Demonstration of the Commercialization of WSP Biomass as a Biofuel Feedstock

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Abstract:

Directly burnable biomass to be used primarily in steam boilers for power production has been researched and demonstrated in a variety of projects in the US. The biomass typically comes from wood wastes, such as tree trimmings or the byproducts of lumber production, or from a cash crop, grown by farmers. Of this later group, the main emphasis has been utilizing corn stover, or a prairiegrass called switchgrass, or using tree seedlings such as willow. This paper proposes an alternative to these energy crops which consist of several different herbaceous plants (WSP) with the one consistent property that they annually generate an appreciable bulk of dried-down burnable mass. The fact that they are a set of plants (nine are offered as candidates) gives this energy crop a great deal of flexibility as far as growing conditions and annual harvest timeline. Their predicted yield is impressive and leads to speculation that they can be economically feasible.

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INTRODUCTION

The analysis and demonstration of new renewable energy sources for power production is in a strong state of development. Biomass sources such as corn, landfill gases, and residues of agricultural production are generating fuel or electricity in a variety of working facilities throughout the US. Still there is one major drawback from development of any of these biomass sources. It concerns their diffuse nature; there just isn't enough of them to make a significant contribution to the total energy requirements of the country. It may be argued that biomass will be a small contributor until a source comes available that is not a byproduct of another process but is generated (grown) strictly as a fuel source. These are the 'energy crops', grown specifically to be burned, or coburned, in steam boilers to operate turbines for electricity production.

Figure 1 WSP have woodlike stems

Proposed energy crops are of three types; monocot herbaceous such as switchgrass and corn stover, woody stalked herbaceous (dicot) such as goldenrod and horseweed, and true wood plants such as willow and poplar. The first and last of these have had a significant amount of demonstration activities such as cofiring with coal in existing pulverized coal burners or liquified bed burners. The middle group, the woody stalked plants (WSP) is a recent entry into the biomass mix[1]. They include up to nine different plants all with the common feature that they have a woodlike stem that dry down readily (Figure 1). These plants include New England aster, kinghead ambrosia, evening primrose, goldenrod, horseweed, field thistle, Dames rocket, cockleburr, and annual sunflower. All of them are native throughout most of theUS.

In this paper we are going to account for the activities to demonstrate the commercialization of this biomass source by performing the various processes required to generate electricity; cultivation, harvest, transport, material handling, and burn. This activity took place in northwest Ohio and southern Michigan.

There are two critical issues that concern a possible energy crop. One of those is that it must be *economically feasible*. This issue has two sides that must be addressed. The crop competes for the farmers attention with other agricultural crops such as corn and soybean. Therefore it must be economically attractive for them to grow. From the users viewpoint, the biomass competes with conventional fuels such as coal. Although there are certainly extenuating circumstances, the delivered cost of the energy crop must compare in some manner with that of coal. At the heart of the economic analysis is the tonnage yield per acre that can be expected for the crop.

The other concern for a proposed energy crop is that it is *commercially* possible in all of its aspects. It must be shown that the crop can have its seed harvested and be planted and managed in the field. It must be shown that it can be harvested into an acceptable form, preferably with conventional harvest equipment rather than specifically designed. It must be shown that is can be removed from the field and transported to the power plant in an acceptable manner. Finally it must be determined what its requirements are for burning in conventional or custom-designed burner and whether it is compatible with material handling systems at power plants.

Of these two concerns, economics and procedural, confirming the economics requires determining probable yields, which could take several years to accomplish since there is no current cultivation of WSP. Therefore is has been our approach to demonstrate that the systems for commercialization of this product are in place, or to identify what redesign of equipment or changes in procedure are necessary for the successful conversion of WSP into power, or to determine whether there were insurmountable obstacles to accomplishing this goal. Therefore we set out to go through each step of the process without any preconceived notions of what difficulties would ensue.

CULTIVATION:

It has been noted that there are no present cultivation activities of WSP. This activity will take some several growing seasons. Therefore instead of planting fields of WSP we took to locating good stands of such plants that were growing wild. During this activity, we were able to study the nine candidate plants that make up the originally proposed WSP and make some critical analysis of each. For example, we agreed with the original study[1] which suggested that field thistle and cockleburr were too difficult to handle to give serious consideration as a commercial product. We also were able to confirm that Dames rocket had such a large percentage pith and such a small percentage of useable biomass, that it would be a low yield candidate and we eliminated it from consideration.

In attempting to find stands of wild sunflower and horseweed, we found that they were grown best in 'disturbed' soils and competed poorly in field with grass and weeds. Therefore the stands of sunflower that were located were not very dense and the stands of horseweed were not very tall, and we did not use any of these plants from this study.

Evening primrose was also found to be very sparse and its biannual nature casts a shadow on its future as a viable biofuel source.

Figure 2 Field of Kinghead Ambrosia

Figure 3 Field of Goldenrod

It was goldenrod, New England aster, and kinghead ambosia that we found in such abundance and concentration as to consider their harvest. Of these three, we selected one field that was exclusively kinghead and a second field that was primarily goldenrod, with a small mix of aster and kinghead.

During these field inspections, we gained some experience with all of the WSP plants and can make some recommendations for the future. The primary selection of kinghead and goldenrod for this study is not to suggest that these two plants should be the primary ones for future investigation. Our criteria for selecting them was based on their ready availability. Indeed, we were impressed with the hardwood nature of the evening primrose stem and feel that it warrants further consideration as a WSP. We were impressed with the height and bulk of some of the sunflower and horseweed stems and feel that in cultivation they may be an exceedingly good product. We noted that the kinghead ambrosia had a large percentage of pith and its burnable mass appeared to be low in density. Along with the fact that it is an allergen, we feel that it should join thistle and cocklebur as not be given future consideration as an energy crop. We used it in this study only because it was prolific in the wild.

HARVEST:

The harvest of two fields took place in late November. It had been delayed for up to two weeks due to the desire on the farmers' part to have an extended period of dry weather. This concern is a carryover from cutting and baling hay. Hay is cut and baled 'green' and susceptible to mold if baled wet. WSP are baled dry and there should be no concern for mold. The researchers did not mind the delay however because they were surprised that the goldenrod was still quite green, even in the middle of November. This late growing pattern is due in part to the lack of a killing frost for the season but also in part to the late maturing of the plant itself. In the scheme of the flexibility of the WSP, particularly the large window of maturing, it was good to find one of the WSP that matured this late in the year. The implication is that if the first WSP matures in early August and the last in December, it will afford the farmer a five or six

month harvest period which not only avoids a rushed harvest but also reduces the need for long term bulk storage of the material at the burn site. In fact, it would be ideal if WSP material could be harvested year round and delivered in a 'just-in-time' mode to the burn facility. We returned to one of the goldenrod fields late in December, after a snow had set for four weeks, and found that the stand was almost entirely upright and intact. This gives hope that the biomass can be stored in the field all winter and harvested on an as needed basis.

Figure 4 A Winter Field of Goldenrod

Fig 5 The Cutter-Conditioner

Both the kinghead and goldenrod fields were cut and windrowed with a conventional hay/straw mower and conditioner (see Fig 5). The kinghead was particularly tall for this machine to cut. However what it did not cut it pushed over and due to the brittle nature of the stalk, they broke as if cut.

Figure 6 The Cut and Windrowed Kinghead Field

Figure 7 Baler on the Goldenrod Field

Three days after windrowing, the fields were baled. A conventional New Holland square baler was used. It picks the material from the field with a rotating head of metal fingers, feeds it into a mechanical compressor, slices the material into bales with a shear knife, then ties them. These machines are designed for a much less brittle, much weaker material, and whether they could perform the cut or the compaction of the stiff WSP was in question. We found that the conventional hay/straw baler worked exceedingly well on the WSP, both the goldenrod and kinghead.

There was one early breakdown of the equipment, but after close investigation it was determined that it was caused by a preexisting condition of the baler and was not related to the WSP material. It was the consensus of the baler operators that the equipment was finding the material 'tougher' than hay and straw, but the process went quickly and satisfactorily.

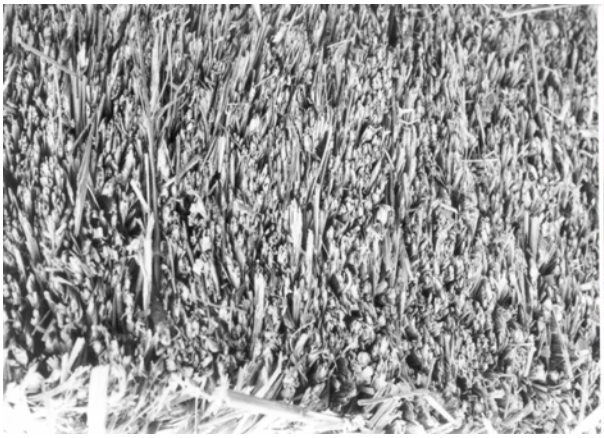

Figure 8 A Bale of Goldenrod Showing the Perfect Cut Showing of the Shear

Figure 9 The Baler on the Kinghead Field Some Residual Left in the Field

If there was one shortcoming of the conventional baler it was that it left a significant percentage of the kinghead on the ground. The kinghead in particular is a very long stalk. In the dry-down period the branches and leaves dry away and breakoff so that only the columnar stalk is left intact. When windrowed, some of the stalks line up perfectly in the row and when the baler comes across it, these stalks may go between the metal fingers and do not get picked up. It was approximated that about 20% of the kinghead crop was left in the field in this manner. It is thought that if this were to be a lasting problem, the fingers should be not be designed to be straight but rather with a hook or angle on the end, to cover the space in between the fingers.

The goldenrod field was baled clean, probably die to the fact that the still had considerable branches on it and considerable leaves and heads, and the fingers were able to grab some part of them and bring the whole stalk into the baler.

As baled for this study, the kinghead bales weighed about 35 lbs and the goldenrod bales about 40 lbs. We found nothing in the process that would not carry over to larger rectangular balers or round balers. The recommendation is that conventional baling equipment is satisfactory for this crop.

Some parts of the fields were measured and the material taken from them was weighed. In this manner we were able to determine that the yields from this study were about one ton/acre for the kinghead and 1.2 ton/acre for the goldenrod. Although these figures do not correlate well with Reference 1, consideration must be given to the fact that these fields were not cultivated but rather the material was wild. In particular, we estimate that the kinghead field had no more than 50% coverage, it having come up as a volunteer in a failed cornfield. In the case of the goldenrod, which was growing in an idle field, we estimate that no more than 1/3 of the field had goldenrod coverage. The remainder of the field was in wild grass.

The bulk of the material that was harvested was almost three tons. It was in bale form and could easily be transported the approximately 50 miles to the power plant site. However a factor arose that meant that the material would have to travel unbaled; in bulk.

MATERIAL HANDLING:

The first demonstration of WSP as a fuel to create electricity was done at Hardwoods of Michigan (HMI), a lumber producer in Clinton, MI. in December, 2002. They have an on-site turbine electrical generator that is fueled by waste residues from their logging operation, sawdust and wood/bark chips. Figure 10 illustrates the components of the power plant. The system stores two different grades of wood residue in different silos. One silo is for relatively dry material (>15% moisture) and the other holds a more green material (>30% moisture). The dry material maintains a hot combustion and the green material allows full usage of the complete combustion chamber. The two materials are mixed in the feed auger system.

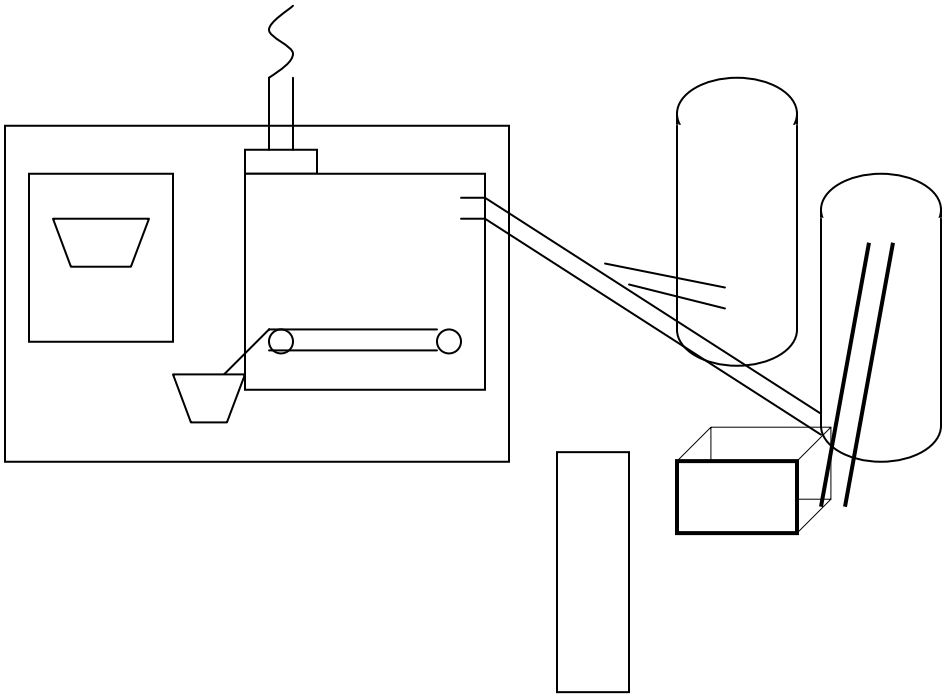

Fig 10 Diagram of the Burn Site Material Handling System and Power Plant

While coordinating with the burn site, it was obvious that the WSP material would have to be chopped or ground before it could enter the material handling system to the boiler. The powerplant material handling system started with a 'holding pit' for material delivered in a truck. The bottom of the pit had a slow moving conveyor which took the material over a set of screens and kicked out oversize pieces. The material then went by auger to a bucket elevator which took it to the top of the silo and deposited it there. In the bottom of the silo, a rotating drum moved the material into the boiler feed auger which transported it to the combustion chamber. The material handling system was designed to handle sawdust or wood chips up to about one centimeter cubes. The bales of WSP would therefore have to be processed to fit this system.

The power plant had a grinder that processed bark and wood byproducts into chips. A sample of the WSP was put through the grinder to assure that the resultant product was consistent with the requirements of the burner. Although the grinder had plenty of power to get through the WSP, it was found that some long pieces of stalk could make it through the grinder gears without being chipped. Therefore it appeared that about 20% of the product consisted of lengths too long to go through the burner material handling system. It appeared that the long stalky nature of this material could go lengthwise through even one inch screens and come out of the grinder at a length that is greater than the screens.

Figure 11 WSP Going through the Power Plant Grinder Figure 12 The result of the Grind

The immediate solution to the problem was to use a different type of chopper/grinder. A local tree service was contracted to do the chipping using a portable tree trimming chipper (Fig 13). The material came out of the process in a more refined state than with the first grinder. Since the chipping was done close to the harvest site, the material had to be hauled in the chopped, bulk form to the burn site. This was done by an enclosed truck van.

Figure 13 Chipping the WSP *Figure 14 Bulk Material in the Holding Pit/Conveyor*

At the burn facility, the chipped material was dumped into the holding pit. As it was processed through the system, it began to backup and plug up at three points in the system. At all of these points, the stalk material would create a matrix of interlocking stems and eventually plug up the system completely or reduce the flow. Although the HMI maintenance staff quickly made modifications to both equipment and

procedures, and although they were able to maintain some level of material flow through the system for about three hours, one of the points of stoppage got increasingly worse and the test was eventually aborted before all of the material had been put through.

In analyzing the failure, there appears to be two characteristics of WSP that make it unconventional for material handling. The first is that when it is cut, it has a tendency to shred, that is, the stalk does not shear cleanly but leaves fibers that are sometimes as long as the chip itself. A typical material handling system requires a 'quasi-liquid' material, in particular one that cannot support shear as it is transported. Because of the fibers, layers of the material would not separate at it was moved and instead 'built-up' at different points of the system.

Secondly, the columnar nature of the material implies that it will not pack efficiently but instead it will form a matrix of stalks with a tremendous amount of void spaced trapped. This is a problem in the silo and also in the auger, which needed more volume to pass the appropriate weight, and at every transfer point in the flow path, where a matrix of material can build up and plug the system.

Figure 15 WSP Filling the Boiler Feed Auger

The question of whether WSPs need to be ground to a sawdust form before entering it into the system has two aspects to it. The first is whether this is possible with conventional equipment. Sawdust is available to this burn facility because sawdust is a byproduct of other operations. To take a mass of material and deduce it to sawdust is a totally different issue and whether there are machines available to perform this function is questionable. A further question is whether it is feasible to do this. How much energy does it take to reduce WSP to sawdust, in particular how much compared to the energy contained in the material itself? WSP is proposed as a directly burnable crop (DBC) and that there are efficiency advantages of this over a fuels that require significant processing, such as ethanol. But, processing WSP to sawdust may be just as energy consuming as processing corn to ethanol. Whatever the case, we must realize that the more processing a material takes, the less it can be called a DIRECT burnable crop.

Material handling at the burn site is therefore one of those areas that will require more initiative if WSP is to become a viable renewable fuel. It may turn out that shredding is far too energy intensive and produces a result that is fibrous and supports matrix growth. *Shearing* may be a better solution, possibly shearing straight off the bale into short pieces.

An alternative approach may be to let the *fire* do the sizing of the material. In fact, WSP are properly sized by nature in two of the three dimensions. Their width and height (actually the diameter) is already sized for efficient firing. Only the length has to be reduced. In this respect it is much closer to efficient burning size than wood log is. Therefore it is possible that the boiler/burners could be designed to continuously take complete bales onto the burner grate, allow the bale strings to burn away, then use the

travel of the grate, or blasts of combustion air to open and separate the bulk material. This would require no material processing outside the fire.

BURN:

For our demonstration, the WSP material was fed from the green silo (Fig 10) even though it's moisture content was more like the dry material. The moisture content of the WSP as it was delivered to the burn site was below 10%. It was impossible to use the dry material silo however because it could only handle sawdust, and not the chipped material which had been brought.

Because the system is operational on an *around the clock* basis, the green silo was never fully depleted of its conventional fuel so as the WSP material was entered into the silo in a conventional manner, there was a wait period while it moved down the silo into a position to be burned. In fact on the day of the burn, HMI had burned the silo very low of conventional material and the WSP reached the boiler feed auger in a manner of minutes. However, throughout the several hours of burning, there was some mixing of WSP material with the conventional wood residue. Therefore it can best be said that for most of the burn time, there was coburning of WSP and green sawdust.

During the test period, the physical state of the flame was monitored, along with steam pressure, and exhaust gas particulates. There was no visible change in the flame in the combustion chamber during the test. After the three hours the screen for exhaust gas particulates indicates absolutely none trapped. During the test, however, a reduction of steam pressure was noted, and at one point it became alarming. It was conjectured that there an insufficient amount (weight) of the fuel getting to the fire, due to the low density of the shredded WSP(see Figure 15). From that point, the boiler operators began mixing more conventional sawdust and the pressure rose.

Figure 16 The Boiler *Figure 17 The Glow of a WSP Fire*

Overall, what was learned from the combustion phase was all positive. There was no smell that came from the exhaust stacks. The flame was appropriate. The WSP material was burned completely as evidenced by the lack of particulates in the exhaust.

Conclusion:

This project demonstrated that the commercialization of WSP as a biofuel will require very few modifications in conventional equipment or procedures. It has identified the material handling system at the power plant as one that may require additional research.

The study offered some insight into expected yields from the WSP. Whereas reference 1 predicted 2.5 ton/acre and reference 2 predicted 5-10 ton/acre, the yields that were taken from the 'volunteer' fields of this study were on the order of 1-1.2 tons/acre. It was estimated that due to the uncultivated nature of the fields, that yields from managed fields would be 2-3 times higher. This seems to substantiate the more conservative estimate of reference 1.

If it can now be stated that biofuel WSP are commercially feasible and practical, then the next goal will be to determine whether they are, or under what conditions they are, economically feasible. To do this, a limited cultivation of the crop will have to be achieved to determine expected yields

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Author: Dr. Kamm is professor of Mechanical Engineering Technology in the College of Engineering. His field of expertise is thermodynamics and fluid mechanics, refrigeration, and energy management. He has written many papers and articles concerning energy efficiency and energy efficient product designs. He heads the University's program of certification for the US/EPA Department of Stratospheric Ozone Depletion and has twice been nominated for the Stratospheric Ozone Educator Award. Dr. Kamm is the nation's leading proponent of woody stalked plant biofuels.