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Large Rectangular Bales for Woody Biomass

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Abstract. *Woody biomass from wildfire prevention and forest health improvement projects is a significant source of feedstock for bio refineries, combustion energy facilities and other value-added uses. Baling into large rectangular bales offers increased bulk density and easier handling for local and long-distance transportation. By preserving large piece sizes, value potential is maximized. We conducted a problem analysis across the Western US that included surveys, interviews and site visits. Subsequent technology analyses and ideation resulted in a conclusion that prefers large rectangular bales as the handling unit.*

Keywords. biomass, woody, bale, energy, wildland, forest

Introduction

Woody biomass is a core element of our nation's strategy to replace imported oil and natural gas with renewable resources. The Western Governors' Association January 2006 task force report concludes that 35% of the biomass available for power generation in the West must come from urban areas.

Low grade logs and wood strands are the primary raw materials for composite lumber and engineered panel products. The demand for the lowest grade of random veneer has doubled in the past year, mostly due to increased demand from panel and laminated veneer lumber producers.

The challenge facing potential users who gaze longingly at urban biomass sources is how to economically recover and transport the material from residential neighborhoods, urban centers and suburban landscapes to distant users. That is where we at Forest Concepts come in. We are systems, equipment, technology, and business development specialists with the expertise to create a biomass recovery and logistics system that works. Forest Concepts is working under a federal contract from the USDA CSREES SBIR program to develop better methods to collect and transport woody biomass collected from small-scale fuels reduction projects (ranging from residential lots to 20 acre parcels) in the true wildland-urban intermix zone (WUI). Our specific objective is to enable more of the material to be diverted to value-added uses including energy, biorefineries, and engineered wood products.

During 2005, we completed a Phase I study of the current situation in the western U.S. During Phase I we conducted two surveys and a number of site visits with community wildfire protection organizations in Washington, Oregon and California. We gratefully acknowledge the time and consideration of our survey respondents and hosts.

Elements of the solution

We believe that there are both products and systems components to any solution for the problem of woody biomass disposal through value-added use. Elements of a more complete solution include:

- Baling to replace chipping
- Smallwood unitizing to reduce cost and preserve value
- Beneficiation of chips and comminuted wood to improve value
- Woody biomass marketing and logistics support to match materials with users
- Central woodyard and reload center to minimize first-mile costs

Of all the potential transport forms, only baling and smallwood unitizing offer viable methods to prepare woody biomass for long distance transport via highway and rail. Longer-term developments include beneficiation of whole-plant chips to separate valuable fractions for engineered wood products, paper, and biorefinery markets. Business system developments that may further improve utilization include creation of market systems to connect biomass sources with customers, and central woodyard reloading centers.

Neither of these two business systems concepts are novel. Others, including the USDA Forest Products Laboratory, have proposed them as part of comprehensive biomass utilization solutions (Dramm, Jackson et al. 2002).

Baling

Once we identified baling as a preferred solution, we embarked on a two-prong proof-of-concept effort. We conducted an exhaustive review of previous woody biomass baling research that was conducted in the 1975 – 1983 era. We collected old published and unpublished research reports, data and photographs from persons who were directly involved in previous projects. We interviewed participants in the earlier work to the extent we could locate them. Interviewees included Dr. Awatif Hassan who worked on baling in Canada and North Carolina, Dr. James Fridley who worked on round woody balers at Michigan Stated while he was a graduate students, Dr. Peter Schiess who conducted West Coast trials of the VPI-Stuart baler, and Rich Lane who was a graduate student under Stuart during field testing on the East Coast. The second prong was to conduct small-scale baling experiments to validate critical assumptions.

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 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 et al. 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.

The following set of photographs are from Dr. Peter Schiess' experiments with the VPI baler.

Figure 1. Bales of branches and forest residuals. (P. Schiess photo)

Figure 2a, 2b. VIP prototype baler overview and baler infeed gripper pushing set of smallwood stems into baler. Baler shears excess material as the plunger strokes. (P. Schiess photos)

At the end of the University of Washington project, the team developed a concept sketch for a second generation baler as shown below. Unfortunately, the USDA Forest Service discontinued funding of the project before it could be designed and built. However, its concept and specifications will provide a good starting point for our own Phase II development.

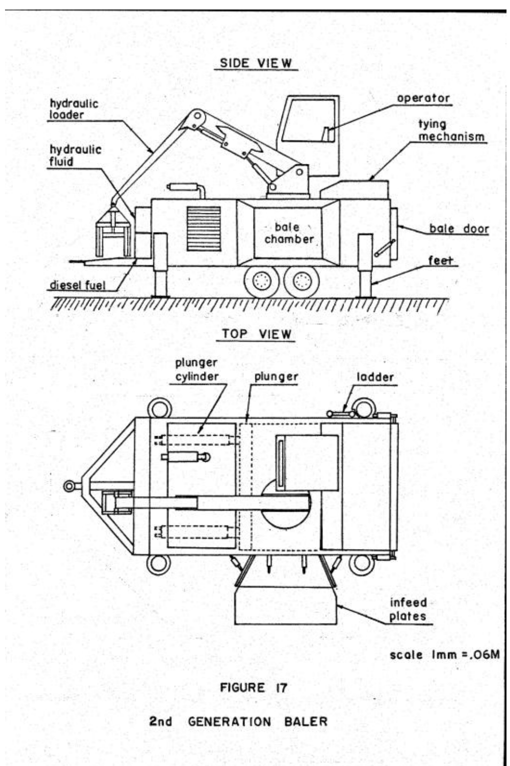

Figure 3. Concept sketch for VPI second generation baler. (P. Schiess)

Even more relevant to our work, Schiess also transported bulk woody biomass from the University of Washington's Charles Pack Research Forest to a recycling center in Tacoma, WA and baled it in a conventional recycling baler. The recycling baler (American Hoist and Derrick Company model HRB SWC-3) produced a contact pressure of 2.8 mPa (406 psi). Resulting bale density ranged from 505 kg/m^3 (31 lb/ft^3) for alder to 518 kg/m^3 (32 lb/ft^3) for fir-pine bales.

The SWC-3 baler produced pressures much higher than we anticipate using in our Phase II studies, primarily because we hope to limit our machine size to make it appropriate for portable use in residential areas. We know that we can maximize the payload for transport if we achieve bale density equal to half of what they achieved in the high-pressure stationary baler test. Thus, we are encouraged that we will be able to design or adapt existing recycling balers to handle woody biomass and still be appropriately sized for the urban/suburban context of our application.

Schiess developed a regression equation that will be useful for optimizing the bale density vs. power requirement relationship. For coniferous material the relationship is:

$$Y = 261 + 0.150(X_1)$$

Where:

Y = bale density in kg/m^3

X_1 = compaction pressure in kPa

(Note: Schiess changed units in this equation from those used in the rest of his report)

From this equation, we can model alternative baler designs. For example, if our objective is to produce a bale density of 270 kg/m^3 (17.0 lb/ft^3), we would need a contact pressure of approximately 60 kPa (8.7 psi). This result is approximately one-third of the pressure we used in our experiments during Phase I where we had a 15 kw power source. Thus, we are confident that we will be able to achieve sufficient baling pressures with relatively low power consumption.

Hassan (Hassan 1976) explored compression as a method to increase the transport density of green pine chips. At a compression pressure of 0.3Mpa (40 psi) she was able to double the uncompressed bulk density and achieved a density of more than 500 kg/m^3 (30.0 lb/ft^3). This is approximately 60 percent of the density of solid green wood, and more than sufficient to maximize over-highway payloads. Like many others, Hassan could not devise an economical packaging method for chipped materials. The density could only be maintained under continuous high-force compression.

Our preferred method for achieving acceptable transport densities, and creating easy-to-handle packages is to bale unprocessed or minimally processed biomass. The Royal College of Forestry in Sweden was among the first to conduct disciplined study of baling (Danielsson, Marks et al. 1977). Their laboratory studies with a high pressure system (1000 kPa, 150 psi) were able to compress unprocessed logging slash to bunk densities of 250 – 400 kg/m^3 (15.5 – 25.0 lb/ft^3).

Our own tests with a baler producing 185 kPa (27.7 psi) were able to bale green brush trimmings and dead bitterbrush from a fuels reduction site to approximately 240 kg/m^3 (15.0 lb/ft^3). Thus, if our Phase II field studies are conducted with higher compression balers, then Danielsson teaches us that we might be able to substantially increase the bulk density.

Schiess and Stuart confirmed observations by others that baled biomass does not risk spontaneous combustion. They monitored internal bale temperature with thermocouples. They reported that while chip and flailed biomass bales recorded maximum internal temperatures of 40-45^o C, the alder and conifer unprocessed material bales “did not exhibit a significant rise in average internal temperature.” (Schiess and Yonaka 1982, p.54). While the baled material temperature measurements by Fridley, Schiess and ourselves provide confidence that spontaneous combustion will not be a problem we will track bale temperatures during the course of our Phase II field studies.

Our USDA SBIR Phase II proposal contemplates construction of a horizontal axis, rectangular baler specifically sized for use in urban and suburban landscapes. Eventually, larger off-road versions may be developed for commercial sale.

Baling Experiments

We conducted two baling experiments to validate critical assumptions about our ability to bale and preserve value of biomass typical of fuel reduction projects. For the first experiment, we collected bitterbrush from a fuel reduction project in eastern Washington and brought it back to our shop. At our shop we placed the bulky shrubs into our small baler and compressed the mass into a bale as shown below.

Figure 4. Seven kilogram (15 lb) bale of bitterbrush in the front and similar mass of bulk bitterbrush in the back. Volume reduction is approximately 5:1.

We expected that the exceptionally woody and springy bitterbrush branches would resist baling. However, we found that the bale was easy to form and held its shape as the compression plate was released.

The next experiment involved baling landscape trimmings in our big recycling baler to make a 200 kg bale. We collected a truckload of loose *Photinia* branches and stems from a yard maintenance project and brought them back to our shop. The material included stems up to 3.5 cm diameter and of various lengths. We used a limb loper to shorten very long branches, but otherwise did not cut up the biomass.

a. b. c.

Figure 5. Landscape brush truckload (a), bin full of loose material (b), and high density bale (c) of the bin full of material showing the degree of volume reduction.

We then took the baled woody biomass to Cedar Grove Compost Company and had them feed it into the greenwaste grinder as shown below. The operator reported that the bale fed very well and that he would not resist delivery of biomass in baled form.

Figure 6. Loader dropping biomass bale into the top of a tub grinder at Cedar Grove Compost.

The two baling trials that we conducted in Phase I helped us build confidence that we can bale woody biomass from fuel reduction projects, and the resulting bales can be easily processed at receiving facilities by tub grinders and similar fuel preparation machinery.

We used the *USFS SRS FORTS v4 Biomass Trucking Simulator* to estimate costs for current methods and our proposed improvements. A chipper and chip van system similar to current methods has a resulting cost of approximately $135 per bone dry unit (bdu) for biomass delivered to a destination 300km (200 miles) from the source. Baling and hauling on flatbed trucks has a projected cost of $71 per bdu, a savings of $64 per bdu, or 47 percent. If we consider the baling costs independent of hauling, we estimate that we can bale biomass for approximately $4.25 - $6.00 per ton. This again is about half of the cost of chipping.

Conclusions

The problem of biomass collection in the wildland-urban intermix is framed by project coordinators as disposal at the least cost. Revenue that reduces the cost is welcome, and the real bonus is if there is a positive story about how some of the biomass is used to create jobs and economic activity.

The system of biomass collection and disposal includes on-site handling, at-site processing (i.e. chipping), transportation, and at-destination handling/processing. Proposed solutions should reduce the cost of one or more of these steps. Our objective is to not only reduce the cost of collection and disposal, but also to preserve the opportunity for value-added utilization.

Our preferred solution would make two system changes. We would bale the bulky biomass at the roadside to reduce the cost of at-site processing, increase payloads during hauling, and preserve physical properties for more appropriate feedstock processing by the customers of baled biomass. The second change would be to provide wood-bunks that enable bundling of larger woody biomass (poles, firewood stock, etc.) to reduce the amount of hand labor required for loading and unloading trucks.

Acknowledgments

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