BIOSYNTHESIS OF INDIGO USING RECOMBINANT *E. COLI*: DEVELOPMENT OF A BIOLOGICAL SYSTEM FOR THE COST-EFFECTIVE PRODUCTION OF A LARGE VOLUME CHEMICAL

Alan Berry, Ph.D., Senior Scientist; Scott Battist, B.S., Ch.E., Development Engineer; Gopal Chotani, Ph.D., Ch.E., Senior Staff Scientist; Tim Dodge, M.S., Ch.E., Senior Scientist; Steve Peck, B.S., Ch.E., Development Engineer; Scott Power, Ph.D., Vice-President and Research Fellow; and Walter Weyler, Ph.D., Senior Scientist
Genencor International. Rochester, NY. 14618-3916.

Abstract

Cost-effective production of any large-volume chemical by fermentation requires extensive manipulation of both the production organism and the fermentation and recovery processes. We have developed a recombinant *E. coli* system for the production of tryptophan and several other products derived from the aromatic amino acid pathway. By linking our technology for low-cost production of tryptophan from glucose with the enzyme naphthalene dioxygenase (NDO), we have achieved an overall process for the production of indigo dye from glucose. To successfully join these two technologies, both the tryptophan pathway and NDO were extensively modified via genetic engineering. In addition, systems were developed to remove deleterious by-products generated during the chemical oxidations leading to indigo formation. Low-cost fermentation processes were developed that utilized minimal-salts media containing glucose as the sole carbon source. Finally, economical recovery processes were used that preserved the environmental friendliness of the biosynthetic route to indigo.

Introduction

Two major problems facing the U.S. chemical industry are dependence on foreign petroleum and mounting environmental concerns and regulations (for review, see reference [1]). This has led to consideration of biosynthetic routes for production of aromatic compounds. Indigo dye is an example of a large volume (worldwide production approximately 1.3 x 10^7 kg [1]), petroleum-derived synthetic compound for which a realistic alternative biosynthesis exists. Cost-effective biological production of indigo (or any other aromatic compound) requires that the primary raw material used be D-glucose, a feedstock that is abundant and relatively inexpensive in the U.S. This article describes the engineering of the aromatic amino acid pathway and of naphthalene dioxygenase to achieve an overall biosynthetic route from D-glucose to indigo in *E. coli*. The impact of yield improvements (i.e., efficiency) in the biosynthetic process in the context of estimated manufacturing costs are also considered.

Engineering the Aromatic Amino Acid Pathway

Background

The conversion of L-tryptophan to indigo in *E. coli* via the combined actions of the native *E. coli* tryptophanase and a cloned naphthalene dioxygenase (NDO) from *Pseudomonas putida* was first described in a landmark paper by Ensley *et. al.* [2]. However, indigo manufacture by simple bioconversion of tryptophan to indigo using recombinant *E. coli* cells is not economically viable because of the high cost of tryptophan. Thus, overall production of indigo from glucose via the tryptophan biosynthetic pathway represents the the only economically viable approach.

Development of a tryptophan over-producing strain of *E. coli*

In order to overproduce tryptophan in *E. coli*, two key points of transcriptional regulation were removed; at DAHP synthase (the first enzyme of the pathway, leading to all three aromatic amino acids) and at anthranilate synthase (the first enzyme of the tryptophan branch of the pathway). We achieved this by cloning the *aroG* gene, encoding the DAHP synthase isozyme that is normally regulated by phenylalanine, and the entire *trp* operon (minus the native promoter and attenuator regions), under control of *lacUV5* promoters. This removes normal transcriptional regulation of *aroG* and the *trp* genes by phenylalanine and tryptophan, respectively, and allows controlled expression of the *aroG* and *trp* genes over a wide range using IPTG or lactose as the inducer.

With respect to allosteric regulation, feedback resistant versions of all three DAHP isozymes from *E. coli* have been reported [3-5], and the nucleotide sequence of some of these mutant isozymes have been determined [3,4]. Likewise, mutant forms of anthranilate synthase (the *trpE* gene product) that are resistant to feedback inhibition by

tryptophan have been reported [6,7]. In addition to being cloned under *lacUV5* promoter control, the cloned *aroG* and *trpE* genes described above also contain mutations that render their products, DAHP synthase and anthranilate synthase, resistant to feedback inhibition by phenylalanine and tryptophan, respectively. The feedback resistant *trpE* used in this work was obtained via a random mutagenesis approach. Not suprisingly, partial sequencing of this mutant *trpE* gene showed that the mutation responsible for the feedback resistance is identical to one of the mutations (C465Y) later reported by Caligiuri and Baurle [6]. The feedback resistant *aroG* gene used in this work has not been sequenced.

Having the approriate modified genes in hand, it is relatively straightforward to assemble a single plasmid that contains all of the genes of interest. However, plasmid copy number and stability must be considered. Stabilization of plasmids without addition of antibiotics is usually desirable for industrial strains, and several methods of achieving such stability have been described [8-10]. Integration of cloned genes (usually with a strong promoter) into the host genome has also been widely adopted.

In addition to developing a plasmid construction, development of a host strain having the appropriate characteristics is equally important. Potential problems such as end product toxicity, high osmolarity and phage resistance must be considered. For tryptophan overproduction in *E. coli*, the only absolute requirement is that the tryptophanase (*tnaA*) gene be inactivated to avoid tryptophan degradation. However, we have found several other mutations in the host (both defined and undefined) to be beneficial to tryptophan production.

The resulting tryptophan producing strain is grown in a fed-batch fermentation with glucose as the sole component of the feed stream. The initial glucose concentration was 1% and was fed to a final concentration of approximately 22%. A final tryptophan concentration of about 40 g/L was achieved (Fig. 1). This is well above the solubility limit of tryptophan resulting in about one-half the material being crystallized in the medium. For a significant portion of the tryptophan fermentation, the theoretical yield (0.227 g tryptophan/g glucose, assuming no PEP recycle [11] is achieved (Fig. 1). It has been reported that *E. coli* tryptophan synthase is inhibited by tryptophan at a concentration of 30 g/L leading to appearance of indole and reduction of tryptophan production rate [12]. That did not appear to be the case with our fermentation. Similar tryptophan fermentation results to those reported here have also been achieved in *Corynebacterium glutamicum* [13].

Further Pathway Improvements

Further improvements in tryptophan production requires manipulation of the aromatic amino acid pathway in two areas; (i) increasing the availability of the two precursors of aromatic biosynthesis, erythrose 4-phosphate (E4P) and PEP, and (ii) removing rate limiting steps within the common aromatic pathway.

With respect to (i) above, much attention has focused on increasing the availability of PEP. Elimination or reduction of pyruvate kinase activity [14] and increasing the level

of PEP synthase activity [11] have been reported to increase intracellular levels of PEP. Furthermore, amplification of PEP synthase has been proven to increase carbon commitment to the aromatic amino acid pathway [11]. Recently, we have found that mutants deleted for the PEP:glucose phosphotransferase system that have regained the ability to grow on glucose as sole carbon source also show an increased comittment of glucose-derived carbon to the aromatic amino acid pathway (F. Valle, N. Flores, J. Xiao and A. Berry, unpublished). This increased carbon flow has been translated into an improvement in tryptophan production in shake flask cultures (Fig. 2, left and center sets of columns). The $PTS^-glucose^+$ strain produced 2x more tryptophan than the control (PTS^+) strain containing the same complement of plasmid-borne cloned genes, and had a 2x higher specific tryptophan productivity (Qp trp).

Another approach to increasing carbon commitment to the aromatic pathway in *E. coli* is to increase the intracellular level of E4P. E4P is produced via the combined actions of transketolase and transaldolase. Amplification of transketolase (the product of the *E. coli tktA* gene) has been shown to have a profound positive effect on carbon commitment to the aromatic amino acid pathway [15, 16]. This increased carbon flow has also been translated into an improvement in tryptophan production in shake flask cultures (Fig. 2, right-hand set of columns). Relative to the control strain, the strain containing amplified transketolase activity had a 2x increase in total carbon flow. Strangely, in this strain the carbon appeared to get restricted within the tryptophan branch of the pathway, resulting in a co-accumulation of tryptophan, anthranilate and indole. However, when all three compounds are added together, the effect of amplifed transketolase is similar to the results with the $PTS^-glucose^+$ mutant (i.e., a doubling tryptophan specific productivity and concentration).

In *E. coli*, the genes encoding the enzymes of the common segment of the aromatic pathway (i.e., the shikimate pathway) are expressed constitutively [17]. This level of expression is adequate to allow production of tryptophan at a high rate and with nearly theoretical maximum yield, provided that DAHP synthase and the enzymes encoded by the *trp* operon are overproduced and deregulated (Fig. 1). However, as the intracellular E4P and PEP levels are increased by the methods described above (i.e., as carbon commitment to the aromatic pathway is increased), some of the enzymes within the common aromatic pathway become rate limiting [18, and authors' unpublished observations]. To identify and relieve these rate-limiting steps, a systematic approach was used that took advantage of the availability of *E. coli* mutants blocked at each step of the common aromatic pathway together with plasmids containing combinations of cloned *E. coli aro* genes encoding all of the enzymes of this pathway. Accumulation of a pathway intermediate in culture supernatents was taken as evidence of a rate limitation at the enzymatic step that normally consumes the accumulated intermediate. This was followed by amplifying the *aro* gene encoding the rate-limiting enzyme. By sequentially "walking" down the sequence of reactions that comprise the common aromatic pathway, eventually all of the rate-limiting steps were identified and the five necessary *aro* genes (*aroB*, *aroE*, *aroL*, *aroA* and *aroC*) were assembled on one plasmid that served to effectively de-block the entire common pathway [18; A. Berry and J. Xiao, unpublished]. It should be noted that in order to achieve the maximum positive effect of

the PTS$^-$glucose$^+$ mutations or amplified transketolase on tryptophan production (Fig. 2), the strains also carried the deblocking plasmid containing the *aroBELAC* genes.

Bioconversion of Tryptophan to Indigo

Production of indigo from tryptophan in recombinant *E. coli* via the combined action of the endogenous tryptophanase and cloned NDO [2] or other oxygenases is now a widely recognized phenomenon. We have developed a fermentation process, using a recombinant *E. coli* strain containing plasmid-borne NDO activity, that efficiently bioconverts tryptophan to indigo. Two different feed streams, glucose for cell growth and energy and tryptophan as the precursor for indigo, were used. During a growth stage, cells are accumulated with mainly a glucose feed. This is followed by a bioconversion stage with tryptophan feed with glucose as needed to maintain the culture. Indigo production by this bioconversion process is shown in Fig. 3. The yield of indigo on tryptophan is nearly stoichiometric with two moles of tryptophan needed to produce one mole of indigo.

Prospects for Production of Indigo from Glucose in a Single Organism

The demonstrated ability to produce high levels of tryptophan from glucose and indigo from tryptophan raises the obvious possibility of combining the two pathways in a single organism to achieve an overall single-stage glucose to indigo process. Such a process could utilize the endogenous tryptophanase activity of *E. coli* to generate free indole for the NDO reaction, or indole could be generated directly using a mutant β subunit of tryptophan synthase [19]. In either case, developing a strain containing all of the necessary mutations and cloned genes, while preserving its ability to maintain a high growth rate and indigo production, is a formidable challenge.

Economic Considerations

Frost and Lievense [1] estimated manufacturing costs of tryptophan and indigo using a model based on rough manufacturing costs for L-lysine. The choice of lysine as a model for an indigo process was based on similarities in fermentation and recovery processes and scale. The estimated manufacturing costs of tryptophan and indigo (taken from reference [1]) are shown in Table 1. The model assumes achieving 80% of the theoretical maximum yield.

Table 1.

Product	Achievable Yield (mol %)	Glucose cost	Manufacturing Cost ($/kg)
Tryptophan	16/33	0.72/0.34	2.60/1.20
Indigo	8/17	1.10/0.53	4.00/1.90

The first set of figures in each column is derived from the lower theoretical maximum yields (assumes 1 PEP/glucose) and the second set of figures is derived from the higher theoretical maximum yield (2 PEP/glucose). This analysis clearly illustrates the importance of increasing the intracellular PEP concentration by the methods described above. The lysine model used by Frost and Lievense [1] assumed that the manufacturing cost of lysine was 50% of the selling price. By comparison, the manufacturing price of indigo (Table 1) could be 11-24% of the selling price (assumed to be about $17/kg [1]), depending on the theoretical maximum yield used in the calculation. Thus the economics of indigo production by fermentation compare favorable with those of lysine, an established high volume fermentation product.

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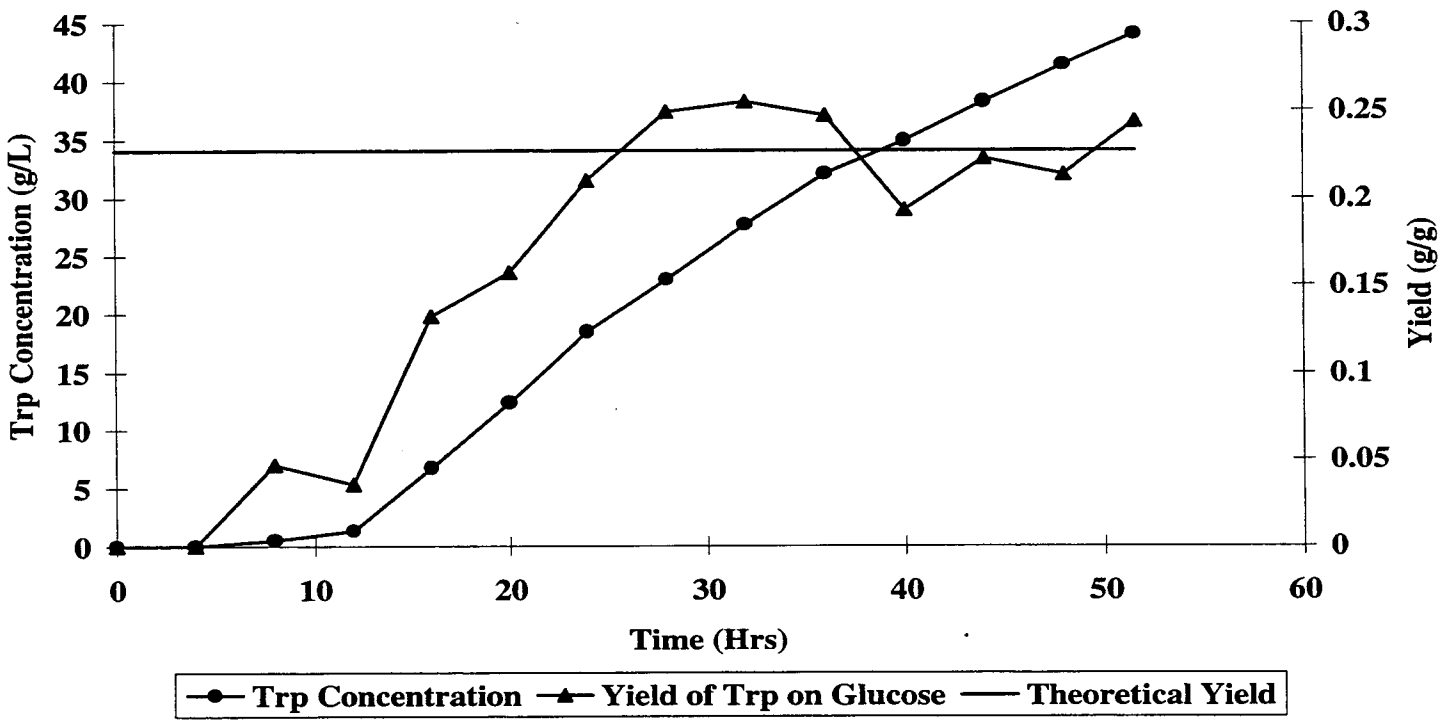


Fig. 1. Tryptophan production and yield in fed-batch fermentation.

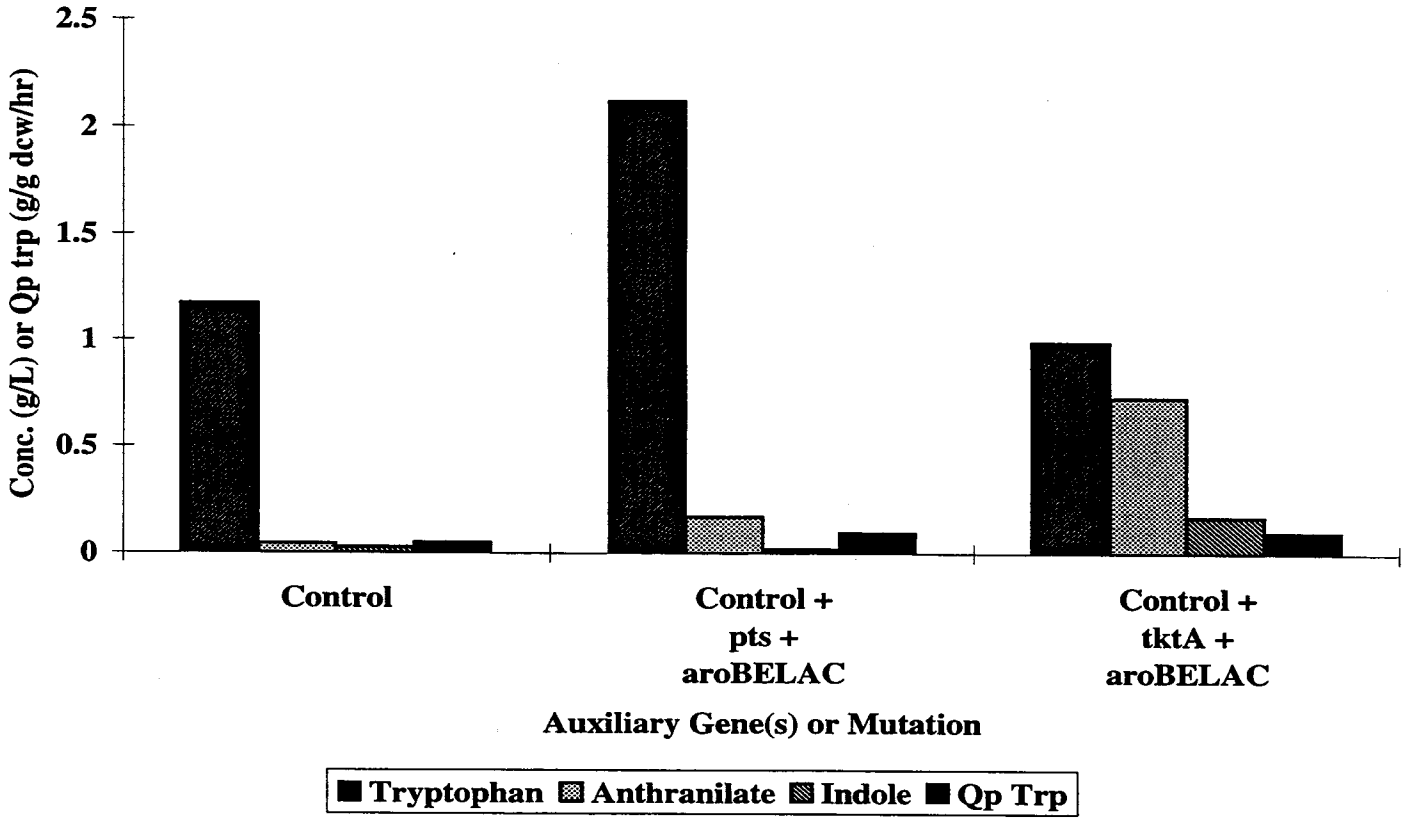


Fig. 2. Effect of auxiliary genes/mutations on tryptophan production.

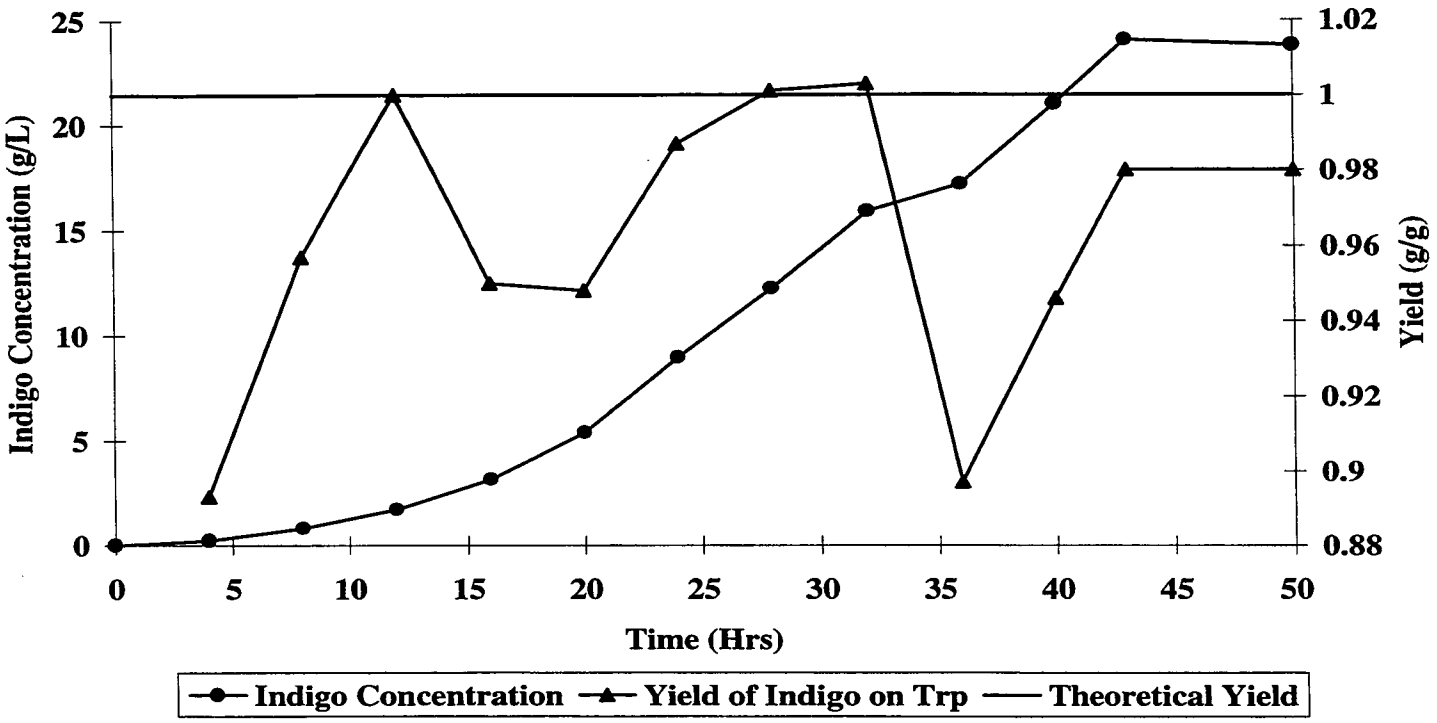


Fig. 3. Bioconversion of tryptophan to indigo.

METABOLIC ENGINEERING AND APPLICATIONS OF POLYHYDROXYALKANOATES (PHAs)

Simon F. Williams, Ph.D., Director; U. Tillman Gerngross, Ph.D., Research Scientist;
and Oliver P. Peoples, Ph.D., Director
Metabolix Inc., Cambridge, MA 02142-1196 U.S.A.

Abstract

Polyhydroxyalkanoates (PHAs) have been recognized for many years as naturally occurring biodegradable plastics. The PHA plastics range from those that resemble polypropylene to others that are more elastomeric. A fundamental understanding of the genetic and biochemical pathways involved in PHA synthesis has now made it possible to produce PHAs commercially at an attractive cost and scale, using Metabolix's transgenic technology. This technology, which was pioneered at The Massachusetts Institute of Technology, allows PHAs to be produced in the short-term by highly efficient fermentation systems, and ultimately, in plant crops. Production of PHAs in plant crops offers the promise of costs competitive with petroleum derived polymers. Millions of acres of transgenic plant crops could provide millions of tonnes of PHAs, increasing the use of renewable resources, and decreasing the U.S. reliance on imported oil. Furthermore, through the production of new PHA products, this technology provides new outlets to expand the U.S. industrial agricultural base. An overview of the scientific and industrial importance of PHAs, including the molecular genetics, biosynthesis, applications, and markets for these materials will be presented.

Introduction

Polyhydroxyalkanoates (PHAs) are naturally occurring biodegradable polymers that can be processed in a similar manner to petrochemical based plastics. Several products made with PHAs, including biodegradable bags and bottles, are already on the market, and many other products are currently under development as a result of increased environmental pressures. The polyhydroxyalkanoates are derived from renewable agricultural resources, and biodegrade in both soil and marine environments to carbon dioxide and water.

Until now, production methods for PHAs have relied upon traditional fermentation processes, and as a result PHAs have been expensive polymers even when environmental considerations are taken into account. This obstacle, which has in part prevented more widespread introduction of these materials, has now been overcome using transgenic technology. At Metabolix, recombinant DNA techniques have been used to develop highly efficient fermentation systems for PHA production which short term can provide PHAs at an acceptable cost. Furthermore, using the same technology, plant crops have been engineered to produce PHAs. This approach promises to provide PHA biopolymers at prices competitive with petrochemical derived plastics.

This article will provide an overview of PHAs, explaining the scientific and industrial relevance of these natural polymers in today's society. In addition to describing how transgenic techniques can be used to convert fermentable substrates, derived from biomass, into useful PHA biopolymers, this paper will also outline how this technique is being used to generate a new PHA containing biomass.

Polyhydroxyalkanoate Structure

Polyhydroxyalkanoates (PHAs) are a class of naturally occurring polyesters that are synthesized by numerous organisms in response to environmental stress (for reviews see: Byrom, 1991; Hocking and Marchessault, 1994; Holmes, 1988; Lafferty et al., 1988; Müller and Seebach, 1993; Steinbüchel, 1991). These biopolymers can be divided into two groups according to the length of their side chains (Figure 1). Those with short side

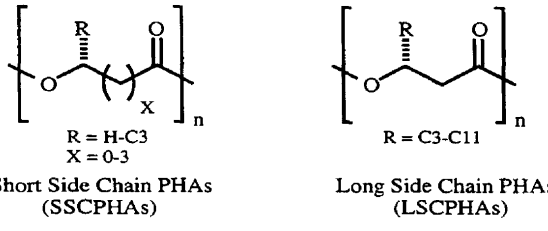


Figure 1

chains, such as polyhydroxybutyrate (PHB), a homopolymer of R-3-hydroxybutyric acid units, are crystalline thermoplastics, whereas PHAs with long side chains are more elastomeric. The former have been known for about seventy years (Lemoigne & Roukhelman, 1925), whereas the latter materials which were first identified in the early 1980's are a relatively recent discovery (de Smet et al., 1983).

Partly as a result of their earlier discovery and also because of their desirable physical properties, the short side chain materials have been more extensively studied. These polymers can be processed using conventional polymer technology and offer properties such as: biodegradability in soil and marine environments; biocompatibility; and, good barrier properties. These characteristics taken singly or together make these materials useful for a wide range of industrial applications.

Biosynthesis and Genetics of Polyhydroxyalkanoates

The PHA polymers may constitute up to 90% of the dry cell weight of bacteria, and are found as granules inside the bacterial cells. These PHA granules accumulate in response to nutrient limitation and serve as carbon and energy reserve materials. Distinct pathways are used by microorganisms to produce each class of these polymers. One of these pathways leading to the short side chain polyhydroxyalkanoates (SSCPHAs) involves three enzymes, namely thiolase, reductase and polymerase. Using this pathway the homopolymer PHB is synthesized by condensation of two molecules of acetyl-Coenzyme A to give acetoacetyl-Coenzyme A, followed by reduction of this intermediate to R-3-hydroxybutyryl-Coenzyme A, and subsequent polymerization (Figure 2). The last enzyme in this pathway, namely the

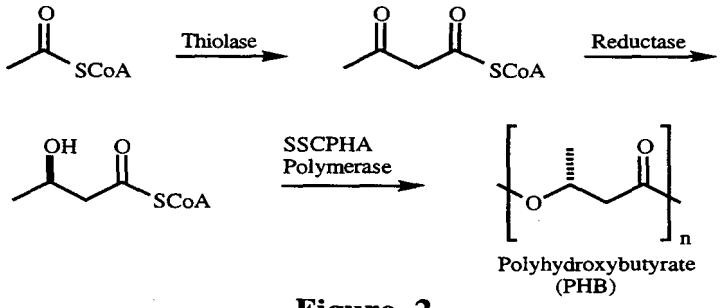


Figure 2

polymerase, has a substrate specificity that can accommodate C3-C5 monomeric units including R-4-hydroxy acid and R-5-hydroxy acid units. This biosynthetic pathway is found, for example, in the bacteria Zoogloea ramigera and Alcaligenes eutrophus.

The biosynthetic pathway which is used to make the long side chain polyhydroxy-alkanoates (LSCPHAs) is still partly unknown, however, it is currently thought that the monomeric hydroxyacyl units leading to the LSCPHAs are derived by the β-oxidation of fatty acids and fatty acid synthase (Figure 3) (Peoples & Sinskey, 1990). The R-3-

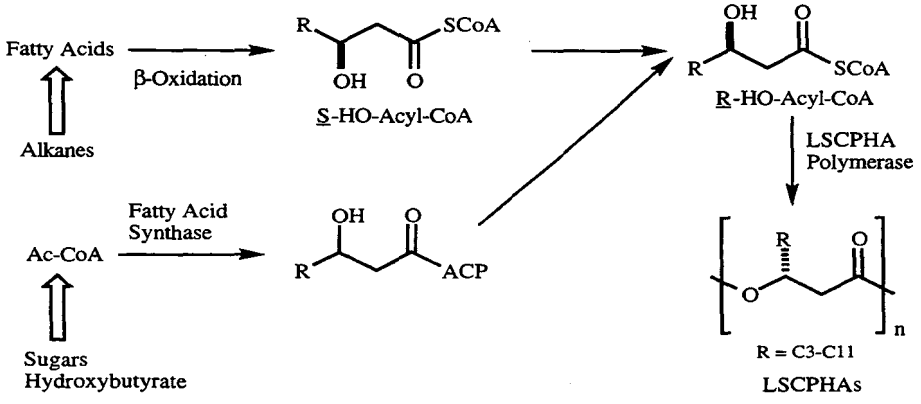


Figure 3

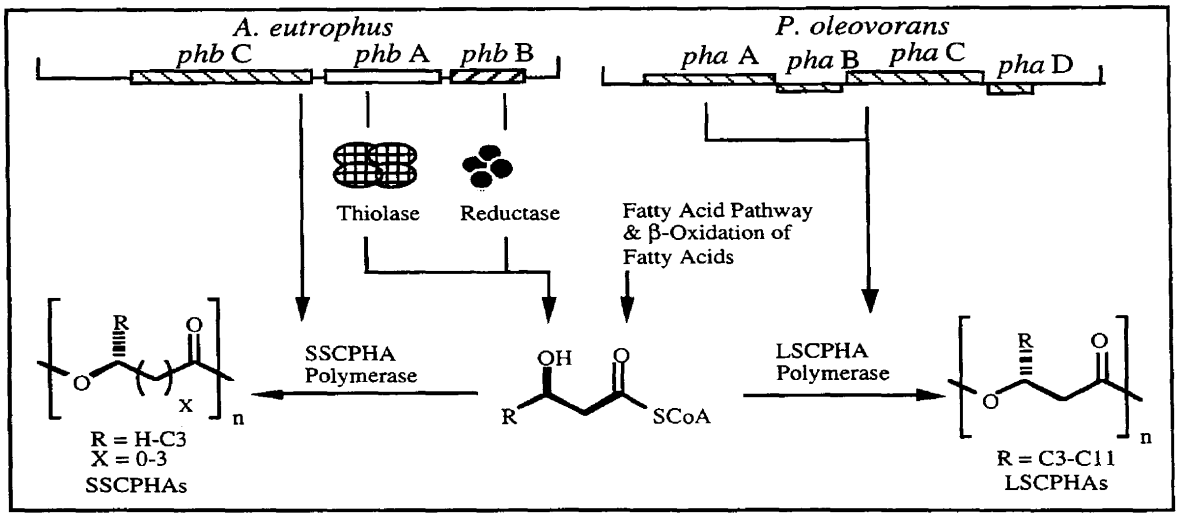
hydroxyacyl-Coenzyme substrates resulting from these routes are then polymerized by PHA polymerases that have substrate specificities favoring the larger monomeric units in the C6-C14 range. Long side chain PHAs are produced, for example, by the Pseudomonas organism.

Several groups were active in the 1980's, identifying both the genes and the gene products responsible for the syntheses of both classes of PHAs (Peoples et al., 1987a,b; Peoples & Sinskey, 1989a-c; Slater et al., 1988; Schubert et al., 1988). The first three patents

describing transgenic PHA production have now issued in the United States (patent numbers: 5,229,279; 5,245,023; and, 5,250,430) to the Massachusetts Institute of Technology. These patents are licensed exclusively to Metabolix and form the basis of the Company's technology for transgenic PHA production.

The genes responsible for the production of SSCPHAs in, for example, A. eutrophus were found to be from an operon containing the phbC-phbA-phbB genes, coding for the enzymes polymerase, thiolase, and reductase, respectively (see Figure 4). For the LSCPHAs, the polymerase enzymes in the Pseudomonas organism were found to be

Metabolix's Technology for Transgenic PHA Production



US Patents: 5,229,279; 5,245,023; 5,250,430 and additional pending applications.

Figure 4

encoded on the pha locus. This locus includes two closely related PHA polymerase enzymes encoded by phaA and phaC, as well as a depolymerase enzyme which is the product of the phaB gene.

The isolation and cloning of the key genes on the biosynthetic operons of both classes of PHAs in the late 1980's provided a means not only to understand PHA physiology, but also to produce PHA polymers at an economical cost. For example, by transferring the phbC-phbA-phbB genes isolated from A. eutrophus into Escherichia coli, it was shown that the new transgenic E. coli organism could now accumulate large quantities of PHB granules. These early experiments thus provided the framework for establishing an avenue for low cost PHA production using transgenic technologies.

Industrial Production of Polyhydroxyalkanoates

Non-Transgenic Production

The first commercial interest in PHAs, specifically in PHB, was shown by the W.R. Grace company in the late 1950's (Byrom, 1991). At that time, competition was based on price relative to petroleum-based plastics, and PHB which was obtained from bacteria by fermentation was considered to be hard to process and costly. These factors eventually caused W.R. Grace to abandon the project.

The British firm, Imperial Chemical Industries, reexamined PHB production in 1975-6, and by feeding glucose and propionic acid to an A. eutrophus bacterial production strain produced a copolymer of R-3-hydroxybutyrate and R-3-hydroxyvalerate (Byrom, 1991). Zeneca, until recently part of Imperial Chemical Industries, currently produces these copolymers in a British plant, sold under the Biopol™ trademark, and has invested heavily in demonstrating the utility of Biopol™ during the last twenty years. Current annual production of Biopol™ is several hundred tonnes, and the material is sold in the U.S. for about $17.50/Kg ($8.00/LB).

In the Zeneca process, the A. eutrophus organism is grown in a two-stage fed-batch fermentation to a total biomass concentration exceeding 100 g/L. When the production strain is limited in nutrient but supplied with carbon, PHB accumulates to around 70-80% (dry weight). By varying the ratio of the glucose to propionate feed it is possible to accumulate random copolymers of Biopol™ containing between 0-30 mole% R-3-hydroxyvalerate. According to the patent literature, PHB is typically purified after fermentation using the following sequence: lysis; protein and nucleic acid removal; solvent extraction to remove lipid (with methanol) or extraction of the polymer (with chlorinated solvents); and, spray drying (Imperial Chemical Industries, 1984). This procedure provides a white crystalline powder suitable for extrusion.

Scale economies, good engineering, and other further improvements could lead to a reduction in Zeneca's pricing for Biopol™. Company sources have reported target prices of around $5-8/Kg (Byrom, 1991).

Transgenic Production Methods

Metabolix believes that a substantial reduction of PHA prices could be achieved using recombinant PHA technology. Two routes are being pursued for low cost PHA production by Metabolix. The first, involving transgenic fermentation decreases the short term cost of PHA production (relative to A. eutrophus) by: reducing fermentation time; increasing cell mass and polymer yield; as well as providing improvements in downstream processing. Projected prices for PHA production are in the $4.40-5.50/Kg range, depending on grade, at an initial annual capacity of around 1,000 tonnes per annum.

Longer-term, the second production route for PHAs, currently under commercial development by Metabolix in collaboration with corporate partners, involves the use of transgenic plant crops. First described by Peoples and Sinskey in July 1989 (see: PCT WO91/00917), and subsequently in a Science editorial (Pool, 1989), this approach involves transferring the genes encoding bacterial PHAs into plant crops. Results obtained to date in Metabolix's collaborations, as well as other reports by Zeneca, and an academic group originally at Michigan State University (now at The Carnegie Institution of Washington) (Poirier et al., 1992 and 1995; Nawrath et al., 1994), have demonstrated that PHB can be produced in genetically engineered plant systems. It has been shown, for example, that introducing just the reductase and SSCPHA polymerase genes into plants is sufficient for PHB production.

While there is still more effort required to develop commercial plant crops producing PHAs, early estimates obtained by analogy with existing plant oil crop production methods indicate that useful PHA polymers can be produced at prices comparable to petrochemical polymers. Plant oils typically account for 10-50% of the seed, and currently sell for $0.66-1.32/Kg (Chemical Marketing Reporter, January 1994). Rough estimates of land use for PHA production in transgenic rapeseed are given below.

Potential of Metabolix's Transgenic PHA Plant Crop Production

Assume 30% PHA in Transgenic Rapeseed

Yields 0.37 tonnes of PHA per hectare

So, 1 Million tonnes of PHA requires 2.5 million hectares of farmland

Although one million tonnes of PHA polymer produced in rapeseed would represent a relatively small fraction (0.5%) of the world's production of industrial plant crop oils, it is equivalent to about 14% of the U.S. thermoplastics packaging market.

PHB: Properties, Processing, and Performance

Zeneca's efforts with Biopol™ have resulted in a number of process and applications patents, and notably, a composition of matter patent on the copolymer of R-3-hydroxybutyrate and R-3-hydroxyvalerate (US Patent 4,477,654, 1984). The simple PHB homopolymer has, however, been known since about 1925 when it was discovered by Lemoigne (Lemoigne & Roukhelman, 1925). For a long time it was thought that the PHB homopolymer was too difficult to process, and therefore of limited commercial value. Fairly recently, this situation has changed and polymer specialists have developed technologies which allow this material to be processed into virtually any form (see for example: Hänggi, 1995; Lafferty et al., 1988). In fact, PHB can be formulated with plasticizers and processed to give a very similar range of properties to Biopol™ copolymers (Hocking and Marchessault, 1994). This is important for several reasons. First, PHB is the cheapest PHA polymer that can be produced by fermentation, and allows Metabolix to enter PHA production with a useful material at an acceptable cost. Second, the utility of Biopol™ has been well demonstrated, and therefore the potential market and product performance has been tested. Third, the first commercial transgenic plant crop product is most likely to be PHB, and not a PHA copolymer such as Biopol™. Production of the latter in plant crops is likely to take significantly longer due to the need to produce two substrates in the plant and at controlled ratios. Continuity between fermentation and plant crop production of PHAs would therefore be established using PHB.

Using Metabolix's technology, polymer production can be controlled to provide PHB in different forms. Using genetic engineering it is possible to vary the molecular weight of the polymer and the particle size. Such flexibility is important in applications development. Metabolix's product list includes PHB powder as well as PHB latex formulations. Polyhydroxybutyrate can be processed by extrusion, injection and blow molding, and fiber spinning (Hänggi, 1995). Film blowing is currently under development. Thus, PHB can be processed much like traditional petrochemical derived plastics, an important issue in controlling costs associated with the introduction of any new polymer. In time, Metabolix's product range will be expanded to include PHA copolymers, LSCPHAs, as well as blends of PHAs with other biodegradable materials.

In addition to conventional processing by extrusion and molding, methods are currently being developed to coat paper with a PHB latex (Lauzier et al., 1993). This is a particularly attractive use of PHB for the following reasons: (1) Paper coated with PHB has desirable properties for many applications. (2) The coated product is still totally biodegradable unlike paper treated with petrochemical-derived materials. (3) The PHB latex is formed during the course of the normal production process, and utilization of this material can eliminate additional downstream processing steps. (4) In some cases it may be possible to incorporate PHB coating directly into the paper production process, allowing coated paper production at a single site.

Polyhydroxybutyrate has good water resistance even though the material biodegrades to carbon dioxide and water. This property as well as an acceptable water vapor transmission

rate means that PHB can be used for a wide range of commodity applications. Unlike polylactic acid (PLA) which degrades mainly by hydrolysis, PHAs are degraded predominantly by enzymatic processes when the plastics are either composted or placed in the marine environment (Brandl and Püchner, 1992). Notably, the degradation of PLA in the marine environment is extremely slow, presumably due to the cold temperatures slowing chemical hydrolysis.

As well as water resistance, PHB has adequate fat and odor barriers for applications with short term storage requirements. The homopolymer can also be heated to about 130°C, a useful range for many applications (Hänggi, 1995). By adding plasticizers and nucleating agents the brittleness of PHB can be reduced and flexibility enhanced without compromising safety and degradability. For example, plasticizers such as acetic and citric acid esters have been blended with PHB to improve flexibility, and nucleating agents including talc and saccharin (Black et al., 1990), have been used to decrease brittleness and increase strength and flexibility. In fact, using such combinations it is possible to produce goods with properties comparable to articles made of polystyrene or polypropylene. Unlike these latter materials, however, PHB is biodegradable, and as a polyester shares the same glossy aesthetic properties of the acrylates. Polyhydroxybutyrate has also been reported to have good UV resistance.

Markets for PHA Thermoplastics

At the beginning of the next century, PHA polymers produced by agricultural plant crops are expected to be able to compete with petrochemical derived plastics directly on price. At that time, markets for PHA polymers and also commodity PHA-based chemicals should expand rapidly, particularly into regions where price sensitivity is a decisive factor. The shear volumes of PHA material that could be generated by plant crops could rival or even exceed production levels of the most widely used petrochemical plastics. In this regard it is particularly interesting to note that while the current worldwide production of synthetic plastics is around 100 million tonnes per annum, worldwide plant oil production is approximately twice this amount at 200 million tonnes per annum.

Until PHA plant crop production begins, substitution of PHA polymers for petrochemical derived materials cannot take place on the basis of selling price. This means that fermentation derived PHA polymers must be brought to market as new materials offering additional benefits, such as novel properties or being natural materials derived from renewable resources.

PHAs: Natural and Biodegradable

Natural materials can command a premium in certain markets such as the toiletries and cosmetics sector. Indeed, it is no coincidence that some of the earliest Biopol™ products were aimed towards this sector. Although PHB produced by fermentation, and subsequently injection and blow molded into bottles, caps, and jars, is likely to sell well in this sector, price tolerance is not without reasonable limitations. We believe that the transgenic approach to PHB production can address these limitations.

Perhaps the most useful property of PHA polymers, distinguishing them from petrochemical derived polymer materials, is their complete biodegradability. This feature makes PHAs a particularly attractive option for users having to deal with increased environmental legislation. It should be noted, however, that biodegradability is only one component in providing a solution to waste management. To be successful other components such as a good composting infrastructure are also required to make this approach work, and this infrastructure is in different stages of development depending upon geographical region. In Germany and The Netherlands, for example, this infrastructure is highly developed, and the other European countries appear likely to follow. In the U.S., bans on the disposal of yard waste in land-fill sites have helped to

establish a composting infrastructure, and this is now growing particularly as land-fill sites are closing across the nation.

Among the uses of commodity plastics, the biodegradability of PHB offers an excellent solution to the problems faced in single-use markets such as fast food serviceware, disposable diapers, and packaging. In these cases, the plastic often becomes highly contaminated during use making it difficult to recycle by other technologies. For example, in the fast food industry the waste stream can contain a significant fraction of food which, along with PHB and paper, is well suited to composting. Similarly, collection of yard waste in trash bags made of PHB provides a totally compostable unit needing no further sorting.

Pricing Issues and Environmental Taxes

While these clear advantages for the environment can exist whenever PHB is used in such single-use applications, integrated with a composting infrastructure, there still remains the issue of the price premium over non-degradables. In certain countries, such as Germany, strict legislation has been introduced which levies higher charges on non-degradable materials than natural materials. For example, the Duales System Deutschland (DSD) fees impose weight related charges of about $2 per Kg on plastics versus $0.12 per Kg on natural materials. Such fees when added to the resin price can either significantly reduce or even eliminate the short term gap that exists between the price of a natural material like PHB, and a non-degradable plastic.

In this regard, there is one class of products worthy of special consideration. Currently, large amounts of paper are surface treated with non-degradable plastics to improve performance properties such as: print quality, hydrophobicity, mechanical strength, and, grease resistance. Many of these products find use, for example, in packaging and fast food serviceware. However, although coating provides a material with superior performance, at the same time it can convert a natural material with a low environmental tax into a composite subject to a much higher fee. This increase in fee is compounded by the fact that even though only a thin film of plastic is applied to the paper, the disposal fee is based on weight and is therefore magnified by the additional weight of paper. Thus, such disposal fee structures can help to create competitive markets for PHB composites.

Interestingly, there are other reasons why PHB paper composites provide good opportunities for commercial development, even in the absence of legislation favoring natural materials. For example, in contrast to the production of 100% plastic articles, only a fraction of the material in coated paper is plastic. This means that in terms of raw material charges and processing costs only a fraction of the price differential between a petrochemical derived resin and PHB would be passed onto the consumer. As a result, end users appear willing to tolerate prices of $4.40-5.50 per Kg for PHB produced by transgenic fermentation.

Regulatory Issues

Some of the largest potential markets for PHAs involve contact with food. In order to be able to use PHAs in these areas approvals from regulatory agencies, such as the FDA, must be obtained. Regulatory issues include toxicity data on all components of the polymer product (including any plasticizers, nucleating agents, stabilizers, etc.), and, migration rates of any components transferring from the polymer to the food. By selecting additives already used in food contact applications it is possible to ease some of the approval process. Also, the hydrolysis product of PHB, namely, R-3-hydroxybutyric acid, is a natural constituent of human plasma. Nonetheless, even though it is generally accepted that PHB is not toxic, FDA approval is still required for certain applications of this material. Notably, Zeneca (formerly ICI) is currently seeking approval from the FDA for their Biopol™ line of products (Chemical Business, May 1990).

Market Size

One way to estimate future demand for PHAs is to examine price exclusion curves for commodity and engineering thermoplastics. The curve for U.S. thermoplastic consumption is shown in Figure 5. The assumption behind this exercise is that the market

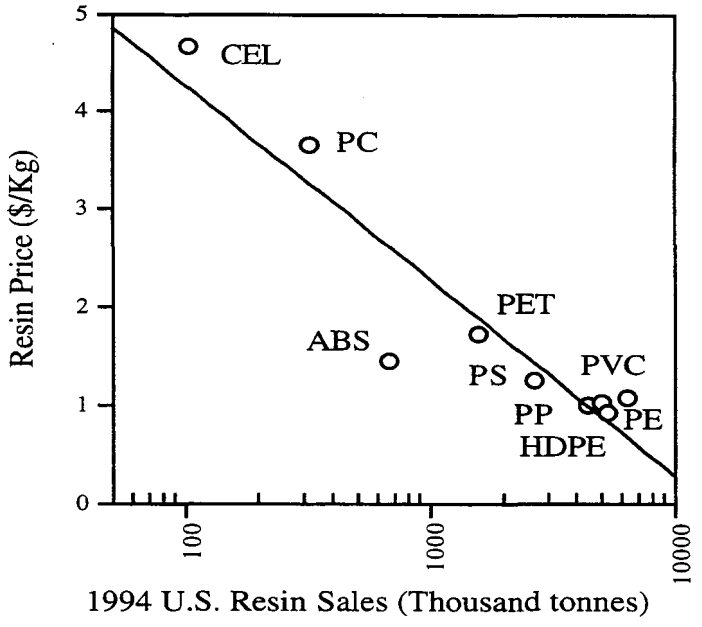


Figure 5

will select the lowest cost material suitable for the end use application. A premium can thus only be sustained when a unique set of circumstances arise, such as biodegradability. Inspection of Figure 5 indicates that at $4.40-5.50 per Kg, PHB might be expected to have an initial market in the 10-100 thousand tonnes range. Longer-term, as plant crop PHAs come on line, the situation forecast by Figure 5 is dramatically different. At prices comparable to petrochemical derived thermoplastics, the price exclusion curve predicts a market size for PHAs in the 1,000-10,000 thousand tonne range in the U.S. alone.

Market forecast data for biodegradable plastics is available from various agencies. For example: a report by Business Communications forecasts a market size of 500 thousand tonnes per annum by the year 2000; Frost and Sullivan have reported that the European market for degradable plastics was $25 million in 1990, and is expected to reach about $175 million by 1995; and, The Freedonia Group placed the North American market for degradable plastics at 550 thousand tonnes in 1992 growing to about 1200 thousand tonnes in 1997. In every instance, significant growth is anticipated.

Conclusions

Advances in recombinant DNA technology have now made it possible to produce PHA thermoplastics at an attractive cost and scale. This technology, under development by Metabolix, promises to provide the chemical industry with a new class of commodity polymers and a new source of chemical feedstocks. In the short term, the approach can use highly efficient fermentation processes to provide PHAs suitable for use in environmentally sensitive markets, particularly where biodegradability is desirable. Longer term, the same

technology promises to provide transgenic plant crops producing PHAs at costs comparable to petrochemical derived plastics. In essence, this technology provides both a method for using existing biomass, and an unique opportunity to generate a new type of commercially useful biomass. The latter has the potential to become one of the world's largest sources of chemicals, all derived from renewable resources.

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PHENOL-FORMALDEHYDE RESIN SUBSTITUTES FROM BIOMASS TARS

D. Andrew Himmelblau, M.S., President
Biocarbons Corporation, Woburn, MA 01801 U.S.A.

Abstract

Approximately 320,000 tonnes of phenol and formaldehyde are currently used annually in North America to make adhesive resins that are used to make exterior-grade structural panels. The demand for phenol-formaldehyde (PF) resins is growing faster than the demand for panels, because more adhesive is required to join/coat the surface of wood flakes (for oriented strand board - OSB) than is required to join veneer; OSB is replacing plywood as logs large enough for veneer become scarcer. Also, competitive uses for phenol and methanol (for making formaldehyde) have increased raw materials cost and threatened avaialbility. Production of adhesive resins from biomass to reduce reliance on raw materials derived from commodity petrochemicals and to lower resin costs looks attractive.

A simple fluidized-bed reactor system can be used to produce tars that can substitute for a major portion of the phenol and formaldehyde in PF resin adhesives. This can be done in an air-fluidized, single-bed reactor; no inert gas or dual-bed system is required. The key is recognizing that optimum phenolic character in the tar is not produced at the maximum tar yield, but at reactor temperatures around 600°C and short gas-phase residence times that produce a yield of about 25 to 30 weight percent. A wide range of phenols, aldehydes and other compounds capable of polymerization are produced. Feedstock can be any wood waste larger than sander dust; low cost agricultural wastes such as bagasse are also suitable.

Adhesive resin is produced from the entire tar product by shifting the pH from acidic to basic with NaOH, and combining and heating the resulting resole with phenol and formaldehyde, similarly to conventional resins. Approximately half of the phenol and formaldehyde by weight can be replace with tar.

A plant producing 13,865,000 kg (30,566,000 lb) annually from 308 tonnes (340 tons) per day of green wood chips would cost approximately $8,400,000. Operating costs with wood at $16.50 per wet tonne ($15/ton) would be about $0.28/kg ($0.19/lb). A 15% after-tax return on investment would add another $0.15/kg ($0.07/lb).

The Market for Phenol-Formaldehyde Resins and Resin Substitutes

Phenol-formaldehyde (PF) resins are used as adhesives for gluing together the veneer plies of exterior-grade (structural) plywood panels and the flakes of oriented strand board (OSB) panels. The cured adhesive is extremely resistant to moisture, preventing delamination of the product panel. Hardwood plywood, particleboard and fiberboards (in North America) are manufactured mainly for interior use and ordinarily use other adhesives such as urea-formaldehyde that are much less expensive. Approximately 320,000 tonnes of phenol and formaldehyde are currently used annually in North America to produce structural panels. Worldwide consumption of PF resin solids for wood composite adhesives in 1992 was approximately 700,000 tonnes (1).

In North America, OSB production is increasing while plywood production is decreasing, because of the decreasing availablity of logs large enough to be peeled for veneer. Consequently, the demand for PF resins is growing faster than the demand for structural panels, because more adhesive is required to join (coat the surface of) wood flakes than is required to join veneer. At the same time, increasing demand for phenol in competitive uses that produce higher-value products (e.g., bisphenol A for polycarbonates) may keep the price of phenol in the range of 84 to 93 cents (U.S.) per kg (38 to 42 cents per lb), that is sought by producers to justify new production facilities (2). In 1995, a shortage of methanol, the raw material for formaldehyde, temporarily tripled formaldehyde prices. **These factors make the production of adhesive resin from biomass look attractive in order to reduce reliance on raw materials derived from commodity petrochemicals and to lower cost, assuming equivalent adhesive properties (3).**

Also, the production of exterior-grade resin material from biomass would allow the production of panels in countries that do not have domestic sources of phenol and formaldehyde and do not wish to import them. Lower cost resin using biomass would also allow the use of native fiber sources in exterior panels that would be too expensive to produce now, because of the additional amount of adhesive required compared to plywood or OSB.

Resin Chemistry

PF resins for structural panels use approximately two moles of formaldehyde per mole of phenol to create about two methylene ($-CH_2-$) linkages per phenol molecule in the resin. Linkages can occur at the para or the ortho positions. Adhesive (B-stage resole) molecular weights are in the range of 300 to 30,000 (4) prior to final curing in the hot press. A typical resin formulation contains about 55% (by weight) phenol, 34% formaldehyde and 11% NaOH before addition of fillers and extenders (5). The phenol-to-formaldehyde molar ratio and the amount of NaOH affect the resin viscosity and molecular weight distribution (6). The resins are made by combining phenol and formaldehyde in water with Na^+ as a catalyst. The NaOH also is used to keep the solution pH basic (forming a resole resin) and to keep the resulting polymers in aqueous solution. The NaOH is usually added in stages to promote a high degree of polymerization in a portion of the resin (5).

The resin ingredients are "cooked" in a kettle at 70 to 95°C for several hours until a desired viscosity and gel time are reached. The mixture is then cooled to stop the polymerization reactions.

Tar Production From Biomass

At temperatures above about 260°C in the absence of oxygen, wood or any biomass breaks down into gas, oil/tar (at room temperature) and char products. The process is called pyrolysis. The three main constituents of biomass - cellulose, hemicellulose and lignin - follow different decomposition pathways that are not well understood. Simplistically, the three constituents break down into tars that further crack to gas species. Because lignin consists of larger molecular fragments than cellulose and hemicellulose, it initially produces higher molecular weight tar species. Some of the tars form char. Cellulose tends to produce carboxylic acids as tars. Especially at slow heating and reaction rates, gas is also produced directly from solids, leaving a char such as charcoal.

Because the initial biomass contains oxygen, the char, oil and gas products contain oxygen. Predominate gas species are H_2O, CO_2, CO, H_2, CH_4, and higher alkanes. Oil/tar species include carboxylic acids and ring compounds. Relative yields of char, oil and gas products depend on the biomass composition, the reactor design, reactor temperature and reactor residence time. At any set of conditions, a large number of different oil compounds are produced. Two general trends occur for all reactors. As reactor temperature is increased, char and oil production reach maximums then fall off as gas production predominates. Also, oil composition seems to be a function of reactor operating temperature (7):

Most pyrolysis of biomass has been directed at producing charcoal or low-Btu gas as fuel substitutes. Oil was considered to be a nuisance byproduct that was avoided by burning any gas that was produced hot, i.e., above the oil dew point. Because the oil is acidic, oxygenated, often very viscous and may polymerize when heated, pyrolysis oil has not been well regarded as a fuel. Research has been done on maximizing oil production (by operating reactors at approximately 500°C and short residence times) to produce boiler or turbine fuels (8,9), and on hydrogenating or catalytically treating the oxygenated content to produce motor fuels (10,11). However, the costs are not competitive with forseeable petroleum prices.

More recently, there has been interest in using the phenols and aldehydes produced as substitutes for phenol and formaldehyde in the production of phenolic (PF) resins that are currently used to bond veneer, chips and other fiber into exterior grade boards (12). The "bad" characteristics of pyrolysis oil, especially its tendency to polymerize when heated, can be used advantageously.

The key factor is that maximum oil production does not necessarily achieve optimum phenolic character/phenol and aldehyde production for polymerizable product production. The mixed oxygenates are products similar to lignin; because of ether groups and steric hindrance, few reactive sites are available for methylene linkages. The phenolic ethers also inhibit cross-linkage. Ethers are not reactive sites and are difficult groups to remove from the aromatic ring. Alkyl phenols are much more reactive. The highest temperature oil products are deficient in species with phenolic character and will not cross-link. It should be kept in mind that a wide distribution of product species occurs at any reaction temperature; no single compound predominates, and at least a trace of most occurring compounds will be found at any reaction conditions.

It is possible to produce sufficient phenols and aldehydes to create an oil from biomass that thermosets like a phenolic resin. This is done by operating at temperatures around 600°C and short residence times (to prevent secondary cracking of the oil), rapidly heating the biomass and removing and quenching the vaporized oil. The reactor is typically a fluidized bed of alumina sand (13). The sand behaves like a liquid when a gas flows upward through the sand. The faster/larger the gas flow, the more roiled the bed becomes. When the gas velocity is greater than the terminal settling velocity of the sand (particles of a certain size), the sand becomes entrained, and is carried out of the bed. An ablative entrained flow (vortex) reactor that throws solids against a heated wall can also be used to make oil from which an extracted fraction can be used to make PF resins (8,14).

Pure pyrolysis by indirect heating or providing heat with a hot, inert carrier (gas or sand) is not necessary; partial oxidation (less than stoichiometric oxygen) with air can provide the necessary heating for the reactor. Biocarbons Corp. has focused on using fluidized-bed partial oxidation to produce phenolic-character oil from biomass . With a fluidized bed, good control of reaction temperature (the bed is well mixed) and residence time can be obtained, and scale-up from a pilot plant is simpler than for other reactor systems. A wide range of operating conditions can be met with a single design, and engineering vendors with commercial plant construction experience with fluidized-bed biomass gasifiers are available (15).

Oil Properties and Resin Production

The oil that is produced from an air-fluidized-bed reactor is acidic and almost entirely water insoluble. Oil yield is about 25 to 30% (dry kg oil per dry kg wood fed to the reactor), depending on reactor temperature and residence time. Oil specific gravity is about 1.1. Viscosity of the raw oil is affected by fine char particulate that is also collected in the scrubber (see below). Water from the scrubber and/or condensed from the gas is emulsified into the oil; the emulsion is extremely stable. Heating the oil above about 70°C will cause it to self-polymerize. Addition of NaOH will also cause polymerization; acid-base reactions provide localized heating and Na^+ acts as a catalyst. Almost instantaneous reaction to a solid can occur if NaOH addition is rapid, due to the exothermic polymerization reactions. However, the oil does not have sufficient linkage sites to substitute completely for a PF resin. Approximately half of the phenol and half the formaldehyde required to make a PF resin can be replaced with the biomass oil. The

entire oil can be used, no fractionation of the oil is required.

The process for making a PF resin from biomass oil is similar to the process for making conventional resin, but first, NaOH must be added gradually to the acidic, water-insoluble oil to produce a water-soluble solution. The addition rate and temperature are controlled to keep the exothermic acid-base and polymerization reactions under control. Additional cross-linking is then promoted by adding phenol and formaldehyde and processing the material like a conventional resin until the proper molecular weight, gel time, viscosity, etc. are reached.

The processing requirements and equipment for incorporating the biomass oil into a PF resin will be approximately the same as for conventional resins. The types and amounts of fillers and additives used will also be approximately the same. Therefore, it is possible to make a cost comparison between conventional PF resins and resins with biomass oil/tar on the basis of raw materials costs only. The labor, overhead, utilities, administrative and capital-related costs should be about the same for both resin products, and raw materials costs are the major variable costs for both resins.

Oil Production - Process Description and Economics

The following assumptions have been used in the process design and cost estimates:

1) Plant size is a nominal 181 tonnes (200 short tons) per 24 hour day feed to the gasifier. Feed moisture content is 17.5 percent (wet basis). Oil production is 42,200 kg. (93,050 lb.) per 24 hour day (dry basis), 13,865,000 kg (30,566,000 lb.) per year.
2) Raw wood is received in the form of green chips (50 percent moisture content, wet basis), 308 tonnes (340 tons) per day. Storage for seven days is provided on the site. The green chips are reduced to pin chips with a maximum size of 10mm x 10mm x38mm (3/8" x 3/8"x 1.5"). Fines are gasified.
3) The gasifier and scrubber are operated at temperatures sufficiently high to maintain a scrubbed-gas higher heating value of at least 712 kcal/m^3 (80 Btu/scf). Char produced in the process is recovered and used to fire the wood dryer. Particulate not captured by the char removal cyclones (approximately minus 15 - 20 microns) is mainly removed with the oil in the scrubber.
4) Dried chip storage for 24 hours is provided. Oil storage for 96 hours is provided.
5) No facilities for the processing of the raw oil product are included.
6) Water, gas and electricity are assumed to be available at the site and only plant distribution is needed. No buildings other than a control room and an administrative building are included.
7) The plant is designed as a single train. Critical equipment and feed equipment prone to jamming are spared. Plant operating rate is assumed to be 90 percent (7884 hours per year). The plant is operated on three shifts except for wood receiving which is operated on a single weekday shift.
8) Land cost is placed at $50,000. No spare parts inventory is included in the capital cost. No direct startup costs or interest during construction are included other than

15 percent for escalation and contingency. Capital costs are for September 1994 (CE Cost Index of 396.4).

9) No NPV rate of return has been included. A plant life of 9.5 years with straight line depreciation has been assumed. This is equivalent to the U. S. federal tax treatment under MACRS, assuming a mid-year convention.

Process Description (See Figure 1)

Trucks delivering wood to the site are weighed on a truck scale before and after delivering wood to the storage pile. Self tipping is assumed. A tractor shovel moves the green chips from the storage pile (first in, first out) to a reclaim hopper and chain conveyor. The chain conveyor deposits the chips on a belt conveyor that feeds a scalping screen (35mm IFO). Overs are sent to a chipper. A magnetic separator is located at the end of the scalper feed conveyor. Accepts are fed to the primary screen (10 mm IFO). Overs are sent to a hog mill and recycled via a blower back to the inlet of the screen. Accepts are sent to the dryer feed conveyor. A rotary, direct-fired dryer is used to dry the chips from 50 percent to 17.5 percent moisture content. The dryer operates on char produced during gasification, supplemented with chips, if necessary. A gas burner is provided for start-up. Pollution control for the dryer is provided by a Rader wet sand filter or equivalent.

The dried chips are recovered from a dropout box and cyclones downstream of the dryer and conveyed to a bucket elevator which feeds a storage silo. A feeder at the bottom of the silo removes chips to a belt conveyor which feeds a bucket elevator. The bucket elevator feeds a twin-screw metering hopper. The chips leaving the metering hopper run onto a weigh belt before being pressurized through a rotary airlock (valve). Nitrogen is used to prevent blowback of low-Btu gas through the rotary valve. The wood chips are run into the fluidized-bed reactor from the rotary valve with a screw feeder that is run lean. The barrel of the screw feeder is water-cooled.

Air for fluidization/gasification (about 15 percent of stoichiometric air) is provided by a rotary pressure blower. A start-up gas burner capable of bringing the bed temperature up to the ignition temperature of the chips is also provided. The chips are rapidly heated in the sand bed and decompose/gasify. The oxygen in the air entering the bottom of the fluidized bed is consumed by combustion of char and chips in the bed-bottom inventory below the chip feedpoint, providing the heat to sustain the reactor temperature. The gas, vaporized oil and small char particles are blown out the top of the gasifier (Miscellaneous tramp material can be removed from the bed through a removal valve and cooling screw; bed sand is recycled). The entrained char is removed by primary and secondary cyclones. At the bottom of each cyclone is a cooling screw and rotary airlock. The char is transported via conveyors to a storage silo. The char is ultimately fed to the suspension burner on the dryer.

The gas and vaporized oil out of the cyclones go to a venturi-type oil scrubber that is operated above the water dew point. Water that becomes saturated with oil is used as the scrubbing medium. The gas is separated from the scrubber liquor and the condensed oil in a cyclonic separator. Additional oil mist removal is done in a low-velocity coalescing filter. The condensed oil and scrubbing liquor flow to a gravity separating tank from

which the scrubbing liquor is pumped through an air-cooled heat exchanger and sprayed back into the venturi scrubber. The net oil product is pumped to storage.

The scrubbed gas is sent to a burner operating on a boiler, dryer, etc. The heating value of the gas is above 712 kcal/m^3 (80 BTU/scf). This can be controlled by the gasifier operating temperature (higher temperatures produce more gas but less oil), but more directly by the scrubber operating temperature, i.e., less lighter oil condensation. The fluidized-bed reactor operates at a sufficient pressure to deliver the gas at a high enough pressure for burner controls. A flare is provided to burn the gas during start-up and when the process using the gas is not operating.

Costs

Capital costs are shown in Table 1. Operating costs are shown in Table 2, without a return on capital. Assuming a 40% tax rate, a 15% after-tax return would add another 15.1 cents per kg (6.85 cents per lb) for a total cost of 43.4 cents per kg (19.7 cents per lb). This is much lower than the current (5/95) price of phenol (84 - 93 cents/kg) and about the current price for formaldehyde (16). Wood/biomass costs are about 43% of the net operating costs when the feed is priced at its fuel value (currently $6.94/Gcal, $1.75 per MBtu). If lower cost feedstocks are available that are undesirable fuels such as wet bark, bagasse or rice hulls, the cost of the raw oil and resin can be reduced considerably.

Table 1 Capital Costs

Feed Preparation and Drying	$2,402,000
Gasifier Area	812,000
Scrubber	941,000
Miscellaneous Plant Equipment	555,000
Subtotal, Installed Equipment	**4,710,000**
Land	50,000
Earthwork, Structural Steel and Buildings	312,000
Fire Protection and Sewer	183,000
Instrumentation	350,000
Piping and Insulation	327,000
Electrical Distribution	377,000
Subtotal, Direct Costs	**6,309,000**
Construction Management	442,000
Design and Engineering	536,000
Subtotal, Direct and Indirect Costs	**7,287,000**
Escalation and Contingency	1,093,000
Total Capital Cost	**$8,380,000**

Table 2 Operating Costs

Item	Basis		Annual Cost
Depreciation	10.53% of Capital Cost		$ 885,000
Maintenance	6% of Capital Cost		504,000
Labor	7 employees, day shift, 3 operators, other shifts		815,000
Power	436 kW/hr @ $.07/kWh		241,000
Wood	$16.50 per wet tonne ($15 per ton)		1,675,000
Gas Credit	$6.94/Gcal. ($1.75/ MBtu)		(421,000)
Insurance & Local Taxes	2.5% of Capital Cost		210,000
Annual Net Cost			**$3,909,000**
Annual Oil Production		**13,865,000 kg**	**30,566,000 lb**
Raw Oil Operating Cost		**$0.283/kg**	**$0.128/lb**

Current Development Status and Development Requirements

Currently, Biocarbons Corporation has an operational, 0.076 m (3 in.) diameter fluidized-bed pilot plant. All components are scaled-down versions of the equipment described in the process design. The pilot plant is capable of feeding up to about 9 kg/hr (20 lb/hr) of feed into the reactor and producing 2 to 3 kg/hr of oil for evaluation. Analysis is currently limited somewhat by lack of in-house analytical equipment.

A commercial-sized plant will use a reactor with an inside diameter of about 2.44m (eight ft.). Although fluidized-bed reactors are easily scaled up, leaping from a 0.076 m reactor to a 2.44 m reactor is not recommended, because solids feeding, air distribution and operating experience with the mechanical equipment and operating conditions chosen should be more thoroughly evaluated, independently from resin chemistry development. Serendipitously, the quantity of resin samples necessary to receive certifying agencies' approval in panel-mill tests of adhesives requires a larger pilot plant - with a diameter of approximately 0.46 m - capable of processing about 300kg/hr of biomass. Successful operation of this facility and good results in mill tests with adhesives produced with the larger pilot plant's oil should generate enthusiasm for commercial production of PF resins using biomass-derived oil/tar as a feedstock.

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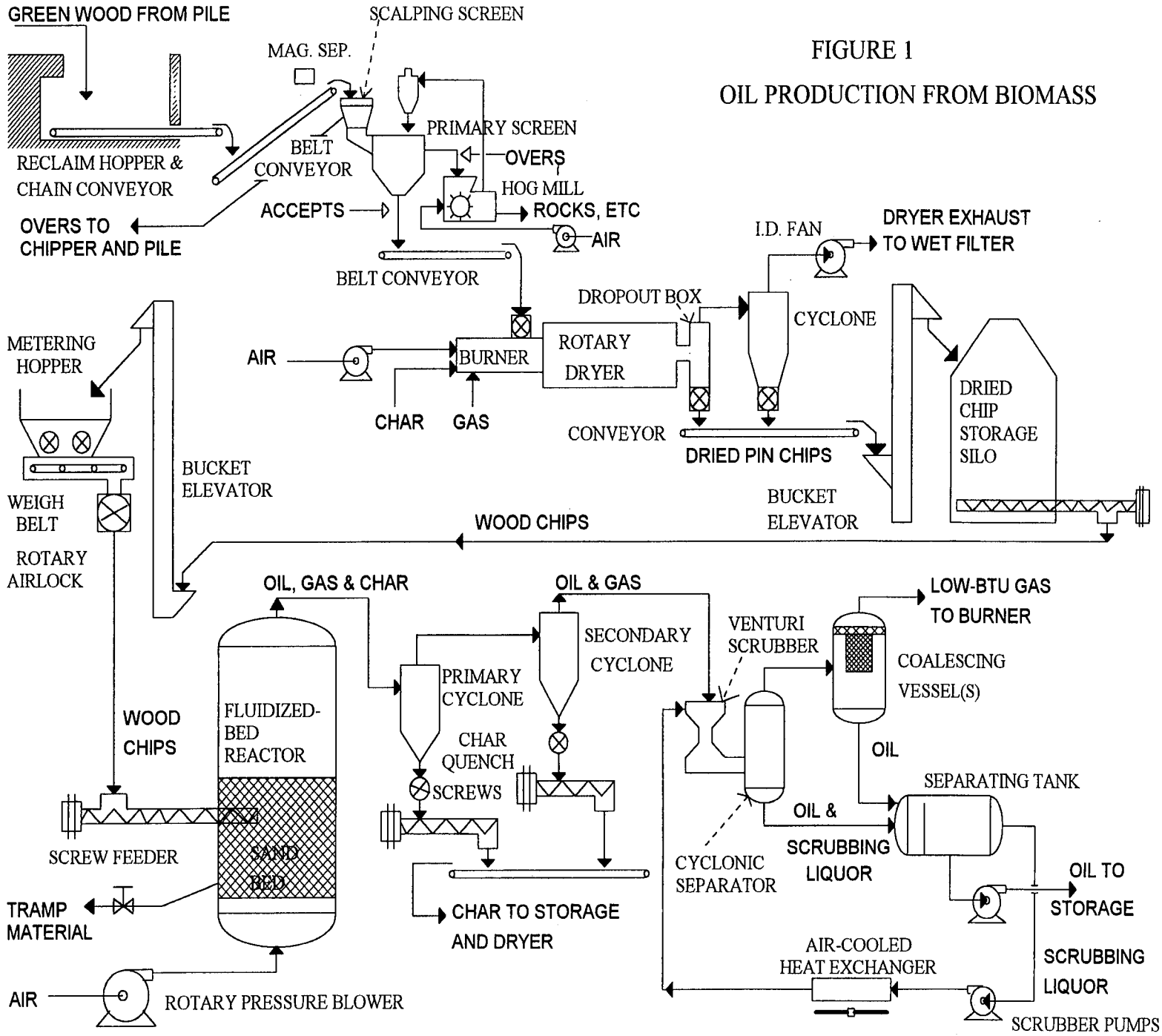

FIGURE 1

OIL PRODUCTION FROM BIOMASS

Figure 1 Oil production from biomass

FAST PYROLYSIS OF PRETREATED WOOD

Jan Piskorz, MASc, Vice President; Desmond Radlein, PhD., President;
Piotr Majerski, Production Manager; Resource Transforms
International Ltd, Waterloo, Ont. Canada
Donald Scott, PhD., Professor, Dept. of Chemical Engineering,
University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1

Abstract

During the 1980's, several research groups reported the fact that pyrolysis in a non-oxidizing atmosphere of wood that had been prehydrolyzed with dilute acid allowed a substantial depolymerization of the cellulose to occur to give anyhydrosugars. More recent work has shown that only deionization of the wood is necessary, and not necessarily a partial hydrolysis. The indigineous alkaline inorganic cations contained in the wood (principally calcium and potassium) have a profound effect on the mechanism of thermal decomposition of the cellulose and hemicellulose fractions. Also, it has been known for many years that alkaline cations are efficient oxidation catalysts for biomass.

We have explored the possibility that oxidation reactions in fast pyrolysis of prehydrolyzed, or of deionized, biomass may be altered much more for carbohydrates than for lignins. Results obtained show that fast pyrolysis of pretreated biomass with controlled levels of oxygen will selectively oxidize lignins with relatively little effect on anhydrosugar yields. This partial oxidation approach generates needed heat in situ. As well, by removing a substantial fraction of the lignin-derived material from the pyrolysis liquid, the recovery of anhydrosugars for use as fermentable sugars or as chemicals is simplified.

Introduction

In recent years, a good deal of interest has been shown in reaching a better understanding of the influence of inorganic ions, particularly cations, on the decomposition mechanisms of cellulose and hemicellulose. The major indigineous cations found in biomass are usually calcium and potassium, and many publications over the past ten years have investigated the important role played by these inorganic substances in determining the mode of thermal decomposition of natural carbohydrate polymers. Following the early pioneering work of Shafizadeh et al , for example (1) (2), additional contributions were made with respect to mechanism and thermal conversion of celluloses and hemicelluloses to anhydrosugars by the authors (3) (4) (5) (6). In recent years, Richards and co-workers have carried out extensive studies on the influence of a variety of inorganic additives on the mechanisms of thermal decomposition and the products resulting from pyrolysis of treated biomass, e.g. (7) (8) (9). The anhydrosugar resulting from depolymerization of cellulose, levoglucosan (anhydroglucose), is now produced as a commercial chemical by Resource Transforms International Ltd., as well as other anhydrosugars obtainable from natural carbohydrate polymers.(10). A successful commercial process was made possible by an understanding of the mechanisms of thermal decomposition in the presence of inorganic ions, and the ability,therefore, to control the selectivity of the decomposition process.(11) (12)

As is now well established, at least two major decomposition pathways are possible for cellulose and hemicellulose. These are shown in Figure 1. Which of the two routes will be followed depends primarily on the nature and amount of the inorganic impurities present. In order to obtain good selectivity for depolymerization, it is necessary to remove the alkaline inorganic cations, principally potassium and calcium. This can be done readily by acid treatment, either by a prehydrolysis with dilute acid, or by deionization with even more dilute acid. In the first case, most of the hemicellulose is hydrolysed and removed as soluble pentosans, leaving the cellulose and lignin fractions now free also of metallic cations. In the second case, only the inorganic cations are removed, and the hemicellulose remains in the pretreated biomass. A different spectrum of anhydrosugars results from the thermal depolymerization by fast pyrolysis if the major carbohydrate present is cellulose, or if hemicellulose is also present. In both cases, volatile lignin fragments are also produced with the anhydrosugars and other thermal decomposition products of the carbohydrates. If it is desired to recover the anhydrosugars from the pyrolysis liquids, then these lignin-derived impurities constitute a major problem in achieving a separation of the desired anhydrosugars.

In the course of many experiments to produce liquids by fast

pyrolysis, we observed that in liquids made from pretreated biomass that oxygen was slowly absorbed over time. Since the phenolic lignin-derived components were the most likely to react readily with atmospheric oxygen, this suggested to us that preferential oxidation of this fraction might be possible in a fast poyrolysis reactor. This report describes the initial results from these investigations.

Experimental

Two feedstocks were used for the tests described here. A softwood, western hemlock, was deionized with dilute (0.5% or less) acid, while a hardwood, a hybrid poplar was prehydrolyzed with hot 5% acid, a procedure which removed the majority of the hemicellulose fraction. The hemlock wood contained about 42% cellulose and 20% hemicellulose, while the poplar wood had about about 48% cellulose. The hemicellulose in softwoods is based in the majority on mannose, while in the hardwood xylans predominate. In all tests the wood was ground and screened to -0.5mm particle size and dried to about 5% moisture content.

The fast pyrolysis apparatus used was the standard bench scale atmospheric fluidized sand bed developed in our laboratory. A diagram is shown in Figure 2. Feed was continuous at a normal rate of 20 to 50 g/h. Full details of this apparatus and its method of operation have been given in earlier publications (13). The apparatus is constructed so that all parts can be weighed before and after a run, and then solvent washed for recovery of all products. Material balances generally closed to within 95% to 100%

Gaseous products were collected in a large gas bag and analysed by GC. Char yields were obtained from the weight gain of the reactor after solvent washing, from char collected in the char pot, and from insolubles in the washings. Liquid product was obtained from the two ice-water condensers and from the solvent washings of the equipment and filters after vacuum evaporation of the solvent. Water content of the washings was determined by Karl Fischer titration, and the organic components were determined by HPLC analysis. The determination of the "pyrolytic lignin" is a somewhat arbitrary measurement. When a portion of the homogeneous liquid pyrolysis product is mixed with two parts of water, phase separation occurs. The precipitated material was assumed to consist almost entirely of lignin-derived components, and it was filtered out, dried , weighed, and reported as "pyrolytic lignin" . Not all components of the liquid which were determined in analyses are reported in the following section, but only those of interest in determining changes in pyrolysis product yields. Nitrogen was used as the fluidizing gas, and when an oxidizing atmosphere was desired, a controlled amount of air was added to the inlet gas stream to the pyrolysis reactor.

Results and Discussion

The behaviour of western hemlock sawdust which has not had any pretreatment is shown in Table 1 when nitrogen alone is used as the fluidizing gas (Run 78) and when nitrogen + air is used (Run 99). Comparison of these two runs shows that the oxidation occuring in Run 99 is non-selective and that both oxygenated species, e.g. hydroxyacetaldehyde, and lignin-derived components are severely reduced in amount. However, comparison of Runs 74 and 97 in which a deionized sawdust was used and pyrolyzed in both nitrogen and nitrogen + air shows that the large increase in levoglucosan yield obtained after removal of alkaline cations is preserved in the oxidizing atmosphere. On the other hand, the pyrolytic lignin is greatly reduced in amount. The pentosans formed during the fast pyrolysis of deionized hemlock are also preserved in the oxidizing atmosphere. The result is a liquid product which is much enriched in anhydrosugar content and which has a much lower concentration of phenolic compounds.

Table 1

Pyrolysis of Western Hemlock Sawdust
0.5 seconds residence, Temperature 450–490° C.

Run No.	78*	74**	99*	97*
Feedstock	Untreated wood	Deionized wood	Untreated wood	Deionized .wood
Atmosphere	Nitrogen	Nitrogen	N2 + air	N2 + air
% Oxygen in gas	0	0	12	12
Yields, wt % mf. feed				
Gas	12.0	5.1	68.0	40.5
Product water	9.4	9.5	27.5	18.2
Organic liquid	56.5	64.7	32.3	54.8
Char	18.2	17.3	12.7	13.3
Total	96.1	96.6	140.5	126.8
Liquid composition, wt. %				
Levoglucosan	2.5	16.8	1.3	18.7
Cellobiosan	0.5	2.5	0.0	3.4
Hydroxyacetaldehyde	10.6	2.2	3.2	2.1
Anhydromannoses	0.0	5.2	0.0	10.6
Formaldehyde/formic acid	4.0	0.0	4.8	0.0
Acetic acid	1.4	1.6	1.0	0.0
Acetol	3.4	0.0	0.0	0.0
Pyrolytic lignin	19.9	21.6	3.4	1.5

*Fluidized Bed
**Transport Reactor

In Table 2, the effect of temperature variation with an oxidizing atmosphere is shown over the range of 410° to 510°C. The results with a non-oxidizing atmosphere are also shown for comparison. These results demonstrate the known fact that the optimum temperature for fast pyrolysis of deionized or prehydrolyzed wood is about 50° lower than that for untreated wood. The results again show the large decrease in phenolic components while the anhydrosugar yields are only slightly affected by the oxidation process, but are reduced at temperatures above the optimum.

Table 2

Effect of Temperature in Selective Oxidation of Lignin
0.5 seconds residence time, fluidized bed, 5% moisture

Run No.	96	97	98	86
Temperature, °C.	410	455	510	455
% Oxygen in Gas	12.9	12.1	11.5	0
Yields, % mf. feed				
Gas	39.0	40.5	67.8	4.4
Product water	20.6	18.2	25.3	7.0
Organic liquid	47.7	54.8	45.1	69.1
Solid residue (char)	21.5	13.3	4.3	16.1
Total	128.8	126.8	142.5	96.6
Liquid Composition, wt. %				
Cellobiosan	1.4	3.3	2.1	5.2
Levoglucosan	18.8	18.7	12.6	15.8
Hydroxyacetaldehyde	1.8	2.1	0.0	3.1
Anhydromannose	10.9	10.6	9.0	9.0
Acetic acid	0.0	0.0	0.0	0.0
Pyrolytic lignin	0.0	1.5	2.7	14.2
% Sugars in liquid	31.1	32.6	23.7	30.0

The large increases in product water and in gas yields also shows that the oxidation reactions are generating considerable amounts of heat in the reactor. This also results in a drop in yield of organic liquids, as must occur if partial oxidation of volatile components is occuring.

The effect of temperature at different levels of oxygen in the fluidizing gas is shown for various product fractions in Figures 3,4,5 and 6. These results suggest that oxygen levels of up to 12% at least can be used at the optimum temperatures for cellulose depolymerization, that is, at about 450°C. Figure 6 shows clearly the small effect of oxygen content up to 12% on the levoglucosan yields as a % of the dry wood fed at the optimal temperature of 450°C. At higher temperatures, the oxygen level should be reduced to avoid too much loss of anhydrosugar, particularly as little further reduction in lignin content is achieved (see Figure 5)

Table 3 shows results for the oxidative pyrolysis of a prehydrolyzed hardwood, poplar. In this case, the pyrolytic lignin fraction apppears to be somewhat more difficult to selectively oxidize than is the case for softwood, and even when air at 21% oxygen is used, only about a 50% reduction is achieved in the amount of these components. At these high oxygen levels the organic liquid yield is also somewhat reduced, so that even though the concentration of anhydrosugars in the liquid is not seriously affected, the overall yield of the anhydrosugars is somewhat reduced. This effect is particularly noticeable at the higher temperature of 500°C.

Table 3

Fast Pyrolysis of Prehydrolyzed Poplar Wood
Fluidized bed, 0.50 seconds, 5.8% moisture

Temperature, °C.	501	436	460	460	460	500
Atmosphere	N_2	N_2+ Air	N_2 + Air	N_2 + Air	Air	Air
% Oxygen in Gas	0	1.6	6.0	12.3	21.0	21.0
Yields, wt. % mf feed						
Gas	4.4	8.7	28.3	36.0	40.7	53.8
Product water	10.1	12.3	15.3	19.1	19.3	22.7
Organic liquid	77.0	68.2	64.3	62.8	61.0	51.8
Char	6.2	14.0	10.0	6.9	8.2	6.4
Total	97.7	103.2	118.0	124.7	129.2	134.8
Liquid Composition, wt. %						
Levoglucosan	27.6	23.2	28.6	26.5	25.7	22.4
Cellobiosan	4.0	1.6	2.3	1.9	1.4	2.1
Hydroxyacetaldehyde	1.7	0.0	0.0	0.0	0.0	0.0
Glucose	0.0	0.0	3.6	1.8	2.4	2.6
Glyoxal	0.7	2.2	2.1	1.8	1.4	2.6
Anhydrofuranose	2.1	ND	3.8	5.3	3.9	3.0
Formaldehyde/formic	0.0	4.7	ND	6.5	ND	5.1
Acetic acid	0.0	0.0	0.0	ND	ND	ND
Pyrolytic Lignin	25.5	4.7	11.9	13.5	13.3	10.6

Conclusions

1. It has been demonstrated that because of differences in oxidation rates between anhydrosugars and aromatic lignin - derived components which are formed in fast pyrolysis of deionized or prehydrolyzed wood, that it is possible to carry out the pyrolysis in an oxidizing atmosphere which will destroy a substantial part of the lignin-derived volatiles but have little effect on the anhydrosugar yields.

2. Preliminary results indicate that lignin-derived volatiles from softwood are more readily oxidized than those obtained from hardwood. The reason for this difference is not yet established.

3. The partial oxidation method for conversion of cellulose or hemicellulose into anhydrosugars, or fermentable sugars, also generates in situ heat required for the pyrolytic process.

4. The reduction in the amounts of aromatic materials such as phenolics in the liquid product as a consequence of oxidative pyrolysis is an advantage in developing separation processes for the recovery of anhydrosugars, or in fermentation processes.

Acknowledgments

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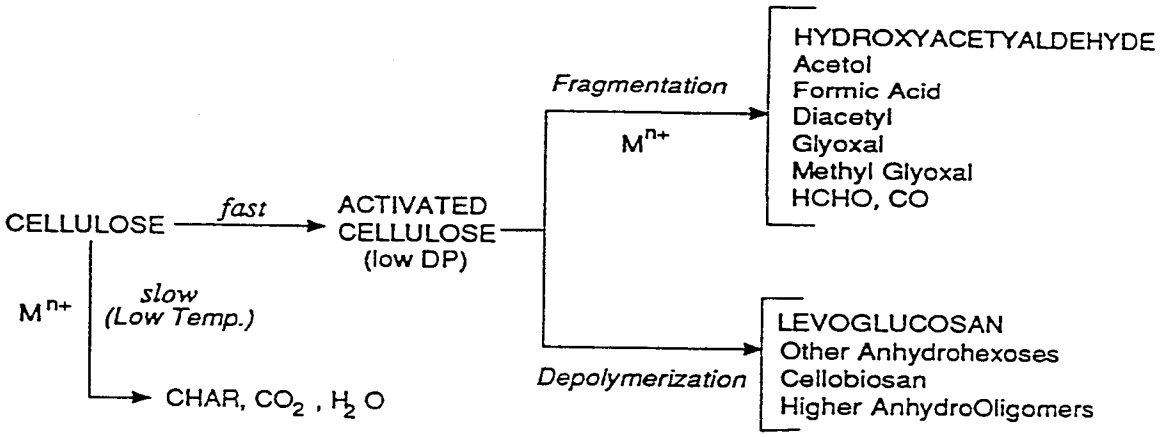
Figure 1



Decomposition Pathways of Cellulose in Fast Pyrolysis

Figure 2

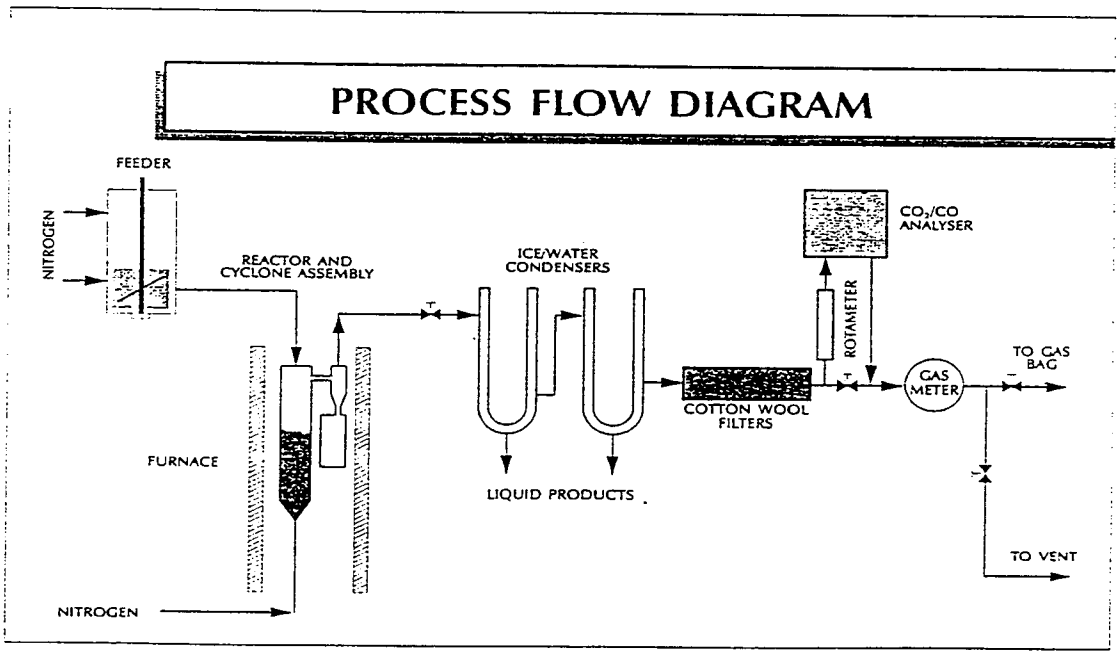


Figure 3

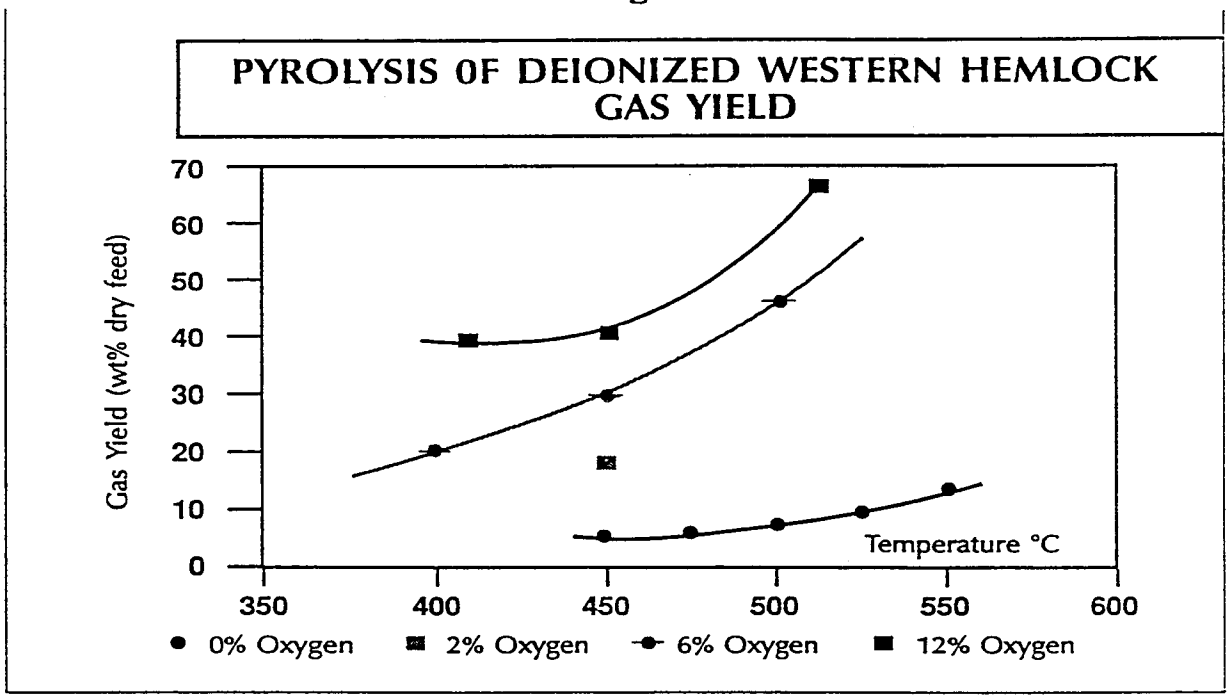


Figure 4

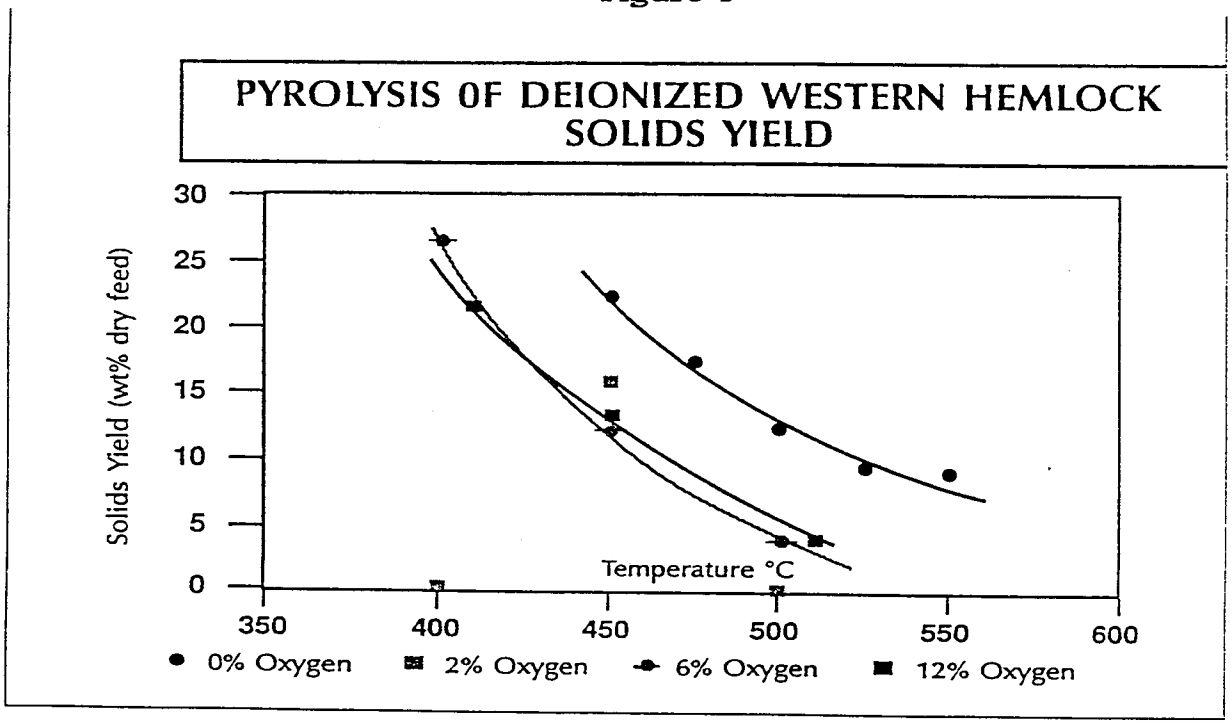


Figure 5

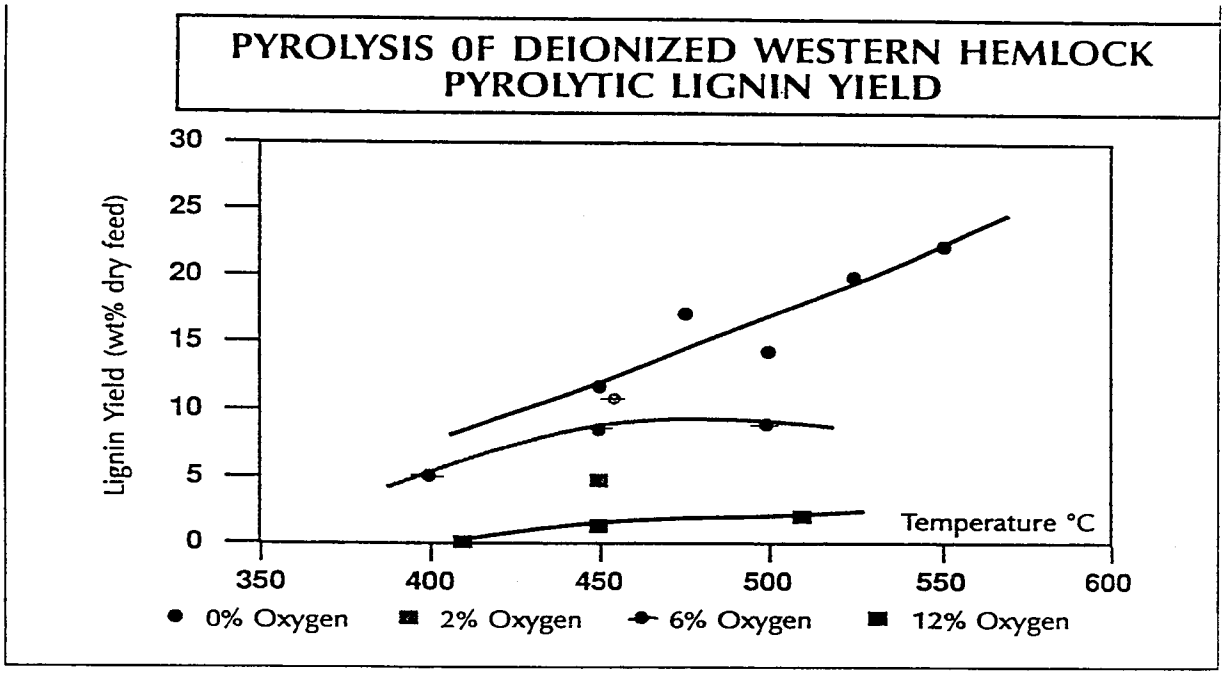
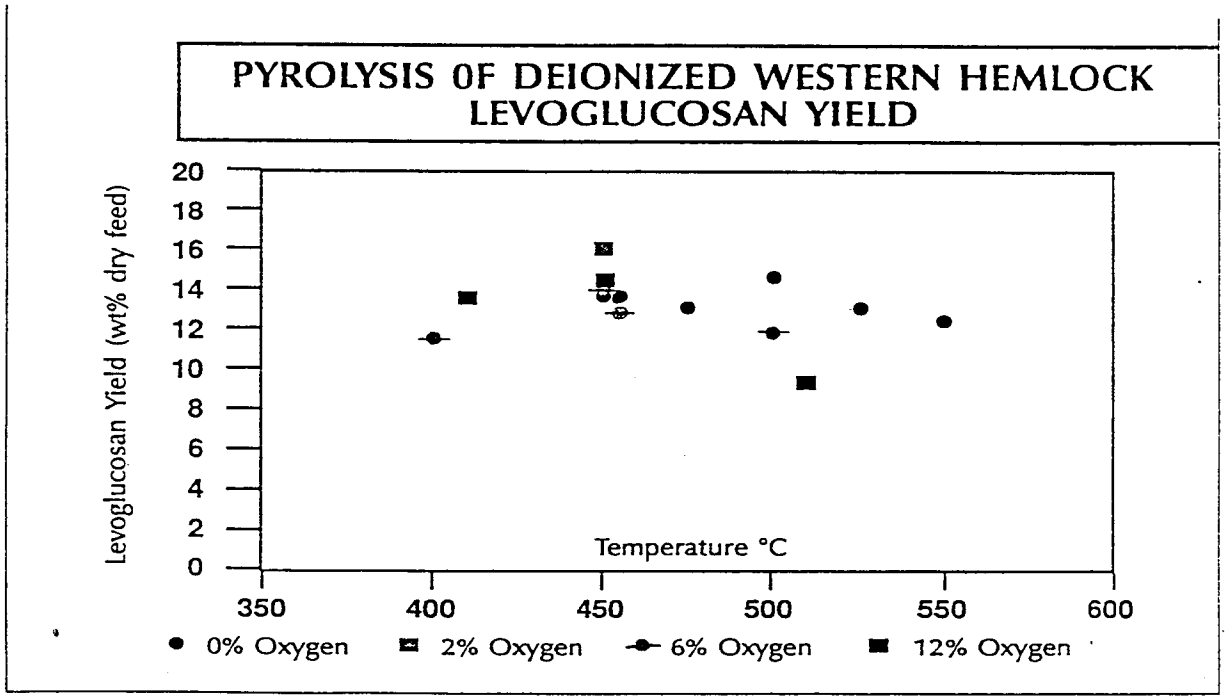


Figure 6



CONVERSION OF LIGNIN INTO A PRECURSOR FOR THE PRODUCTION OF GRAPHITIC CARBON MATERIALS

Chad M. Nelson, Ph.D., Manager, AFR, Inc., East Hartford, CT U.S.A.
Michael A. Serio, Ph.D., Manager, AFR, Inc., East Hartford, CT U.S.A.
Erik Kroo, Chemist Diploma, Chemist, AFR, Inc., East Hartford, CT U.S.A.
Sylvie Charpenay, M.S., Scientist, AFR, Inc., East Hartford, CT U.S.A.
Rosemary Bassilakis, B.S., Research Associate, AFR, Inc., East Hartford, CT U.S.A.
Ripudaman Malhotra, Ph.D., Leader, Carbon Materials Group, SRI International, Menlo Park, CA U.S.A
Peter R. Solomon, Ph.D., President, AFR, Inc., East Hartford, CT U.S.A.

Abstract

Lignin is the most abundant renewable aromatic material. There are roughly 25 x 10^6 tons of lignin produced each year as a byproduct of pulp and papermaking which has a fuel value of between $0.00 and $0.04 per pound. Carbon materials are among the highest value products which can be produced from lignin. Consequently, the development of processes which can utilize lignins for carbon fibers or the production of other high value carbon materials has the potential for a high payoff. It would also result in the utilization of lignin as a raw material for high technology, internationally competitive industries. The ability to form graphitic carbon materials from pitch depends on the development of a liquid crystal system called mesophase. A major problem with using lignin as a precursor for the production of mesophase pitch is the high oxygen functional group concentration of lignin which makes it reactive toward crosslinking. Hydrothermal treatment of lignin allows for selective removal of the reactive oxygen functional groups from lignin which normally prevent extensive mesophase formation. Hydrothermal pretreatment of lignin substantially increases the mesophase content of lignin-derived pitch. This development will make lignin a suitable precursor for a range of carbon materials applications.

Introduction

Lignin is the most abundant renewable aromatic material. There are roughly 25 x 10^6 tons of lignin produced each year as a byproduct of pulp and papermaking which has a fuel value of between \$0.00 and \$0.04 per pound (1). While the chemical uses of lignin-derived products have received a lot of study, the material uses have a larger potential for production of high value products and have received relatively little study. Carbon materials are among the highest value products which can be produced from lignin (2). Carbon fibers have traditionally been made from cellulose (rayon) or polyacrylonitrile (PAN) fiber precursors. However, these precursor materials are expensive, and the manufacturing process to produce the finished product is also expensive, with a relatively low yield (< 55 wt.%). Consequently, there has been increased interest in the use of relatively inexpensive petroleum or coal-tar pitches to manufacture fibers (3). The ability to form carbon fibers and several other graphitic carbon materials (e.g., graphite, coke, electrodes, etc.) from pitch depends on the development of a liquid crystal system called mesophase. A major problem with using lignin as a precursor for the production of mesophase pitch is the high oxygen functional group concentration of lignin (1) which makes it reactive toward crosslinking. This paper describes the hydrothermal treatment of lignin to selectively remove the reactive oxygen functional groups from lignin which normally prevent extensive mesophase formation. The proposed steps for converting lignin to high performance carbon fibers are outlined in Figure 1. (Steps described here are denoted by solid arrows.) This development will make lignin a suitable precursor for a range of graphitic carbon materials applications.

Materials and Methods

Lignin

ALC lignin was obtained from Repap Technologies, Inc. of Valley Forge, PA. This is an experimental lignin made from mixed hardwoods by an organosolv process using aqueous EtOH.

Hydrothermal Treatment

The reactor system used for hydrothermal treatment is depicted in Figure 2. The system operation has been previously described (4). Treatment times ranged from 15 min to 8 hrs, covering a range of treatment conditions from mild to severe.

TG-FTIR Analysis

A series of programmed pyrolysis experiments was performed in a TG-FTIR system. The apparatus consists of a sample suspended from a balance in a gas stream within a furnace. A schematic is shown in Figure 3. The system continuously monitors: 1) the time-dependent evolution of the gases (including individual identification of species such as CH_4, CO_2, CO, H_2O); 2) the heavy liquid (tar) evolution rate and its IR spectrum; and 3) the weight of the non-volatile material (residue).

Transmission FT-IR

The raw, biotreated, and hydrothermally treated ALC lignin samples were also analyzed by transmission FT-IR spectroscopy. A measured quantity of the raw or treated lignin was pressed with KBr into a pellet, and the resulting absorbance spectra were normalized

to the mass of material. A semiquantitative measure of the functional group content was obtained by curve resolving the resultant absorbance spectrum (5).

Field Ionization Mass Spectrometry (FIMS)
The technique of field ionization (FI) consists of passing vapors of the material to be analyzed through a region of intense electric field (6). The FIMS facility at SRI International consists of an activated tantalum foil field ionizer interfaced with a 60° magnetic sector mass analyzer and a PDP 11/23 computer for data acquisition and processing. Approximately 50 μg of the sample is introduced via a heatable direct insertion probe. Mass spectral data of the evolving volatiles are collected by repeatedly scanning the magnet over a preset range while the sample is gradually heated from the initial temperature (sometimes as low as 78° C) to approximately 500° C.

Polarized Optical Microscopy
The suitability of a hydrocarbon pitch for the production of graphitized structures (carbon fibers, electrodes, etc.) is governed by the formation of a mesophase state (7). The mesophase content of pitch or pitch melts can be visualized using reflection microscopy where the incident and reflected light traverse crossed, plane polarizers. Reflections from an isotropic surface fail to modify the polarization angle while reflections from an anisotropic region (lamellar mesogen) change the polarization angle and result in bright areas in the field of view.

Results

Figure 4 compares the FT-IR absorbance spectrum for the raw ALC lignin with ALC lignin that was hydrothermally treated for 30 min and for 8 hr. The spectral region plotted contains the main vibrational bands for the majority of the oxygen functional groups initially present in the material. As the severity of the hydrothermal treatment increased, the bands due to individual oxygen functional groups began to lose definition.

Tables 1 summarize the TG-FTIR results for the raw and hydrotreated ALC. Based on the temperature of evolution (profile not shown), the CH_3OH produced is likely the result of hydrolysis of methoxyl functional groups. Hydrothermal treatment of the ALC lignin results in a substantial reduction of the CH_3OH yield, indicating a reduction in the methoxyl content. In addition, the yield CO_2 dropped after hydrothermal treatment. This drop in CO_2 is likely due to the reduction of carboxyl and carbonyl functional groups as indicated by the FT-IR analysis (see Fig. 4).

Table 1. Gas Yields During TG-FTIR Analysis of Raw and Treated ALC

Product	Raw ALC	H.T. 30 min	H.T. 8 hr
CO_2	**6.6**	2.4	3.4
CH_3OH	**2.2**	1.6	0.6

As illustrated in Fig. 4, and quantified by curve resolving, long-time hydrothermal treatment results in the near total removal of the free carbonyl, methoxyl, alkyl-aryl ether, and

hydroxyl functionalities. Less severe hydrothermal treatment results in complete removal of the aliphatic hydroxyl, reduction of the free carbonyl, alkyl-aryl ether, and carboxyl content, but a relative *increase* in the phenolic hydroxyl and ring oxygen. By varying the treatment time, temperature, and pressure during hydrothermal treatment, it is possible to produce a lignin derived pitch from which reactive functional groups have been selectively removed. This feature can also be exploited for other possible uses of the modified lignin since the product properties can be tailored by the exact choice of reaction conditions and duration to produce a product pitch with adjustable oxygen content and mesophase content.

Table 2 summarizes the effects of hydrothermal treatment on the oxygen functional group content of the ALC lignin. Based upon these results, hydrothermal treatment has a profound effect on the oxygen functional group content of the resulting tar or pitch.

Table 2. Effects of Treatment on the Functional Group Content of ALC

	CH_2OH	Ph-OH	Ar-O-R	Ar-O-CH_3	Ring-O	C=O	Anh.	COOH
H.T. 30 min	0	↑	↓↓	↓↓	↑	↓	↓	↓↓
H.T. 8 hr	0	↓	0	0	↓	↓↓↓	↓	↓↓

↑ increase relative to raw lignin
↓ slight decrease
↓↓ moderate decrease
↓↓↓ substantial reduction
0 complete removal
— no change

To help understand the effects of the hydrothermal treatment, the low temperature product FIMS were compared (products evolved below 165° C). Figure 5 (a&b) presents the low temperature FIMS spectra for the raw and short term treated lignin. The spectrum of the raw lignin (Fig. 5a) is characterized by a relatively small number of peaks, with M/z ranging from 182 to 418. The low temperature FIMS spectra for the hydrothermally treated ALC (Fig. 5b) demonstrates an extensive amount of low molecular weight products with very little evidence of the dimeric lignin structures (diguaiacylethene, syringaresinol) present in the raw samples. Figure 6 presents the single ion temperature-resolved mass chromatograms of the main monomeric and dimeric pyrolysis products. As discussed in reference (8), the evolution of lignin dimers (M/z 272-418) between 150 and 350° C for the raw ALC lignin (Fig. 6a) indicates that these compounds are linked to the lignin polymer by single bonds, while the evolution of coniferyl alcohol (180 M/z) and sinapyl alcohol (M/z 210) at these temperatures indicates the presence of α- and ß-alkyl-aryl ether linkages. Hydrothermal treatment (Figs. 6b) does not substantially shift the evolution of the dimers to lower temperatures, but rather is cleaving the dimeric units themselves. The near absence of the high temperature evolution of coniferyl and sinapyl alcohol from the hydrothermally treated sample supports the conclusion that the alkyl-aryl ether linkages are being substantially removed.

The treated lignins were thermally treated at low temperature (200° C) to produce a mesophase pitch. The procedure was as follows: The treated samples (≈50 mg) were placed in cylindrical sample wells bored into an aluminum bar. The bottom of the well

was covered with a removable glass slide. A qualitative measure of the mesophase content was obtained by observing the samples with crossed, polarized light. Figures 7(a,b) are low (1.8x objective, 5x eyepiece) and high (8x objective, 5x eyepiece) magnification (respectively) micrographs of the annealed lignin that was hydrothermally treated at 250° C for 30 min. (The dull green line present in the photographs was due to an overhead fluorescent lamp.) Figures 7(c,d) are similar micrographs of pure, mesophase petroleum pitch for comparison. This material is characterized by a matrix of small (< 30 μm), well distributed, mesogens throughout the entire structure. The micrographs of the hydrothermally treated samples are characterized by a much larger number of well dispersed mesogens. Although the mesophase content of the hydrothermally treated samples is not as extensive as found in the pure mesophase pitch, there are a substantial number of liquid crystalline domains and coalescence of some of the domains is evident. This mesophase content represents a dramatic increase over pitch produced from the raw lignin. It is likely that further optimization of both the hydrothermal treatment conditions and the thermal treatment step will result in a very high quality mesophase product suitable for the production of high performance carbon fibers.

Acknowledgements

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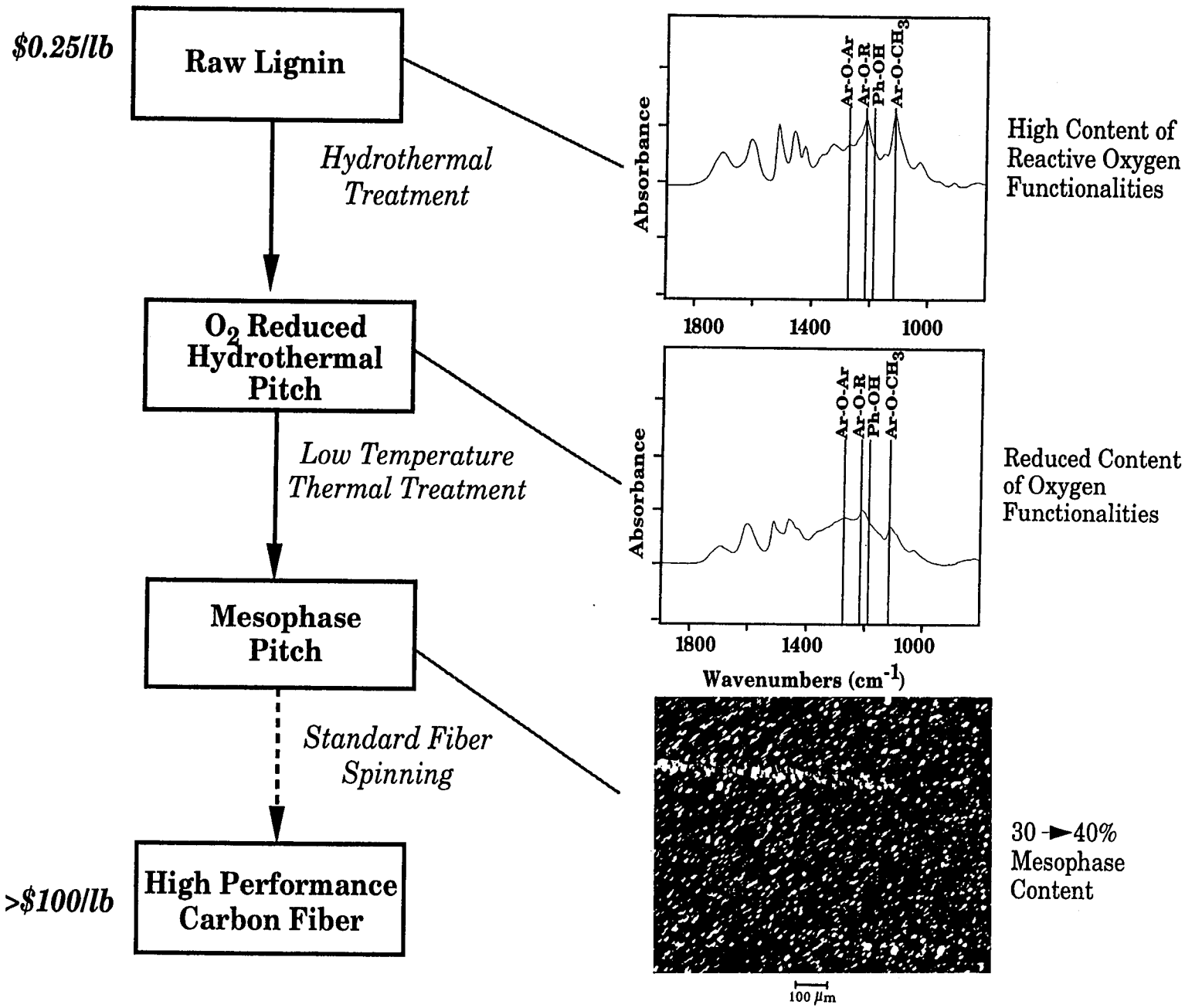
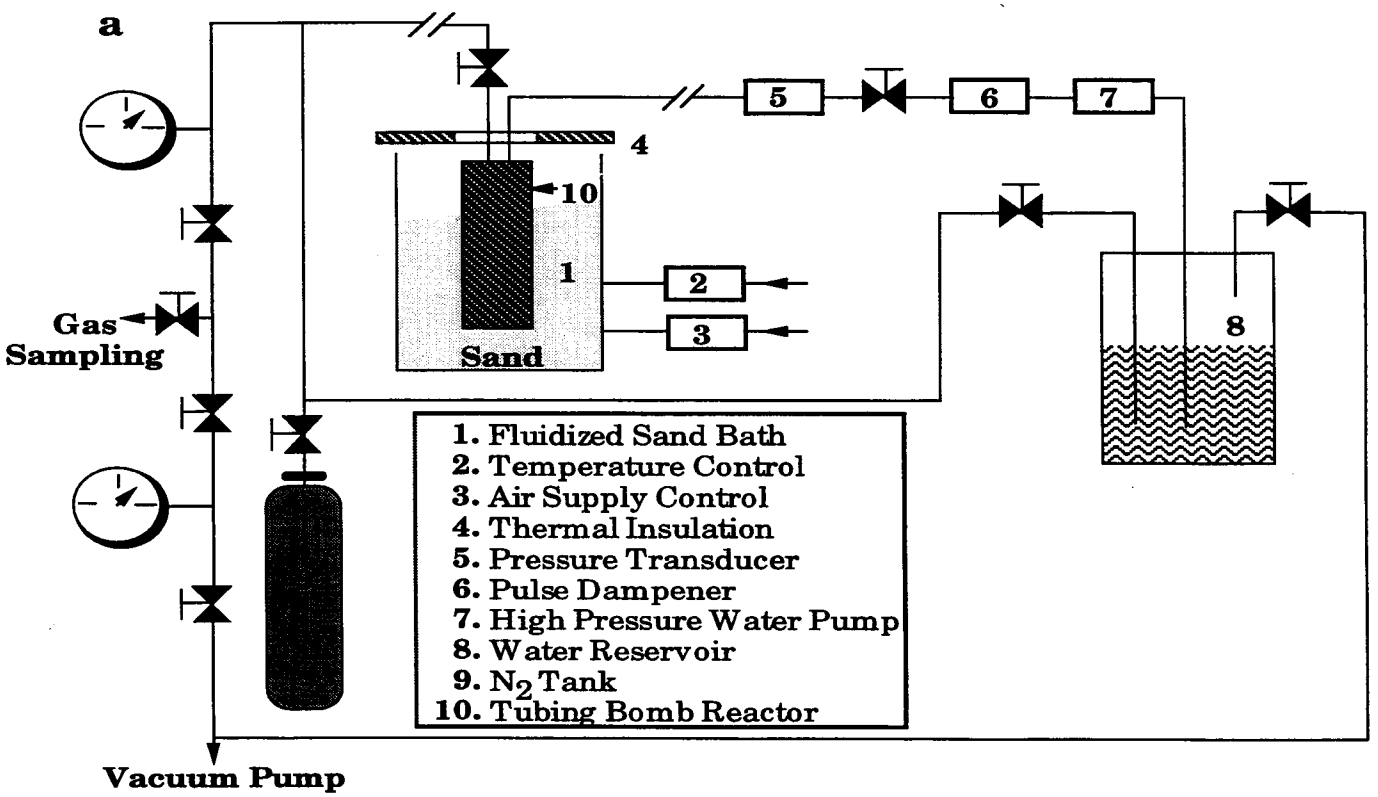


Figure 1. Proposed pathway for conversion of lignin to graphitic carbon fibers.



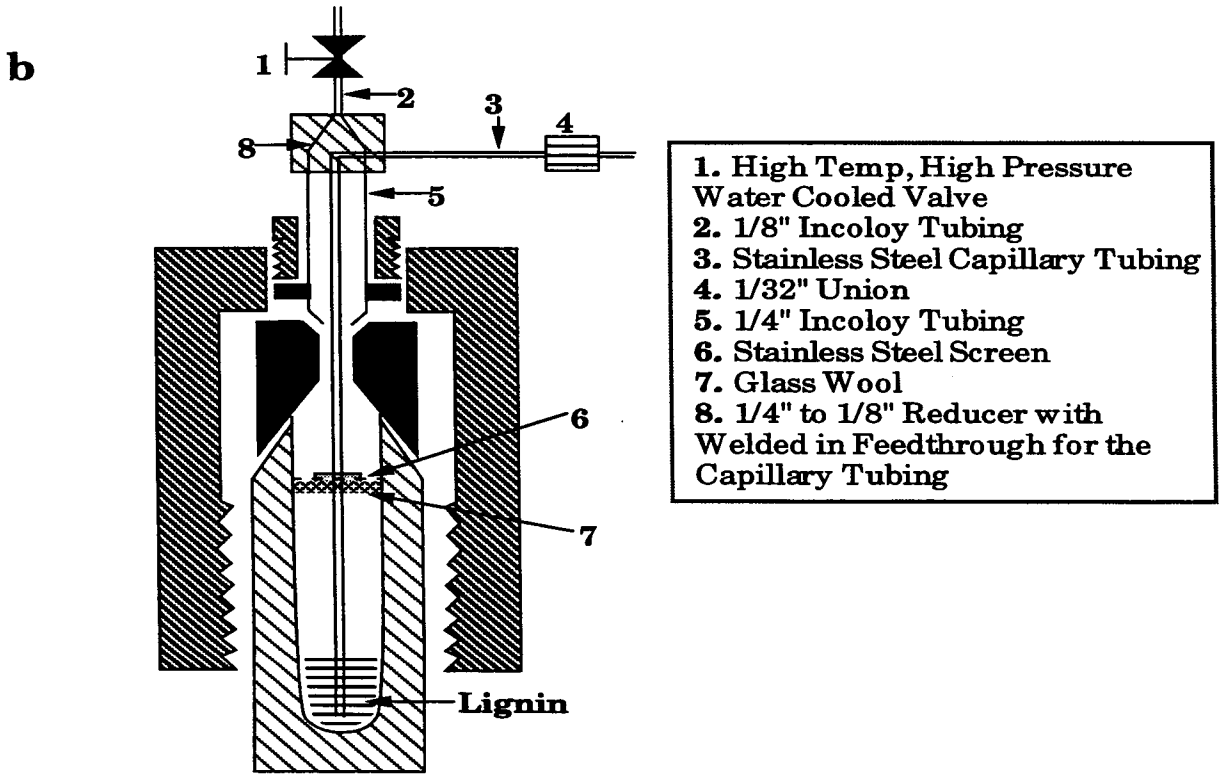


Figure 2. Schematic diagrams of the a) hydrothermal treatment system and b) bomb reactor.

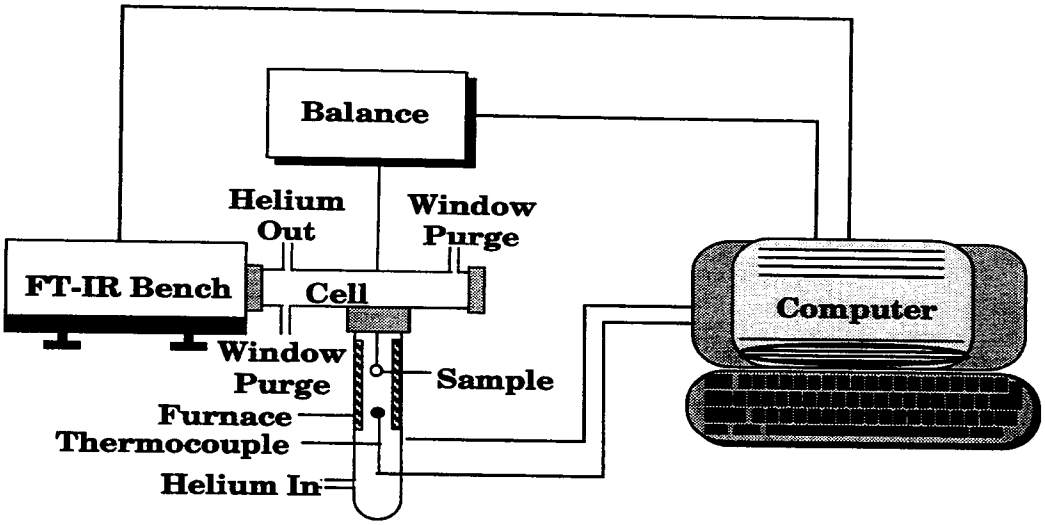


Figure 3. Schematic of TG-FTIR apparatus.

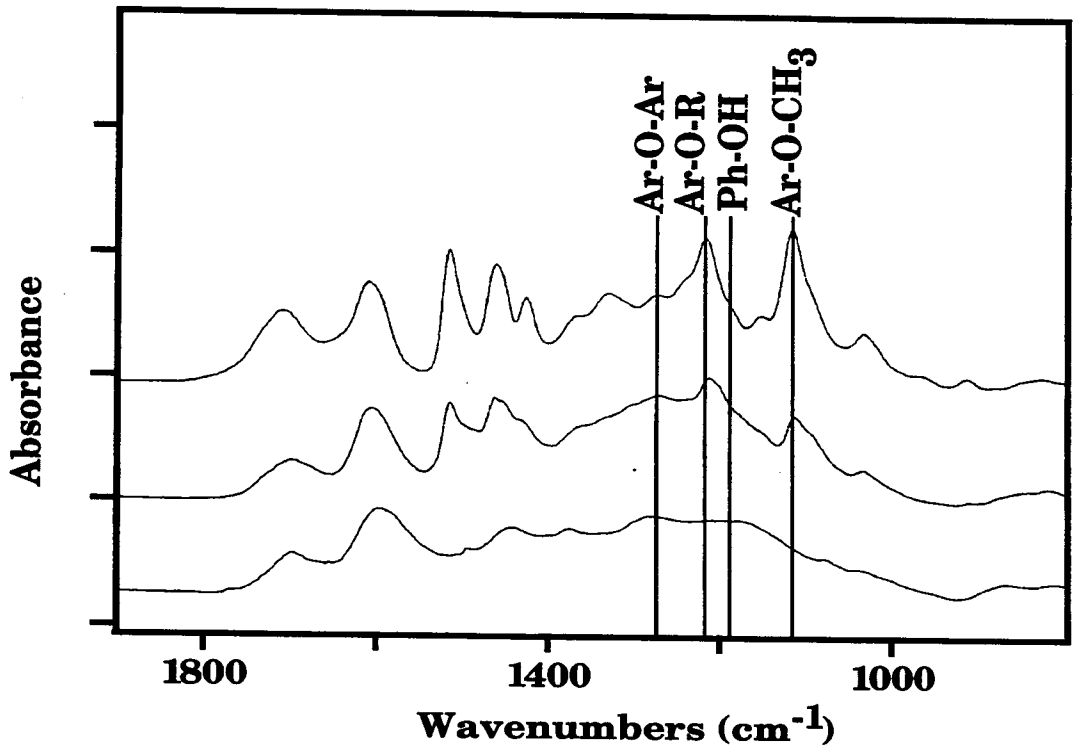


Figure 4. Comparison of FT-IR absorbance spectra for a) raw ALC, b) short-time (30 min) hydrothermal treatment, and c) long-time hydrothermal treatment.

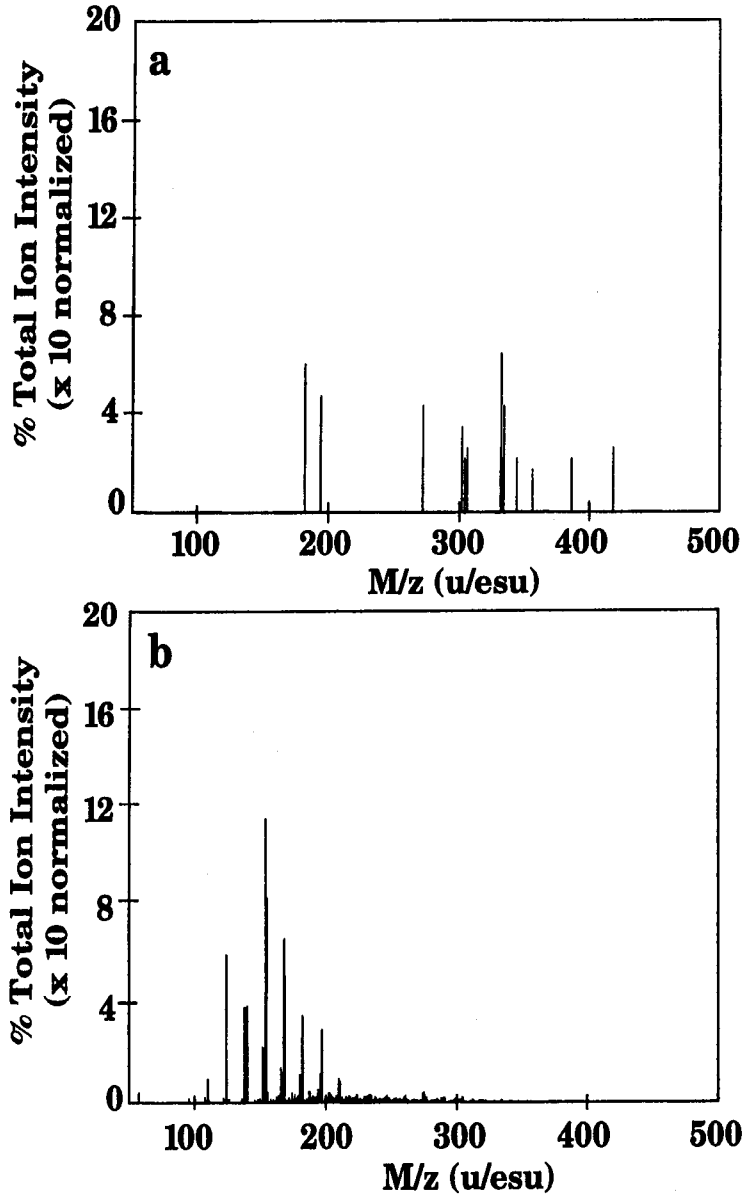


Figure 5. Low temperature FIMS spectra for a) raw ALC lignin (28-150° C) and b) short-time (30 min) hydrothermally treated ALC (1-151° C).

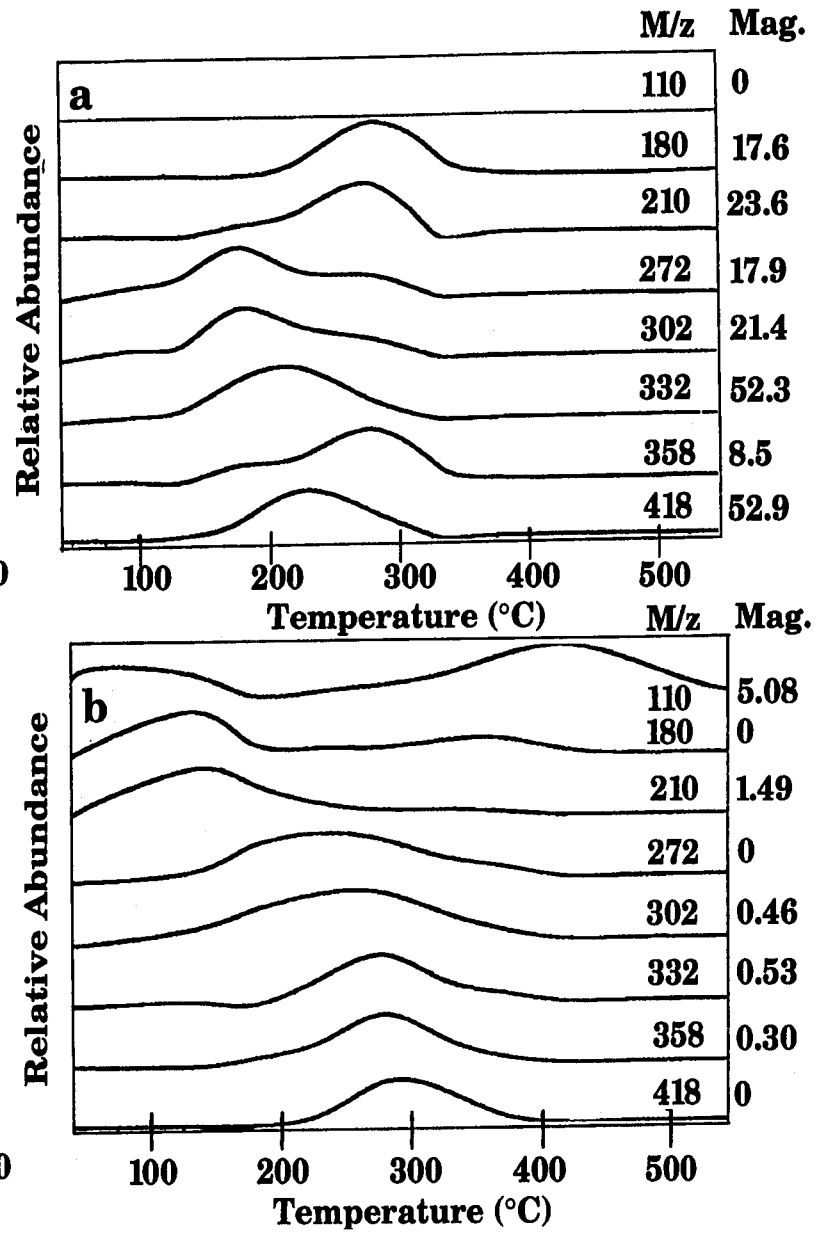


Figure 6. Single-ion, temperature-resolved mass chromatograms of the main monomeric and dimeric FIMS pyrolysis products for a) raw ALC lignin and b) short-time (30 min) hydrothermally treated ALC

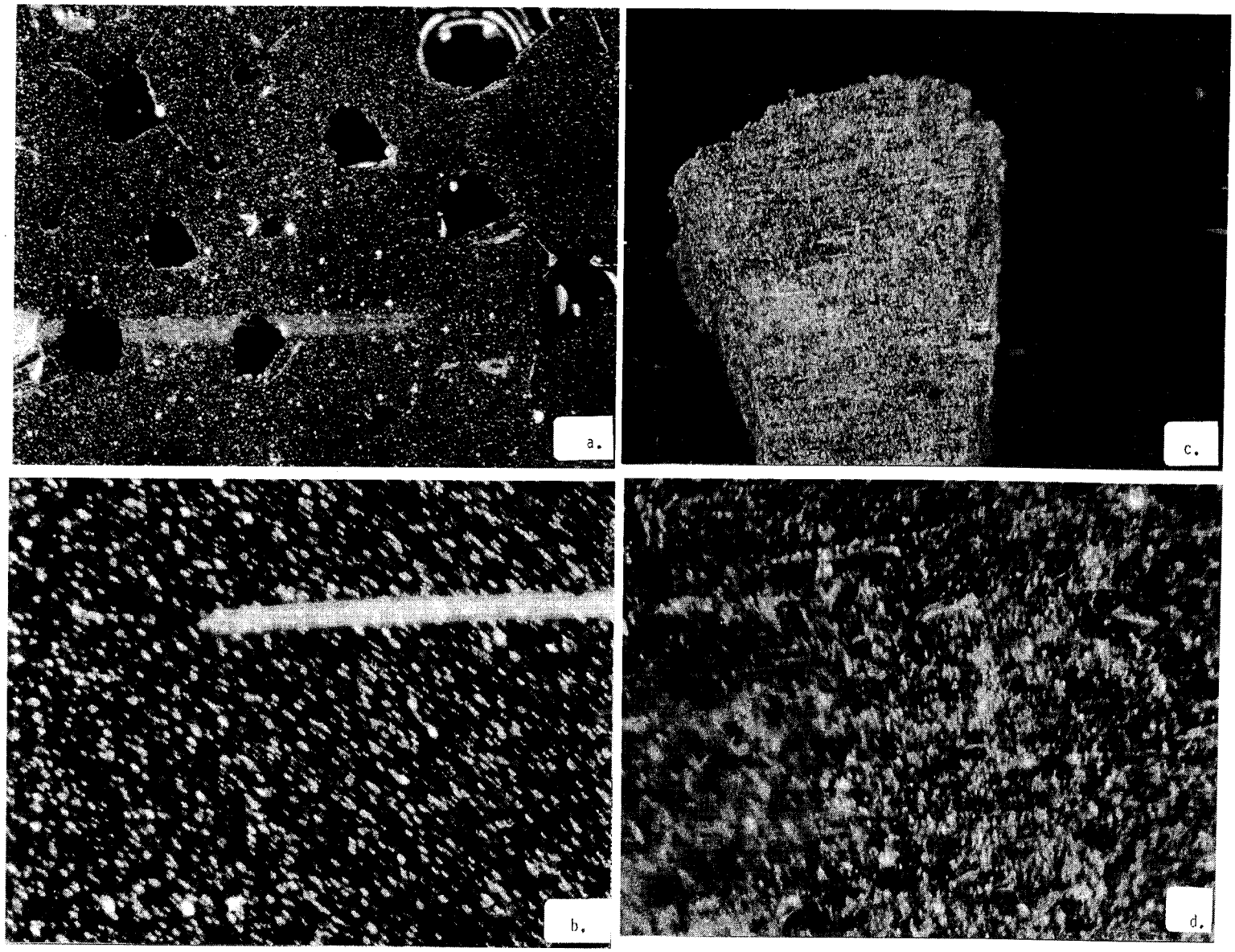


Figure 7. Reflection optical micrographs of a&b) thermally treated ALC lignin that had been hydrothermally pretreated and c&d) pure mesophase pitch (petroleum).

RECENT DEVELOPMENTS IN ANNUAL GROWTH LIGNOCELLULOSICS AS REINFORCING FILLERS IN THERMOPLASTICS [1]

R. E. Jacobson, M.S., Engineer; D. F. Caulfield, Ph.D., Research Chemist; and R. M. Rowell, Ph.D, Project Leader,
Forest Products Laboratory, Madison, WI 53705, USA
and
A. R. Sanadi [2], Ph.D., Research Associate, University of Wisconsin-Madison, Russell Labs, 1630 Linden Drive, Madison, WI 53706, USA

Abstract

Recent interest in reducing the environmental impact of materials is leading to the development of newer agricultural based materials that can reduce the stress to the environment. Several billion pounds of fillers and reinforcements are used annually in the plastics industry and their use is likely to increase, to reduce the amount of plastics used in a product, with improved compounding technology and new coupling agents. The use of lignocellulosic fibers (eg. kenaf, jute, etc.) as reinforcing fillers in plastics has generated significant interest in recent years. The use of lignocellosic fibers permit the use of high volume fillings due to their lower densities and non-abrasive properties, and therefore reduces the use of plastics in a product. The specific tensile and flexural moduli of a 50 % by volume of kenaf -polypropylene (PP) composite compares favorably with a 40 % by weight of glass fiber-PP injection molded composite and are superior to typical calcium carbonate or talc based PP composites. Results indicate that annual growth lignocellulosic wastes and fibers are viable reinforcing fillers as long as the right processing conditions and aids are used, and for applications where the higher water absorption of the agro-based fiber composite is not critical.

Introduction

Newer materials or composites are being developed to reduce the stress to the environment. In light of petroleum shortages and pressures for decreasing the dependence on petroleum products, there is an increasing interest in maximizing the use of renewable materials. The use of agricultural materials as source of raw materials to the industry not only provides a renewable source, but could also generate a non-food source of economic development for farming and rural areas.

Several billion pounds of fillers and reinforcements are used annually in the plastics industry. The use of these additives in plastics is likely to grow with the introduction of improved compounding technology, and new coupling agents that permit the use of high filler/reinforcement content (Katz and Milewski, 1987). As suggested by Katz and Milewski, fillings up to 75 pph could be common in the future: this could have a tremendous impact in lowering the usage of petroleum based plastics. It would be particularly beneficial, both in terms of the environment and also in socio-economic terms, if a significant amount of the fillers were obtained from a renewable agricultural source. Ideally, of course, an agro-/bio-based renewable polymer reinforced with agro-based fibers would make the most environmental sense.

Advantages Of Using Agro-Fibers In Plastics

The primary advantages of using annual growth lignocellulosic fibers as fillers/reinforcements in plastics are (a) low densities, (b) non abrasive, (c) high filling levels possible resulting high stiffness properties, (d) high specific properties, (e) easily recyclable, and (f) tougher fibers resulting in reduced fiber attrition during processing. There are also some environmental and socio/economic advantages that cannot be ignored. These include biodegradable, a wide variety of fibers available throughout the world, generates rural jobs, non-food agricultural/farm based economy, low energy consumption, low cost and low energy utilization.

Material cost savings due the incorporation of the relatively low cost agro-fibers and the higher filling levels possible, coupled with the advantage of being non-abrasive to the mixing and molding equipment are benefits that are not likely to be ignored by the plastics industry for use in the automotive, building, appliance and other applications.

Prior work on lignocellosic fibers in thermoplastics has concentrated on wood based flour or fibers and significant advances have been made by a number of researchers (Woodhams, et al.,1984, Klason and Kubat, 1986 a &b, Myers, et al. 1992, Kokta, et al. 1989, Yam, et al. 1990, Bataille, et al. 1989 and Sanadi, et al. 1994a). A recent study on the use of annual growth lignocellulosic fibers indicate that these fibers have the potential of being used as reinforcing fillers in thermoplastics (Sanadi, et al. 1994b). *The use of annual growth agricultural crop fibers such as kenaf has resulted in significant property advantages as compared to typical wood based fillers/fibers such as wood flour, wood fibers and recycled newspaper.* Properties of compatibilized PP and kenaf has mechanical properties comparable with those of commercial PP composites (Sanadi, et al. 1994b).

Limitations

The primary drawback of the use of agro-fibers is the lower processing temperature permissible due to the possibility of lignocellulosic degradation and/or the possibility of volatile emissions that could effect composite properties. The processing temperatures are thus limited to about 200 °C, although it is possible to use higher temperatures for short periods. This limits the type of thermoplastics that can be used with agro-fibers to commodity thermoplastics such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS). However, it is important to note that these lower

priced plastics constitute about 70% of the total thermoplastic consumed by the plastics industry, and subsequently the use of fillers/reinforcement presently used in these plastics far outweigh the use in other more expensive plastics.

The second drawback is the high moisture absorption of the natural fibers. Moisture absorption can result in swelling of the fibers and concerns on the dimension stability of the agro-fiber composites cannot be ignored. The absorption of moisture by the fibers are minimized in the composite due to encapsulation by the polymer. It is difficult to entirely eliminate the absorption of moisture without using expensive surface barriers on the composite surface. If necessary, the moisture absorption of the fibers can be dramatically reduced through the acetylation of some of the hydroxyl groups present (Rowell, Tillman and Simonson, 1986) in the fiber, but with some increase in the cost of the fiber. Good fiber-matrix bonding can also decrease the rate and amount of water absorbed by the composite. Research on this area is presently underway at the University of Wisconsin (UW) and the Forest Products Laboratory (FPL).

It is important to keep these limitations in perspective when developing end use applications. We believe that by understanding the limitations and benefits of these composites, these renewable fibers are not likely to be ignored by the plastics/composites industry for use in the automotive, building, appliance and other applications.

Sources Of Agricultural Fibers

There are a wide variety of agro-fibers and wastes that are available. Our work has primarily concentrated on fibers that are easily available and are presently an important source for clothing, rope, sacking and rugs in Asia and Africa. Fibers such as kenaf are now being grown in the United States and the quantity and the types of fibers grown is likely to increase with new uses being developed for natural fibers.

Processing Considerations And Techniques

Separation of the fibers from the original plant source is an important step to ensure the high quality of fibers. The limiting processing temperatures when using lignocellulosic materials with thermoplastics is important in determining processing techniques. High processing temperatures (> 200°C) that reduces melt viscosity and facilitates good mixing cannot be used (except for short periods) and other routes are needed to facilitate mixing of the fibers and matrix in agro-fiber thermoplastics.

The ultimate fiber lengths present in the composite depends on the type of compounding and molding equipment used. The properties of the agro-based thermoplastic composites are thus very process dependent. Yam, et al. (1990) at Michigan State University, studied the effect of twin screw blending of wood fibers and HDPE and concluded that the level of fiber attrition depended on the screw configuration and the processing temperature. Use of stearic acid in HDPE/wood fibers improved fiber dispersion and improved wetting between the fiber and matrix (Woodhams 1984) and resulted in significant improvement in mechanical properties. Work by Raj and Kokta (1989) indicate the importance of using surface modifiers to improve fiber dispersion in cellulose fibers/PP composites. Use of a small amount of stearic acid during the blending of cellulose fibers in polypropylene decreased both the size and number of fiber aggregates formed during blending in an internal mixer (Brabender roll mill).

Another technique that is gaining acceptance is the high intensity compounding using a turbine mixer (thermokinetic mixer). Woodhams et al. (1990) and Myers, et al. (1992) found the technique effective in dispersing lignocellulosic fibers in thermoplastics. Addition of dispersion aids/coupling agents further improved the efficiency of mixing. The high shearing action developed in the mixer decrease the lengths of fibers in the final composite. However the improved fiber dispersion resulted in improved composite

properties. Recent work using a thermokinetic mixer to blend kenaf in PP (Sanadi, et. al., 1994b) has confirmed the usefulness of the compounding technique in effectively dispersing natural fibers in the thermoplastic matrix. An added advantage is that no pre-drying of the fibers is needed prior to the blending stage in the mixer.

Properties Of Composites

Cellulosic fillers/fibers can be classified under three categories depending on their performance when incorporated in a plastic matrix. Wood flour and other low cost agricultural based flour can be considered as particulate fillers that enhance the tensile and flexural moduli of the composite with little effect on the composite strength. Wood fibers and recycled newspaper fibers have higher aspect ratios and contribute to an increase in the moduli of composite, and can also improve the strength of the composite when suitable additives are used to improve stress transfer between the matrix and the fibers. The improvement in modulus is not significantly different than the cellulosic particulate fillers. The most efficient cellulosic additives are some natural fibers such as kenaf, jute, flax, etc. The specific Young's modulus and specific flexural modulus, the ratio of the composite modulus to the composite specific gravity of composites with natural fibers such as kenaf are significantly higher than those possible with wood fibers. The specific moduli (the ratio of the composite modulus to the composite specific gravity) of high fiber volume fraction bast fibers-PP composites are high and in the same range as glass fibers-PP composites. The most efficient natural fibers are those that have a high cellulose content coupled with a low micro fibril angle resulting in high filament mechanical properties.

Cellulosic fillers/fibers have been incorporated in a wide variety of thermoplastics such as PP, PE, PS, PVC, polyamides (Klason and Kubat, 1986 a & b). In general, dispersing agents and/or coupling agents, are necessary for property enhancement when fibers are incorporated in thermoplastics. Grafting chemical species on to the fiber surface has also been reported to improve the interaction between the fibers and matrix. Although grafting can improve the properties of the composite to a significant extent, this process increases the material cost of system. The use of dispersing agents and/or coupling agents is a cheaper route to improve properties and makes more practical sense for high volume, low cost composite systems.

In general, cellulosic fillers or fibers have a higher Young's modulus as compared to commodity thermoplastics thereby contributing to the higher stiffness of the composites. The increase in the Young's Modulus with the addition of cellulosics depends on many factors such as the amount of fibers used, the orientation of the fibers, the interaction and adhesion between the matrix, the ratio of the fiber to matrix Young's modulus, etc. The Young's modulus of the composite can be crudely estimated through the simple rule of mixtures and other simple models if the Young's modulus of the filler/fiber is known (Hull, 1981). The use of dispersing or coupling agents can change the molecular morphology of the polymer chains both at the fiber-polymer interphase and also in the bulk matrix phase. Crystallites have much higher moduli as compared to the amorphous regions and can increase the modulus contribution of the polymer matrix to the composite modulus.

In order to use any models to estimate composites properties, it is necessary to know the property of the fibers. In general, natural fibers such as kenaf and jute are in the form of filaments that consist of discrete individual fibers, generally 2 mm to 6 mm long, which are themselves composites of predominantly cellulose, lignin and hemicelluloses. Filament and individual fiber properties can vary widely depending on the source, age, separating techniques, moisture content, speed of testing, history of the fiber, etc. The properties of the individual fibers are very difficult to measure. Earlier work on a natural bast filament, sun hemp (*Crotalaria juncea*) suggested that the filament properties ranged widely.

Although several plastics have been used with cellulosic fibers, the major part of the work at the University of Wisconsin-Madison and the Forest Products Laboratory has been on polypropylene (PP). The work reported here will concentrate on this versatile plastic in combination with kenaf.

Experimental Methods

Kenaf filaments harvested from mature plants were obtained from AgFibers Inc., Bakersfield, CA, and cut into lengths of about 1 cm. The fibers were not dried to remove any of the moisture present, and the moisture content of the fibers varied from 6 % to about 9 % by weight. In all our experiments the weight and volume percent reported is the amount of dry fiber present in the blend. The homopolymer was Fortilene-1602 (Solvay Polymers, 1991) with a melt flow index of 12 g/10 min. as measured by ASTM D-1238. A maleic anhydride grafted polypropylene (MAPP) was used as a coupling agent to improve the compatibility and adhesion between the fibers and matrix.

The filaments were not pulped prior to compounding as the former procedure can consume a significant amount of energy. The short fibers, MAPP and PP (the latter two in pellet form) were compounded in a high intensity kinetic mixer (Synergistics Industries Ltd., Canada) where the only source of heat is generated through the kinetic energy of rotating blades. The blending was accomplished at 4600 rpm and then automatically discharged at 190 °C. A total weight (fibers, PP and MAPP) of 150 g were used for each batch and about 1.5 kg of blended material was prepared for each set of experiments. Fiber weight varied from 20 % to 60 % and coupling agent weight varied from 0 to 3 %. The total residence time of the blending operation depended on the proportions of fiber and PP present and averaged about 2 min.

The mixed blends were then granulated and dried at 105 °C for 4 hours. Test specimen were injection molded at 190 °C using a Cincinnati Milacron Molder and injection pressures varied from 2.75 MPa to 8.3 MPa depending on the constituents of the blend. Specimen dimensions were according to the respective ASTM standards. The specimens were stored under controlled conditions (20 % Relative Humidity and 32 °C) for three days before testing. The cross-head speed during the tension and flexural testing was 5 mm/min. Although all the experiments were designed around the weight percent of kenaf in the composites, fiber volumes fractions can be estimated from composite density measurements and the weights of dry kenaf fibers and matrix in the composite. The density of the kenaf present in the composite was estimated to be 1.4 g/ cc.

Results And Discussion

Mechanical Properties

Effect Of Coupling Agent On Composite Properties

A small amount of the MAPP (0.5 % by weight) improved the flexural and tensile strength, tensile energy absorption, failure strain and un-notched Izod impact strength. The anhydride groups present in the MAPP can covalently bond to the hydroxyl groups of the fiber surface. Any MA that has been converted to the acid form can interact with the fiber surface through acid-base interactions. The improved interaction and adhesion between the fibers and the matrix leads to better matrix to fiber stress transfer. There was little difference in the properties obtained between the 2 % and 3 % (by weight) MAPP systems. The drop in tensile modulus with the addition of the MAPP is probably due to polymer morphology. Transcrystallization and changes in the apparent modulus of the bulk matrix can result in changes in the contribution of the matrix to the composite modulus and will be discussed later. There is little change in the notched impact strength with the addition of the MAPP, while the improvement in un-notched impact strength is significant.

Use of the MAPP increases the failure strain and the tensile energy absorption. Thermodynamic segregation of the MAPP towards the interphase can result in covalent bonding to the -OH groups on the fiber surface. Entanglement between the PP and MAPP molecules results in improved interphase properties and the strain to failure of the composite. There is a plateau after which further addition of coupling agent results in no further increase in ultimate failure strain. Any further increase in the amount of MAPP does not increase the failure strain past the critical amount. However, a minimum amount of entanglements are necessary through the addition of about 1.5 % by weight for the critical strain to be reached.

Strength and Modulus

There is little difference in the tensile strength of uncoupled composites compared with the unfilled PP, irrespective of the amount of fiber present. This suggests that there is little stress transfer from the matrix to the fibers due to incompatibilities between the different surface properties of the polar fibers and non-polar PP. The tensile strengths of the coupled systems increases with the amount of fiber present and strengths of up to 74 MPa were achieved with the higher fiber loading of 60 % by weight which is about 49 % by volume. As in case with tensile strength, the flexural strength of the uncoupled composites were approximately equal for all fiber loading levels, although there was a small improvement as compared to the unfilled PP.

The specific tensile and flexural moduli of the 50 % by weight kenaf coupled composites were about equivalent to or higher than typical reported values of 40 % by weight coupled glass-PP injection molded composites. Table 1 shows typical commercial PP composites compared with kenaf-PP composites. Data on mineral filled systems from various sources, Modern Plastics Encyclopedia (1993) and Machine Design: Materials Guide Issue (1994). The specific flexural moduli of the kenaf composites with fiber contents greater than 40 % were extremely high and even stiffer than a 40 % mica-PP composite.

Failure Strain And Tensile Energy Of Absorption

The failure strain decreases with the addition of the fibers. Addition of a rigid filler/fiber restricts the mobility of the polymer molecules to flow freely past one another and thus causes premature failure. Addition of MAPP followed a similar trend to that of the uncoupled system, although the drop in failure strain with increasing fiber amounts was not as severe. The decrease in the failure strain with increasing amounts of kenaf for the coupled systems is apparent. The stress-strain curves are non-and this is mainly due to plastic deformation of the matrix. The distribution of the fiber lengths present in the composite can also influence the shape of the curve since the load taken up by the fibers decreases as the strain increases and detailed explanations are available elsewhere (Hull, 1981). The tensile energy absorption, the integrated area under the stress-strain curve up to failure behaves in roughly the same manner as the tensile failure strain. The difference between the coupled and uncoupled composites increases with the amount of fibers present, although the drop in energy absorbed for the coupled composites levels off after the addition of about 35 volume % of fiber.

Impact Properties

The impact strength of the composite depends on the amount of fiber and the type of testing. i.e., whether the samples were notched or un-notched . In case of notched samples, the impact strength increases with the amount of fibers added until a plateau is reached at about 45 % fiber weight , irrespective of whether MAPP was used or not. The fibers bridge cracks and increase the resistance of the propagation of the crack. Contribution from fiber pullout is limited since the aspect ratio of the fibers in the system are well below the estimated critical aspect ratio of about 0.4 mm (Sanadi, et al; 1993). In

case of the un-notched impact values of the uncoupled composites, the presence of the fibers decrease the energy absorbed by the specimens. Addition of the fibers creates regions of stress concentrations that require less energy to initiate a crack. Improving the fiber-matrix adhesion through the use of MAPP increases the resistance to crack initiation at the fiber-matrix interface and the fall in impact strength with the addition of fibers is not as dramatic. The impact strength can be increased by providing flexible interphase regions in the composite or by using impact modifiers and some work has been done in this area by our group at the UW and FPL.

Physical Properties

Water absorption and specific gravity of lignocellulosic fiber composites are important characteristics that determine end use applications of these materials. Water absorption could lead to a decrease in some of the properties and needs to be considered when selecting applications. It is difficult to entirely eliminate the absorption of moisture in the composites without using expensive surface barriers on the composite surface. Water absorption in lignocellulosic based composites can lead to a build of moisture *in* the fiber cell wall and also in the fiber-matrix interphase region. Moisture build up in the cell wall could result in fiber swelling and concerns on the dimension stability cannot be ignored. A typical 50% by weight of kenaf-homopolymer PP blend absorbed about 1.05 % by weight of water in a 24 hr water soak test. This is considerably higher than any mineral filled systems. It is therefore very important to select applications where this high water absorption is not a critical factor such as in electrical housing components.

The specific gravity of lignocellulosic based composites is much lower than the mineral filled thermoplastic systems. The apparent density of the lignocellulosic fibers in PP is about 1.4 g/cc as compared to mineral fillers/fibers (about 2.5 g/cc). The specific gravity of a 50 % (by weight) kenaf-PP composite is about 1.07, while that of a 40 % (by weight) glass-PP composite is 1.23. The specific mechanical properties of kenaf-PP composites compare favorably to other filled commodity plastics. Since materials are bought in terms of weight and pieces or articles are in general sold by the number, more pieces can be made with lignocellulosic fibers as compared to the same weight of mineral fibers. This could result in significant material cost savings in the high volume and low cost commodity plastic market.

Concluding Remarks On Economic Aspects And Potential Markets

The cost of natural fibers are in general less than that of the plastic and high fiber loading can result in significant material cost savings. The cost of compounding is unlikely to be much more than for conventional mineral/inorganic based presently used by the plastics industry. Due to the lower specific gravity's of the cellulosic based additives (approximately 1.4 as compared to about 2.5 for mineral based systems), composite properties considering the weight of the composite is an advantage that may have implications in the automotive and other transportation applications. Furthermore, using the same weight of plastic/natural fiber as for example plastic/glass fiber, about 20 % more pieces are possible with the cellulosic based system. Cellulosic fibers are soft and non-abrasive and high filling levels are possible.; 60 % by weight of fiber has been incorporated in PP at the FPL and UW. Reduced equipment abrasion and the subsequent reduction of re-tooling costs through the use of agricultural based fibers is a factor that is definitely a factor that will be considered by the plastics industry when evaluating these natural fibers. It is important to point out we do not anticipate nor intend the total replacement of conventional based fillers/fibers with agricultural based fillers/fibers. We do however believe that these natural material will develop their own niche in the plastics filler/fiber market in the future.

The volume of thermoplatics used in the housing, automotive, packaging and other low-cost, high volume applications is enormous. Recent interest in reducing the environmental

impact of materials is leading to the development of newer materials or composites that can reduce the stress to the environment. In light of petroleum shortages and pressures for decreasing the dependence on petroleum products, there is an increasing interest in maximizing the use of renewable materials. The use of agricultural materials as source of raw materials to the industry not only provides a renewable source, but could also generate a non-food source of economic development for farming and rural areas. Appropriate research and development in the area of agricultural based fillers/fibers filled plastics could lead to new value-added, non-food uses of agricultural materials.

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[1] The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. The article was partially written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright laws.

[2] To whom correspondence should be addressed to.

Table 1. Results of Our Previous Work on Biodegradable Fiber in Polypropylene (PP). (Comparison with data on commercially available PP's.)

Filler/Reinforcement in PP	ASTM Standard	no filler	kenaf	Talc*	Glass*	Mica*
% filler by weight		0	50	40	40	40
% filler by volume (estimated)		0	39	18	19	18
Tensile Modulus, GPa	D638	1.7	8.46	4	9	7.6
Specific Tensile Modulus, GPa		1.9	7.9	3.1	7.3	6.0
Tensile Strength, MPa	D638	33	69	35	110	39
Elongation at Break, %	D638	>>10	2.2	X	2.5	2.3
Notched Izod Impact- J/m	D256A	24	37	32	107	27
Specific Gravity		0.9	1.07	1.27	1.23	1.26

* Data from Modern Plastics Encyclopedia and Materials Selector 1994.

AGRICULTURAL FIBRES FOR PULP AND PAPER MANUFACTURE IN DEVELOPED COUNTRIES

Al Wong
Arbokem Inc.
Vancouver,Canada

Abstract

Agricultural fibres are routinely used for the manufacture of paper products in developing countries. The agriculture (non-wood) pulp industry accounts more than 50% of the national pulp production in China and in India. In contrast,paper manufacturers of the developed countries have relied largely on wood pulp fibres since the 1950's. During the past 3 decades,the global wood pulp production capacities had expanded substantially.

There is a renewed interest to use agriculture-based fibres in place of wood,for the production of pulp and paper in developed countries. The alternative is driven,in part,by the growing shortage of commercial wood supply as caused by the over-cutting of the standing forest and the accelerated re-allocation of forest land for ecological and recreational uses.

Although the shortage of wood supply can be alleviated partially by the adoption of higher-yield wood pulping technologies and by the increased use of waste paper. But ultimately,these remedial steps will be inadequate to meet the growing demand for paper products.

There are several important factors which affect the use of agricultural fibres for pulp and paper manufacture in developed countries. For some on-purpose fibre crops,continued farm subsidy and repeal of certain sections of the Narcotics Act would be required.

Agri-pulp production from agricultural cropping residues appears to be the most practical economic means to supplement the fibre needs of the paper industry. In the social context,agri-pulp implementation in North America would also provide lower taxes that would be accrued from the elimination of substantial annual subsidies to grain farmers from the government.

Introduction

During the past 50 years,the use of wood for the manufacture of pulp and paper products has become predominant throughout North America. Considerable pressure is put on the natural and plantation forests to supply the growing demand of wood for industrial uses. Wood for pulping and subsequent papermaking is typically supplied by whole logs directly or by saw mill chips.

With increasing public awareness of the importance of ecological preservation of the natural forests,there is a renewed interest to investigate new ways and means to reduce the use of wood for paper production.

One obvious approach is reduce the usage of paper products. The other two principal remedial methods are: increase the yield of pulp from wood and concurrently increase the use of waste paper.

Higher Yield of Chemical Pulp from Wood

More papermaking fibre can be made from wood by the adoption of higher-yield chemical pulping technologies. Near-term realization of this goal could require existing kraft pulp mills to change to an alkaline sulphite pulp mills [1,2]. The product quality is essentially unchanged; the technical modification is not substantial. One important environmental benefit of the change is that alkaline sulphite pulp is notably easier to bleach than kraft pulp to high brightness. Indeed,total chlorine-free (TCF) bleached pulp can thus be made more readily and economically.

The highest practical yield of alkaline sulphite pulp from wood is about 60%. In contrast,kraft pulping provides a yield of about 47% from softwoods. Although mechanical pulping provides still higher yields (e.g.,80 to 95%),mechanical pulp does not have the same quality and versatility of kraft or alkaline sulphite chemical pulp.

Increased Usage of Deinked Office Waste Paper

The American Forest and Paper Association [3] has reported that the consumption of recovered waste paper as a percentage of paper industry production has reached 33% level at the end of 1994 and is expected to reach 36% by 1997. The overall recovery rate in the United States is reported to be 44%. The difference is due to processing losses and export of waste paper.

It can be noted that highly-disciplined smaller countries such as Japan,Switzerland and Germany are now approaching the generally-recognized practical limit of about 60% overall recovery rate [4]. Economical collection and sorting of post-consumer waste paper is the major obstacle. Because of specific life style and geographical vastness of the United States,it is doubtful that the same level can be approached.

There is a technical limit to the recycling of papermaking fibre. In each cycle of reuse,pulp fibre is degraded physically and chemically. Fibres are fragmented and shortened. Multi-cycled fibres become excessively hydrated such that the drainage properties of the pulp fibres (during papermaking step) are adversely reduced. It is very important to cull inferior pulp fibres and replenish with new pulp fibres in the overall paper "production-use-recycle" system.

Ultimately,increased pulp yield from wood and increased usage of waste paper would be inadequate to meet the continued growing demand of paper products in developed countries. Other new sources of papermaking fibres are needed.

It is interesting to note that China is the largest producer of agri-pulp in the World. Its estimated production is about 7.5 million tonnes annually,about 60% of the World's production [5]. Typically,imported softwood pulp is used to reinforce the basic agri-pulp stock. China has now embarked on a new industrial policy to shut-down the 5,000+ agri-pulp mills. With a continuing acute shortage of wood resources, China will become even more dependent on imported virgin wood pulp for its paper production needs. Most of the pulp imports may in fact come from developed countries.

The Agri-Pulp Alternative

Only limited quantities of agri-pulp are made presently for the commodity paper business in North America. There is production of cotton,abaca and flax pulps in the United States currently. Prior to the 1950's,considerable amount of corrugated medium was made in the United States with agricultural residues such as straw and bagasse [6]. Pollution control at these smaller straw mills was virtually non-existent.

The present USA pulp industry would need to be re-configured significantly to use agricultural fibre as the principal raw material. The present pulp mills are all designed to use wood chips which contains very low amount of non-process elements such as silica and potassium.

Agricultural fibre contains high natural content of these elements. Thus,the use of agricultural fibres would aggravate the operation of the chemical recovery system of a conventional kraft pulp mill within modern pollution control standards [7]. The high cost of re-tooling the pulp industry is a major economic barrier to greater immediate usage of agricultural fibres.

A major weakness of the agri-pulp option is that the raw material is harvested only once each year,over a short 2-month period. Considerable attention must be paid to the procurement logistics even for small-size pulp mills.

Because the agricultural fibrous raw material is typically very bulky and costly to transport over a long distance,the pulp mill needs to be located to match the economic raw material supply. Present data indicate that the practical economic radius for the procurement of straw for an agri-pulp mill is about 30 km.

Small-scale operation does not necessarily mean high cost of pulp production. A small pulp mill can be practicable economically if appropriate manufacturing technology is used [8]. Lower capital and fibre costs of the small community-size pulp mill could be traded-off against high wood and capital costs for the large world-scale pulp mill.

There are basically 2 means to provide fibrous raw material for agri-pulp production: a) on-purpose fibre crops and b) cropping residues.

a) <u>On-Purpose Fibre Crops</u>

Kenaf (Hibiscus cannabinus) is an annual fibre crop which provides both long and short papermaking fibres in a single plant. A cropping yield of 5 to 10 bone-dry tonnes whole stalk/hectare per year can be achieved with optimal inputs of,among other things,water and fertilizer [9].

Kenaf cropping requires a significant amount of water [10]. It grows best when there is adequate water during its early growth stage. For states such as California and Arizona, irrigation water is very expensive. For many American land sites,on-purpose fibre cropping will be too expensive for the manufacture of commodity printing and writing paper,in the absence of farm subsidies.

Because of prevailing high labour costs in the US, cropping has to be highly mechanized. The logistical problems of fibre cropping and procurement for the traditional large-size pulp mills are enormous [9,11].

Decortication of kenaf stalk to extract the bark fibre (30 to 35% of whole stalk) for pulp production adds to the cost of the pulp fibre significantly. Fibre cost could be reduced if a high value end use for the "discarded" core (65 to 70%) material can be realized. The most economical approach might be to pulp the whole stalk directly without decortication.

Hemp (Cannabis sativa) is being considered with new interest in North America as a fibre crop [12]. It has grown routinely for the production of pulp fibre for cigarette paper in several countries in Eastern Europe. More recently,limited amount of low-THC hemp (i.e.,low content of tetrahydro-cannabinol) has been licensed for cultivation as a fibre crop in the UK [13]. Despite the low lignin content of hemp fibre (with little or no hurd content),it is surprisingly difficult to pulp and to bleach. The specific nature of the lignin of hemp is suspected to be the problem. In comparison,flax fibre (also with low lignin content) is somewhat easier to pulp and to bleach. The technical benefits of hemp cropping for pulp fibres are questionable.

Low-narcotic hemp plant can not be easily distinguished from high-narcotic hemp plant. In view of the present political mandate of the Drug Enforcement Agency,there is no prospect that hemp can become a practicable fibre crop in the United States in the foreseeable future.

b) Cropping Residues

The other method is to use existing agricultural cropping residues. The available choices include cereal straw,corn stalks and oilseed straw. The cost of such plant fibre has already been "pre-paid" by the concomitant production of grain and oilseeds.

Existing farm machineries can be used readily for the procurement of these fibres. The case for the industrial use of cropping residues is that no new inputs of herbicides, pesticides and fertilizers would be needed; these chemicals are already in use for the production of grain and oilseeds. In the United States,cereal (including corn) cropping would yield typically 2 to 7 tonnes grain/hectare/year plus 2 to 4 tonnes straw (stalks)/hectare/year. The estimate availability of straw in the United States is more than 120 million tonnes annually from existing agricultural cropping activities [14]. The 1945 USDA estimate of surplus cropping residues was over 200 million tonnes [6].

With such a raw material resource,there is no need to expand present agricultural land base. Soil structure and soil fertility can be readily maintained with normal crop rotation practice and straw retrieval practices [15]. Much of this agricultural residue is under-utilized. Depending on location, straw is presently disposed by usage as animal bedding, ploughing back into the soil and burning. With increasing "no-till" practice for soil erosion control,straw will increasingly become a surplus co-product of grain production.

Although many agri-fibres have lower lignin content than softwood or hardwood,the choice of pulping (delignification) process has a considerable influence on the ultimate ease of bleaching of the pulp fibre [7]. An example is kenaf bark fibre. If the kraft process is used,4 stages of bleaching including one chlorine-containing stage would be required to reach 86 brightness. The comparison is the alkaline sulphite process in which the 86 brightness pulp can be attained with only 2-stage hydrogen peroxide bleaching.

Economic and Social Context

The annual budget deficits of virtually all levels of government are high. Because of conflicting demands by various sectors of society,governments are encountering considerable difficulties in cutting public spending. Taxpayers are becoming very resistant to paying ever higher taxes.

If every grain (excluding corn) farmer in the United States receives an average $25 per acre ($61.73 per hectare), then the total annual subsidy could be in the range of $1.9 billion. The development of a new pulp and paper industry which is based on agricultural cropping residues would provide a means to reduce such subsidy quickly and painlessly. There must be a better way to maintain farm income.
Table I shows an example on the economic impact of straw sales to an agri-pulp mill on wheat farming.

Reliance on high grain price is unrealistic as more countries are becoming more self-sufficient in the supply of basic grains. Even with increasing size of the average farm,it is difficult for many grain farmers to keep up economically. The fundamental problems of larger farms include the needs for more expensive farm equipment and the shortage of seasonal farm workers. Subsidies from government becomes common practice in one form or another. Off-farm jobs become a necessity for farmers to maintain even a modest style of living. Many citizens prefer rural life. De-populating the countryside is not an acceptable way to rationalize agriculture. It is futile and a waste of money to provide more formal education and skill training without the concomitant creation of commensurable jobs in rural communities.

Table I - Example Economic Returns to Grain Farmers

Basis: Wheat grown on stubble in black soil zone
1993 Saskatchewan Agriculture Cropping Cost Data

	C$/acre	Remarks
Total cash costs	- 67.96	including seeds,herbicides and fertilizer
Product value	+ 88.66	wheat at $2.86/bushel and 31 bushels per acre
Straw value	+ 40.00	estimated transaction price of $40/ton and 1 ton/acre; delivery <25 mile radius
Straw costs	- 15.00	including collection, baling and shipping
Return over total cash costs	+ 45.70	

Source: Ref. 16.

In the United States,there are about 2.5 billion bushels of wheat grown annually on about 76 million acres. With a typical average yield of 2 tons of straw per acre (4.47 tonnes per hectare),there would be a corresponding production of about 136 million tonnes of straw each year. And if only 28 million tonnes of straw are used for processing into pulp for paper manufacture,the national economic impact could be as follows:

* 14 million tonnes of pulp can be produced with an economic value of more than $10 billion.

* Farm communities would have a new (aggregate) gross income of $560 million,from the sale of 28 million tonnes of straw to new agri-pulp mills. The indicated purchase price for straw could represent an extra 25 to 30% net income,on a per acre basis,to many cereal grain farmers.

* Total new direct jobs created to operate the community-based agri-pulp mills could exceed 24,000.

The social value of using recycled paper is the effective management of urban landfill problem. The social value of using agri-pulp is lower taxes; there would be less need for direct subsidy to grain farmers.

Concluding Remarks

The development of an agri-pulp industry is driven by the increasing shortage of economical supply of wood and by the growing public interest to preserve the forests for recreational and ecological purposes. As the consumption of paper products continues to grow,agri-pulp will be needed,in conjunction with present strategy to effect higher pulp yield from wood and to use more waste paper.

The use of agricultural cropping residues appears to be a more viable option to supply large-volume of new papermaking fibres in the near-term,under a subsidy-free scenario. On-purpose fibre cropping would require government subsidy to maintain economic viability in today's commodity paper market.

The secondary benefit of using agri-pulp is that a new source of income is made available to the farmers. Over $1 billion new farm income would be realized annually. The ultimate result could be lower taxes for all citizens.

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DENSIFIED FUELS FROM WOOD WASTE

W. H. Pickering, Ph.D., President

Lignetics, Inc. La Canada, CA 91011

Abstract

Wood compressed to a specific gravity of about 1.2 constitutes an excellent clean burning fuel. "Prestologs" were marketed before 1940, but in the past ten years a much larger and growing market in densified pellet fuel has developed.

The market for pellet fuel is about 90% residential, using special pellet burning stoves. Initial sales were almost entirely in the northwest, but sales in other parts of the country are now growing rapidly. Approximately 300,000 stoves are in use.

Note that this industry developed from the private sector with little or no support from federal or state governments.

Densified fuel is manufactured by drying and compressing sawdust feedstock. Combustion is different than that of normal wood. For example, wood pellets require ample supplies of air. They then burn with a hot flame and very low particulate emissions. Volatile organic compounds are burned almost completely and carbon monoxide can also be kept very low. Stoves burning pellets easily meet EPA standards.

This paper discusses technical and economic factors associated with densified fuel and considers the future of the industry.

The largest use of biomass for energy production is the burning of firewood for residential cooking and heating. In much of the world this is almost the only energy source. In the U.S. today wood accounts for about 2% of our energy production.

Domestic wood fuel is in the form of solid wood in sizes from twigs to logs. Commercial wood fuel is usually waste wood as hogged-fuel or sawdust. Very large amounts of waste wood are available to be used as fuel, but are not being so used.

Wood is not considered a high quality fuel for the following reasons:

- Lack of uniformity
- Variable moisture content
- Low heat content per pound or per cubic foot.
- Poor storability

However, a manufactured fuel, based on densified wood, avoids these difficulties. For many applications, the value added exceeds the cost of manufacture.

Densified wood fuel is produced from sawdust by drying to about 10% moisture content, then compressing through a die with about 20,000 pounds per square inch pressure. The result is a product with a density of more than 70 pounds per cubic foot. As a fuel, it has the following characteristics.

- Uniformity
- Low and constant moisture content
- Heat content about 8500 BTU per pound
- Sulphur content essentially zero
- Ash content less than 1%

Given a properly designed appliance or furnace, this product is a very satisfactory clean burning fuel.

Most of the densified wood fuel is manufactured as pellets, 1/4 inch in diameter and 1/2 to 3/4 inches long. Manufacturing capacity in the U.S.A is 600,000 tons per year. The market for the product is 90% residential. Stoves designed to burn pellets at high efficiency are available from some 20 manufacturers. About 300,000 stoves have been sold in the past decade.

Attempts to convert waste sawdust into pelletized fuel were made 20 years ago with the expectation that this would be an economically viable commercial fuel against a rapidly increasing price of oil. Two things happened, the price of oil did not increase as expected, and the quality of the pellets was low. The major problems were:

- The pellets broke down into dust
- Slag and clinkers formed

In 1985 Lignetics solved these problems and, at the same time, a well designed pellet burning stove appeared on the market. The residential pellet market has been growing steadily since that time. Until 1992, almost all pellet stoves sales were in the Northwest. Pellet production was also concentrated in that area.

Pellet stoves easily meet the EPA requirements for low emissions. In fact, these stoves burn so clean that several municipalities which have established "no burn" days for certain meteorological conditions, exempt pellet stoves from the restrictions.

Commercial applications of pellet fuel are usually replacements for coal. The motivation for change is, of course, the much lower emissions from pellet fuel, plus clean handling, low ash and no sulphur. Retrofit problems depend on the furnace configuration. Moving grate systems may require no modifications except to air flows. The only significant modification could be to the fuel inventory storage. Pellet fuel must be kept dry.

Another form of densified wood fuel is the densified log or briquette. These are essentially large pellets manufactured in the same way by drying sawdust and subjecting it to high pressure.

In the 1930's, Pres-to-logs appeared on the market. These were 4 inch diameter, 12 inch long, densified logs. They were used in stoves, and fireplaces, but were not popular. About ten years ago some manufacturers began to make them again, and several new types of machines appeared. These were continuous extrusion machines. The original machine was a batch device. Piston-type machines also appeared. These load the die with metered packets of sawdust instead of feeding the die with a continuous screw.

Densified logs of various dimensions are now on the market but they have not made much of an impact on sales of so called wax logs, as exemplified by Duraflame. These logs are about 50% wax and are not densified. They burn more like wax than wood, do not produce much heat and do produce large amounts of soot.

Densified wood, as might be expected, burns differently than normal wood. Since the cell structure is crushed and the density almost doubled, there is not the large burning surface of normal wood. Therefore, ignition is more difficult and combustion requires an adequate supply of air. In some ways combustion is more like that of eharcoal, or coal. However, most of the volatiles are still in the fuel. The heat content for pellet fuel is in the neighborhood of 8500 BTU per pound.

The EPA has established emission standards for domestic wood stoves. The more rigorous phase II standards went into effect on July 1, 1992. The standards require: catalytic wood heaters, particulate matter, PM, emission less than 4.1 grams/hour. Non-catalytic, the level is 7.5 grams/hour. These emissions are for a weighed average of test burns in four rate categories.

The emission standards did not address other emissions such as POMs and CO, on the grounds that if the particulate emissions were reduced these other emissions would also be reduced.

Wood stoves that meet EPA standards must have efficient combustion if the particulate emissions are low. Pellet burning wood stoves have PM emissions much lower than the EPA standards, even the 4.1 gram per hour standard for catalytic stoves. Typical stoves will be between 1 and 2 grams per hour for the EPA test protocol. The emission

of various hydrocarbon compounds is also low because, with complete combustion, flame temperatures are high enough to destroy most of these compounds. Carbon monoxide emission correlates with particulate emission and is also low.

Pellet burning wood stoves are thus the best available technology to meet EPA standards. Recently, tests have been conducted with EPA certified wood stoves and pellet stoves in actual residential use. As should have been expected, the EPA certified stoves did not perform as well in actual use, as in the laboratory tests. The reason is that the laboratory tests were conducted, as specified by the EPA, with dry douglas fir 2 x 4 firewood. In actual use, firewood is generally wetter and dirtier, and some household trash is burned, so that performance is lower than the laboratory tests. On the other hand, pellet stoves use a manufactured fuel, and the fuel is fed to the stove by an automatic mechanism which maintains a more even combustion. The stove operates in the house in the same way that it does in the laboratory.

The pellet stove is a more complex device than a normal wood stove. It requires electric motors to set up a forced draft for combustion air, to circulate heated room air, and to drive an auger to feed fuel into the burn pot. These motors require electronic circuitry to control their operation. The early pellet stoves required a great deal of service, however stoves now being manufactured are much more reliable and more "user friendly".

At the present there are about 50 plants manufacturing pellet fuel in the United States. Most of these plants are small and the quality and uniformity of their product is uncertain. Currently, Lignetics, with plants in Idaho and Missouri, with a combined capacity of 125,000 tons per year, is the largest manufacturer.

For residential use, the product is normally sold in 40 pound plastic bags. Pellet stoves are designed with a fuel hopper which holds 50 to 80 pounds of fuel. Since the burning rate is of the order of 2 pounds per hour, the stove is refuelled once every day or less frequently. The pellet industry has a trade association, the Pellet Fuel Institute, which has published standards for residential pellet fuel. These are:

	Premium Grade	Choice Grade
Content	Any biomass material	Any biomass material
Ash	Not more than 1 percent as received	Not more than 2 1/2 percent as received
Fines	Not more than 0.5 percent by weight shall pass 1/8 inch screen	Not more than 0.5 percent by weight shall pass 1/8 inchscreen
Density/Cu Ft	Not less than 40 pounds	Not less than 40 pounds
Salt	Less than 500 parts per million	Less than 500 parts per million
Length	Maximum of 1 1/2 inches	Maximum of 1 1/2 inches
Diameter	0.235 inch to 0.350 inch	0.235 inch to 0.350 inches

Note that BTU content is not specified, nor is moisture content.

Premium grade pellets require clean sawdust, free of bark and dirt. Pellets made from other forms of biomass will not meet the ash specification for premium grade. Not all commercial species used for lumber make pellets which will meet the fines specification. The salt specification requires that sawdust used for pellets cannot come from lumber that has been floated in salt water. Pellets containing salt cause serious corrosion in residential stoves and commercial boiler systems.

The residential fuel pellet industry is thus dependent on the lumber industry for its raw material. Sawdust of course has other uses, ranging from agricultural in the form of compost or animal bedding material, to the paper and pulp industry for energy or furnish, to the particle board industry. At the present time, the pellet industry is able to purchase sufficient good quality sawdust to supply its needs. There is concern that in the future the industry will have to pay more for top quality sawdust. Consequently, top quality pellets will be more expensive, and more lower quality pellets will be on the market. The residential pellet stove industry is aware of the problem and is making stoves which are tolerant of higher ash content pellets.

Looking at the industry in the broadest sense, the growth of sales will be determined by customer's acceptance of the pellet stove as a non-polluting, energy-efficient, user-friendly device that uses a waste product as fuel. All indications are that this market is a long way from being saturated.

As the industry grows, this fuel will inevitably become a commodity. However, before that can happen the manufacturer must have a better understanding of the technical problems of making premium grade pellets.

For example, one problem with some pellet fuel is the formation of solid clinkers which upset the air flow in the burn pot and even stop the operation of the stove. This problem is usually associated with high ash content, but is almost certainly related to the chemicals present in the ash, which lower the ash melting point temperature.

Another technical problem is the determination of the operating parameters of the pellet mill which are required to make good, dust free pellets.

At the present time, most of the technology used to manufacture pellets is empirical, based on operating experience. Data is needed on the behavior of sawdust from different species of tree, and also other biomass waste material. With a better understanding of the pelletizing process and of clinker formation, these data will then make possible a wider range of feed stock material, and a more uniform product.

The other side of the pellet fuel market is the stove. Pellet specifications and stove design must be matched. Because of the existing inventory of stoves in use, any evolution of pellet specifications should continue to be compatible with these stoves. The end product must be a combination of fuel and stove that is attractive for the user and acceptable to the environmental community.

Residential burning of wood falls into two categories, the older use for heating and cooking and the newer use for appearance. The pellet burning stove is the best answer for heating. It is efficient, and very clean burning. The open fireplace is the typical way to burn wood for appearance. It is inefficient, has to be watched and stoked, but it burns with a picturesque flame, and the odor of burning wood permeates the house. It does emit smoke and pollutes the neighborhood. In some areas of the northwest and northeast where wood burning stoves and fireplaces are popular, very serious winter smog can develop. Popular pressure has resulted in "no-burn" days in some areas when weather conditions are particularly bad. Some areas restrict the kind of stoves that can be installed in new houses, or offer tax rebates to people who substitute clean stoves for their old ones.

The pellet stove market can potentially grow to many times its present size. There are over 10 million wood stoves in the USA. Householders who install pellet stoves are typically well educated, interested in the environment, not intimidated by electronic devices, willing to try something new, but still attracted to the idea of using wood for heat as their ancestors did.

The Health Product Association estimate of pellet stove distribution in the USA places 66% in the Pacific and Mountain area, 27% in the Northeast and Southeast area, and 7% in the Mid-West.

Percentage growth is most rapid in the Northeast, estimated as 38% as compared with the Pacific at 16%, but the absolute number of stove sold is greater in the Pacific area.

However, because of the much larger population in the Northeast, it is only a matter of a few years before the Northeast is the larger market.
The economics of using pellet stoves versus gas stoves and EPA approved cord wood stoves obviously varies with

location. Pellet stoves, installed in a house, presently cost around $2000. They do have the advantage that, if no chimney is available, they can be vented through the wall in much the same way as a clothes dryer.

Pellet fuel costs to the ultimate consumer vary with distance to the manufacturing plant, but an average would be $3.00 per 40 pound bag. The equivalent cost of heat energy is $8.82 per MMBTU.

Assuming that gas heaters have an overall efficiency of 80% and pellet stoves also have 80%, the cost of pellet fuel translates into $0.88 per therm for gas. The equivalent cost for propane would be $8.82 for 11 gallons, or $0.80 per gallon.

Cord wood stoves have lower efficiencies. Assuming a stove efficiency of 50% and good quality cord wood with 20 MMBTU per cord, the equivalent cost of fuel would be $110 per cord to provide the same house heating as pellets at $3.00 per 40 pound bag.

At these prices, a decision to use a pellet stove will frequently be made on factors other than fuel costs. These include:

- Clean burning, very low emission
- Clean handling of fuel, very little ash
- Automatic operation
- Safety, no ashes or flaring residue on the floor
- Satisfaction of using a fuel made from a waste product
- Using a highly efficient heater
- Visual impact of a wood fire.

The rate of growth of sales of pellets stoves is an indicator of popular acceptance of the idea of the pellet stove.

So far I have been focussing on pellet fuel for stoves. There are other uses such as barbecues, patio heaters, camp stoves etc, but these are small. Pellet burning central heaters for houses exist but have not been popular.

Bulk sales of pellets to commercial or industrial customers will be at lower costs because there are no bagging costs. An FOB plant cost of $75 is typical. This is about $4.40 per MMBTU. The value to the customer is related to the savings in pollution control costs and possibly in operating and maintenance costs. It is possible to use mixtures of pellets and coal with some interesting and unexpected values caused by catalytic reactions between the coal and wood.

The densified wood pellet has become accepted as a premium fuel. Its widespread use will make a contribution of negligible emissions to replace the numerous particles and complex organic molecules contained in wood smoke.

Furthermore this fuel is manufactured from sawdust, a waste product which is sometimes used inefficiently and is difficult to dispose of.

As we understand better the parameters of successful densified fuel, we can perhaps manufacture it from other forms of biomass waste.

No matter how we look at our energy problems, there is no doubt that modern society is a profligate user of energy. Therefore all promising sources of energy need to be examined. Energy from biomass with always be high on the list. It is renewable, and, because of the short life cycle, it does not contribute to the greenhouse effect.

The densified wood fuel industry manufactures the highest quality biomass fuel now on the market. It is uniform, with very low moisture content, very low ash and burns with very low emission. The industry is young but growing rapidly.

THE *DESIGNER PELLET* PROJECT: CLEAN FUEL FROM URBAN WASTE

Carmine Iadarola, President, The Aquasan Network, Inc.
45 Mule Deer Trail, Littleton, CO 80127
John R. Brown, President, Colorado Synergistics
1280 Canyon Drive, Castle Rock, CO 80104
Stephen L. Sargent, Program Manager, U.S. Department of Energy
Denver Regional Support Office, 2801 Youngfield Street, Golden, CO 80401

ABSTRACT

The **"Designer Pellet"** (*) project aims at determining the viability of a business in the Denver area to produce clean-burning, high-ash, fuel pellets from the cellulosic component of municipal solid waste. The project is utilizing data from the low-ash (i.e., wood) pellet industry as well as empirical production and environmental data being developed during the course of the project.

While the efficacy of such a product depends upon technical considerations, it is also highly dependent on the business climate in which it will operate. The community risk profile is a key element to that. The project will therefore explore external risk factors as well as the perceptual risks of such a project. That assessment will drive the underlying industry assumptions and economics.

Project results to date indicate that a waste-based pellet business is potentially viable in the Denver market, dependent on the ability to attract a good partner group. This paper presents a report on the progress of this effort to date, and the requirements for success.

INTRODUCTION

The "Designer Pellet" project aims at assessing the technical and economic viability of converting municipal solid waste (e.g., paper, homebuilding material, milk cartons, and coffee grounds) into fuel pellets, with a view toward establishing a profitable business in the Denver area. The pellets are intended for use in the home burning "hearth" fire market.

The primary objectives of the project are to:

1. Identify biomass feedstocks in the municipal waste stream that have high heat content, and investigate feedstock availability, trends, and supply channels.

2. Ascertain the ability of a Denver-area pellet mill to manufacture several prototype pellet designs, based on the results of #1 above, and to manufacture pilot quantities of two or three of the most promising formulations.

3. Identify one or more pellet stove manufacturers willing to perform combustion tests on the high-ash prototype pellets; perform the tests and analyze the results. This includes the willingness of the stove manufacturer to warranty stove performance using the high-ash pellets.

4. Define the economics of manufacturing and marketing high-ash pellets. This includes an estimate of future demand for high-ash stoves and pellets.

Project results to date indicate that a waste-based pellet business is potentially viable in the Denver market, dependent on the ability to attract a good partner group. This paper presents a report on the progress of this effort to date, and the requirements for success.

POTENTIAL MARKET

It appears that the efficient use of resources is more than an environmental gesture or passing fad, but is becoming tightly woven into the nation's economic fabric. For example, the federal government, one of the largest paper users, now requires its agencies to buy paper with 20% recycled content and major corporations, from McDonald's to DuPont, believe that resource efficiency is good for business and actively boast of their resource recycling programs. More than 7,000 U. S. communities now have curbside recycling, up from 1,000 five years ago.

Polls, national and industry magazines, and empirical results have shown that "green" sells and is an important marketing wave of the future. The May 6, 1992, *Wall Street Journal* (page A11) reported on a poll that showed most people give priority to environment over economy, even if it hurts economic growth.

A Gallup Poll of 22,000 people in 22 nations showed that a majority would accept higher prices to pay for environmental measures. *Better Homes and Gardens* magazine said that the "green home" is the fastest growing building phenomenon ln its history. According to

McStain Homes, a Denver Area builder, a "green home" is worth $5000 to $10,000 more to home buyers. The "green home" representative of the Colorado Homebuilders' Association stated that home buyers not only prefer, but are beginning to demand, improved resource efficiency in their homes.

From Florida to Washington, the "green home" concept has proven to be a very successful marketing tool. In Colorado, a much touted "green home" subdivision built in Steamboat Springs sold out faster than the homes could be built. McStain homes has produced similar results with their "green homes" in the northern Denver suburbs.

There are several reasons for this increasing consumer demand:

1. Natural resources are becoming more scarce, more difficult to develop and more costly.

2. The Federal government is mandating development of resource- efficient homes.

3. Technology has developed that allows for more efficiency in a cost-effective manner.

4. It's good business. Communities and water supply and zoning entities are requiring sustainable low impact developments.

The Denver area market was selected because of its potential demand for "designer pellets". This projected demand is based on the Denver area's high winter demand for "hearth" fires, the availability of feedstock, and local interest in recycling. Today Denver has an annual demand of 30,000 tons of wood-based low-ash pellets. A recent study [1] estimated that the Denver pellet market could grow at over 37% over the next five years and could eventually grow to 300,000 tons per year. Pellet industry officials also believe that, although the existing market is dominated by low-ash stoves, high-ash stoves will soon be available, perhaps as early as 1996, and that a significant portion of that market will eventually use high-ash pellets. Finally, large metropolitan areas such as Denver generate significant quantities of potentially high-quality biomass waste.

Furthermore, Denverites like wood-burning fires, historically consuming over 100,000 cords annually. However, because of clean air considerations, a wood-burning ban is periodically imposed in the six-county Denver metropolitan area. Homeowners therefore have turned instead to gas fireplaces. But it appears Denver is again yearning for the age-old magic of a fire crackling away in the hearth.. Wood stove sales have increased dramatically in Denver because wood stoves can now meet "no-burn day" regulations for smoke emissions and because the hearth industry has learned that style is a hot seller. Also, government cooperation has been a major consideration. In an effort to reduce wood stove emissions, a program was started in 1992 which provided incentives to convert fireplaces and wood stoves to clean- burning technology. Many local governments offer sales tax rebates and building permit fee waivers, and have arranged for disposal and recycling of old woodstoves.

Several Denver area homebuilders have indicated an interest in offering a pellet stove burning "designer pellets" as part of Colorado's "green home" or "EcoHouse" programs. Denver homebuilders have found that a "green glow" is very advantageous in marketing their homes. Because of this strong market, a major Denver homebuilder is presently planning on converting all their models to the "green home" program and offering a "designer pellet" stove as an option.

FEEDSTOCK IDENTIFICATION AND AVAILABILITY

A guaranteed long-term supply of reasonably-priced feedstock is essential to the development of the "designer pellet.". It appears from a recent report [1] and the National Association of Homebuilders that there is an abundance of waste wood for making pellets. It is our plan, however, to develop pellets that also incorporate residential waste such as milk cartons and coffee grounds. In addition to long-term availability and low cost, desired feedstock characteristics include a high heat content and low moisture content.

Homebuilders are interested in the "Designer Pellet" project in part because of the amount of waste produced during home construction and the cost of disposing of the waste. According to the National Association of Home Builders, it costs about $400 to dispose of the waste produced from the construction of a 2,600 square foot home. A 1992 study conducted by Palermini and Associates of Portland, Oregon , found that more than 6,300 pounds of dimensional and manufactured wood waste is produced from a residential construction site, along with about 200 pounds of waste corrugated cardboard. Peter Yost, analyst at the NAHB Research Foundation, said " Builders should not focus on today's tipping fees, but should look five years out. That's because landfill capacities will affect builders' long-term costs." Clearly, homebuilders are very interested in reducing their wastes and their associated tipping fees. It appears particularly appealing if waste from the building construction could be recycled to provide clean-burning heat for the home.

Another source of feedstock for the designer pellets is waste shake shingles. Over 1,000 tons of waste shake shingles were produced in 1992 in the Denver area. There appears to be an ongoing supply of these because of the hail storms that visit Colorado. In 1992, less than 1 % of the pellets produced in Canada and the U. S. were high-ash pellets, but within the next five years industry projections indicate that high-ash pellets will account for at least 20% of the market.

In addition to wood feedstocks from the construction industry, we have also identified the following residential wastes which show promise as possible sources of feedstock for a "designer pellet". The selection criteria were based on common availability in the Denver area, and ash, moisture and Btu content:

Waste Feedstock	Thermal Content (Btu/lb)	Ash Content (weight %)	Moisture Content (weight %)
Coated milk cartons	11,330	1	3.5
Animal Fats	17,000	0	0
Coffee Grounds	10,000	2	20
Wax paraffin	18,620	0	0

In a separate test conducted by Oxbow Biomass Engineering, pellets made of municipal solid waste had a thermal content of 7434 Btu/lb. In comparison, white oak had 7689 Btu/lb.

All of these feedstocks are commonly available, produced in the home, are presently not separated for recycling, are affordable, and abundant. At present, we do not know the exact amount of each feedstock being produced in the Denver metropolitan area. It is known, however, that none of these feedstocks is presently being recycled in any large amounts. We are in the process of collecting data regarding the amount of each of the identified waste feedstocks being produced in the Denver area.

It is our conclusion that designer pellets can be produced from municipal solid waste and that feedstocks do exist which can be obtained at little or no cost except for collection and sorting.

PELLET MANUFACTURER AVAILABILITY

Oxbow Biomass Engineering in Kansas and the Argonne National Laboratory [2] have reported on successfully making pellets from various municipal wastes. The key issue appears to be the availability of a low moisture feedstock. With the proposed combined feedstock of wood, coffee grounds, wax paraffin, and milk cartons, it appears that at least two pellet manufacturers can produce the designer pellet, The Heartland Company in Spearfish, Montana, and a second company in Laramie, Wyoming, according to their Denver representatives.

PELLET STOVE MANUFACTURERS

Three stove manufacturers appear capable of handling the high ash pellets. The Whitfield and Winrick stoves are certified and can apparently handle high-ash pellets by adjusting the air/fuel ratio. Both stoves are top-feed units which extricate ashes by blowing them before they can plug up the air holes. If the air holes are plugged by ashes the combustion rate will suffer and problems with stove operation will mount. The designers of both

stoves are working with us to identify potential problems and make adjustments to the stoves' operation to ensure that the pellets do not affect the stoves' warranty.

A third stove manufacturer Hi-teck (Jamestown) Stoves in Salt Lake City, UT, is presently in the process of manufacturing high-ash stoves. A company representative stated that they would also work with us to test the pellets in their stoves. The tests will include ash volume, Btu content, and burn time.

PRODUCT ECONOMICS

A preliminary cost estimate for pellet manufacture is as follows:

Component	Cost ($/ton)
Raw material	10
Direct production	45
Inventory, storage, flooring	5
General and administrative	7
Amortization and profit	18
Total	$85

Since the plant will presumably be located in the metropolitan Denver target market area, shipping costs should be a small add-on to the above total.

However, the pellet manufacturing cost, while important, is only one factor in the overall economics of the proposed business. More broadly, the economics of any business venture depend upon the twin issues of the perceived **riskiness** of the project and the **expected returns** required to compensate adequately for the risks assumed. These factors are discussed below.

Risk

Risk relates to the degree of uncertainty associated with the various assumptions underlying the return analysis. Those assumptions are established from an assessment of the four broad constituency groupings of a particular project. The following analysis is based on a community/constituency model of business risk assessment developed for strategic investment work in collaboration with faculty of the University of Denver [3, 4].

***Markets*:** We have a good understanding of the current state of the market in Denver. It is in its infancy, however, and, as such, will change rapidly and dramatically. The issues remain: Who will the market participants be? What will they be willing to spend for their system? What will be their preference patterns relative to Btu content, ash content, etc.?

How will this change over time? What response will alternative heating and fireplace competitors make and how will the market respond?

Employees and Management: Starting up this operation provides several challenges. We need to obtain experience as fast as possible to run the plant and to market our products. A well-selected partner can reduce the impact of this startup. Whether partnering or not, we will need to understand the following: What are the issues that will drive cost? What will be the learning curve for bringing a plant to Denver? Are adequate operators available in Denver? Will we need to hire from outside the area? Are there opportunities for partnering and collaborating? What are the organized labor impacts, if any?

***Community*:** This represents both the community-at-large (for which the proxy is often government) and the vendor community.

We are working hard to make sure that emission and other environmental concerns are met. We also hope to be contributing a partial solution to the problem of landfill capacity concerns. The vendor community on the other hand may have a vested interest in not being supportive. It is our hope that partnering with trash collection operators may contribute to reduced costs and some increased certainty of waste stream flows. This may also increase the vendor community's commitment to such a project.

***Investors*:** To reduce the risk attendant to the investor community requires a knowledgeable investor group as it relates to MSW and designer fuel pellets applied to consumer markets. This group does not exist outside of the private trash collection industry, designer fuel pellet stove manufacturers, pellet manufacturers, and government. No one group has all the requisite knowledge. Partnering with one or the other of these groups has the most likelihood of reducing investor risk, but substantial investor risk is still attendant with the project.

While our risk assessment is not yet final, our expectation is that even partnering with a solid knowledge partner, the risk profile is analogous to a venture capital investment (perhaps Stage II). In purely private capital terms, this could require a 60% to 85% return on invested capital per annum [5].

An interesting possibility exists, however, in partnering with a governmental unit, probably a municipality. The advantage here is that much risk and cost can be reduced via the mandate process, providing a steady and controlled waste stream, and asset conversion. Overlaying these risk and cost reduction objectives is the government's reduced requirement for an economic return in excess of invested capital. The challenge is to get a municipality to visualize the benefits and the means to achieve this success, as well as understanding its exposure management potentials. Our early discussions with a Denver-area municipality were very unsatisfactory because the municipality was seeking a purely expeditious solution.

Return on Invested Capital and Exposure Management

While the risk assessment is fairly far along in our project, our return computations are less developed. They are really dependent upon the final results of our risk assessment. There are, however, three issues which appear to be paramount from the vantage point of our work to date:

Waste Streams: From a cost perspective (and perhaps with an adverse market impact), we probably will suggest that further separation of MSW is impractical. First, it may put an onerous burden on the citizenry who is asked to (voluntarily) further separate their trash. From an energy and environmental perspective, further separation would be beneficial, but the overriding desire in today's society for convenience will make this a very difficult sell.

At the same time, to further separate rubbish at the landfill or other staging area is generally very cost prohibitive. If we can identify a mixed MSW that would be adequate from an energy and environmental perspective, we are likely better off to address the marketing issues arising from higher ash and lower energy density rather than purer streams. We should also obtain, with the right partner, a substantial cost advantage, a very important market factor.

The Market: Many of the unresolved issues here were enumerated above. Again, a governmental partner could have a substantial impact here via the mandate process.

Partnering and Exposure Management: The best partner profile is likely a trash collector rather than a stove manufacturer. Trash collectors have ready access to waste streams and landfills often have land and building assets which can be converted to such a project via temporary means such as lease contribution. Transportation as a cost factor can be shared also. This kind of partner can therefore reduce risk, lower costs, and thereby reduce the return expectations of investors. When coupled with a governmental entity, return expectations can be reduced further. This is very important to a project's viability, especially in the early venture stages.

Finally, the action of partnering of the type described above reduces the amount of overall outlay considerably, reducing the exposure of the project. For the partner described above, little in the way of cash should be required, and the overall operation of the landfill improved. If the project does not work from a market perspective, the partner is out little. If it does work, privatization (i.e., sale of all or part of the operation) should be achievable. In all cases exposure (i.e., the maximum losses to the partner) should be substantially minimized and publicity should be positive.

CONCLUSIONS

It appears clear from our research that a great body of knowledge exists about feedstocks, waste streams, and production costs. Clearly from our research all the technical problems appear resolvable: suitable feedstocks exist; designer pellets can be manufactured at least at the same cost of existing "premium" pellets; they can operate in pellet stoves as

efficiently as other pellets; and there will be a substantial market for "high-ash" pellets. In fact, substantial research has been done on these issues to the point that technology is not where the industry needs more information. It appears that the key issues facing the pellet industry are the economics, risk and the ability to attract the most knowledgeable partner.

Having looked at the issues surrounding the production and marketing of consumer designer pellets, many of the business pieces are in place or are becoming available. None of the components have been effectively brought together yet, however. In fact, some who may have attempted the creation of this type of business are now out of the business: doing something else or closed down. Why is this, when many of the engineering and environmental issues are solved or in the process of resolution? The problem is the classic business failure of engineering and design LEADING market understanding and economic considerations. It is the issue of solutions to problems (or needs) preceding the existence of the problem, or perhaps as important, the perception of the need or problem. This can relate to any constituency.

Therefore, the key issues now to commercialize designer pellets as a successful consumer product are not primarily production, stoves, and environmental issues. The issues of creating a new (feasible!) industry are **risk** and **economics.** And the first and key issue within a holistic risk assessment is MARKETS. We believe from what we have seen that a market is birthing at this very moment. Its size, vitality, and development cycle are unknown at this time. We could be decades from a size that would support a viable industry. While this is not our view, it is an area that needs more exploration.

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COPOLYMER RESINS MADE OF AGRICULTURAL AND FOREST RESIDUES EXTRACTS FOR WOOD LAMINATING ADHESIVES

Chia M. Chen, Ph.D.
School of Forest Resources
The University of Georgia
Athens, Georgia 30602-2152

Abstract

Extracts of Southern pine bark, peanut hulls, pecan nut pitch, and pecan shell flour were used to synthesize copolymer resins using resorcinol, phenol, and formaldehyde. The test joints of both southern pine and oak were laminated in room temperature. The gluability of these copolymer resins were evaluated with shear compression loading test. The effects of resorcinol level, the molar ratio of formaldehyde to phenolic, and the composition of the hardener on bonding quality were investigated.

With a more than 80% wood failure after vacuum pressure treatment, several copolymer resins provided good bonding quality as a wood laminating adhesive. Different extracts required different formulations of copolymer resin and hardener to obtain the best bonding quality.

Introduction

The total utilization and low processing costs of agricultural and forest biomass residues are the keys to a more feasible and practical use of these residues for industrial chemicals and adhesives. Georgia, along with other southeastern states, has tremendous amounts of biomass resources in the form of forest and agricultural residues. At the present, the wood products industry is almost entirely dependent on chemicals derived from petroleum and natural gas for adhesives. The wood products industry is virtually dependent on adhesives to utilize smaller trees, as well as mill residues, in order to produce various products to meet the needs of consumers. As the quality of harvested timber declines due to the declining commercial forest land base, the future of wood utilization will require an even higher dependence on adhesives to convert limited timber resources into needed products.

In view of the environmental strain caused by fossil fuels and chemicals and its inherent limited supply, efforts to develop renewable sources of chemicals and energy must be accelerated. The photosynthetic products of green plants --BIOMASS-- in its various forms, represents one of the truly renewable resources upon which the planet earth can and must build in order to ensure a sustainable future.

A cold-setting waterproof wood laminating adhesive was developed by blending western hemlock bark extract with resorcinol oligomer (Herrick & Conca 1960). Cold-setting adhesives containing wattle tannin and resorcinol can be obtained through several different approaches. Bonding quality was comparable to the PRF control cold-setting adhesives, but simple mixtures of resorcinol, tannin, and paraformaldehyde without pre-reaction are unreliable, and the results are never reproducible (Pizzi and Roux 1978).

Kreibich and Hemingway reported (1985) that the reaction of 2 parts southern pine bark extract and 1 part resorcinol under acetic acid catalyst at 120°C for 24 hours yielded a product containing 39% oligomeric procyanidin-4-resorcinol adducts and 20% unreacted resorcinol. These reaction products can be used as a resorcinol replacement for wood-laminating adhesives of room temperature curing.

As the author reported in previous papers (Chen 1981, 1982, 1994), a family of fast curing phenolic copolymer resins containing extracts of forest and agricultural residues was developed for exterior grade plywood as well as structural particleboards and flakeboards. Copolymer resins, with 40% of their phenol by weight replaced by extracts of biomass residues, proved to require shorter press times than commercial phenol formaldehyde resins. The biomass copolymer resins are also capable of gluing southern pine veneers of higher moisture content while providing satisfactory wood failure results. Based on these results, it was of interest to investigate if the newly developed biomass extracts could be used to synthesize copolymer resins for use as a room temperature wood laminating adhesive.

The objective of the project is to study the resorcinol and cross-linking agent requirements for the room temperature setting of laminating copolymer resins of biomass extracts.

Materials and Methods

Alkaline extracts of peanut hulls, pecan shell flour, pecan nut pith and southern pine barks were used in this study. The ground biomass materials were extracted with both 10% and 22% sodium hydroxide solution at 95°C for an overnight period of approximately 17 hours.

All experimental resins were prepared by loading the extract, phenol, and formaldehyde into a resin reaction flask, followed by the addition of water to the mixture to adjust the target nonvolatile content of the resin to 45 percent (by weight). This was followed by a stepwise addition of NaOH and moderate heating to effect the chemical addition of formaldehyde to the phenolic ring while incurring minimal formaldehyde loss due to the Cannizzaro reaction (Chen 1989).

The mixture was then heated and polymerized to a target resin viscosity of approximately 1,000 centipoise, as measured at 25°C using a (Brookfield) viscometer. The prescribed amount of resorcinol, dissolved in water or water-alcohol, was then added to the copolymer of biomass extracts and phenol and reacted for another 30 minutes to graft the resorcinol onto the copolymer resin. Four levels of resorcinol - 5%, 7.5%. 8.75% and 10% - based on the non-volatile content of resin, were used. The molar ratio of formaldehyde to phenolic materials (combination of phenol, biomass extracts and resorcinol) ranged from 0.80 to 1.20, depending on the type of biomass extracts.

Kiln dried tangential Southern pine, red oak, and maple boards were planed to a 3/4 inch thickness and then cut into 2-1/2 inch by 12 inch blocks. The average equilibrium moisture content of the wood blocks was 9.3% for Southern pine, 8.6% for red oak, and 7.9% for maple.

The resorcinol grafted copolymer resins were mixed with hardener immediately before being used to glue the wood blocks. Two different hardeners were examined. The total formaldehyde to phenolic materials ratio, after adding the hardener, was 1.5 and 1.725, respectively. Glue was applied onto one surface of the wood block with a hand roller for a spread rate of 7g/ 30 sq. inch single glueline. Two blocks were then glued together with grain parallel at a pressure of 190 psi. The open assembly time ranged from 3 to 5 minutes and total assembly time ranged from 10 to 30 minutes. The glued blocks were kept under pressure at a room temperature of 18 to 20°C for 17 hours to ensure complete resin cure. Two duplicate wood blocks were glued for each wood species and resin combination.

Each of the two duplicate glued wood blocks was cut into five standard block-shear test specimens according to ASTM D-905 standard test method. The ten test specimens were divided into two groups, one group for test of dry specimens and another group for test after vacuum/pressure water soak. The block-shear specimens were tested to failure at a speed of 0.2 in./min. Both shear strength and percentage of wood failure were recorded.

Results and Discussion

The composition and characteristics of the copolymer resins used in this study are listed in Tables 1 and 2. Complete information on commercial resins A and B was not available. However, they were included in this study to compare the strength and durability of presently available industrial adhesives to the experimental biomass copolymer resins.

Table 1. Characteristics of Copolymer Resins Contained 6% Ethanol

Resin composition		Resin analysis				
Type of extract	Extra/ Phenol	Resor-cinol (%)	pH	NaOH (%)	N.V. (%)	Viscosity @25°C (cps)
Peanut hulls extracts A	40/60	5.0	12.34	7.47	46.75	710
	40/60	7.5	11.93	5.00	46.32	950
	40/60	10.0	11.75	4.76	47.96	525
Peanut hulls extracts B	40/60	5.0	11.98	5.12	47.16	640
	40/60	7.5	12.43	6.88	44.87	150
	40/60	10.0	12.19	4.95	48.62	280
Pecan shell flour extracts	40/60	7.5	11.83	4.56	44.07	505
	40/60	10.0	11.57	4.14	45.91	890
Southern pine bark extracts	40/60	7.5	11.54	3.98	46.22	6,000
	40/60	10.0	11.37	3.93	48.18	1,900

Average shear strength and percent wood failures for laminated wood blocks from the bonding tests are presented in Table 3 for the copolymer resins contained 6% ethanol and Table 4 for the copolymer resins containing no alcohol.

The application of constant pressure to all laminates was intended to force excess glue out of the bonding area and insure a close contact of two bonding surfaces with uniform adhesive spread while preventing a thick glueline formation. However, after careful examination of the gluelines, it was found that this squeeze-out and uniform adhesive spread phenomena were not observed in all samples. Some samples showed a possible precured glueline within a possible low pressure area and other showed somewhat thicker gluelines.

Table 2. Characteristics of Copolymer Resins Contained No Alcohol

Resin composition			Resin analysis			
Type of extract	Extra/ Phenol	Resor-cinol (%)	pH	NaOH (%)	N.V. (%)	Viscosity @25°C (cps)
Peanut hulls extracts	40/60	5.0	11.60	5.27	46.02	455
	40/60	7.5	11.16	4.75	45.99	645
	40/60	8.75	10.27	3.85	44.60	365
	40/60	10.0	10.15	3.88	44.35	760
Pecan shell flour extracts	40/60	5.0	11.57	4.62	45.37	1,050
	40/60	7.5	10.92	4.22	43.93	260
	40/60	8.75	10.36	4.16	43.12	140
	40/60	10.0	10.57	3.81	43.73	450
Southern pine bark extracts	40/60	5.0	10.84	5.08	43.11	250
	40/60	7.5	10.54	4.78	43.60	140
	40/60	8.75	10.45	4.67	42.90	250
	40/60	10.0	10.33	4.51	43.47	140

As the tables indicate, bonding strength increases with increasing resorcinol content and a resorcinol content of approximately 10% was required to achieve a more than 80% wood failure. It seems that different type of biomass extracts required different quantities of formaldehyde to obtain good gluability.

Several of the experimental copolymer resins provided superior bonding quality than that of the two commercial PRF resins. These experimental biomass copolymer resins provided a higher bonding strength and better durability with higher wood failure percentages than the two commercial PRF resins.

Table 3. Shear-Block Test Results of Copolymer Resins Contained 6% Ethanol

Resin type	Reso-rcinol (%)	Hard-ener*	Oak				Southern pine			
			Dry specimens		After V/P Water soak		Dry specimens		After V/P Water soak	
			PSI	WF %	PSI	WF %	PSI	WF %	PSI	WF %
Peanut hull ext. A. copolymer resin	5	A	1165	0	618	0	960	16	122	0
		B	2247	36	406	21	1465	83	566	22
	7.5	A	1032	10	408	0	165	0	28	0
		B	1709	20	672	13	1498	60	703	51
	10	A	2630	60	1690	27	1761	42	811	21
		B	1974	45	1065	20	1837	73	770	49
Peanut hull ext. B. copolymer resin	5	A	940	0	463	0	583	0	0	0
		B	244	20	154	35	900	0	290	0
	7.5	A	1657	0	781	0	1159	38	300	12
		B	1841	19	786	16	1419	80	312	16
	10	A	1191	0	669	0	36	0	0	0
		B	1465	83	566	22	2247	36	406	21
Pecan shell flour copolymer resin	7.5	A	728	4	472	0	867	10	190	0
		B	1892	41	1029	59	1500	52	805	31
	10	A	2880	83	1887	59	2130	83	1221	100
		B	2215	76	1427	62	1610	98	846	87
Southern pine bark copolymer resin	7.5	B	1641	18	942	45	1573	62	732	30
	10	A	2852	78	1720	68	1938	91	1172	100
		B	1939	60	1434	60	1581	63	903	76

Resin type	Reso-rcinol (%)	Hard-ener*	Oak				Southern pine			
			Dry specimens		After V/P Water soak		Dry specimens		After V/P Water soak	
			PSI	WF %	PSI	WF %	PSI	WF %	PSI	WF %
Commercial PRF resin A	?	C	1995	40	1371	37	1141	83	924	75
Commercial PRF resin B	?	D	1913	39	1641	29	2006	63	865	66

*Hardener A: A mixture of 50 parts pecan shell flour and 50 parts 95% paratormaldehyde.
B: A mixture of 30 parts pecan shell flour and 70 parts 95% paraformaldehyde.
C and D: Commercial hardener formulated for use with the resin.

Table 4. Shear-Block Test Results of Copolymer Resins Contained No Alcohol

Resin type	Reso-rcinol (%)	Hard-ener*	Maple				Southern pine			
			Dry specimens		After V/P Water soak		Dry specimens		After V/P Water soak	
			PSI	WF %	PSI	WF %	PSI	WF %	PSI	WF %
Peanut hull copolymer resin	5	A	1091	0	64	0	1229	40	330	0
		B	1094	0	0	0	1356	18	325	18
	7.5	A	2503	0	522	14	1523	83	645	35
		B	1686	13	58	22	1395	11	325	14
	8.75	A	2553	12	820	56	1812	77	820	63
		B	2917	0	1031	0	1722	43	776	14
	10	A	3048	91	1405	92	1729	90	921	85
		B	2657	88	1169	82	1974	87	965	85

Resin type	Reso-rcinol (%)	Hard-ener*	Maple				Southern pine			
			Dry specimens		After V/P Water soak		Dry specimens		After V/P Water soak	
			PSI	WF %	PSI	WF %	PSI	WF %	PSI	WF %
Pecan shell flour copolymer resin	5	A	696	0	30	0	1116	8	191	0
		B	1202	0	0	0	1220	25	523	0
	7.5	A	2019	0	985	42	1900	49	827	41
		B	2057	0	225	25	1670	74	814	66
	8.75	A	2348	10	1089	15	1829	30	716	24
		B	2496	0	782	0	1663	43	794	14
	10	A	3030	100	1310	93	1860	94	890	90
		B	3145	95	1344	85	1695	94	911	88
Southern pine bark copolymer resin	5	A	694	0	0	0	482	0	0	0
		B	983	0	15	0	1296	29	176	0
	7.5	A	943	0	170	0	1532	11	170	0
		B	1416	0	218	0	1510	35	456	0
	8.75	A	1827	13	462	13	1545	0	462	0
		B	1655	10	409	0	1945	44	759	20
	10	A	2113	73	607	68	1585	25	607	12
		B	2782	73	1057	0	2007	51	939	10

*Hardener: A mixture of 50 parts pecan shell flour and 50 parts 95% paratormaldehyde.
A: Total molar ratio of paraformaldehyde/phenolic materials = 1.5.
B: Add 15% paraformaldehyde to hardener to obtain 1.725 molar ratio.

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UNITED STATES BASED AGRICULTURAL "WASTE PRODUCTS" AS FILLERS IN A POLYPROPYLENE HOMOPOLYMER

Rodney E. Jacobson, M.S., Materials Engineer; Roger M. Rowell, Ph.D., Sr. Research Chemist; Daniel F. Caulfield, Ph.D., Sr. Research Chemist.
USDA, Forest Products Laboratory[1], Madison, WI
Anand R. Sanadi, Ph.D., Engineering Sciences
Dept. of Forestry, University of Wisconsin, Madison, WI

Abstract

With the advent of modern coupling agents (MAPP or maleic anhydride grafted polypropylene), the potential use of various types of renewable, sustainable agricultural by-products as fillers in thermoplastics is explored. Over 7.7 billion pounds of fillers were used in the plastics industry in 1993. With sharp price increases in commodity thermoplastics (i.e. approximately 25% in 94'), the amount of fillers in thermoplastic materials will increase throughout the 90's. Various types of agricultural fibers are evaluated for mechanical properties vs. 50% wood flour and 40% talc filled polypropylene (PP). The fibers included in this study are: kenaf core, oat straw, wheat straw, oat hulls, wood flour (pine), corncob, hard corncob, rice hulls, peanut hulls, corn fiber, soybean hull residue, and jojoba seed meal. Composite interfaces were modified with MAPP to improve the mechanical properties through increased adhesion between the hydrophilic and polar fibers with the hydrophobic and non-polar matrix. The agro-waste composites had compositions of 50% agro-waste / 48% PP / 2% MAPP.

All of the agricultural waste by-products were granulated through a Wiley mill with a 30 mesh screen and compounded in a high intensity shear - thermo kinetic mixer. The resultant blends were injection molded into ASTM standard samples and tested for tensile, flexural, and impact properties. This paper reports on the mechanical properties of the twelve resultant composites and compares them to wood flour and talc-filled polypropylene composites. The mechanical properties of kenaf core, oat straw, wheat straw, and oat hulls compare favorably to the wood flour and talc-filled PP, which are both commercially available and used in the automotive and furniture markets.

Introduction

Lignocellulosic fibers (wood flour) have been used in the plastics industry for almost 90 years. Bakeland used wood flour to both extend and improve the processability of thermosetting resins in 1907. The use of fillers and reinforcements in plastics has changed the face of the industry. Over 500 million pounds of fibrous material (mostly glass) is being used in the plastics industry yearly (Ref. 1). The total amount of fillers being used is estimated at 7.7 billion pounds in 1993. As the plastics industry grew and developed, the cost of introducing and marketing new polymers became cost prohibitive. So, the industry turned to the idea of using existing plastics and filling / reinforcing them to close the performance gap between the new and more expensive engineered polymer resins. The need for polymer composites to perform in service applications require certain levels of strength, stiffness, and fracture toughness, in various conditions (i.e. high temperature, indoor / outdoor applications, etc.). In the 60's and 70's, the plastics industry began using more fillers / reinforcements to improve performance as well as reduce the overall cost of production. The use of fillers and reinforcements in the plastics industry have seen a steady growth throughout the past 30 years and this trend will continue into and beyond the 90's.

As commercial industry seeks to offset price increases in base resin costs, increase product recyclability, and maintain composite performance, they will search for new materials to fill existing product niches and create new products for developing countries. China and India have over two billion potential buyers of goods and services in the global market place. These newer materials must be economically and more environmentally friendly then in previous years. Recent research into the use of annual growth lignocellulosics as reinforcing fillers in thermoplastics suggests they have high potential for industrial end uses. Results indicate that the mechanical properties of agro-waste / PP composites compare favorably to talc, calcium carbonate, and wood flour filled PP for certain applications (Ref. 2,3) where water absorption is not a problem. Furthermore, due to the softer non-abrasive nature of the agro-wastes it is possible to obtain a higher loading (by volume) of agro-wastes in the composites than other more traditional inorganic fillers (talc and calcium carbonate). As a result of the lower densities, more finished products are possible with a ton of agro-waste thermoplastic composites then are possible with a ton of conventional filler / thermoplastic composites.

Twelve different agro-wastes have been compatibilized with a polypropylene homopolymer. This study included the following agro-wastes: kenaf core, oat straw, wheat straw, oat hulls, wood flour (pine), corncob, hard corncob, rice hulls, peanut hulls, corn fiber, soybean hull residue, and jojojba seed meal. The tensile, flexural, and impact toughness properties are compared by the type of fiber and the fiber loading level. The fiber loading is based on the dry weight of the fibers. Also, the effect on the mechanical properties of the composites due to the modification of the interphase / interface region with MAPP coupling agent is evaluated. MAPP has been shown to improve the surface adhesion between the hydrophilic and polar lignocellulosic fibers and the hydrophobic and non-polar PP (Ref. 4). All twelve agro-waste composite systems had the following composition of 50% agro-waste / 48% PP / 2% MAPP.

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[1]The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright laws.

Experimental Procedures

Materials

The base resin was a polypropylene homopolymer, Fortilene 1602 (generously donated by Solvay Polymer, Houston, TX.) with a melt flow index of 12 gr. / 10 min. at 230 C (ASTM - D1238). A maleic anhydride grafted polypropylene (MAPP) modifier, Epolene G3002 (donated by Eastman Chemical, Kingston, TN.) was used to enhance the surface adhesion between the agro-wastes and the PP matrix. The agro-wastes used in this study were kenaf core from AG-Fibers Inc., corncob, hard corncob from Composition Materials Inc., corn fiber from Cargill, Inc., oat hulls from Quaker Oats Co., rice hulls from Busch Agricultural Resources Center, peanut hulls from Seminole Peanut Co., and soybean hull residue from WI Soybean Assoc., oat / wheat straw, wood flour, and jojoba seed from other sources.

Methods

The agro-wastes were run through a Wiley mill with a 30 mesh screen. The agro-wastes, PP, and MAPP were compounded in a 1 liter - high intensity shear - thermokinetic mixer (Synergistics Industries Ltd., Canada). No external heat sources are required due to the high shearing / smearing of the PP which produces friction and generates heat. The shearing action causes softening and flow of the composite system. A thermally controlled monitor regulated the dump temperature at 168 C (360 F) to 199 C (390 F) depending on the fiber type. The composites were compounded at 5000 rpm (tip speed = 32.9 m/s) and 150 gram batches were standard. Directly after reaching the dump temperature, the material was pressed flat to enhance cooling and prevent fibers in the core of the composite from burning.

The resultant composite blends were then granulated and dried at 105 C for 4 hours to drive off residual fiber moisture in preparation for injection molding. A 33-ton Cincinnati Milacron injection molder was used to produce standard ASTM tensile, flexural and impact specimens. Samples were placed in a controlled humidity room for three days prior to testing to assure complete thermal stability of the test samples. Test conditions were performed according to the following ASTM standards: tensile testing (ASTM D638), flexural testing (ASTM D790), impact testing (ASTM D256).

Results and Discussion

In the United States alone, there is approximately 120,000,000 metric tons (Ref. 5 - 1982 data) of non-wood plant straws available as raw materials for industry. Wheat straw, oat straw, and barley straw compose the largest volumes. Other crops, such as corn stalks and sorghum stalks, are available in the 190,000,000 metric ton (Ref. 5) range. There is approximately 2,000,000 metric tons of rice straw and rice hulls are available in the range of 1,000,000 metric tons that are located at point sources in the southern regions. Peanut hulls are located mainly in the southwestern states, such as, Georgia. The availability of potential fibers to be used by the United States plastic industry is governed by the location of the fiber sources. Each geographical region has its own type of fiber supply.

Farmers of fledgling non-food crops, such as, kenaf, jojoba seed, guayule, and milkweed, search for innovative applications for use in industrial applications. Currently, there is approximately 4,000 - 6,000 thousand acres of kenaf grown in the U.S. from California to Mississippi. As more potential markets are created, the acreage of these non-food crops will increase. The potential for using agro-wastes as fillers in commodity thermoplastics (i.e. PP, PE, PS, and PVC) is enormous if markets are developed and expanded over the next decade. Certain restrictions do apply for lignocellulosic reinforced polymers in terms of applications were moisture adsorption and creep resistance are required.

Tensile Strength and Modulus

Figures 1 and 2 show the tensile strength and tensile modulus properties of the agro-waste polypropylene based composites. For purposes of comparison, 100% PP, 40% talc, and 50% wood flour composites are included because they are commercially available products. The figures show that the tensile strength properties of kenaf core, oat straw, wheat straw, and oat hulls compare favorably to both wood flour and talc filled PP composites. All other fillers have mechanical properties which are slightly less then the 50% wood flour, but still compare favorably to 40% talc filled PP. The 50% corncob-un is an uncoupled system (i.e. no MAPP) and is used for comparison vs. the 50% corncob. The tensile strength of the un-coupled system increased 95% with the addition of 2% MAPP for the coupled corncob composite. All of the filler systems will react in a similar fashion when no MAPP is used during the compounding stage.

The tensile modulus of agro-waste composites show dramatic property improvement characteristics vs. 100% PP. Wood flour shows a 225% increase in modulus, while kenaf core, oat straw, and wheat straw shows a 200% increase in modulus vs. 100% PP. Other systems, such as, oat hulls, corncob, hard corncob, and rice hulls show an increase in modulus of 100% vs. virgin PP. For coupled and uncoupled systems, there is little change in the tensile modulus properties between 50% corncob and 50% corncob-un. Previous work at the Forest Products Laboratory (Ref. 6) indicates that some fiber systems will show a decrease in tensile modulus with a coupled system. Therefore, no discussion of the other fiber systems will be presented until further testing is done.

The addition of MAPP has the most dramatic effect on the tensile strengths of agro-waste composites. The uncoupled fiber systems have strengths approximately half that of coupled systems. MAPP migrates to the interface between the non-polar PP and polar fiber surfaces. In addition, the maleic anhydride present in the MAPP can covalently link to the hydroxyl groups on the lignocellulosic fibers (Ref. 7). Under a tensile load, the improved adhesion at the fiber / matrix interface results in a more efficient stress transfer from the matrix to the reinforcing fillers. As a result, strength properties of agro-waste composites can be improved with small additions of MAPP.

Flexural Strength and Modulus

Figures 3 and 4 show the flexural strengths and flexural moduli for the agro-waste polypropylene based composites. The addition of MAPP increases the flexural strengths of these agro-waste composites by approximately 50% of the value of un-coupled systems. Values for the 50% corncob-un and 50% corncob in Figure 3 shows an increase of 57% for a coupled system and is an indication of how the other composite systems flexural strengths would be if no MAPP were present in the composites. Increased adhesion between the lignocellulosic fibers and the matrix provides for increased stress transfer from the matrix to the filler. This results in an increased stress at failure and the higher values

for flexural strengths in the coupled systems verses un-coupled systems. The flexural strengths of composite systems composed of kenaf core, oat straw, wheat straw, and oat hulls are equivalent or superior to both wood flour and talc filled polypropylene composites. The kenaf core composite shows an increased flexural strength of 75% vs. 100% PP. Other systems, such as, corncob, hard corncob, and rice hulls have flexural strengths slightly less then wood flour and talc filled composites. These systems still show an increase in flexural strengths of approximately 50% over virgin PP.

In terms of the flexural modulus, Figure 4 shows that wood flour has the highest flexural modulus with an increase of 270% over 100% PP. On average, the top eight agro-waste composites show an increase in flexural modulus of 200% over virgin PP. The kenaf core, oat straw, and wheat straw composites have flexural moduli between wood flour and talc filled composites, while all other agro-waste / PP composites have flexural moduli less then talc and wood flour.

Notched and Unnotched Izod Impact

Figures 5 and 6 show the notched and unnotched Izod impact properties for the agro-waste composites. The commercially available 40% talc / PP has a notched impact toughness of 26.7 J/M, while 100% PP has a value of 24 J/M. Various types of talc filled PP is available and the notched Izod impact toughness can range up to 75 J/M. The mechanism for the toughness is due to the plate-like particles of talc which have a higher aspect ratio then the finely ground (i.e. 30 mesh) agro-wastes. Overall, the top eight agro-waste composites notched Izod impact toughness equals 22.1 J/M (i.e. average) and compares favorably to the wood flour. In comparing the agro-wastes composites to the talc filled PP and 100% PP, there is an 8-10% decrease in the notched toughness.

Figure 6 shows the unnotched Izod impact toughness of 100% PP equals 640 J/M, while the 40% talc filled PP equals 240 J/M. The average value for the agro-waste composites is approximately 95 J/M. The addition of MAPP results in a 100% increase in the unnotched toughness over un-coupled systems. The 50% corncob-un has a value of 40 J/M, while the 50% corncob has a value of 80 J/M. Further research and development involving impact copolymers will improve the toughness of these composites, but at a loss in strength properties (Ref. 8).

Conclusions

-With the addition of a maleic anhydride grafted PP to agro-waste composites, the tensile strength, flexural strength and un-notched impact toughness values are shown to improve substantially over un-coupled systems.

-Twelve different agro-waste composites have been successfully compatibilized with a polypropylene homopolymer. Results indicate that kenaf core, oat straw, wheat straw, and oat hulls have equivalent mechanical properties to commercially available wood flour and talc filled polypropylene composites.

-Continued research and development of agro-waste composites will show that these material systems are viable alternatives to commercially available wood filled and talc filled PP systems.

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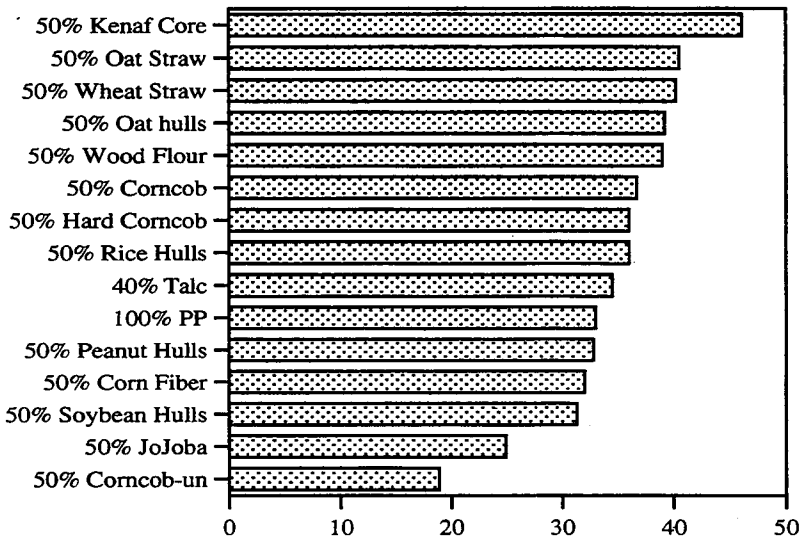


Figure 1 - Tensile Strength (MPa) Properties.

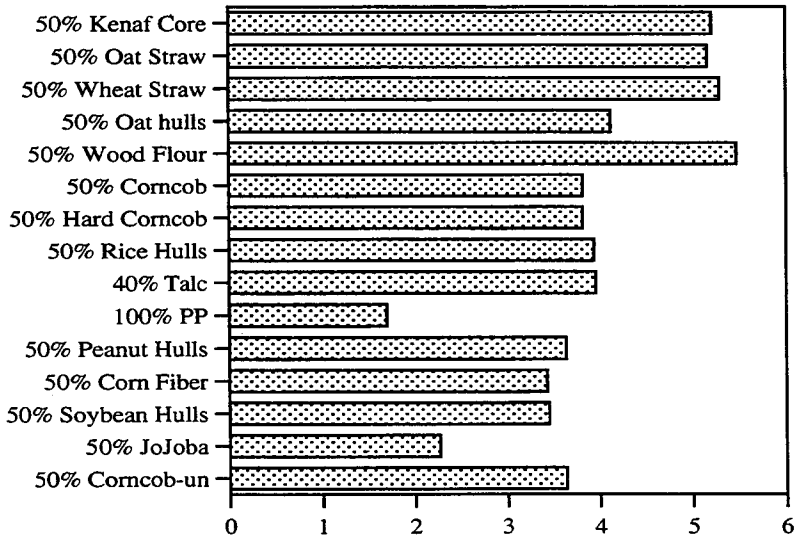


Figure 2 - Tensile Modulus (GPa) Properties.

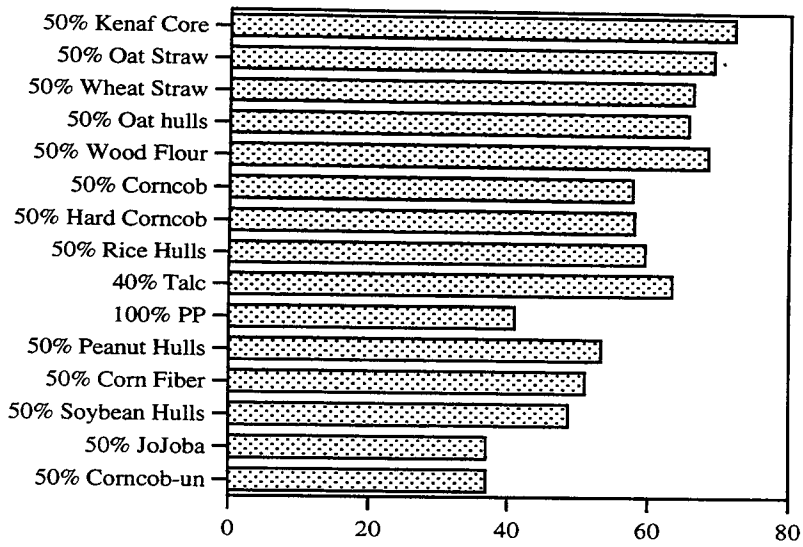


Figure 3 - Flexural Strength (MPa) Properties.

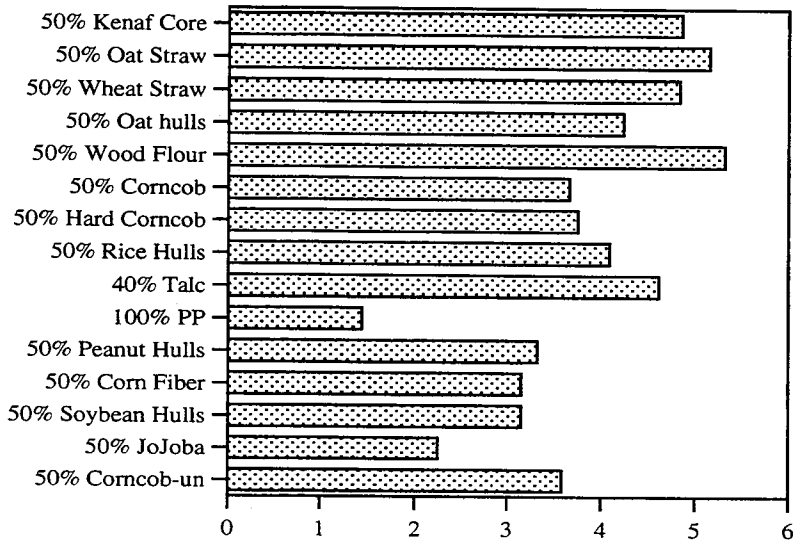


Figure 4 - Flexural Modulus (GPa) Properties.

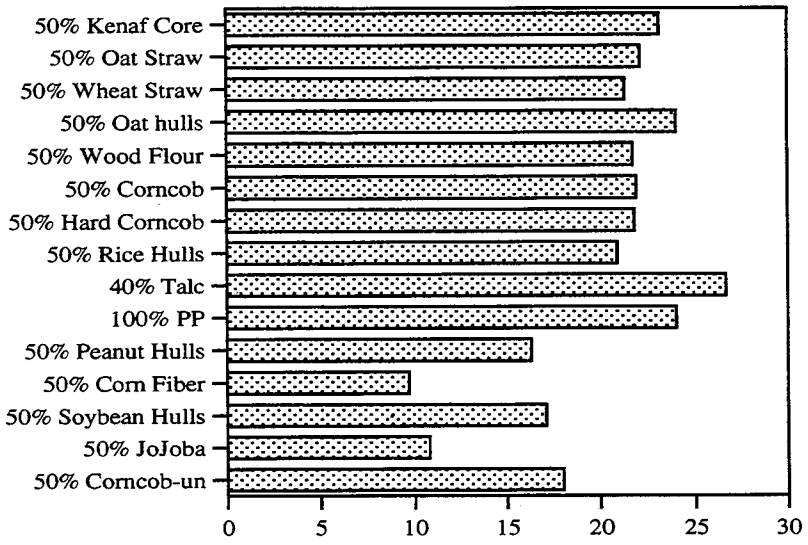


Figure 5 - Notched Izod Impact (J/M) Properties.

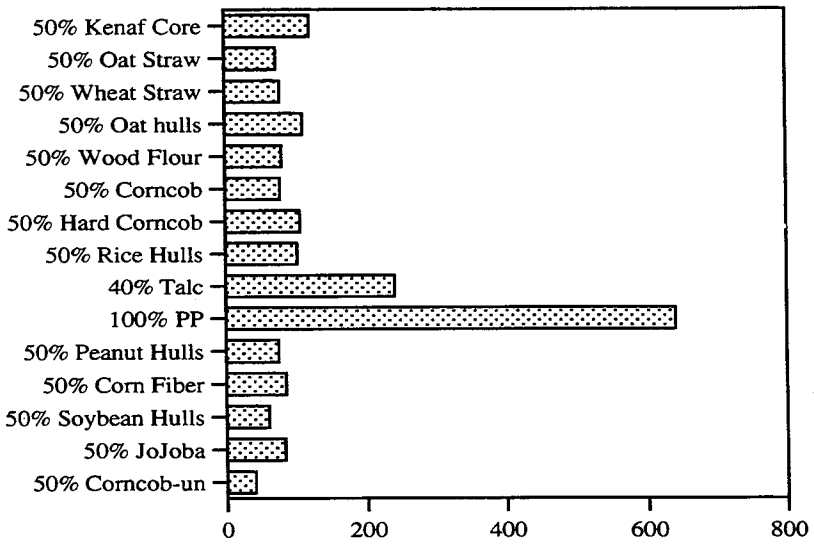


Figure 6 - Unnotched Izod Impact (J/M) Properties.

A NEW SYSTEM OF HARVESTING BIOMASS IS BORN

Oberregierungsrat Dr. Peter Sutor
Bayerisches Staatsministerium fur Ernahrung, Landwirtschaft und Forsten,
Munich, Germany

Abstract

A new, transportable system for harvesting agricultural biomass and converting it into fuel pellets has been designed and operated. It consists of the integrated operations of biomass cutting, particle size reduction, heating, and compression into pellets having a density of about 1.2 kg/L. The system has been demonstrated in the BIOTRUCK 2000. It is the first land vehicle that uses the waste heat of the engine in the pelletizing process.

1. Why biomass?

In the federal republic of Germany mainly four different kinds of regenerated resources of energy are available:

- water
- wind
- biomass
- solar energy

In Germany the potentials of water energy are nearly completely utilized. The wind energy plays an very important part especially in areas near the coast, but not in Middle-Europe. Biomass is a resource of energy which is abundantly available in Middle-Europe and which is almost competitive. On the opposite solar energy is still far from reality.

In the long run about 4.5 Mio ha (= 2.4711 acres) of agricultural areas in Europe, 4.5 Mio ha in Germany and 800 000 ha in Bavaria will be available for the cultivation of renewable resources of energy. 1% of the primary energy consumption could be sufficiently supplied by regrouping of 100 000 ha of that agricultural areas in favour of renewable resources of energy. The potential of biomass of forestry works and of agricultural areas is at least 12% of the primary energy consumption.

Within the utilization of the existing potential of biomass there are some technological and logistical problems. This is shown by considering the different available kinds of biomass:

- wood
  - treated residues of wood
  - untreated residues of saw-mills
  - wood of forestry works

- biomass of agricultural areas
  - biomass of landscape conservation works
  - straw of cereals and oil seeds
  - energy crops (straw and cereals, miscanthus, switch grass, and the like)

It is an very important aim to use this regional available biomass for the production of warmth, steam and electricity. For this it is necessary to build plants for the production of energy, which transform biogenic combustibles in warmth, steam and electricity. An essential simplification in this connection is the standardization of the combustibles by compressing them into pellets; because then, the number of necessary combustion systems can be reduced.

The combination of different combustibles is an essential factor within the successful developing of a market for solid biogenic combustibles. The following advantages within the utilization of different biogenic combustibles are given:

- improved availability of biogenic combustibles
- reduced storage costs
- reduced average combustible costs

Obviously the biogenic combustibles, which are available in any case, have to be utilized first. Especially wood of residues of building constructions, of saw-mills, of industries and also of forestry works and landscape conservation works belongs to these combustibles.

Of course the utilization of biomass of forestry and landscape conservation work, which is necessary within the use of regenerated resources of energy, causes production costs. In Bavaria it was shown that in many cases costs of chips of wood are higher than the costs of the production of agricultural biomass. The labour costs are the most important cost factors, which lead to comparatively high prices of biomass. Thus, it is absolutely necessary to reduce the labour costs in the production of biomass.

2. Harvesting biomass from agricultural areas

Principally the utilization of agricultural biomass to produce warmth, steam and electricity is available in three different forms:

- in form of loose pour material
- in form of round and square stone bales
- in form of pellets

Loose, chaffed material as a combustible of heating plants based on biomass has not been proved. Its extremely high volume and high transport and storage costs doesn't lead to an economic operation.

The use of round and square stone bales has to been rated clearly better. But still the transport volume is very high. In many cases special equipment is needed for the transport and storage. Disadvantages are the high losses within production of biomass based on energy crops (cereal losses). Moreover it has been shown, that power stations with a high ecological quality need a steady supply of combustibles and thus bales have to be untied in a first step before being brought into the combustion. In many cases there are also technological problems because of the high percentage of plant dust, resulting from the dissolution of the bales.
With this the use of pellets based on biomass offers great advantages. Pellets have a high weight of about 900 kg/m^3. These pellets based on biomass can be transported and stored without any problems with the existing mechanics in the agriculture. The combustion quality of pellets is clearly better than of loose biomass, because of the equal compression that leads to determinable residues of combustion. Moreover it is possible to use pellets based on biomass in connection with chips of wood as a combustible.

So far the cost-effective production of pellets has been a problem. Until now installations to produce pellets have been stationary and the output of pellets were very small connected with high energy consumptions. The production of pellets in stationary installations would have been led to very high rises in costs.

3. New ideas of biomass harvesting

The idea to utilize biomass as an resource of energy could have been only successful, if the problem to produce pellets based on biomass has been solved in a cost-effective way. Similar to the 1930's when the combine harvester must have been made ready for production, now an automatic biomass harvesting machine has to be constructed to build up new jobs in the agriculture.

With that a few conditions must have been concerned:

- Biomass must have been compressed to more than 1 kg/litre, to reduce transport and storage costs.
- The pellets produced by the harvesting machine had to be loose and storable. As an aim existing transport and storage systems should be used.
- The product should have been storable. The process of fermentation and thus losses of energy were stopped by a thermic preliminary treatment.
- The losses within the harvesting, the transport and within the transformation of biomass into warmth, steam and electricity should have been minimized.
- The harvesting costs, especially the labour costs, should have been reduced. 1991 a Bavarian company could introduce a proposal to realize such a biomass harvesting machine, which combines the following four steps:

  - cutting the biomass
  - reducing (chaffing) the biomass to small pieces
  - heating and processing of biomass
  - compression the biomass into pellets of about 1.2 kg/litre.

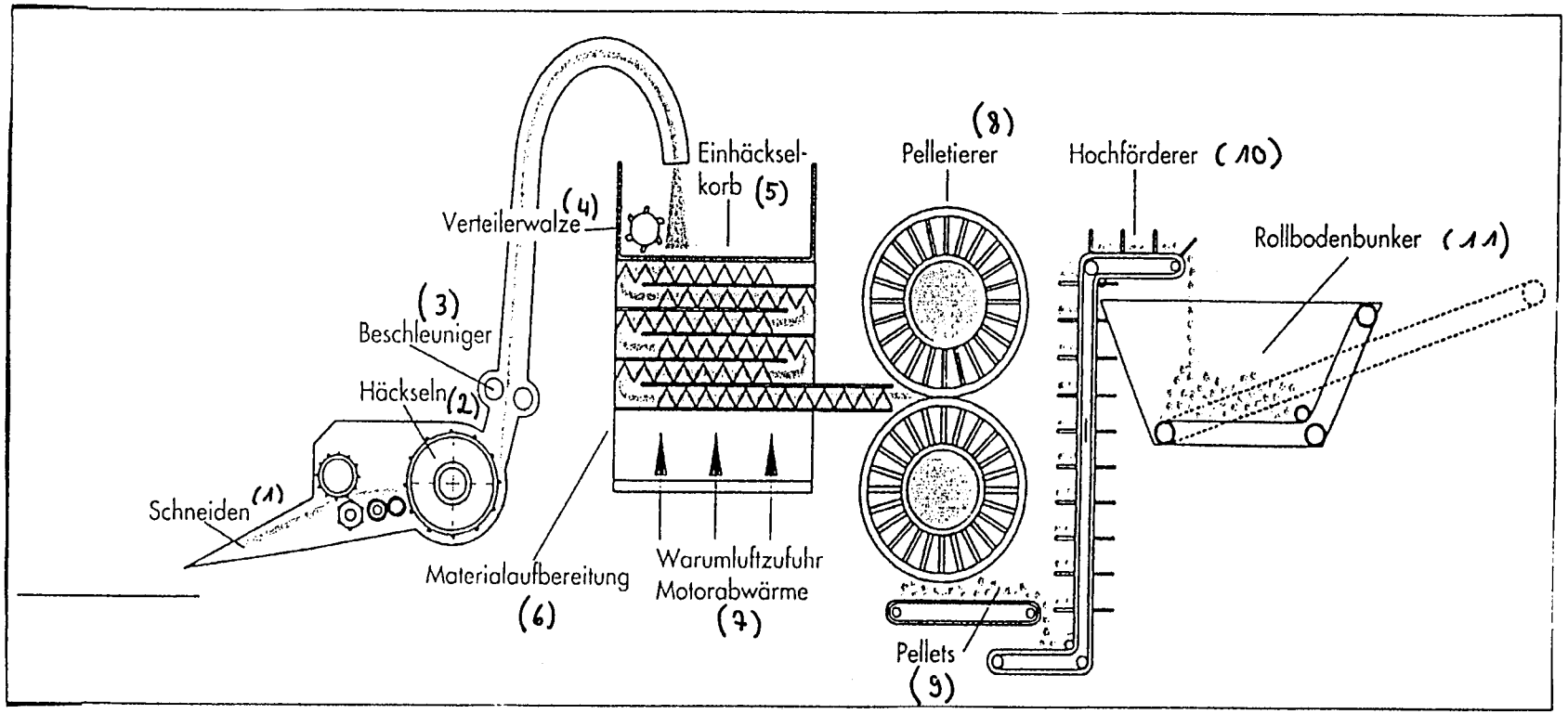
The schematic construction of the biomass harvesting machine is shown in figure 1; photograph 1 shows the first testing machine. Principally it is typified by four components:

- Cutting and chaffing the biomass to small pieces:
  With a common chaff aggregate produced of the firm Claas the biomass is cut in small pieces of about 0.6 mm. After that the biomass is transported to the preparation process.

- Processing of the material:
  The chaffed biomass is now heated by the waste heat of the engine (exhaust gases, engine oil) to temperatures of between 80 and 120° C. Screw conveyors equalize the transport of the biomass. About 7% of the moisture content of the biomass is withdrawn during the preparation of the material.

- Compressing the biomass into pellets
  The biomass gets over a double screw conveyer into the pellet process that looks like a toothed wheel press. Also the pellet process is indirectly heated by the waste heat of the engine. Depending on the kind of biomass the temperature is between 120 and 180° C. Because of the warmth the agricultural biomass becomes able to be formed and thus a good gluing of the biomass is guaranteed.

Figure 1: The schematic Construction of the Biomass Harvesting Machine "Biotruck 2000"



1	Cutting	7	Heating with the waste heat of the engine
2	Chaffing	8	Compressing the biomass into pellets
3	Accelerator	9	Compressing the biomass into pellets
4	Screw conveyor	10	Conveyor equipment
5	Storage of the chaffed material	11	Storage of the biomass in a bunker
6	Processing of material		

Photograph 1: The First Testing Machine "Biotruck 2000"

- Storage of the biomass in a bunker
  the enormous technological progress is especially shown in the use of the waste heat to heat the biomass that kind, that the starting pyrolyses strengthen the elasticity of the biomass and a gluing is possible. Because of the utilization of the waste heat the engine power can be have a even smaller dimension (about 50%).

The technical datas of the machine are shown in table 1:

Table 1: Technical Datas of the Biotruck 2000

length	10.10 m
breadth	3.30 m
height	3.98 m
model with 3 axles:	
power	480 PS
drive	hydrostatic, all wheel drive
weight	about 24 tons
price	1 000 000.-- DM)*
power of producing pellets	about 8 tons per hour of cereals
specific density of the pellets	0.8 - 1.2 kg/dm^3
weight of the pellets	about 500 - 700 kg/m^3
reducing of the moisture content	about 7%
moisture content of the material after the process	about 22%
measurement of the pellets	about 6 cm x 1.5 cm x 4 cm
quality of the pellets	compression without binding agent
kind of plants	cereals, hay, straw, grasses, miscanthus, switch grass)**

)* planed selling price about 600 000.-- to 700 000.-- DM
)**automatic electric process controlling depending on the form of condensed biomass concerning the temperature and the quantity of biomass

In spite of the high costs of about 700 000.-- DM a good efficiency is given, because of the long using time in Germany (May until November). The possibility of harvesting feeding stuff is not yet fully tested. But there will be high potentials in Europe in future. Until now about 5 Mio tons pellets of feeding stuff are produced in stationary drying plants per annum. If we succeed in producing feeding stuff with the Biotruck 2000 a new potential of that machine will be created.

4. Resume

The "Biotruck 2000" makes it possible to utilize agricultural biomass as a regenerated resource of energy. Only the pellet is a suitable resource of energy based on biomass, because it can be used in connection with wood and there are suitable power stations on the market. The Biotruck 2000 reduces the labour costs more than proportional. Thus it is possible to have smaller labour costs per unit of energy in the agriculture than in the forestry. But the fixed and variable costs still have to be reduced within a

further development of that machine. The Biotruck 2000 stands even for a very important progress in the development of the market for hay. The common production of hay and silage is completed by an third powerful method of a high quality.

The Biotruck 2000 is world-wide the first land vehicle that uses the waste heat of the engine. Because of that it is economically preferable and a very important investment for the future.

CONTROL OF THE STRUCTURE AND PROPERTIES OF A FROST-RESISTANT FIBER-CEMENT BUILDING PLATE ON THE BASIS OF WASTE CELLULOSE FIBERS

Galina Telysheva, Dr. Chem. habil., Chief of Laboratory;
Tatiana Dizhbite, Dr. Chem., Senior Researcher;
Alexander Arshanitsa, Researcher; Wilhelmina Jurkjane, Assistant; Anna Kizima, Assistant
State Institute of Wood Chemistry, Riga LV-1006, Latvia

Edgars Lacis, Director; Svetlana Rituma, Chief Manager
Cement Building Plate Enterprise, Riga LV-1007, Latvia

Abstract

Different aspects of the application of environmentally friendly fibers of the plant origin in building materials instead of the cancerogenic asbestos fiber have been studied. A whole range of the investigations have been performed, and some developments have been patented and produced on an industrial scale.

The object of the present work is the use of the waste cellulose-containing fiber material instead of asbestos in the production of the fiber-cement material and the development of a technique of the control of its structure and properties depending on the content of non-cellulosic admixtures in fiber materials. A formulation of mixtures and a method of obtaining building plates, in which various types of recycling paper are used, have been developed and tested under industrial conditions.

Techniques enhancing the compatibility of the raw material mixture components have been developed. A range of organic and inorganic additives enhancing the physico-mechanical characteristics of the materials have been proposed for various stages of the process. An enhanced frost-resistance of the material, as compared to asbestos-cement plates, is explained by the formation of the close porous structure as well as the change of the tension relaxation mechanism.

Introduction

At present replacement of asbestos widely used at production of asbestos-cement materials is the essential requirement from the environmental point of view. Plant materials, especially different types of cellulose and cellulose-containing fiber wastes are the main substitute of asbestos.

In literature the dominant attention concentrates on the sulphate cellulose, although recycling paper is mentioned too. High pressures and temperatures are characteristic features of the most of proposed methods. In some processing the modification of cellulosic fibers is the separate stage including consequent drying and grinding of modified fiber.

The aim of the present work was to develop:

- methods of regulation of fiber-cement materials structure and properties depending on the amount of cellulose introduced, its characteristics and presence of non-cellulosic admixtures;
- techniques allowing to use sulphite pulp and waste paper at production of fiber-cement materials without complication of the existing technology and equipment for asbestos-cement plates manufacture.

Experimental

Spruce sulphite cellulose was the main object of our investigation. Kraft packing paper (76 gm^{-2}) and two kinds of print paper (59 gm^{-2} and 55 gm^{-2}), differed by the level of gluing, were used as recycling paper (RP) specimens.

Sodium silicate with Si/Na ratio equal to 3.2, pH about 12 (further named as water glass) was employed as Si-containing modifier.

The composition of reference specimen of asbestos-cement sheet was following: 14% asbestos and 86% portland cement.

Cellulose-cement and reference sheets were obtained in laboratory and industrial scale.

Isotherms of water adsorption were measured at 20°C.

SEM was used to characterize the swelling of cellulose fibers.

The presence of water-soluble admixtures in cellulosic materials was registered by UV-spectroscopy of water extracts at 240 nm (gluing substances) and 280 nm (lignin-like substances) using Specord UV-VIS.

Mechanical characteristics as well as water sorption, density and foam-forming ability were determined accordingly standards of the former USSR.

Results and discussion

Cellulose fibers are widely used as armature of different composite materials. However, to provide a high performance of materials obtained it is necessary to enhance a compatibility of composite components. For this purpose sodium water glass with high affinity to cement was applied in the present work for modification of cellulose fibers. A modification of the cellulose with silica containing compounds is recommended as the method for hydrophobization of fibers, for enhancing of their thermostability as well as for improving of cellulose compatibility with other ingredients of different composites.

It is experimentally shown, that the retention of water glass depends on the treatment time and, for example, for 10% dosages, in terms of cellulose, is changed from 2.3% to 2.5% and 3.9% for 15, 30 and 60 min., respectively. The same correlation has been established for the retention of water glass against its dosage (Fig.1).

It is known that both silica and alkali are sorbed by cellulose from water glass, but they interact with pulp separately. Alkali is sorbed faster: after 1 hour its amount adsorbed changes insignificantly.

The retention of alkali increases with the growth of water glass dosages. However, the amount of the alkali adsorbed irreversibly is only 25 ... 35% of the whole content of alkali determined in the cellulose sample before washing (Fig.2).

It may be noted that a part of the silica component of water glass is also washed off, but unlike alkali, 60 - 70% of its amount adsorb irreversibly (Fig. 1, curve 3).

It has been shown that the influence of water glass on properties of cellulose fibers depends on the duration of its action. The long action (12 h) causes weakening of inter-fibrillar bonds and promotes the fibrillation of fibers as well as their swelling. A short treatment (till 1 h) can inhibits the swelling. This effect depends on the water glass dosages. For example, 1 hour treatment of cellulose with 5% dosage of water glass (in terms of cellulose) manifests itself especially clear in smaller swelling of the fiber damaged by fungi as well as places of bending and mechanical damages of the fibers. The swelling is significantly inhibited under the action of a 10% dosage of water glass during 1 hour.

According to the tensile strength at the zero length - the strength of individual fibers enhances by 25% at 5% dosage (in terms of cellulose) of water glass .

Strengthening of cellulose fibers and inhibition of their swelling observed under the action of water glass probably due to silica net formation on the surface of fibers. However this net is of low density owing to a

competitive sorption of sodium component of water glass. If a silicon-containing modifier contains smaller amount of alkali (for example, silica sol), the net formed is more dense. The latest manifest itself in a decrease in ability to adsorb water vapour and in narrowing of histeresis loop on the water sorption isotherm (Fig. 3).

Owing to the steric structure of water glass it is possible to propose that only a part of silanol groups can form links with cellulose while another one is able to interact with cement components. It manifests itself at the comparison of mechanical properties of fiber-cement plates containing modified and unmodified cellulose fibers (Table 1). Really at the substitution of 25 and 100% of asbestos on cellulose the strength decrease by 17 and 34%, correspondingly. At the same time if the modified cellulose is used, this characteristic decreases by 3-5% only.

Table 1.

Influence of Sulphite Cellulose Modification on Fiber-Cement Material Quality

Cellulose	Degree of asbestos substitution, %	Properties after 7 days of storage			
		Density gcm^{-3}	Water absorbtion, %	Bending strength MPa	Compres. strength MPa
	0	1.56	27.6	5.5	14.0
Unmod.	25	1.46	28.5	4.9	n.d.
Unmod.	50	1.38	35.3	3.9	11.15
Modif.	50	1.38	27.7	n.d	n.d.
Unmod.	100	1.31	40.6	3.9	10.8
Modif.	100	1.30	27.8	5.3	13.3

Varying of modification conditions (duration and temperature of the process, hydromodulus and content of fibers in the cement composition) allows, to some extent, to regulate the quality of sulphite cellulose fiber-cement plates. From the data shown in the Table 1 it could be seen that one of the main characteristics of the roof materials - water absorption value - could be controlled by usage of modified cellulose.

An application of recycling paper in manufacture of fiber-cement plates has additional difficulties, comparing with sulphite cellulose. It is connected with the presence of glues and other auxiliary substances and non-cellulosic lignin-like compounds in paper, that has been shown by UV spectroscopy. These admixtures transferring in water phase can enhance foam-forming and reduce the rate of the processes of cement hardening. Besides of type of recycling paper (Table 2), foam-forming of technological solutions depends on conditions of fiber-cement production (temperature, media pH, etc).

Table 2.

Characteristic of Filtrates of Modified Cellulose Fiber Suspension (pH range 10.3-10.6).

Type of cellulose/ recycling paper	Fiber conc. %	UV absorbance at maximum:		High of foam pillar mm
		240nm	280nm	
Kraft RP	3	*)	0.36	30
Print RP(58 gm^{-2})	3.8	*)	0.74	40
Print RP(55 gm^{-2})	4.1	0.94	*)	45
Sulphite cellulose	4.0	*)	0.53	35

*) - corresponding maximum is absent

An application of proposed method of modification with water glass provides a possibility to use different kinds of recycling paper at the production of fiber-cement plates (Table 3), however foam-forming remains rather intensive.

To control foam-forming a method of precipitation of water-soluble admixtures on fiber or cement particles has been applied, taking into account that lignin-like compounds and the main part of auxiliary substances form undissolved complexes with multivalent cations.

Table 3.

Properties of Cellulose-Cement Materials on the Basis of Different Kinds of Cellulose Fiber

Type of Cellulose/ Recycling Paper	Properties after 7 days storage	
	Density, gcm^{-3}	Sorption, %
Kraft RP	1.38	27.0
Print RP (58 gm^{-2})	1.37	30.6
Print RP (55 gm^{-2})	1.44	28.5
Sulphite cellulose	1.40	27.1

Experiments have shown that $FeSO_4$ is the most effective in our case among other tested salts ($CaCl_2$, $AlCl_3$, $FeNH_4(SO_4)_2$, $Al_2(SO_4)_3$, $KAl(SO_4)_2$). Application of ferrous sulphate allows to decrease foam-forming five-fold and to diminish drastically a foam stability. The amount of $FeSO_4$ required for foam suppressing depends on type of used recycling paper and varies around 10% in terms of fiber.

On the basis of results obtained an experimental batch of cellulose-cement sheets has been produced on the industrial technological line for asbestos-cement sheets

production by a wet method without additional pressing at the end of the process (Riga, Cement Building Plate Enterprise). Modification of cellulose has not been separated as a new independent stage but has been included in the existing continuous process. The sheets obtained are taken off from a drum without difficulties and easily profiled. Delamination of sheets obtained never observed. Cellulose-containing sheets display close to asbestos-containing ones values of impact strength and water absorption at lower density (Table 4).

Table 4.

Properties of Cellulose-Cement Sheets Obtained under Industrial Conditions (30 days of hardening)

Characteristics	Composition on the basis of:	
	Cellulose	Asbestos
Bending strength ⊥, MPa	10.3 - 13.5	14.9 - 16.0
Bending strength //, MPa	8.5 - 10.5	13.2 - 14.3
Impact strength $kgcmcm^{-2}$	1.53 - 2.00	1.50 - 1.80
Density gcm^{-3}	1.30 - 1.60	1.65 - 1.76
Water absorption, %	20.7 - 27.6	20.8 - 27.8

The distinguish feature of sheets obtained by proposed technique is higher freezing stability in comparison with asbestos-cement sheets. It has been established that the mechanical strength of such sheets increase after 25 freeze-thaw cycles up to 106.5% in terms of initial value. Under the same conditions the mechanical strength of asbestos-cement sheets decrease on 25%. The observed phenomenon could be connected with hydrofility of cellulose components, which keeps water and step-by-step supply cement with it at the development of hardening process. This mechanism of hardening may lead to the formation of a porous structure containing conditionally closed pores. Besides that cellulose is able to absorb water located in micropores, partly dewatering it, that decrease destructive tensions arising at freeze-thaw cycles. The high elasticity of cellulose fibers in comparison of asbestos ones provides relaxation of the tensions which take place during the freezing of the material without residual deformations.

Summary

Techniques allowing to use sulphite pulp and recycling paper at production of fiber-cement materials without complication of the existing technology and equipment for asbestos-cement plates manufacture has been developed. It has been shown a possibility to control a quality of

cellulose-cement materials depending on a type of cellulose-containing sources and the presence of water-soluble admixtures in them .

To provide a high performance of materials obtained a compatibility of components of the composite has been enhanced by application of sodium water glass. It has been shown that the action of water glass is owing to silica net formation on the surface of fibers and interaction of a part of silanol groups with cement components.

The distinguish feature of sheets obtained by proposed technique is higher freezing stability. The possible mechanism of this phenomenon is discussed.

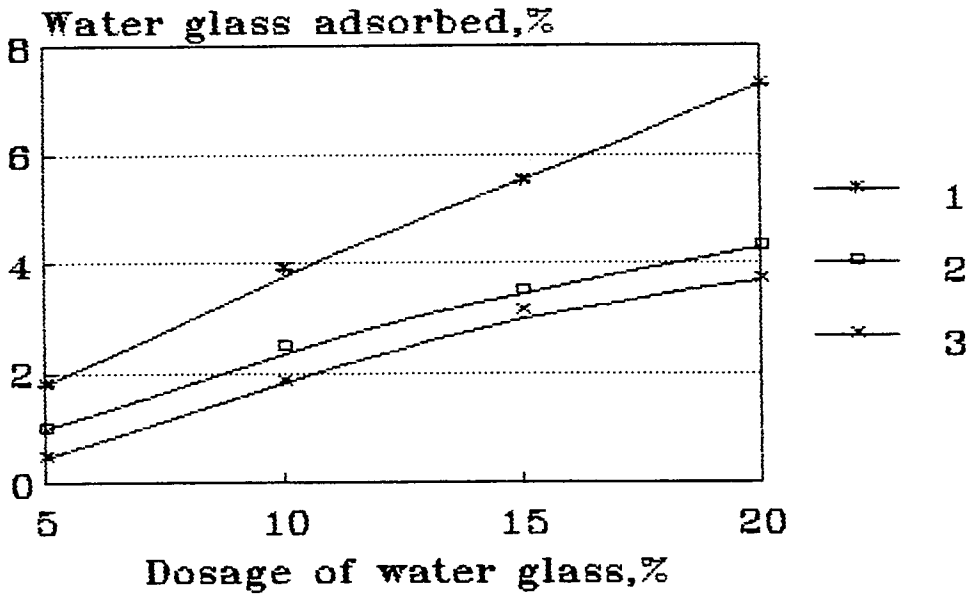


Fig.1. The influence of dosage of sodium water glass dosage (in terms of cellulose) on its adsorption on fiber. (1) the sample of cellulose after adsorption of water glass; (2) the same sample washed with water; (3) a calculated curve of adsorption of silica.

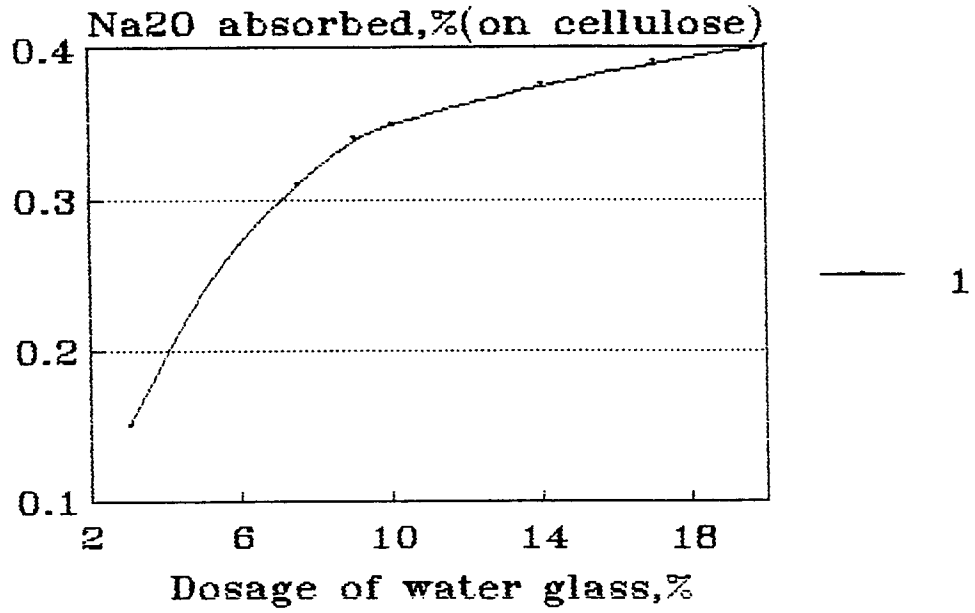


Fig.2. The influence of sodium water glass dosage on Na_2O adsorption.

Fig. 3

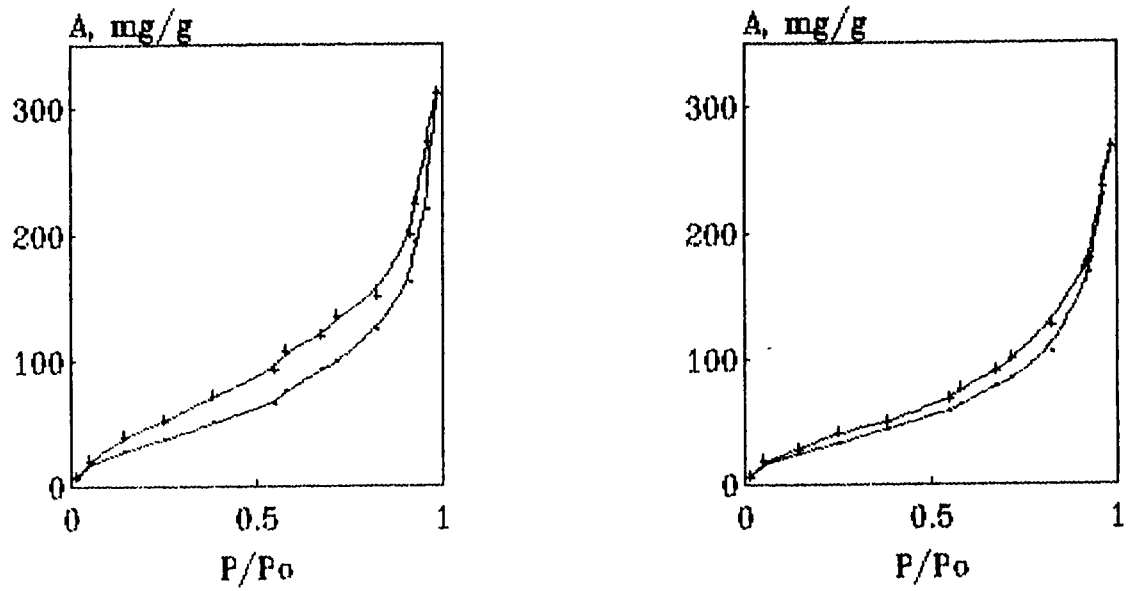


Fig.3. Water sorption isotherms of cellulose. (left) unmodified cellulose; (right) modified with silica sol (dosage of 5% on terms of cellulose).

MECHANICAL PROPERTIES AND POTENTIAL COMMERCIAL APPLICATIONS OF AGRICULTURAL COMPOSITES

Mahmoud Asadi, Ph.D., Sr. Research Scientist, Meetech Corp.
Lawrence, KS 66049 U.S.A.
Steven L. McCabe, Ph.D., P. E., Associate Professor of Civil Engineering, University of Kansas Lawrence, KS 66045 U.S.A.
Saeed Farokhi, Ph.D., President & Director of Research, Aerotech Engineering & Research/Meetech Corp., Lawrence, KS 66049 U.S.A.
Suman K. Saripalli, B.S., Research Engineer and Jim E. Stilwell, B.S., Research Engineer, Aerotech Engineering & Research, Lawrence, KS 66049 U.S.A.

ABSTRACT

This paper reveals information on the mechanical properties of the agricultural composites and their commercial potential as a substitute for plastics and woods leading to a lower cost for these products. Chopped and particulate agricultural co-products (hereafter referred to agro-fibers) such as wheat, brome hay, switchgrass, and corn were mixed at a ratio of 66:34 fiber/epoxy by volume to manufacture agricultural composites (hereafter referred to agro-composites) using the hand lay-up molding technique. The manufactured composite samples were tested for their mechanical properties such as tensile stress, compressive stress, moisture absorption, and thermal expansion. According to results, chopped switchgrass agro-composite samples showed the highest tensile strength, yet less than that of soft woods and slightly higher than that of plastics (high density polyethylene known as HDPE). As a result, a second set of agro-composite samples using only chopped switchgrass was manufactured at 10%, 20%, 30%, 40%, and 50% agro-fiber content to obtain the optimal fiber/epoxy ratio for which agro-composite samples show the maximum tensile stress. The same procedure was followed for compressive strength, thermal expansion, and moisture absorption measurements. According to the obtained results, at 50:50, agro-composite samples showed the highest tensile stress at 2,925 psi compared to that of plastic at 2,000 psi and of soft wood at 6,600 psi. At 10:90 agro-fiber/epoxy, compressive strength of the agro-composite samples were 60% higher than that of plastic and 80% higher than that of soft woods. Thermal expansion and moisture absorption of the manufactured agro-composite samples showed better performances than both woods and plastics. Optimized agro-composite samples, due to their cost competitiveness and low weight, could replace woods and plastics in some applications. A small fraction of plastic and wood market would lead to new sources of revenues for farmers, economic development to rural communities from manufacturing jobs, and a reduction in U.S. oil demands as an oil based product is partially replaced with a haydrocarbate based product.

Introduction

Advanced composite materials have gained increased usage and acceptance by the engineering community over the past two decades. Composites offer the engineers several desirable characteristics such as strength, light weight, reduced life cycle cost (development, production, maintenance, and replacement), and improved corrosion resistance. In addition, composites can be tailored to meet the specific requirements of the application.

Composite materials have two main constituents 1) the resin matrix and 2) the reinforcing fibers. The most commonly used resins are epoxy, polyester, vinylester, and polyurethane. Composites that have been designed for structural applications have used a variety of fibers including glass, carbon, aramid (Kevlar), and ultra high molecular weight polyethylene (Spectra).

The primary objective of this research was to manufacture agro-composites from readily available agricultural materials (agro-fibers) and to develop a preliminary market analysis and business plan, based on the manufactured agro-composite's mechanical properties such as tensile strength, compression strength, thermal expansion, and moisture absorption, for the agro-composites[1].

Experimental Procedure

The selected agro-fibers (wheat, brome hay, switchgrass, and corn) were washed with water. Dilute muriatic acid was then used to remove agro-fiber's natural waxy coating. The agro-fibers were soaked in the acid for 10 minutes and rinsed with water. The agro-fibers were then oven dried and cut to chopped (1/4 in. to 1/2 in. long agro-fibers) and particulate (1/8 in. to 1/4 in. short agro-fibers) sizes. The chopped and particulate fibers were mixed with the epoxy resin at at various ratios of agro-fiber/epoxy by volume. The mixture was purred into the pre-deigned and fabricated plastic molds of various geometries to manufacture test coupons. Hand lay-up molding technique was used to manufacture coupons samples of agro-based composite for tensile stress, compressive stress, thermal expansion, and moisture absorption measurements.

Tensile Stress

Plastic molds of 1.0 in. by 7.0 in. by 0.08 in. (Some of the test samples, due to the amount of fibers used, had a thickness of 0.118 in. Appropriate corrections were made for this in the calculations.) were designed and fabricated. Agro-based composite coupons of wheat, corn, brome hay, and switchgrass using both particulate and chopped, at 66% agro-fiber, were used for tensile stress measurements (3 samples per agro-fiber using particulate orientation and 3 samples per agro-fiber using chopped orientation for a total of 24 agro-

composite samples). To compare the agro-based composite samples mechanical properties with that of epoxy's, 3 samples were made of only epoxy. Each sample was placed in the Universal Testing Machine (UTM) where tensile load was applied to the sample (parallel to the sample's length and to the orientation of fibers) at an increment of 20 lbs. until the sample failed. Longitudinal elongation of the samples, while under tensile load, was measured at 20 lbs increment. Tensile stress and strain of each sample were calculated.

In a second test, a series of samples at 10%, 20%, 30%, 40%, and 50% chopped switchgrass content were manufactured and tested for tensile stress measurements. Also, to obtain the effect of fiber orientation on tensile stress, acid washed corn husk was used to make a set of samples using uni-directional orientation.

Compressive Stress

Cylindrical polyvinyl chloride (PVC) molds of 1.00 in. diameter and 3.00 in. length was used to fabricate compressional coupon samples. Agro-based composite samples were made at 0%, 10%, 20%, 30%, 40%, and 50% agro-fiber content using only switchgrass (switchgrass was selected based on it's high tensile stress value). Samples were tested for compressive stress using UTM. Each sample (2 per ratio) was placed under a gradually increasing compression load. The maximum compressive stress at which the sample failed was recorded.

Thermal Expansion

Agro-composite samples were made at 0%, 10%, 20%, 30%, 40%, 50%, and 66% agro-fiber/epoxy using chopped switchgrass. Sample's longitudinal dimensions were measured at room temperature (70 °F). Samples were placed in a kiln at 100°F for one hour. Sample's lengths were measured and compared to that at room temperature's. In a second test, samples were paced in the kiln at 150°F for one hour, and temperature effect on dimensions were measured.

Moisture Absorption

Chopped agro-based composite samples were made of switchgrass at 0%, 10%, 20%, 30%, 40%, and 50% agro-fiber content. The samples were oven-dried for one hour at 100 °F. Dry weight of each sample was measured. Samples were immersed in water at 70° F for 24 hours. Wet weight of each sample was then determined. Percent moisture content, PMC, of each sample was calculated using the following equation[2].

$$PMC = \frac{Moisture\ Content}{Dry\ Weight} x100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

PMC	percent moisture content, %
Moisture Content	is the difference between dry weight and weight after sample has been immersed in water, (in grams)
Dry Weight	is the weight after sample has been in oven or kiln, (in grams)

Discussion

Tensile Stress

The pure epoxy sample showed the highest tensile stress and strain at 3305 psi and 3.56% respectively. Chopped switchgrass exhibited the most tensile stress at 2458 psi among the agro-composites. Chopped orientated wheat showed the best strain at 1.02%. At 66% agro-fiber, chopped corn showed the least tensile stress and strain at 55 psi and 0.36% respectively.

Results indicated that the optimal agro-fiber/epoxy ratio for which composite samples showed the maximum tensile stress, 2,925 psi, was at a 50-50 ratio. At this ratio, switchgrass composite showed a tensile stress of only 12% less than that of pure epoxy, 3,300 psi, yet it costs 40% less (Polypropylene is at $0.39/lb while agro-based composite is at $0.24/lb) and weighs 22% lighter (Polypropylene's density is 60 lb/ft^3 while agro-based composites's is 47 lb/ft^3, also, the cost and weight comparisons of the agro-based composites depends on the amount of the agro-fiber/epoxy ratio[2]). Therefore, depending on the applications, one could substitute agro-composites for woods or plastics at a lower cost and less weight. The amount of agro-fibers could be increased if one uses resin transfer molding (RTM) instead of the hand lay-up technique. This will further reduce the cost and weight of the agro-composite samples.

The manufactured agro-composite samples using uni-directional corn husk at 66% agro-fibers showed a tensile stress of 5,426 psi, 40% more than that of pure epoxy. Noticing that chopped and particulate orientations corn composite samples showed the least tensile stresses, one could expect that other agro-composites have a much higher tensile stress if uni-directional, bi-directional, or angular orientations are used rather than random orientation. At this point, however, it is believed that the bonding between the agro-fibers and epoxy is not completely satisfactory. Further research to identify a chemical compatiblizer needs to be performed if the end-use demands structural strength. Table 1 shows the tensile stress for switchgrass at 50%, plastic, soft and hard woods, and uni-directional corn orientation. Figure 1 shows stress/strain relations for the optimal agro-fiber/epoxy ratio, unidirectional corn, and pure epoxy.

Table 1. Comparative Tensile Stress for Various Materials

Material	Tensile Stress, psi
Hard Wood[3]	15,600.00
Soft wood[3]	6,600.00
Uni-Directional Corn-Composite, at 66%	5,426.00
Chopped Switchgrass Composite, at 50%	2,925.00
Plastic, HDPE[4]	2,000.00

Compressive Stress

Based on the obtained results, agro-composites, at every ratio (10% to 50%), showed a higher compressive strength than that of plastic (HDPE), and in most cases higher than that of soft woods (1,690 psi). Agro-based composite samples at 10% agro-fiber content showed the highest compressive stress at 9,220 psi. while agro-composite samples at 50% agro-fiber showed the least compressive stress at 5,860 psi. Since the practical usage of woods are mostly in compressional situations rather than tensional, agro-composites may well substitute woods for most applications. Table 2 shows the compressive stress for switchgrass at 10%, plastic, soft wood, and hard wood. Figure 2 presents a bar graph of the compressive stress for agro-composites, woods, plastic (HDPE), and epoxy.

Table 2. Maximum Compressive Stress for Various Materials

Material	Compressive Stress, psi
Hard Wood[3]	10,180.00
Switchgrass composite, at 10%	9,165.00
Plastic, HDPE[4]	3,450.00
Soft Wood[3]	1,690.00

Thermal Expansion

The thermal expansion of completely dry wood is known to be positive along all axes. That is, wood expands on heating and contracts on cooling. Woods with high moisture react differently to temperature change. Temperature effects are more pronounced in wet woods. Woods at intermediate moisture level, 8 to 20%, tend to expand when first heated, then gradually shrink to a volume smaller than the initial volume. Unless wood is initially dry (with < 3% moisture), the temperature effect is negative, that is wood will expand at first and then start to contract. Therefore contraction for a moist wood is more than expansion[3]. A bar graph presentation of the effect of elevated temperature on agro-composite samples, wood, and epoxy at 100 °F is shown in Figure 3. With different wood types, the expansion and contraction of woods varies, consequently Figure 3 does not show a numerical value of this contraction.

Agro-composite samples are temperature resistance at 100 °F. These samples, however, with less than 40% agro-fiber content, were either bent or deformed at 150 °F. Agro-composites, at high agro-fiber content (more than 40%), were more resistant to elevated temperature than plastics. This advantage, opens a new market for the agro-based composites where ambient temperature is high. In addition, the lower cost and density of agro-composites is an advantage in these applications.

Moisture Absorption

Agro-composite samples showed to be moisture resistance at any agro-fiber/epoxy ratio. In general, plastics are moisture resistance, woods however, tend to absorb moisture from 6 to 14%. Figure 4 is a bar graph comparative change in weight due to moisture for various materials.

Markets for Agro-Composites

Plastic Market

General purpose (commodity) thermoplastics are usually manufactured in large quantities using well established technology. The bulk of general purpose plastic goes to a relatively small number of large volume users. Among the general purpose materials are the simpler monomers such as the polyethylene, polystyrene and polyvinyl. Typical specialty resins are the cellulosic, the polycarbonates and the polyetheretherketones. Thermoplastics differ from thermoset in that thermoplastics can be reheated and remolded repeatedly, while thermoset can be heated and molded to a final shape only one time. About 75% of the total U.S. production of plastic materials covered is thermoplastics. Total output of U.S. plastic materials in 1992 reached an estimated 66.6 billion pounds. Output of thermoset plastic materials was thus approximately at 16.65 billion pounds. The fastest growing segments of the plastic materials industry in 1992 were engineering resins, high-density polyethelenes, polyvinyl chlorides, and the polyolefins segment.

Consumption of plastic products is highest in the electronics, health care, construction, transportation, automotive and food packaging industries. This market in the U.S. was valued at $73 billion in 1992, of which $4.5 billion worth of product was exported (primarily to Canada and Mexico) and $4.3 billion was imported into the U.S. (primarily from Canada, Taiwan, China and Japan). These figures excludes bottles and plumbing. The plastic products industry is approximately a $73 billion dollar industry, with the materials and resins industry approaching $36 billion. The plastics industry has had rather flat growth over at least the last eight years[5]. While the demand for materials and products is not expected to decrease in the years ahead, it is becoming increasingly necessary to compete for a market size that is fixed.

The plastics markets that can be focused on are those which involve the dimensional stability and low-cost properties of plastics. The markets where the high-strength of plastics is crucial can be avoided at this point in the development of agro-composites. Based on this discussion, two distinct commercialization potentials have emerged as 1) the development of agro-composite plastic finished goods and 2) the development of agro-composite pellets for supply to plastics manufacturers.

Development of Agro-Composite Plastic Finished Goods

Agro-composites can be brought to the market in a rapid fashion by forming finished parts by injection molding. Injection molding is a mature technology and can be adapted easily to incorporate agro-fibers in the plastic matrix. It is not expected that major changes will need to be made to existing injection molding equipment such as twin screw extruders. Using commercially available equipment, agro-composites can be formed into continuous shapes or individual parts. One of the very attractive markets that can be exploited almost immediately is the plastics toy market. The application does not require very high strength. The agro-composites possess superior environmental exposure qualities they do not degrade as easily as regular plastics when exposed to heat or moisture.

Agro-Fibers as Fillers for Plastics

Agro-fibers can be also used to add volume and bulk to plastic products in lieu of the wood flour, talc or glass spheres presently used by the industry. For example, plastic pellets are the source materials for plastic milk containers. Presently, man-made reinforced pellets (containing ground glass) are the source used in manufacturing plastic containers. The man-made reinforced pellets cost approximately 39 cents per pound. Our investigations show that agricultural fiber-reinforced pellets can be produced and sold for approximately 25 cents per pound. While these pellets don't produce the rigidity of plastic that a man-made reinforced pellet does, it has been determined that 60% of the material used in manufacturing a plastic milk container can be replaced with fiber-reinforced pellets with no obvious or noticeable effects, and obvious cost savings.

Agro-Composites for Wood Markets

The wood markets that can be focussed on at this point are where the end-product does not have to meet high-strength requirements. It is evident that the market for agro-composites is so vast and diversified that it cannot be estimated with accuracy. Agro-composites will be inserted into the market as a wood-substitute and can be expected (at a conservative estimate) to capture about 0.005% of the wood products market within the first year of introduction. This could be driven by the fact that in preliminary testing, agro-composites have performed better than wood in tensile (in most cases), compression, thermal deflection and moisture absorption tests. Another advantage of agro-composites over wood is that they can be molded into any form unlike wood that needs to be cut and sanded to shape. In effect, the product can be cast in near-net shape using agro-composites via a single step (such as panelling, doors, door frames, window frames, shelving and siding for houses, telegraph and electricity posts, guard rail and sign posts along highways sound barriers along highways fences, livestock sheds and other agricultural facilities, decorative panelling, molded furniture, decorative objects d'art, shelving, outdoor decks, patios, etc...), while wood needs several processing steps to achieve the final geometry. This reduces the processing costs considerably in terms of processing time and labor costs. The material costs are also reduced since the wastage of agro-composites is much lower than that of wood. Also, the waste material can be recycled and used again.

The value of the agro-based composites that would result from these efforts would greatly enhance the overall value of the crops. The business of agro-based composites could be therefore considered as a source of increased income for the farmer. This would also provide an additional market for the crops. It is also estimated by the USDA's Alternative Agricultural Research and Commercialization Center that a typical facility that manufactures agro-composites and plastics will generate 75- 100 jobs over the first 4 years with of 5-25 initial job creation potential[6].

Manufacturing agro-composites will increase the revenue by using agricultural co-products as an agro-composite feedstock. In addition, due to more demands for these fibers, more lands need to be farmed, enhancing the farmer's income. An important spinoff of this technology is deceleration of depletion of valuable forests.

Conclusions

The concept of using agro-fibers to manufacture agro-composites is proven feasible. These agro-composites can be used as a substitute for plastics due to their superior mechanical properties such as tensile stress, compressive stress, thermal expansion, and moisture absorption, and can compete with most woods in the areas of compressive stress, thermal expansion, and moisture absorption. The feasibility may be further enhanced by using a chemical for pre-processing of the agro-fibers to remove fiber's natural coating. In addition, an automatic mechanical system could facilitate the process of agro-fiber aligning for manufacturing composites using uni-directional, bi-directional, and angular orientation configurations.

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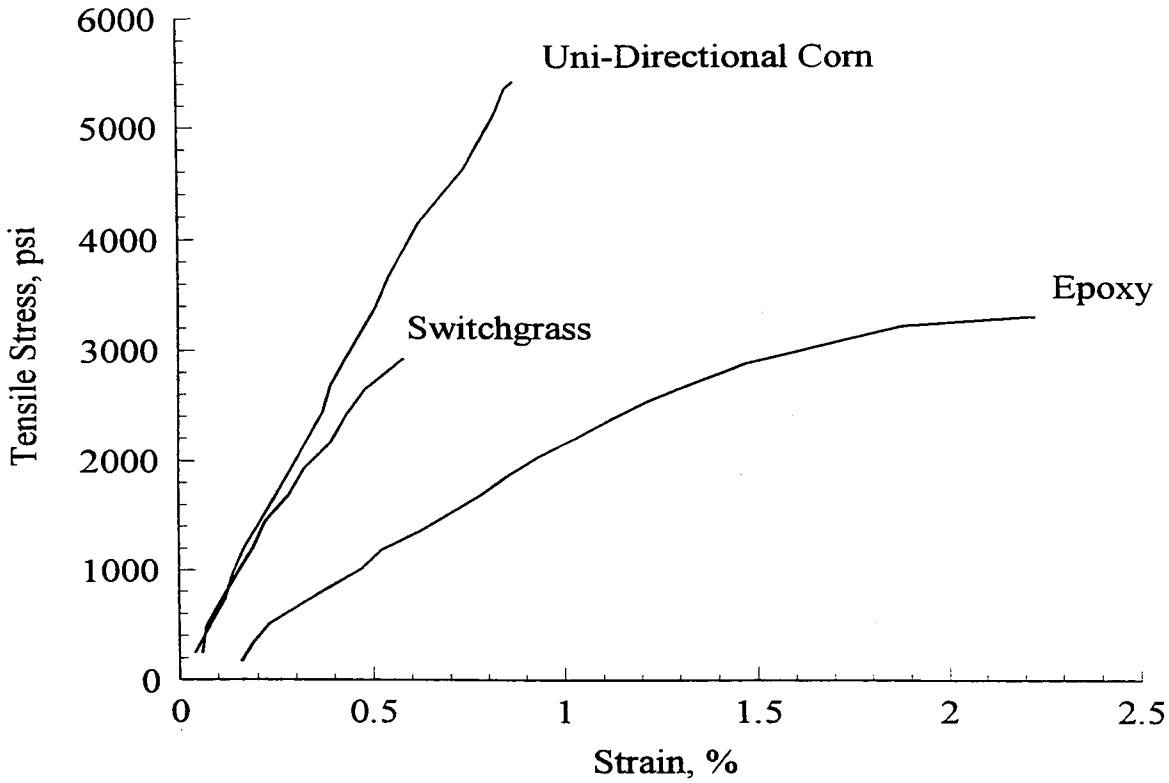

Fig. 1-Comparative Stress/Strain Relation for Various Materials

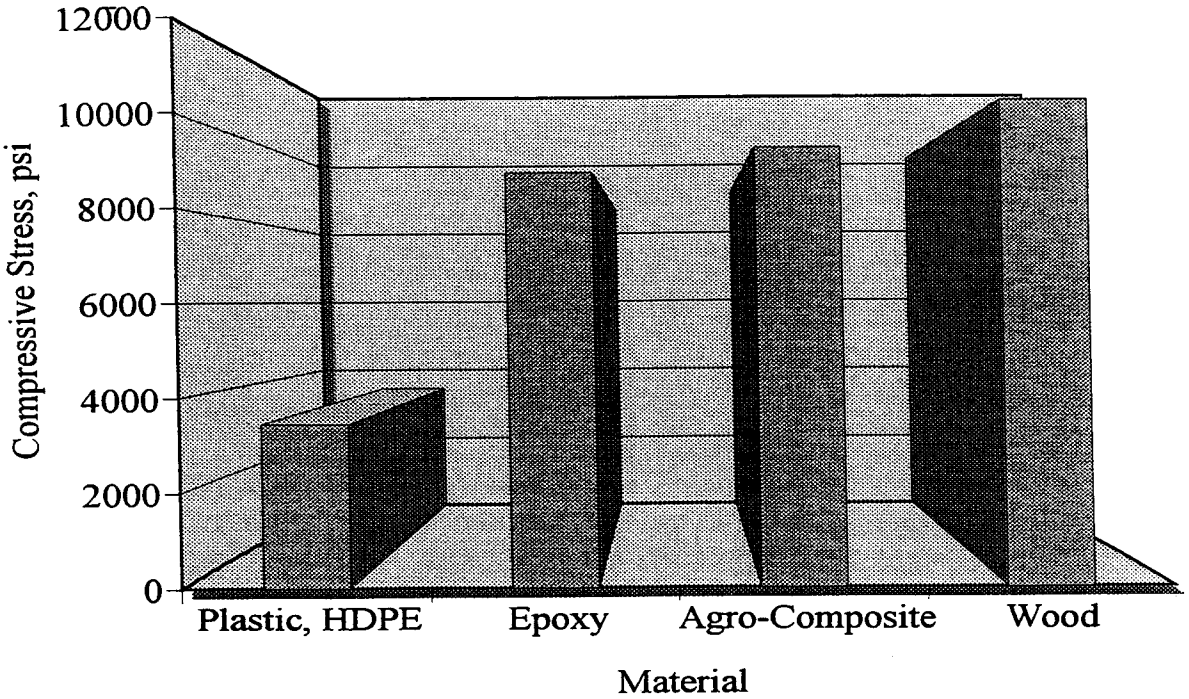

Fig. 2-Comparative Compressive Stress of Various Materials

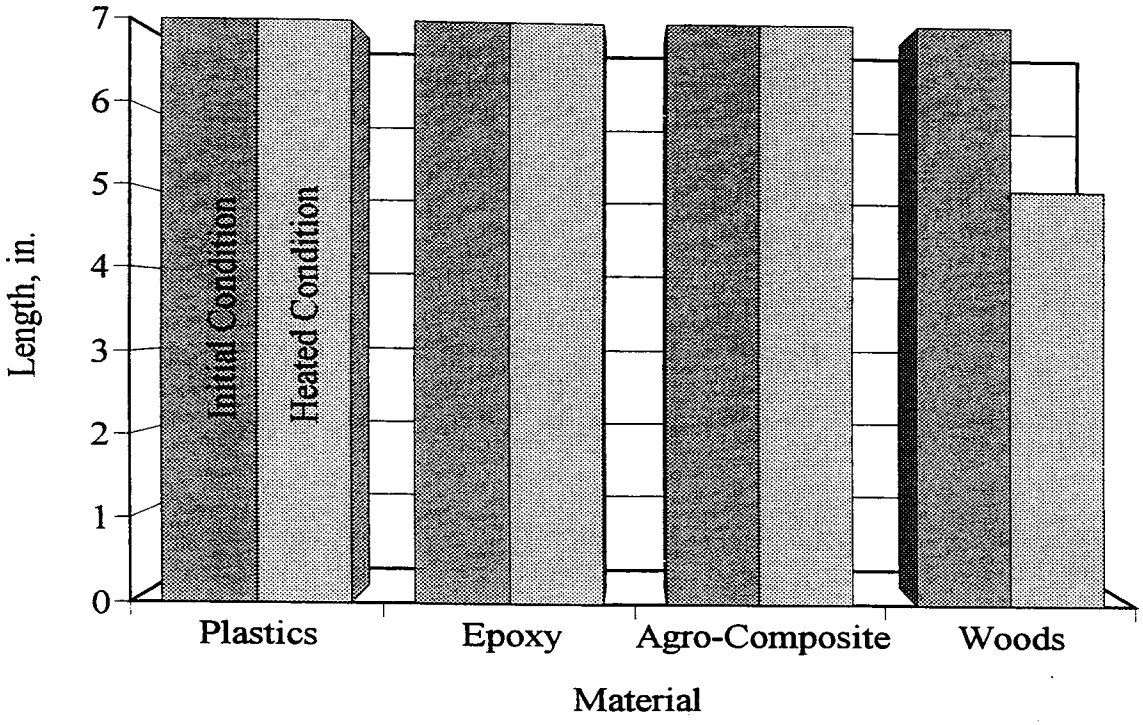

Fig. 3-Comparative Change in Length Due to Temperature for Various Materials

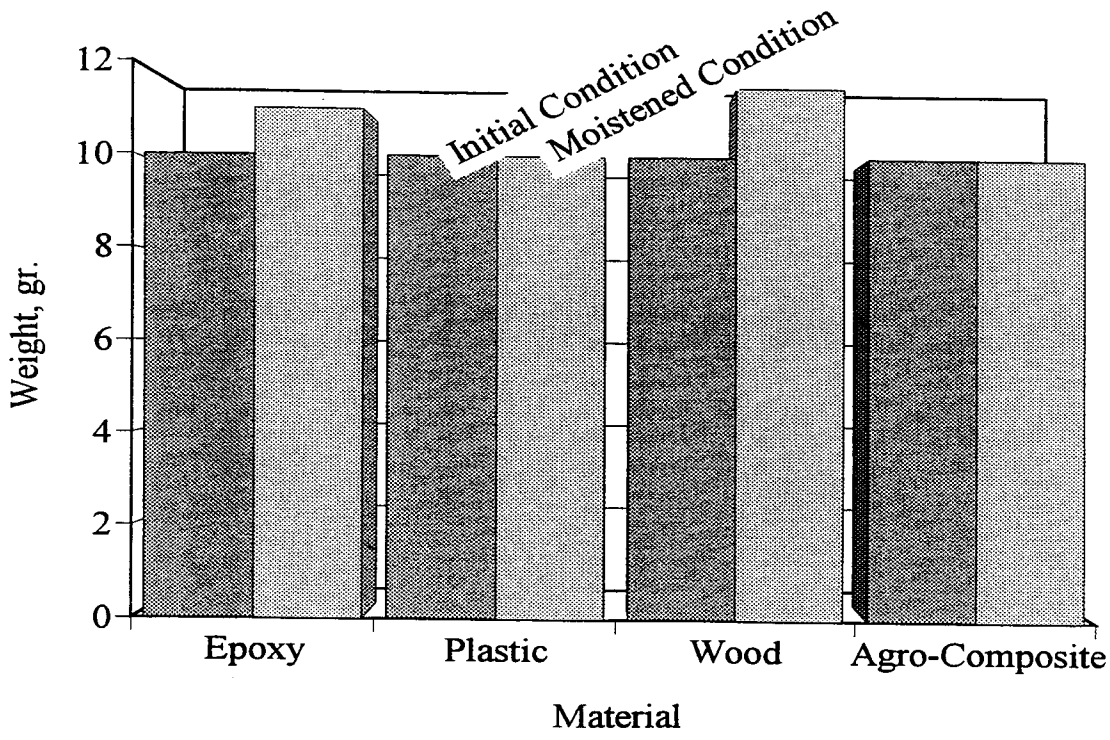

Fig. 4-Comparative Change in Weight Due to Moisture for Various Materials

BIOMASS IN CLEAN COAL PRODUCTION

Curtis L. Knudson, Ph.D., Principal Scientist;
and Mel P. Pedersen, B.S.E.P., Process Dev. Engineer,
Grand Forks Activation Technologies
Grand Forks, ND 58203 U.S.A.

Abstract

In physical cleaning processes for coal, the coal is initially crushed and then cleaned, resulting in a fine clean coal product. The fine nature of this clean coal makes it more difficult to ship and handle. Combining biomass with cleaned coal is one method to produce a dust-free, lump, biomass-coal product that is readily shippable.

The University of North Dakota Energy and Environmental Research Center (UND-EERC) in Grand Forks North Dakota has recently completed work funded by the North Dakota Industrial Commission and Knife River Coal Mining Company demonstrating that cleaned coal could be successfully briquetted using biomass (a waste paper filler and a pulverized wheat binder). Grand Forks Activation Technologies (GFAT) is working with Knife River Coal Mining Company in the further development and commercialization of the coal cleaning process. GFAT is also working with Producers Renewable Products, LLC to further develop and commercialize the use of other agricultural waste products, such as stillage concentrate, in the production of biomass-coal fuel products.

This process addresses two problems: 1) how to inexpensively clean centrate water for recycle in an ethanol plant and 2) how to get an inexpensive binder for reconstitution of coal by pelletization.

In the Phase I work, the feasibility of each processing step and end product would be evaluated as well as the overall economic benefits of the process. If successful, it will improve the reconstitution, dewatering, and handling of coal making it a more marketable product.

Demonstration of this process would have a number of economic and environmental benefits. The use of cleaned coal as a plant fuel would 1) free up valuable propane or natural gas for use in homes, 2) prevent plant interruptions due to winter demand shut-downs, 3) decrease plant fuel costs, and 4) increase the number of jobs in the local community since coal is a more labor-intensive fuel than natural gas, propane, or oil. The integration of coal into water treatment in an ethanol plant could increase ethanol yields by 9% while providing a byproduct of clean, pelletized fuel. Using city water treatment sludge in the process would enable a second use and possibly a third since the calcium-enhanced ash could be a better soil stabilizer or could be used to treat alkali farm land.

Introduction

The processing of agricultural materials into upgraded products results in the production of lower value byproducts or waste if markets can not be found for them. For instance, in the production of sugar there may be excess molasses and there is usually waste calcium sludge. A malting plant can have excess barley screenings, a "D" grade barley, and waste sprouts, while local grain elevators have screenings from grain cleaning. Potato processing plants have excess starchy material and waste water to process as do ethanol production plants which can produce excess stillage. Byproducts can have a use as animal feed, although this market can be saturated resulting in the byproducts being waste.

All of the processing plants have a need for steam for use in processing and making electricity or purchase electricity produced from steam. Steam can readily be produced using oil, gas, coal, and biomass. Biomass would be environmentally preferred but is not always available and has a lower heating value than oil, gas or coal. If a natural gas pipeline is available, it is a quick way to obtain fuel for generating processing steam. Both low-sulfur oil, natural gas, propane, and butane have relatively low capital costs for installation and operating costs when producing steam. However, they have higher fuel costs and are subject to market fluctuations. Market fluctuations are determined by both supply and demand. At present, natural gas is in high supply but is very subject to demand increasing to exceed the supply. Natural gas or propane are often used in home heating since it is clean and efficiently burned in small furnaces. However, it is also increasingly being used as a feedstock to produce methanol which can be used to produce MTBE for use as a liquid fuel in automobiles. While ethanol and ETBE will also be important automotive fuels, the market is very large. With a continued increase in the use of "high quality" liquid and gaseous fuels by individuals, their price can only increase in the future.

In the long run, coal remains as the most inexpensive fuel for producing steam. However, the initial capital investment required is greater, and coal fired boilers and handling systems are more labor intensive to operate than boilers fired by more expensive fuels. But in time the cheaper cost of coal offsets the capital and labor costs. Both the local community and plant will realize greater benefits in that the more labor intensive coal boilers will create more local jobs, and the price of the coal will likely be very stable compared to natural gas or oil.

Besides coal being used to provide steam to an agri-process, the agri-process can provide byproducts to the production of clean burning upgraded coal fuels. It may also be possible to use certain coals (lignites) to aid in processing wastewater. These are the topics of this paper.

Biomass in Clean Coal Production

North Dakota lignites, on an as-mined basis, contain nominally 40 wt% moisture and have a higher moisture-free oxygen content of 20 wt%. As-mined, therefore, they have a low heating value and are generally being used in mine-mouth electricity generation or in the production of synthetic natural gas. In order to produce a quality solid fuel the

following steps are desirable:

1. Ion exchange treatment to reduce the sodium content and/or increase calcium content.
2. Physical cleaning to reduce the sulfur and ash contents.
3. Pelletizing to produce transportable lumps.
4. Drying to reduce moisture content.
5. Sealing to prevent moisture reabsorption, to prevent dusting, and to eliminate spontaneous combustion.

The above results in:

1. reducing ash fouling of boiler tubes during combustion,
2. reducing sulfur emission to below 1.2 lbs-SO_2/MMBtu making it an environmentally compliant fuel,
3. producing a high heating value product which reduces transportation costs, and
4. producing a high quality, stable product.

Ion exchange processing step 1 has been demonstrated in prior work (1,2) on run-of-mine lignite and again more recently in work by GFAT on physically cleaned lignite. The recent GFAT work was funded by the U.S. DOE-SBIR Program (3). Processing steps 2 to 4 were evaluated in a study performed at UND-EERC which was jointly funded by Knife River Coal Mining Company, the North Dakota Industrial Commission (after recommendation by the Lignite Research Council), and U.S. DOE-METC (4). In the latter work, it was found that nominally 8% pulverized waste wheat or a combination of nominally 3% chipped newspaper and 4% wheat could be used to produce 1" briquettes of reasonable strength. This work was extended to pilot scale and over 1 ton of briquettes were produced (see Table 1 for analysis) in a follow-up project (5). In the larger scale demonstration, wheat flour (feed grade) provided by the North Dakota State Mill and Elevator was used as a binder.

Present work involves the engineering economic evaluation of the physical cleaning processing components with an emphasis on the production of a sulfur emission compliant fuel and the investigation of methods to integrate sodium reduction into the physical cleaning process. An earlier economic evaluation (2) indicated that a process producing only an ion-exchanged product was not economical. However, when integrated into a physical cleaning process the costs benefit ratio based on decreased boiler down-time due to ash fouling should be very favorable. When the economic evaluation work is completed, funding is in place to do vendor testing on equipment recommended by the engineering company.

The production of 1 million tons of a premium fuel would utilize 1 million bushels of low-grade wheat. Since recycle newspaper has become more expensive, it is hoped that the use of waste chaff from grain milling and/or a malting operation can be tested and found to be a suitable filler. Testing has indicated that waste calcium-rich sludge may also have a role in producing a clean burning fuel.

TABLE 1
UPGRADED LIGNITE PRODUCT

Proximate Analysis	As Determined	As Received	Lab Number 9421 Moisture Free	Moisture-Ash Free
Air dry Loss	0.00			
Moisture	8.93	8.93	--	--
Volatile Matter	47.08	47.08	51.70	55.07
Fixed Carbon	38.41	38.41	42.18	44.93
Ash	5.58	5.58	6.13	--
Total	100.00	100.00	100.00	100.00

Ultimate Analysis	AR	mf	maf
Moisture	8.93	--	--
Carbon	59.49	65.32	69.58
Hydrogen	4.44	4.87	5.19
Nitrogen	0.80	0.88	0.94
Oxygen (dif)	20.32	22.31	23.77
Sulfur	0.45	0.49	0.52
Ash	5.58	6.13	--
Total	100.00	100.00	100.00

Heating Value, Btu/Lb	9,845	9,845	10,810	11,516

Ash Analysis	Elemental wt% (from Norm.)	As Oxides, wt% of Ash: Oxide	As Determ.	Normal	SO3 Free
Silicon	8.31	SiO_2	17.53	17.78	20.43
Aluminum	6.42	Al_2O_3	11.96	12.13	13.94
Iron	3.68	Fe_2O_3	5.19	5.26	6.05
Titanium	0.13	TiO_2	0.21	0.21	0.24
Phosphorous	0.77	P_2O_5	1.74	1.77	2.03
Calcium	23.81	CaO	32.84	33.31	38.28
Magnesium	7.55	MgO	12.35	12.53	14.39
Sodium	2.60	Na_2O	3.45	3.50	4.02
Potassium	0.45	K_2O	0.53	0.54	0.62
Sulfur	5.19	SO_3	12.78	12.96	--
Total	58.91	Total	98.58	100.00	100.00
Molar Ca/S Ratio		2.38			
Emissions, from sulfur content lbs-SO_2/MMBtu		0.91			

Coal (Lignite) in Biomass Processing

Coal is typically shipped to the end-user where it is used as plant fuel. However, the physical cleaning process used to remove pyrite for sulfur reduction results in a fine clean coal product. The fine nature of this clean coal makes it more difficult to ship and handle. Combining biomass with clean coal is one method to produce a dust-free, lump, biomass-coal product that is readily shippable. Work is currently being done by GFAT and Producers Renewable Products, LLC to further develop and commercialize the use of other ag waste products, such as stillage centrate, in the production of biomass-coal fuel products. More specifically, the purpose of this work is to demonstrate and commercialize the use of coal to 1) remove fibrous solids from, and moderate the pH of, an industrial processing water stream, 2) to produce low-grade lime from city water treatment waste during the production of plant heat and 3) to produce coal/calcium/biomass pellets. This opportunity exists since in the production of ethanol, a "centrate" stream is produced during the concentration of stillage by centrifuge.

Because the centrate contains about 7 wt% of fibrous solids, recycling the centrate without solids removal reduces ethanol fermentation yields by 9%. Lab tests have indicated that coal particles settled through the centrate will concentrate the solids. The full process to be evaluated would involve 1) combusting coal and water treatment waste to produce plant heat and calcium oxide, 2) coagulating soluble solids from ethanol plant recycle water using the calcium oxide and added coal particles to facilitate precipitation of fibrous and flocculated material, 3) compressing the coal-calcium-biomass mixture, removing water, and producing pellets, and 4) marketing of excess fuel. The use of a low-rank coal should result in the production of a near-neutral pH recycle water due to the buffering capacity of the coal. Excess calcium-enhanced ash would likely have cementing properties and be usable as a soil stabilizer.

The physical cleaning of coal reduces pyrite and ash contents of the coal but is accompanied with size reduction which creates difficulties in handling and shipping. Reconstitution of the finer coal material into pellets and/or briquettes can reduce handling problems and increase marketability of the clean coal product. However, in pelletizing, a binder is generally needed which can range in cost from $2 to $10 per ton of product. With increased building of ethanol plants there is a potentially new source of inexpensive binder material which can be reclaimed from water streams and improve the economics of the ethanol production and coal reconstitution.

Agricultural processing facilities such as ethanol plants recycle untreated water, or "centrate", by backsetting the liquid to the process. In ethanol production, recycling centrate (7 wt% solids) increases osmotic pressure, resulting in reduction in fermentation ethanol yield from 14% to 12.8% ethanol. Although suspended solids and dissolved matter contained in the stream can be used in cattle feeds, as with distillers dried grain (DDG), because of higher drying costs with this option, it has a low or negative value to most operations. Another dilemma facing processing facilities is wastewater treatment and disposal. For processing plants without in-house waste treatment programs, relying on municipal systems is an expensive alternative. The development of an integrated coal-water clean-up technology could assist producers with both of these concerns. Successful development and commercialization of this idea will enable production of a compliance biomass/calcium/coal fuel and remediation of process water for recycle in agricultural processing facilities.

Two main economic incentives exist for investigating integrated coal-water clean-up for use in the agricultural processing industries. The first incentive is that by using proven technology, a sulfur dioxide emission compliance fuel derived from coal, biomass, and waste calcium, can be produced. A second incentive is that the production of this compliance fuel is also an innovative method for cleaning process water. Capital and operating costs of current process/wastewater handling systems are reduced, and plant efficiency is improved. An additional environmental benefit is that finely divided waste calcium from municipal water treatment and other industrial plants (such as sugar beet processing plants) could be reused rather than directly landfilled.

In the city of Grand Forks, North Dakota, numerous truck loads of a calcium carbonate/hydrated lime mixture are transported from the municipal water purification plant to a landfill every day. Across the river in East Grand Forks, Minnesota, a sugar

beet processor has hundreds of acre feet of landfill capacity devoted to "spent" calcium carbonate. The proposed research will use samples of this material to test the economic and technical feasibility of the combined process water remediation and coal/calcium/biomass fuel production. The main objectives of this research will be to produce a cleaned water that can be backset to the processing step, meeting actual industry parameters, and to produce a commercially viable, compliance, biomass\calcium\coal fuel.

The proposed process (Figure 1) will recycle "waste" calcium from municipal water treatment and industrial plants for use as a flocculent and for potential sulfur dioxide (SO_2) reduction when incorporated into a pelletized fuel. In addition, coal particles, applied in a falling bed design, will "knock" suspended fibrous solids from the centrate. Following collection, the coal/calcium/biomass mixture will undergo water reduction and pelletization for marketing as a solid compliance fuel. This fuel could be utilized onsite and/or sold in the expanding pellet fuels market.

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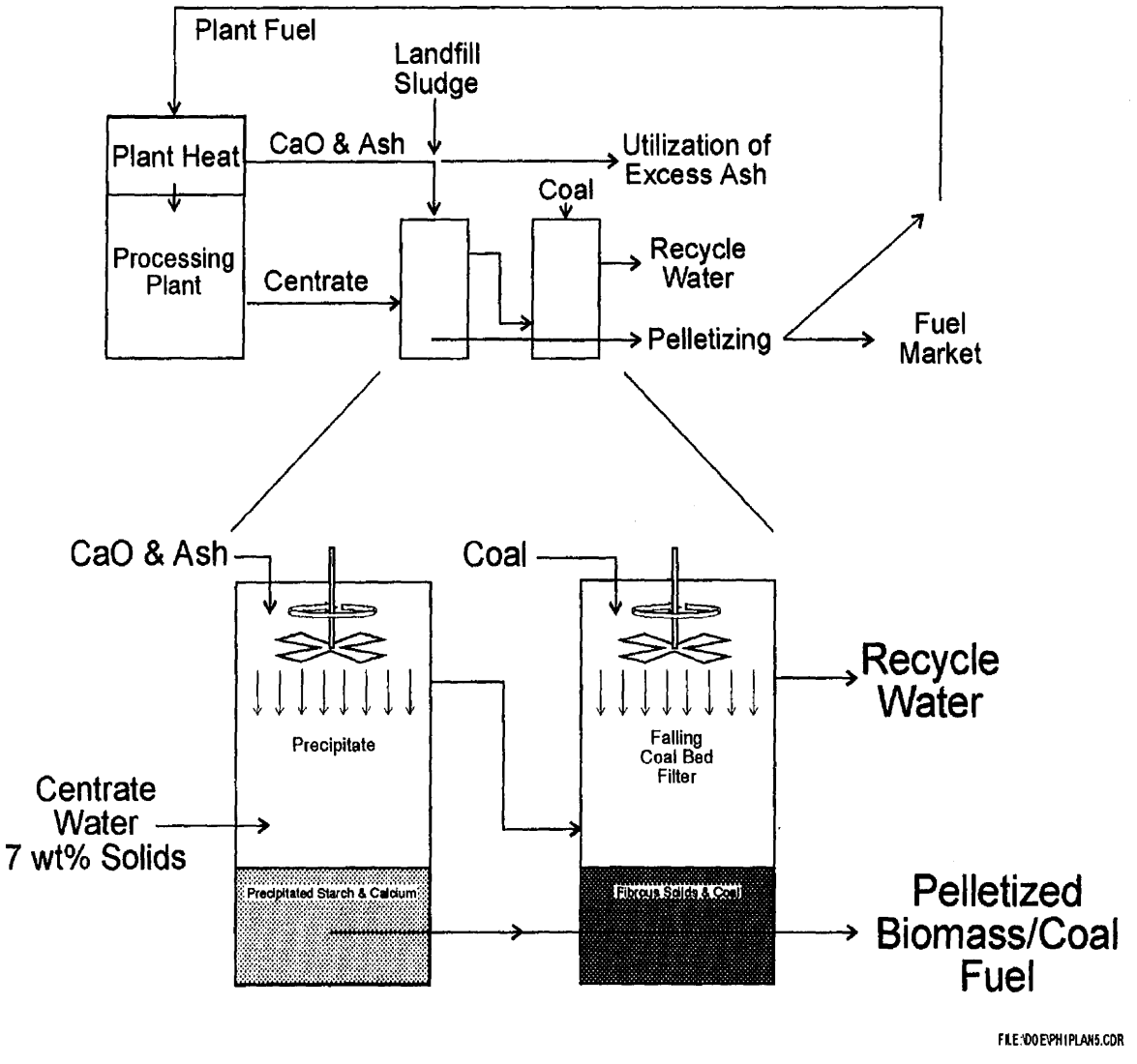


Figure 1. Integrated Coal-Water Clean-Up.

THE ECONOMICS OF BIOMASS AND BIOMASS-DERIVED ENERGY AND FUELS

George C. Bluhm, M.S., National Meteorologist, NRCS-USDA, Washington, DC, USA
Roger K. Conway, Ph.D., Director, OENU-USDA, Washington, DC, USA
Vernon O. Roningen, Ph.D., Economist, ERS-USDA, Washington, DC, USA
Hossein Shapouri, Ph.D., Economist, OENU-ERS-USDA, Washington, DC, USA

Abstract

Biomass crops (e.g. grasses, wood) could become important feedstocks for the production of power, liquid fuels, chemicals, and other industrial products. With successful research programs that boost biomass crop yields and develop competitive power and chemical conversion technologies, these crops might compete with fossil fuels for a broad range of uses. The development of a biomass industry could bring significant environmental benefits while providing new income opportunities for farmers and processing jobs in rural communities. Economic trends, technological developments, the policy environment, and demonstration efforts at the site-specific local level will determine whether the opportunities for a biomass industry are realized.

The economic competitiveness of crops as inputs to energy and chemical production has improved, relative to fossil fuels. Projections of crop and energy prices suggest that these economic trends are likely to continue. Many economic factors can influence the future of biomass crops, including changes in world energy prices, increased environmental costs associated with fossil fuel use, major advances in technology that reduce the cost of biomass production and processing, and the development of profitable product mixes from biomass processing. The potential of biomass as a fuel for electricity generation illustrates these factors. With current technology, biomass based-electricity generation is a niche market in situations where electricity is expensive and fuel is cheap or incurs a disposal cost, e.g. waste wood, sawdust, etc. Some utilities are now interested in co-firing wood with coal because of environmental reasons, provided wood fuel costs are low enough. If dedicated biomass production and power systems demonstrate themselves to be workable, a larger competitive biomass-based power industry could develop. Policies that pursue environmental goals, encourage energy diversification, or encourage biomass production could also influence the development of a biomass-based electricity industry.

While national and regional economic conditions for the competitiveness of biomass are important, the potential for biomass production and processing has to be evaluated on a site-specific basis under local economic conditions. Successful demonstration projects in the field are crucial to the future of the industry. The existing ethanol industry serves as an example where, given the incentives in place, the success of existing plants encourages the construction of new ones. USDA is cooperating with the Department of Energy (DOE) to fund and encourage demonstration projects that will give the biomass industry the opportunity to develop and succeed. Wise and flexible management of this process at the national and local level is needed if all participants are to realize the potential of biomass-derived energy and fuels as a new use for American agricultural resources.

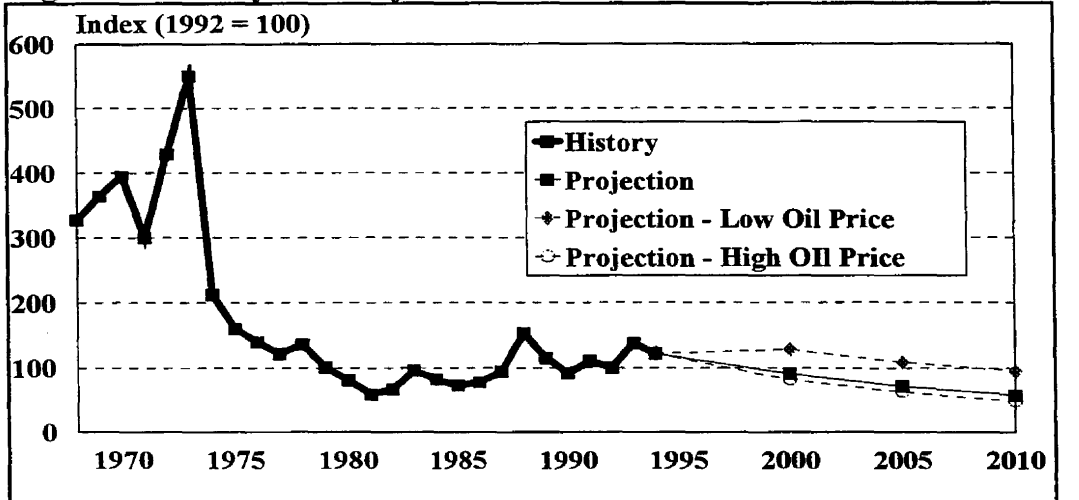
Background

Agricultural crops have an opportunity to be used as feedstocks for the production of electric power, liquid fuels, and chemicals in addition to their traditional use for food, feed, and fiber. Biomass feedstocks (e.g. grasses, wood crops) have environmental benefits compared to fossil fuels during their life cycle. As renewable fuels they would not add greenhouse gasses to the atmosphere during their life cycle. Products made from biomass may be more biodegradable than those made from fossil fuels. Biomass crops appropriately raised, might also serve to protect water quality and prevent erosion. Research by DOE suggests that yields of biomass crops, such as poplar, willow, and switchgrass, could be increased significantly. If efficient gassification systems and gas turbines were developed for power production, biomass feedstocks might become competitive with fossil fuels. The development of a biomass industry could benefit farmers by adding energy crops to traditional food and fiber production and the rural economy by creating processing jobs. Economic, technological, environmental, policy, and site-local economic conditions will determine the future of the biomass industry.

Economic Trends

Corn is an example of a traditional agricultural crop which is increasingly being used as an industrial feedstock for the production of ethanol and sweeteners. Long term price trends for corn and fossil fuels are consistent with this development. Figure 1 shows the history and projections of the ratio of the real corn/oil price. Since the energy crisis of the mid-seventies, the ratio has come down considerably, making corn a more competitive feedstock for liquid fuel (ethanol) production and other industrial purposes. Projections into the future appear unlikely to reverse this development. They suggest that even with

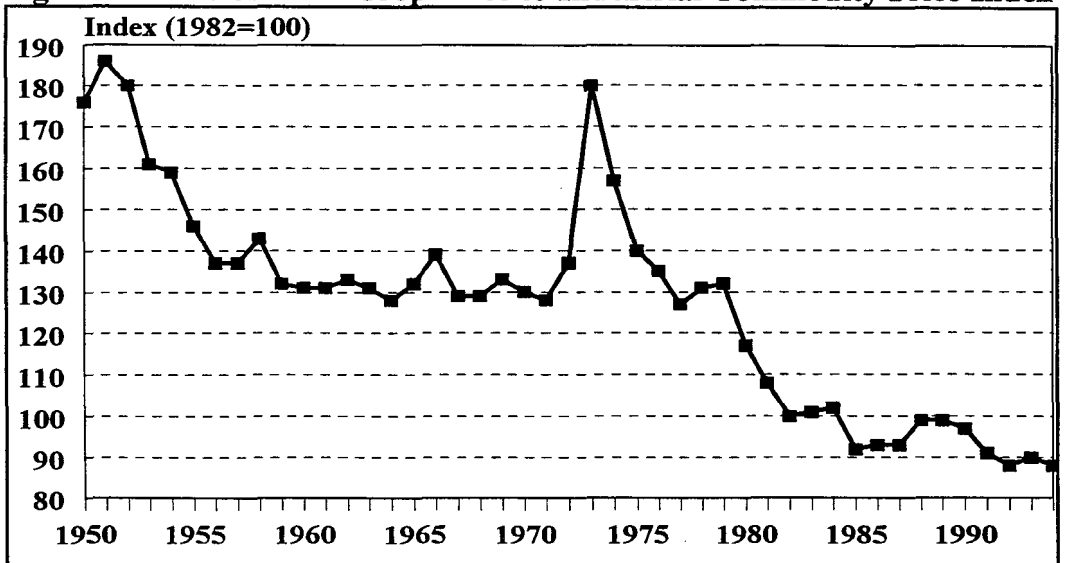
Figure 1: History and Projection of the Ratio of Corn/Oil Price



Source: Calculated using a) corn price from USDA historical data and 1995 "Long-term Agricultural Baseline Projections" and b) oil price data and 1995 projections from DOE Energy Information Administration "Annual Energy Outlook - 1995".

the lowest alternative oil price (a proxy for fossil fuel prices in general), the current advantage for corn as an industrial feedstock is likely to persist and even improve. A similar ratio of real farm crop (all crops) to real industrial commodity prices (textiles, hides and leather, fuels and power, chemicals) shown in Figure 2, suggests that market trends are becoming more favorable for the industrial use of renewable agricultural resources such as biomass crops.

Figure 2: Ratio of Farm Crop Price to Industrial Commodity Price Index



Source: Calculated from data on real farm product and real industrial producer price indices from the "Economic Report of the President".

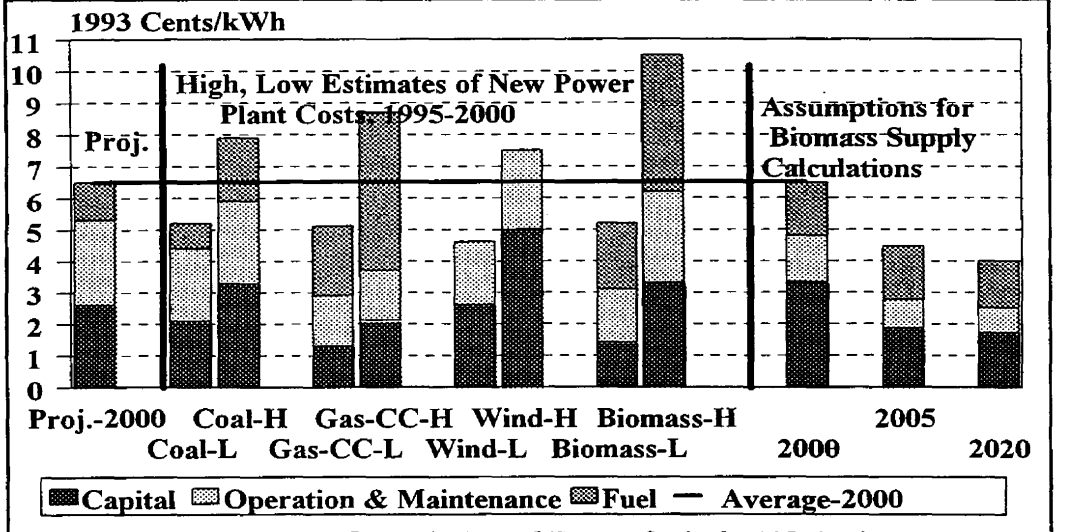
The opportunities available from the biological revolution which can increase crop productivity and engineer crops for specialized industrial use, is likely to accelerate these trends. Expanding world populations and economic growth will increase demands on the finite reserves of fossil fuels in the 21st century, further fueling the future of alternative energy sources including renewable ones such as biomass crops.

Technological Advancement

Technological advancement is important for the cost effective development of a biomass industry. An example is a DOE-USDA estimate of the research possibilities for increasing biomass yields (lowering the energy cost per ton) which would allow low cost biomass to fuel new generation efficient power plants. Figure 3 shows estimates of electricity price components in this decade from various sources as well as estimates in 2005 and 2020 assuming the successful deployment of advanced gassification-gas turbine power generation technology that could use biomass (grasses, wood) for fuel. The electricity cost assumptions for biomass power under current technology start off in 2000 in the average range and fall in the middle of a range of estimates for biomass power generation. But if new technologies succeed as projected in 2020, biomass-derived electricity might become competitive with power generated by natural gas at 4 cents per kWh. Figure 4 shows an estimate of the potential electricity supply from biomass under three scenarios.

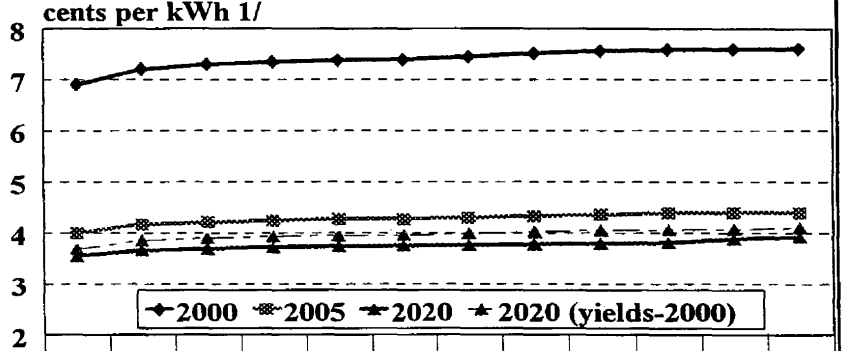
The scenarios for 2005 and 2020 include significant yield improvements (cost reductions) in biomass production for all uses. However the alternative 2020 scenario using lower year 2000 yields shows that success with this new power generation technology is crucial

Figure 3: Estimates of Electricity Price Components - 2000, 2005, 2020



Source: Projections from DOE-EIA *Annual Energy Outlook 1995*. Estimates of new power plant costs for 1995-2000 by fuel type from *Powering the Midwest, a Report by the Union of Concerned Scientists"*. Assumption by OENU/DOE use Electric Research Institute (EPRI) model: 2000-Conventional steam, 2005-IGCC-gasifier & turbine, 2020-IGCC-ATS - advanced gasifier & turbine. Fuel costs are 1.7-1.5 cents/kWh (1.5 allows 4 cents/kWh electricity in 2020).

Figure 4: Potential Biomass Based Electricity Supply



Quad. Energy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Million Acres	0	3	7	10	16	21	26	29	32	40	46	54
Billion kWh-2000	0	36	73	109	145	181	218	254	290	327	363	399
Billion kWh-2005	0	57	115	172	230	287	345	402	460	517	575	632
Billion kWh-2020	0	65	130	195	260	325	390	455	519	584	649	714

1/ Scenarios include fuel, capital, operating & maintainence costs: 2000 - (1.7, 3.31, 1.48); 2005 - (1.6, 1.86, .90); 2020 - (1,5, 1.70, .80) cents/kWh.

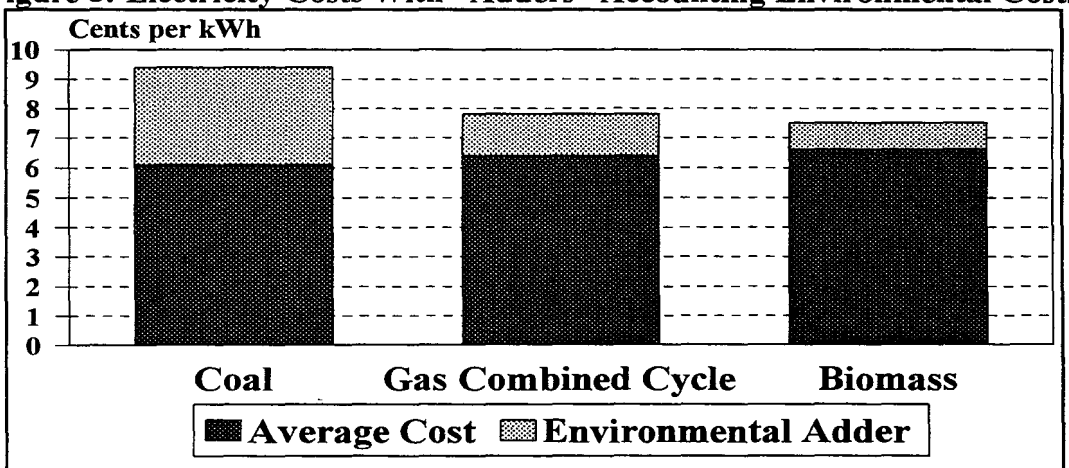
if biomass-based electricity costs are to be competitive with natural gas in 2020. Figures 3 and 4 assume that biomass would be grown exclusively as fuel for a power plant. But other processes where biomass may be used to produce power and liquid fuels or a range of products including chemicals, may offer a more promising economic configuration. Although the figures are based upon the best available budget data on potential biomass production and DOE estimates of the costs of new power generation technology, biomass production and usage systems have not yet met the true test of experience. Before farmers and businesses invest in biomass production and processing, working systems have to be demonstrated and their profitability has to be proven.

Environmental Considerations

Biomass feedstocks can offer environmental benefits in many ways. Biomass fuels do not add greenhouse gasses to the atmosphere during their life cycle as do fossil fuels. Many products made from agricultural materials are biodegradable and potentially offer low disposal costs. Biomass derived fuels such as ethanol contribute to clean air goals. Biomass crops can be grown with low input use/sustainable production methods and they might be used to conserve soil on fragile lands, to serve as filters that prevent fertilizer and pesticide runoff from entering the water supply, and to provide wildlife habitat.

Environmental programs that discouraged carbon emissions or other pollutants could indirectly encourage biomass crops. Alternatively, incentives encouraging biomass crops could be viewed as tools for reaching attain environmental goals. Figure 5 shows the cost implications for electricity production where some states have "added" environmental costs to the calculations required for electric power plant construction. The addition of environmental cleanup costs ("adders") to electricity cost pricing could make biomass-derived power a more attractive alternative to fossil fuel use.

Figure 5: Electricity Costs With "Adders" Accounting Environmental Costs



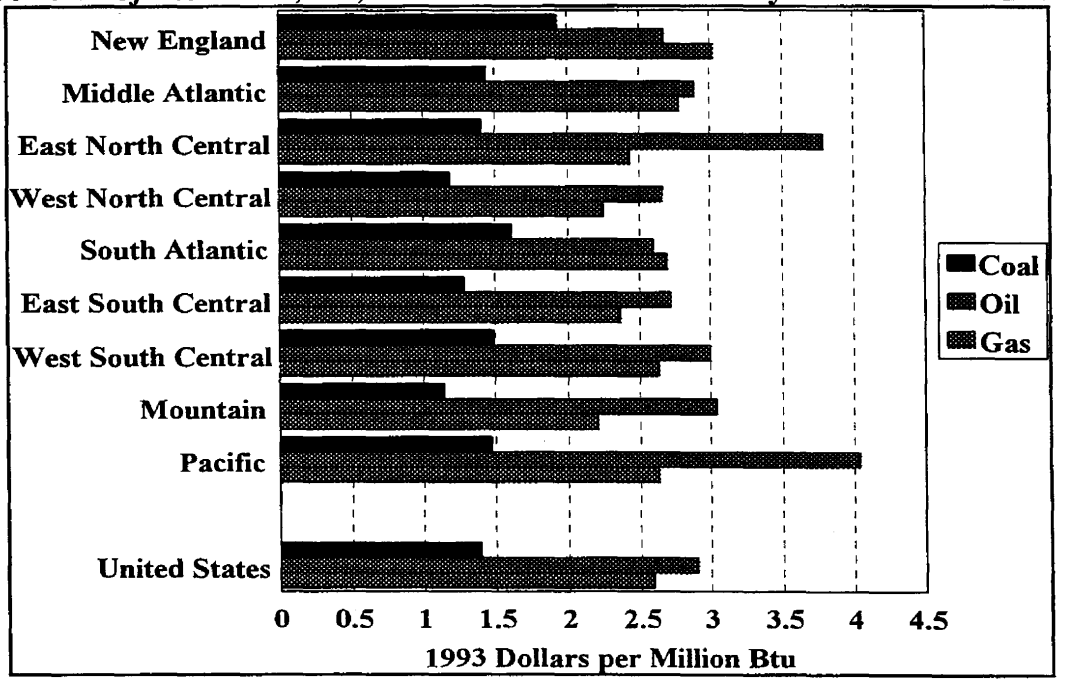
Source: "Powering the Midwest", a report by the Union of Concerned Scientists. "Adders" are based calculations required in Massachusetts and Nevada rules when calculating costs for new power plants.

While the quantification of environmental benefits and cleanup costs may be difficult, it could be an important consideration when making choices between fossil fuels and renewable agricultural resources such as biomass for industrial and energy use.

Site-Local Economic Conditions

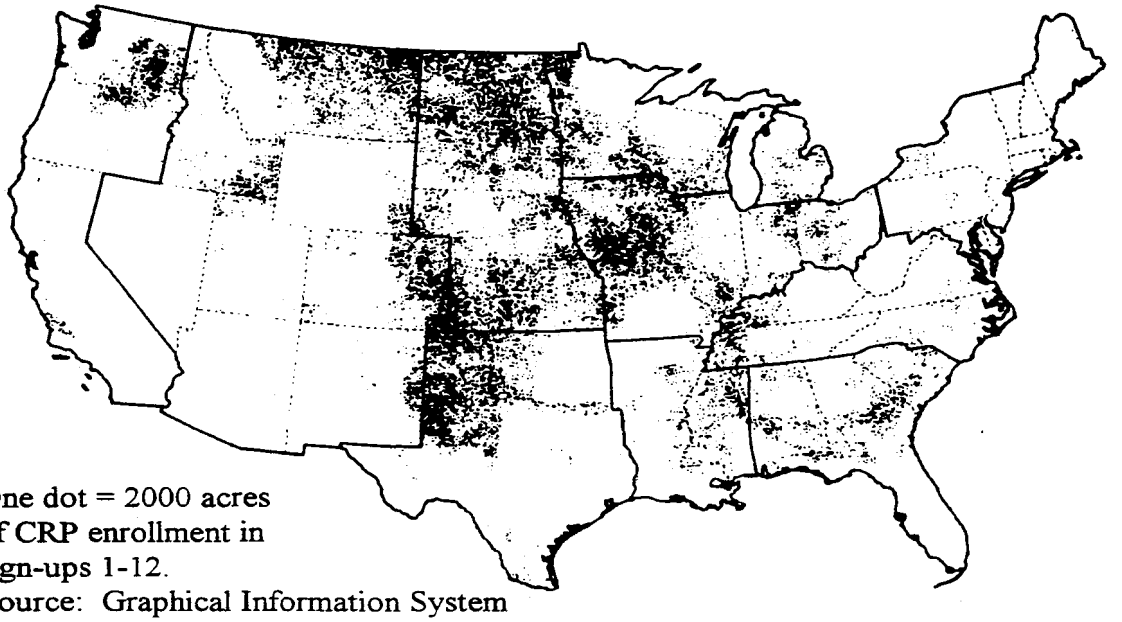
While the national economic and policy environment is important for the development of a competitive biomass industry, opportunities may differ significantly among regions of the United States. Furthermore, actual opportunities for biomass production and processing systems have to evaluated on a site-specific, local basis. Figure 6 shows that fossil fuel costs for electricity production vary significantly by region. The competitive price level that biomass-derived energy and fuel have to meet are likely to differ by region as well as by specific location within a region. Biomass crops themselves are climate and region specific. For example, the electricity supply derived from biomass in Figure 4 assumes that biomass production is viable only in areas with suitable land and adequate rainfall.

Figure 6: Projected Coal, Oil, and Gas Costs for Electricity Generation in 2000



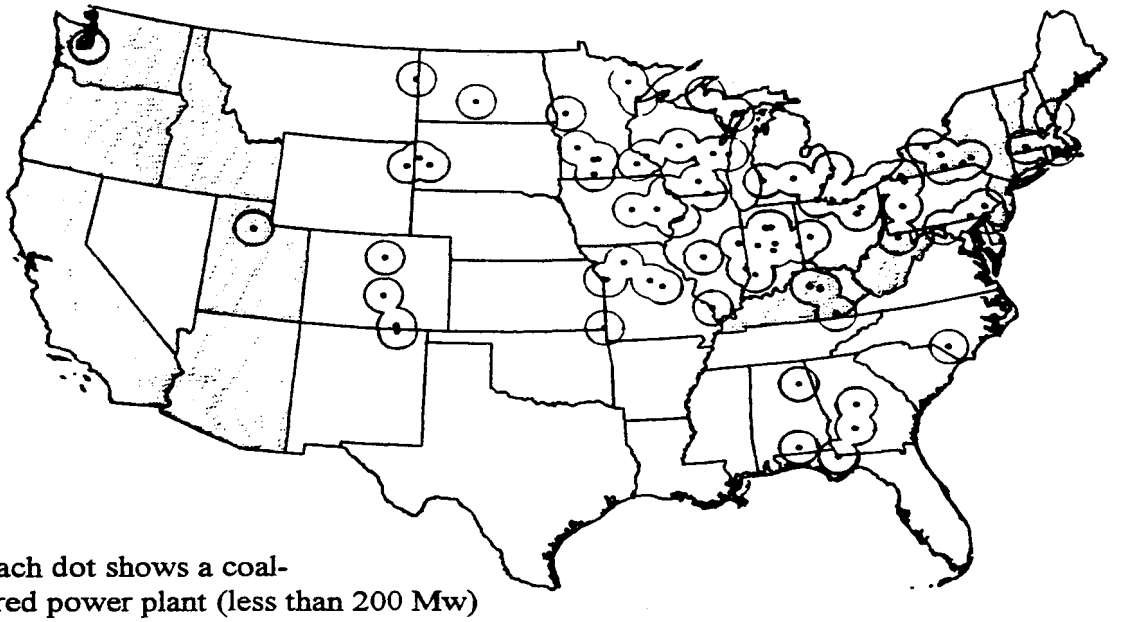
Biomass crops have high transportation costs. This means that biomass power/processing facilities have to use crops grown on surrounding land and that each potential site has to be evaluated for profitability from the producer and processor viewpoint. While national and regional calculations generally account for crop production, harvest, transport, drying, storage, and processing costs, each individual site has to prove profitable if farmers are to deliver a steady biomass supply and if processors are to produce power, fuel, or other biomass based products competitively. Figure 6 shows the distribution of land currently in the Conservation Reserve Program (CRP) that might be available for future biomass production. Figure 7 shows the location of older small power plants that might need replacement in coming years and therefore could become biomass power sites.

Figure 7: Conservation Reserve Program Acres



One dot = 2000 acres
of CRP enrollment in
sign-ups 1-12.
Source: Graphical Information System
of USDA's Natural Resource Conservation Service.

Figure 8: Areas Within 50 Miles of Older, Small Coal Fired Power Plants



Each dot shows a coal-
fired power plant (less than 200 Mw)
built prior to 1965. Each circle shows a 50 mile radius from the power plant.
Source: Electric Power Research Institute (EPRI) data in the Graphical Information System of USDA's Natural Resource Conservation Service.

These two figures suggest that there may be many site-specific opportunities for biomass production systems and power plant sites in the United States. The CRP land distribution shown in Figure 7 includes about 36 million acres of land which is not currently used for crop production. Some of this land is considered fragile or highly erodible and will always require special conservation practices. Other CRP land might go back into crop production if the CRP is ended. In addition to CRP land, commodity programs have kept up to as much as 14 million acres of land out of production in recent years. Some proposals have suggested that CRP and other idled land in the United States might be suitable for biomass production without displacing existing food and fiber crop production, especially if conservation goals could be met at the same time.

Issues for the Future of Biomass-Derived Energy and Fuels

Many issues are important to the future of biomass-derived energy and fuel. Economic events and political processes surrounding these issues will likely determine the future of a biomass industry.

The future of energy prices and developments in energy markets are very important. If another energy crisis with rising prices should occur, the economic setting for biomass-based energy would improve markedly. On the other hand, if energy markets remain competitive and prices low, it will be more difficult for a competitive biomass industry to develop without subsidies or mandates. An argument can be made for policies to encourage alternative domestic energy sources such as biomass--such policies would discourage cartel behavior by the oil exporters, encourage competition in world fossil fuels markets, and help to keep energy prices low in general. From an analytical viewpoint, a developing biomass industry has to be treated an integral part of the overall U.S. and world energy market.

Declining Federal budgets for energy and agricultural programs and research are another immediate issue for concern in this era of deficit reduction. Current knowledge about the potential for biomass for energy is the result of a modest, but sustained research program that has explored and encouraged alternatives to imported fossil fuels after the energy crisis of the 1970s. Subsequently, environment considerations, especially global warming trends, encouraged research because of the environmental benefits associated with biomass feedstocks. Since it is problematic that research and development funding will be expanded or that biomass production and processing will be encouraged directly by cash incentives or indirectly by mandates, it is especially important that the market potential for biomass crop and power production be demonstrated fairly soon. On the other hand, smaller budgets for the support of existing food and fiber crops might have a positive effect on the biomass industry because of lower land and input costs for biomass production. On the power generation side, continuing deregulation of power markets could make electricity markets even more price competitive at the same time that biomass opportunities are approaching technical feasibility.

Environmental issues surrounding biomass, other agricultural crops, and future energy use are important. Environmental costs and benefits are controversial and difficult to quantify. But when attempts are made to include environmental considerations in project analysis, they can tip the balance in favor of renewable resource use. The environmental impact can

be accounted for directly by a cost calculation, or indirectly by a mandate which enforces compliance with environmental rules. But without an explicit cost or mandate, environmental considerations might be totally ignored in economic and business calculations. Better ways will have to be found to integrate environmental considerations into resource use questions like those surrounding the development of a biomass industry.

If biomass production does expand in a significant way, an important issue for agriculture is the potential competition with traditional food and fiber production. If biomass production displaces traditional food and fiber crops, then short supplies of those crops would bid prices up and make biomass crops less competitive. Under current United States cropping patterns, it is possible that biomass could be grown on some of the 50 million acres of land idled in recent years under conservation and set-aside programs without affecting traditional crop production. However some multi-crop analysis suggests that competitive effects could become important if biomass production approached 30 million acres. It is likely that if biomass production approached 30-50 million acres or about 3 to 5 quads (quadrillion British Thermal Units) of energy, existing food and fiber production, markets, and farm programs would be affected, possibly changing the competitive situation for biomass production. Therefore if a significant biomass industry develops, it will be important for USDA to incorporate it into its farm commodity forecasting and projection efforts. In a similar vein, local site-specific evaluations of biomass production and processing systems will have to account for the total economics of agricultural production in the area.

Even if program budgets are reduced, future farm programs could make a difference for the development of a biomass industry. It has been suggested, for example, that a farm bill might allow industrial crops such a biomass to be grown on lands idled under the CRP or other farm programs. The Administration's farm bill proposal suggests that legislation should "permit, under certain circumstances, economic use of CRP acres, such as for the production of biomass, in exchange for a reduced rental rate" (USDA). If such policies were put into place, conservation program funds would not only pursue conservation goals, but would also provide financial incentives for biomass production.

USDA is providing limited support for biomass research with its own research system and by cooperating with DOE in its research efforts. In addition, USDA and DOE are cooperating to sponsor a few site-specific biomass demonstration projects that could prove concepts on the ground and work out biomass development problems at a practical level. USDA is supporting this effort with programs and services in place, including those of the Consolidated Farm Service Agency, the Natural Resource Conservation Service, the Rural Economic and Community Development agency, the Forest Service, the Research, Economic, and Education agencies, and the Alternative Agriculture Research and Commercialization Center. USDA will continue to encourage a wide ranges of new uses for agricultural resources as part of its overall mission. The Administration's farm proposal suggests that USDA should "maintain an on-going research program to develop new uses for agricultural commodities that have potential for value-added processing in rural communities", "support collaborative economic and technical research involving federal, state, and private parties to identify viable products for local processing", and "support human capital investment in the skills needed in value-added processing and to

provide supporting infrastructure improvements". Biomass-derived energy and fuels is one such important new use or "value-added" product.

In the near future, biomass production, harvest, and processing systems will have to be demonstrated at specific sites. All of the logistical, organizational, contracting, technical, production, processing, transportation, harvesting, and integration (of biomass crops with existing crop production) problems will have to be solved on the ground if farmers and businesses are to be convinced to invest their time and treasure in a biomass industry. Creative, business oriented analysis at the local level is needed to evaluate demonstration projects as they proceed and to explore site-specific opportunities as they arise. Experience from demonstration projects will be crucial to the future development of a biomass industry. If demonstration projects prove that biomass production and utilization systems can be profitable, the industry will develop. If not, then the industry will languish without subsidies or improved economic circumstances.

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COST VERSUS SCALE FOR ADVANCED PLANTATION-BASED BIOMASS ENERGY SYSTEMS IN THE U.S.A. AND BRAZIL

Christopher I. Marrison,* Ph.D. and Eric D. Larson, Ph.D., Research Engineer
Center for Energy and Environmental Studies
School of Engineering and Applied Science
Princeton University, Princeton, NJ 08544

Abstract

A unique feature of biomass energy systems is that the feedstock must be gathered from a wide area around the energy production facility. For a small-scale facility, transport costs will be relatively low, but capital cost per unit of output will be high. For a large-scale facility, transport costs will be high, but capital costs will be relatively low. At some intermediate scale, the total cost of energy should reach a minimum. This paper examines the effects of scale on the prospective costs of electricity and alcohol fuels from plantation-grown switchgrass in the North Central and Southeast regions of the USA and from eucalyptus in Bahia state, Brazil.

Biomass cost-supply curves for the year 2000 and 2020 are developed for the USA sites using estimates by the Oak Ridge National Laboratory for switchgrass yields and costs. A geographic information system (GIS) is used to analyze soil quality (and yield) distributions and road transport distances. A simplified approach is outlined for developing biomass supply curves to avoid data-intensive, time-consuming GIS analysis. The approach is applied for the analysis of data collected at the Brazil site.

Conversion technologies considered include one commercial electric generating technology--the steam rankine cycle--and one nearing commercial readiness--the gasifier/gas turbine combined cycle. Two alcohol fuels are considered: methanol via thermochemical gasification and ethanol via enzymatic hydrolysis. Both of these processes could be commercially ready early in the next century. Estimates of installed capital costs for all of these conversion systems are based on published sources.

In all cases, the minimum cost of electricity (COE_{min}) or alcohol (COA_{min}) is reached at relatively large plant capacity, because up to that point the rate of decrease in unit capital costs is more rapid than the rate of increase in biomass transportation costs. However, around the capacity corresponding to COE_{min} or COA_{min}, there is a wide range over which costs change very little. In general, higher biomass yields lead to larger capacities at COE_{min} or COA_{min}. Costs in the USA are higher in the NC than SE region, and (in both regions) costs are lower using year-2020 biomass costs compared to year-2000 costs. Energy costs at the Brazil site, which assume present biomass production costs, are lower than in the USA, except in the SE region in 2020.

Introduction

A unique feature of biomass energy systems that is the focus of this paper is that the feedstock must be gathered from a wide area around the energy production facility. For a small-scale facility, transport costs will be relatively low, but capital cost per unit of output will be high. For a large-scale facility, transport costs will be high, but capital costs will be relatively low. At some intermediate scale, the total cost of energy should reach a minimum. This paper examines the effects of scale on the prospective costs of producing electricity and alcohol fuels from plantation-grown switchgrass in the North Central and Southeast regions of the US and from eucalyptus in the state of Bahia, Brazil.

The basic components of the total cost of energy supply from biomass are *(1)* the cost to grow and deliver the biomass to the conversion facility and *(2)* the cost of the conversion. A number of studies have examined these two elements independently, but there does not appear to have been any previous effort to marry biomass supply with biomass conversion studies, as we do here, to examine the issue of energy cost versus scale.

Biomass Costs

North Central and Southeast United States

Development of energy crops in the US is focussed on short-rotation woody crops for some regions and on herbaceous crops for others [Hohenstein and Wright, 1994]. Switchgrass is a primary candidate energy crop for the North Central (NC) and Southeast (SE) regions that are considered in the analysis here. Expected switchgrass production costs span a significant range between these two regions: relatively high in the NC region and relatively low in the SE region. The starting point for the analysis was the selection of a specific site to provide a case-study variation in soil quality and transportation distances for a typical agricultural area. A four-county area in South Central Iowa (Appanoose, Lucas, Monroe, and Wayne counties) was chosen. The total area is approximately 5100 km^2, over 90% of which is used for growing crops today. Soil type [IGS, 1973] and road [USGS, 1986] maps of the region were digitized and loaded into a geographic information system (GIS). (See Marrison [1995] for details of the digitization process.)

The GIS system was used to calculate road transport distances from each acre in the region to a central processing facility that was assumed to be located near the center of the region. The cost of growing biomass on each acre (dependent primarily on soil type) was then calculated and added to the transport cost associated with the distance between the acre and the conversion facility. We took the characteristics of the Iowa site (relative soil quality and road layout) to represent a typical agricultural area in the North Central (NC) region (which includes Iowa), and in the Southeast (SE) region.

Production costs and transportation costs

Switchgrass yield and cost projections made by analysts at the Oak Ridge National Laboratory [Walsh and Graham, 1995] provide the basis for the biomass production costs we present here. Walsh and Graham estimate per-hectare yields and costs for four regions of the US (Northeast, North Central, Southeast, and South Central). They identify sub-regions by land capability class (LCC). Among the 8 LCC levels, LCC 1 has few

restrictions on use for crops. LCC 5 to 8 are generally unsuited for crop production. Within each LCC, soils are sub-defined by the primary reason for restrictions on their use as cropland. For each sub-class of each LCC, Walsh and Graham estimate the area, projected switchgrass yield, projected first-year establishment costs, projected annual plantation maintenance costs (incurred in ensuing nine years, after which it is assumed that replanting is required), and estimated annual land rents.

For the selected site, the available soil map included three grades of soil: loess, which is generally very good agricultural land; complex alluvial deposits, which are of intermediate quality for agriculture; and till-and-outcropping paleosols, which are the least desirable of the three for farming. The yields and costs of switchgrass from these three soil types were assumed to be the area-weighted averages of Walsh and Graham's estimates for sub-LCC2, sub-LCC3, and sub-LCC4, respectively (Table 1).

Table 1 provides the inputs for calculating levelized switchgrass production costs. The calculation accounts for an assumed zero yield in the establishment year, two-thirds of the steady-state (Table 1) yield in the next year, followed by eight years at the steady-state yield. Post-harvest losses of 10% are also included [UMinn, 1994] post-harvest losses. A 6.5% discount rate is assumed, as suggested by Walsh and Graham [1995].

The standard form for biomass transport costs is: Cost (in \$/tonne) = **A** + (**TC**·**TD**), where **A** is the fixed cost (e.g. truck loading and unloading), **TC** is the variable transport cost (\$/tonne-km), and **TD** is the one-way transport distance in km. After reviewing several transport cost studies (see Marrison and Larson [1995]), baseline values for transport of switchgrass bales were selected: **A** = \$3/dry tonne and **TC** = \$0.18/dt-km.[1]

Total costs of biomass delivered to a conversion facility

Production and transportation costs associated with each acre of land were summed to derive the total cost of biomass delivered to the conversion facility from each acre of land. Fig. 1a shows qualitatively the cost distribution. Fig. 1b shows the production costs against the total tonnage of biomass available at that cost or less within the four-county area studied (assuming 94% of the area is used for switchgrass production, which excludes, primarily, towns and lakes).

For the NC region in 2000, biomass costs start at \$71/dry tonne, or \$3.9/GJ.[2] The maximum production within a radius of about 32 km (the limit of the four-county area examined[3]) is 1.7 million dry tonnes/year, with a marginal cost of \$79/tonne (\$4.3/GJ) and average cost of \$77/tonne (\$4.2/GJ). Using projections for 2020, biomass costs start

[1] The actual transport cost we assume per tonne of useable biomass at the conversion facility is [3 + 0.18*TD]/0.9, which assumes 10% storage losses at the facility.

[2] All fuel energy contents in this paper are given on a higher heating value basis. The higher heating value for switchgrass is assumed to be 18.44 GJ per dry tonne.

[3] The area analyzed is not circular (see Fig. 1a), but the greatest transport distance was limited in the analysis to the minimum distance between the conversion facility (near the center of the four county area) and the outer border of the area. This defined a circle with a radius of about 32 km.

Table 1. Average Projected Yields and Costs (in 1994$)[a] for North Central and Southeast USA.[b]

Land Class	Year 2000			Year 2020		
	Yield (dry t/ha/yr)[c]	Year-1 cost ($/ha)	Year 2-10 ($/ha/yr)	Yield (dry t/ha/yr)[c]	Year-1 cost ($/ha)	Year 2-10 ($/ha/yr)
	NORTH CENTRAL REGION					
LCC2	10.4	539.11	504.71	14.8	549.02	554.87
LCC3	10.0	537.68	502.80	14.2	547.57	552.58
LCC4	9.2	519.46	478.44	13.1	528.92	523.18
	SOUTHEAST REGION					
LCC2	15.2	486.99	356.42	21.7	501.04	448.50
LCC3	14.2	486.99	356.42	20.3	501.04	448.50
LCC4	13.6	486.99	356.42	19.4	501.04	448.50

(a) Costs are expressed in 1994$ using US GDP deflators [Council of Economic Advisors, 1995].

(b) See Marrison and Larson [1995] for details of the calculation of area-weighted average yields and costs. All costs shown in this table include land rent (assumed to be the same in 2000 and in 2020) as follows in 1994$/ha/yr: For the NC region land rent in LCC2 = $212; LCC3 = $209; and LCC4 = $191. For all LCCs in the SE region, land rent = $71/ha/yr.

(c) Dry metric tonnes per hectare per year, before losses.

at $55/dry tonne ($3.0/GJ), and the maximum production is 2.4 million dry tonnes/year [marginal and average costs of $63/tonne ($3.4/GJ) and $61/tonne ($3.3/GJ)]. Biomass costs are considerably lower in the SE region. For example, using 2020 projections biomass costs start at $32/dry tonne ($1.7/GJ) and rise to an average cost of $39/dry tonne ($2.1/GJ).

Southern Bahia state, Brazil

For comparison with the above USA-based analysis, a similar, but simplified analysis is carried out for a site in southern Bahia state, Brazil. A simplified approach is used because the GIS-based method used above is cumbersome and time-consuming. Here, the simpler approach is derived, tested against GIS-derived results, and applied to the Brazil site. (See Marrison [1995] for details of this approach.)

Simplified approach to calculations

In the above analysis, the GIS was used to determine production and transportation costs for each map-unit as a function of the soil quality and road layout. A first assumption simplifies the production cost calculation: all land in a given area is assumed to have a yield (**Y**) and production costs that are area-weighted averages for the region.

A second assumption simplifies the transport cost calculation. For purposes of the analysis, we assume that biomass is grown in concentric rings at a distance, *r*, from the conversion facility, with one segment of the ring removed to account for "no-grow" areas--towns, roads, lakes, etc. The total biomass supply from an area of radius, **R**, around a

conversion facility can then be calculated by integrating the production over each ring: total biomass production = $\mathbf{Y}\rho\pi\mathbf{R}^2$, where ρ is plantation density: ρ = 1 - ("no grow" area/total area).

For each ring, the transport distance to the conversion facility is $\mathbf{F}\cdot r$, where **F** is a constant that accounts for the layout of the road system. For roads spreading radially from the conversion facility, **F** = 1.0. For the road system at the Iowa site, which is typical for agricultural regions in the US, **F** = 1.4, as derived from the GIS data [Marrison, 1995]. For a square grid road system, **F** = 1.25 [Marrison, 1995]. From a circular area of radius **R**, the average transport distance, which is used to calculate transport costs, is $\mathbf{F}\cdot(2/3)\cdot\mathbf{R}$.

The average levelized cost of delivered biomass is then the sum of the production cost per tonne (including the fixed portion of transportation costs) and the variable transportation cost per tonne (= $/tonne-km x average transport distance). Figure 2a compares results from the full-GIS analysis (also shown in Fig. 1b) against results obtained for the same region using the simplified approach. The two agree well, especially for larger supply tonnages. The larger difference between the full-GIS and simplified curves at the lower tonnages is due primarily to the fact that the full-GIS analysis takes account of asymmetry introduced by the large lake in the center of the region (Fig. 1a).

Delivered biomass costs at the Bahia site

The simplified approach to determining the biomass cost-supply curve is applied to the Brazil site. For inputs, presently achieved average yield and cost data for an operating industrial eucalyptus plantation in southern Bahia state were obtained from a site visit (see Marrison [1995]). This plantation was established well over a decade ago by Shell Brasil. At the site, eucalyptus is harvested on a six-year rotation, with total production of 60 dry tonnes expected from the year-6 harvest, 53 dry tonnes in year-12, and 43 dry tonnes in year 18. The maximum planting density is 0.8 (ρ = 0.8), because Brazilian law requires at least 20% of the area of a plantation to be left in natural vegetation. The road system is a square grid (**F** = 1.25). The year-zero establishment cost is $471/ha.[4] Annual maintenance costs (including $44/ha in fertilizer and $24/ha in land rent) for years 1,7, and 13 is $136/ha/yr; for years 2, 8, and 14 is $99/ha/yr; and for other years is $74/ha/yr. Assuming a 10% discount rate, the levelized cost of production is $30.1/dry tonne ($1.6/GJ). Harvesting plus fixed transport costs are $4.4/dry tonne, chipping costs (from Perlack and Wright [1995]) are $5.5/dry tonne, and the variable transport cost is $0.20/dry tonne-km.[5] Fig. 2b shows the resulting cost-supply curve.

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[4] Costs in 1992$ have been converted to 1994$ using the US GDP deflator. The establishment cost per hectare includes: $57 for ground clearing, $10 to mark and survey the site, $93 for establishment of roads, $51 for first plowing, $10 for second plowing, $38 for ant killing, $70 for seedling production, $10 for planting of seedlings, $6 for replanting where originals died, $44 for fertilizer, and $82 for administration. A land rent of $24/ha is included, based on estimated land values ($120-364/ha) at several industrial plantations in the general vicinity of southern Bahia [Carpentieri et al., 1993].

[5] In Brazil, transport costs have been estimated as follows by Professor Carlos C. Machado (Dept. of Forestry, Univ. of Vicosa, Minas Gerais, personal communication, Sept. 4, 1992). For good forest roads, $/dry tonne = 1.04 + 0.118·TD, where TD is in km. For fair forest roads, $/dt = 1.05 + 0.167·TD. For

Energy Conversion Technology Costs

Several technologies are commercially available or under development for converting biomass into electricity or transportation fuels [Larson, 1993]. Several systems suited to the use of plantation-grown biomass are considered here. For electricity production, commercial steam-rankine cycle systems are considered (see EPRI [1992]), together with two varieties of gasifier/gas turbine combined cycles (BIG/GTCC)--one using low-pressure gasification and one using pressurized gasification [Consonni and Larson, 1994]. BIG/GTCC systems are not commercially established at present, but are likely to be commercially ready by the turn of the century. The pressurized BIG/GTCC is more efficient than the low-pressure version, but is expected to be more costly below a certain capacity range. Two alcohol production systems are considered: methanol via thermochemical gasification [Williams et al., 1995] and ethanol via enzymatic hydrolysis [Wyman et al., 1993]. For methanol production, only the initial gasification step is not commercial, but biomass gasifiers are under active commercial development worldwide. Advanced designs of enzymatic hydrolysis ethanol production are undergoing pilot-scale testing and development at the unit level in the USA [Wyman et al., 1993].

The analysis here requires only overall cost and performance characteristics, so details of the technologies are not discussed. The overall performance and cost characteristics assumed here are probably achievable within about the next decade with continued commercialization efforts. Still further advances in the technologies have been identified and are likely to improve performance and/or lower costs compared to those assumed here. Uncertainties in the cost estimates among the different technologies considered here are due largely to differences in the extent of commercial development and scaleup. Cost estimates for electricity technologies (especially the steam cycle) are more certain than those for the alcohol production systems.

Capital costs

The total installed capital cost per unit of output capacity for each technology is assumed to vary with capacity as follows:

$$UnitCost = \mathbf{C} + \mathbf{D} \cdot (Capacity)^{\mathbf{E}} \qquad (1)$$

where **C**, **D**, and **E** are constants for a given technology, values for which can be determined from available cost projections. For electricity generation, *UnitCost* is given in $\$/kW_e$. For methanol and ethanol production, *UnitCost* is in $\$/(MJ/hr)_{output}$. For all technologies considered, **E** is a negative number (unit cost falls with increasing capacity), and thus **C** corresponds to the unit cost for a very large facility. If the costs for two facilities with different capacities are available, values for two of the three coefficients in Eqn. 1 can be determined, once a value for the third coefficient is established.[6]

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poor forest roads, $/dt = 1.05 + 0.23·TD. These costs must be multiplied by 1.2 to account for administrative costs (J. Rivelli [formerly head forester at the Shell Brasil plantation], personal communication, Sept. 1992]). The estimate for fair forest roads is used here.

[6] For example, if a value for **C** is established, then $\mathbf{D} = (UnitCost_1 - \mathbf{C})/Capacity_1^{\mathbf{E}}$, where $\mathbf{E} = \{\log([UnitCost_1 - \mathbf{C}]/[UnitCost_2 - \mathbf{C}])\}/\{\log(Capacity_1/Capacity_2)\}$.

Table 2 summarizes all of the capital cost information used to establish the parameter values for Eqn. 1. Figure 3 shows the resulting capital cost versus capacity relationships. These relationships are most accurate in the capacity range shown in Table 2 (e.g. between 10 and 50 MW_e for the steam-rankine power plant technology).

To convert capital costs to annualized costs, we assume capital charge rates (CCRs) of 0.101 for electricity and 0.151 for alcohol production plants. The electricity CCR assumes utility financing.[7] For alcohol production, the CCR is based on average financial parameters for major US corporations between 1984 and 1988.[8]

Feedstock costs and operating and maintenance costs

Fuel/feedstock costs are determined by the efficiencies of the conversion systems. For simplicity, efficiencies are considered to be fixed with capacity for all except one technology (Table 2). Because the steam-rankine technology is commercial today, its efficiency at different capacities is well established, and an equation having the same form as Eqn. 1 has been fit to available performance estimates for use here.[9] For simplicity, operating and maintenance (O&M) costs per unit of output are also assumed fixed regardless of scale for each technology (Table 2).

Total Cost of Electricity and Alcohol Fuels Versus Plant Capacity

For a specific conversion plant capacity, the total levelized cost per unit of output can now be calculated by combining the cost of the feedstock with the capital charge and O&M charges. The levelized cost of electricity (COE) in $/kWh is:

$$COE = (C_b \cdot 3.6)/(HHV \cdot \eta_e \cdot 1000) + UnitCost \cdot CCR/(8766 \cdot CF) + OM \qquad (2)$$

where C_b is the average delivered cost of biomass in $/dry tonne (e.g. from Fig. 1b), HHV is the higher heating value of the biomass (18.44 GJ/dry tonne for switchgrass, 19.34 GJ/dry tonne for eucalyptus), η_e is the electricity generating efficiency (Table 2 for BIG/GT systems and footnote 9 for steam-rankine systems), *UnitCost* is the installed capital cost in $/kW (from Fig. 3), CCR is the capital charge rate (0.101 for power generation), CF is the capacity factor (assumed to be 0.75), and OM is the O&M cost (from Table 2). The levelized cost of alcohol (COA) in $/GJ is:

$$COA = (C_b/HHV)/(\eta_a) + UnitCost \cdot CCR \cdot 1000/(8766 \cdot CF) + OM \qquad (3)$$

where elements on the righthand side are defined as for Eqn. 2, except that η_a is the

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[7] For the USA, the CCR is for utility-financed renewable energy power plants, based on a 30-year life, 6.2% real pre-tax discount rate, and 38% income tax [EPRI, 1993]. For Brazil, the CCR corresponds to an assumed 9.5% discount rate and 30-year plant life.

[8] Average financial parameters for major US corporations during 1984-1988 were 9.91% real return on equity, 6.2% real return on debt, 30% debt fraction, and 44% corporate income tax. The CCR also assumes a 25-year plant life and property tax plus insurance of 1.5% per year of the initial capital cost.

[9] For the steam-rankine cycle, η_e (%) = $100 \cdot [0.27 - 0.25 \cdot (MW_e)^{-0.56}]$. See Marrison and Larson [1995].

efficiency of alcohol production (Table 2), *UnitCost* is the installed capital cost in $/MJ/hr (Fig. 3), CCR is assumed to be 0.151, and CF is assumed to be 0.9.

Table 2. Estimated Unit Installed Capital Costs (1994$), Conversion Efficiencies, and Operating and Maintenance Costs (1994$) for Biomass Energy Conversion Systems at Various Capacities.[a]

Electricity production systems	Capacity[b] (MW_e)	Generating efficiency (%)[c]	Capital cost ($/$kW_e$)	O&M[d] ($/kWh)
Steam rankine cycle	10	20	3510	0.0125
	50	n.r.[e]	1647	0.0125
	large	27	1200	0.0125
Biomass-gasifier/gas turbine (BIG/GT) combined cycle using near-atmospheric pressure gasifier and wet scrubbing cleanup	10	37	2577	0.008
	60	37	1288	0.008
	large	37	1200	0.008
Biomass gasifier/gas turbine combined cycle (BIG/GT) using pressurized gasifier and ceramic filter hot gas cleanup	30	40	1800	0.008
	60	40	1425	0.008
	large	40	1100	0.008
Alcohol fuel production systems[f]	Capacity (GJ/hour)[g]	Production efficiency (%)	Capital cost ($/MJ/hr)	O&M ($/GJ)
Methanol via indirectly-heated gasifier	811	60	317	2.61
Methanol via indirectly-heated gasifier, earlier design estimates	1049	n.r.	162	n.r.
	5245	n.r.	112	n.r.
Ethanol via enzymatic hydrolysis	1355	50	151	2.18
Ethanol via enzymatic hydrolysis, earlier (circa-1990) process design	590	n.r.	341	2.46
	2956	n.r.	230	2.46

(a) See Marrison and Larson [1995] for sources and other details.

(b) "Large" refers to the capacity at which it is assumed that the minimum unit installed capital cost is reached.

(c) 100 times the electricity or fuel production divided by the higher heating value of the input biomass.

(d) Assumed constant for all capacities.

(e) Not required for the analysis in this paper.

(f) Best estimates for methanol and ethanol system capital costs were available only for a single capacity. For these systems, the scaling exponent, **E**, in Eqn. 1 was assumed to be -0.3, a typical value for scaling total plant costs for many chemical processes. Coefficients **C** and **D** in Eqn. 1 were scaled from those determined using the "earlier design" estimates shown here. See Marrison and Larson [1995] for details.

(g) To convert GJ/hr to liters/hr, divide by the appropriate higher heating value: 0.0181 GJ/lit for methanol and 0.0228 GJ/lit for hydrous ethanol (95% ethanol, 5% water).

Baseline results are presented here. Marrison and Larson [1995] examine the impact of changing (for the USA sites) the variable transport costs ($0.18/dry tonne-km, baseline), planting density (0.94 baseline), switchgrass yields, and land rents.

Electricity production costs

Fig. 4a and 4b show the calculated results for the COE versus scale for the USA, and Fig. 5a shows results for the Brazil site. For small capacities, falling unit capital costs with scale for the conversion systems more than offset increasing biomass costs that arise from increased transportation costs. The total COE reaches a minimum (COE_{min}) at the capacity at which the rate of decrease in unit capital cost equals the rate of increase in the transport costs. At capacities larger than this, there is a very gradual rise in the COE as the transport costs become increasingly more important.

For a given technology, the considerably lower biomass costs projected for 2020 compared to 2000 or in the SE compared to the NC regions (Fig. 1b), lead to considerably lower COE_{min} in 2020 compared to 2000 and in the SE compared to the NC regions, and higher installed capacities at which these minima are reached (Table 3). At the Brazilian site, biomass costs, and correspondingly the values of COE_{min}, are somewhat higher than those for 2020 in the SE USA. However, for a given technology, the capacity at which the COE_{min} is reached is smaller at the Brazilian site than in either of the US regions. This is due in large part to the lower assumed planting density, ρ, (0.8 for Brazil vs. 0.94 for USA), which leads to a greater weighting of transport costs in Brazil.[10] If lower planting densities are assumed in the USA, the capacity at which COE_{min} is reached falls [Marrison and Larson, 1995].

In all cases, the capacity at which the COE_{min} is achieved is relatively large (e.g. up to 500 MW_e for the steam rankine cycle). However, because of the flatness of the COE curves around their minima, the COE_{min} is actually approached at much smaller capacities: the capacity at which the COE is within 1% (5%) of COE_{min} is about half (one-quarter) of the capacity at COE_{min} (Table 3).

For the steam-rankine cycle, the capacities for being within 5% of the minimum COE (85-111 MW_e for the lowest-cost cases in Brazil and the USA) are larger than existing biomass-fired steam-rankine power plants. Most such plants rely on low-cost biomass (e.g. byproducts of industrial processing), and their scales are set by the availability of feedstock, rather than by economies of scale.

The COE_{min} with BIG/GTCC cycles are approached at much smaller capacities than with the steam-rankine cycles (COEs within 5% of COE_{min} at 27-91 MW_e--Table 3), because most of the scale economy gains in capital cost occur at smaller capacities (Fig. 3).

At any scale, the higher efficiency (and lower capital costs) of the BIG/GT systems make them a significantly less costly source of electricity than steam-rankine cycles. With the

[10] Marrison [1995] shows analytically using the simplified approach to estimating delivered biomass costs, that the capacity at COE_{min} is determined not only by ρ, but by the interaction between ρ, **E** and **D** (coefficients in Eqn. 1), **Y** (yield), **TC** (variable transport cost), and **F** (road layout factor).

Table 3. Minimum Cost of Electricity (COE_{min}) as a Function of Installed Capacity for North Central and Southeast USA and for Southern Bahia, Brazil and Related Installed Capacities.

Electricity technology	Year	Minimum COE (1994$/kWh)	Installed Capacity (MW_e)		
			For COE = minimum	For COE within 1% of minimum	For COE within 5% of minimum
NORTH CENTRAL USA					
Steam-rankine cycle	2000	0.090	366	212	86
	2020	0.077	470	227	101
Low-pressure BIG/GTCC	2000	0.066	114	60	27
	2020	0.057	127	61	30
Pressurized BIG/GTCC	2000	0.062	269	123	65
	2020	0.054	290	137	72
SOUTHEAST USA					
Steam-rankine cycle	2000	0.065	424	214	99
	2020	0.060	519	244	111
Low-pressure BIG/GTCC	2000	0.049	130	61	37
	2020	0.046	142	64	37
Pressurized BIG/GTCC	2000	0.046	285	140	85
	2020	0.043	319	154	91
SOUTHERN BAHIA STATE, BRAZIL					
Steam cycle	1995	0.065	280	155	85
Low-Pr. BIG/GT	1995	0.048	110	60	35
Press. BIG/GTCC	1995	0.046	230	135	80

costs in Table 3, BIG/GTs would be competitive with power from new coal-fired plants in the USA: coal-based electricity in 2000 and in 2020 is projected to cost $0.049/kWh and $0.052/kWh, respectively, in the NC region and $0.047/kWh and $0.049/kWh, respectively, in the SE region.[11] BIG/GTCC systems might become competitive in the

[11] These electricity costs are based on capital and operating costs and performance estimates of the Electric Power Research Institute for 300 MW_e pulverized coal subcritical-steam plants with flue gas desulfurization in the East-West Central and Southeast regions [EPRI, 1993] (corresponding to the NC and SE regions in the analysis in this paper) and on electric utility steam-coal prices projected by the US Department of Energy for the West-North Central and South Atlantic regions [EIA, 1995]. For the NC region (in 1994$), the capital cost for the coal facility is $1662/$kW_e$, with fixed and variable O&M costs of $48.8/kW-yr and $0.0021/kWh, and a heat rate of 10.719 MJ/kWh. For the SE region, the corresponding figures are

NC region only when year-2020 targets are achieved with the system using pressurized gasification. In the SE region, BIG/GTCC systems would compete in year 2000 as well as 2020. In Brazil, the low COEs (assuming present biomass production technology) are likely to be able to compete with a variety of other new power sources in the future, including new hydroelectric facilities (see Carpentieri, et al. [1993]).

Alcohol fuel production costs

Fig. 4c and 4d show calculated results for the COA versus scale for the US sites and Fig. 5b shows results for the Brazil site. Similar patterns are observed as with the electricity costs, with one major difference for the US sites: the capital costs of the fuel production facilities dominate the total costs for capacities up to those that can be supported by biomass supplied from the entire site used for our analysis (circular area of about 32 km radius). (No constraints were placed on the physical extent of the Brazilian site.) For the US sites, even at capacities requiring transport of biomass from the 32-km limit, capital costs are still falling at a faster rate than biomass transport costs are rising. No absolute minimum is reached within the limits of the capacity scale shown in Fig. 4c and 4d.

Table 4 gives values of the lowest COA's reached (subject to the biomass availability constraint) and related installed capacities. In general, when biomass costs are relatively lower, plant capacities that give minimum COAs are larger.

Methanol production costs reach 5% of the minimum COA at capacities of 1322 GJ/hr (169 million gal/yr) and 2018 GJ/hr (258 million gal/yr) for the NC and SE USA in 2000, respectively, and 1849 GJ/hr (236 million gal/yr) and 2786 GJ/hr (357 million gal/yr) in 2020. These capacities are comparable to those of the largest existing industrial biomass processing facilities or methanol-from-natural gas plants.[12]

Ethanol production costs approach a minimum at smaller plant capacities than for methanol due to the lower assumed capital intensity (Fig. 3) of ethanol plants. Capacities for a COA within 5% of the minimum range from 650-1470 GJ/hr (66-149 million gal/yr) among all of the cases considered (Table 4).

For the USA sites, the COA_{min} for methanol in 2020 ranges from \$10.1-12.4/GJ (\$0.70-0.85/gallon), with the lower cost in the SE region (Table 4). The corresponding range for ethanol is \$8.6-11.2/GJ (\$0.75-0.97/gallon). For comparison, the average wholesale price of gasoline in 1993 in the US was about \$4.5/GJ (\$0.6/gallon), and is projected to rise

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\$1359/kW_e, \$42.0/kW-yr, \$0.0015/kWh, and 10.371 MJ/kWh. The DOE projects coal prices in 2000 and 2010. Assuming a continuation of the projected growth rate between 2000 and 2010 to estimate year 2020 prices, coal prices in the NC region in 2000, 2010, and 2020 would be \$1.14/GJ, \$1.27/GJ, and \$1.40/GJ, respectively. For the SE region, the corresponding prices would be \$1.56/GJ, \$1.66/GJ, and \$1.77/GJ.

[12] The Puenta Arenas facility in Southern Chile is among the largest methanol producing facilities operating today using natural gas as the feedstock. Its capacity is about 300 million gal/yr. The capacities of the largest facilities in the US producing ethanol from corn today are of this order, and the largest ethanol-from-sugarcane factories in Brazil are about half this capacity. The biomass input capacity of a typical modern large integrated pulp and paper mill today is equivalent to that of a methanol-from-biomass facility that would have a capacity of about 200 million gal/yr.

Table 4. Minimum Cost of Alcohol (COA) as a Function of Installed Capacity for North Central and Southeast USA and Southern Bahia, Brazil and Related Installed Capacities.

Alcohol Type	Year	Minimum COA (1994$/GJ)	Installed Capacity (GJ per hour)		
			For COA = minimum[a]	For COA within 1% of minimum	For COA within 5% of minimum
NORTH CENTRAL USA					
Methanol	2000	14.2	> 2700	2373	1322
	2020	12.4	> 3800	3235	1849
Ethanol	2000	13.1	> 2200	1532	652
	2020	11.2	> 3200	2267	952
SOUTHEAST USA					
Methanol	2000	10.9	> 3800	3451	2018
	2020	10.1	> 5400	4930	2786
Ethanol	2000	9.4	> 3200	2435	1070
	2020	8.6	> 4500	3199	1471
SOUTHERN BAHIA STATE, BRAZIL					
Methanol	1995	10.9	10789	6178	2553
Ethanol	1995	9.7	3783	1898	795

(a) For all USA cases, the biomass available at the site was exhausted before an absolute minimum COA was reached. The COA_{min} indicated for these cases is the lowest COA achieved up to this limit in biomass supply.

to about $6.8/GJ in 2010 ($0.9/gal).[13] With these costs for gasoline, neither ethanol nor methanol are competitive on a per-unit of energy basis. However, ethanol and, especially, methanol will be suitable fuels for fuel cell vehicles (FCVs) that are under intensive development for commercial application early in the next century [Williams, 1994]. With gasoline-equivalent fuel economies[14] of methanol-FCVs expected to be some 2.4 times those for comparable gasoline internal combustion engine vehicles [Ogden et al., 1994], methanol would be able to compete on a cost-per-vehicle-km basis with gasoline with methanol prices (in $/GJ) up to 2.4 times those for gasoline.

[13] The 1993 gasoline cost is the 1993 average retail price of $8.64/GJ ($1.14/gal) (across all fuel grades of motor gasoline and including state and federal taxes) [EIA, 1995] minus $0.31/gal in state and federal taxes and $0.23/gal in distribution and filling station costs [Ogden, et al., 1994]. The US DOE projects an average retail gasoline price (including taxes) of $10.85/GJ ($1.43/gal) in 2010.

[14] For methanol, the gasoline-equivalent fuel economy (km/liter of gasoline equivalent) is the distance traveled per unit of methanol (in km/GJ) times 0.0349 GJ/liter, the higher heating value of gasoline.

Conclusions

This paper examined the impact of scale on prospective costs of electricity and alcohol fuels from plantation-grown biomass at sites in the USA and Brazil. All results are based on assumed biomass production and conversion technology costs, most of which have not yet been commercially demonstrated. A simplified approach was developed to estimate biomass supply costs for the Brazil site after validating the approach against a detailed GIS-assisted analysis. The simpler approach eliminates the need for the GIS analysis and provides a tool that can be used in future analysis of the type described in this paper.

A key conclusion of this paper is that for any of the technologies examined, the capacity needed to achieve a minimum levelized energy production cost is relatively large, but costs are relatively insensitive to large changes in the capacity around that value.

There are important distinctions among cost-capacity characteristics of different systems. The cost of electricity generation (COE) is considerably lower at all scales for gasifier/gas turbine combined cycles (BIG/GTCCs) compared to steam-rankine cycles, and BIG/GTCCs achieve minimum costs at much smaller capacities than steam-rankine cycles. Assuming year-2020 switchgrass production systems in the USA, the COE for steam-rankine cycles reaches within 5% of its minimum at 100-110 MW_e. BIG/GTCC COEs reach 5% of their minimum at capacities of 30 to 40 MW_e with unpressurized gasification and at 70 to 90 MW_e with pressurized gasification. The latter technology is the lowest-cost electricity producer at capacities larger than 50 to 75 MW_e. The lowest cost of electricity production is in the Southeast region (4.3 to 4.6 c/kWh for BIG/GTCC), where delivered biomass costs are the lowest. At the Brazilian site, COEs are slightly higher than for the year-2020 in the SE USA, but the biomass production costs are based on existing commercial plantations.

Projected costs of alcohol (COA) are lower for ethanol than for methanol by 8-10% at the NC USA site, 15% at the SE site, and 11% at the Brazilian site. Plant capacities that achieve a COA within 5% of the minimum for methanol are twice those for ethanol at the US sites and triple those for ethanol at the Brazilian site. Methanol facilities achieve COAs within 5% of the minimum when they are comparable in size to the largest existing industrial biomass processing facilities (e.g. a state-of-the-art pulp and paper mill).

Acknowledgements

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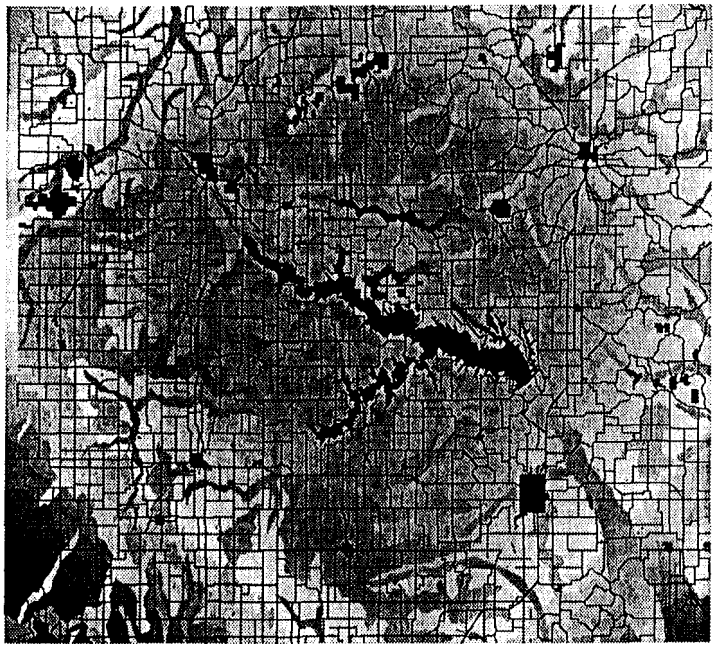

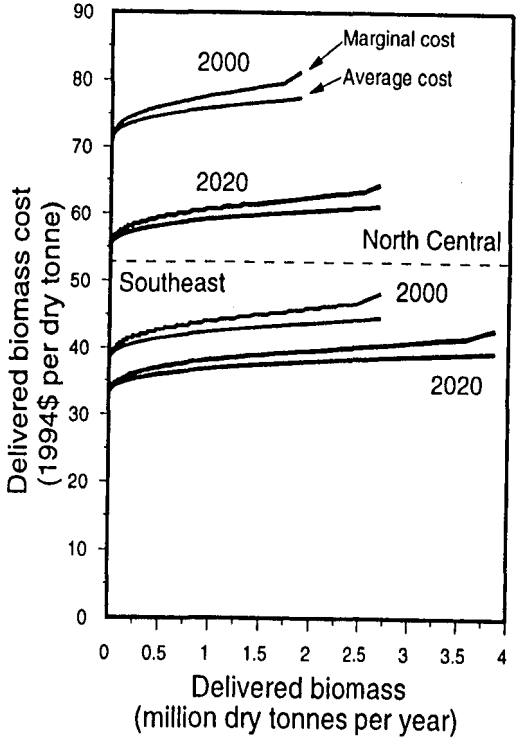

(b)

Fig. 1. Levelized costs of switchgrass delivered to an energy conversion facility from a 5100 km^2 area in south central Iowa, USA, as estimated from a GIS analysis.
(a) **Qualitative results: extent of shading reflects relative cost, taking account of soil productivities and road-transport distances to the facility at a one-acre resolution. Black areas represent towns, lakes, and other areas where biomass cannot be grown. The conversion facility is assumed to be on the edge of the centrally located lake. Costs generally rise with radial distance away from the facility. In some places land that is physically further from the facility but more productive than land closer to the facility gives lower biomass costs.** ***(b)*** **Quantitative results: switchgrass cost-supply curve for production systems in 2000 and 2020 in the North Central and Southeast regions of the USA. Costs rise with tonnage supplied due to increasing transportation distances and/or decreasing soil productivities.**

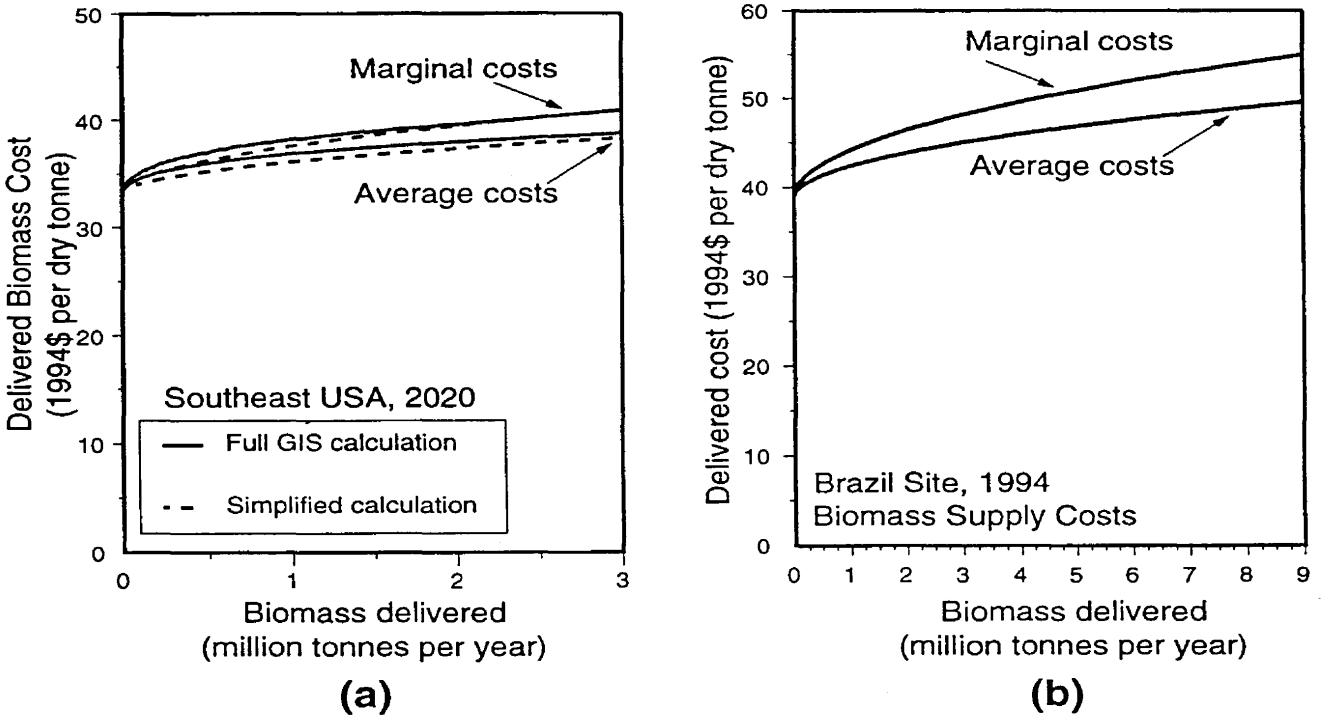

Fig. 2. ***(a)*** **Comparison of the costs of delivered switchgrass bales for a site in the SE USA in 2020 as predicted by the GIS analysis (from Fig. 1*b*) and by the simplified approach outlined in the text.** ***(b)*** **Eucalyptus cost-supply curve for the Brazilian site, assuming present plantation practice in Brazil.**

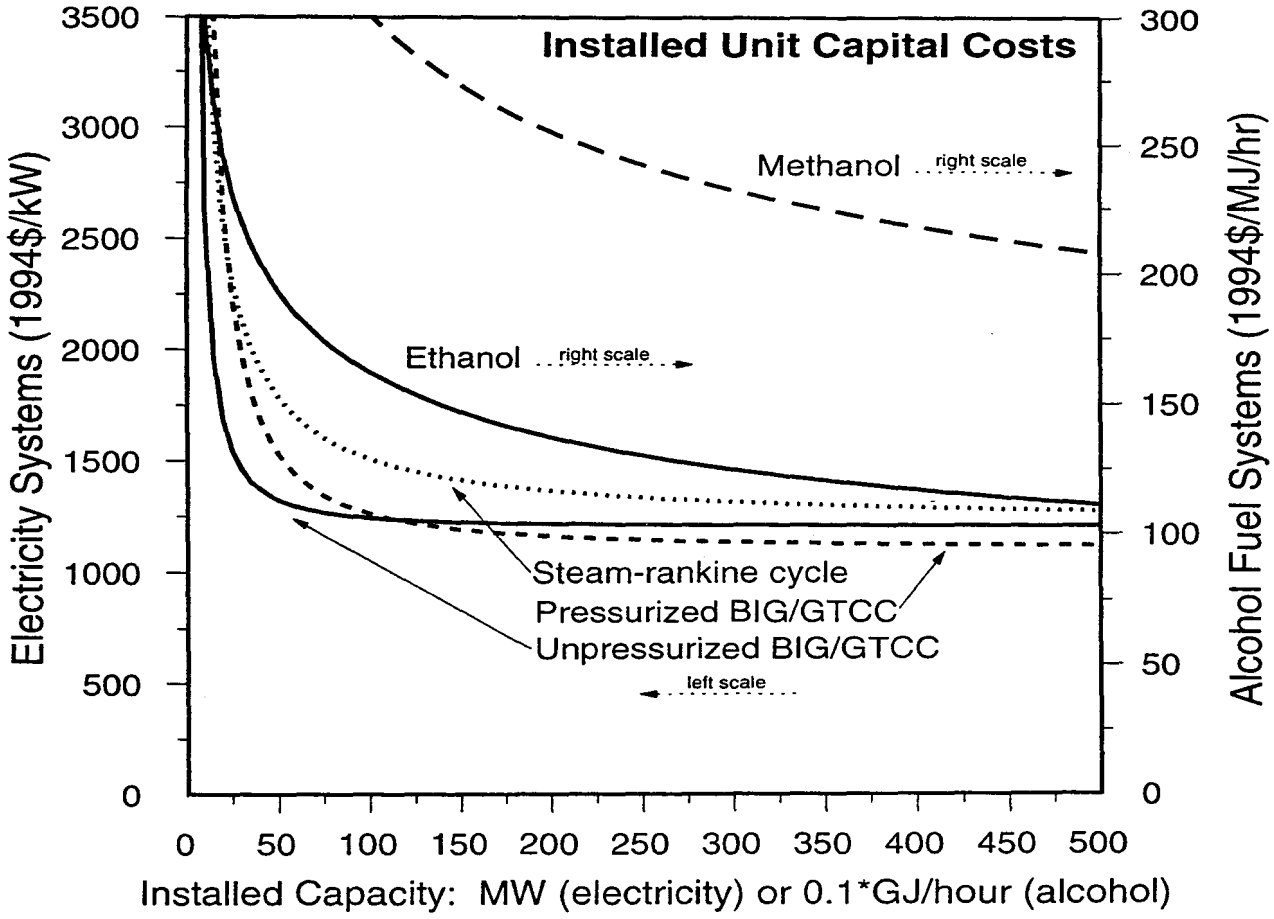

Fig. 3. Estimated installed capital costs of biomass-fed electricity generation and alcohol fuel production. See Marrison and Larson [1995] and Marrison [1995] for details. The curves plot the following derived relationships:
Steam-rankine cycle, $/kW = 1200 + (22195)·MW$^{-0.93}$
Pressurized BIG/GTCC, $/kW = 1100 + (110420)·MW$^{-1.42}$
Unpressurized BIG/GTCC, $/kW = 1200 + (47198)·MW$^{-1.56}$
Methanol: $/MJ/hr = 57.7 + (1934)·(GJ/hr)$^{-0.3}$
Ethanol: $/MJ/hr = 28.0 + (1070)·(GJ/hr)$^{-0.3}$

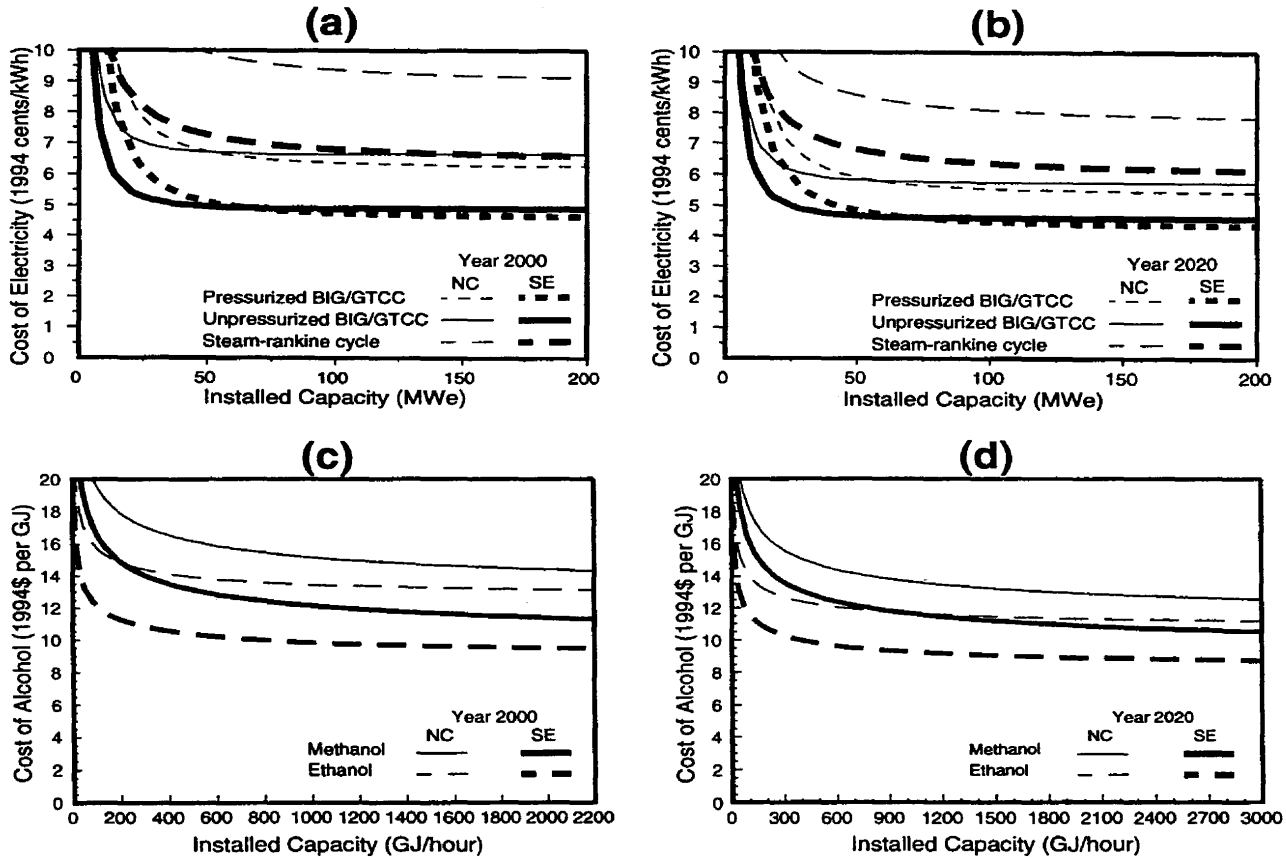

Fig. 4. ***(a) and (b)*** **Total levelized cost of electricity production as a function of installed capacity for the selected site in the NC and SE regions of the USA in year 2000 and year 2020.** ***(c) and (d)*** **Total levelized cost of methanol and ethanol production as function of capacity.**

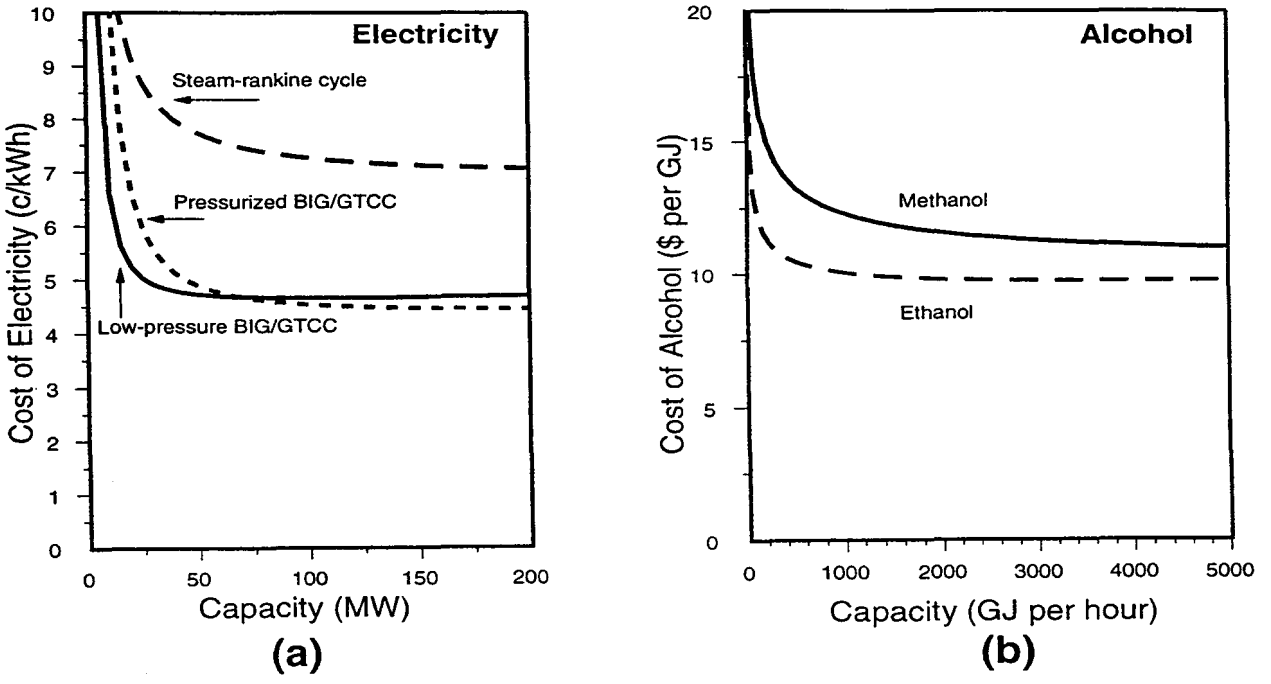

Fig. 5. Total levelized cost of *(a)* electricity production and *(b)* alcohol fuel production, as functions of installed capacity for the Brazilian site, assuming delivered eucalyptus costs from Fig. 2b, corresponding to present industrial plantation practice in the region of the selected site.

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* Present address: Oliver, Wyman & Company, LLC, 666 Fifth Ave., New York, 10103.

COMPARATIVE EVALUATION OF FUEL COSTS FROM ENERGY CROPS

Evan E. Hughes, Ph.D., Project Manager, Electric Power Research Institute, Palo Alto, CA
George A. Wiltsee Jr., MBA, Appel Consultants, Inc., Stevenson Ranch, CA

Abstract

Experience with establishment, cultivation, and harvesting of biomass crops is limited to the work of forest products companies and a few small government-funded research trials of energy crops. This experience is not yet sufficient to allow renewable energy project planners to estimate the cost of fuel from energy crops with confidence. This paper summarizes, compares, and evaluates the results of several recent engineering-type studies that address the cost of farm-grown biomass fuel, with emphasis on short rotation woody crops (SRWC). These studies -- by such organizations as Oak Ridge National Laboratory, University of Minnesota (Natural Resources Research Institute - Duluth), University of California (Davis), Pennsylvania State University, State University of New York (Syracuse), and the Electric Power Research Institute -- identify the key cost elements, the likely ranges of those cost elements, and the conditions, government policies, and technical developments that will help drive down the cost of biomass fuel to a competitive level.

Fuel from energy-dedicated SRWC using fast-growing clonal varieties of trees is projected to cost as little as $1/MBtu and as much as $4/MBtu, depending on conditions. Key cost elements include (1) "stumpage" price (establishment and cultivation costs, i.e., pre-harvest costs), estimated to range from $18 to $41/dry ton (dt); (2) harvest and handling cost, estimated to range from $2 to $19/dt; and (3) transport cost, estimated at about $8.50/dt for a nominal 40-mile haul. (The higher heating value of wood is about 17 MBtu/dt.) Conditions necessary to achieve the low end of the cost range, and thus make biomass a competitive fuel, include either (1) an agricultural subsidy such as the Conservation Reserve Program; and/or (2) very high yields of biomass (e.g., ≥ 10 dt/acre/year); and (3) development of an agricultural-type harvesting machine to place trees directly on transport vans without separate skidding and loading operations.

Short Rotation Woody Crops

Growing short rotation woody crops (SRWC) is "intensive culture"; it is agriculture, not forestry. The key figure of merit for an energy crop is the yield, or "mean annual increment" (MAI). Yield is the average amount of harvestable dry plant matter ("biomass") that grows per unit of land area per year.

Yields of commercial interest are in the range from five to 20 dry tons/acre/year (dt/a/y) -- much larger than the yields of forests, which are below one dt/a/y. High yields of SRWC are obtained by selecting individual trees that have demonstrated especially fast growth and other desirable properties such as drought or frost tolerance. These individuals ("clones") are propagated by cutting sticks 3/8" to 3/4" in diameter and planting them to produce more individuals of that same genetic material.

The most critical parameter determining the yield from a given clone is water. The species used for SRWC are prolific water users that originated on river bottom sites (cottonwood "poplars", silver maple, willow), or in wet climate areas (some eucalyptus). They achieve best growth under unrestricted water availability. [Hansen 1995] Soil properties -- moisture-holding capacity, porosity, resistance to water evaporation, permeability, and access to the water table -- are also critical factors. Precipitation, especially during the growing season, is the major factor of climate. Although biomass captures the solar energy of sunlight, water rather than direct sunlight is the limiting factor in biomass growth.

This fact has led many to conclude that a map of energy crop potential in the U.S. is essentially a map of precipitation, with some regions excluded due to steep slopes. Irrigation is considered too expensive, given the low value of biomass fuel compared to food, feed, or fiber products. Others hold that irrigation will turn out to be an acceptable cost component in SRWC production schemes. They believe that optimum systems will be those that exercise control over water input and thus reduce risk while increasing yields.

Hybrid Poplar Cost Estimates

Natural Resources Research Institute (NRRI)

Table 1 shows some results of the University of Minnesota's Natural Resources Research Institute (NRRI) analysis of establishment and cultivation costs for hybrid poplar in the upper midwest. [Berguson 1994] NRRI gathered information on land and climate suitability and Conservation Reserve Program (CRP) acreage in the states of Wisconsin, Minnesota, the extreme northwestern portion of upper Michigan, and northeastern Iowa. NRRI then summarized land rental and hybrid poplar yield data in each of the geographic units, and used a cash flow model of the production system to estimate wood production costs ("stumpage prices") based on a 3% after tax discount rate (roughly equivalent to a 5% before tax rate). Cost-share options offered by two farm programs, the CRP and the Agricultural Conservation Program (ACP), were compared to a baseline scenario in which no government incentives were available.

Interestingly, the table shows that more expensive farmland produces lower-cost biomass when the CRP is available. This is because the CRP provides an annual payment roughly equal to the rental value of the land. The CRP also provides a cost share of about 50% of the site preparation and establishment cost (reduced by any previous CRP cost share, for example to establish grass on the same land). Stumpage prices in the scenarios with the

Table 1
NRRI Estimates of Hybrid Poplar SRWC Stumpage Prices

Geographic Unit	Average Rent, $/a/y	Yield, dt/a/y	Stumpage Price, $/dt With CRP	With ACP	With No Cost Share
IOWA-NE	94	5	4.85	27.70	35.00
MN-P3: 2	83	5	5.05	24.90	32.25
MN-CH2	69	5	5.25	21.30	28.65
WI-SW	55	5	5.60	17.80	25.05
MN-P3: 1	55	4.5	6.20	19.70	27.85
WI-CENT*	36	4.5	6.85	14.30	22.45*
MN-CH1	32	3.75	8.40	15.80	25.60
MN-P1	39	3.5	8.65	19.45	29.95
WI-NE	23	3	11.30	15.90	28.15
WI-NW	19	3	11.70	14.20	26.40
MN-NP	17	3	11.85	13.30	25.55
MI-WUP	23	2.5	13.60	19.10	33.80
MN-AB	15	2.5	14.45	14.95	29.65

(SOURCE: Berguson 1994) *(lowest cost case)

ACP and with no subsidies are much higher than in the CRP scenario ($13.70-30.15/dry ton or $0.81-1.77/MBtu higher). They also tend to go in the opposite direction, again because the annual cost of land (rent) is a large part of the biomass production cost.

The case labelled WI-CENT is an example of the kind of niche that project developers will look for in early SRWC projects. The low land rent ($36/a/y) combined with the relatively high yield (4.5 dt/a/y) produces a relatively low stumpage price with no subsidy.

Oak Ridge National Laboratory (ORNL)
ORNL's cost estimates use a "full economic cost accounting approach", which assumes that all resources used in the production of SRWC have value, even if that resource is currently owned, rather than purchased, by the producer. Full economic cost of production budgets include variable and fixed cash costs, as well as the opportunity cost of labor, land, and investments in other non-land capital. [Walsh and Graham 1995] ORNL has produced detailed cost of production budgets for hybrid poplar, willow, and switchgrass plantations. Table 2 shows one of ORNL'S SRWC production budgets for hybrid poplar.

Pennsylvania State University
Charles Strauss of the School of Forest Resources at Pennsylvania State University has developed models of the economic and energy costs of SRWC using data from the ORNL R&D program. [Strauss and Grado 1992] This work is based on data and assumptions that are now somewhat dated. Plantation establishment and cultivation practices were very similar to those in the NRRI study. Costs for individual operations are shown in Table 3.

The SRWC plantations were based on hybrid poplars planted on good quality agricultural sites at a density of 850 trees/acre (about 7.2' spacing). Rotation length was placed in the probable range of five to eight years, with two or three rotations anticipated from any given planting. Optimum rotation was selected on a least-cost basis using a discounted cash flow analysis.

Table 2
ORNL Production Budget for Hybrid Poplar SRWC in the North Central Region -- Soil Classes 2C, 3S, 4S, 4W (Dollars/Acre)

Year:	1	2	3	4	5	6	7
Variable cash:							
Cuttings	120.25						
Fertilizer	8.60	23.40		23.40		23.40	
Chemicals	83.10						
Fuel/lube	6.28	8.38	3.57	1.23		1.23	
Repairs	6.55	4.89	3.39	0.55		0.55	
Soil testing	0.25						
Hired labor	74.00						
Custom harvest							670.20
Subtotal	299.03	36.67	6.97	25.18	0.00	25.18	670.20
Fixed cash:							
Overhead	9.46	9.46	9.46	9.46	9.46	9.46	9.46
Taxes/insurance	16.13	16.13	16.13	16.13	16.13	16.13	16.13
Interest (op loan)	5.20	0.64	0.12	0.44	0.00	0.44	13.32
Interest (r.e.)	10.65	10.65	10.65	10.65	10.65	10.65	10.65
Subtotal	41.44	36.88	36.36	36.68	36.24	36.68	49.56
Owned resources:							
Land	54.00	54.00	54.00	54.00	54.00	54.00	54.00
Labor	9.10	10.97	4.68	1.61	0.00	1.61	0.00
Nonland capital	2.95	2.80	1.29	0.21	0.00	0.21	0.00
Cap. replacemt	6.26	5.73	2.60	0.52	0.00	0.52	0.00
Subtotal	72.31	73.50	62.57	56.34	54.00	56.34	54.00
Total costs	412.78	147.05	105.90	118.20	90.24	118.20	773.76

Irrigated Eucalyptus Cost Estimates (UC Davis)

Bruce Hartsough of the Biological and Agricultural Engineering Department at the University of California, Davis (UC Davis) has analyzed SRWC operations on an irrigated eucalyptus pulpwood and energy plantation in California. His primary focus has been on the potential for cost reduction through additional mechanization and improved technology. He has projected large potential cost reductions from an improved method of delimbing and debarking, and other large gains from a continuous-travel felling machine and a better method of handling drip irrigation lines. Minor benefits would accrue from lighter chip vans and from further mechanization of some cultural operations: planting, stump removal, and thinning of coppice sprouts. [Hartsough and Richter 1994]

The specific plantation studied was Simpson Timber Company's Tehama Fiber Farm, located near Corning, California (about 100 miles north of Sacramento). The plantation will provide a large part of the hardwood supply for Simpson Paper Company's pulp mill,

Table 3
Penn State/ORNL SRWC Cost Estimates

Operation	Cost, 1993 $/acre
Establishment:	
Fall/spring herbicides (3 lb/acre)	89
Mowing/brushing	10
Plowing/harrowing	24
Liming (900 lb/acre)	21
Fertilization (54 lb/a each P and K)	22
Planting (850 cuttings/acre)	65
Summer herbicides, year 1 and 2 (2 lb/ac)	59
Total establishment costs	290
Maintenance (not all are annual costs):	
Insecticide/fungicide (1.4 lb/ac/application)	15
Fertilization (107 lb of N/ac/application)	18
Land rent	43
Land taxes	7
Managerial	18
Approximate average annual costs	165

(SOURCE: Strauss and Grado 1992)

and residues will be used as fuel by Wheelabrator Shasta Energy Company's freestanding electric power plant. The plantation covers about 10,000 acres; the first block (1,239 acres) was planted in 1989, and the last block was scheduled to be planted in 1995. Rotation age is expected to be eight years, and yields are assumed to average 9 dt/a/y. Planting densities have varied somewhat; 620 trees/acre (7' x 10' spacing) was used by Hartsough as a typical value. The site is dry during the eight warmest months of the year, so drip irrigation is required. Haul distances are 44 miles to the pulp mill and energy plant.

Hartsough and coauthors estimated the costs of establishment, annual, harvesting, and reestablishment activities. Each set of activities is performed on a different number of acres. Establishment activities occur on 1,250 acres/year for eight years. Annual costs (opportunity cost of land, management and overhead, irrigation, fertilization, pest and weed control) apply to all 10,000 acres of the plantation. Harvesting activities occur on 1/8 of the plantation each year, or 1,250 acres. Simpson is debating whether to remove stumps and replant at the end of each rotation or to rely on coppice regeneration, so Hartsough assumed a fifty-fifty mix of both methods. Thus, replanting occurs on 625 acres and coppicing occurs on 625 acres each year. (The need to thin sprouts actually makes the coppicing case slightly more expensive than the replanting case.) The annual harvest was assumed to be 72 dry tons/acre (9 dt/a/y x 8 years) from 1,250 acres, totaling 90,000 dry tons. Because of length limitations on this paper, Hartsough and coauthors' cost estimates are presented only in the comparison table below (Table 5).

Willow Cost Estimates (SUNY)

Dr. Edwin White and his colleagues at the State University of New York (SUNY) College of Environmental Science and Forestry have been working with a consortium including

Niagara Mohawk Power Corp. and New York State Electric & Gas Corp. to develop SRWC using willow in the northeastern U.S. Willow SRWC can use very close spacing (e.g., an average of 2.5') and short rotation times (e.g., three years), with a large number of crops (e.g., six rotations) produced by coppicing from the original stumps. Table 4 presents the cost estimates developed by SUNY for a willow plantation in rural New York.

Comparison of SRWC Cost Estimates

Table 5, in three parts, presents a comparison of (A) establishment costs, (B) annual costs, and (C) delivered fuel costs for SRWC from the five sources discussed above: the NRRI study, the ORNL 1995 estimates, and the Penn State study on hybrid poplar in the upper midwest; the UC Davis studies on irrigated eucalyptus in California; and the SUNY study on willow in New York. In cases where the cited studies do not provide estimates for specific cost elements, estimates from one of the other studies have been inserted to allow comparison of the total costs. These "filled in" estimates are marked with an asterisk (*) and are included in totals. In cases where the authors' estimates for specific cost elements are zero, that is indicated in the table. Some costs are incurred in years 2 and 3 that are not incurred in later years (e.g., fertilizer, herbicide, cultivation). Although these costs could arguably be included in establishment costs, they are included here as part of annual costs, spread out evenly in years 2 through the harvest year.

As shown in the table, the cost estimates for site preparation activities for hybrid poplar and willow range from $73 to $144/acre. For the eucalyptus plantation, the site preparation costs include drilling wells for irrigation water, and establishing a network of mains and submains to distribute water to driplines. The estimated cost of this capital investment, which we have assumed to have a useful life of four rotations (32 years), is $746/acre; adding the cost of discing the former pastureland, the total site preparation cost estimate for the eucalyptus plantation is $856/acre.

"Year 1" establishment cost estimates for hybrid poplar and eucalyptus range from $133 to $231/acre. The plants (cuttings) themselves are estimated to cost $0.10-0.13 each, giving a cost of $62-120/acre at the planting densities of 620-910 trees/acre. The estimated costs of the planting operation range from $34 to $74/acre ($0.05-0.08/plant) for hybrid poplar, and $97/acre ($0.16/plant) for eucalyptus. Willow is planted at much higher density (7,200 trees/acre or about 2.5' average spacing). At 10¢/cutting, the cost of the cuttings alone is $720/acre, giving a total establishment cost estimate for willow of $808/acre.

Comparing the NRRI and ORNL site preparation establishment cost estimates for hybrid poplar, ORNL is higher on several key items. The tree density is higher (910 vs. 680 trees/acre); herbicide cost is estimated at $83/acre compared to $20/acre; and the cost of cuttings and planting totals $194/acre vs. $102/acre. The result is that ORNL's site preparation and establishment cost estimate is over 50% higher than that of NRRI, $317/acre compared to $208/acre.

In the NRRI case with the CRP subsidy, the government's payment to the farmer as its cost share of the establishment costs is estimated at $71/acre. This reduces the total NRRI establishment cost estimate from $208 to $137/acre, which is equivalent to reducing the annual cost per dry ton of fuel from $7.33 to $4.83/dry ton.

Part B of the table shows the annual costs of operating the tree farms. Excluding the cost of irrigation, these costs range from $95 to $108/acre/year. For eucalyptus, irrigation adds

Table 4
SUNY Willow DFSS Biomass Production Costs, $/acre

	Contract Price	Farm Price	Years Incurred
Land rental cost	36.90	36.90	All
Consulting fees	50.00	50.00	1
Mowing	8.00	6.80	1
Contact herbicide:			
Materials	24.60	24.60	1
Service	7.00	5.95	1
Plowing	13.10	11.14	1
Cross-discing	20.00	17.00	1
Preemergent herbicide:			
Materials	9.65	9.65	1
Service	7.00	5.95	1
Planting:			
Cuttings	720.00	720.00	1
Service	13.08	3.15	1
Cutback	8.00	6.80	1
Fertilization:			
Materials	31.50	31.50	2,5,8,11,14,17
Service	6.00	5.10	2,5,8,11,14,17
Harvesting	31.14	7.00	4,7,10,13,16,19
Supplemental items:			
Mulch:			
Materials	0.00	0.00	
Service	46.60	39.61	
Supplemental herbicide:			
Materials	15.29	15.29	2
Service	8.75	7.44	2
Insecticide:			
Materials	0.87	0.87	11
Service	6.50	5.53	11

(SOURCE: White 1995)

$101/acre/year to this amount (which approximately doubles the annual cost). In the NRRI case with the CRP subsidy, the farmer collects an annual payment from the government equivalent to the rent payment ($55/acre/year). This reduces the cost from $103 to $48/acre/year, which reduces the annual cost portion of the fuel cost from $27.55 to $12.71/dry ton.

Part C of the table shows the delivered fuel costs per dry ton of biomass from the five plantations. The first two cost elements are the totals from parts A and B of the table, the site preparation and establishment costs and the annual costs. Together these comprise the "stumpage price". NRRI's stumpage price comes out to $34.88/dry ton without the CRP subsidy, and $17.54/dry ton with the subsidy. The CRP subsidy reduces the price of fuel by $17.34/dry ton, or $1.02/MBtu. Eighty-six percent of the $17.34 difference comes from the annual payment.

The ORNL stumpage price estimate is higher, at $38.97/dry ton. As discussed above, the major difference from the NRRI estimate is in the establishment costs. The high yield of

Table 5
Comparison of SRWC Cost Estimates

A. Site Preparation and Establishment Costs (Years 0 and 1)

	Hybrid Poplar				Eucalyptus	Willow
	NRRI (Berguson)		ORNL (Walsh)	Penn State (Strauss)	UC Davis Hartsough)	SUNY (White)
		(CRP)				
Sources (see below)	1	1	2	3	4	5
Tree spacing, feet	8	8	6x8	7.2	7x10	2.5 avg
Number of trees per acre	680	680	910	850	620	7,200
Years of rotation	10	10	7	6	8	3 x 6
Yield, dt/a/y	5	5	5	7	9	7.5
Site preparation cost (year 0 or 1), $/acre:						
Clip/mow	8	8	0	10	0	8
Herbicide	20	20	83	89	0	32
Plow, disc, and/or harrow	37	37	40	24	110	33
Install wells, mains, submains	0	0	0	0	327	0
Install driplines	0	0	0	0	419	0
Liming	0	0	0	21	0	0
Cover: seed and planting	10	10	0	0	0	0
Total site preparation cost	75	75	123	144	856	73
Establishment cost (year 1), $/acre:						
Consulting fee	0	0	0	0	0	50
Herbicide	20	20	0	59	0	17
Cuttings, $/plant	0.10	0.10	0.13	0.10*	0.10	0.10
Cuttings, $/acre	68	68	120	85*	62	720
Planting, $/plant	0.05	0.05	0.08	0.08	0.16	0.0018
Planting, $/acre	34	34	74	65	97	13
Irrigation	0	0	0	0	44	0
Fertilization	0	0	0	22	3	0
Cultivation (cutback for willows)	11	11	0	0	0	8
CRP cost share	0	-71	0	0	0	0
Total establishment cost	133	62	194	231	206	808
Total site prep and estab cost, $/acre	208	137	317	375	1,062	881
Site prep and estab cost, $/dry ton**	7.33	4.83	13.22	12.23	13.73	12.01

Notes: *Estimate "filled in"; no estimate was provided by cited study.
**The amount per dry ton required at harvest to set the net present value of cash flows to zero using a 6.5% discount rate. For eucalyptus, it is assumed that the wells, mains, and submains last for four rotations (32 years), and that the cost of replanting is $235/acre. For willow, establishment costs are spread over six rotations (18 years), with no replanting until year 19.

the irrigated eucalyptus plantation (9 dt/a/y) helps to overcome the high cost of establishing and operating the irrigation system, giving an estimated stumpage price of $41.47/dry ton. The high yield and use of coppice regeneration for an assumed six rotations combine to give willow the lowest stumpage price of the five systems, $26.58/dry ton.

For the poplar and eucalyptus systems, the total of harvesting plus transportation costs add about $25 to $28/dry ton to the stumpage price, to produce the delivered fuel cost estimates. The ORNL and UC Davis estimates produce nearly equal delivered fuel costs of $66.62 and $65.76/dt, or $3.92 and $3.87/MBtu. NRRI's estimate is $62.53/dt or $3.68/MBtu. The Penn State estimate is $53.39/dt or $3.14/MBtu.

Table 5 (continued)
Comparison of SRWC Cost Estimates

B. Annual Costs (Years 1 through Harvest)

	Hybrid Poplar				Eucalyptus	Willow
	NRRI (Berguson)		ORNL (Walsh)	Penn State (Strauss)	UC Davis Hartsough)	SUNY (White)
		(CRP)				
Sources (see below)	1	1	2	3	4	5
Tree spacing, feet	8	8	6x8	7.2	7x10	2.5
Number of trees per acre	680	680	910	850	620	7,200
Years of rotation	10	10	7	6	8	3 x 6
Yield, dt/a/y	5	5	5	7	9	7.5
Annual costs, $/acre/year:						
Land rent	55	0	54	43	54*	37
Land taxes and insurance	16*	16*	16	7	16*	16*
Tending (e.g., fertilizer, herbicide)	7	7	13	33	10	17
Irrigation	0	0	0	0	101	0
Overhead, interest, etc.****	25*	25*	25	18	25*	25*
Total annual costs, $/acre/year	103	48	108	101	206	95
Annual costs, $/dry ton**	27.55	12.71	25.76	15.91	27.74	14.57

C. Delivered Fuel Costs

Costs per dry ton, $/dt:		(CRP)				
Site prep and establishment cost	7.33	4.83	13.22	12.23	13.73	12.01
Annual costs	27.55	12.71	25.76	15.91	27.74	14.57
Stumpage price	34.88	17.54	38.97	28.14	41.47	26.58
Harvesting costs (incl. chipping)	19.15*	19.15*	19.15	18.00	15.83	1.38
Transportation costs (40 mi)	8.50*	8.50*	8.50	7.25***	8.46	8.50*
Delivered fuel cost, $/dt	62.53	45.19	66.62	53.39	65.76	36.46
Delivered fuel cost, $/MBtu	3.68	2.66	3.92	3.14	3.87	2.14

Notes: *Estimate "filled in"; no estimate was provided by cited study.
**The amount per dry ton required at harvest to set the net present value of cash flows to zero using a 6.5% discount rate. In year 1, the costs of tending and irrigation (if any) are excluded.
***Adjusted from $5.00/dt for a 25-mile haul in the cited study.
****"etc." refers to owned resources, including labor, capital recovery, and capital replacement.

SOURCES:
1. Berguson 1994.
2. Walsh and Graham 1995; Walsh 1995.
3. Strauss and Grado 1992.
4. Hartsough and Richter 1994; Hartsough and Jenkins 1990.
5. White 1995.

Again, in the NRRI study, the CRP subsidy produces a reduction in fuel cost of $17.34/dry ton or $1.02/MBtu. The delivered fuel cost estimate with the CRP subsidy is $45.19/dry ton or about $2.66/MBtu.

The willow plantation is able to take advantage of an agricultural-style harvesting system that has already been developed for closely-spaced young trees. The machine moves through the field at 5 miles/hour or higher, cutting and processing the trees in one step, blowing chips into vans as it harvests. The SUNY estimate for the harvesting cost is $1.38/dry ton, more than an order of magnitude lower than the $15-19/dt estimates for the

forestry-type harvesting systems assumed in the hybrid poplar and eucalyptus studies. Because of the low harvesting cost, the delivered fuel cost estimate from the willow plantation is the lowest of the five systems, $36.46/dry ton or $2.14/MBtu.

Cost Reduction Pathways

Two opportunities for significant cost reduction are (1) major yield improvements, and (2) application of agricultural-style harvesting to widely-spaced trees such as hybrid poplar and eucalyptus. ORNL and others have pointed out that SRWC are in early stages of development and great potential for genetic improvement of yields exists. [Walsh and Graham 1995] For illustrative purposes assume that the yields in Table 5 double. Also assume that an agricultural-style harvesting system similar to one proposed by Energy Performance Systems, Inc. for its Whole Tree Energy™ technology is developed and reduces the harvesting cost to $2.50/dry ton. Finally, assume the increased yields allow a reduction in the average fuel transport distance from 40 to 25 miles, reducing the transport cost from $8.50 to $6.25/dry ton (using the formula $2.50/dt + $0.15/dt-mile loaded).

These changes would reduce the delivered fuel costs to those shown in Table 6. A CRP case is included for each of the three crop types, in the event the CRP is reauthorized in the 1995 Farm Bill. The CRP is assumed to pay annual rent payments, plus 50% of non-irrigation site preparation and establishment costs (minus $40/acre assumed as a previous CRP payment to establish grass on the same land). With no subsidy, Table 6 shows delivered fuel costs between $1.23 and $1.73/MBtu. With the CRP subsidy, the costs drop to $0.90 to $1.48/MBtu.

Table 6
Potential SRWC Cost Improvements with Doubled Yields, Agricultural-Style Harvesting, and CRP Subsidy

C. Delivered Fuel Costs

	Hybrid Poplar NRRI (Berguson)		Eucalyptus UC Davis (Hartsough)		Willow SUNY (White)	
		(CRP)		(CRP)		(CRP)
Yield, dt/a/y	10	10	18	18	15	15
Costs per dry ton, $/dt:						
Site prep and establishment cost	3.67	2.41	6.87	6.28	6.00	3.28
Annual costs	13.78	6.35	13.87	10.09	7.29	4.40
Stumpage price	17.44	8.77	20.73	16.37	13.29	7.68
Harvesting costs	2.50	2.50	2.50	2.50	1.38	1.38
Transportation costs (25 mi)	6.25	6.25	6.25	6.25	6.25	6.25
Delivered fuel cost, $/dt	26.19	17.52	29.48	25.12	20.92	15.31
Delivered fuel cost, $/MBtu	1.54	1.03	1.73	1.48	1.23	0.90

The analysis does not rule out farm-grown biomass projects. It appears that projects can and will be found that take advantage of special opportunities. These might include low-cost land that produces high yields, or CRP lands (if the program is continued). EPRI has information and models that will assist in identifying and evaluating such opportunities.

Conclusions

In the context of natural gas prices below $2.50/MBtu and coal prices well below $1.50/MBtu, the primary conclusion from this work is that delivered fuel costs from SRWC are too high to allow farm-grown biomass to compete in the electric generation market. Yields must increase significantly, by 50 to 100% from presently assumed values, before biomass fuel costs will enter the competitive range.

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IN THE AFTERMATH OF PURPA: THE FUTURE OF THE BIOMASS ENERGY INDUSTRY IN MAINE

S.J. Adams, Policy Advisor
Maine State Planning Office
State House Station 38
Augusta, Maine 04333

J.F. Connors, Biomass Program Director
Maine State Planning Office
State House Station 38
Augusta, Maine 04333

Abstract

During the 1980's the biomass power industry in Maine grew to nearly 500 MW of installed capacity in 21 cogeneration and stand alone plants. By 1992 these plants consumed four million tons of woody fuels annually, while providing 25% of the states electricity supply. Moreover, this new industry supported over 2500 jobs throughout rural Maine, generated substantial local property taxes and provided a critically needed management option for forest management and mill waste disposal. All of this capacity was developed by non-utility generators as Qualifying Facilities (QF) under PURPA rules. Most power contracts were fixed price, must take agreements guided by avoided cost calculations that assumed high future costs for energy alternatives.

Circumstances have changed. Historically low oil prices, economic recession, and rising electricity rates have made biomass fueled power plants some of the most expensive sources of electricity on the power grid. Utilities are responding to rising rates, to public and political pressure to control costs and lower rates by seeking to renegotiate or buy out power contracts and closing biomass plants. While there are strong demands to control electricity costs, there are equally strong concerns about losing the benefits that accrue from the use of indigenous renewable resources.

This article evaluates the actions of Maine utilities, independent power producers, the Maine Public Utilities Commission, and the Maine Legislature related to PURPA contracts and their likely effects on the future of the biomass power industry in Maine. In particular, we will describe Maine's new Electric Rate Stabilization Program and subsequent efforts of the Executive Branch to mediate a compromise solution in one case of a utility buy out of a biomass power plant.

Introduction

State and Federal PURPA laws have had a dramatic impact on the energy and economic profile of the State of Maine. The combination of growing energy demand, the need to replace planned electricity supply from the Seabrook nuclear power plant, and clearly established public policy to encourage the development of renewable indigenous energy sources created a booming independent power industry in Maine. While hydro-power played a roll, the bulk of the new indigenous electricity was fueled by wood chips, wood waste and other biomass materials.

Over the span of a less than a decade, Maine's private power industry would be seen alternatively as an economic blessing and curse. During the eighties it would provide competitively priced electricity to Maine utilities while supporting jobs and local tax bases in Maine's rural communities. Yet, by 1990, purchased power agreements would place a serious drag on an economy struggling to recover from recession.

Preserving this valuable economic asset while providing energy price relief presented a vexing public policy dilemma. In response, the State of Maine has adopted an experiment in encouraging the re-negotiation of purchased power agreements. While the path to its adoption was ragged, the Electric Rate Stabilization Act is playing an important role in holding down rate increases while maintaining the viability of Maine's biomass power industry.

Setting the Stage: Purchased Power Agreements

While in some states utility regulatory authorities are party to power purchase agreements through a contract approval process, the Maine Public Utilities Commission (MPUC) established an "arms length" arrangement. Rules for PURPA agreements set the bounds for a power deal, but the utility was left to strike the best deals it could, from any qualified source, and enter into a binding agreement. As long as the utility and independent power producer developed a mutually agreeable deal within the bounds of the PURPA rules, the MPUC role would be limited to performing a prudence review after the fact. This approach would greatly limit the ability of the MPUC to amend purchased power agreements.

Maine's biomass industry was developed on the basis of fixed-price, must-take purchased power agreements based on predicted avoided cost calculations that assumed rising prices of oil and other energy alternatives. Thus, depending on when contracts were negotiated, long-term levelized prices paid for biomass power ranged from 13 cents down to six cents per kilowatt hour, with annual inflation adjustments, under contracts extending for 15 to 30 years. The bulk of this capacity (80%) was held by Central Maine Power Company (CMP), Maine's largest investor-owned public utility. In fact, by 1994 purchased power represented 46.5% of CMP sales, up from 12% ten years before.

During the 1980's the biomass power industry in Maine grew to over 500 MW of installed capacity located in 21 cogeneration and stand-alone non-utility generators (NUGs). By 1992 these plants were consuming four million tons of woody fuels annually to generate over 3.2 million megawatt hours of electricity for Maine's three host utilities. This

production came to represent 21% of the states electricity supply.

The development of this indigenous biomass power industry supported over 2500 jobs throughout rural Maine in wood harvesting and transport, power plant construction and operation and retail and service sectors. In addition, biomass power plants became important sources of local property taxes in rural Maine towns and provided a valuable resource and waste management tool for Maine's forest-based industries. Finally, the biomass industry helped Maine to meet important energy objectives of reducing reliance on imported oil, increasing use of renewable resources, diversifying the energy mix, and improving price stability. These benefits were expected to continue at reasonable costs since QF projects were priced at or below avoided cost rates

From Policy Success to Public Controversy

The 1990/1991 recession, which was particularly harsh in Maine, turned a public policy success into an intense controversy. QF contracts were set at 1980's avoided costs with regular inflation adjustments. The average annual cost of purchase power grew by over 50% between 1984 and 1994 and were scheduled to see regular increases through their contract periods through the rest of the decade.

While the energy surplus created by the 1990 recession pushed down real oil and electricity costs, Maine electricity rates were rising. At the same time, the recession had cut into the ratepayer base as businesses closed and residents moved away. Combining a shrinking ratepayer base with Maine's reliance on NUG power priced at 1980's plus prices meant that electricity costs in Maine were rising at a time when consumers were least able to absorb these price increases. Residential consumers responded by increasing pressure on elected officials to remedy the situation. Commercial and industrial customers responded by shifting to alternative electricity sources, or in extreme cases, threatened to leave the state.

Utility Efforts to Renegotiate Power Contracts

Suddenly, the competitive deals of the 1980s became the most expensive sources of electricity in the system. Maine utilities sought to reduce excess capacity and reliance on expensive sources through renegotiations of power sales agreements, contract buy downs or buy-outs, turning off dispatchable plants, and ending plans for new projects. As a result, several wood-fueled plants planned for Aroostook County were not built, while two dispatchable facilities were placed in caretaker status. By 1995, cancelled small scale power purchase agreements, and other arrangements had reduced the capacity of on-line generation to about 450 MW from its 1992 zenith of 500 MW.

In the case of CMP Co. efforts were quietly underway to renegotiate power purchases, which was relatively easy with micro-generators since power agreements were essentially buy/sell agreements, and the utility could make an offer of lower cost electricity than the generators own cost of production. These actions, however, only resulted in ending power purchases with two producers, and one relatively small contract buy out amounting to

about twelve megawatts of capacity.

Most of this downsizing was accomplished through mutual agreements to cancel power purchases with small (one MW or less) wood products plants or by turning off dispatchable plants. However, the large (60 - 80 MW) capacity agreements with pulp and paper mills remained in force, as did contracts with most medium sized (15 - 40 MW) stand-alone facilities operated independent power producers.

These steps affected only a small share of QF contracts, leaving Maine utilities to labor under a significant amount of relatively expensive power that would continue to drive up electric rates. Given the relatively lucrative nature of the contracts and CMP's weakened financial condition, it was not surprising that negotiations between NUGs and the utilities stalled.

Relations between utilities and the NUGs grew increasingly contentious. NUGs operating with fixed price, must-take contracts were reluctant to negotiate away a profitable situation, especially in the case of large co-generation facilities associated with pulp and paper mills. In these cases the power plant is an integral part of the operation, and a source of income which essentially lowered the cost of energy as a production cost. The NUGs, on the other hand did not feel that CMP was seriously interested in renegotiation, but would rather pursue a legislative solution to their NUGs problem.

The Policy Dilemma

The friction between utilities and NUGs quickly spilled over into the political arena. During the 1993 Legislative session CMP sought support from lawmakers to pressure NUGs to renegotiate their lucrative power purchase agreements. CMP asked the Governor and Legislature to consider imposing an "excess profits" tax on NUG earnings and diverting the revenue toward reducing the rate impacts of rising NUG costs if NUGs and CMP were unable to settle their differences on their own. This strategy would not lead to negations, but it would bring CMP and NUGs together in an unusual way.

Policy makers faced a particularly difficult predicament. The NUG contracts had become a serious drag on a weak economy. However, getting out from under the contracts could mean shutting down the biomass plants and foregoing the associated real benefits. In particular, it would further harm small rural communities and the wood harvesting sector, both reeling from the recession. The power purchase contracts had become an important revenue stream for large cogenerators suffering from recessionary sales reductions.

Finally, there remained the possibility that NUGs could be cost competitive in the not-to-distant future. The regional energy market was on the brink of significant change. Slow but steady economic growth was gradually absorbing the electricity surplus. Consequently, avoided costs were expected to begin rising again about the time that NUGs contracts begin to run out. Moreover, the shift toward retail competition opened the possibility of specialty markets for some Maine power producers. Most power purchase agreements were quite lucrative, set at avoided costs rather than actual operating costs (ranging from 9 cents/kwh to nearly 13 cents/kwh). While it was not clear at what price the plants could remain profitable, it was definitely well below the contract price.

Thus, the public policy dilemma was finding a strategy that reduced the rate impacts of power purchase agreements, retained existing economic benefits at some level while not foreclosing future viability of NUGs. The optimal policy outcome would be one that lowers the costs of purchased power , thereby hemming in rate increases, while allowing larger NUGs to continue to operate thus retaining economic benefits and providing an opportunity for NUGs to compete in future energy market.

Crafting the Policy Response

The first policy response to the growing crisis was a surprise proposal developed in a private meeting of Democratic legislative leadership, CMP and NUG representatives. The heart of the measure was the use of publicly-backed low-interest loans to utilities to facilitate contract buy-outs. However, several aspects of the proposal reflected the interests of its authors and not necessarily a broader public interest. It provided virtually unlimited access to State-backed bonds with no meaningful public oversight. It greatly restricted PUC involvement in reviewing proposed buy-out, and sought to void a recent MPUC decision of imprudency against CMP. Its greatest weakness was the absence of any incentive to expedite the re-negotiation of contracts.

Recognizing serious policy flaws, Governor John R. McKernan, Jr. blocked an effort to rush this measure through the Legislature. Instead, the Governor called on a bipartisan subcommittee of the Legislature's Utilities Committee to work with him to craft a more balanced approach to this vexing policy dilemma. The proposal that emerged included State-backed financing of contract buy-outs or buy-downs. However, in also included extensive public oversight requiring MPUC approval of any new energy contract arrangement using state financing, and Finance Authority of Maine (FAME) approval of the financial package.

The Electric Rate Stabilization Act (ERSA), signed into law as Chapter 712 of the Laws of 1994, would provide low-interest loans to utilities to finance electric rate stabilization projects. These are projects defined as an agreement between an electric utility and a qualifying facility that will result in the reduction of costs to the utility and that meets a series of public policy standards. To be eligible for ERSA financing a project must receive PUC-certification that:

- it will provide near-term benefits to ratepayers that will be reflected in rates;
- the near term benefits to ratepayers are not disproportionate to potential future adverse rate impacts;
- it will not result in the cessation of operations of a facility of more than 50 megawatts (to prevent public financing of the closure of a major operation like the S.D. Warren paper mill in Westbrook);
- it will not adversely impact the diversity and reliability of the utilities energy mix; and
- it is consistent with the Maine Energy Policy Act.

Given the intensity of the rate problem and the weak economy, it was critical to gain as much benefit from renegotiations as quickly as possible. To create an incentive for rapid negotiations, ERSA capped the amount of available financing at $100 million, well below the potential demand, and established a May 1, 1995 deadline for contract execution.

ERSA's First Test-Fairfield Energy Ventures

The effectiveness of the new policy tool was to face an immediate test. Even before the effective date of the measure was reached, CMP announced a $78 million agreement to buy-out Fairfield Energy Ventures (FEV) through the ERSA. FEV is a 32 megawatt facility in the town of Fort Fairfield in northern Maine with a 15-year contract with CMP. The contract price of power in 1993 was 12 cents/kwh. The buy-out promised to provide $36 million in benefits to CMP ratepayers and would allow CMP to achieve 20% of its electric rate stabilization goal.

The crafters of the Act hoped that it might encourage buy-outs with small NUG contracts and buy-downs with large facilities. Instead, CMP sought to use the Act to buy-out and close one large facility. At 32 MW, the Fort Fairfield facility was below the statutory limit of 50 megawatts. However, it was an important part of the northern Maine economy, providing 30 jobs at the plant, over 100 forest harvesting jobs and over 30% of Fort Fairfield's property tax base.

The Town of Fort Fairfield, already reeling from the recent closure of nearby Loring Air Force Base and a devastating flood, pursued an aggressive strategy to prevent the approval of the buy-out. In an effort to forestall the closure of the FEV facility, the Town of Fort Fairfield threatened to take legal action to delay and thus block the deal.

Governor McKernan, interceded in the dispute, asking both sides to devise a solution that would generate the rate benefits of the buy-out without devastating the Town of Fort Fairfield. Under the auspices of the Governor's Office, a settlement was brokered between CMP and Fort Fairfield. The agreement called for the Town and CMP to work together to reduce operating costs of the FEV facility through a combination of property tax reductions, operating efficiency improvements, and fuel cost reductions. If, after three months, the plant met an agreed-upon target, CMP would commit to operating the plant for at least three years. The settlement became the basis of PUC certification and FAME approval of financing. After a summer of negotiations and review the CMP/FEV buy-out was finalized .

In a second application of the ERSA, Bangor Hydro Electric has recently gained approval of a $105 million buy-out of two contracts with Babcock Utrapower. The total cost of the buy-outs will be $160 million but will save Bangor Hydro ratepayers $60 million over the life of the contract. The plants involved began operation in 1986 but have been rarely on-line given the weak demand and high cost of the power. Bangor Hydro has agreed to provide some property tax relief to the host communities should the plants be devalued.

Conclusions

The implementation of PURPA in Maine opened the door for the development of a large

number of hydro and biomass power facilities at prices competitive with other more traditional sources. These NUGs have proved to be dependable and reliable sources of electricity, while providing additional economic and environmental benefits. Changing economic conditions, coupled with unexpected low oil cost, have significantly altered the circumstances in which power purchases with non-utility generators were negotiated. Excess capacity and potentially lower cost alternatives make biomass fueled plants some of the most expensive electricity currently available. The social and economic pressures of rising electricity prices has fundamentally changed the energy equation in Maine, demanding a public response to control electricity cost, even at the risk of backsliding on the progress made in meeting important energy objectives.

The Electric Rate Stabilization Act is a public policy response designed to help control electricity costs, while seeking to preserve the benefits accruing from the development of indigenous renewable energy resources. The act provides publicly supported financing for cash strapped utilities to buy down or buy out expensive power contracts, while stating a preference to keep theses plants operating.

In the case of CMP's purchase of Fairfield Energy Ventures these public policy goals have been met. The cost of the electricity has been halved, and the plant is still operating at full capacity. A second application of the Act will result in a less balanced outcome. The buy-out of the power contracts with Ultrapower will leave the two plants without a power customer. Ultimately these two facilities may be dismantled and sold to the highest bidder.

The future for biomass power development in Maine, in the short term may not be very bright. Slow economic recovery, excess generating capacity, continued low oil prices, and the potential for expanded natural gas capacity defines a highly competitive situation. But the ability of wood-fired power plants to compete is not fully tested in a truly open market. In the long run, future changes in the energy picture, ample supplies of wood fuels, the need for new capacity, and export wheeling could provide a competitive opportunity for biomass power plants in Maine.

These experiences offer some valuable lessons in public policies in an changing economic and regulatory environment. Perhaps most importantly is the need for greater flexibility in contract pricing over time as power needs and costs vary. Equally important is the need to view energy supply issues from a longer term perspective. It is altogether possible that today's expensive purchased power agreements could be tomorrow's bargain. Finally, one set of public policy goals almost always come at some cost, sooner or later. Finding the appropriate balance between desirable outcomes and costs will be the on-going challenge confronting energy policy makers in Maine and across the nation.

RESPONSES OF ALABAMA FARMERS TO A SURVEY ON GROWING SWITCHGRASS FOR ENERGY

S.E. Sladden and D.I. Bransby
Auburn University, Auburn, AL 36849 U.S.A.

Abstract

A survey was conducted among Alabama farmers to determine (1) what competition switchgrass for energy would face from existing enterprises, (2) how much hay making equipment was already present on farms, and (3) the level of interest among producers in growing switchgrass for energy. Farmers estimated that return/acre for beef cattle from pasture, row crops, hay and forestry (the major agricultural activities in the state) were $69, $110, $50 and $24, respectively. Thirty-two percent of respondents indicated that they had an average of 122 acres idle, while 24% indicated they had an average of 190 acres in the Conservation Reserve Program, for which an average of $39/acre/year was received. Eighty percent of respondents made their own hay and 18% bought hay at an average price of $58/ton. The proportion of respondents that owned equipment was: tractors, 99%; mowers, 80%; hay rakes, 77%; big balers, 68%; and mower-conditioners, 42%. Eighty-four percent indicated that they would produce, harvest, bale and transport biomass themselves, in preference to contracting any part of the operation out. Eighty percent indicated that they would plant an average of 155 acres of switchgrass if they could make an average profit of $93/acre/year.

Introduction

Successful commercialization of energy production from energy crops depends on meeting several economic conditions. These include competing successfully with existing farm enterprises, limiting the need for large capital expenditure on new equipment, and meeting economic expectations of farmers. However, relatively little is known about these conditions. Therefore, the objective of this paper is to report results of a survey conducted in 1994 among Alabama farmers to determine: (1) what competition switchgrass for energy would face from existing farm enterprises, (2) how much hay making equipment was already present on farms, and (3) the expectations and level of interest among farmers in growing switchgrass for energy.

Scope of Survey

The survey was mailed to a little over 2000 members of the Alabama Farmers' Federation who were considered as a leader group. These leaders were chosen in preference to a sample that was representative of the full range of farmers in Alabama, because it is usually leaders that play the most important role in adopting and developing new practices. Survey forms with a one-page explanation of the potential future of energy crops were mailed with self addressed and stamped return envelopes. The survey form appears as Table 1. A total of 214 forms (about 10%) were returned. In the subsequent analysis it was assumed that the forms returned were representative of the 2000 farmers surveyed.

Results and Discussion

Results of the survey are discussed according to the structure of the survey form. Even though a total of 214 forms were returned, all respondents did not answer each question. Therefore, responses to each question were calculated in relation to the number of respondents for that question, and not in relation to the total number of forms returned. In certain cases, distributions were skewed by a relatively low number of large operators.

Land Tenure

The average total area of land operated by each respondent was 1069 acres (median 700 acres; range 8 - 6500 acres). Of the total acreage operated by all respondents, 65% was owned by them, and only 30% of the respondents owned all the land they operated. On average, respondents owned 648 acres (median, 370 acres: range 0 - 3900 acres). At least some property was leased by 67% of the respondents and, on average, these respondents leased 44% of the land they operated (578 of 1304 acres). Only 7% of the respondents were involved in partnerships.

Table 1. Survey Form

1. How many acres do you operate? (a) Total _____ (b) Owned _____ (c) Leased _____ (d) In partnership _____ (separate from b & c above).

2. Farm operations and estimated profit.

	Acres	Estimated net profit/acre/year
(a) Pasture (for beef)	_____	_____
(b) Row crops	_____	_____
(c) Hay (for sale)	_____	_____
(d) Forest (commercial)	_____	_____
(e) Idle	_____	_____
(f) CRP	_____	_____
(g) Other (identify below)	_____	_____

3. Beef Operation. How many brood cows? _____ How many stockers per year ? _____ Estimated average weaning weight? _____ Estimated calving percent? _____

4. Hay making and equipment. Circle what is true for you. (a) Do you make your own hay? (YES NO) (b) Do you buy hay? (YES NO) If yes, how much and at what price _____? (c) Do you own any of the following machinery? tractor (YES NO), mower (YES NO), rake (YES NO), big round baler (YES NO) mower/conditioner (YES NO)

5. Cost/return estimates for producing and handling switchgrass are provided below:

   $231/ac for production, harvesting and hauling yourself.
   $110/ac for production ($60/ac) and hauling ($50/ac or $2.50/bale) yourself.
   $200/ac for custom harvesting and baling ($10/bale).
   $80/ac for custom hauling 10 miles ($4/bale).
   Gross return on 10 tons/ac at $35/ton = $350/ac.

   Based on these estimates, circle your choice of options A, B or C below:

Option	Net Return/ac
a. Produce, harvest and haul yourself (you invest 12 hours/ac)	$119
b. Produce and haul yourself, but custom harvest and bale	$ 40
c. Produce yourself, but custom harvest, bale and haul	$ 10

6. What is the minimum net profit/ac you would require to plant and grow switchgrass? _____

7. If you could make your net profit indicated in (6) above, how many acres might you plant to switchgrass? _____

Existing Enterprises

Data in Table 2 summarize the responses to question 2 about existing farm enterprises. In several ways, results are typical of leading farmers in the state. The most distinctive of these is the greater acreage in row crops than in pastures for beef cattle: based on the means and medians, there was about 50% more land in annual cropping than in pasture. In contrast, for the state as a whole, there is about twice as much land in pasture (approximately 4.5 million acres) as there is in cropping (just over 2 million acres). Clearly, leading farmers are attracted to row crops due to their higher profitability.

Table 2. Area Devoted to Different Existing Farm Enterprises, and Estimated Profit.

Enterprise	% of Respondents	Acreage			Estimated Profits ($/acre/year)
		Mean	Median	Range	
Pasture for Beef	78	352	210	14 - 2500	69
Row Crops	56	520	320	5 - 5000	110
Hay	33	119	60	10 - 660	50
Forestry	52	468	285	6 - 3000	24
Idle	32	122	100	5 - 600	--
CRP*	24	190	90	5 - 1200	39

*Federally subsidized Conservation Reserve Program

The $69/acre profit predicted for beef pastures is higher than the $50 or less that most analysts would project. This is probably because a fairly large proportion of respondents (35%) ran stocker programs, which are generally more profitable than cow-calf operations. Again, this is typical of row-crop farmers who often rotate their summer crops with winter annual pastures on the same land for grazing young beef cattle.

Beef Operations and Hay

Beef herds were owned by 75% of respondents, and average herd size was 155 head (median, 90; range, 9 - 1600). This is much larger than the average state herd, which is only about 20. Hay was made by 80% of respondents, and 18% bought hay at an average price of $58/ton. Hay making equipment was owned by a large proportion of producers: 99% owned tractors, 80% mowers, 77% hay rakes, 68% big balers and 42% mower-conditioners.

Production Options

Eight-four percent of the respondents indicated that they would produce, harvest, bale and transport switchgrass biomass themselves, in preference to contracting any part of the operation out. Clearly, this is related to the marked increase of projected profitability for

self-operated activities (Question 5, Table 1), and the high ownership of hay making equipment. Projections at this stage suggest that there is very limited opportunity for custom activities in the early phase of energy crop development.

Farmer Expectations and Projections

A total of 80% of respondents indicated that they would plant an average of 155 acres of switchgrass (range, 3 - 5000) if they could make an annual profit of $93/acre (range 5 - 200). This profit expectation falls between the estimated profit for beef and row crops (Table 2), suggesting that switchgrass would replace mainly pasture. The projected acreage is about half that currently in pasture. If these figures are applied to the 2000 farmers surveyed, a potential 248,000 acres would be planted to switchgrass. Furthermore, if a yield of 7.5 tons/acre/year is assumed, which we feel is entirely reasonable at this stage, a total of 1.86 million tons would be produced each year by these farmers. Alternatively, it would amount to 5314 tons/day for a 350-day year.

Summary and Conclusions

The survey reported in this paper indicates strong interest among Alabama farmers in growing switchgrass for energy. This is probably related to projected profitability, little competition from existing farm enterprises, and plans to phase out several federal support programs. Based on these results, there should be no major difficulty in obtaining farmer participation in developing initial commercial operations for energy production from switchgrass in Alabama, especially if some financial assistance was available for planting the crop.

THE ECONOMICS OF BIOMASS PRODUCTION IN THE UNITED STATES

Robin L. Graham, Ph.D., Economist, ORNL, Oak Ridge, TN, USA
Erik Lichtenberg, Ph.D., University of Maryland, College Park, MD, USA
Vernon O. Roningen, Ph.D., Economist, ERS-USDA, Washington, DC, USA
Hossein Shapouri, Ph.D., Economist, OENU-ERS-USDA, Washington, DC, USA
Marie E. Walsh, Ph.D., Economist, ORNL, Oak Ridge, TN, USA

Abstract

Biomass crops (e.g. poplar, willow, switchgrass) could become important feedstocks for power, liquid fuel, and chemical production. With successful research programs that boost crop yields and develop appropriate power and chemical conversion technologies, biomass might compete with fossil fuels for a broad range of uses. Compared to fossil fuels, biomass feedstocks can offer significant environmental benefits. For example, biomass crops do not add greenhouse gases to the atmosphere during their life cycle.

This paper presents estimates of the potential production of biomass in the United States under a range of assumptions. Estimates of potential biomass crop yields and production costs from the Department of Energy's (DOE) Oak Ridge National Laboratories (ORNL) are combined with measures of land rents from USDA's Conservation Reserve Program (CRP), to estimate a competitive supply of biomass wood and grass crops. Estimates are made for one potential biomass use--electric power production--where future costs of electricity production from competing fossil fuels set the demand price. The paper outlines the methodology used and limitations of the analysis.

Currently, biomass-based electricity generation is a niche market where electricity is expensive and fuel is cheap or incurs a disposal cost, e.g. waste wood, sawdust, etc. However, if biomass production and usage systems demonstrate themselves to be workable at DOE's projected costs, biomass crops might become competitive for electricity production and other uses. Increases in fossil fuel prices, more rapid advances in gassification-gas turbine power generation technology, or rapid market development for biomass-based co-products such as pulp wood or chemicals could accelerate the production of biomass for electricity generation. Policies that discourage greenhouse gas emissions or encourage biomass production on idle land could also make biomass feedstocks more competitive with fossil fuels for a range of uses.

Biomass crops could be produced on some of the land idled by farm programs in recent years. However, if biomass crop production should expand beyond 30 million acres, then the interaction of biomass with traditional agricultural crops, markets, and programs becomes important. While the outlook for biomass feedstocks for energy and other uses offers promise, the practical viability of biomass production and usage systems needs to be demonstrated. Given the uncertainty about the competitiveness of the biomass industry, projects that successfully demonstrate biomass production and utilization systems hold the key to the future of biomass production in the United States

Background

This paper discusses the economic potential of biomass production and utilization. Biomass crops are being promoted as feedstocks for the production of electric power, liquid fuels, and chemicals. Biomass feedstocks have environmental advantages compared to fossil fuels. For example, they would not add greenhouse gasses to the atmosphere during their life cycle. These crops might be grown on fragile lands and could perform other environmental tasks such as the filtration of fertilizer and pesticide runoff. DOE research suggests that yields of biomass crops such as poplar, willow, and switchgrass could be increased significantly. If new generation efficient gassification systems and turbines were developed for power production, biomass might become competitive with fossil fuels as an energy source. Such a development would benefit farmers by adding energy crops to traditional food and fiber production. Rural communities would benefit from jobs created by biomass production and utilization.

Methodology

The supply of a product is the quantity that will be produced with a unit of resources at a price that is competitive with other uses for the same resources. Given a fixed amount of biomass production, the competitive price is set by the last unit of resources coming into production which just meets production expenses. The potential supply of biomass can be estimated given data on land productivity, biomass production costs, and the cost of land for alternative uses. Since biomass crops have a life cycle of several years, the stream of biomass revenues and costs has to be discounted in order to compare returns from biomass production with alternative investments (Strauss and Wright).

The supply price estimates for biomass on an acre of land can be done by calculating the present value of estimated revenue and costs over a production cycle (n years). Let $p \equiv$ average annual biomass crop price per ton harvested, $y_t \equiv$ biomass yield per acre (in period t), $c_t \equiv$ total production cost per acre (including a competitive return to the land) , and $r \equiv$ the discount rate over the crop cycle period. For each acre of biomass, the discounted revenue $\equiv \sum_{t=1 \text{ to } n} [(p^*y_t)/(1+r)^t] = p^* \sum_{t=1 \text{ to } n}[y_t/(1+r)^t]$, since p is defined as an average price over the crop cycle. This discounted revenue from biomass production must equal the discounted cost $\equiv \sum_{t=1 \text{ to } n} [c_t/(1+r)^t]$. Solving for p, $p = \{ \sum_{t=1 \text{ to } n} [c_t/(1+r)^t\}/\{\sum_{t=1 \text{ to } n} [y_t/(1+r)^t] \}$. The average biomass supply price depends on the ratio of discounted production costs to discounted yields (resource productivity). This calculation was repeated for land units with differing productivity (yields) and value (rental rates).

The quantity of biomass produced on a unit of land is simply the area times the average annual yield. The total quantity q supplied to the market at a price p is the sum of production on all land where the equivalent discounted price $<= p$ (p is the marginal price for the last unit of land to go into production at that price). Land units were ranked by their estimated "break even" price p, and production was summed over all units of land with an equal or lower price. This calculation gives the total quantity of biomass produced at each price level (current prices), i.e. the potential biomass supply.

Data for the Estimation of the Potential Biomass Supply in the United States

A data set for four potential biomass production regions in the United States was created. Acreage was broken down into land units by land capability class (Walsh and Graham, 1995) and average land rental values from the 12th sign-up of USDA's Conservation Reserve Program (Osborn, Liacuna, and Linsenbigler, 1992). Data on potential biomass yields and production costs by land class was assembled by ORNL for land suitable for biomass (crop, CRP, and pasture land with medium to high conversion potential) in the four regions shown in Figure 1. Calculations assume that biomass yields, production budgets, and CRP land rents applied to all land in a unit. Switchgrass was the representative grass crop while poplar was the wood crop for all regions except for willows in the North East. The yield scenarios (labeled by year) represented judgments about the potential success of biomass research programs: 2000 - yields attainable with current technology, 2005 - yields with improved management and clonal and varietal selection, and 2020 - yields that could be achieved with a sustained multi-regional genetic improvement program. Table 1 summarizes the data set used for estimation of the potential biomass supply in the U.S.

Figure 1: Biomass Production Regions

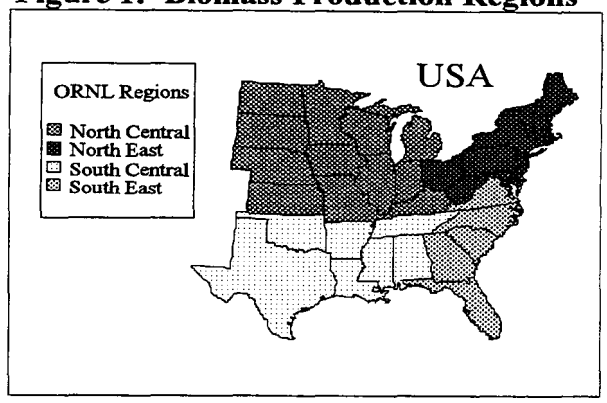


Table 1: Potential Biomass Crops, Suitable Acreages, and Average Yields 1/

	Grass Crops					Wood Crops				
Region	Crop	Million Acres	Yield Scenarios (Dry Tons/Acre) 2000	2005	2020	Crop	Million Acres	Yield Scenarios (Dry Tons/Acre) 2000	2005	2020
North Central	Switch grass	200	4.2	4.8	6.0	Poplar	177	3.1	5.1	7.1
North East	Switch grass	36	3.7	4.3	5.3	Willow	36	4.2	6.4	8.1
South Central	Switch grass	64	5.1	5.9	7.4	Poplar	41	2.6	4.6	6.8
South East	Switch grass	22	6.0	6.9	8.6	Poplar	22	3.0	5.0	7.3

1/ Production cycles assumed in ORNL biomass crop budgets were: switchgrass - 10 years, poplar - 7 years, and willow - 22 years. Regions included suitable acreage with adequate rainfall. Acreages shown overlap for grass and wood crops. The number of land class/rental observations were: North Central - 182, North East - 91, South Central - 61, and South East - 60. Land data included 12 land capability classes/subclasses with different potential yields assigned to each. Crop budgets were assigned to land classes by ORNL (5 switchgrass budgets, 3 poplar budgets, and 1 willow budget). Average CRP 12th sign-up rents (and standard deviations) in dollars/acre for the regions are: North Central -74 (41), North East - 78 (24), South Central - 49 (19), and South East - 42 (19).

Figure 2 shows a sample ORNL switchgrass crop budget and associated average yield scenarios for 2000, 2005, and 2020 for the North Central region. Budgets included variable cash, labor, and operating capital costs of production. This data was combined with a 6.5 percent discount rate and a CRP rental rate for the land unit (representing the required return from the land to cover ownership costs, profits, and taxes) to calculate an annualized farmgate price (cost) per ton that would allow normal returns for the land owner, given estimated revenues and costs. Budgets did include some variation in production costs associated with different yields (e.g. harvesting, transportation).

Figure 2: Switchgrass Production Budget Spreadsheet For a North Central Region Unit of Land With ORNL Yields and CRP Land Rent

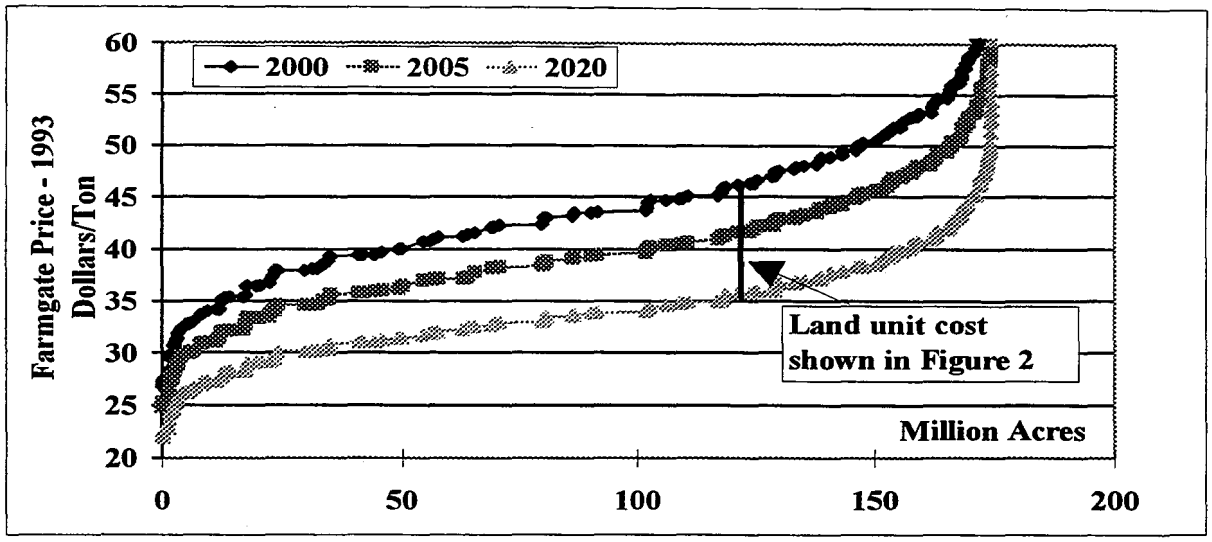
	A	B	C	D	E	F	G
2	Switchgrass Budget	2000-YR. 1 ESTAB. COST	2000-YRS. 2-10 ANNUAL MAINT. & HARV. COST	2005-YR. 1 ESTAB. COST	2005-YRS. 2-10 ANNUAL MAINT. & HARV. COST	2020-YR. 1 ESTAB. COST	2020-YRS. 2-10 ANNUAL MAINT. & HARV. COST
3	VARIABLE CASH COSTS						
4	Seed	14.63		14.63		14.63	
5	Fertilizer	30.76	21.91	31.50	22.19	33.88	25.03
6	Chemicals	13.06		13.06		13.06	
7	Fuels/Lube	4.41	0.38	4.41	0.38	4.41	0.38
8	Repairs	8.29	0.55	8.29	0.55	8.29	0.55
9	Harvest		17.61		18.55		20.90
17	COSTS OF OWNED RESOURCES						
18	Capital Replacement	7.60	10.03	7.60	10.69	7.60	12.34
19	Oth. Nonland Capital	3.65	4.51	3.65	4.80	3.65	5.53
21	Labor	9.60	13.54	9.60	14.67	9.60	15.45
24	**Present Value (PV) Cost Calc. (1993 $/Acre)**						
25	Discount rate (%)	0.065	Assumed Transport Cost ($/T):				
26	Annual land rental rate-CRP data:	74	3.00	**PV-2000**	**PV-2005**	**PV-2020**	
27	A=R. 4-8, C. B,D,F	Estab. cost-yr. 1		71.15	72.19	74.27	
28	B=R. 4-8, C. C,E,G	Maint. harv. cost-2-10		269.24	277.36	311.91	
29	C=R.18-19,21; All	Cap. lab. depr.-1-7		207.75	221.60	242.63	
30	D=R.26, C.B,D,F	Land rental cost-1-10		566.55	566.55	566.55	
31	= A + B + C + D	10 Y. Farm C.(93 $/A)		1114.69	1137.70	1195.36	
32	Yield Assum.-ORNL:	Average (dry tons/acre/yr)	Transport costs-yrs. 2-10				
33	2000	3.69	70.25				
34	2005	4.22	80.34				
35	2020	5.27	100.33				
36							
37	**Annualiz. Farm C./Ton (93 $/Ton)**		Annualized Delivered Cost (93$/T)				
38	**2000**	**47.60**	**50.60**				
39	**2005**	**42.48**	**45.48**				
40	**2020**	**35.74**	**38.74**				

Calculations of annualized cost of switchgrass production, given ORNL budgets, yields, and land rental costs from CRP data sources.
<----------
Shaded areas show budget data used. Underlined numbers are resulting annualized farm costs.

Figure 2 shows the calculations for an observation with a CRP rent of 74 dollars per acre that is expected to yield 3.7 tons per acre of switchgrass in 2000, 4.2 tons in 2005, and 5.3 tons in 2020. When similar spreadsheet calculations were performed for all rental observations in the North Central region, they were sorted by price (annualized farmgate cost). Then total acreage and production was cumulated for all land units with equal or lower prices. This process yielded a supply estimate with the lowest "break even" farmgate price per ton (left axis) verses the total acreage of land used (bottom axis) shown in Figure 3. The left part of the supply response scenario estimates shows the minimum price needed to bring switchgrass into production in competition with existing land use while the right part of the figure indicates the price that would be needed to bring all of the

land in the North Central region into switchgrass production. The point representing the results of the spreadsheet calculation shown in Figure 2 is marked with a vertical line.

Figure 3: Potential Switchgrass Supply for the North Central Region



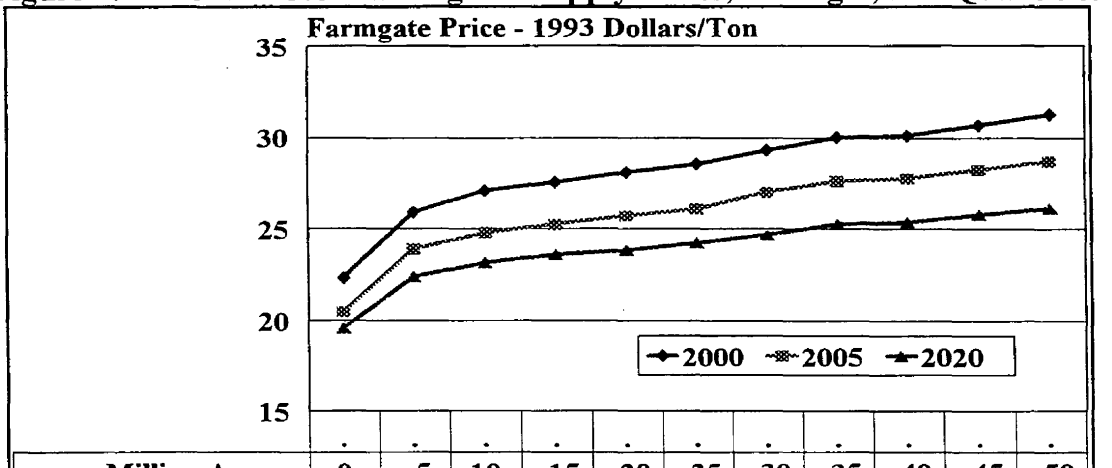
When the supply estimate is presented in terms of total acreage in a region, the scenarios with increased yields move the supply prices downward, i.e. they lower supply costs. Improved yields in 2005 with a modest research program lower costs at the line shown in Figure 3 from $47.60 per ton to $42.48, a reduction of $5.12 per dry ton or 11 percent. By 2020 with a long term research program, the costs are lowered to $35.74 per ton, down $11.86 or 25 percent from the costs projected in 2000. This calculation shows that given production costs and a variety of land prices and productivity; a) there is some land available that could produce switchgrass at a low price, e.g. $30 or less per ton, b) if research programs could successfully increase yields, switchgrass at $30 per ton would be competitive on more acreage (or at any of the acreages shown in Figure 3, the competitive price would be reduced). The calculation of a national biomass supply estimate follows the same methodology, combining land data from the four regions shown in Figure 1.

There is an important caveat about this type of analysis. The land rent distribution comes from a survey with existing crop production patterns in place. For example, the North Central region shown in Figure 1 has over 60 million acres in corn production, accounting for almost 80 percent of corn production land in the U.S. While Figure 3 suggests that all of this land could be converted to switchgrass production if prices approached $60 per ton, the resulting removal of 80 percent of U.S. corn production would raise feed grain, livestock, and food prices dramatically. In turn this would raise the prices required to maintain all of this land in switchgrass production. Therefore the supply estimates using this methodology are appropriate for smaller acreages or biomass on idle land that is not competing with mainstream crops (e.g. the 50 million acres in conservation and crop set-aside programs in recent years). If biomass crops were to seriously compete with traditional food and fiber crops, a full multi-commodity global market analysis would be needed to analyze the interaction of biomass crops with the existing farm economy.

Biomass Supply Estimates for the United States

Figure 4 shows supply estimates for switchgrass on the lowest cost 50 million acres. The downward shift of supply prices in each scenario results from the yield increases assumed to follow from stepped-up research programs. The numbers in the table below the acreage show the total switchgrass production expected with each scenario. For example, a price of 28 dollars per dry ton would encourage production of 128 million tons on 20 million acres in the scenario for 2000. For 2005, 20 million acres could produce 146 million tons at a price of 26 dollars per ton. The 2020 scenario suggests the same 20 million acres could produce 159 million tons for less than 24 dollars per dry ton. The small amounts that could be produced under 25 dollars per ton with research progress, constitute a niche market that might develop.

Figure 4: Potential U.S. Switchgrass Supply Prices, Acreages, and Quantities

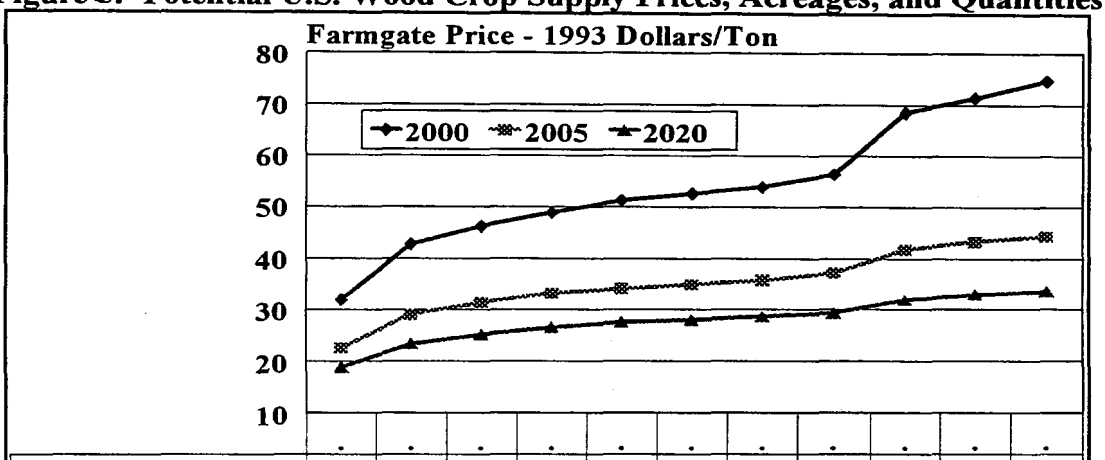


Million Acres	0	5	10	15	20	25	30	35	40	45	50
Million Tons -2000	0	29	54	85	128	148	176	193	215	258	280
Million Tons -2005	0	33	77	105	146	164	200	223	231	295	301
Million Tons - 2020	0	51	92	117	159	198	238	262	277	318	352

The quantities supplied in these estimates are very sensitive to price. This is consistent with the long run methodology used for the estimates and is appropriate for land currently idle. Experience with long-run multi-crop estimates suggests that each quantity produced would require higher prices if biomass production significantly displaced existing crops.

Estimates for U.S. wood crop production on 50 million acres are shown in Figure 5. The interpretation is the same as for Figure 4. The left part of the estimates at lower prices represent lower costs associated with willow production (relative to poplar). The supply estimates in these two figures include much of the same land. Therefore an additional calculation is needed in terms of a common energy metric, allowing either grass or wood production, to determine how much of each particular biomass crop is produced. Since wood and grass crops have different energy contents per ton, a combined estimate can be made by converting wood and grass tonnage to common energy units and prices.

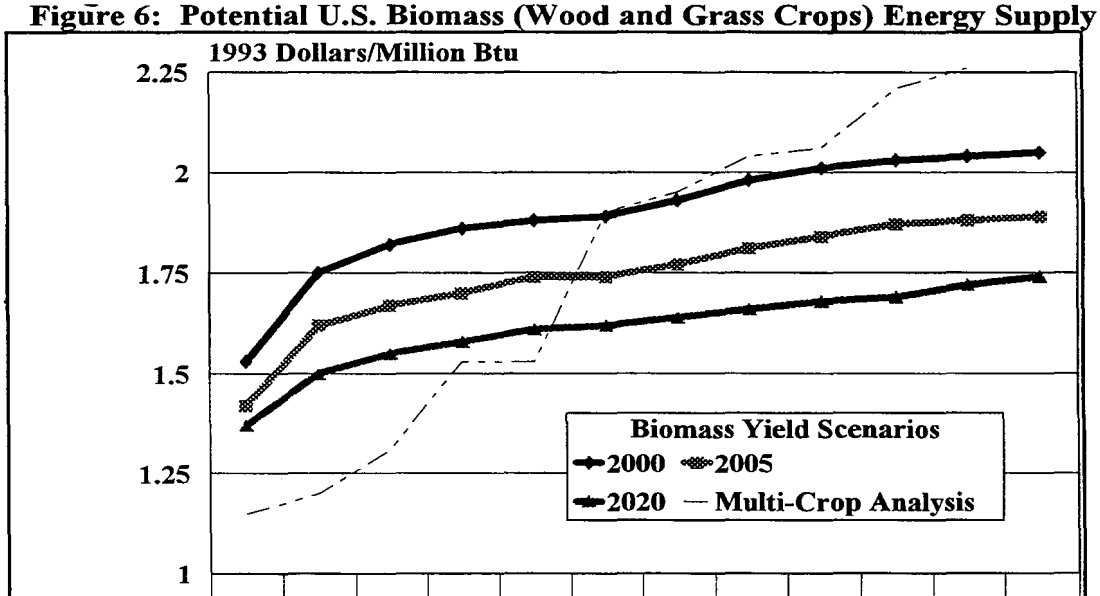
Figure 5: Potential U.S. Wood Crop Supply Prices, Acreages, and Quantities



Million Acres	0	5	10	15	20	25	30	35	40	45	50
Million Tons -2000	0	28	47	62	80	92	107	149	166	186	213
Million Tons -2005	0	37	70	99	128	149	190	224	253	272	287
Million Tons - 2020	0	46	83	139	180	235	261	288	330	350	380

Assuming wood and grass crops contain 16.5 and 14.5 million Btu of energy per dry ton, respectively, the tonnage and prices shown above (with transport costs added) were converted to energy units. Ranking the data for about 50 million acres by energy prices and cumulating the energy content gives the national biomass supply in Figure 6.

Figure 6: Potential U.S. Biomass (Wood and Grass Crops) Energy Supply



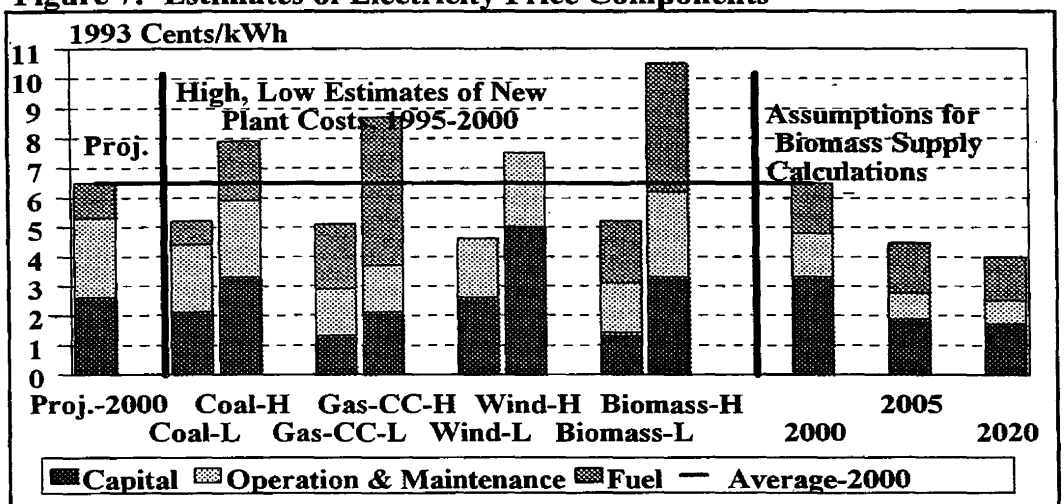
Quad. Energy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Million Acres	0	3	7	10	16	21	26	29	32	40	46	54

Note: Btu ≡ British thermal unit of energy. One Quad. of energy ≡ 10^{15} Btu. As a point of reference, the U.S. consumed about 80 Quad. of energy in 1988.

The steeper (dashed) line in Figure 6 shows an alternative biomass supply estimate by McCarl using a multi-crop model (Adams, et. al.) for 2020. At lower prices, the McCarl analysis includes waste wood. As the biomass acreage climbs above 30 million acres and biomass crops compete with existing ones, the multi-crop methodology suggests that higher prices would be needed to cause biomass to displace existing crop production.

Regardless of the estimated biomass supply in energy terms, additional assumptions about technology are required if biomass is to be evaluated exclusively for use as a fuel for electric power generation. Figure 7 summarizes some technical cost assumptions as three components of electricity prices. DOE and Electric Power Research Institute (EPRI) electric power cost assumptions for the three scenarios are shown at the right and are compared to other estimates using various energy sources, including biomass. Lower cost estimates in 2005 and 2020 basically assume greater cost and production efficiency using new generation gassification-gas turbine systems to convert biomass to electricity.

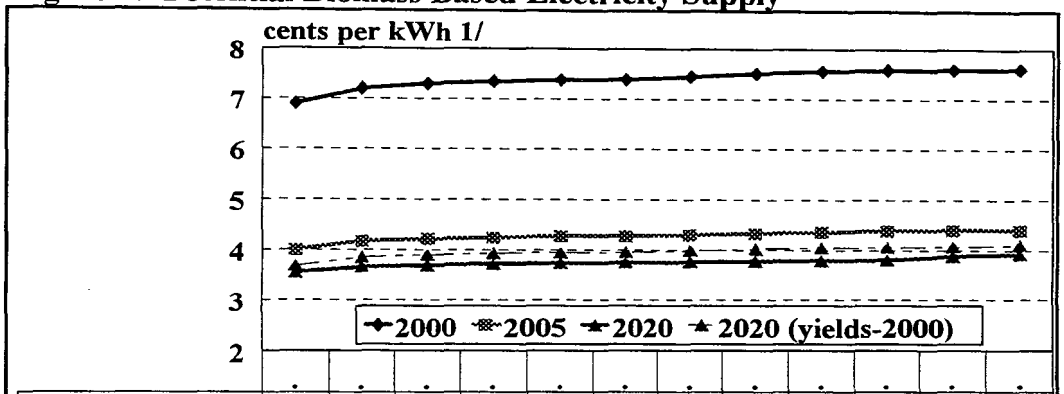
Figure 7: Estimates of Electricity Price Components



Source: Projections from DOE-EIA *Annual Energy Outlook 1995*. Estimates of new power plant costs for 1995-2000 by fuel type from *Powering the Midwest, a Report by the Union of Concerned Scientists*. Assumption by OENU/DOE uses Electric Research Institute (EPRI) model: 2000-Conventional steam, 2005-IGCC-gasifier & turbine, 2020-IGCC-ATS - advanced gasifier & turbine. Fuel costs are 1.7-1.5 cents/kWh (1.5 cents fuel allows 4 cents/kWh electricity in 2020).

Since capital and operation and maintenance costs make up over half of the electricity price, their reduction with new technology is crucial to the attainment of a 4 cents per kWh biomass based electricity price that is thought to be competitive with power production from other fuels in 2020 such as coal and natural gas. The power cost assumptions in Figure 7 are combined with the biomass energy supply estimates in Figure 6 to produce the potential biomass-based electricity supply for the three scenarios in Figure 8. An additional alternative scenario for 2020 assuming yields from 2000 gives electricity price estimates only 0.2 cents per kWh higher on average. Therefore the required cost reduction for competitive electricity production in 2020 in Figure 8 comes almost entirely from the new lower-cost electricity generation technology. If these cost assumptions hold true and if biomass production does not crowd out existing crops, then up to 50 million acres of competitive biomass crops might exist in the future.

Figure 8: Potential Biomass Based Electricity Supply

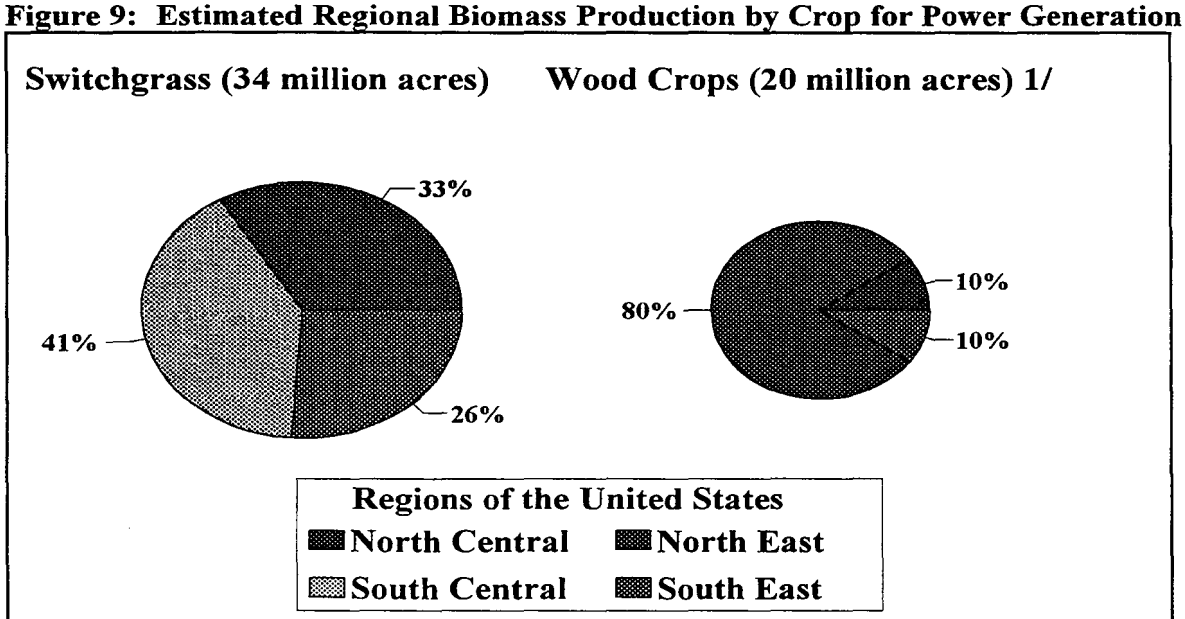


Quad. Energy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Million Acres	0	3	7	10	16	21	26	29	32	40	46	54
Billion kWh-2000	0	36	73	109	145	181	218	254	290	327	363	399
Billion kWh-2005	0	57	115	172	230	287	345	402	460	517	575	632
Billion kWh-2020	0	65	130	195	260	325	390	455	519	584	649	714

1/ Scenarios include fuel, capital, operating & maintainence costs:
2000 - (1.7, 3,31, 1,48); 2005 - (1.6, 1.86, .90); 2020 - (1.5, 1.70, .80)

These calculations and underlying assumptions lead to a distribution of biomass supply by region and crop shown in Figure 9. Willows could become a major wood crop in the North East while switchgrass could be a major biomass crop in the other regions. Low cost power technology and improved feedstock production systems are keys to this future.

Figure 9: Estimated Regional Biomass Production by Crop for Power Generation



1/ Poplar for the North Central, South Central, and South East Regions; Willows for the North East Region

To summarize, biomass crops could become feedstocks for industrial uses, given optimistic assumptions about the success of research programs for production and utilization. The successful development of a new generation of efficient power generation technology could make biomass generated electricity a reality. Some low cost biomass production and biomass wastes such as wood, make a niche biomass power market possible now. Successful biomass research programs, rising fossil fuel prices, and/or biomass incentive policies could expand the biomass industry. However, the optimistic U.S. biomass scenarios assume that improved production, harvesting, delivery, and utilization systems implied by crop budgets and power/utilization cost estimates are in place. Much hard engineering, organizational, and research work will be required to demonstrate the workability of these systems. Future biomass farmers and processors need to see practical and successful demonstration projects on the ground that before they begin to participate on a large scale.

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THE EFFECT OF LOCATION AND FACILITY DEMAND ON THE MARGINAL COST OF DELIVERED WOOD CHIPS FROM ENERGY CROPS: A CASE STUDY OF THE STATE OF TENNESSEE[1]

R.L. Graham, Ph.D.; W. Liu, M.S.; M. Downing, Ph.D.
Biofuels Feedstock Development Program
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6038, U.S.A
C. Noon, Ph.D. and M. Daly, M.S.
Management Science Program
The University of Tennessee, Knoxville, Tennessee 37966-05628, U.S.A.
A. Moore, M.S.
Energy Technology Support Unit
Dept. of Trade and Industry, Harwell, Didcot OXON 0X11 ORA, U.K.

ABSTRACT

Cost-supply curves for delivered wood chips from short rotation woody crops were calculated for 21 regularly-spaced locations spanning the state of Tennessee. These curves were used to systematically evaluate the combined effects of location and facility demand on wood chip feedstock costs in Tennessee. The cost-supply curves were developed using BRAVO, a GIS-based decision support system which calculates marginal cost of delivering wood chips to a specific location given road network maps and maps of farmgate prices and supplies of woody chips from short rotation energy crops.

Marginal costs of delivered chips varied by both facility location in the state and facility demand. Marginal costs were lowest in central Tennessee unless the facility demand was greater than 2.7 million dry Mg per year (3 million dry tons per year) in which case west Tennessee was the lowest cost region. Marginal costs rose rapidly with increasing facility demand in the mountainous eastern portion of the state. Transportation costs accounted for 18 to 29% of the delivered cost and ranged between $8 and $18/dry Mg ($7 and $16/dry ton). Reducing the expected farmer participation rate from 100% to 50% or 25% dramatically raised the marginal costs of feedstock supply in the east and central regions of the state. The analysis demonstrates the need to use geographically-specific information when projecting the potential costs and supplies of biomass feedstock.

Introduction and Purpose

The purpose of this study is to systematically quantify both regional differences in the cost of supplying wood chips to biomass energy facilities in the state of Tennessee and the effect of facility demand on those differences. While it is well known that biomass feedstock cost-supply curves will be location-specific, no study has systematically quantified the expected geographic variation in feedstock supply curves for a region. Without some understanding of the geographic variation, it is impossible to assess the magnitude of error of generalizing from one location to another or using aggregate data to make site-specific estimates. This study goes the next step and demonstrates a methodology for quantifying the geographic variation in feedstock supply curves using the state of Tennessee as a case study.

The study extends previous studies by Noon, Graham and Downing in this region (Graham and Downing 1995, Downing and Graham 1995, Graham and Downing 1993, Downing and Graham 1993, Noon et.al. 1993). These studies mapped projected farmgate prices and woody biomass supplies[2] at a county-level using a breakeven analysis which took into account the density of crop and pasture land, expected yields of woody crops, and current profitability of crop and pasture land[3]. In conjunction with the biomass production estimates, a GIS-based decision support system called BRAVO was developed and applied to assess the probable cost of supplying wood chips from SRWC plantations to specific Tennessee Valley Agency (TVA) power plants in this region. BRAVO uses road networks and farmgate price and supply maps in conjunction with a transportation model to develop delivered cost supply curves for a given location or collection point.

In this study BRAVO is used to develop delivered cost-supply curves for 21 locations evenly spaced across the State. These supply curves are then systematically examined at 10 facility demand levels corresponding to a range of likely power plant or ethanol plant sizes. Regional differences in costs at each demand level are quantified as are (1) portion of the cost attributable to transporting biomass from the farm to the facility, and (2) effect of reducing farmer participation rate (the proportion of the land that is converted to SRWC plantations if the projected farmgate price for wood from that land is met).

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[2] The term "farmgate price" refers to the wood price needed to induce a farmer to grow SRWC plantations ($/Mg). In this study the farmgate price is assumed equivalent to the breakeven price - the wood price needed to assure the farmer a profit equal to his current profit. The supply amount associated with a specific farmgate price is the wood that could be grown if all the land of that farmgate price were put into SRWC production.

[3] Profitability of crop land ranged from $0 to $450 per hectare ($0 to $182 per acre) after variable costs (e.g., seeds, fertilizer, farmer labor, custom harvesting), and fixed costs other than land were accounted for. The rental rate of pasture defined the profitability of pasture and ranged from $36.30 to $66.44 per hectare per year ($14.69 to $26.89 per acre per year). SRWC plantations were assumed to yield 5.4 to 9.6 dry Mg/ha/yr (2.4 to 4.3 dry tons/acre/yr) after harvest losses depending on the land type.

Methods

Selection of Sites for Supply Curves

A grid of 21 points evenly spaced across the state was used to define the locations for the BRAVO runs (Figure 1). The collection points were assigned to their respective regions - East, Central, and West. The state of Tennessee falls into three physiographic regions. The eastern third is part of the Appalachian Highlands. It is heavily forested and mountainous with marked parallel ridges and valleys. Agricultural land is limited to valley bottoms and roads tend to parallel the ridges. The central third of the state is part of the Interior plains and is much flatter. The density of agricultural land is higher although forest is still the dominant land cover in many of the counties. The road network is more uniform. The western third of the state is part of the Gulf - Atlantic Plain. Streams flow towards the Mississippi. The agricultural density of the land is higher in this region than the others. As in the central portion of the state, the road network is well developed but the Mississippi River poses a transportation barrier.

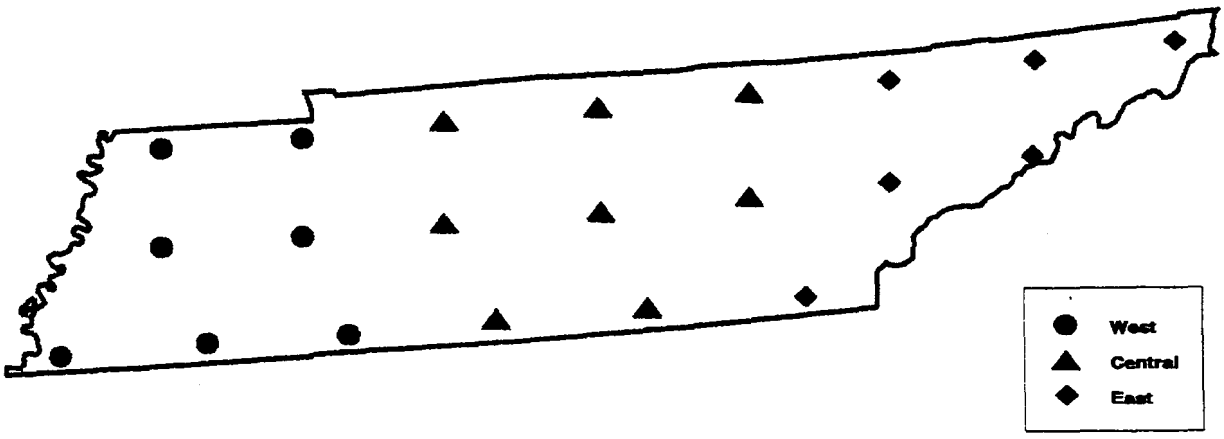

Figure 1. Hypothetical Bioenergy Plant Locations

BRAVO Model Runs

Previously-developed county-level farmgate price and supply maps for the TVA region (Graham and Downing 1995, Downing and Graham 1995) were used as the biomass maps for the BRAVO runs. The potential wood chip supplies were assumed to be located at the centroid of the county. Each county had 14 potential supplies of wood chips each corresponding to one of the fourteen types of land that could be used to grow SRWC plantations[4]. The amount of each

[4] The crop and pasture land in the counties was divided into 14 classes which captured the range of soil suitability for growing conventional crops and/or SRWC. Each class had a unique SRWC yield and farmgate price.

potential supply was based on the assumption that all the land with that farmgate price was used to grow SRWC plantations (e.g., assumed 100% farmer participation in SRWC production if the farmgate price was met). BRAVO was run at each collection point to generate a supply curve for that point. Only supplies from counties within 80 km (50 miles) of the collection point were eligible[5]. The amount, farmgate price, transport cost and minimum delivered price (sum of the farmgate price and the transport cost) of each supply used in creation of the supply curve was extracted from the BRAVO run and entered into spreadsheets. Supply curves associated with 25% and 50% farmer participation rates were generated in the spreadsheet by reducing each individual supply amount (as extracted by BRAVO) by 75% or 50%[6].

Cost and Demand Levels

The marginal costs of supplying the 10 quantities of wood chips listed in Table 1 for 100%, 50% and 25% farmer participation were extracted from the supply curves in the EXCEL spreadsheets. The mean transportation cost and farmgate price of the supplies needed to achieve a specific demand level were calculated for each location.

Table 1. The demand levels examined in the study.

Type of facility	Size of facility	Wood demand (000 Mg/yr)
Power	20 MW	90 (100 tons/yr)
Power	50 MW	230 (250 tons/yr)
Power	100 MW	450 (500 tons/yr)
Power	150 MW	680 (750 tons/yr)
Power	200 MW	900 (1,000 tons/yr)
Ethanol	2,300 Mg/day (2,500 tons/day)	750 (825 tons/yr)
Ethanol	4,500 Mg/day (5,000 tons/day)	1,500 (1,650 tons/yr)
Ethanol	6,800 Mg/day (7,500 tons/day)	2,200 (2,475 tons/yr)
Ethanol	9,000 Mg/day (10,000 tons/day)	3,000 (3,300 tons/yr)
Ethanol	18,000 Mg/day (20,000 tons/day[7])	6,000 (6,600 tons/yr)

[5] Counties outside of Tennessee but within 80 km (50 miles) were included in the runs. To be included only some portion of the county needed to be within 80 km.

[6] Halving participation or doubling demand will have the same effect on marginal cost of the supply. But as participation and demand are different concepts, it is useful to separate them.

Once the marginal costs for a specific demand level were extracted from the curves for the 21 locations they were grouped by their region - east, central, west as were the mean transportation costs and farmgate prices. The regional means of those variables (6 to 8 locations per region) were calculated as were the standard error about those means. Plots showing the mean regional marginal costs, transportation costs and farmgate prices by demand were created. Maps were also made showing the marginal cost of chipped wood from SRWC plantations at each location for supplying a 100MW power plant and a 9,000 dry Mg/day (10,000 dry ton/day) ethanol plant.

Results

Marginal Delivered Costs by Location and Demand

Figure 2 shows the mean marginal cost of supplying chipped wood in the three regions of Tennessee assuming 100% farmer participation - a best case. The central region is the least cost region unless very large amounts of woody chips are

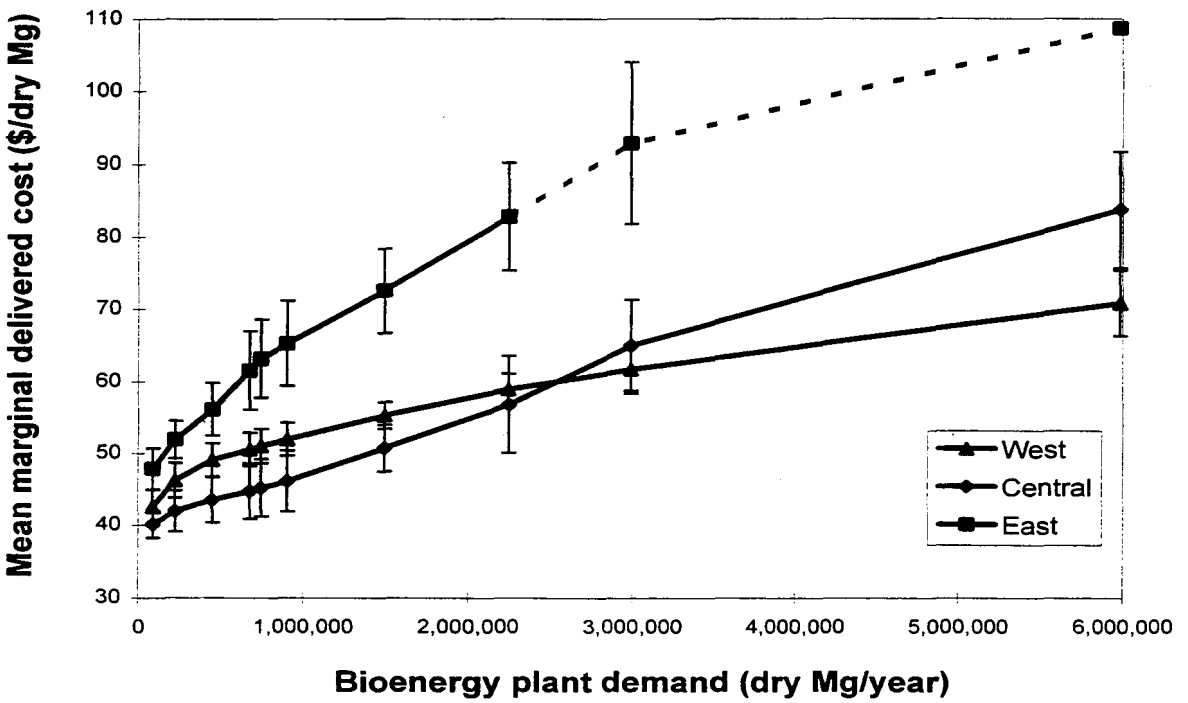

Figure 2. Short-rotation Woody Crop Marginal Cost vs Demand

[7] The 18,000 Mg/day (20,000 tons/day) plant is larger than cellulosic ethanol plants are likely to be built. This value was included to show the shape of the curve. Cellulosic ethanol plants may be built that are smaller than 2,300 Mg/day (2,500 tons/day) but they are unlikely to be smaller than 450 Mg/day or 300,000 Mg/year (500 tons/day or 330,000 tons/yr) because of capital costs.

required (greater than 2.7 million Mg/yr). The eastern region is the highest cost region. Examination of the standard error reveals that the western region is the most homogeneous region; biomass supplies will cost about the same any place within this region regardless of demand. The eastern region shows considerable site to site variation in costs and this variation increases as demand increases. The central region appears intermediate in all regards. Figures 3 and 4 illustrate the point to point variability in feedstock costs at two demand levels.

Production versus Transportation Costs

Mean transportation and farmgate costs varied noticeably among the three regions (Figures 5 and 6). The central region had the lowest transportation costs and the lowest farmgate costs until very high levels of wood chips were required (> 3 million dry Mg/yr). Farmgate costs were slightly higher in the western region than in the central region but transportation costs were markedly higher. The higher transportation costs in the west region can be attributed to the transportation barrier presented by the Mississippi River. The east region had the highest transportation costs averaging better than $15/dry delivered Mg ($13/dry ton) even at demands as low as 500,000 dry Mg per year and assuming 100% farmer participation. The high transportation costs can be attributed to both the mountainous terrain and the low density of agricultural land. Average farmgate prices were high in the east because the low density of crop and pasture land forced the use of land with high farmgate prices.

Impact of Farmer Participation Rates

Figures 7 and 8 illustrate the impact that farmer participation has on the marginal cost of supplying woody feedstock in the central and west regions[8]. The impact of farmer participation rate is much greater in the central region than in the west region. Assuming 100% farmer participation, the west region is the least cost region only for facilities demanding more than 2.7 million dry Mg/year (e.g. all but the very largest ethanol plant). Assuming 50% farmer participation, the west region is the least cost region for facilities demanding more than 1.3 million dry Mg per year (e.g. most ethanol plants) and some of the collection points in each region have an inadequate landbase (within the 80 km collection radius) for producing 6 million dry Mg (6.6 million dry tons) of wood a year. At a 25% participation rate, the western region is the least cost region for any plant requiring more than 750 million Mg per year (e.g. large power plants and all ethanol plants). Furthermore none of the collection sites in either region could support a 18,000 dry Mg per day ethanol plant without taking wood from counties farther than 80 km (50 miles) away and some sites in the central region could not support a 6,800 dry Mg day (7,500 dry ton day) ethanol plant. The within-region variability in delivered costs at a given demand level increases in the central region but not the western region as the farmer participation rate decreases. Thus from

[8] The east region shows the same trends as the central region but more dramatically. Most of the east sites cannot supply more than 2 million dry Mg regardless of delivered price because the total agricultural landbase is inadequate.

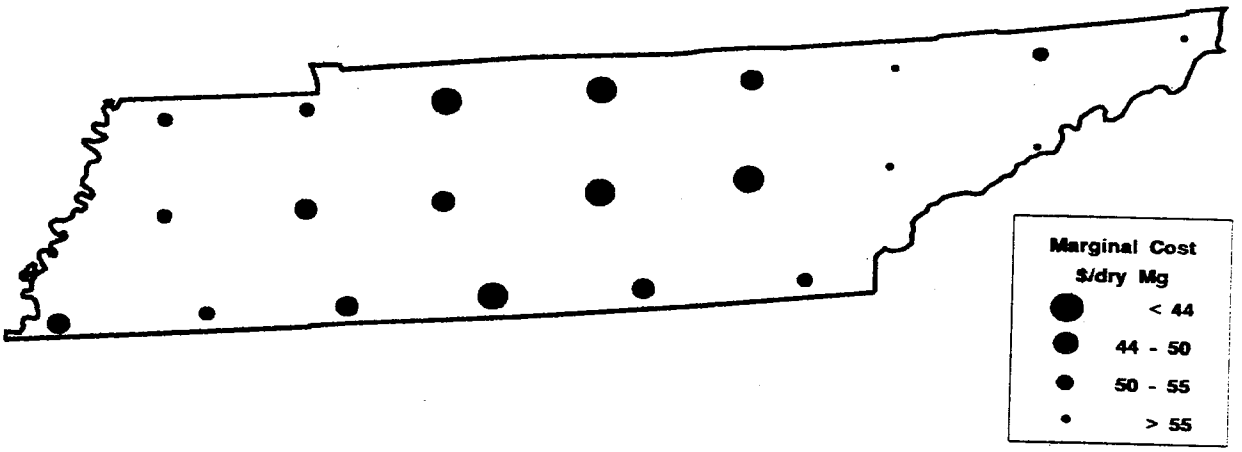

Figure 3. Marginal Cost of Delivered Short-rotation Woody Crop
Facility demand = 450,000 dry Mg/year (100 MW)

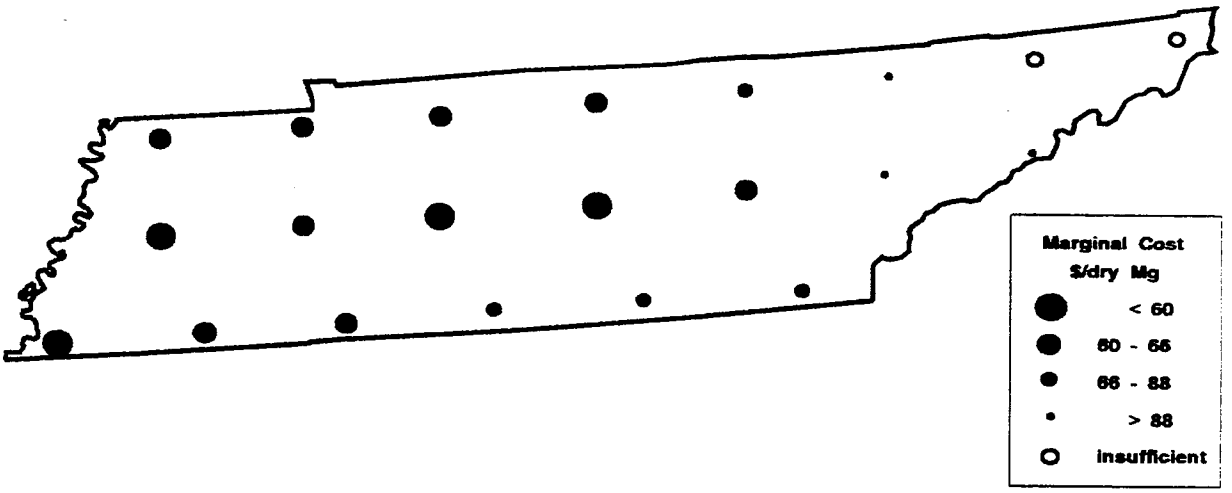

Figure 4. Short-rotation Woody Crop Marginal Cost vs Demand
Facility demand = 9,000 dry Mg/day (3.13 million liter/day)

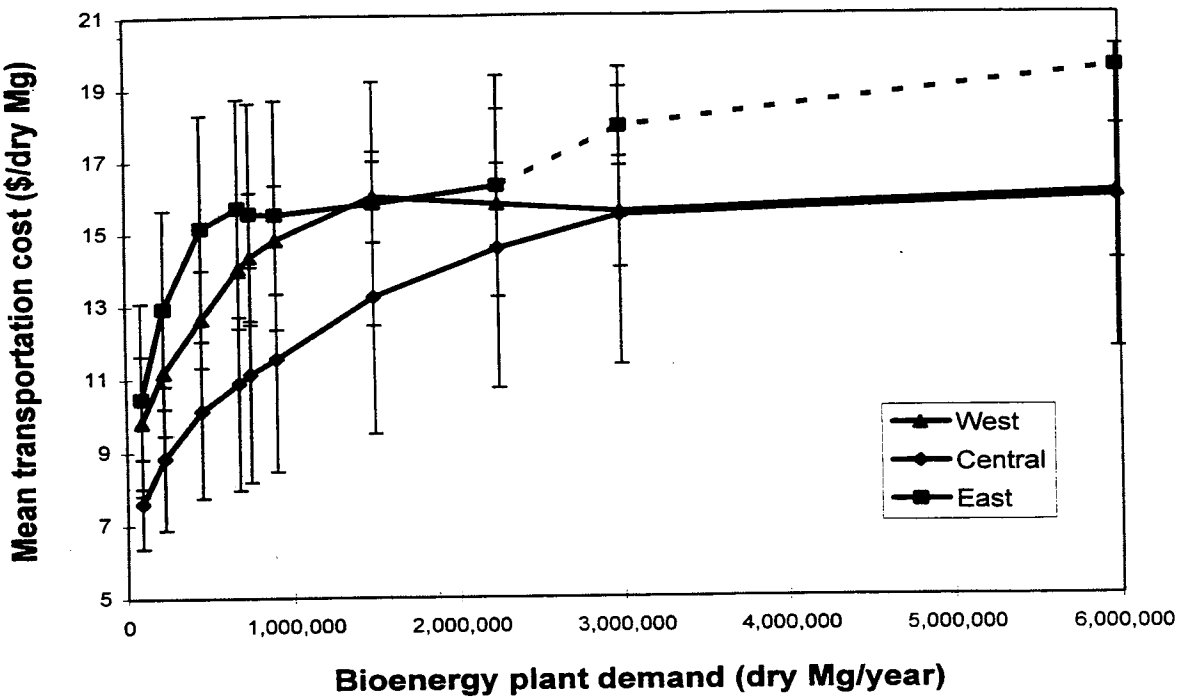

Figure 5. Short-rotation Woody Crop Transportation Costs

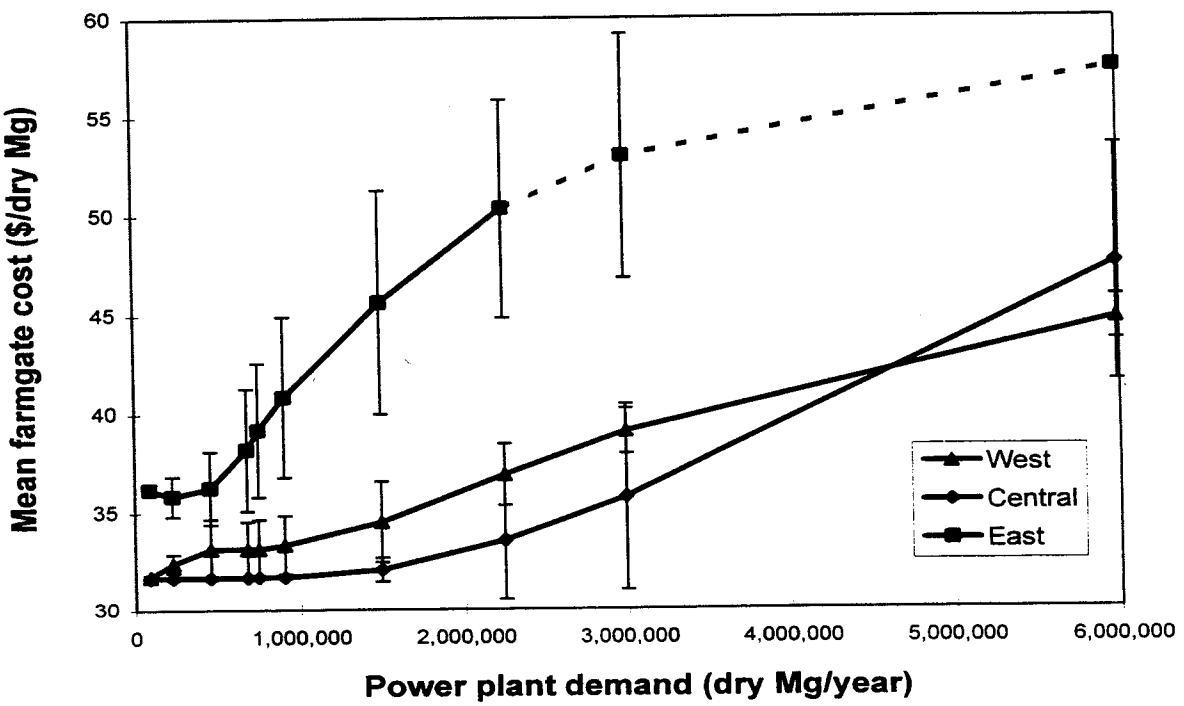

Figure 6. Short-rotation Woody Crop Farmgate Costs

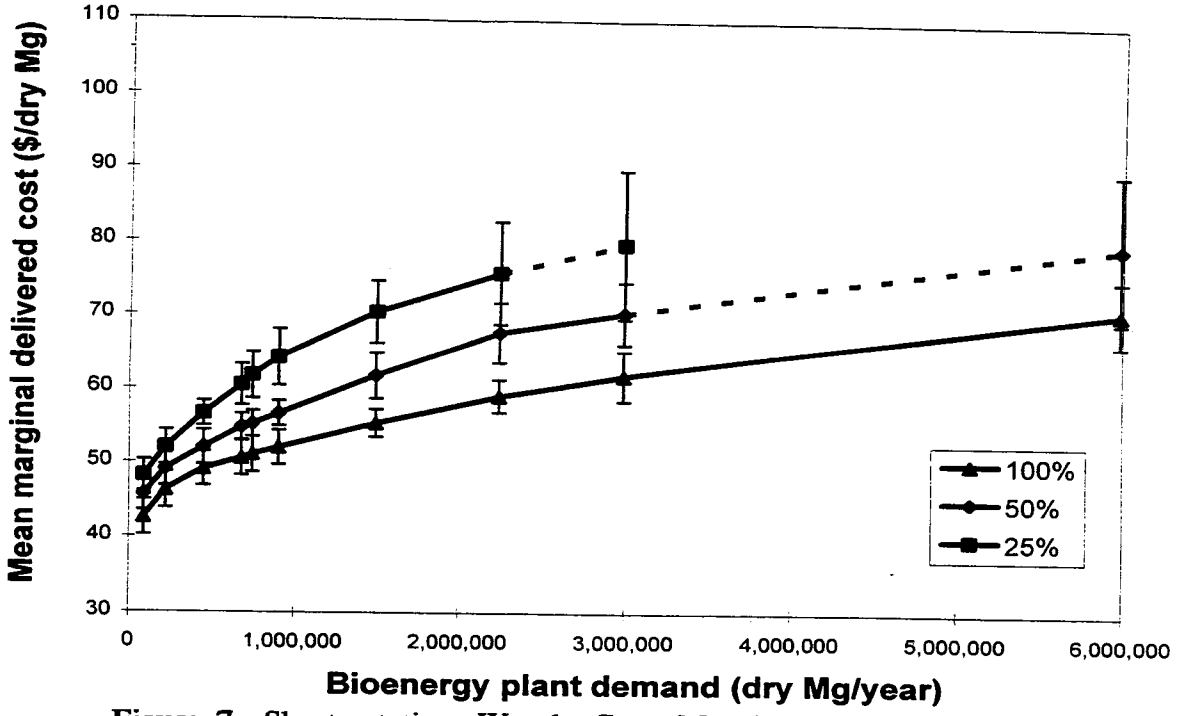

Figure 7. Short-rotation Woody Crop Marginal Cost vs Demand and Farmer Participation Rate - West

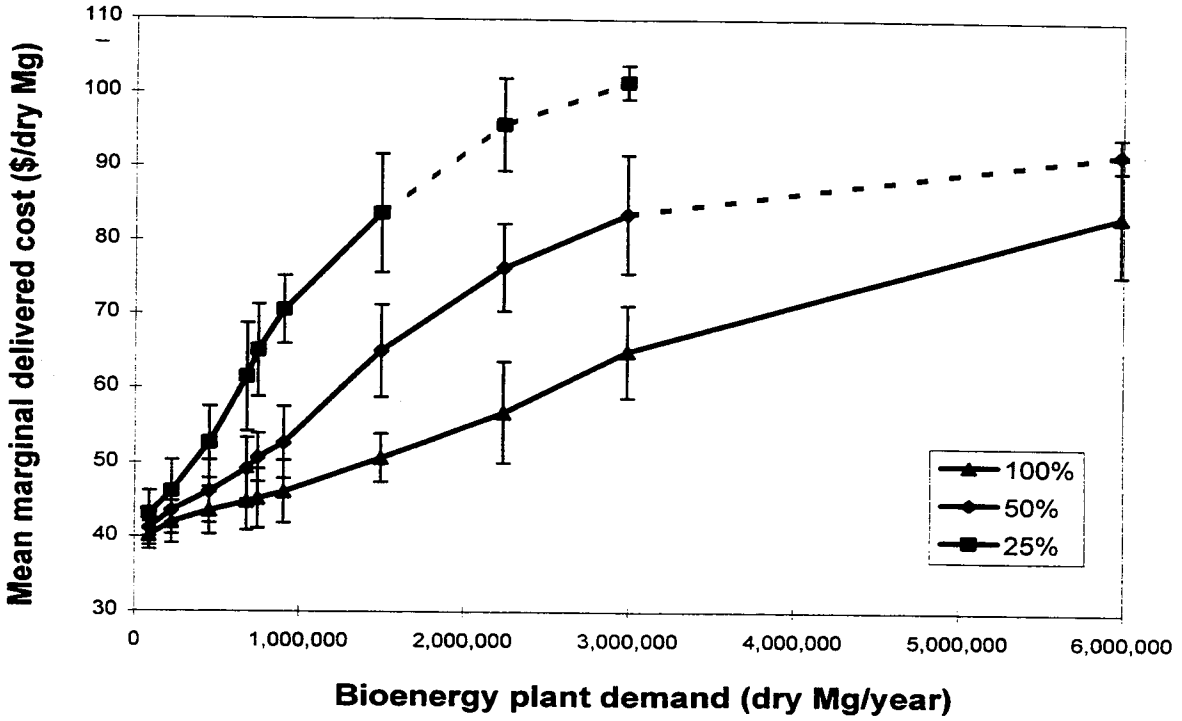

Figure 8. Short-rotation Woody Crop Marginal Cost vs Demand and Farmer Participation Rate - Central

the perspective of risk reduction, all but the smallest-demand facilities would be better off sited in the western region than in the central region unless they had some mechanism to ensure high farmer participation rates.

Summary

Biomass facilities will always be faced with dilemma that their feedstock cost will be highly location specific. Using supply curves that are based on aggregate farmgate price information and uniform transportation costs can be misleading. Such curves may obscure opportune locations where biomass supplies can be had inexpensively while at the same time overestimating the total number of facilities that can be supported by feedstock under a specific price. Capturing the geographic complexity of potential biomass supplies is a necessity and one for which GIS is well-suited.

This study demonstrates one approach for quantifying the geographic complexity of biomass supplies and illustrates the need to consider the adoption rate of energy crops by farmers in projecting the likely cost of biomass feedstock.

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GUIDELINES FOR OBTAINING FAVORABLE PROJECT FINANCING, FEDERAL TAX INCENTIVES, AND VARIOUS STATE INCENTIVES TO FUND BIOMASS ENERGY DEVELOPMENT

Michael Lubin, M.S., Financial Advisor, and
Gregory A. Sanderson, J.D., LL.M., Attorney

Lubin Financial, San Diego, CA 92116
Gomel & Davis, Atlanta, GA 30303

Abstract

This paper outlines methods for funding biomass project development. This paper discusses sources of project financing, identifies potential problems associated with financing biomass projects, and provides a brief summary of typical lender requirements. In addition, this paper identifies potential tax incentives and other benefits available from federal and state governments to promote biomass energy.

Project Finance

Project finance is generally defined as nonrecourse financing, which depends on the credit of the project once built, rather than the credit of the developer. Thus, while the project finance lender will expect the developer of the project to have a proven track record in the industry, and to be financially viable, the lender's major task is to evaluate the construction risk and the ability of a project to service its debt when construction is completed. Usually there is only limited recourse to the developer during the construction and shake out period. The developer will typically form a separate special purpose corporation or partnership to develop, own, and operate the project. Once the project is up and running, the lender has no recourse to the parent company should the project under perform or fail financially.

Project finance almost always requires an equity investment of between 20% and 30%. This equity can come from either the developer or a third party investor, although some lenders require at least some risk equity from the developer.

Project finance can provide either a fixed rate loan or a floating rate loan, which is usually tied to an accepted interest rate index such as U.S. Treasury bills or the London interbank rate (LIBOR). The term of the debt can be as long as 25 years but more often will be between 10 and 15 years. A critical factor in determining the term of the debt is the length of contracts which provide the project income, such as power purchase agreements or fuel sales agreements. In general, banks are more restricted than other institutions, such as insurance companies, with regard to the length of the financing term, and may be reluctant to provide a term longer than 10 years.

Project finance may be obtained from the following sources:

Banks

Large regional, national, or international banks are a major source of project finance. They usually have a separate project finance department with loan officers that have specialized backgrounds often including engineering and law as well as finance. Many banks restrict their project finance activities to energy projects that use more traditional fuels such as natural gas, fuel oil or coal. Banks may reject biomass projects because they are uncomfortable with the fuel supply risk, or unfamiliar with the equipment, and are not willing to put in the time and effort to overcome their reservations. Local banks will often lend on a biomass project even if they do not have a project finance department, if there is a strong working relationship with the developer. Particularly for smaller projects with budgets of $5 million or less, the local bank may be the best source. In addition, the local bank may be less concerned about performing its own due diligence on the project, and rely more on its experience with the developer, particularly with good contracts guaranteeing the project income. Local banks may view a project's risk as identical to a long term, asset secured loan given to a trusted and valued banking customer. This approach may save the developer the cost of a full engineering report on the project.

National Insurance Companies
Many insurance companies have project finance departments which specialize in both energy and industrial projects. They have the advantage of low interest rates combined with the ability to give very long term loans. With a power purchase agreement that matches the length of the loan, a term of as long as 30 years is possible. Some insurance companies can provide equity as well as debt. Unfortunately, many insurance companies will not provide financing for biomass projects. An additional problem is the requirement that insurance companies maintain an investment portfolio that meets a relatively low risk profile as determined by the National Association of Insurance Companies (NAIC). Thus, some projects are rejected because the income to the project is not coming from an investment grade entity. Very few insurance companies will consider projects with total budgets of less than $10 million.

National Commercial Lenders
Many commercial lenders have project finance departments for both energy and industrial projects. Generally these companies are the financial subsidiaries of large corporations such as General Electric or Chrysler with various investment criteria driven by the financial health, business goals, and tax considerations of their parent companies. They function much like commercial banks, but may offer longer term debt at somewhat higher interest rates than banks and insurance companies. They are usually open to considering biomass projects and are more flexible in their evaluation of project risk. In some cases they can provide part of the required project equity. Some commercial lenders may require a profit participation from the project, which has the effect of increasing the interest rate considerably. In general, commercial lenders represent a more expensive source of financing than banks and insurance companies.

Equipment Leasing Companies
There are several national equipment leasing companies that have project finance departments which will consider biomass projects. They function in much the same way as commercial lenders. It may also be possible to use simple equipment leases to finance some biomass projects, on a nonrecourse basis, if the fuel supply is very predictable and the revenue to the project is coming from a customer with a high credit rating. Most important is the nature of the promise to pay by the purchaser of the power or commodity that brings revenue to the project. If the agreement to purchase the power or commodity is guaranteed (i.e., the payment is made regardless of delivery of the power or commodity), then an equipment lease may be appropriate. The advantage of this approach would be avoidance of engineering reports, high legal fees and extensive due diligence usually associated with project finance. If the lease is a true lease, involving residual risk, the lessor will require additional assurances concerning the life and remarketing of the equipment and will insist on proven technology.

Equity Investment Funds
There are several energy investment funds which invest equity in biomass projects. They can provide the necessary equity to qualify for debt financing. Since most of these funds expect pretax returns of between 18 and 25% or more, the project must be very profitable to qualify without the leverage provided by debt. The expected return on equity will

depend on the perceived risk level (equity invested early in the development phase is at greater risk) and on whether the developer also contributes risk equity. While this method of finance can be very expensive and can result in loss of ownership in the project, the cost may be mitigated by reduced financing costs such as legal and engineering fees. In addition, equity funds may be able to utilize tax incentives associated with biomass projects, such as income tax credits and short tax depreciation schedules. If the equity fund includes the value of tax benefits in its return on investment analysis, the amount of cash return required by the fund may be significantly reduced, thereby leaving more cash in the project for the developers, operators, or other parties. The time required to close on equity financing can also be considerably less than the time necessary to close on combined equity and debt financing.

Municipal Bond Financing

With private ownership by the developer, a project may qualify for tax-exempt governmental bond status, provided that the project meets certain criteria. To qualify, the project must generally provide some form of public benefit such as the following:

- ***Local Furnishing of Electricity***
  Tax-exempt status is provided for a power project that sells electricity to a utility that is a net importer of power and serves no more than two contiguous counties or one county and one contiguous city.

- ***Local District Heating and Cooling***
  Tax-exempt status is provided for an energy project that sells steam, chilled water, and/or other thermal energy to two or more unrelated entities, which must be within two counties.

- ***Solid Waste Disposal***
  Tax-exempt status is provided for facilities that dispose of solid waste that has no market value as a salable product.

Availability of tax-exempt bond financing varies from state to state. Some states, such as California, may have an excess allotment every year, and other states, such as Texas, may have less than is needed to satisfy all applicants. Qualified financial experts are needed to determine if a project can qualify for tax-exempt municipal bond financing and to evaluate the likely market for such bonds. The market for bond issues of less than $5.0 million is very limited. Care must be exercised in identifying an underwriter with experience in this marketplace. While tax-exempt bonds may allow financing with very low interest rates, especially with investment grade projects, the costs associated with municipal bond financing can be so high as to bring the total financing costs very near to the cost of other forms of debt. For those projects with very low risk, a possible alternative to the expensive process of public bond underwriting is a private placement with an institutional investor. This option may be available with both taxable and tax-exempt bonds. While this marketplace is limited, private placement may allow the lowest cost of financing available. However, the benefits of lower interest rates that come with tax-exempt financing may offset the benefits of tax credits. Thus, a project may not be

able to benefit from both tax credits and tax-exempt financing, unless parts of the project have separate ownership, with one party benefiting from tax-exempt financing and another party receiving the tax credits.

Special Problems in Financing Biomass Projects

Developers should consider the following potential problem areas when seeking financing for biomass projects:

Fuel Supply
Traditionally, project finance has involved energy projects with reliable conventional fuel supplies from major oil, gas or coal companies. With biomass projects that consume fuels that are less reliable, such as landfill gas or waste wood, uncertainty over the future reliability of the fuel supply can become the most critical factor in financing a project.

Project Technology
Some biomass projects use new technology which has not been proven to be historically and economically reliable. A guarantee of the technology performance, provided by a major vendor with excellent credit may successfully overcome this problem.

Sales Agreements
Project finance usually relies on income generated from long-term power sales agreements with utilities or major corporations which have excellent credit. Some biomass projects sell fuel or energy to small companies with credit ratings far weaker than those associated with utilities. This may prove an insurmountable obstacle for project finance with national lending institutions.

General Lender Requirements

The following is a list of typical lender requirements:

Fuel Supply
Borrowers may need executed long-term supply contracts, samples of fuel or test wells for landfill gas projects, or models of gas production for landfill gas projects.

Power Sales Agreement
For power projects, borrowers should have a signed power sales agreement with the utility or industrial plant with a term that matches the debt repayment schedule. It is helpful if the agreement has a capacity payment that covers expenses, with force majeure provisions and escalation clauses. Additionally, an interconnection agreement should be executed.

Permits
It is advisable to have all required permits prior to financing wherever feasible. Only those permits which are certain to be given should be obtained after financing.

Equipment
The project should employ proven technology, with performance guarantees and warranties from the vendor. Where possible the project should use major vendors.

Operations and Maintenance
The project should use a qualified operator with a proven track record. Additionally, it may be desirable to have this service provided by an equity investor.

Construction
Borrowers should obtain fixed price turnkey contracts which contain completion bonding, equipment acceptance standards, and penalties for late performance.

Financial Model
Lenders will usually expect to see a financial pro forma which includes debt coverage ratios (usually in the range of 1.3 to 1.6 is required by lenders), debt reserve accounts, working capital requirements, interest during construction schedule, income tax calculations, tax credit calculations, budget for major equipment overhauls, complete detailed construction budget and complete project sources and uses analysis. If the developer is not experienced in building the pro forma, it is advisable to secure a financial advisor to perform this service.

IRC §29 Biomass Gas Credit

Section 29 of the Internal Revenue Code contains a credit for the production and sale of gases derived from biomass and synthetic fuels derived from coal. The term "biomass" is defined broadly for purposes of §29 to include any organic material other than oil, natural gas and coal (including lignite), or any products thereof. In some instances, waste materials that contain processed products of petroleum may qualify as biomass. Biomass may include waste tires, plastics or asphalt shingles. The §29 credit is available for biomass gasification and coal fuels facilities placed in service by December 31, 1996, pursuant to written contracts signed by December 31, 1995. Facilities which meet these deadlines, and are originally placed in service after December 31, 1992, can qualify for the §29 credit until January 1, 2008. The §29 credit is based on a barrel-of-oil equivalent adjusted annually for inflation. The 1994 credit was $5.76 per barrel, resulting in a credit of $0.99 per 1.0 million btu's produced and sold. The credit is generally applicable to landfill gas recovery systems, anaerobic digestors, and thermal air or oxygen gasifiers.

To qualify for the §29 credit, the facility must produce a combustible gas from biomass and sell this gas to an "unrelated" party. In a brother-sister business structure, two companies may be considered "unrelated" if there is less than 80% common ownership of the two companies. In a parent-subsidiary structure, the parent company can own no more than 50% of the subsidiary. Other than the "sale" requirement of §29, there is no prohibition on where or how the gas is consumed, although it may be implied that the gas must be used for a legitimate business purpose. Therefore, close-coupled, or directly connected, gasifiers and boilers or gas burners may qualify. This result is supported by private letter rulings. When claiming the credit on close-coupled gasifier systems, a

taxpayer should be prepared to prove that the gasifier is a potentially stand alone component of the system, such that the gasifier could be moved apart and the gas piped into the boiler or burner, and that the gas produced is combustible when separated from the biomass itself. Of course, the gasifier must be owned by a party unrelated to the owner of the boiler/combustor, and the gas must be sold prior to its combustion under a legitimate operating arrangement.

The §29 credit is phased-out when oil prices exceed a certain level which is adjusted annually for inflation. The 1994 credit would have begun to phase-out if oil prices had exceeded $45.14 per barrel, and would have been completely phased-out if the price per barrel had exceeded $56.66. The credit is reduced by the amount of grants or subsidized financing used to fund a particular project, and is coordinated with certain other tax credits to prevent double usage of credits. The §29 credit will not offset alternative minimum tax, and will offset regular tax liability only to the extent that it exceeds tentative minimum tax. Any unused credit in a particular year may not be carried backward or forward to any other year, unless the credit is not used due to an alternative minimum tax limitation, in which case the disallowed portion will increase the minimum tax credit carryover.

IRC §45 Renewable Biomass Electricity Credit

Section 45 of the Internal Revenue Code provides an income tax credit for electricity produced from "renewable resources," defined as wind and "closed-loop biomass." The term "closed-loop biomass" means any organic matter from a plant which is planted exclusively for the purpose of generating electricity. The Congressional Committee Reports state that the credit is not available for the use of waste materials (including waste wood), or standing timber. Despite the restricted definition of closed-loop biomass, §45 may be applicable to timberland owners who are currently planting new trees and intend to make interim thinning cuts, such as cuts at 10-year or 15-year intervals, prior to harvesting saw timber. It may be possible for these timberland owners to dedicate, or contract to sell, their thinning cuts as energy trees for producing electricity. This application of §45 appears reasonable because the statute defines closed-loop biomass as matter derived from "a plant." While §45 requires use of the whole plant or tree for power production, it does not appear to require dedication of an entire crop or harvest. If timber growers can sufficiently identify the trees to be thinned, and sufficiently document dedication of the trees as energy crops, it may be possible to bring these trees within the purview of §45. Currently, however, there is no guidance regarding acceptable methods of plant dedication or identification.

The amount of the credit is 1.5 cents for each kilowatt hour of electricity produced from wind or closed-loop biomass. This amount is adjusted annually for inflation. The credit is phased out as the "reference price" of electricity produced exceeds a threshold price range of 8 cents to 11 cents. A "qualified facility" must be placed in service after December 31, 1992 (December 31, 1993 for wind), and before July 1, 1999. The Internal Revenue Service has ruled that a facility used prior to the §45 placed in service date may qualify for the credit if the facility is reconstructed after the applicable date, and the fair

market value of the used equipment is not more than 20% of the facility's total fair market value after reconstruction.

The credit may be claimed on the sales of electricity occurring during a 10-year period beginning after the facility is placed in service (assuming the July 1, 1999 in service date is met). The electricity must be sold to an unrelated party in order to qualify. Section 45 incorporates the same definition of "unrelated" as is used for §29. The §45 credit is reduced for grants and subsidized financing in a manner similar to §29. Additionally, the §45 credit is reduced by "any other credit allowable with respect to any property which is part of the project." The Congressional Committee Reports state specifically that the §45 credit is reduced when a facility has received the business energy credit or the investment credit. Once the allowable amount is determined, then the §45 credit may be reported by the taxpayer. The use of the allowable credit may be limited by other provisions, but if the allowable credit is limited, it may be carried forward 15 years and backward three years. (Except that the credit may not be carried back to a taxable year ending before January 1, 1993 for closed-loop facilities and before January 1, 1994 for wind facilities). Unlike §29, the §45 credit is part of the §38 general business credits, and, as such, use of the §45 credit is limited to tax liability reduced by the greater of either (1) tentative minimum tax, or (2) 25% of tax liability in excess of $25,000 after reducing tax liability for certain other credits (including the §29 credit).

D.O.E. Renewable Energy Production Incentive

An incentive payment exists under 42 U.S.C. 1331, entitled "Renewable Energy Production Incentive," for electricity generated and sold from solar, wind, biomass or geothermal energy. This electricity incentive amount is 1.5 cents per kilowatt hour, adjusted annually for inflation, and is available to states, political subdivisions, and nonprofit electrical cooperatives that produce electric power for sale in, or affecting, interstate commerce. The incentive payment appears to be available for all forms of biomass power facilities, except that burning municipal solid waste and producing energy from certain dry steam geothermal reservoirs will not qualify. The incentive is scheduled to expire at the end of a 20 fiscal year period, beginning October 1, 1993 and ending September 30, 2013. To qualify, the facility must be first used during the 10 fiscal year period beginning October 1, 1993 and ending September 30, 2003. A facility may not receive payment for more than the 10 fiscal years, beginning with the first year in which electricity from the facility is eligible for payments.

On May 13, 1994, regulations were proposed by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, for implementation of this incentive payment program. The regulations provide that an owner of a qualified facility may file application for incentive payments only in response to an annual notice in the Federal Register. Additionally, priority will be given to facilities using wind, solar, geothermal and "closed-loop biomass" technologies, according to the proposed regulations. If insufficient appropriations are available for all approved applications, the Department of Energy shall make payment to these applicants first, and the remaining funds, if any, may be applied to other technologies. "Closed-loop biomass" is defined as "plant matter, other

than standing timber, grown for the sole purpose of being used to generate electricity." At the date of this writing, the proposed regulations are under revision, and are scheduled to be finalized in 1995. No funds have been disbursed, and funds will not be made available until the regulations are final. For 1995, $3.0 million was requested to fund 1994 payments, and Congress authorized a total of $10.0 million. For 1996, an additional $3.0 million has been requested. However, with potential budget cuts currently under consideration, Congress may possibly rescind the $10.0 million in funds previously authorized.

Alcohol Fuels Incentives

The following tax incentives are contained in the Internal Revenue Code for alcohol fuels:

Excise Tax Exemptions for Alcohol Fuels

Exemptions from excise taxes levied on gasoline, diesel and aviation fuels are available under IRC §§ 4041, 4081 and 4091. These tax exemptions are generally equal to 5.4 cents per gallon off the Highway Trust Fund financing rate, and 0.05 cents off the Leaking Underground Storage Trust Fund financing rate. The exemptions may apply when fuel mixtures consist of at least 10% of alcohol which is not produced from petroleum, natural gas or coal. Additionally, reduced tax rates exist for gasoline mixed with gasohol, where the gasohol contains at least 5.7% alcohol which is not derived from petroleum, natural gas or coal.

Alcohol Fuels Credit

Three types of alcohol fuels income tax credits exist under IRC §40. These credits are (1) the alcohol mixture credit, (2) the alcohol production credit and (3) the small ethanol producer credit. Whereas the small ethanol producer credit applies only to ethanol, either ethanol or methanol may qualify for the alcohol mixture credit and the alcohol production credit, as long as the ethanol or methanol is not produced from petroleum, natural gas or coal. The amount of the alcohol mixture and alcohol production credits are generally 60 cents per gallon for alcohol which is at least 190 proof, and 45 cents per gallon for alcohol which is of a proof ranging between 150 to 190. In the case of ethanol, however, the alcohol mixture credit is reduced to 54 cents for 190 proof ethanol, and to 40 cents for ethanol of a proof between 150 and 190. The credit for small ethanol producers is 10 cents per gallon for up to 15 million gallons produced per year by a "small producer." A small ethanol producer is a producer with an alcohol production capacity not exceeding 30 million gallons per year.

Special Deduction for Alcohol & Clean Fuels Property

IRC §179A contains a special income tax deduction for "qualified clean-fuel" vehicle and refueling property. "Clean-fuel" includes, among other things, any fuel which is at least 85% alcohol. The deduction amount ranges from $2,000 to $100,000, depending on the type of property.

Depreciation for Biomass Energy Facilities

Two particularly short tax depreciation lives are available for certain biomass energy facilities. These two types of facilities are set forth in Table 1.

Table 1. Special Depreciation Lives for Biomass Energy Facilities.

Asset Description	Tax Life
Small Power Plants: Biomass Property qualifying as a "small power production facility," which includes facilities that produce electricity from biomass and generally have a power production capacity of 80 megawatts or less (May not apply to landfill gas power projects)	5 years
Waste Reduction and Resource Recovery Plants: Includes assets used in the conversion of solid waste and biomass into heat or into a solid, liquid, or gaseous fuel, including waterwall combustion systems, oil or gas pyrolysis systems, or refuse derived fuel systems to create hot water, gas, steam and electricity	7 years

Potential State Incentives

States and municipalities may provide assorted tax breaks and incentives applicable to biomass energy projects. A publication entitled "National Directory of Federal and State Biomass Tax Incentives and Subsidies" was prepared by the author of this paper in association with the U.S. Department of Energy, Tennessee Valley Authority, Southeastern Regional Biomass Energy Program, to help identify incentives offered by each of the 50 states. A copy of this publication is available by contacting Philip Badger, Program Manager, or David Stephenson, Assistant Program Manager, at (205)386-3086 (phone) or (205)386-2963 (fax).

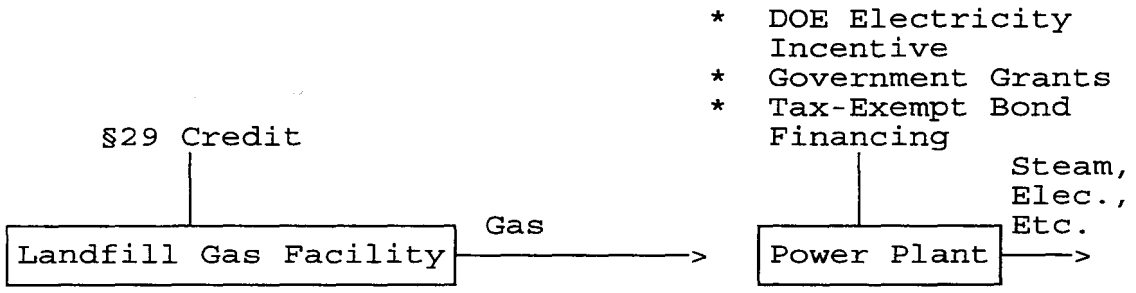
Generally, the types of state incentives which may be available are as follows:

- Direct Project Grants
- Subsidized Financing or Tax-Exempt Bond Financing
- State Income Tax Credits
- Property Tax Exemptions
- Sales and Use Tax Exemptions (either for equipment purchases or for energy sales)
- Special State Income Tax Deductions or Expense Elections
- Special Power Rate Structures

Structuring to Maximize Benefits

A facility may be prohibited from claiming tax incentives, such as the §29 credit, while, at the same time, accepting grants or subsidized financing to fund a particular project. To avoid such limitations, it may be possible to divide the use of tax breaks and incentives between separate, unrelated parties. A structure designed to accomplish this division of benefits is set forth in Table 2.

Table 2. Coordination of §29 with other Incentives.



One potential problem with the above structure could exist under §29 if the gas facility and the power plant were considered to be two components of a single "project," since the §29 credit is reduced by grants used to fund a "project." Nevertheless, it appears proper not to reduce the §29 credit in this case. The owner of the gas facility and the owner of the power plant must be unrelated within the statutory rules for the gas sales to qualify for §29. The §29 credit would be claimed by one party, and the incentive payments or other benefits would be received by a separate, unrelated party. Hence, it is conceivable that this structure could generate the §29 credit for the gas producer and allow the power plant to qualify for the incentive payments and other benefits.

PRIVATE FUNDING OF A BIOMASS POWER PROJECT: WILLIAMS LAKE CASE HISTORY

Beverly Z. Baker, M.B.A., Managing Partner
Tondu Energy Inc., Houston, TX 77056 U.S.A.

Abstract

Private funding for a biomass power project is available if the project is properly structured, the cash flow can be forecasted with a high degree of confidence, the project provides long-term benefits and the risks have been mitigated or allocated among the participants. The Williams Lake Project, a 60 MW wood waste fueled power plant in British Colombia, has all of these elements. Twenty two year fixed rate financing was provided from a group of Canadian life insurance companies and pension funds without any type of government guarantee. The syndicate provided 90% of the $150 million (Cdn.) cost and 10% was financed by equity.

The original partners of the project were Tondu Energy Systems, a developer of independent power projects and owner of a 54 MW coal fired cogeneration facility in Michigan, a subsidiary of the Washington Water Power Company who owns and operates a 50 MW wood waste project in Washington and a subsidiary of BC Gas who has extensive knowledge and experience of doing business in British Colombia.

A 25 year Power Purchase Agreement was executed with B.C. Hydro which provided for the payment of electricity. The project provided B.C. Hydro with long-term, reliable electricity. Fuel for the project is provided by local sawmills who were able to close down their beehive burners. This significantly reduced the particulate emissions in the Williams Lake area solving a severe, long standing air pollution problem. Long term fuel supply agreements were executed with the local sawmills which provided fuel at no acquisition cost for 25 years. Supplemental wood waste supply agreements were also executed, further reducing any risk of fuel supply. Construction risk was minimized because of the Turnkey Construction Agreement which provided performance guarantees and liquidating damages. Also, construction management was provided by the owner to ensure the plant was built in accordance with the design specifications. Operating risks were managed by using proven technologies, hiring qualified personnel to run the facility and ensuring adequate funds were available for operation and maintenance expenses.

As British Columbia's first independent power plant project, Williams Lake created the model agreements for numerous contracts, environmental regulations and project financing. Since beginning commercial operations in April, 1993, the Williams Lake Project has operated above its design limits and well below emissions requirements.

The Williams Lake Project Description

The Williams Lake Project is a 60 MW wood waste fueled power plant located in Williams Lake, British Columbia, about 300 miles north of Vancouver. Williams Lake is located in the center of a major lumber industry region with five large sawmills located within five kilometers of each other. These sawmills cut over one billion board feet of lumber per year and produce over 600,000 green tons of bark, sawdust and other wood waste products per year. Prior to the operation of the Williams Lake Project, the sawmills burned this wood waste in beehive burners, creating a serious environmental problem. The city was plagued with smoke and ash particles, and at times the smoke alarms were set off in the local schools.

The Williams Lake Project was developed in response to a request for proposals ("RFP") issued by the British Columbia Hydro and Power Authority ("B.C. Hydro") in December, 1988. A proposal was submitted in response to this RFP in May, 1989. In late 1989, the Williams Lake Project was selected by B.C. Hydro and the Power Purchase Agreement was executed in June, 1990. The financing for the project was closed on May 2, 1991. When the financial closing occurred, the Williams Lake Project was the largest independent power plant debt financing in Canada and the second largest non-recourse financing in Canada. It was also the first Canadian non-recourse transaction funded by financial institutions prior to completion of construction. A syndicate of Canadian life insurance companies and pension funds provided $135 million (Cdn.) of 22 year, fixed rate debt. The plant was designed and built by CRS Sirrine. Commercial operation of the plant began on April 2, 1993.

The plant is a conventional steam cycle, wood waste fired electricity generating facility consisting of a steam generator, a turbine generator and auxiliary equipment with a guaranteed design net output of 60 MW. It is in compliance with all current environmental requirements. It has greatly improved the environment by burning wood waste in a boiler utilizing emission control devices instead of disposing of the wood waste in beehive burners. The plant has a Babcock and Wilcox boiler and a GE turbine generator.

The plant is operated by 31 people, who report to the plant manager and business manager. The plant manager is responsible for the operation and maintenance of the plant. The business manager is responsible for the financial and administrative functions.

Benefits of the Williams Lake Project

The Williams Lake Project provides many benefits to B.C. Hydro, the City of Williams Lake and the Province of British Columbia. These benefits include the generation of low-cost electricity, significant reduction of air pollution, the creation of new jobs and revenues and the enhancement of future economic development.

The plant provides power to B.C. Hydro at a unit cost of energy comparable to B.C. Hydro's long-term marginal cost of energy. Electricity generated by the plant circumvented the need for B.C. Hydro to build additional capacity.

The plant eliminated significant airborne ash emissions caused by incinerating wood waste from the five sawmills within Williams Lake. Historically, these sawmills disposed of wood waste in beehive burners. The smoke and ash from these burners created unacceptable levels of air pollution. The Williams Lake Project now burns this wood waste using technology that virtually has eliminated this air pollution problem. The plant was designed to reduce particulate levels to meet the most stringent provincial and federal guidelines. The ash is non-hazardous and disposed of in a dedicated landfill located near the plant site.

The plant has had significant social and economic impacts on the local, provincial and national economies. There is a strong provincial and local support for the Williams Lake Project since it has significantly improved the air quality in Williams Lake and created three hundred construction jobs and approximately forty full-time jobs at the plant and ash landfill.

Project Financing

Project finance is the art of lending on dreams, commitments and convenants and making those dreams realities. In a non-recourse financing, the lenders only have recourse to the project's assets as their collateral which includes all contracts and tangible assets. The value of the lender's collateral is in the revenue producing operation of the plant. The most significant agreement for a power plant is the power purchase agreement since it defines the power plant's gross income.

There are many factors which determine a lender's willingness to provide project financing for a biomass power project. These different factors will be weighed differently depending on the type of project. The key to project finance is risk allocation and managing the risks. The risks associated with a project must be allocated among the participants, including the developer, lender and contract parties.

Some of the factors determining the feasibility of a project finance transaction are as follows. These will be discussed in greater detail and specific examples from the Williams Lake Project will be used to explain these concepts.

- Credibility of Project Sponsors
- Power Purchase Agreement
- Creditworthiness of Electricity Purchaser
- Comparative Cost of Electricity
- Fuel Risk
- Structure
- Construction Risk
- Operating Risk
- Projected Financial Analysis

Credibility of Project Sponsors

The project sponsors must have extensive knowledge and experience in developing and owning power plants to assure the lenders that the project will be built as designed and the plant can be operated at the targeted levels. Also, equity will be required by the lenders so the project sponsors must have the financial capability to satisfy this requirement.

The project sponsors of the Williams Lake Project were Tondu Energy, WP Energy and Inland Pacific Energy Corp. ("IPEC"). Each of these project sponsors have extensive credibility. Tondu Energy had gone through the entire developmental process for a 54 MW cogeneration facility in Michigan. This process included negotiating all of the project contracts including the site acquisition agreement, coal dock lease, steam sale agreement, power purchase agreement, coal purchase agreement, power interconnection and the financing documentation. Tondu Energy also obtained the required environmental permits and actively participated in the project's construction management.

WP Energy was a subsidiary of Washington Water Power ("WWP"), a combination utility providing electricity and natural gas to customers in eastern Washington and northern Idaho. WWP owns and operates the Kettle Falls Generating Station, a wood waste fired facility with a name plate capacity rating of 50 MW. This power plant began operations in December, 1983 and has enjoyed a high availability factor.

IPEC is a subsidiary of BC Gas, the fourth largest natural gas distribution utility in Canada. BC Gas has a strong presence in British Columbia, is highly experienced in the British Columbia regulatory processes and has been involved with the community of Williams Lake since the 1960s.

Power Purchase Agreement

The power purchase agreement determines the foundation for a project's financeability as it provides the source of revenue to service the debt. It is very important to the lender that this agreement be effective for the term of the debt. Some key provisions in a power purchase agreement are termination clauses, payment provisions and regulatory out clauses.

The lenders will want to be able to correct any events of default under the power purchase agreement before the utility can terminate the contract. Also, the term of the debt will typically be structured to be less than the term of the power purchase agreement. The term of the Power Purchase Agreement for the Williams Lake Project is 25 years which may be extended for two additional 5 year periods. The debt for the Williams Lake Project provided a two year construction loan to match the construction period during which time only interest was paid. Upon completion of the performance tests, the construction loan converted to a 20 year term loan with required payments of principal and interest.

Most power purchase agreements provide for capacity and energy payments. The capacity payment is designed to pay all debt service and fixed operation and maintenance costs. The energy payment should pay for all variable expenses, including fuel.

As the pivotal contract for a power plant, the terms and conditions of the power purchase agreement are extremely important. Complex interrelated issues need to be carefully analyzed in order to equitably allocate both costs and risks among the participants. The Power Purchase Agreement for the Williams Lake Project took nine months to complete in order to meet the needs of the utility and the financial community.

The Power Purchase Agreement provides for several different types of payments. The Firm Energy Component provides a specified monthly payment and is the capacity payment for the plant. Various operation and maintenance components provide for payment of operation and maintenance expenses, property taxes, insurance, ash disposal and fuel. Incentives were built into the payment structure for the owner to reduce costs.

The payment structure was designed to allow the plant to operate at reduced availability factors during the first nine months of commercial operation and in major maintenance years and at approximately 85% in normal operating years. At these levels, the plant generates sufficient income to meet its debt service coverage ratios required under the terms of the loan agreement.

Creditworthiness of Electricity Purchaser

The creditworthiness of the purchaser of electricity generated from a biomass project is essential to ensuring the projected cash flows will be available to service the project's debt and meet its other obligations. The financial strength of a utility is reflected in its bond ratings. Even if the purchaser begins to experience cash flow problems, if a project is very well structured, with low cost, reliable power, the utility will be incentivized to continue to honor its obligations to that project before evaluating other alternatives.

The purchaser of the electricity generated by the Williams Lake Project is B.C. Hydro, a Crown corporation of the province of British Columbia. At the time of financing, B.C. Hydro was the third largest electric utility in Canada, generating, transmitting and distributing electricity to 92% of British Columbia's population. Hydroelectric plants accounted for 90% of B.C. Hydro's generating facilities with a total capacity of approximately 10,000 MW. At the time of financing, B.C. Hydro's bonds were rated as high investment grade.

Comparative Cost of Electricity

Generally, power generated from biomass projects is not as economical as other sources of energy because of the high capital costs. The price of electricity is fundamental to the utility's commitment to the project and may be necessary to local, regulatory and political support. Many times projects cannot obtain financing because the proposed price of power is too expensive when compared to the utility's alternatives. If projects provide an economic source of power and other benefits, the owner and the utility have strong incentives to keep the project operating.

The Williams Lake Project was unique in that it solved a significant pollution problem and benefited not only the city, but the province of British Columbia and the sawmill industry. The City of Williams Lake had been, prior to the commercial operation of the Williams Lake Project, one of the largest single source emission points in the province because of the industry practice of burning wood waste in beehive burners. New environmental regulations would have required the sawmills to upgrade their facilities

and burn their waste in non-polluting equipment. Operation of the Williams Lake Project has reduced fly ash emissions by over 95%.

Because of these environmental benefits, the Williams Lake Project received a 15% environmental premium which allowed the project to be financed. Exclusive of this premium, pricing for the Williams Lake Project was competitive when compared to B.C. Hydro's next scheduled capacity.

Fuel Risk

Historically, many wood waste fired power plants have experienced difficulties in obtaining sufficient fuel to operate their facilities at costs and projected availabilities to meet the terms of their debt requirements. Many projects did not have long term commitments for their wood waste supply. As demand for wood waste increased, the price of wood waste became very expensive. Many plants were shut down because it was uneconomical to operate them. As a result, the availability of wood waste at a reasonable cost and on a long-term basis is a key concern to lenders providing project finance for biomass power plants.

Wood waste is the fuel for the Williams Lake Project and it requires 600,000 tons annually. The five sawmill and plywood operations in Williams Lake signed Wood Waste Agreements, dedicating 100% of their wood waste at no acquisition cost to the plant for 25 years. The owner must pay for handling and transportation expenses related to the fuel. One of the sawmills with other operations in Quesnel and 100 Mile House also signed a Supplemental Wood Waste Agreement providing an option on 100% of their wood waste from those operations for 25 years.

The plant was designed to dispose of the entire estimated future annual production of wood waste from the five sawmills located in Williams Lake. A study analyzing the availability of wood waste concluded that the long-term projection of wood waste produced by the five sawmills in Williams Lake was greater than the amount required to operate the plant. Also, there is fuel available from sawmills in nearby locations. As an added protective clause for the fuel availability, B.C. Hydro committed under the terms of the Power Purchase Agreement to not enter into agreements with other independent power producers in the Williams Lake and proximate areas if such agreements would substantially reduce the availability of the fuel supply for the Williams Lake Project.

Structure

The ownership vehicle for a biomass power project is typically a single purpose investment vehicle which limits liability to the project sponsor while maximizing investment flexibility. A single purpose limited partnership is a very common structure in domestic power plant financings because it eliminates double taxation concerns for individuals and corporations. In international projects, other common vehicles are special purpose corporations, joint ventures and tenancies in common. The Williams Lake Project is owned by a British Columbia limited partnership. The project sponsors created a special purpose entity that is the general partner, while the

limited partnership is owned by other special purpose entities including another limited partnership.

Equity from the project sponsors will be required for a project finance transaction and will range from 5% to 25% of the total capital. The amount of the equity is dependent upon factors of the project including technology, cash flows, fuel risk, etc. Projects with higher risks to the lender will require greater amounts of equity. Projects with new technologies or without a proven track record will need more equity than those projects with simple, proven technologies. The developer may not be required to fund its equity requirement until completion of the project. However, this commitment must be evidenced by parent guarantees or letters of credit that may be exercised by the lenders upon conversion of the construction loan to a term loan or if an event of default occurs under the loan agreement.

The Williams Lake Project utilizes a wood waste fired stoker boiler, generating approximately 535,000 lb./hr of steam fed into a condensing turbine capable of providing a net output of 60 MW. Many other wood waste fired plants similar to this one have been built in North America. Since the plant utilized proven technology, a plentiful wood waste supply existed, and the project sponsors were experienced in the development and operation of a power plant, 10% equity was required by the lenders.

Other features which need to be incorporated in the structure of a biomass project include providing adequate reserves, construction contingencies, working capital and insurance. Reserves are needed for unexpected difficulties and reasonable amounts should be escrowed monthly for scheduled major maintenance. Sufficient working capital should also be allocated in the capital budget to account for start-up costs and timing differences between receipt of payment for the sale of electricity and operating expenses. Insurance will be a requirement of the lenders during the construction and operation phases. The construction insurance will typically include all risks builder's risk, liability and delayed start-up business interruption insurance. Once the plant begins commercial operation, common types of insurance include all risks, business interruption, liability and comprehensive general liability. All of these features were structured in the Williams Lake Project.

Construction Risk

Most power projects are built on a turnkey basis which means it is built for a fixed price and delivered on a date certain. The credibility, reliability and financial strength of the contractor becomes very important. It is very desirable for the contractor to assume as much of the completion related risk as possible. Most contractors will be required by the developer and lender to provide delay damage provisions to ensure the project is completed by a specified date. The contractor will also have to guarantee performance levels of such factors as heat rate, emissions levels and electricity output. If the plant does not pass its performance tests at the specified levels, then the contractor is obligated to pay negotiated amounts to the owner. The contractor must also have the financial resources which would allow him to perform under the terms of the contract. Typical amounts for contractor-paid damages and penalties for substandard performance or late completion is not greater than 25% of the contract price. The turnkey contractor will also be required to provide payment and performance bonds.

CRS Sirrine Engineers, Inc. ("CRSS") built the Williams Lake Project for a fixed price under the terms of the Turnkey Construction Agreement. CRSS has a good reputation in the industry, designed over 150 power plants and has the financial wherewithal to provide the necessary bonds and guarantees. The Turnkey Construction Agreement is a very detailed agreement and provides for insurance requirements, retainage provisions, specifies the work of CRSS, type of equipment to be used, identifies the specific tests that must be satisfactorily completed prior to acceptance of the facility, defines amounts of liquidated damages for substandard completion and late delivery and establishes the payment mechanism and procedures. CRSS completed the Williams Lake Project on schedule and under budget.

To ensure the plant was built in accordance with the terms of the Turnkey Construction Agreement, an on site representative for the owner was hired. He was assigned to the construction site and in constant communication with the contractor. The on-site representative reported to the Project Director for the owner who was responsible for the timely completion of the Williams Lake Project. He approved the monthly drawdown requests from the contractor and ensured the project was built in accordance with the projected milestone schedule.

Operating Risk

Using proven technologies and past operating experiences of similar plants is crucial in obtaining project financing for biomass projects. The lenders must be assured that the project can produce electricity at the projected capacities and costs over the term of the debt. A key player in assisting the lenders reach the conclusion that the project is technically feasible is the lender's independent engineer. R. W. Beck and Associates ("Beck") was retained by the lenders for the Williams Lake Project to conduct an independent engineering review. The lenders wanted some assurance the project was technically feasible, consistent with the project's pro forma and consistent with the terms, conditions and permitting requirements of similar projects.

Other wood waste fired power plants had experienced significant problems with the fuel and ash handling systems, undersized boilers and auxiliary equipment and higher stack emissions than expected. The design of the Williams Lake project was based on seven years of operating experience at one of the project sponsor's wood waste fired facilities. Beck concluded the Williams Lake Project was well conceived. The preliminary design was good and incorporated the lessons learned not only at the Kettle Falls facility but at other wood waste fired plants. Beck also reviewed the major types of equipment proposed for the project and the auxiliary systems. They determined that the systems and equipment proposed for the project supported the assumptions for generating availability and capacity factors as outlined in the project's pro forma.

Other factors impacting the long-term operation of the plant are operation and maintenance expenses and qualified operators of the plant. Some projects have tended to minimize maintenance expenses to reduce costs. The Williams Lake Project was developed with an annual maintenance schedule based on the past operating experience of other wood waste fired plants. Also, provisions were made in the Operation and Maintenance Component to allow a monthly amount to be escrowed

in a Major Maintenance Account to ensure sufficient funds would be available for pay for major overhauls.

The hiring and training of the plant personnel prior to the start-up of the plant was also a cornerstone in minimizing the amount of operating risk. A third party O&M firm was not hired but a consulting firm with experience in operating power plants was retained to assist in hiring the plant personnel, writing manuals, training, etc. Over 1,000 people were screened for 31 positions. An extensive training program was developed and the plant staff was hired up to nine months ahead of scheduled completion to ensure the plant would operate as expected. This staffing schedule ensured a smooth transition from the construction phase to commercial operation of the plant.

Projected Financial Analysis

The underlying projected cash flows of a biomass project are only as good as their assumptions. The basic contracts create the foundation for the project pro forma. The power purchase agreement defines the revenue stream, the turnkey construction agreement defines the cost of the project which is generally 70% of the entire capital budget and the fuel supply agreements determine the major component of the operating expenses. As described in the Operating Risk section, Beck performed an independent engineer's review of the Williams Lake Project. One aspect of their review included analysis of the project pro forma.

It is beneficial to create very detailed models which should approximate the minimum economic performance of a project. The base case pro forma should be conservative representing the guarantee performance levels of the facility. Projected income should be based on the terms of the power purchase agreement. Operation and maintenance expenses should include all expected expenses and be based on the projected availability and consumption rates of the plant. These expenses include fuel, labor, property taxes, insurance, annual plant maintenance, major maintenance, plant expenses, general and administrative, management, water acquisition and water disposal, water treatment, chemicals and ash disposal. The base case pro forma for the Williams Lake Project was based on the terms and conditions of the Power Purchase Agreement, Turnkey Construction Agreement, Wood Waste Supply Agreement and operating experience of the project sponsors and actual expenses incurred at their power plants. Projected principal and interest payments were based on the proposed terms of the project financing. Wherever possible, actual bids or quotes for projected expenditures should be obtained to ensure accuracy in the model.

In the Williams Lake Project, Beck reviewed the total project cost, project schedule, estimated power plant availability and all revenue and expense items. Beck concluded the project cost estimates were reasonable based on similar projects and the terms of the Turnkey Construction Agreement, the revenues were consistent with the terms of the Power Purchase Agreement and the expense estimates were reasonable.

Conclusion

Project financing is available for biomass power projects if the project is properly structured with the goal of meeting the needs and standards of the financial community. The project needs to be economic, provide a benefit to the utility and community and the participants involved must have the necessary experience to ensure they can perform. The underlying agreements must take into consideration the fair and equitable allocation of risk among the project participants. Risk should be allocated to the parties who are responsible for such risks or who can control them.

The Williams Lake Project is unique in that it is a win-win-win-project. The Williams Lake Project provided B.C. Hydro with a long-term source of low cost, reliable electricity. A serious and long outstanding environmental problem was solved for the community by disposing of the sawmills' wood waste in a stoker boiler with state of the art emissions controls instead of burning wood waste in beehive burners. It virtually eliminated the air pollution problem in the area. The local sawmills benefited by not incurring significant expenditures which would have been required to meet future provincial environmental regulations. This has positively impacted the community of Williams Lake and the province of British Columbia. The Williams Lake Project also created hundreds of jobs during its two-year construction period and 41 permanent operational positions. The Canadian institutions were willing to provide first of its kind financing in Canada for the Williams Lake Project because of the carefully structured project agreements, the many benefits resulting from the project and the ability of the project sponsors to perform.

THE ROLE OF THE WORLD BANK IN FINANCING BIOMASS ENERGY PROJECTS

Ernesto N. Terrado, Ph.D., Principal Energy Planner
The World Bank, Washington, DC 20433 USA

Abstract

The World Bank's financing of biomass energy projects has been principally in relation to the excessive use of biomass for fuel in developing countries and the measures that are needed to curb demand and reduce its adverse environmental impacts. With respect to projects for the conversion of biomass into liquid and gaseous fuels and electricity, the Bank's role has been more limited. The major reasons for this limited role include the still unfavorable economics of many of the technologies in comparison to the current cost of conventional fuels, the small size and dispersed nature of some of the already economic biomass projects and the general lack of information in the Bank on the technology status and economics of the more modern biomass. energy applications. Nevertheless, in the early 80s, the Bank financed one of the largest and most important biomass projects in developing countries, the Brazil Alcohol and Biomass Energy Development Project. During this period, it also conducted various preinvestment studies on biomass gasification, bagasse cogeneration in sugar mills and other technologies for the generation of power from biomass resources. None of these studies led to Bank lending to governments, but a number were financed by the private sector directly or through the International Finance Corporation (IFC), the arm of the Bank Group that deals with the private sector. With the current worldwide concern for global warming and the creation of the Global Environment Facility (GEF) , the World Bank group is revisiting its involvement in the promotion of environmentally benign energy generation technologies. It recently launched a new program called the "Solar Initiative" that seeks to increase Bank investments in direct solar, wind and biomass energy applications in developing countries. The most recent Bank activity in biomass energy is financing for a prototype 30 MW biomass gasification project in Brazil.

Introduction

The World Bank's financing of biomass energy projects has been principally in relation to the use of fuelwood in developing countries. Some 2 billion people still use biomass (wood, charcoal, residues, dung) for fuel and will continue to do so for the foreseeable future. In many countries, particularly in Africa and South Asia, biomass can comprise up to 80% of total national energy demand. The excessive and inefficient use of biomass for basic needs has contributed significantly to global environmental degradation. The Bank has sought to address this issue by lending to projects that improve the management of existing forests, establish fuelwood plantations and curb demand through the use of higher efficiency stoves and alternative fuels. Between 1980 to 1993, the Bank financed a total of 40 projects directly related to fuelwood supply and conservation at a cost of approximately $1 billion. Other projects—such as energy sector loans that include rural energy planning and the distribution of modern fuels in rural areas—also helped to address the problem but the biomass portions of these projects are difficult to quantify.

With respect to projects for the conversion of biomass into liquid and gaseous fuels and electricity, the Bank's role has been more limited. The major reasons for this limited role include the still unfavorable economics of many of the technologies in comparison to the current cost of conventional fuels, the small size and dispersed nature of some of the already economic biomass projects (e.g., bagasse cogeneration in sugar mills for power export to the grid) and the general lack of information in the Bank on the technology status and economics of the more modern biomass energy applications. With the current worldwide concern for global warming, the World Bank group is revisiting its involvement in the promotion of environmentally benign energy generation technologies. It recently launched a new program called the "Solar Initiative" that seeks to increase Bank investments in direct solar, wind and biomass energy applications in developing countries.

Biomass Energy Activities in the 80s

Power Alcohol

In the 80s, the largest and most important biomass project financed by the Bank was the Brazil Alcohol and Biomass Energy Development Project. The loan of $250 million that became effective in 1981 was made to support the Government's National Alcohol Program (PROALCOOL) which objective was to develop an economic, renewable liquid fuel energy source as a substitute for imported petroleum products. The loan sought to finance alcohol production facilities and to sustain research, development and demonstration (RD & D) activities to improve the efficiency of alcohol production from sugar cane and other biomass sources. It may be recalled that this loan occurred at a time of deep international crisis in world oil and financial markets. A loan to Mali for a much smaller power alcohol project ($8 million) was also made by the Bank at that time.

The project achieved important successes that included attainment of many physical targets—alcohol production capacity was augmented to an excess of 13 billion liters by 1987, agricultural yields of sugar cane and industrial yields of alcohol increased

by more than 25%; and the economic costs of producing alcohol declined by about 30% between 1979 and 1987. More difficult to quantify but nonetheless important are marked improvements in air quality in major cities in Brazil as a result of substitution of alcohol for leaded gasoline, and the benefits of employment opportunities in rural areas generated by the program. However, the project—and the PROALCOOL program—suffered high economic losses from the unforeseeable collapse of oil prices in 1986.

During this period, the Bank also provided a credit of $8 million to Mali for a much smaller power alcohol project. The project would enable Mali to produce about two million liters of anhydrous alcohol from molasses annually to replace an equal amount of imported high cost gasoline. The exact fate of this project is not known to the author but presumably it was also affected adversely by the decline of oil prices in the mid-80s.

Bagasse Cogeneration

The Bank conducted several studies to determine investment opportunities in the sugar industry that would improve energy efficiency in the sugar production process, produce excess bagasse and use this biomass residue to generate surplus power for export to the grid. It was estimated in a Bank study that the potential for surplus power production from this source at that time could be as high as 22 billion kWh worldwide. Because the installed cost per kilowatt of incremental generation in sugar mills is normally lower than in dedicated power plants, this was thought, from an energy standpoint, to be a good way to help address the dearth of investment capital for power generation in developing countries.

Country-specific assessments for bagasse cogeneration possibilities were conducted by the Bank in several countries, including India and Guyana. In India, in the State of Maharashtra, investments were proposed in 13 mills of more than 3500 tons cane per day crushing capacity that would add some 102 MW to the grid power at a total investment cost of about $86 million. The investments proposed were in high pressure boilers and additional turbo- alternator sets, as well as bagasse drying equipment. In Guyana, where critical power shortages and high costs of diesel imports was the impetus for a search for alternatives, an attractive investment in one sugar mill that would add 24 Gwh to the grid during the milling season was proposed as a pilot project. A bagasse dryer was also recommended here but to limit the cost, only boiler modifications were proposed.

These studies recommended Bank lending to the projects identified, principally as part of industrial sector projects, with energy production as an added benefit. None resulted in actual World Bank projects, although some investments along the lines identified by the study were made eventually by the private sector. In the case of India, follow-up preinvestment studies were later conducted by other agencies, including the USAID. Such a study for the State of Tamil Nadu has resulted in privately-financed bagasse cogeneration projects totaling some 80 MW.

Biomass Gasification

Biomass gasifiers were the subject of a major study carried out jointly by the Bank and UNDP in the early 80s. The study covered direct-heat and shaft-power gasifiers, in the 7.5 to 480 kW range. The applications considered were electricity generation, irrigation, vehicle power and process heating. The study concluded that direct-heat gasifiers are generally more practical to operate and have better economics than shaft-power or engine gasifiers for the range of applications needed in developing countries. Although various types of biomass residues can in principle be used as fuel, the study found that wood and charcoal are the only biomass fuels that could be confidently recommended. The long term-supply of biomass was concluded as the main limitation to the deployment of gasifiers. During the period of the study, gasifiers were being widely used in Brazil and the Philippines, partly in a commercial mode and partly for demonstration. The experience in these countries showed that the availability and convenience of conventional alternatives (e.g., diesel gensets) favored their use over gasifiers even in instances where their costs are slightly higher than the equivalent gasifier systems. Biomass gasifiers never made it to any Bank project.

Other Studies in Biomass Energy

In 1983, the Bank conducted a study on the technical and economic aspects of power production from dedicated plantations of fast growing trees. Base on data obtained from an ongoing "dendrothermal power" program in the Philippines, it was concluded that the scheme would have limited applications because of the large land requirements (over 6000 hectares for a 10 MW plant, for example, using wood grown in four-year cycles at a yield of 10 bone-dry ton per ha per year). Electricity generation costs were found to be strongly dependent to biomass yield, plant capacity factor and labor costs. Previous expectations that the scheme would enable the utilization of marginal lands (not useful for agricultural production) did not prove true because of the importance of biomass yield to project economics.

More recently, studies in two countries assessed investment opportunities for power production from residues of major agricultural products. In Indonesia, where residues from palm oil mills, rubberwood sawmills, sugar mills and plywood mills were considered, it was found that medium (1-5 MW) biomass-based power plants could be viable options to diesel power for near base load operation, and small (50-100kW) systems have an economic niche in village electrification. The Philippine study examined power project opportunities for utilizing residues of the rice, coconut and sugar sectors. It found an economic potential of about 60-90 MW for the sugar industry, about 40 MW for the rice sector and 20 MW for the coconut sector. The individual investments were expected to be undertaken mainly by the private sector but the report concluded that the Government must promote the concept actively and facilitate the identification and implementation of actual projects.

cogenerated power at a fair price, for example, will not encourage investments in such projects. An energy pricing policy that keeps the price of petroleum based fuels artificially low will make it hard for new technologies to compete. And the lack of a manpower and institutional base that can handle the implementation of projects and programs using new technologies will impede the take-up of such technologies. Although the institutional and policy environments in the energy sector in developing countries have been improving steadily, this is still a major constraint to the commercialization of renewable energy technologies.

Renewed Interest in Renewables

Due to the above constraints, the Bank's past activities in renewable energy have been confined mainly to "niche" applications--essentially rural-based applications that are already economic because of remoteness of the project site and the high cost of conventional alternatives[1]. The increased attention to renewable energy at present not only by the Bank but also by other national and international bodies is due primarily to three reasons: (1) technological advances and the accumulation of operational experience, particularly in installations in California and in Europe; (2) dramatic reductions in costs in the last decade of many renewable energy technologies, and (3) heightened environmental concerns. In particular, concern for potential global warming due to accumulation of carbon dioxide in the atmosphere has convinced many that non-carbon emitting technologies must become a key goal of future energy production strategies.

The most important offshoot of these concerns for potential global warming is the creation in 1992 of the Global Environment Facility (GEF). After a three-year pilot period, the GEF is now a permanent institution. Its funds were recently replenished with $2 billion, about 40% of which is earmarked for financing activities that would mitigate global warming (the other areas are biodiversity and international waters). The two principal areas for applying the $800 million global warming fund—which are grant funds— are energy efficiency and renewable energy. The creation of GEF has thus not only revitalized interest in commercially-ready renewable energy technologies but has opened up opportunities for bringing near-commercial applications into the investment stage. As was demonstrated in the recently initiated India Renewable Energy Project, it may be possible on environmental grounds for GEF grant financing to "buy down" the high capital costs or transaction costs of near commercial renewable energy technologies to enable them to meet Bank investment criteria and put them into practical operation *now*. The Solar Initiative aims to look actively for similar opportunities that can bring these new technologies into the mainstream of the Bank's lending program.

[1] Certain biomass investments, such as direct combustion of captive residues in industries, however, have been made and are constantly being made by private firms. This discussion refers mainly to solar and wind technologies, and biomass technologies that are not yet in the commercial mainstream.

Constraints to Lending

The World Bank is really a group of institutions. For project lending purposes, the most important ones are the International Bank for Reconstruction and Development (IBRD), International Development Association (IDA) and the International Finance Corporation (IFC). The term "World Bank" generally refers to IBRD/IDA that lends to governments only. IDA lends only to the poorest countries. Its loans carry no interest (as opposed to about 7% today for IBRD loans) and the payment term can be up to 35 years. IFC is the private-sector arm of the World Bank Group. It participates directly in private sector projects though lending or equity participation (up to 25%). It rates are close to those of commercial Banks.

World Bank lending for renewable energy projects, including biomass, is generally constrained by various factors. First, it must be realized that since Bank loans must be repaid by the borrowing countries, the Bank and the client governments require that the projects be based on technologies proven not just in the laboratory but also in previous commercial projects. For example, while not all diesel-fired genset installations have functioned well, the technology clearly has a much longer track record than a charcoal-fired gasifier system and is the first preference of a Bank project officer interested in ensuring the success of the project.

All World Bank projects must meet criteria for both economic and financial feasibility, as measured by internal rates of return calculations. As most renewable energy applications still have high capital costs and hence inferior economics (e.g., solar thermal power plants, as compared with combined cycle gas turbines), they are not yet a major area for Bank lending. On the other side of the coin, projects that have a high financial rate of return are not a priority for Bank lending, on the grounds that the Government can obtain financing from commercial banks for such projects. This is paradoxically one of the reasons why certain attractive biomass projects, such as cogeneration with captive biomass residues in an industrial plant, have not made it into the Bank's portfolio.

The project packaging and supervision process in the Bank favors single,large projects. Other things being equal, the Bank--and other financiers -- would prefer investing in one 100 MW power project over twenty 5 MW ones. The huge difference in preparation time and staff supervision needs is obvious. This is one reason why Bank project officers involved in power expansion planning of client countries do not normally look at possibilities for obtaining power from, say, bagasse cogeneration projects in sugar mills.

Finally, an important constraint to developing innovative biomass and other renewable energy projects in developing countries is the lack of an "enabling environment" in many of these countries. In the Philippines, for example, the Bank study found that the biggest impediment to investments by sugar mills in cogeneration for power export to the grid is the existing cane sharing system between farmers and millers which obligate the miller to share any power sales benefit with the cane farmers even if the latter did not actually contribute to the plant investments. Often the problem is with the existing national framework. An electricity law that does not permit utility purchase of

The Solar Initiative

The Solar Initiative is a new effort by the World Bank to work with its member countries and the energy industry, research and NGO communities to hasten the commercialization of solar and other renewable energy technologies and significantly expand their applications in developing countries. It has two main thrusts: (a) the preparation and finance of commercial and near commercial applications, and (b) facilitation of international RD & D.

For the project development objective, the Bank will intensify its efforts to look for opportunities to include renewable energy investments not only in energy projects but also in projects in agriculture, health, rural development and water supply. This will be done by actively reviewing the Bank lending program in relevant sectors in the various regions and identifying opportunities to introduce renewables as an energy supply option. The strategies and specific actions for achieving the RD & D facilitation objective are yet to be fleshed out and refined through consultations with other international organizations, research establishments and government agencies. The basic idea is to leverage the Bank's considerable project financing capability to provide a focus on ongoing RD &D work, especially in the developed countries, and steer some of these efforts, if seen fit, towards areas considered by the Bank to be more highly needed by the developing countries.

The Solar Initiative covers applications using direct solar, wind and biomass energy resources, all of which are renewable and indigenous to almost all countries. It is generally agreed that large-scale hydropower, mainly because it is a conventional, long-established power generation application, should not be included even if it is a renewable energy technology. Geothermal energy is included because it is generally considered an inexhaustible resource and is still not widely used. In the context of the World Bank, the Initiative covers all renewable energy applications that are considered important for developing countries but for various reasons have not yet received significant attention in the regular lending program. Biomass energy applications are likely to be re-examined closely under the Initiative.

Recent Biomass Energy Activities by the World Bank

During the GEF's pilot phase, two small but significant biomass energy projects were financed. In Mauritius, some $3.3 million in grants was contributed to project looking at ways to fully tap the energy potential of sugar cane tops, leaves and refinery residues. The activities included the development and testing of technologies for gathering, storing and using the biomass residues, including the assessment of options for reducing the cost of bagasse transport. The Bank provided $15 million in loans and $23.1 million was obtained by Mauritius from other external sources. The project is being implemented.

In Brazil, GEF is grant financing with $7.7 million the implementation of a prototype demonstration project for a 5 MW Biomass Integrated Gasification/Gas Turbine Combined Cycle (BIG/GTCC) system. The purpose is to resolve important engineering, economic and financial issues associated with adapting commercial gasifiers for gas

turbine applications. The preliminary investigation for the project (Phase I) was first funded by the Rockefeller Foundation, Winrock International, USAID and USEPA. The current project (Phase II) has two independent teams working in parallel to develop distinct technology packages: one using pressurized gasification and the other using atmospheric gasification. Bioflow, a joint venture of Ahlstrom (Finland) and Sydkraft (Sweden) is responsible for the high pressure system and TPS Thermiska (Sweden) for the low pressure technology. Both teams will use the General Electric aero-derivative LM2500 which will be adapted by GE for the biomass system. Although the Brazilian Ministry of Science and Technology is the implementing agency for the project, a consortium of public and private agencies are actively participating.

Although the choice of pressurized or atmospheric gasification technology is still to be made, the Bank is already preparing the next phase: a 30 MW demonstration thermal power plant based on the BIG/GTCC concept. It will use biomass (wood eucalypts and sugar cane bagasse) as fuel. Some 5,000 ha. of an existing eucalypt plantation will be utilized. The estimated total project cost is $70 million or about $2,300 per kW installed. GEF is expected to provide grant financing of $23 million for this phase.

The above support to what is essentially technology development is not normally a World Bank activity and was made possible only by GEF's role. Nevertheless, it heralds the possibility of similar support for the demonstration of other biomass technologies deemed highly promising to developing countries.

Conclusions

Biomass energy projects offer many economic, environmental and social benefits. Since biomass is an indigenous fuel, countries benefit from supply security and foreign exchange savings. Biomass power plants can obviate the need for fossil-fueled thermal plants and result in lower levels of SOx and NOx emissions. In projects where biomass is derived from plantations, the projects contribute to afforestation efforts and can generate significant employment opportunities in rural areas. There is no question that programs seeking to enhance the role of renewables in the energy sector must feature biomass projects prominently.

Many biomass energy technologies are already commercial and do not need government intervention to obtain financing. For this reason, it is likely that the role of the World, which lends money only to Governments, in financing biomass energy projects will be minimal. However the International Finance Corporation (IFC), could be more actively involved in such projects.

Emerging biomass energy technologies, can be assisted at the demonstration stage by new environmental programs such as the GEF. The mechanics for this type of assistance has been demonstrated in the Brazil biomass gasification project.

TAX ISSUES AND INCENTIVES FOR BIOMASS PROJECTS

by Keith Martin, Esquire
Chadbourne & Parke, Washington, DC 20005 U.S.A.

Abstract

The more sophisticated developers of biomass projects figure out ways to structure their projects to take advantage of tax subsidies. The federal government offers at least eight tax subsidies for biomass. This is rather like building a house. One tries to design the house to build in as many of these features as possible. The more tax benefits that can be built into the ownership structure for a project, the less the project will cost at the end of the day.

Text

One legacy of the Arab oil embargo of the mid-1970's is that the federal government subsidizes efforts to use biomass as fuel. Most of these subsidies are buried in the Internal Revenue Code. There are at least eight.

Early in the development process, a developer should review the list of possible tax subsidies, decide which benefits his project might qualify for, and be careful to structure the project in a manner that makes it eligible for as many as possible. Here are the eight.

Unconventional Fuels Credit

If biomass can be converted to gas before using it as a fuel, then the project might qualify for a tax credit of 99.3¢ an mmBtu on the gas under section 29 of the Internal Revenue Code. This can be a very significant benefit, given that delivered prices for natural gas are currently in the range of $1.60 to $2.14 an mmBtu depending on quality and location of the fuel.

The tax credit is claimed by the person producing the gas. He must sell the gas to an "unrelated person." This means that the equipment that produces the gas and the power plant or other facility that will use it must be owned by separate legal entities. The Internal Revenue Service has ruled that there can be up to 50% overlapping ownership. For example, in a private letter ruling in 1984, the agency ruled that a joint venture of four corporations formed to produce gas could sell the gas to the corporations that were partners in the joint venture and still qualify for the credit. The corporations were "unrelated" to the joint venture, since the interest of each in the joint venture was less than 50%.

The amount of the credit is adjusted each year for inflation. The figure 99.3¢ was the credit for gas produced during 1994. The IRS is not expected to announce the credit for gas produced this year until April 1996.

There are three important deadlines to meet. First, the facility that produces the gas must be placed in service by December 1996. "Placed in service" is a term of art meaning that the facility has been tested and shown capable of operating for its intended purpose, even if it is not actually in operation.

Second, the facility must be placed in service "pursuant to a binding written contract in effect" by December 1995. This means that it is important to sign a binding construction contract for the project before placing it in service. What's considered "binding" for tax purposes is a term of art. For example, a contract that limits liquidated damages by the project developer in the event of a default to less than 5% of the total contract price is <u>not</u> a binding contract. Similarly, a contract is not binding if material terms are left to the discretion of the developer. In the past when Congress has required a binding contract, it has denied tax benefits to anyone who "substantially modifies" his contract before placing the project in service. (That's because the original contract that was his basis for tax relief no longer exists.) It is unclear whether such a rule will apply here. It would make sense for projects placed in service during 1996, but not before.

Third, assuming the other two deadlines are met, then gas produced at the facility will qualify for the credit through the year 2007.

One practical problem with the unconventional fuels credit is that it cannot be used to offset liability under the alternative minimum tax. Since many corporations pay "minimum" taxes today rather than regular income taxes, this can be a significant impediment to realizing on the value of the credit. The federal government has essentially two different income tax systems for corporations. A corporation must calculate its regular income tax at a 35% rate and its alternative minimum tax at a 20% rate but using a broader tax base and pay essentially whichever amount is greater. The tax credit is only of limited value to a company on the alternative minimum tax. It can be carried forward and used once the company is back on regular taxes, but it cannot be used in the meantime to reduce regular tax liability below the point where the minimum tax takes hold.

Until recently, there were more companies interested in "selling" their section 29 tax credits, but relatively few buyers. The situation has probably reversed in the last year. Among the structures that have been developed to transfer credits is the "royalty trust." This is a grantor trust in which individuals can invest. The grantor trust is organized by a corporation that owns a portfolio of gas producing properties. The corporation retains the properties, but transfers the trust a right to receive royalties or a share of net profits from sales of gas. A number of tax issues are raised by the royalty trust structure, but the IRS settled the main issue in July 1993 by ruling that a person can claim the tax credit even though he has only a royalty interest in the gas.

Many project developers need to take another look at the royalties they pay landfill owners for the rights to remove gas. In a typical project, the developer pays a municipality that owns the landfill a percentage of his revenue from selling landfill gas or from selling electricity produced with the gas. This royalty is paid in exchange for rights to remove the gas. An IRS ruling in 1993 suggests, in such cases, that a percentage of the tax credits from gas production belongs to the municipality. Most projects fail to take this erosion in tax credits into account in their economic projections. The key to avoiding this result is to give the municipality a "production payment" rather than a "royalty."

Production Tax Credit

Taxpayers are allowed a tax credit of 1.6¢ a kilowatt hour for electricity generated from "closed-loop biomass" under section 45 of the Internal Revenue Code. This credit is available for 10 years starting when the power project is placed in service. However, the project must be in service by June 1999 to qualify.

"Closed-loop biomass" means plants that are grown exclusively for use as fuel in a power plant. Congress had in mind so-called electricity farms where plants are grown specifically to be burned as fuel. A Congressional committee report said when this tax credit was enacted,

> "Accordingly, the credit is not available for use of waste materials (including, but not limited to, scrap, wood, manure, and municipal or agricultural waste) to

generate electricity. Moreover, the credit is not available to a taxpayer who uses standing timber to produce electricity."

A number of special rules are worth noting. The credit is adjusted for inflation. It starts phasing out if the "reference price" for electricity ever exceeds 8¢ a kWh (also adjusted for inflation). The electricity must be sold to an unrelated party. The credit applies only to electricity generated in the United States or a U.S. possession, although there is apparently no restriction on its sale across the border.

The credit is reduced if the power project benefits from any government grants or tax-exempt financing -- even indirectly. An example of an indirect subsidy is a government program that rewards banks "for extending low-interest loans to taxpayers who purchase or construct qualifying facilities." Only subsidies paid by a government in the United States are taken into account. Thus, for example, export credits from Sweden or Germany on equipment purchased in those countries would apparently not reduce the 1.6¢ a kWh credit.

Congress may have inadvertently ruled out lease financing for projects that want to claim the credit. The statute makes it a condition for claiming the credit that the person producing and selling the electricity must also own the power plant.

Alcohol Fuels Credit

Taxpayers can benefit from a tax credit of up to 60¢ a gallon by converting biomass into ethanol or methanol.

There are actually three different credits. To claim an "alcohol mixture credit," the taxpayer must mix alcohol with gasoline or another fuel used in internal combustion engines and either use the mixture himself as fuel or sell it to someone else for use as fuel. "Alcohol" means ethanol or methanol, but not if it was produced from petroleum, natural gas or coal. The IRS ruled in 1993 that landfill gas is not natural gas, so that methanol from landfill methane qualifies potentially for the credit. A 1995 private letter ruling held that crude methanol made from wood and steam also qualified.

It is enough that the final mixture is derived from methanol or ethanol, even if the alcohol is chemically transformed in producing the fuel. For example, one can blend a chemical compound *derived from* alcohol with gasoline, provided there is no significant loss in the energy content of the alcohol. An example would be mixing ETBE with gasoline.

The alcohol must be at least 190 proof. A person mixing methanol gets a tax credit of 60¢ a gallon. A person mixing ethanol gets a credit of 54¢ a gallon. If the alcohol is less than 190 proof, but at least 150 proof, the taxpayer may still claim a credit, but only 45¢ a gallon for methanol mixtures and 40¢ for ethanol.

The "alcohol mixture credit" is claimed by the company that does the mixing.

There is a separate "alcohol credit" where alcohol is used as a fuel directly without mixing it with gasoline or another fossil fuel. The fuel must be at least 10% alcohol in order for this credit to apply. The rates are the same as for the alcohol mixture credit: in other

words, the credit is 60¢ a gallon for methanol and 54¢ for ethanol that is at least 190 proof. It is less for weaker alcohol.

The "alcohol credit" is claimed by the owner of the filling station where the alcohol is sold at retail and put into vehicle fuel tanks. If the alcohol is used directly as fuel in a trade or business without a retail sale, then the company using it as fuel gets the credit.

Finally, there is a credit of 10¢ a gallon for "small" ethanol producers. A "small" producer is someone who has the capacity to produce no more than 30 million gallons a year of alcohol fuels (including alcohol fuels made from petroleum, natural gas and coal). A small producer may claim this credit on his first 15 million gallons of output a year.

These tax credits are less valuable than appear at first glance. Section 87 of the Internal Revenue Code requires a company to include the amount of any alcohol fuel credits in taxable income, even if the credits could not be used. Consequently, the potential benefit in tax savings is only 65% of the credit amount (for example, 39¢ a gallon rather than 60¢) for a regular corporation.

The alcohol fuel credits are scheduled to expire in December 2000. They have come under fire in Congress from tax reformers and Senators from oil-producing states. The oil companies charge that the credits give an unfair advantage to the use of ETBE, which is made from grain, as a fuel additive over MTBE, which is made from fossil fuel. Senator Bill Bradley (D.-N.J.) introduced a bill in 1994 to phase out the credit over three years for feedstocks such as corn that receive price supports from the Department of Agriculture.

Accelerated Depreciation

Equipment in a power plant or other facility that uses biomass or disposes of "waste" may qualify for an unusually generous depreciation allowance.

Certain equipment in an electric generating plant that uses biomass for fuel qualifies for depreciation over five years using the 200% declining-balance method, provided the plant is a "qualifying small power production facility" within the meaning of the Public Utility Regulatory Policies Act. There may be a limit of 80 megawatts on size of the generating unit, depending on whether the fuel is classified as "biomass" or "waste" by the Federal Energy Regulatory Commission.

The following equipment qualifies: boilers, burners, pollution control equipment required by law to be installed, and equipment for "the unloading, transfer, storage, reclaiming from storage and preparation" at the place where the biomass will be used as fuel. This is basically all equipment up to the point where electricity is produced.

The ability to depreciate an asset over five years is a valuable benefit. Equipment in a power plant is normally depreciated over 15 or 20 years. Each dollar of depreciation deductions spread over 20 years produces a tax savings of 13¢ in present-value terms, while the same dollar deducted over five years produces a tax savings of 25¢ -- almost <u>twice</u> as large. If the developer cannot use the tax benefits himself, he may be able to transfer the tax benefits to another company that can use them in exchange for equity to help finance the project.

Be careful of two things. First, the power plant must burn biomass directly -- not a "synthetic fuel." A synthetic fuel is a fuel that differs significantly in chemical composition from the original biomass. Thus, biomass can be pelletized, dried, compacted or liquefied before it is used. However, a process that results in defiberization goes too far. Methane gas from a landfill is not biomass -- the raw garbage is. Thus, a power plant can burn garbage and qualify for 5-year depreciation, but not methane produced by decomposition.

Second, be careful of any involvement in the project by a government or-tax-exempt entity. If they are viewed as "using" the project, then the IRS will insist that depreciation be stretched out and claimed on a straight-line basis over anywhere from 10 to 28 years, depending on the type of equipment.

The fuel does not have to be entirely biomass. It is enough for biomass to be the "primary" fuel, meaning more than 50% of the fuel mix measured in terms of Btu content.

Equipment that does not qualify for depreciation over five years because the project is not a "qualifying small power production facility" may still qualify for 7-year, 200% declining-balance depreciation. This is available on

> "assets used in the conversion of refuse or other solid waste-or biomass to heat or to a solid, liquid, or gaseous fuel. Also includes all process plant equipment and structures at the site used to receive, handle, collect, and process refuse or other solid waste or biomass to a solid, liquid or gaseous fuel or to handle and burn refuse or other solid waste or biomass in a waterwall combustion system, oil or gas pyrolysis system, or refuse derived fuel system to create hot water, gas, steam and electricity. Includes material recovery and support assets used in refuse or solid refuse or solid waste receiving, collecting, handling, sorting, shredding, classifying, and separation systems."

Tax-Exempt Financing

The federal government allows roads, schools, hospitals and other public facilities to be financed in the tax-exempt bond markets. However, private projects and government-owned facilities where there is more than 10% "private business use" are allowed into the tax-exempt bond markets for financing only in limited circumstances. An example of private business use is where a garbage-burning power plant is owned by a local government, but it is leased to a private company.
Assuming there is more than 10% private business use, most biomass projects will qualify for tax-exempt financing only if they fit into one of two categories:

• Two-county rule. A project can be financed in the tax-exempt bond markets if it supplies gas or electricity to an area no larger than two contiguous counties or one city and a contiguous county. (New York City is considered one city for this purpose, notwithstanding that it has five boroughs.) A common problem with power plants that burn wood waste, garbage, rice hulls or other forms of biomass is that they sell to a utility that serves too large a service territory. The IRS will look through the utility in such cases so that the project is disqualified. Also, many utilities are tied into regional grids. If

they sell more than a *de minimis* amount of electricity into the regional grid, this is also grounds for disqualification.

• Solid waste disposal facility. Tax-exempt financing can be used for a project that disposes of "solid waste." "Solid waste" means "useless, unused, unwanted, or discarded solid material which has no market or other value at the place where it is located." The IRS has ruled privately that "culm" -- a byproduct of anthracite coal mining -- is solid waste for this purpose so that a power plant using culm for fuel qualifies as a "solid waste disposal facility." A word of practical advice: anyone planning to claim his fuel is solid waste should be careful to structure contracts so that nothing is paid for the fuel. Money can be paid to the supplier to transport the fuel, but not for the fuel itself.

Only two parts of a project qualify for tax-exempt financing as a "solid waste disposal facility." One is the part up to where the first marketable product is produced. For example, consider a cogeneration facility where garbage is burned to produce steam. The steam is run through a steam turbine to generate electricity. Some of the steam is then sold to a local food processor and the rest is put into a condenser and returned to the boiler. Steam is the "first marketable product." Tax-exempt financing can be used for the equipment that converts the garbage to steam, but not for later equipment that generates electricity.

The other part is the equipment at the back end that disposes of ash and other solid pollutants. Some developers have argued that as much as 25% of the capital cost of their projects falls into this category.

There is a trade-off to using tax-exempt financing -- accelerated depreciation and certain tax credits must be forfeited. Equipment financed in the tax-exempt bond markets must be depreciated using the straight-line method over the "class life." This is 10 years for most biomass projects, although it may be as long as 28 years in some cases. The unconventional fuels credit and production tax credit are reduced to the extent the facility has been financed with tax-exempt bonds.

Each state is limited in the amount of tax-exempt bonds it can issue each year to finance private projects. The limit is $50 times the population or $150 million, whichever is greater. However, there is <u>no</u> volume cap for bonds issued to finance a solid waste disposal facility that a government will own. The facility can be leased to a private company for a term of up to 20 years or -- if longer -- 80% of the reasonably expected economic life of the facility. The private company cannot have an option to purchase the facility at a fixed price.

1.5¢ Cash Subsidy

The Energy Policy Act of 1992 authorized a program of "incentive payments" of 1.5¢ a kWh by the Department of Energy for power plants that use sunlight, wind, biomass or geothermal energy for fuel. The first payments were supposed to have been made last spring for electricity produced during fiscal year 1994, but no payments had been made by early summer.

The future of the program is in doubt. Congress appropriated $10 million for the spring 1995 payments. However, it then voted to rescind $30 million in spending on solar and renewable energy programs as a whole, leaving the Department of Energy to decide where to make the cuts.

Meanwhile, President Clinton has asked for another $3 million for the program for next year.

The incentive payments will be subject to the following conditions if the program ever gets off the ground: The power plant must be owned by a state or local government or nonprofit electric coop. The payments can be made to the owner or the operator. A project qualifies for the payments only if it is "first used" during the period October 1993 through September 2002. The electricity must be "for sale in, or affect, interstate commerce." Once approved for a project, the incentive payments will continue for 10 years. Power plants that burn "municipal solid waste" are ineligible for the payments.

The Department of Energy published proposed rules in May 1994 explaining how the program will operate. In general, the department will pay the cash subsidies once a year in the spring following the year during which the electricity was produced. Each December, the federal government will publish a notice in the Federal Register asking anyone who generated electricity during the year that he believes qualifies for the 1.5¢ a kWh payments to submit an application to the Department of Energy by March 15. Payments were supposed to have been made in the spring of 1995, for example, for electricity generated during 1994. There will be only a single annual payment.

Landfill gas is an eligible fuel. However, the proposed rules said money would be distributed first to electricity generators using sunlight, wind, geothermal energy or "closed-loop biomass," with others getting payments only to the extent there is money left. At least 50% of the capital cost of a project must be spent on U.S.-made equipment.

Investment Credit

It is still possible for some power plants that burn garbage to qualify for a 6.5% investment tax credit. Congress repealed the investment credit for most equipment in 1986. However, the credit remained available for another four years for many power plants. A special "grandfather" rule in the Tax Reform Act of 1986 authorizes the credit for certain power projects that burn garbage collected from the general public -- with no deadline for placing the projects in service.

In order to qualify under this special rule, one of two things must have happened by March 1, 1986. A government or "service recipient" must have made a "financial commitment of at least $200,000 for the financing and construction" of the project. An example of a "service recipient" is a paper mill that will receive steam from the facility. Alternatively, the project must have a contract signed by that date to sell electricity or steam or to take in the garbage that will be used as fuel.

In a ruling in 1989, the IRS told a developer he could count toward the $200,000 that must have been incurred by March 1986 general spending by a municipality on studying garbage disposal options. The IRS said it would count money spent on a general

symposium a municipal agency held to gather information about feasibility of different garbage disposal technologies, public opinion polls to gauge local attitudes toward garbage disposal options, payments to a consultant who was hired to collect and evaluate bids from private companies that were interested in building projects, and money spent on a project that was later abandoned. The taxpayer represented that a significant amount of value from spending on the abandoned project carried over to the new project.

The IRS issued a similar private ruling in 1990 covering a project that was an outgrowth of a resource recovery task force that a county set up in the early 1980's to study whether to build a refuse-to-energy facility, rather than continue to bury all its refuse in landfills. The county finally got around to collecting bids from private developers to build the refuse-to-energy facility in 1990.

STRATEGIES FOR THE DEVELOPMENT OF BIOMASS IN INDUSTRIALIZED COUNTRIES

Catherine de Silguy, Engineer & Philippe Chartier, Director, Science Division
French Agency for the Environment and Energy Management (Ademe)
Science Division
27, rue Louis Vicat, 75737 Paris Cedex 15, France

Abstract

Ademe is currently conducting a study commissioned by the European Commission (DG XII) on "Strategies for the Development of Biomass in Industrialized Countries." This study surveys twelve countries. As the study is not yet completed, this report presents results from six countries.

Energy, agricultural, industrial and environmental policy all have an impact on strategies in biomass production and on the priorities of research–development programs. These policies vary from country to country, but certain common trends can be observed.

At present biomass is produced primarily for heating use. In the future this raw material could become a prime resource for the production of electricity and vehicle fuels. Each country gives priority to one or two forms of production.

The principal strategic goals are the following :

- Attain cost-competitiveness in various market segments
- Occupy specialized and niche markets as feasible
- Structure markets and production processes when acceptable cost levels are reached
- Prepare future activity via R&D programs

The European Commission has commissioned Ademe to carry out a study on "Strategies for the Development of Biomass in Industrialized Countries." This study, currently underway, is based on the analysis of the situation in twelve industrialized countries whose characteristics are fairly representative of the OECD countries. Certain countries, or regions, have set ambitious goals for the advancement of the use of biomass as an energy source. In Finland the aim is to increase the use of bioenergy by 25% by 2005. In Styria (Austria) the aim is to progress from 12% to 20% in ten years.

The results presented here concern six countries: Austria, Finland, France, Portugal, the United Kingdom, and as a reference for comparison with these European countries, the United States.

This paper presents only the most significant aspects regarding the six countries studied. The final report will analyze the fundamental principles underlying policies and research programs, national and regional product development strategies, policy orientations of research–development and demonstration programs, and program implementation and management.

1992 Primary Energy Supply, Energy Demand and Degree of Autonomy					
	Demand Mtoe	Production %		Demand Mtoe	Production %
Austria	25.9	33.7	Portugal	17.8	8.7
Finland	28.0	41.9	United Kingdom	216.2	98.7
France	231.2	48.3	United States	1984.1	83.6

(*Source: Energy Policies of IEA countries, 1993 Review*)

1993 Contribution to Indigenous Production from Biomass Energy (%) *			
Austria	12	Portugal	9
Finland	44 (1)	United Kingdom	<1
France	9	United States	4

* Assuming correct evaluation of self-consumption.
(1) excluding peat
(*Source: Energy Policies of IEA countries, 1993 Review*)

Policy Foundations and the Relative Importance of Different Approaches

Biomass is located at the intersection of several different policy domains : energy, agriculture, environment, industry, local development and employment. Their relative importance varies and evolves differently depending on the country and the region. These policies have an impact on biomass production strategies and on the priorities of R&D programs. Social forces and the organization of actors in the field are crucial in determining these policies.

Energy

Historically, interest in biomass unquestionably arose out of concern for security of energy supply and the uncertainty engendered by the oil crises. Today tensions have receded and energy security seems to have become a secondary issue. However, looking beyond the current détente which will probably last a few more years, an imbalance is foreseen

between future energy demand and oil supplies, due primarily to population growth, industrialization of developing countries and the depletion of some oil fields in non-OPEC countries.

Meanwhile, dependence on outside producers remains very high in certain countries, and is even increasing where liquid fuels and in some cases electricity are concerned. After a drop from 70% in 1977 to 50% in 1985, oil imports have once again started to rise in the OECD countries. Despite the increase in petroleum production in the North Sea, Europe still imports over 60% of its oil consumption. The situation in the United States is not much better, with oil imports standing at slightly over half of consumption. The transportation sector is particularly vulnerable, because it is more than 90%-dependent on oil. These imports weigh heavily in trade balances. Furthermore, more than 70% of known world oil reserves are located in the Middle East, and this concentration of resources, which is gradually growing more marked, creates an increasingly unstable situation.

Where electricity is concerned, the restrictions on investment in coal and/or the rejection of nuclear power in quite a few countries have spurred the search for alternative solutions for electricity generation, including biomass-fired generation in power plants with a capacity of several megawatts.

The need for diversification, to enhance energy security, remains a fairly strong concern, with biomass taking a more or less prominent position. But the inertia of entrenched energy supply systems and the pressure exerted by lobbies representing centralized distribution of fossil fuels and nuclear power considerably slow down the penetration of renewable energy resources, including biomass.

Agriculture

Agricultural productivity has risen strongly and steadily in industrialized countries since the Second World War. The increase in yields is the fruit of progress in genetics, of a better exploitation of factors influencing production, and of growing recourse to capital investment and inputs. The dominance of "major" crops and the stagnation of the population have led, most notably, to the accumulation of surplus stocks, abandonment of farmlands, and thus to radical changes in agricultural policy.

Further productivity gains can be expected in coming years, driven in particular by biotechnology, which will allow farmers to increase yields of certain species, obtain plants better suited to their farmlands and climates, with characteristics more closely adapted to projected uses.

In the United States the Farm Bill of 1985 introduced measures in the framework of the "Conservation Reserve Program" combining land set-aside and cultivation of herbaceous plants to combat erosion. This policy led to the setting aside of 15 million hectares of land, at a cost of 2 billion dollars.

In Europe, both the setting aside of land and the use of available land for non-food crops such as energy crops are supported by subsidies, representing identical amounts per hectare whether the land is cultivated or not. These compensatory subsidies are modulated on a regional basis, and are calculated as a function of the yields recorded between 1986-87 and 1990-91. Mandatory setting aside of arable lands was applied to 15% of lands planted with major crops (grains, legumes and oilseed crops) starting in 1993-94. In certain countries, such as Germany, the Netherlands and England, efforts have focused primarily on industrial-scale non-energy crops.

The rate of set-asides was lowered to 12% for 1995-1996, representing 6.26 million hectares set aside in 1995-96, compared to 7.3 million hectares in 1994-95. This was expected to lead to a certain temporary drop in the quantity of land left fallow, but experts esteem that the overall trend is rising.

For instance in France 143,200 hectares of cropland were planted with biofuel crops in 1994, including 130,300 hectares of rape, altogether less than 10% of set-aside lands. The income that farmers earn from these crops is limited, despite the compensatory subsidies, but most farmers would rather grow crops, even with low earnings, than leave the land fallow, incurring only charges.

Extracting added value from farm byproducts is sometimes encouraged as a way to increase farm income, reduce pollution and slow down the rural population exodus. In Austria for example, farmers and agricultural cooperatives receive investment aid: subsidies of up to 50% and reduced-rate loans covering 50% of installation costs for wood-fired boiler plants. Half of the country's forests are owned by farmers, and through these grants the government's aim is to provide farmers with supplementary income obtained by exploitation of "small wood" resources. In Portugal subsidies are granted for biogas facilities to process pig-farm wastes.

Industry

The use of wastes and byproducts is sometimes essential for obtaining economic equilibrium in certain industries. In several countries, notably Portugal and Finland, the paper and paperboard industry has been the driving forces behind the use of wood, primarily industrial waste wood). In Finland the success of energy technology is tied to the most highly developed industries. These technologies are backed by a veritable industrial policy, including a strategy for exportation in world markets. At the crossroads of the energy and the paper sectors, technologies to process biomass for added value are strongly supported; this is the case for gasification, for instance.

Environment

Protection of the environment has a major role in today's energy choices and the development of technological options. The environmental impact of energy systems is relevant to maintaining certain global balances (mitigation of the greenhouse effect), as well as to preserving physical elements and habitats (land, water, air) and living organisms (health, biological diversity). Because of its prevalence in the biosphere, biomass can become a key feature of local and global environmental management. This means implementing "clean" techniques that are compatible with the environment, at all stages from production to end use. Eco-balance-sheets can be used to identify both positive and negative impacts. But in the environmental arena public opinion is of prime importance:

- either in favor of biomass in certain countries, based on worries related to the greenhouse effect, urban pollution, nuclear power, etc.;
- or impeding its development, due to fear of pollution stemming from intensive crop or forestry plantations.

The concerns of public opinion can thus inflect energy choices, and these worries vary widely from one country to the next.

Protection of the Environment: Main Topics of Concern		
EUROPE	- Austria	Nuclear power ban (national referendum in 1978) Air pollution, greenhouse effect
	- Finland	Greenhouse effect
	- France	Municipal waste treatment Air pollution Reducing pollution due to intensive farming
	United Kingdom	Municipal waste treatment Air pollution, greenhouse effect
	- Portugal	Fighting forest fires
UNITED STATES		Urban pollution, municipal waste treatment Greenhouse effect Fear of intensive forestry practices Reducing pollution due to intensive farming

Local Development and Employment

The exploitation of local resources induces economic and social development by encouraging short economic circuits, particularly in disadvantaged regions. Decentralized jobs are created upstream and downstream of agricultural activity, and throughout all phases of wood and waste activity, from collection to end use.

Estimated job creation : some examples

Biofuels :

- United States : According to the USDA Economic Research Service 15,000 jobs would be created by doubling current ethanol production to attain 2 billion gallons (7.57 billion liters) per year (which would represent roughly 3% of current gasoline consumption). At a production level of 5 billion gallons (18.9 billion liters), 100,000 jobs would be created.
  (*Source : Economic Research Service, U.S.A.*)
- France : 8,700 jobs could be created or maintained with production of 306,000 metric tons of biofuels and 500,000 metric tons of biodiesel.
  (*Source : "Les Biocarburants", report by H. Levy, February 1993*)

Fuelwood :

The collection, processing, transport and use of fuelwood would generate an estimated four times as many jobs as the use of fuel-oil or natural gas.

In the European Union as a whole, it is estimated that a 5% increase in the share of biomass used to meet energy needs would lead to the creation of 160,000 new jobs.
(*Source : "An Action Plan for Renewable Energy Sources in Europe", 1994*)

National and Regional Biomass Strategies

At present biomass is produced primarily for heating use, particularly in countries with abundant forest biomass resources. In this context biomass is consumed primarily by rural

populations for individual home use. In the future this raw material could become a prime resource for the production of electricity and vehicle fuels.

Each country gives priority to one or two forms of biomass production, with a strong tendency to exploit low-cost resources first, notably municipal and industrial wastes that require treatment for environmental reasons.

In addition, when farmers venture into energy-crop production they tend to choose traditional crops (corn, rape, beets) that they are familiar with and which require no new investment. They also prefer annual plants to perennial plants, for short-rotation coppicing does not generate income until several years after planting, causing cash-flow problems.

Preferred Strategies		
Country	**Resources**	**Energy Vector**
AUSTRIA	Wood (forestry cuttings) Rape	Heat (combustion) Biodiesel
FINLAND	Wood	Electricity / heat (gasification and combustion)
FRANCE	Rape, beets, wheat Wood	Biodiesel, ethanol, ETBE Heat
PORTUGAL	Wood (wastes) Pig slurry, industrial wastes	Electricity / heat Biogas
U.K.	Municipal wastes Energy crops	Biogas Electricity / heat (gasification)
UNITED STATES	Corn Wood, lignocellulose Wood, lignocellulose (in R&D) Soybeans, rape, tallow Energy crops: SRC, herbaceous plants, high-starch plants	Ethanol Heat /electricity Ethanol Biodiesel

The Principal Strategies are the Following :

- ***Attain cost-competitiveness in various market segments***

The mass markets are often linked to letting farmlands lie fallow, and involve non-competitive crops that are supported for political reasons. The main obstacle to the commercialization of biomass is the lack of competitiveness compared to fossil fuels. The first priority is therefore to reduce costs, particularly the costs of raw materials that constitute the major share of overall costs. The other strategic aspect is to have externalities recognized and taken into account, particularly social and environmental impacts.

Reducing biomass costs in order to penetrate energy markets is the main objective; some countries have set goals for specific forms of biomass production, which is a good way to mobilize industrialists.

Examples of Goals Set for Biomass	
Biofuels for vehicles	
United States	The goal is to bring the cost of ethanol down from $1.22 per gallon ($0.322/liter, of which $0.25 for corn) in 1995 (derived from corn and including commercialization of byproducts: $0.10) to $0.67/gallon ($0.177/l) in 2005 (derived from lignocellulose).
France	The goal is to bring the cost of biodiesel derived from rape down from FF3.00/l to FF1.00 /l (from $0.60/l to $0.40/l) in 2005. These costs are not comparable, insofar as they depend on the cost of raw materials. What is interesting is to compare the projected evolution.
Cost reduction focuses on reducing the cost of raw materials. The main strategies are the following: . increase crop yields using environmentally friendly methods (improved energy and environmental balance-sheets); . make use of all parts of crop plants by seeking out new added-value applications for byproducts; . improve processing technologies . exploit wood and other lignocellulosic resources that could constitute a significant low-cost resource, provided cost-competitive processing technologies are perfected.	
Electricity	
U.K.	The goal set for renewable energy is to attain 1,500 MW of net production capacity in the year 2000, while progressively reducing costs from $0.133-0.141/kWh to $0.063/kWh.

- ***Penetrate specialized and niche markets as feasible***

The commercial opportunities to be seized are influenced by a number of factors, including :

Legislation, regulations, fiscal arrangements

A number of measures have been taken to support biomass, or more generally to promote alternative forms of energy. These measures have in certain cases been taken under

pressure from interest groups, and are intended to take into account the positive macroeconomic benefits engendered: enhanced energy security, minimization of pollution, job creation.

These measures include:

- legislation to protect urban air quality (United States)
- mechanisms guaranteeing market access via favorable pricing policies for non-fossil and renewable-resource electricity (U.K., Portugal, United States)
- subsidies for energy crops on "set-aside" lands (European Union)
- investment grants for facilities to produce and/or consume biomass (Austria, France, Portugal)
- fiscal arrangements favoring biofuels (United States, France, Austria) and taxations of fossil carbon (Finland).

Site location : remote and pollution-sensitive areas

Biomass is often cost-competitive for remote areas far from fossil-energy distribution networks. Areas that are particularly vulnerable to pollution risks also constitute "niche" markets that are adapted to the specific advantages of biodiesel fuel (works equipment in forest areas, ski-resort equipment, city buses, boats, etc.). These target markets vary from country to country and region to region. This implies a diversification of priorities in R&D work aimed at developing suitable technologies; there is no single model for the promotion of biomass.

The need for waste treatment to minimize pollution

Municipal wastes, animal wastes from large-scale livestock operations, industrial wastes– all require treatment. Energy recovery is one way to minimize the pollution caused by these wastes.

- ***Structuring markets and production when acceptable cost levels are reached***

The structuring of markets and production implies an assessment of energy needs and resources. Regional energy policy has proven to be a particularly useful tool for obtaining an overall perspective, encompassing energy, environmental, economic and sociological issues. The region of Styria in Austria, for instance, drew up a plan for 1984-1991 that outlined local needs and potential resources, energy fluxes and pollutant emissions. This programming effort was effective in attaining its initial goals. In the subsequent program the goal is to raise the share of biomass in energy supply from 12% to 20%. A special effort is made to mobilize partners who are in a position to promote biomass; to this end socioeconomic studies have been carried out to analyze the behavior of actors, particularly end-users, and also to identify innovative social action and cultural factors that can promote project success. Separately, energy policy has encouraged cooperation and agreements between competing energy supply companies (gas, electricity).

The development of partnerships between all the actors involved– farmers, forestry operators, equipment installers, local authorities, industrialists and the various end users– fosters the setting-up and consolidation of production structures, by guaranteeing regular supply at a steady price. The involvement of industrialists at all stages is essential. Such partnerships and coherent research programs can be facilitated by creating forums for consultation and collaboration, such as the AGRICE group in France.

Launching and developing production structures requires identification and mobilization of actors and social forces. Farmers have constituted powerful lobbies for the promotion

of biomass derived from traditional agricultural products, especially in the United States and France for biofuels, and in Austria and Finland for fuelwood via the development of district heating. These lobbies have a growing influence in orienting research programs and in the choice of development support measures.

By contrast, pressure in favor of solid biofuels is non-existent, because forestry operators are for the most part dispersed, and not particularly interested in obtaining added value from their forests which they see as passive property, with little concern for productivity. In this domain the success of bioenergy requires a strong political will, implying investment aid for boilers, heating plants and district heat networks, funding for the organization of production structures, and significant research subsidies for conversion to electricity and liquid fuels. More intensive efforts can be made to inform the elected officials of local authorities.

The market approach to bioenergies, and/or pressure from vested interests, has led to an inflection of research programs, which are strongly influenced by perspectives of economic competitiveness and by concern for short-term results. There has been a notable shift in the programs and measures implemented, towards the use of easily obtained wastes (municipal and industrial wastes) and of traditional crop plants. This focus has helped launch processing and production structures, but could jeopardize promising options in the longer term.

- ***Preparing the future via R&D programs***

Public authorities play a central role in supporting the development of advanced technologies. And yet a survey of the existing situation shows that no country has a veritable R&D strategy for biomass, but rather a series of government decisions and an implementation of research activity. In certain cases strategies for the development of energy technologies, as in Finland, or regional strategies as in Austria, have led to research programs.

For short- and medium-term research, collaboration with industrialists and the relevant interest groups is crucial for setting goals, elaborating programs, establishing priorities and, above all, for their participation in funding and in practical work. Industrialists are willing to make a commitment when medium-term commercial applications appear likely. This has been the case in the paper and paperboard sector in Finland and Portugal. The participation of industrialists helps ensure that relevant choices are made for research topics and technology transfers. In the area of short- and medium-term R&D, some countries have thought it necessary to undertake work not only on innovative technologies, but also on technologies proven by experience; sometimes it is useful to pursue work to improve and consolidate these technologies. In Austria, for example, contests have been organized to encourage industrialists to submit improved designs for fuelwood combustion installations (comfort, ease of use, emissions reductions, esthetic design, etc.).

For demonstration operations and watershed technologies that are highly uncertain but which represent promising long-term potential in domains where the stakes are high, countries should continue their commitment to multiyear programs, evaluating them regularly to make adjustments as needed. This implies simultaneously planning financial resources over a long period for these research programs. Different research directions should be explored, so as to avoid "putting all the eggs in one basket." In contrast, development and demonstration operations should be chosen carefully, because the budgets involved are much larger. Priority should be given to processes and products that

can be expected to play a major role in the diversification of energy resources in the next century. Lignocellulose materials are probably the most promising, whether for producing heat, electricity or liquid vehicle fuels. Lignocellulose has a large potential, and is totally independent of foodstuffs markets. The planting of fallow lands could be extended. Plant species suitable for low-grade lands could be found among the broad range of lignocellulosic plants.

It is indispensable to carry out prospective analyses in order to establish specific objectives for R&D programs and prepare initial programming measures in detail. To maintain future options and preserve biomass as an energy resource, a balance must be found between short- and long-term projects. But given the budgetary restrictions linked to funding uncertainties, it is often very difficult today to draw up long-term strategies .

THE CALIFORNIA BIOMASS POWER INDUSTRY IN THE ERA OF RESTRUCTURING

Gregory Morris, PhD
Future Resources Associates, Inc.
2039 Shattuck Ave., Suite 402
Berkeley, CA 94602

Abstract

During the 1980s California led the world in the development of the biomass power industry. By 1995 the industry had overcome a series of hurdles and achieved a comfortable operating equilibrium. Nevertheless, menacing clouds on the horizon threaten to shut down most of the industry by the year 2000 unless solutions are found. Should the worst happen, it would represent an unmitigated disaster for the long-term development of the biomass energy potential of the U.S., the Americas, and the world.

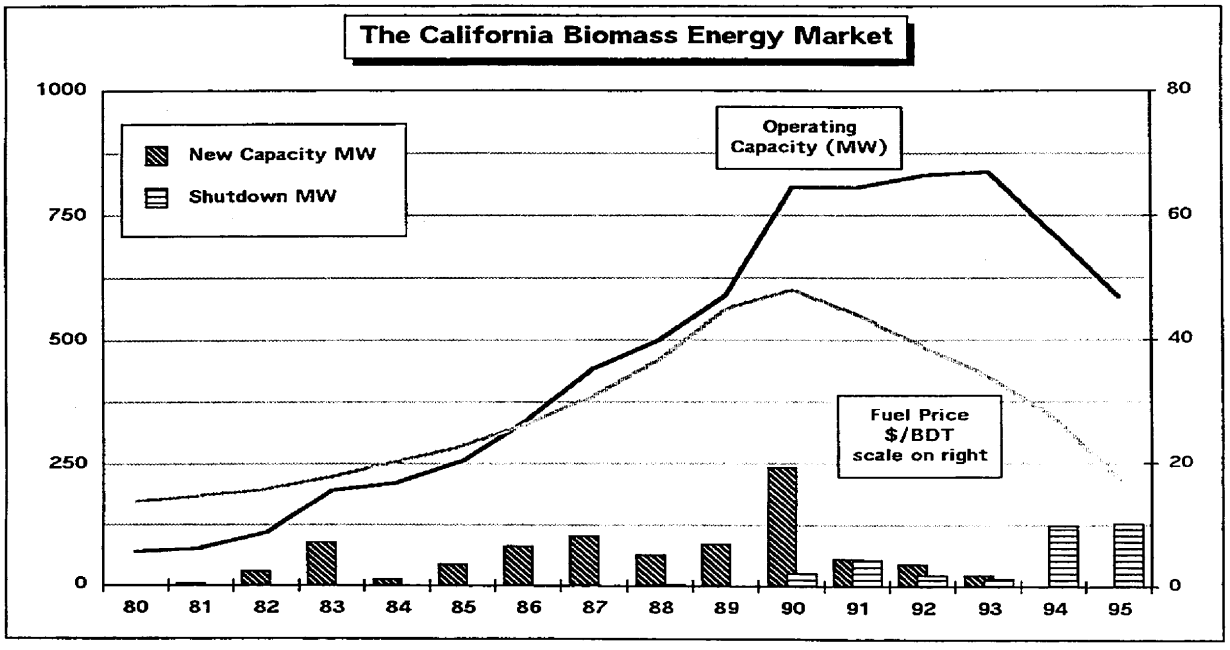
Most of the biomass facilities in California operate under power sales agreements in which energy prices decrease significantly after ten years of operations. Furthermore, the electric utility restructuring process that has begun in California threatens to place additional downward pressure on the price that biomass generators earn for their product (electricity). Biomass power generation simply cannot compete in a deregulated world of 2½ ¢/kWh power purchase prices unless a mechanism is established to credit it for its environmental benefits, particularly those in the areas of solid waste disposal and greenhouse gas reduction.

This paper describes the current state of the industry, how it has arrived where it is, and efforts being pursued to secure its future.

The California Biomass Energy Industry

During the decade of the 1980s the California biomass power industry grew at an average rate of 28 percent per year. By 1990 California had the world's largest and most diverse biomass power industry, with a working capacity of 807 MW and an annual fuel demand of almost seven million BDT. And the California power industry found itself with a terrible dilemma. Its growth had outstripped the ability of the fuel production sector to provide fuel. As a result, fuel prices were topping $50 per BDT, at least 2½ times higher that most developers had planned on. Most facilities were operating in the red.

Between 1990 and 1993 the operating capacity of the California biomass energy industry grew at an annual rate of 1.3 percent, reaching 838 MWs by the end of 1993. The fuel supply infrastructure expanded rapidly during this period, with the result that fuel prices stabilized in the range of $30 - 35 per BDT. Beginning in 1994 the state's utility companies, with the approval of the PUC, began making buy-out offers for the standard offer power purchase agreements that were a major factor in the development of the industry. During the next 16 months the industry contracted to only 584 MWs of capacity in operation! More than 250 MW of capacity accepted buy outs and shut down operations, half of the total in the first four months of 1995 alone. The most shocking part of the story is that the loss of 30 percent of total industry capacity has occurred during a period when most of the biomass power facilities, including the ones shutting down, are able to operate efficiently, reliably, and profitably. Figure 1 shows the growth and contraction of the California biomass energy industry.



Hardest hit by the shut downs has been the fuel supply sector of the California biomass energy industry. Biomass fuel demand in the state has fallen to less than five million BDT/yr. This is a substantial quantity, but some two million BDT/yr of waste and residue material that was being used as fuel during the beginning of the 1990s now has no useful application, and is being forced back into undesirable waste disposal alternatives such as land filling, agricultural burning, and fuel loading in the forests. This is an environmental calamity in the making, and nobody seems to be able to stop it.

Due to the positive environmental link that exists between biomass energy use and the disposal of a variety of waste and residue materials in the state, the actions that are being taken to shrink the biomass industry, regardless of one's opinion about their benefits for the electricity sector in the state, are having (or are about to have) unquestionably negative effects on state air quality and solid waste disposal. State agencies like the Air Resources Board, the Integrated Solid Waste Management Board, and the Department of Forestry are lining up to support the efforts of the biomass energy industry to survive. The California Energy Commission is leading an inter-governmental effort to find solutions to the industry's predicament. However the legislative and regulatory processes move at a snail's pace in comparison with the current rate of industry shrinkage, and it is unlikely that any of these efforts will be able to have a short-term impact.

In the meantime at least two million BDT of waste material are re-entering the state's already overburdened waste streams. The largest immediate effects will be on landfills in many of the state's largest cities, and on air quality in the San Joaquin Valley, a multi-billion dollar center of agricultural production. Both of these impacts will seriously compromise efforts to achieve environmental compliance requirements.

Biomass fuel use provides a potential recycling outlet for some 15 percent of the material entering typical urban landfills. More than a third of the biomass fuel used in the state during the peak of demand (1990-1993) came from this source. The production of urban waste wood fuels not only diverts material directly from landfill burial, in addition the profitable and stable biomass fuels market is responsible for stimulating and subsidizing a range of associated solid-waste recycling activities in the state. The chances of meeting the recycling goals that are imbedded in California state law are much lower if the biomass energy industry is not an active participant.

Restructuring of the California Electric Utility Industry

A shock jolted the electric power industry in California in April, 1994, when the state Public Utilities Commission announced its intention to restructure the industry. The original restructuring proposal, commonly referred to as "retail wheeling," is based on the principal that market deregulation and competition will bring down the cost of electricity for all classes of customers in the state. Retail electricity

prices are high in California compared to the rest of the country, and are detrimental to economic growth. The retail wheeling proposal would effectively break up the monopoly status of the regulated utilities, allowing customers to purchase electricity directly from competing suppliers, much as has occurred in the long-distance telephone industry. According to the original PUC proposal, cost alone would serve as the basis for determining which generating resources would be utilized in the state. The electric utility companies would become electric distributors.

The original PUC restructuring proposal was withdrawn in December, 1994. At that time the PUC formed several public working groups to produce reports that would guide it in formulating the next phase of the process. Phase two of the restructuring process was set in motion at the end of May, 1995, when the PUC issued an OIR that favors a slower pace of electricity restructuring than was envisioned in the original retail-wheeling proposal. The new PUC proposal is commonly referred to as "wholesale wheeling," and sets up a situation in which the electric utility companies can set up buying pools and purchase the lowest-cost power available to them, rather than relying primarily on their own generating resources. Retail purchases of electricity directly from suppliers is delayed under the wholesale wheeling proposal. In effect, the wholesale wheeling proposal encourages the utility companies to become power brokers *and* distributors for their customers.

Is there a role for biomass power in a competitive power market, when it clearly is not the low-cost generating source? Should environmental considerations, as well as price, be taken into account in the choice of generating sources used in the state? The only reasonable rationale for promoting policies that will allow survival of the biomass generating industry requires an affirmative answer to the question of inclusion of environmental considerations in the source-selection process. And, of course, the clear demonstration that biomass generating facilities do, indeed, achieve superior environmental performance. State law (the California Environmental Quality Act) specifies that environmental and energy-diversity considerations, as well as price, should be taken into account in the determination of the energy supply mix employed in the state.

All power generating facilities are subject to environmental regulation by applicable environmental agencies on a facility by facility basis. However, there is no formal mechanism in place for taking environmental considerations into account in the selection among alternative electricity generating sources. The PUC is the most appropriate forum for this process. In the past, the PUC has taken various means to promote renewable generating sources, including offering favorable power purchase provisions, and providing set-asides or adders in utility resource-acquisition plans. The restructuring proposal issued in April, 1994, excluded consideration of environmental impacts. This stance was modified in December when the PUC announced that environmental considerations *would* be included as the restructuring process progresses.

Price Competition and Environmental Impacts

Wholesale electricity is in plentiful supply across the country, with prices in the neighborhood of 2 ¢/kWh or less. Opportunities for biomass power plants to prosper at that price level are few and far between, with the result that only under special circumstances can facilities operate, such as on-site availability of "free" fuel, situations based on retail electricity displacement, and utilitypower purchase agreements with 1980s pricing.

In fact, the trend of biomass facility shut-downs that has begun in California and Maine might very well sweep across the nation if biomass is forced to compete on a price-only basis as a utility power source. Only a well structured and well executed effort by the biomass energy industry can stem the current tide. The areas in which the case for biomass energy can be made include environmental performance, fuel diversity, and jobs. In fact, biomass energy has a very compelling case to make for itself in each of these areas.

All renewable energy sources offer the opportunity to produce electricity without the environmental impacts associated with the use of fossil fuels. However biomass energy has the unique characteristic of not only avoiding the impacts associated with fossil fuel use, but actually providing significant additional environmental benefits in the form of reductions in the environmental impacts associated with the disposal of the biomass fuels themselves.

There are a number of areas in which biomass energy use provides significant environmental services in addition to the environmental benefits of fossil fuel reduction. These include a significant reduction in greenhouse gas emissions for material that would otherwise be buried in landfills, the avoidance of open burning of agricultural and forestry residues, forest-fire risk reduction, and the promotion of better forestry management practices. Biomass energy production also provides greater employment opportunities than do other renewables or conventional energy sources, due to the labor-intensive nature of the fuel-production process. In current practice biomass energy production receives no compensation or credit for the environmental services it provides. Unless this is changed, society will not receive the benefits that biomass energy use is capable of providing. Indeed, as biomass energy use contracts in California, its associated environmental services are being inexorably lost.

Making the case for providing special consideration for biomass energy requires making a convincing case that the benefits associated with its use are indeed worth paying for. At a minimum, this case must be at least as compelling as the case being made for reducing governmental budget deficits. In order to do so, the industry must produce the following information: (1) A detailed characterization and quantification of the environmental costs and benefits of biomass energy use. This analysis should take into account the environmental consequences of alternative disposal options for the materials being used as fuel, and should focus on impact areas like greenhouse gas emissions, emissions of regulated and toxic

pollutants, solid waste disposal impacts, and effects on forestry and agriculture. (2) A detailed analysis of the legitimate cost of supporting biomass energy production, and of ensuring that the support is provided with a least-cost mechanism.

Biomass energy is not alone in seeking to secure special consideration within domestic energy markets. An environmental case can be made for all non-fossil energy sources. In fact, due to the dynamics of the regulatory and legislative processes, there is a significant possibility that all of the renewables could be lumped together in consideration for and competition for environmental incentives. This could be very detrimental to biomass for two major reasons: (1) Biomass is unique among energy sources in providing distinct environmental services in the course of energy production, unlike the other non-fossil sources whose major environmental benefits are the displacement of fossil fuel use. (2) The economics of energy production from biomass are balanced between the capital and O&M cost categories, in contrast to the other renewables and nuclear, whose costs are heavily weighted to capital costs. Thus the economic needs of biomass differ from those of other environmentally desirable energy sources. The biomass energy industry needs to define its unique benefits, and secure its own niche in the nation's energy supply mix.

Initiatives Being Pursued by the California Biomass Energy Industry

The California biomass energy industry is fighting for its life. For the first time it is doing so collectively, a situation that would have been inconceivable just five years ago. At that time the facilities were engaged in a cut-throat competition with each other over access to fuel. Now fuel supplies are reasonably secure but the future is not, and the threats to the industry's future are shared collectively. In particular, market trends and deregulation threaten to shrink the revenues paid to biomass power plants in the future to levels that simply do not allow profitable operations, even for the most efficient facilities.

In order to pursue their collective and unique interests, most of the biomass power facilities in California have banded together to form the California Biomass Energy Alliance (CBEA). The CBEA is pursuing a two-pronged approach intended to securing the future for their industry. This includes a legislative agenda that involves support for three different initiatives (two state, one federal), and participation in the electric utility restructuring processes currently in progress in California.

The first of the legislative initiatives being pursued by the CBEA in the California legislature would secure an allocation of 1.5 percent for biomass-produced energy in all future resource allocation plans that may be carried out in the state. This would include set-asides of that amount within supplier pools, should such pools become the practice in a deregulated market environment. A 1.5 percent

allocation is large enough to accommodate the existing biomass power facilities, and to allow for future growth through competition and overall market growth.

The second Californialegislative initiativebeing pursued by the CBEAwould secure a temporary floor price for electricity produced by biomass energy facilities and sold to the state's utilitycompanies. The proposed legislation would be financed by levying a surcharge on all customer electricity bills in the state. These funds would underwrite a base rate for biomass power producers of 6.5 cents per kWh, making up the difference (if any) between short-run avoided cost rates and the floor level for the eligible facilities. The necessary surcharge to fund this initiative would be small.

A biomass facility would become eligible for the 6.5 ¢ per kWh base rate when it reaches the end of its fixed price period, and remain eligible for a period of three to five years. The intention is that the base rate willprovide a bridging period for the facilities to transition from the high fixed rates in the SO#4 contracts to the (currently low) short-run avoided cost. In return, the facilities will make every reasonable effort to retire their debt as quickly as possible, and use the floor-rate transition period to work their fuel supplies to a cost that is low enough to allow them to be competitive in a deregulated market. This will be a very challenging task.

The third legislative initiative being pursued by the California biomass energy industry is an effort to extend the 1.5 ¢ per kWh federal closed-loop biomass tax credit to allbiomass power generating facilities. This tax credit, which is contained in the 1992 National Energy Policy Act, is restricted to biomass facilities that grow the fuel they consume, leaving facilities that use waste and residue forms of biomass out in the cold. This despite the fact that it is easily demonstrated that waste biomass use is environmentally superior to fuel farming in virtually every way. Waste and residue biomass use is also cheaper than fuel farming, and accounts for virtually the entire biomass power plant fuel supply in the U.S. The 1.5 ¢ per kWh tax credit is not close to being large enough to promote any substantial development of closed-loop biomass power generators in the U.S. It might be large enough to allow the continued operation of existing generators who use waste and residue forms of fuel and sell electricity in a price-driven marketplace. The California Energy Commission is expected to take the lead in this effort, with the support of the state's biomass power industry.

Finally, the California biomass energy industry is preparing to participate in the electric utilityrestructuring process currently underway in the state. Regardless of the overall direction taken, e.g. retail vs. wholesale wheeling, the interest of the biomass energy industry is in defining a mechanism that will allow for current operation of the industry, and future competition. This willentailpursuing the same policies that are being pursued legislatively (1.5% allocation and temporary floor price), and working to avoid policies that do not account for the differential environmental impacts of competing energy sources.

Future Outlook for Biomass Energy

Should anybody care about the viability of the existing biomass power industry in California? To those involved in the development of the future biomass industry both domestically and abroad: Be concerned! A serious erosion in the California's installed biomass energy capacity would not only be a loss in the short term, it would also make the long-term development of biomass energy resources and technology much more difficult. California has been a bellwether state, and a catalyst of innovation in the energy field. The loss of the biomass industry in California, especially at a time when most of its early growth difficulties have been overcome, would seriously erode confidence in the industry. In particular, the financial community would be very wary of investing funds in biomass energy projects, either domestically or abroad. Capital, not fuel, is likely to be the limiting resource restraining the continuing development of biomass energy industry. The biomass energy industry must demonstrate that in can operate with stability over the long term in order to attract the capital necessary for its continuing development.

A PREMIUM PRICE ELECTRICITY MARKET FOR THE EMERGING BIOMASS INDUSTRY IN THE UK

Richard Kettle, B.Sc., Assistant Programme Director,
UK Department of Trade and Industry, London, England

Abstract

The Non-Fossil Fuel Obligation (NFFO) is the means by which the UK Government creates an initial market for renewable sources of electricity. For the first time the third round of the competition for NFFO contracts included a band for 'energy crops and agricultural and forestry wastes'.

The NFFO Order which obliges the Regional Electricity Companies (RECs) in England and Wales to contract for a specified electricity generating capacity from renewable resources was made in December 1994. It required 19.06 MW of wood gasification capacity and 103.81 MW from other energy crops and agricultural and forestry wastes.

The purpose of these Orders is to create an initial market so that in the not too distant future the most promising renewables can compete without financial support. This paper describes how these projects are expected to contribute to this policy. It also considers how the policy objective of convergence under successive Orders between the price paid under the NFFO and the market price for electricity might be accomplished.

Non-Fossil Fuel Obligation Policy

The Non-Fossil Fuel Obligation (NFFO) is the means by which the UK Government creates an initial market for renewable sources of electricity so that in the not too distant future the most promising renewables can compete without financial support. An essential element of the Government's policy is the objective of convergence under successive Orders between the price paid under the NFFO and the market price for electricity, i.e. *price convergence*. NFFO 3 was the first time that 'energy crops and agricultural and forestry wastes' projects had been invited to bid for NFFO contracts.

The invitation to bid projects into the 'energy crops and agricultural and forestry wastes' band was open. There was no constraint on technology to be used providing the fuel qualified for inclusion in the band definition. The principle caveat was that the Minister for Energy may decide to sub-divide the band into two or more bands but no indication was given as to how this might be done, i.e. whether by technology employed or fuel used. The Minister did however state that in deciding on the size of the band(s) he would take into account:

- the cost and quality of proposals received;
- his assessment of the implications of the policy objective of helping the different renewable technologies to enter the commercial electricity generating market.

The Minister also indicated that he expected this band to "stimulate substantial commitment to coppicing".

The Third Non-Fossil Fuel Obligation Order

The third Non-Fossil Fuel Obligation Order (NFFO 3) was announced on 20 December 1994. Table 1 gives details of the Order made.

Table 1: The NFFO 3 Order

Technology Band	Contracted Capacity	Number of Projects	Lowest Contracted Price	Weighted Average Price	Highest Contracted Price
Energy Crops / Forestry Waste - Gasification	19.06 MW	3	8.49 p/kWh	8.65 p/kWh	8.75 p/kWh
Residual (Other)	103.81 MW	6	4.90 p/kWh	5.07 p/kWh	5.23 p/kWh

The Order obliged the 12 Regional Electricity Companies (RECs) in England and Wales to contract for nine projects in the technology band for energy crops and agricultural and forestry waste. These are given in Tables 2 and 3.

Table 2: NFFO 3 Projects to Gasify Coppice Wood and Forestry Wastes

Developer	Capacity	Location
South Western Power Ltd	5.528 MW	Eye, Suffolk
YW Enterprises Ltd	8.000 MW	Eggborough, North Yorkshire
South Western Power Ltd	5.528 MW	Cricklade, Wiltshire

Table 3: Other Projects under NFFO 3

Developer	Capacity	Location	Main Fuel
Attwell Farms Ltd	0.300 MW	Redditch, Hereford and Worcester	Farm Slurry
Agrigen Ltd	8.825 MW	Northampton, Northamptonshire	Poultry Litter
Fibrowatt Ltd	38.500 MW	Thetford, Norfolk	Poultry Litter
Agricultural Energy Co Ltd	10.930 MW	Wellington, Somerset	Poultry Litter
EPR Corby Ltd	14.250 MW	Corby, Northamptonshire	Poultry Litter
European Development Corp PLC	31.000 MW	Ely, Cambridgeshire	Straw

Were all these projects to proceed as planned they would be commissioned between early March 1995 and the end of February 1998. The cost of the projects over electricity pool price is recovered by the RECs from electricity consumers through a Fossil Fuel Levy.

The NFFO 3 Competition

The bidding process imposed considerable competitive pressure on those bidding, particularly for those bidding projects using fuels at the higher end of the range of prices seen. This fulfilled a further objective that there should be effective competition in the allocation of NFFO contracts. In the event the band was heavily oversubscribed and competition was keen. During the bidding process, at about the time the initial non-binding bids were made, the Department published Energy Paper Number 62, 'New and Renewable Energy: Future Prospects in the UK' (EP 62). This statement of renewable energy policy included estimates of the contribution that 'energy crops' and 'agricultural and forestry wastes' might make to the Government's aim of 1500 MW of new electricity generating capacity from renewable sources for the UK by the year 2000.

EP 62 estimated around 100 MW from 'energy crops' but over 180 MW was bid into NFFO 3 in 43 wood-fired projects. Furthermore, there were likely to be two more Orders in 1996 and 1998 which might include projects which could also contribute to the estimate of 100 MW. So it was inevitable that many developers were to be disappointed. Although many of these projects used forestry wastes to at least some

degree, it was those that used coppice (short rotation arable coppice of willow or poplar grown for use as a fuel) that were the more competitive. The risks in establishing a new crop and, in the case of gasification, employing a novel technology for electricity generation, meant that average project size was small and prices high. Conventional steam-cycle plant averaged 6 MW as bid and no projects were contracted, whereas gasification projects averaged only 0.5 MW as bid but 6.3 MW as contracted.

EP 62 also estimated around 100 MW for 'agricultural and forestry wastes' and 36 projects totalling over 420 MW were bid. Again there were likely to be two more Orders. Again many developers were to be disappointed. Projects which anaerobically digested farm slurry to produce methane were bid at an average of 0.5 MW but only one project was contracted at 0.3 MW. Projects which combusted poultry litter were bid at an average 16 MW and 4 were contracted at an average of 18 MW and straw projects averaged 21 MW as bid and only one was contracted at 31 MW.

Will the contracted projects get built?

The challenge successful developers now face is that of taking their project forward to construction and profitable operation. An important characteristic of the NFFO arrangements is that the premium price for electricity is only paid if the project generates. In other words the developer accepts the risk and costs incurred if the project does not generate - the electricity consumer only pays if it does. The key steps for the developer are to organise a secure supply of fuel and obtain planning permission in order to draw on the finance to build the plant. A number of projects are likely to fail. Indeed at least one project, a straw fired project, which did not obtain a NFFO contract has already been refused planning permission.

Poultry Litter and Farm Slurry

Contracting for a secure fuel supply is perhaps easier for those projects fuelled by a waste that otherwise has to be disposed of. The fuel supplier has an interest in the project going ahead. To the extent that ever more stringent environmental controls might impact upon him in the future he is also likely to be committed to the project in the long-term. These characteristics are very valuable when it comes to arranging finance. Lenders will be reassured that the fuel supply risk can be left with the fuel supplier where he has an interest in the disposal of the waste i.e. the utilisation of the fuel. These arguments are strongest in the case of poultry litter and farm slurry where there can be restrictions on land spreading or landfilling.

Straw

These arguments are less compelling in the case of straw. Until 1992, when the practice was banned, farmers used to burn around 7 million tonnes (t) of straw in the field after each harvest. Now chopping of the straw as part of the combined harvesting process is common practice followed by later incorporation as part of the cultivation cycle. Although these activities incur some cost, typically around £10 /t, farmers tend not to see straw as a waste product and this is reflected in the initial asking price,

particularly as other more lucrative beneficial uses exist. A straw purchase price of say £5/t in the swath can add a very small amount to the gross margin for the farmer but he takes the risk that the straw may not be removed from the field in time for its cultivation for the next crop. Developers will therefore need to devise ways of keeping farmers committed to supplying fuel for the life of their project.

Coppice

Energy crops grown solely for the purpose of supplying fuel for a NFFO project which has a life of perhaps 15 or 20 years demand a high degree of commitment from the fuel supplier. Those providing project finance are likely to demand a 'put or pay' contract is in place for the life of the project. Under such a contract the supplier either provides the fuel supply as contracted, or pays an amount related to the developer's loss of revenue if the fuel supplier defaults. Vertical integration of the project whereby the developer, or by then the owner of the project, controls the fuel supply is one way in which the fuel supply risk can be dealt with. Alternatively, a farmer co-operative or established agricultural merchant may be better placed than an individual farmer to provide the guarantees likely to be required.

Conversion Technologies

The conversion technologies required to utilise these fuels are largely conventional. The novelty is mainly in their application to these fuels. Gasification of wood provides the greatest challenge to developers as it requires the wood chip to be adequately gasified, the hot gas catalytic cracker to take out the tars and the gas turbine to run reliably on the resultant fuel gas. Special purpose 'cigar' burners, in which whole Hesston bales are fed into a combustion chamber and burned end on, is one approach to straw combustion. Fluidised bed combustion is being considered for poultry litter in order to accommodate variations in moisture content and thus calorific value, although a moving grate could be used to co-fire with other biomass in order to control moisture content. Anaerobic digestion involves maintaining the farm slurry at an elevated temperature, 55-60 ^{o}C for thermophylic digestion, long enough to allow sufficient methane to be yielded to fuel a conventional spark ignition or dual fuel engine.

The supplier of the technology will be expected to take the 'technology' risk and provide guarantees. The novelty of the application, if not the technology, will mean that in accepting the 'technology' risk the supplier will reflect the cost of the guarantee to him in the purchase price. This is one reason why the less proven the technology is in the application, the more expensive it is likely to be. This effect is compounded where the developer perceives a residual risk which by default stays with him and is reflected in his required rate of return. In addition a similar process can occur in respect of fuel supply risk and again there is a further compounding effect. This could explain why novel fuels such as coppice using novel technology such as gasification are disproportionately more expensive than existing fuels such as chicken litter using more conventional technology.

Planning Permission

No matter how clever the fuel supply strategy or how sophisticated the conversion technology the project cannot be built without planning permission, i.e. consent to build the power station. The commercial and technological skills the developer will have exercised to get this far will be of limited use in winning the hearts and minds of the projects prospective neighbours. Developers start at an advantage in that most people are in principle in favour of exploiting renewable sources of energy, but few have direct personal experience of what this entails in practical terms. So developers have the opportunity to sell their project to the local community on the back of a considerable amount of goodwill.

What can happen so often is that developers don't talk to the community until they really feel they have to. This is usually when it is too late and just after the point at which the community has decided the project will adversely affect property prices, pollute the environment, dominate the landscape, cause more lorry movements, etc. etc. Of course the developer will bounce back and explain that the project will bring new jobs and help protect property prices, will abate greenhouse gases and cause less emissions than any other combustion process, will be designed to enhance the existing sprawl of car parks, sheds and warehouses, generate less traffic than other development for which the site is zoned, etc. etc. But he will be too late to undo the damage already caused. Even promises of 'free' heat won't help - streets dug up for years on end and more traffic congestion. The lesson from one ill-fated project from which the foregoing examples are taken is - do not start from here.

As with any development proposal, the appointment of a strong professional team at the outset is important to ensure that proper advice is obtained and all potential problems are adequately addressed. Early consultation with the local planning authority is important to identify particular issues that may be of concern to them. This should develop a more co-operative, rather than confrontational, attitude and save time and expense for the professional team. The planning officer always has a delicate task in balancing the issues, particularly where is strong objection from a section of the community. He will require assistance from the developer in providing information in support of the proposal. The planning authority will already have their own procedure for carrying out a consultation process, as with every planning application. It will be important, therefore, that the planning officer is informed of any separate consultation or lobbying process which the developer intends to undertake. The planning officer's advice, based on his local knowledge, can be invaluable. At the end of the day, however, the decision is made by a committee of elected Councillors and the result is never a foregone conclusion.

How will these projects point the way to *price convergence*?

Poultry Litter and Farm Slurry

The NFFO 3 projects will point the way to price convergence in a number of ways. Projects utilising wastes will show how recovery of energy is a beneficial use which can, depending on the circumstances, offer the 'best practical practicable environmental

option' (BPEO). As environmental controls become more stringent and alternative disposal routes are closed or become comparatively more expensive energy recovery will become economically more attractive. Anaerobic digestion offers a much lower net energy yield than combustion and will rely on sale of the digestate as a plant growing medium for it to be commercially viable. In both cases NFFO projects will help establish the optimum scale of operation as well as demonstrate initial markets for the by-products of phosphate from the combustion bottom ash and fibre from the digestion. The NFFO projects will also help establish confidence in the performance of the technologies involved. Their providers will then be able to offer them with adequate guarantees and at lower cost.

Straw

For the reasons mentioned earlier straw does not offer the same potential for reduction in fuel costs as do other agricultural wastes. Nevertheless there is some scope for reducing the delivered cost of the fuel through economies in baling, transport, handling and storage. There may also be some scope for optimising the scale of the project by trading lower operating costs of a larger power station against the higher transport costs of a larger catchment area. Ultimately it may be that straw demands the higher conversion efficiencies available from gasification for the route to commercial viability to be secure.

Coppice

This resource presents the greatest challenge. Coppice yields need to be increased from the present yields of typically 11-13 dry tonne / hectare (dt/ha) to 15-21 dt/ha. Initially this is likely to be achieved by selection of clonal material most likely to provide these yields on the particular site being considered. The cost of harvesting, transport and storage needs to be minimised so that the delivered cost of the fuel is competitive with other solid fuels. The conversion efficiency available from gasification means that the cost of fuel can then become a less significant element in the cost of electricity. Attention then turns to the capital cost and there are already, even before any projects have been built, signs that there is scope for capital costs to come down. Projects are almost certainly going to be replicated at a larger scale, probably in the region of 30 MW which would require something approaching 10,000 hectare of coppice at current yields but proportionately less as higher yields are realised.

Conclusion

Biomass projects constructed under NFFO 3 are the first step towards these renewable sources of energy generating electricity without financial support. The intention is that further orders will be made in 1996 and 1998 although future orders may not cover the same technology bands. Within government an inter-departmental group ensures the co-ordination of the policy and programmes concerned with biomass. The emerging biomass industry in the UK is being stimulated by the market-pull offered by the NFFO policy. However, the future success and long-term sustainability of the biomass industry relies for the large part on the commitment and ingenuity of the developers concerned.