Square Bales of Woody Biomass for Improved Logistics

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Abstract: The majority of fuels reduction work is conducted by hand crews in the wildland-urban interface and near in-forest recreation/administrative assets. Today, most of the biomass is either piled for burning at some future time or is dragged to the roadside for chipping. In many districts, disposal of chipped or whole brush is costly. However, if the material could be densified into a form that makes it easily transportable, it may be directed to bioenergy firms distant from the project site. Engineering research led to the development of street-legal balers specifically designed to bale woody biomass and replace many of the tow-behind chippers used by agencies, tree service firms, and forest management contractors today. A moment-method study of an engineering prototype was conducted to determine how baler and ground crew unit operations contributed to total cycle time. Although total productivity of more than one bale per hour was adequate to support hand-crews, improvements to ground operations and loader operator strategies resulted in a quick 30% production increase.

Keywords: Woody biomass, baler, biofuel, thermochemical, biochemical, feedstock, forest operations

Introduction:

Woody biomass is a core element of our nation's strategy to replace imported oil and natural gas with renewable resources. Approximately 200 million tons of wood waste is generated by the forest products and paper industries, most of which is being used for co-products or energy. Additionally, more than one hundred million tons of woody biomass is available, but not currently used, per year from forest management, wildfire fire protection, and urban woody debris (Perlack et al. 2005). As forested landscapes in rural and urban areas are more intensively managed in the future, the amount of available woody biomass will increase.

Recent national, regional, and local emphasis on community wildfire protection in the wildland-urban intermix is dramatically increasing the amount of woody biomass available from urban and suburban landscapes. Perlack et al. estimated this component to be 60 million tons per year. The challenge with urban/suburban sources is that they are small quantity per site, widely dispersed, and often long distances from bioenergy facilities or biomass power plants.

There are already thousands of firms of all sizes, including independent arborists and landscapers to the multinational waste management, tree service, and industrial forestry firms engaged in harvest and collection of woody biomass as a waste product of their daily work. As the demand for biomass feedstocks increases, market forces will stimulate change to better collect and handle woody biomass. The objective of our development effort has been to enable cost-effective collection and transport of woody biomass from these sources.

Today, the typical independent landscaper collects less than 0.5 tons (1,000 lb) (about a pick-up truck full) per day of grass, leaves, and woody trimmings. That material is typically dumped at a compost processor and a tipping fee is paid for the privilege. Arborist chips are frequently donated to horse stables, nurseries and compost facilities.

In the not-too-distant bio-economy the grass clippings and green leaves will likely be wet processed through local digesters into producer gas and other products. The woody material will be reprocessed into biorefinery feedstocks or consolidated for transport to industrial scale users. Only the debris and waste from these processes is likely to be available to local composters for conversion to mulch. However, the organic waste, char and other detritus of urban bioconversion facilities are likely to provide new and yet undefined feedstocks for compost and mulch producers.

At the other end of the spectrum of woody biomass producers are hog fuel contractors who process logging debris and land clearing biomass into fuel for combustion energy facilities. They may operate one or more 500-1000 kw (350-750 hp) grinders, screens, truck loaders and a fleet of dedicated chip vans. One processor may produce as much as 300 – 400 tons per day and deliver the biomass to users within 100 km.

The primary objectives for in-field grinding is to reduce the bulk volume and thus increase the transport density. Grinding generally increases the bulk density of woody biomass (at field moisture content) from about 50 kg/m^3 (3 lb/ft^3) to approximately 170 kg/m^3 (10 lb/ft^3). In-field grinding of woody biomass into chips or hog fuel is a dusty, energy intensive process that yields a bulk material for hauling and handling with specialized equipment.

The combination of low bulk density, high energy requirements, and need for specialized hauling equipment has stimulated recurring searches for better biomass handling methods. A common element has been efforts to adapt agricultural baling to woody biomass. If technically achievable, baling would offer the advantages of high transport density, easy materials handling with proven hay loaders, stackers and processors, and low cost transport on conventional flatbed trucks and in dry vans.

Literature Review:

Dr. William Stuart at Virginia Polytechnic University was among the early U.S. developers of forest biomass balers (Jolley 1977; Schiess and Yonaka 1982). His baler was brought to the University of Washington in 1982 for testing by Dr. Peter Schiess (Schiess and Stuart 1983). Concurrently with Stuart’s development, James Fridley and Dr. Thomas Burkhardt at Michigan State University worked to adapt round agricultural balers to handle forest biomass (Fridley and Burkhardt 1984) . Unfortunately, both projects stopped when the price of oil began to fall and public interest in biomass energy waned. However, much of the flurry of research was documented in conference proceedings such as *Energy from Forest Biomass* (Sturos 1982).

Outside of the U.S. there were projects in Canada (Guimier 1985) and Europe (Danielsson, Marks, and Sall 1977). Guimier compared the potential of five existing systems (round agricultural baler, square baler, garbage truck, garbage compactor, and cotton module builder). His team found that square bales of the type made by recycling balers and large cotton modules showed the most promise.

Renewed interest in woody biomass as a fuel and feedstock during the 1990s stimulated a number of development programs around the globe. Baling, chopping, and intermodal bulk hauling are being concurrently developed, with each being an optimal solution for particular circumstances. Chopping and intermodal bulk hauling are particularly attractive for very short haul distances. However, once the haul distance exceeds about 60 km (35 miles), the need for high bulk density solutions becomes apparent.

Baling woody biomass to achieve high bulk density is being pursued by three technical approaches, again each approach being preferred for particular situations. Timberjack, now John Deere Forestry, commercialized a biomass bundling system was developed in Finland to enable forest materials to be handled similar to logs. Savoie's team in Canada has been developing round baling for woody biomass crops such as willow (Savoie et al. 2006), and more recently with SuperTrak has adapted the round bale technology for use in forestlands to cut and collect understory saplings and brush. Round bales can be collected, transported and handled like round bales of hay. The third technology, square bales is the subject of this paper. Square bales of woody biomass are optimal for high density long distance transport, large volume storage and drying in "hay stacks," and for collection of biomass from highly dispersed piles or windrows. The Forest Concepts square bale technology is particularly appropriate to replace tow-behind chippers in urban and suburban environments where neither of the other approaches are practical.

Forest Concepts' Square Baler Technology

The engineering design parameters and development of the Forest Concepts baler technology have been previously described in other conference papers. The logic for handling woody biomass in large square bales was presented in 2006 (Dooley et al. 2006). Design factors including functional requirements and constraints were described in 2007 (Lanning et al. 2007). Testing and evaluation of the baler functions were presented at the Council on Forest Engineering conference in 2008 (Dooley et al. 2008).

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Figures 1a, 1b. Computer model of self-loader trailer with prototype baler and specially designed grapple as engineered in November 2007.

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Figures 2a, 2b. Fully assembled self-loader trailer with prototype baler and grapple during initial testing in April 2008.

Figures 3. Field trial of prototype biomass baler at BRC Inc. yard waste facility in Auburn, WA.

The photos above show how the loader picks up biomass from the ground and places it into a top-loading infeed section. During bale compression the two infeed grates close to pack biomass into the chamber and form the top surface of the baler. Completed bales are ejected out the curb side of the baler to facilitate tying and lifting by the loader. Finished bales can be lifted onto companion haul trailers or trucks, or set on the roadside for later collection.

Figures 4. Bales of woody biomass produced by the prototype and research balers.

We conducted bale processing experiments with biomass processors in Washington and Oregon.

- Rainier Wood Recyclers – Auburn, WA – 6 miles
- Cedar Grove Compost – Maple Valley, WA – 19 miles
- Grays Harbor Paper and Cogeneration – Hoquiam, WA – 94 miles
- Vaagen Brothers Lumber / Avista Power – Colville, WA – 353 miles
- Biomass One – Medford, OR – 426 miles

a b c

Figures 5a, 5b, 5c. Woody biomass bales being processed by cooperators. a) Vaagen Brothers processing with Peterson horizontal axis grinder, b) Rainier Wood Recyclers dropping onto infeed conveyor to large fixed Universal Grinder, c) Grays Harbor Paper & Cogeneration feeding into large tub grinder.

All materials for the field trials were baled and then palletized for handling and shipment. Depending on the type of material in each bale, the bales were either stacked two or three high for trucking. All trucks were tarped to prevent shedding of small particles onto the roadway. The five biomass users in Washington and Oregon who processed prototype bales all commented that baled biomass would be easier and less costly to handle and process than bulk biomass. Although all of our test partners had onsite grinding, a concern from users was about how baled material would be priced since the cost of grinding would be transferred from the biomass collector to the user.

Baler Productivity Study – City of Auburn Field Trial

On February 26 – 27, 2009 Forest Concepts conducted a two-day field trial and demonstration in cooperation with the City of Auburn, Washington. The objective of the field trial was to evaluate baling of woody biomass as an alternative to chipping. The current practice of chipping provides chip mulch for use on City parks and landscapes, as well as a source of biomass to local compost producers. A premise of the field trial was that baled biomass could be collected and consolidated just like other recyclables and sold to cogeneration and other bioenergy facilities in the region.

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Figures 6a, 6b, 6c. a) Urban forest and road maintenance woody biomass was piled by cooperator, **b)** slashing and baling by Forest Concepts, and **c)** resulting baled woody biomass.

The Auburn parks and roads maintenance crews collected tree trimmings for approximately three weeks prior to the trial and dumped them on a play field at the GSA Park on “C” Street in Auburn, WA. Several additional truckloads were delivered during the trial and dumped in space that opened up as earlier piles were baled. The Forest Concepts biomass baler produced bales that were approximately 812x1220x1625 mm (32x48x64 inches) in size that weighed approximately 600 kg (1,300 pounds). The entire field of woody biomass provided by the City of Auburn resulted in nine bales which were neatly stacked next to the road. Maximum productivity was approximately 45 minutes per bale.

Although the time per bale was better than our design objective of one hour per bale for tree service and hand thinning crews, we wanted to determine the potential for productivity improvement. On the second day of the field trial, we conducted a "moment method" study to determine how much time each unit operation contributed to the total time to produce bales. We expected the results of our time-motion study to provide insights into how to modify the ground operations, loader/baler operator training, and/or the design of the baler itself to improve productivity.

Method:

The moment method employs an adjustable timer that makes a beeping sound on predetermined intervals. While an observer watches the operation, each time the timer beeps a tally is made of which unit operation is happening at that "moment." The process continues for a complete bale cycle, or a complete "flake" cycle which is one complete cycle of the platen. The study reported here includes observation of eight flake cycles, with the time interval being 10 seconds per observation.

The general process for baling biomass with the Forest Concepts baler is for the loader/baler operator to pick up a bunch of brush from the ground using the grapple and drop the brush into the infeed hopper of the baler. Several grapple loads may be needed to fill the hopper. Once the hopper is full to capacity, the baler automatically cycles through closing the infeed grates, pressing the material into the bale chamber to form a flake, and then retracting to the full open position ready for the next load of biomass. It typically takes 5-7 compression cycles to make a complete bale. Once the bale is fully formed it is tied off and ejected to the curb side of the baler.

For our purposes, we divided the unit operations into:

- Saw maintenance delay – Ground crew has the responsibility to prepare the brush or slash for baling. That entails using a chainsaw to precut long, large diameter pieces to fit into the baler chamber. The chainsaw operator occasionally became limiting when the grapple loader operator could not handle material because the chain saw ground operator is clearing a jam in the chain, the chain runs off the bar, or other work stoppage.
- Slashing grapple grip – The maximum length for materials larger than 50 mm diameter is 1.2 m (48 inches) in order for them to fit into the hopper. Thus, the ground person must use a chainsaw to cut overlength materials. The best time to do the slashing is at the time the brush is brought to roadside. However, long pieces that end up in a full grapple load must be trimmed. This operation is recorded when the grapple/loader operator is waiting while the ground person slashes long pieces.
- Getting grapple load – The grapple/loader operator must open the grapple, position it onto a pile of brush and close the grapple. Many times, the operator will bunch and move material to accumulate a full grapple load.
- Rebunching/drop and rebunch – when the operator is focuses more on bunching, piling and building grapple loads than getting a load to place into the baler, this time is charged.

- Loading – once the grapple is closed on a bunch of brush, the loading time is the loader movement cycle from the ground to the hopper, dropping materials into the hopper, and returning the grapple to the pick-up point.
- Rejiggering material in baler – On occasion the loader operator will use a closed grapple to press material down into the hopper or baling chamber in order to increase the load, pull straggling long sticks into the hopper, or compact large masses of fine branches.
- Grates closing – Once the hopper is fully charged with biomass, then the operator triggers the auto-baling cycle which sequences through closing the grates, cycling the platen cylinder and then opening the grates. This operation is marked if the grapple-loader operator is waiting for the grates closing portion of the baling cycle.
- Grates opening – Once the platen returns to the fully retracted position, the grates that form the hopper open. This operation is marked if the grapple-loader operator is waiting for the grates opening portion of the baling cycle. Typically, the operator will have prepositioned a full grapple load above the hopper while waiting for the grates to open.
- Grate jams with material clearing – Occasionally, the hopper grates may jam on a long piece of branch wood.
- Platen Cycling – When the operator and the ground person run out of other tasks to do while the baler platen is cycling, then the baler platen cycle time becomes limiting.
- Maintenance / breakdown – Baler operator leaves his/her seat to conduct maintenance, add fuel, or other work stoppage due to the baler, not the ground crew or chainsaw.

Results and Discussion:

The table below shows the allocation of time within each flake cycle. The ground crew person changed at lunch break after the first five flakes were completed. Also, there are obvious work-method improvements during the study. Of particular note is that the rebunching of material on the ground by the loader operator was stopped after the morning data was reviewed during the lunch break.

Table 1. Percentage total time for each flake by unit operation.

		Percentage of Time in Flake Cycle Event							
	Operation	Flake 1	Flake 2	Flake 3	Flake 4	Flake 5	Flake 6	Flake 7	Flake 8
	Ground Operator	Pers A	Pers A	Pers A	Pers A	Pers A	Pers B	Pers B	Pers B
ground	saw maintenance delay			13%					
ground	slashing grapple grip	7%	19%	16%	19%	10%	21%	26%	19%
Grapple	getting grapple load	7%	8%	13%	9%	7%	18%	8%	12%
Grapple	rebunching/drop& rebunch	3%	17%	19%	13%	17%	0%	0%	5%
Grapple	Loading	7%	7%	9%	13%	10%	13%	10%	10%
Grapple	rejiggering material in baler	13%	12%	4%	8%	15%	8%	10%	14%
Baler	Grates closing	3%	3%	1%	1%	0%	0%	3%	2%
Baler	Grates opening	3%	0%	1%	8%	2%	0%	3%	2%
Baler	Grate jams with material clearing		7%						
Baler	platen cycling	56%	27%	22%	23%	39%	41%	41%	36%
Baler	maintenance/breakdown				6%				
Total	Minutes	5.00	9.83	11.33	13.00	6.83	6.50	6.50	7.00

The moment method study was intended to inform our baler engineering program and to begin to understand best operation methods for eventual training of baler users. The data presented from this study demonstrates the utility of moment method techniques to obtain objective allocation of time across a set of interacting unit operations. Key findings from this study include:

Baler engineering findings:

- Grapple opening and closing cycle times are not limiting factors with the hydraulic cylinders and flows of the current design.
- Platen cycling is the dominant source of total cycle time, representing approximately 40% of total operating time. This was expected for this particular 40 kw (30 hp) baler configuration that was designed for low daily volumes of hand crews. The data enable our engineers to estimate the total productivity gains to be obtained from higher power engines and higher flows to the platen cylinders. We would expect that if we cut the platen cycle time in half that other operations may become limiting.

Operational findings:

- As noted earlier, we quickly quantified the lost production when the loader operator was occupied moving biomass around on the ground to gather bunches or repiling. After lunch, the ground person was instructed to hand pile materials where practical into semi-oriented full grapple loads. This and other improvements reduced the flake time from about 10-11 minutes in the morning to 6.5-7 minutes in the afternoon. Debriefing a week after the field trial identified a number of other operational changes that may save additional time.
- The woody biomass used in this study had been dumped from dump trucks onto the site. We suspect that the dumping served to tangle materials more than would be expected from hand crews that were trained to prep materials for baling.
- The materials for this study were also loaded into the dump trucks at the collection sites without any regard to the subsequent baling operation. Thus, the crews that cut the

material did not make any attempt to cut large diameter stems and branches to preferred lengths.

Summary and Conclusions:

Forest Concepts developed an engineering prototype of a woody biomass baler optimized to replace tow-behind chippers in support of forest operations crews, fuels reduction projects, and urban tree service operations. The prototype demonstrated sufficient productivity to bale as much or more material than is typically chipped by hand crews.

In an effort to better understand how each unit operation of the baler and the two-person crew contribute to total cycle time, we conducted a moment method study of eight platen or flake cycles. The moment method data quickly identified ground operations improvements and grapple/loader operator methods improvements that reduced cycle time by an initial 30% in the course of the demonstration and field trial.

Data on the platen cycle times as a function of total flake cycle activities may inform engineering decisions about the size of engines and hydraulic systems that would maximize total productivity.

The moment method of characterizing the contribution of time for interconnected unit operations proved valuable to the designers of baling systems for woody biomass.

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