TECHNOLOGY FOR BIOMASS FEEDSTOCK PRODUCTION IN SOUTHERN FORESTS AND GHG IMPLICATIONS

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ABSTRACT

Woody biomass production in the South can come from four distinct feedstocks—logging residues, thinnings, understory harvesting, or energywood plantations. A range of new technology has been developed to collect, process and transport biomass and a key element of technology development has been to reduce energy consumption. We examined three different woody feedstock production systems with detailed field studies including logging residues in central hardwoods, whole-tree pine thinning and clearcuts, and understory baling. Productivity ranged from 5 Mg per hour to over 23 Mg. However the corresponding energy consumption (diesel fuel) was very similar ranging from about 4 to 5.5 l/Mg. Intensive management technology for short rotation woody crops will have additional energy inputs for planting and stand management. Equipment manufacturers are working on even more efficient technology such as energy recovery swing systems, new powertrain designs, and improved productivity. This comparison suggests that intensive energywood production systems and understory harvesting may have the lowest harvesting energy input per ton of wood produced.

INTRODUCTION

The use of woody biomass for energy has the potential to become a major output from southern forests. In the Southern Forest Futures Project, Alavatapati and others (2011) evaluated biomass use over a range of potential scenarios reflecting population, markets, and forest stocks. By 2050 their analysis suggests that woody biomass use for energy would be somewhere between 50 and 100 percent of the volume used for conventional forest products. Some of this volume could come from shifts in demand for traditional pulp and sawlog harvest, other material will come from increased recovery of logging residues, energywood thinning and purpose-grown energywood plantations. The driving factors behind increasing woody biomass utilization are energy demand, policy developments encouraging renewable energy sources, and forest owners seeking new markets for biobased products.

While there are always concerns about the environmental effects of forest operations and wood utilization, the fact that woody biomass may be used for energy production has raised interest in the greenhouse gas (GHG) implications of these types of operations. For example, the Energy Independence and Security Act of 2007 sets threshold GHG levels for qualifying renewable fuels relative to conventional petroleum-based fuels. The EPA is mandated to conduct full life-cycle emission assessments for alternative fuel production processes. Similarly, the European Union developed a goal of a 20 percent reduction in GHG emissions concurrent with a 20 percent increase in renewable energy generation by 2020. In California, a timber company was recently sued for inadequately considering GHG implications of harvesting plans (Winship 2011). Ultimately the suit was dismissed although it highlights the need to have scientific assessments to quantify GHG implications of resource use.

There have been many studies examining the life-cycle impacts of forest production. Table 1 summarizes a sample. The Consortium on Research for Renewable Industrial Materials (CORRIM) developed life-cycle assessment metrics for biomass-based products (pulpwood and sawlogs) in the U.S. (Puettman and others 2010). For wood utilization in the southeast U.S. CORRIM considered a system boundary that encompassed stand establishment through harvesting and loading onto trucks. They modeled two harvesting systems—a small feller-buncher and grapple skidder working in thinning and a larger feller-buncher with a skidder working in final sawlog harvests. Athanassiadis (2000) performed similar calculations for cut-to-length harvesting in Sweden and Klvac and others (2003) evaluated cut-to-length operations in Ireland. These studies found CO_2 emission rates ranging from 9.7 to 15.0 kg/Mg_{dry} for felling and moving biomass from stump to truck. Trucking likely consumes as much energy as felling and skidding. Johnson and others (2005) estimated transport emissions for hauling forest products in the US South as 19.7 kg/Mg_{dry}.

Conventional forest harvesting systems typically focus on collecting and moving merchantable roundwood material. In cut-to-length harvesting biomass material is left in the woods and only solid logs are carried to roadside. Southern whole-tree harvesting systems may remove the stem with limbs and tops to roadside, but production effort is focused on recovering the stem. By contrast, biomass harvesting

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systems will add some activities to collect and transport the smaller components such as limbs and tops or even smaller typically non-merchantable trees. Because these materials have relatively low volume in each piece that is handled there is tendency for productivity to drop and the energy input per unit of volume output to increase. The objective of this paper is to review the types of forest operations that might be employed to recover woody biomass in southern forests specifically for energy and to compare estimated CO_2 emission values with conventional forest operations.

SOUTHERN WOODY BIOMASS HARVESTING SYSTEMS

Woody biomass in the South can come from four primary sources of material: logging residues, thinnings, restoration treatments, or purpose-grown wood. Each of these sources represents a unique combination of operating conditions, piece sizes, and potential energy applications. The systems that are evolving to operate efficiently involve highly specialized machines matched to the stand and materials.

LOGGING RESIDUES

Many studies have documented logging residues left behind after conventional product harvest. Bentley and Johnson (2008) measured harvest recovery factors on 80 active logging operations in Alabama for example. They found that about 12 percent of total softwood harvest volume was left as logging residue. Applying that value to annual harvest rates suggests that about 3.1M Mg_{dry} of softwood logging residues are generated each year in Alabama. There are similar studies for other southern states. The residue material is often the limbs and tops along with other non-merchantable material such as small trees or cull logs. With typical whole-tree logging systems the residues have been dragged on the ground, pushed into piles, driven over, and otherwise roughly handled. Because of this logging residues will often carry high ash content and are generally only useful for direct combustion as hogfuel.

The challenge is to collect logging residues in a cost-effective manner. Most southern harvesting systems are whole-tree operations that fell trees, drag them to roadside, and then process out the merchantable volume leaving limbs and tops in piles at roadside. Some operations will drag the residues back into the woods and scatter them while others will leave residues piles for later disposal or burning. A logging residue recovery system will either chip or grind material at roadside to reduce material to a form that improves truck transport and handling. If chipping occurs after logging is completed (cold chipping) then the residue recovery operation would likely use a large chipper or grinder with a separate loader. Cold chipping production is limited by the capacity of the chipper. Chipping concurrently with the logging operation (hot chipping) is limited by the production rate of residues and large chippers are often underutilized. One solution for hot chipping is to use a smaller less expensive chipper to better match residue production and improve machine utilization.

Westbrook and others (2007) compared a logging crew with and without residue recovery while clearcutting a 33-year-old pine plantation. The conventional operation recovered about 150 Mg/ha of sawlogs and only used about 2.7 l of fuel/Mg_{dry}. They tested residue recovery by adding a 260-hp chipper at the landing to hot chip residues. Residue recovery added 8.5 Mg/ha of chips with an additional 2.9 l/Mg_{dry} fuel consumption to operate the chipper. A final treatment added additional felling and skidding to collect even more of unmerchantable stand volume. Residue volume increased to 24.2 Mg/ha (about 15 percent of total stand volume). Fuel consumption per unit chip output in the most intensive recovery system was 5.6 l/Mg. The small chipper was well-matched to the production rate of residues in this system.

Logging residues are considered the “low-hanging” fruit of woody biomass feedstocks. Residues are generally available with little or no cost for felling or skidding because they are a by-product of the logging operation. In some management plans residue utilization actually creates savings on site preparation by avoiding additional clearing or pile burning. There have been concerns raised however about nutrient removals, erosion, and impacts on site productivity. Westbrook and others (2007) also analyzed chip samples in the study described above and estimated that in the most intensively utilized treatment an additional 27.0 kg/ha N, 2.8 kg/ha P, and 8.0 kg/ha K were removed.

BIOMASS THINNING

Southern forests are commonly prescribed thinning treatments to reduce competition and stress, address disease or insect outbreaks, and to maximize rotation productivity. For silvicultural reasons, there is a window of opportunity with earlier thinning favored to maximize biological response. Later thinning however improves the economics of the operation by getting higher product value and lower operational costs per acre. Generally the timing of thinning is determined by the combination of market and stand conditions. Thus a market for woody biomass in energy products may affect southern thinning opportunities by providing more economic value in smaller trees.

Munsell and Fox (2010) modeled various management scenarios for loblolly pine plantations. The analysis considered variation in planting density, management intensity, product recovery options and site classification. They concluded that an intensive management regime (fertilization, competition control) with integrated product recovery over a 24-year rotation was the most financially attractive scenario. Thinning entries were generated whenever the stand reached a basal area of 30 m^2/ha. Harvest volumes were segregated to the highest product values with a mix of biomass, pulp and sawlog outputs. They also modeled an energy-only management regime of

8-year rotations planted at 1835 trees/ha. With a biomass stumpage price of about \$11.50/Mg_{green} landowners would breakeven between the integrated or energy-only management regimes. The conclusion of such analysis shows that given a market for energy products, forest landowners would have new options for treatments, product recovery and financial return.

The general pine thinning model has even been refined to optimize production of multiple products. In this scheme, rows of open-pollinated pines (biomass crop) are alternated with rows of genetically selected pine for sawlog production (Arborgen 2009). This trademarked management system optimizes economic inputs of planting stock, fertilization and vegetation control.

Conventional mechanized thinning systems are well-adapted to biomass thinning treatments. Smaller wheeled feller-bunchers equipped with sawheads are the most common felling machine. Grapple skidders efficiently move piles of wood to roadside. This system would have energy input like the southern thinning operation modeled by the CORRIM study (approximately 4.8 l/Mg). A simple variation would add roadside processing to convert the feedstock to chips prior to transport.

RESTORATION TREATMENTS

Biomass markets may give forest landowners new options for vegetation removal to accomplish objectives like invasives control, fuel reduction, or stocking manipulation. Traditionally such treatments generate unmerchantable material that has to be shredded or burned for disposal. Mulching machines are commonly used to clear vegetation up to about 15 cm diameter. Several manufacturers have developed modified versions that can collect the chopped biomass. One manufacturer's design cuts and chops and then blows the chips into a trailer for transport to roadside. Two alternative designs collect the chopped material in baling systems that create dense round bales like agricultural material.

Klepac and Rummer (2010) evaluated a baling machine harvesting understory biomass from a 28-year-old pine plantation in south Georgia. The baler cut and baled vegetation between planting rows including a mix of understory shrubs (i.e., wax myrtle, gallberry, saw palmetto, red maple). Pre-treatment sampling estimated 12.6 Mg/ha of total understory aboveground biomass. About one-third of the total biomass was recovered in bales with the remainder left as uncut stems, stumps and down material. At a production rate of 4.9 Mg/hr the net fuel input for the baler was 2.7 l/Mg_{dry} and bale forwarding added 1.4 l/Mg for a total of 4.1 l/Mg. Because the baler produces a very coarse material additional energy input may be necessary to re-chip the bales at the point of use.

Understory biomass can be available for zero or negative cost since its removal accomplishes other valuable management objectives. An understory treatment may be used in lieu of burning to reduce fuels. It may also be used to reduce vegetative competition or improve herbaceous composition for wildlife. The value of these treatments should be combined with the value of the removed biomass in determining economic feasibility of this type of biomass recovery.

PURPOSE-GROWN ENERGYWOOD

Biomass assessments like the Billion Ton report (Perlack and others 2005) suggest that potential energy demands could exceed available biomass from existing sources such as thinning, logging residues, and fuelwood. Depending on how market demand develops there may be opportunities for purpose-grown energywood. There are many options for short-rotation woody crop (SRWC) plantations in the South including eucalypts, hybrid poplar, willow and pine (Schuler and others 2009). The selection of the most appropriate species is affected by many factors and there are still many uncertainties about how and where short rotation woody crops could be deployed. A generic model however could be a hardwood, grown on 3-year coppiced rotations. The Oak Ridge Energy Crop County Level database (Graham and others 1997) estimates woody crop growth rates in the South of about 10 Mg_{dry}/ha/yr.

Harvesting technology for coppicing SRWC plantations is still in its infancy. The most developed approach is a modified forage harvester that cuts and chips into a shuttle trailer system (Volk and others 2010). Recent tests have demonstrated a production rate of up to 0.7 ha per hour with willow stems up to 10 cm in diameter. The development team is working to improve performance for both willow and hybrid poplar. A current estimate of energy input would be about 3 l/Mg for the cut-and-chip operation. To get the chips to roadside would require an additional 1.5 l/Mg for a chip forwarding system.

There are other forms of purpose-grown wood that may be applicable for the South. For example, Scott and Tiarks (2008) describe a trial of direct-seeded pine grown between rows in a conventional pine plantation. The energy wood planting harvested at age 5 produced an additional 10 Mg/ha without reducing conventional plantation yield at final harvest. Like coppice systems however production harvesting technology is not fully developed. Another concept is the "flex stand."

SUMMARY

The development of woody biomass markets will change management practices in southern forests. The option to remove material that has previously been unmerchantable will allow forest managers more flexibility in prescriptions. Early thinnings may be more economically viable, initial planting density and intermediate treatments can be reconsidered. At the extreme, purpose-grown energywood plantations may be developed to meet demand for energy products. Biomass markets could return additional value to landowners. By adding additional value to management, biomass markets could help maintain southern forests.

This review of biomass production studies suggests that direct energy inputs for producing woody biomass are not greatly different from conventional forest products harvesting, ranging from about 4 to 6 l/Mg (Table 2). Logging residues are the least energy-intensive feedstock when the residues are available at roadside. Chipping is currently energy-intensive and requires about as much energy input as felling and skidding combined. Stump-to-truck energy inputs will be about half of the total delivered energy input of woody biomass feedstocks. Efforts to reduce GHG emissions from biomass utilization must address transportation efficiencies as well as in-woods operations.

Finally, forest operations are evolving. Off-highway equipment engineers are finding new ways to operate more efficiently and these developments are beginning to show up in forest machinery. Improved operator interface systems, more efficient hydraulics, and new off-road engine designs will reduce fuel use per unit of work. Diesel-electric hybrids have even been introduced for construction applications. The basic operational technology of handling wood is also being reconsidered. Purpose-grown wood, with smaller piece size, offers new opportunities for alternative methods of cutting and handling. Balers, swath cutters and modified agricultural machines may find new applications in forest management.

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Table 1—Direct energy input and CO_2 emissions for production forest operations (per Mg_{dry})

Reference	Region	Harvesting system	Fuel Use (l/Mg)	CO_2 output (kg/Mg)
Johnson and others (2005)	Southeast U.S.	Thinning with small feller-buncher/skidder	4.8	13.0
Johnson and others (2005)	Southeast U.S.	Final harvest large feller-buncher/skidder	5.2	14.0
Johnson and others (2005)	Southeast U.S.	Truck transportation	7.3	19.7
Athanassiadis (2000)	Sweden	Cut-to-length harvester/forwarder	3.6	9.7
Klvac and others (2003)	Ireland	Cut-to-length harvester/forwarder	5.7	15.4

Table 2—Direct energy input and CO_2 emissions for woody biomass harvesting (per Mg_{dry})

Feedstock	Reference	Harvesting system	Fuel use (l/Mg)	CO_2 output (kg/Mg)
Logging residues	Westbrook and others (2007)	Chipping only roadside residues	2.7	7.3
		Felling, skidding and chipping residuals	5.6	15.1
Pine thinning	Johnson and others (2005)	Wheeled feller-buncher, grapple skidder	4.8	13.0
Understory	Klepac and Rummer (2010)	Baling harvester with forwarder	4.1	11.1
Short rotation	Volk and others (2010)	Coppice harvesting	4.5	12.2