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DESIGNING AND TESTING A SMALL-SCALE BIOMASS HARVESTING SYSTEM IN THE EASTERN UNITED STATES

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Abstract: *A substantial amount of woody biomass feedstock is available on a sustainable basis from forests in the eastern United States. Current harvesting methods are limited in their ability to sustain the growing demand for biomass feedstock and cannot cost-effectively harvest small diameter material. To address this problem, we propose to develop, test, and if successful, promote a cost-effective harvesting method for producing biomass feedstock. The components of the system include equipment for felling (a John Deere 75C with a Fecon® shear head), extraction (an Awossos MD-50 skidder), and processing (a Morbark® Typhoon self-loading chipper). This system will be used under a variety of silvicultural prescriptions in both pine and hardwood ecosystems. Basic machine rate calculations show that biomass harvesting equipment costs approximately 50% less to operate compared to its larger, conventional equivalents. Anticipated benefits of the harvesting system include cost-effectively utilizing small diameter material, maintaining low residual stand damage in dense or sensitive stands, and the ability to work on small tracts and urban areas.*

1. Introduction

Approximately 368 million dry tons of biomass are available annually and on a sustainable basis from forest resources in the U.S. (Perlack et al. 2005). This represents a huge potential resource for energy production (Rummer et al. 2004), as well as, the production of a variety of industrial and consumer bioproducts that directly displace petroleum-based feedstocks (Energetics 2003). Biomass feedstock is generally defined as plant or animal materials used as a source of energy; for the purpose of this proposal biomass will refer to plant materials, more specifically, forest resources (trees or parts of trees). Biomass feedstock primarily comes from residues generated by traditional logging activities and residues generated from forest cultural operations or clearing of timberlands (Perlack et al. 2005).

Based on current forest practices, the majority of woody biomass feedstock in the United States will come from the Southeast (Perlack et al. 2005). The current, dominant logging technique in the Southeast is fully-mechanized, whole-tree harvesting, and the most cost-effective method for biomass feedstock removal are in-woods chipping systems which are adapted to work on fully mechanized operations. In-woods chipping operations such as these produce "dirty" chips in conjunction with pulp wood and chip-n-saw sized material. Therefore, the amount of chips produced is dependent upon the amount of available material that is not merchantable otherwise. Additionally, in-woods chipping operations are limited to areas within close proximity to biomass feedstock consuming facilities, because the relatively low market value for feedstock ($18-$20/ton) limits the economic feasibility of moderate to long hauling distances.

As the biomass market continues to grow, harvesting systems that are capable of producing biomass feedstock as a primary output on a consistent and cost effective level will be needed. Systems such as these would target material with no other commercial value; this material would primarily be between 3 and 9 inches DBH. Trees of this size can be found in upland hardwood areas throughout the eastern U.S., and in early pine plantations in the southeastern U.S. Additionally, a biomass market would minimally compete with the pulpwood market since the biomass market would operate in diameters below pulpwood size, and in areas where there is no pulpwood market.

There are currently no known harvesting systems which can target only small diameter material on a cost-efficient basis. Therefore, the objective of our research is to develop, test, and if successful, promote a cost-effective harvesting and transportation method for producing biomass feedstock for the market. Development will focus on a small scale, efficient and effective harvest and chipping system for the production of biomass. Although biomass production will be the primary goal, minimizing capital requirements and operating costs is key to its successful commercialization. This proposal will demonstrate new and innovative approaches to addressing this growing demand.

2. Methodology

2.1 Study Area

The harvesting system will be tested in two geographical locations. The first location will be in the Piedmont region of eastern Alabama. The system will be operated primarily in pine ecosystems (both natural and plantation), and will be implemented on first thinnings in pine stands, pole size hardwood thinning, and in areas needing fuel reduction in the urban interface. The second location will be in the Ozark region of southern Missouri. The system will be operating on USDA Forest Service land (Mark Twain National Forest), which is primarily an oak/hickory ecosystem. These stands will receive various levels of timber stand improvement treatments.

2.2 System Components

The components of the system include equipment for felling, extraction, and processing. The machine makes and models listed only give an indication of the size of the equipment – the exact model leased will be dependant on availability and cost.

Felling: a small excavator (Figure 1) with a bunching shear head (Figure 2) will be the system's felling component. When felling heads were first developed they are adaptable to a variety of carriers. Specialization for high production in pine has lead to the nearly exclusive use of purpose-built, wheeled, feller bunchers. Tracked feller-bunchers have evolved into large specialty machines for difficult terrain and large trees. The system envisioned requires a carrier that can minimize soil disturbance, maximize operating time and lower capital cost. The ability of this machine to reach for trees rather than driving from tree to tree should enhance productivity with the small stems. It will also minimize residual stand damage and ground disturbance. This machine will also be light enough to be hauled with a typical heavy-duty pickup truck.

Figure 1: Small excavator with bunching shear head (John Deere 75C)

Figure 2: A Fecon® shear head mounted on a skidsteer machine

Extraction: The primary extraction machine will be an Awassos MD-50 skidder. Much research has been done evaluating different types of small scale extraction systems, primarily with agricultural tractors and skid steer machines. These machines tend to be ill-equipped for high production (agricultural tractors), have high operating costs (skid steer) or result in high levels of residual damage (agricultural tractors and skid steers). On the other hand, conventional harvesting systems have moved almost exclusively to purpose-built skidders. The Awassos MD-50 will provide the system with the benefits of a purpose-built forestry machine on a level that promotes low residual stand damage and low fixed and operating costs.

Figure 3: An Awossos® MD-50 skidder

Processing: Once the material is brought to the landing, it will be processed into chips with a self-loading chipper. An ideal chipper would be the Morbark® Typhoon self-loading chipper (a similar chipper is shown in figure 4). This chipper is approximately 300hp and is small enough to keep fixed costs low, yet powerful enough to maintain a profitable production rate. This chipper, as a method of processing, is more beneficial than conventional systems because two machines (a loader and a chipper) are combined into one.

Figure 4: A self-loading ~300hp chipper

2.3 Study Design

A typical trial format for the small scale harvesting system will have the crew operating the system for a period of several weeks to become familiar with the equipment and gain some experience with the system as a whole. This phase will include safety training as well as familiarization with the desired silvicultural regime.

Once the operators are familiar with the machinery, the harvesting system will be tested through field trials consisting of various thinning and silvicultural regimes in both hardwood and pine forests. Tests in hardwoods will focus on various basal area thinnings or timber stand improvements (TSI) and woodland/oak savannah restoration. Tests in pine ecosystems will consist of pre-commercial thinning in both natural and plantation settings. Each field trial will be conducted on experimental units 1 hectare in size.

2.4 Data Collection and Statistical Analysis

Productivity: Prior to the start of harvesting (during the familiarization process) pine trees with DBH's ranging from 3-14 inches will be cut, weighed, and measured. This data will be compared with that of Clark and Saucier (1990) to ensure the pine trees we are harvesting follow their DBH/height to weight tables. If the DBH/height to weight tables have no major deviations from our samples, then data from Clark and Saucier (1990) will be used as the basis for green weight of the harvested trees. On hardwood applications, similar methods will be used to determine green weights of the trees.

Stands of similar composition and age class structure will be inventoried pre-harvest and a silvicultural treatment will be randomly assigned. While it is anticipated that the trees harvested will be chosen at the discretion of the operator, trees may need to be marked at the beginning of the study to familiarize the operator with the selected silvicultural regimes. Post-harvest inventories will be conducted to determine the level of accuracy to which the operator accomplished his/her goal.

Elemental time studies will be performed on each piece of machinery. Small video cameras will be the primary method of this data collection. The cameras will be adapted to each piece of machinery in a location that will record the machine functions of each element/process and the number of stems per load or cycle. A measuring system will be adapted to the machinery to estimate DBH (on the excavator) or butt diameter (on the skidder). Additionally, where time and money permit, DBH measurements will be taken manually to gather more accurate data.

The elements of the excavator that will be studied are; felling time, tree selection time – no bunch, tree selection time – with bunch, laying bunch down, movement without tree selection (no arm movement), and various types of delays (mechanical {excavator or head}, operational, other). The elements of the skidder that will be studied are; gathering a load, haul loaded, haul unloaded, unloading, deck preparation, and various types of delays (mechanical, operational, other). The elements of the loader that will be studied are; movement with load to the chipper, adjusting trees in the chipper, movement from chipper to gather another load, deck/area cleaning, adjusting the load on the ground, and various types of delays (mechanical, operational, other). Video tape will be reviewed in the office to determine times for each element.

In addition to the basic time and production data we will also look at other factors that affect the system or are important when analyzing it. These include such things as: (a) The average trees per bunch and their DBH will be combined with cycle times to measure the capabilities of the system, (b) The arrangement of bunches will be studied to determine the best configuration for the skidder. For example, are scattering the bunches generally in the same location opposed to stacking them side-by-side more beneficial to the skidder, or is choking one large bunch (a pile of 3 or 4 shear bunches) faster than choking 3 or 4 individual bunches, and (c) The average trees per excavator location will be collected for comparisons between silvicultural treatments (i.e. on average, how many trees can the excavator reach before having to move the machine). Other factors that will be recorded are slope, terrain roughness, understory composition, weather conditions, soil type, and soil conditions.

To record movement in the woods of the felling and skidding machines, GPS units will be installed. Data from the units will be used to determine skidding distances, and look for any unique movement characteristics that the machines (thus, their operators) follow. Skidding distances will be used to determine optimal skidding distances for the system.

Cost: In addition to the classic productivity calculations, machine costs will also be calculated to determine a $/ton basis for each silvicultural regime. Machine costing will be calculated using methods described by Tufts (1982 and 1985). Data for costing will be collected from the equipment manufacturer, relevant literature reviews, and from field collection (fuel and lube, repair and maintenance). This data can then be used to determine the overall viability of the system and as a cost comparison to other biomass harvesting systems. Additionally, transportation costs will be estimated from literature reviews, transportation trucking models, and concurrent research being conducted at Auburn University. This cost will be combined with the system's cost to determine a viable hauling distance and total cost to mill.

Stand Damage: Line transects will be used to evaluate soil disturbance and residual tree damage. Soil disturbance will be classified on a descriptive scale similar to ones used by McMahon (1995) and Turcotte et al. (1991). At selected points along the transect 30m plots will be established to assess residual tree damage. Damage will be assessed by factors of wound size and depth and/or percentage of crown damaged.

3. Justification

Machine rates were estimated for the biomass harvesting system using methods from Brinker et al. (2002) and Visser (2007). Machine rates were also estimated for "conventional" sized equivalent machinery to serve as a cost comparison. The conventional machines used were a Tigercat 845B feller-buncher, a Caterpillar 525 skidder, and a Tigercat 240B trailer-mounted loader with a Bandit model 1850 whole tree chipper, and were chosen based on their median purchase prices as compared to other machinery in their respective categories. The estimated machine costs can be seen in Table 2.

Table 2: Machine costs per SMH for selected equipment

Harvesting Component	Conventional System ($/SMH)	Biomass System ($/SMH)
Felling	81.31	39.95
Extraction	65.89	37.42
Processing	114.55	48.42
Total	**261.75**	**125.79**

The total cost of the biomass harvesting system is estimated to be $125.79/SMH, which is 48% the cost of its conventional counterparts. While all components are estimated to be less for the biomass system, the processing costs provide the greatest savings due to the fact that the conventional system carries the costs of both a trailer mounted loader and a chipper. When we combine these costs with estimated productivity (Table 3), we get an approximate valuation of the cost per ton that is required to operate the biomass harvesting system. Table 3 also gives the equivalent production rates necessary to match the biomass harvesting system on a per ton basis.

Table 3: Estimated production rates (per day) and costs per ton for biomass and conventional machinery

Biomass		Conventional	
Truck Loads (25 tons)	$/ton	Truck Loads (25 tons)	$/ton
3	13.41	6	13.96
4	10.06	8	10.47
5	8.05	10	8.38

Why are these numbers important? Generally, in the Southern United States, biomass consuming facilities pay $18.00/ton at the gate for feedstock (fuelwood). If we assume an average haul distance of 50 miles at $0.12/ton/mile we get a cost of $6/ton (50X0.12) for trucking. If we add trucking to the cost/ton to produce the material, we can see that it is feasible to have a biomass harvesting system that will cover its costs. When we compare this to current timber stand improvement costs of $75/acre, which targets the same diameter material, we can start to see the benefits of the system. As a landowner, it makes sense to use a specialized biomass harvesting system at a minimum of no profit rather than paying $75/acre for a conventional timber stand improvement, when the outputs are the same.

While it may appear that the conventional machinery we are using for cost comparisons are able to produce more material for the same costs, other factors must be considered which are not accounted for in the cost analysis. The first factor is the indirect costs associated with conventional machinery. Two of the more significant indirect costs include those associated with moving the equipment from site to site, and the costs associated with the clearing of landings. To move conventional machinery, a tractor trailer and lowboy must be used, sometimes requiring an overweight permit for the heavier equipment, whereas the biomass system can be transported behind a heavy duty pickup truck and trailer. Additionally, the cost of clearing and preparing landings for conventional machinery is greater than that of biomass machinery, primarily due to the size differences. By reducing costs and landing sizes the biomass harvesting machinery will be able to both economically and physically operate on smaller tracts of land than conventional machinery. The second factor is that cost curves for conventional harvesting systems have a harvesting limit of 6 inch material; continually harvesting trees under this diameter proves to be inefficient for the system. The last factor is that operating in thinning and timber stand improvement situations involves maneuvering around residual and crop trees. Large conventional machinery are not adapted for this type of operation. The residual (soil and tree) damage left by this machinery would be counterproductive to the purpose of the harvest, whereas the smaller and much lighter biomass harvesting equipment is adapted and designed to leave a very small footprint resulting in low residual damage.

4. Expected outcomes

Many beneficial and applicable results are anticipated upon the completion of the project. We anticipate that a cost effective harvesting system will be established that can economically work in large thinning and TSI operations, as well as small urban interface tracts. In addition to the revenue generated from the harvests, additional value will be gained in the residual trees due to the reduction in competion for scarce resources. The system can be used as a tool to improve forest health by removing and utilizing the small, less desirable and unmarketable trees and turning them into a marketable product. The lighter and smaller equipment should limit ground disturbance, which will minimize sedimentation into nearby streams.

We believe this system will be available for immediate implementation once production and profitability is demonstrated. Such systems can be targeted to tree-care companies, can complement existing logging contractors, or be a niche market for new contractors. The intended system has the potential to provide employment opportunities in rural areas consistent with the skill of the local workforce. Future development of additional plants in rural areas will increase the scope of opportunity by providing close and stable markets for biomass.

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