Harvesting and Transportation of Forest Biomass

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Abstract

A key challenge in using woody biomass for energy production is getting the feedstock harvested, processed, and transported at reasonable costs. Efficient feedstock harvesting methods must match the unique requirements of each source. Logging residue collection, for example, can be accomplished by integrating biomass processing into a conventional logging operation. Understory biomass and small woody species present special problems that are not readily overcome with existing harvesting methods. A wide range of new technology is being developed.

Harvesting technology can be described and evaluated by looking at the performance of basic functions: felling, primary transport, processing, and highway transport. Three basic felling methods are described here including manual (chainsaw), feller-buncher, and swath cutting. Primary transport of small woody biomass can be achieved by manual skidding or forwarding. An intermediate processing step to convert the biomass into chips or bundles can significantly reduce biomass extraction costs.

Several new technology developments to improve small woody biomass harvesting include variations of swath cutters and chip forwarders. In addition, a portable conveyor system has been tested to improve manual biomass cutting and removal.

With the wide range of possible equipment configurations and interactions among site conditions and biomass characteristics, it is difficult to compare alternative harvesting approaches. A generic biomass removal model, based on defining common parameters for the basic functions, allows any combination of equipment to be evaluated and compared. The generic model is described in this report.

Keywords biomass, cost, harvesting, models

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Introduction

The opportunity to utilize woody biomass for energy production has renewed interest in finding cost effective operations to harvest and recover woody feedstocks. Regional and national assessments of feedstock availability (i.e., Perlack et al. 2005) have documented distinct types of woody biomass. The most readily available source is manufacturing residues from the forest products industry. Additional biomass can be recovered from logging residues, thinning and fuel reduction treatments, urban wood waste, and from short rotation woody crops (SRWC).

Each of these sources has unique characteristics that affect the type of equipment and operation required to efficiently recover the material. Logging residues, for example, can be recovered in a whole-tree harvest by adding a chipper or grinder to process biomass as it accumulates at roadside. Westbrook et al. (2006) examined the addition of a small chipper to a conventional harvesting operation in Georgia. They found that the logging residues could be produced for about the cost of operating the chipper. When additional understory biomass was harvested to supplement chipper production, the resulting forest biomass cost slightly more.

Cut-to-length operations require some method to collect residues in the stand and transport them to roadside for processing. New terrain chipping systems such as the Valmet 801 Bioenergy offer integrated harvesting of fuelwood and merchantable products in the cut-to-length harvesting model. The 801 combines a harvester head with a terrain chipper. This special harvester can fell and merchandize logs, then chip the biomass material directly into a holding bin on the back of the machine. The bin can hold about 27 m^3 of chips. An alternative method is to compress the biomass into bundles that are forwarded to roadside with a machine like the Timberjack 1490 Bundler.

While operational solutions are available for logging residues and thinning operations, understory or brush harvesting remains a challenge. This type of woody biomass is found in a wide range of forms including woody shrubs and small trees. It may be present as the understory in a forest stand or as brushfields or rangelands. Examples include mesquite rangelands in Texas, southern coastal plain pine stands with woody shrub understory, brushfields in the Lake States, doghair regeneration in conifer forests, manzinita and chapparal. The common features of this resource are small diameter, poorly formed stems and a high number of stems per acre. Additional operational constraints include typical forest conditions including slope, obstacles, and soft soils.

Working under the International Energy Agency Task 31, Stokes (1992) provided a synopsis of then-current harvesting systems for small trees and forest residues in eight different countries. The North American database of harvesting systems included 160 different system and equipment configurations. This report reviews new developments in woody biomass harvesting specifically appropriate for the brush harvesting challenge. While these new methods take very different approaches, common functions can be defined. Finally, a generic analytic model is described that can be used to compare alternatives and guide systems development.

Understory Biomass Harvesting Operations

In order to harvest woody biomass certain functions must be accomplished. Initially the stems must be severed or pulled from the ground (the felling function). The cut material has to be collected and transported to roadside (primary transportation). Somewhere in this process the biomass material may be converted into a different form like chips, bundles, or bales that is more efficient to handle. This conversion could take place at the stump or at the roadside landing. Finally, processed biomass is loaded onto highway transport. Some general technical approaches to achieving these functions for small understory biomass are described below.

Felling

Manual felling, slashing and piling are commonly used to treat forest understory in fuel reduction treatments. Working with chainsaws avoids the soil disturbance associated with equipment operation. Manual crews are also easy to mobilize and can work on very small units and in difficult terrain. Generally manual operations are used to create piles for later burning. However, in some cases, the biomass must be removed rather than burned. Chainsaw felling productivity is primarily a function of piece size and the volume per acre. Other factors such as brushiness or obstacles have been found to affect manual production rates.

Mechanized felling, using a feller-buncher, can accomplish the same function. Feller-bunchers can be wheeled or tracked swing machines. Cutting with either shears or some type of saw, a feller-buncher moves to individual stems, collects a bunch as it cuts, and then lays the cut material down in a pile. A swing feller-buncher can accumulate biomass from a 20-meter circle without moving the base machine. The primary limitation with feller-bunchers is that the cutting device will only operate on one stem at a time (unless two are growing very close together). This means productivity is significantly affected by the size (volume) of the individual stems. Specially-designed felling heads have been developed to improve efficiency in harvesting small biomass (Spinelli et al. 2007).

Swath cutting attempts to overcome the problem of single-stem processing by cutting a wide path (swath) through the stand in one pass. Some type of cutter bar at the front of the machine severs everything standing in the swath. Productivity then becomes a function of the volume per acre rather than a function of piece size. Swath harvesters were developed in the 1970's and are experiencing new interest with the growing bioenergy market. Some of these machines are intended for SRWC harvesting (i.e., Savoie et al. 2006), while others are more rugged and intended for forest applications. A swath cutting system combining a forestry mulcher with a pickup trailer has been developed to harvest mesquite (Ansley 2007).

Primary Transport

Moving biomass from the point of cutting to roadside can be accomplished in many ways. At a very basic level, hand crews have been used to physically carry material out of the stand when the extraction distance is relatively short. This is clearly very labor-intensive work and presents numerous safety and health issues.

Recently, a system using portable conveyors for biomass removal was tested at Lake Tahoe. The application for forest biomass removal envisioned sections of conveyor deployed into the stand with hand crews bringing slash to the conveyor line rather than to hand piles. A main conveyor line would be fed by shorter spur lines to collect residues from a wider area. Moving at speed of about 60 fpm, the conveyor would carry the biomass to roadside where it would be piled or loaded into bins. In the demonstration test, the conveyor system was effective at moving chips, but had some technical problems with the wide range of slash configurations.

An alternative approach to hand-carrying slash is to use a forwarder to collect and transport piles. A forwarder is basically a self-loading off-road truck. Usually the load space is defined by log bunks, although different types of bins or dump boxes have been used to more efficiently carry slash. In operation, the forwarder drives through the stand collecting biomass from the piles into the load space. The full load is driven to roadside and dumped or unloaded with the crane. Klepac et al. (2006) evaluated productivity of a forwarder for slash transport in western fuel thinning. The productivity averaged 4.8 m^3 /PMH resulting in a forwarding cost of about $17/odt.

The most critical functional specification of a forwarder is the payload. Loose slash piles have low density making it difficult to get a reasonable load. A solid-sided load box allows the operator to pack material with the crane. There are also modified forwarders with bunks that compress the load (e.g., Continental Biomass Industries Brush Transport System), or with bunks that expand to increase the load volume. In any case, the payload is defined by the load volume and the biomass density.

Forwarder cycle time consists of travel (out and back), loading time, and unloading time. Travel speeds are limited by terrain. Loading time is a function of the number of stops the machine has to make to get a full load which in turn is affected by the volume per acre and the type of piling ahead of the forwarder. Unloading time is generally a constant with grapple unloading slower than dump methods.

Piled biomass could also be removed with a bundling machine. A biomass bundler collects material, runs it through some type of compressing system and produces composite residue "logs" (CRLs) that are significantly more compact than loose woody biomass. The CRL's are dropped in the woods and transported on standard forwarders. By increasing the biomass density through bundling, forwarder productivity is greatly improved. The Timberjack 1490 Bundler was tested in the western United States (Rummer 2004) across a range of forest and treatment types. Based on observed production rates and estimated operating costs, bundling loose logging residues cost about $16/odt. Forwarding bundles only cost about $5/odt. At least three other manufacturers make different forms of bundling machines.

Biomass can also be chipped in the stand and then transported to roadside in some form of chip carrier (referred to as terrain chipping in Europe). The most sophisticated machine in this class is the Valmet 801 Combi Bioenergy, a cut-to-length harvester equipped with a chipper and a 27 m^3 chip container (about 4 odt). When the container is full it can either be dumped at roadside or dumped into a chip forwarder. One machine accomplishes felling, chipping, and transport. This machine has seen trials in Europe, but has not been introduced to North America yet.

Several projects in the U.S. are developing a similar terrain chipping operation using separate machines for felling, chipping and transport. Terrain chipping was tested in California in pinyon-juniper. A tracked feller-buncher cut the trees, followed by a tracked chipper (Morbark Mountain Goat). The chip discharge was directed into a chip container carried on a forwarder. Two chip forwarders shuttled biomass to roadside. A similar system is being developed in eastern forests partially supported by the US Forest Service, Biomass Grants Program. That system will use modified agricultural forage wagons as the chip carriers.

Processing and Conversion

Woody biomass, in the form of slash or loose stems, has a solid volume factor (ratio of solid wood volume to total volume) of 0.15 to 0.25. Comminuted biomass in the form of chips or chunks has an SVF of 0.35 to 0.45, more than double the density of loose slash (Johnson 1989). Bundled material (Rummer 2004) has a SVF approaching 0.7. SVF is a critical factor affecting the productivity and cost of woody biomass feedstocks. Generally, the closer to the stump the material can be increased in density the lower the total delivered cost of the biomass. Processing is the function that can increase density and convert the raw biomass into a form that is more usable in energy production.

Chippers reduce biomass by a slicing action into pieces with some controlled dimensions. Chips may be required for some energy production uses where material handling or combustion processes impose constraints on the feedstock. Grinders reduce biomass with a tearing or shredding action and generally produce coarser material with a wider piece size range. Mulching cutters are a special form of grinder that reduces material and drops it on the forest floor.

New developments are occurring in chippers and grinders to more efficiently produce biomass specifically for energy use (Mitchell 2005). Conventional chippers have been optimized for pulpwood chip production and may need modification to produce particular forms of energy chips. A recent test in Alabama modifed a horizontal grinder to incorporate knives in place of the grinder teeth, combining features of both types of biomass reduction machines. Several of the terrain chipping systems being developed use different types of comminution. The mesquite harvester relies on a forestry mulcher to reduce biomass and the Laval harvester uses an agricultural shredder. Each type of reduction equipment has its own operating characteristics in terms of power consumption, piece size, and ability to handle debris.

Conversion in the form of baling or bundling deserves special mention. Bales and bundles not only densify the biomass, but also package it in a form that affects storage and ultimate utilization. Bundles of softwood slash in the western U.S. have been re-measured after one year of field storage with little loss of biomass or degradation. European bundling appears to be standardizing on the CRL form (Spinelli et al 2007) with biomass directly compressed into bundles. The Laval harvester (Savoie et al 2006) uses a different compression method, shredding the biomass before packaging into round bales. The CRL technology is specifically designed to be compatible with existing forest products transportation and handling systems. The round bale approach will likely require additional system design to optimize transport and loading functions.

Analytic Model

With the wide range of possible machine and system configurations it becomes very difficult to objectively analyze alternatives. The most common approach has been to conduct field trials of each system to determine productivity relationships and estimate costs. When systems are tested in different stands, or manufacturers change equipment specifications, the results of the field studies become difficult to extrapolate. It is also difficult to separate operator and crew effects when testing prototype technology.

The Forest Operations Research Unit of the US Forest Service is developing a generic analytic model that describes the biomass harvesting process in terms of the basic functions. Specific system approaches are then modeled by developing appropriate production functions for each. The production functions are derived from basic engineering processes as much as possible.

For example, consider the primary biomass transport function. As a process this involves some operation to load the biomass, carry the biomass, and then unload the biomass. The loading function depends on piece size and the number of loading cycles to fill the carrier. The transport function depends on the density of the biomass, the volume of the carrier and travel speed. The unloading function can be described as some constant time per unit volume. Figure 1 illustrates a process comparison of five generic biomass transport technologies. The basic functions are derived from specific assumptions about the critical factors listed above.

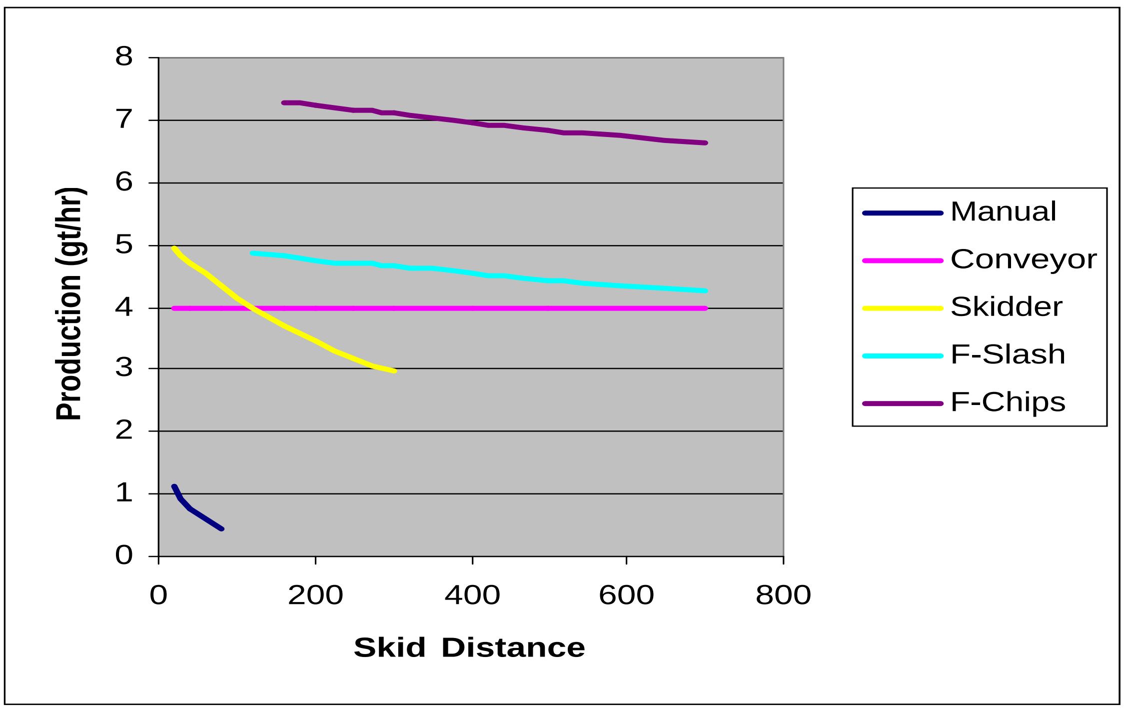

Figure 1. Generic production functions for biomass transport derived from engineering analysis.

The figure illustrates the functional performance of each alternative. Manually carrying biomass is a low production operation that is very sensitive to skid distance. A conveyor belt system has constant production rate regardless of skid distance as long as the loading operation isn't production limiting. A grapple skidder picking up slash can be more productive than the conveyor at short distance, but loses productivity as distance increases. The two forwarder options—carrying slash or carrying chips—are less sensitive to distance since most of their cycle time is associated with loading. Carrying the denser form of biomass increases transport productivity.

With these production functions coded into a model, underlying assumptions can be changed to determine the effect on the relative efficiency of each biomass transport technology. The model that is being developed includes felling, processing and transport functions as well as costs.

Conclusions

Woody biomass collected as part of integrated forest harvesting operations will be the most cost-effective feedstock for energy production. This material can be obtained for the cost of chipping and transportation. Harvesting additional biomass from understory or cull trees as part of the logging job is the next most cost-effective source of woody feedstock. This volume however carries the total cost of felling and extraction and is significantly more costly to recover. There are many new developments in forest operations technology to more efficiently harvest small wood and understory biomass. Swath harvesters and terrain chipping systems are promising methods, especially for the small wood biomass resource. Biomass processing into denser forms (bales, chips or bundles) appears to be a critical function to reduce feedstock cost.

Generic engineering process models can facilitate system development and to help determine the site and stand conditions that favor one approach over another. One such model is being developed specifically to examine small wood understory harvesting systems.

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