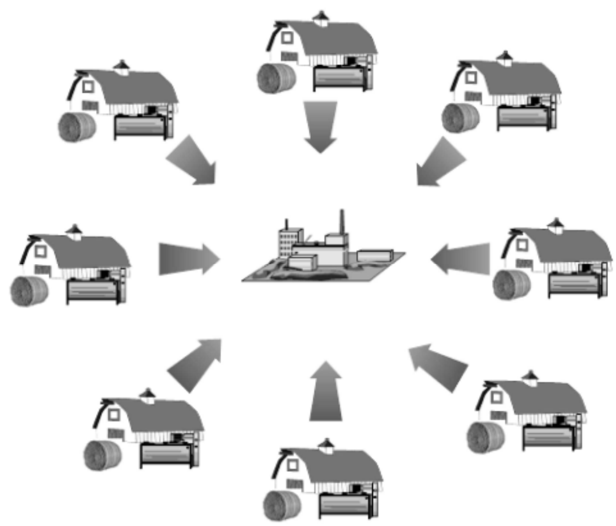

Figure 2 Distributed biomass processing scheme

The Distributed Biomass Energy Production System (DBEPS) concept relies on scalable technologies that can be implemented on average-size farms where crop residues are converted to bio-oils with minimal transportation. The bio-oils produced can be used as home heating oil or transported to a central biorefinery where upgrading and manufacture of other products can be carried out. Any DBEPS must meet the following criteria: (1) affordable capital cost, (2) low transport costs, (3) easy to operate (turn-key) technology, and (4) economic and social benefits for the rural community. A 40～50 million gallon cellulosic ethanol plant costs about $300 million to build while the cost for building an on-farm DBEPS facility would be lower than $200,000. Feedstock may be collected from one farm or neighboring farms with minimal transport costs. Operating a DBEPS facility should not require special experience or expertise. Farms can use the bio-oils or sell for profit.

Is DBEPS technology available?

Generally, thermochemical processing facilities are less expensive than biochemical processing facilities, such as the predominant dry-mill ethanol plants using corn grain, making the thermochemical approach is a good candidate for DBEPS. Gasification and pyrolysis are two popular thermochemical processes. Large scale gasification and pyrolysis facilities face the same problems associated with large scale cellulosic ethanol plants. Small scale on-farm gasification is not realistic because the farm cannot use all the produced syngas gas, and it is impractical to have an expensive syngas reforming or fermentation system onsite. We conclude that pyrolysis can be a very promising thermochemical process for production of liquid fuels. Pyrolysis of biomass is normally carried out in the absence of oxygen at a temperature about 400−500 ℃. All biomass components including lignin can be completely converted while cellulosic ethanol technology can only convert cellulose and hemicelluloses. Pyrolytic products include bio-oils, pyrolytic gas, and charcoal. Commercial pyrolysis facilities are very limited with just three North American companies using pyrolysis to produce bio-oil and other products[11]. They are Ensyn Technologyes, Inc., DynaMotive Energy Systems Corp., and Renewable Oil International. Ensyn and DynaMotive have plants up and running while Renewable Oil International is a small startup company with experience in demo systems. Current plant sizes are in the range of 45 to 100 tons per day, which will require a huge supply of feedstock. A 100 ton per day plant costs about $5.6 million to build. A big challenge for the Ensyn and DynaMotive systems is the cleanup of the bio-oils and pyrolytic gas.

The microwave-assisted pyrolysis (MAP) under development at the University of Minnesota[12] is a potential candidate for DBEPS. The key advantage of the MAP process is that thermochemical reactions can take place rapidly in large-sized biomass materials such as woody biomass or cornstalks thanks to the nature of fast internal heating by microwave energy. Therefore, very fine feedstock grinding required by conventional pyrolysis is not necessary for MAP, resulting in substantial energy savings. Because there is no rigorous agitation and fluidization during the process, the presence of particles in the vapor stream is minimal and, therefore, the collected bio-oils and gas are very clean. Furthermore, microwave is a mature technology and relatively inexpensive and highly scalable. Researchers at the University of Minnesota have developed a continuous MAP pilot system (Figure 3 schematic). The pyrolytic gas produced is used to generate the electricity to power the MAP process. The condensation and distillation devices are designed with recycling water or coolant to minimize water usage in the process. A 0.5 ton/hour system can be easily mounted on a trailer and moved to different farms.

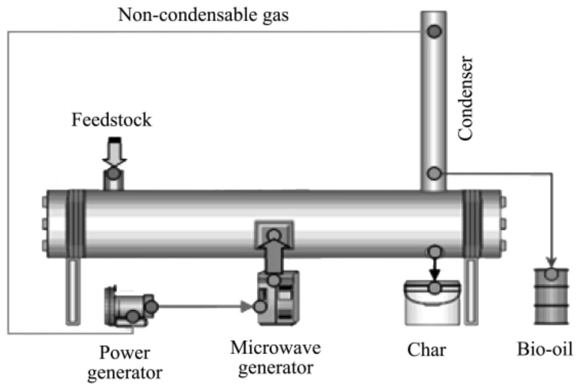

Figure 3 Microwave Assisted Pyrolysis (MAP) System

A MAP scenario

We assume that a farm with 1,000 acres of corn crop yields 3,000 tons of corn stover, with 50% collected as feedstock. The farm purchases a small scale pyrolysis facility with 0.75 ton/h capacity at $200,000, similar to the cost of a combine harvester used for the corn crop. The facility is expected to have at-least 10-year life time. The facility will be run 8 hours/day and process 6 tons/day. Facility operation time is 250 days per year. Pyrolysis of the feedstock yields 50% bio-oil, 20% char, and 30% pyrolytic gas. The compositions and properties of these products[12] are similar to those produced by other commercial pyrolytic processes[13]. The bio-oil price is estimated at $1/gallon based on the published #2 heating oil price in March 2007 [14]. The pyrolytic gas is used to generate electricity and heat, which could provide all the electricity needed for the pyrolysis process. Additional electricity is purchased to power peripheral equipment, such as the stover chopping system. The char, which is believed to be an excellent slow-release fertilizer and soil conditioner[15], may be sold at $50/ton. Table 1 shows an estimate of income and costs. The feedstock cost is significantly lower than that for large ethanol or pyrolysis plants, chiefly because of savings in transportation. The $42,545 additional net income, based on the conservative estimates, should certainly be attractive number to many farmers seeking an enterprise that utilizes their biomass and employs their labor.

Compared with current large-scale biomass energy systems, DBEPS is more technologically feasible, economically viable, and sustainable. The DBEPS offers a valid near-term solution to the realistic utilization of bulky biomass, and presents substantial opportunities for greater economic benefits with the biomass energy industry, and smaller-scaled distributed processing facilities. The DBEPS should also be particularly attractive in developing countries where funds for large-scale plants are scarce, technical management skills are lacking, and the income generated is attractive in the rural community.

Table 1 Estimation of income and costs*

Items	Quantity	Value /unit	Amount
Revenue			
Sale of Bio-oil (gal)	168,000	$1.00	$168,000
Sale of Char as fertilizer & liming (dry tons)	300	$50	$15,000
	Total Sales		$183,000
Costs			
Feedstock (Dry Tons)	1500	$32.91	$49,365
Processing Labor (Hours)	1000	$12	$12,000
Pyrolysis Machinery Depreciation			$30,000
Electricity Purchased			$8,640
Consumables			$9,150
Maintenance			$10,000
Other Expenses			$18,300
Transportation of Bio-oil to Market (ton)	750	$4.00	$3,000
	Total Costs		$140,455
	Net Income		$42,545

* Calculations are based on data from references [7, 11, 14, 16].

Conclusions

There is a tremendous interest in utilization of cellulosic biomass feedstock for production of renewable energy owing to the sharp food price increase. Cellulosic ethanol has been the center of attention of research and government investment. Our analysis shows that current large scale cellulosic based energy systems are facing technical and economic barriers, among which is feedstock transportation. Development and implementation of small scale conversion systems will help overcome several major obstacles including high capital costs, high technicality, and high feedstock related costs. The microwave assisted pyrolysis is a highly scalable conversion process that can be easily implemented and operated on farms. Such distributed biomass energy production system will provide extra income of farmers and truly involve biomass feedstock producers in the bio-economy, an important factor in sustainable development of renewable energy.

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