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Conceptual Specification of Large-Bale Forest Residuals Balers

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Introduction

A Task 2.2 objective of the Biomass Research and Development Initiative (BRDI) forest residues utilization research program is to conceptualize new versions of the Forest Concepts biomass baling technology that would be more optimal for use on large-scale logging operations in the western United States.

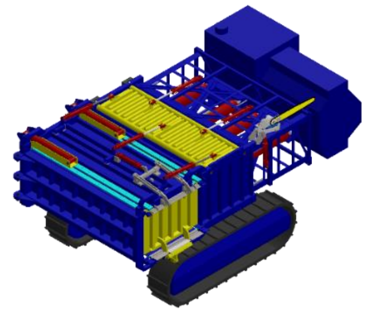

Figure 1. Concept rendering of track-mounted self-propelled large-bale baler for forest applications.

The new-concept biomass balers stem from recommendations of the forest engineering team at Humboldt State University to sort logging slash into poles that can be transported with conventional log trucks and into piles of finer tops and branches. While cost-effective collection and transport of small-diameter poles is well understood, handling and processing of branches and tops is problematic. Thus, the conventional forest management practice is to burn the piled fine woody biomass when weather conditions allow. Instead of burning the slash piles, the finer materials from slash including brush, tree tops and limbs can be ground into hog fuel on-site and transported in chip vans, or potentially can be baled by the envisioned new class of forestry balers for removal from the forest and processed into higher value products off-site.

Forest Concepts' earlier development of mobile woody biomass balers was focused on street-legal "chipper replacement" balers for use in urban and rural environs. That work is documented in a number of publications (Dooley, Lanning et al. 2008; Dooley, Lanning et al. 2009; Dooley, Lanning et al. 2011). The earlier work was also the subject of five United States Patents (798776, 7992491, 8205546, 8850970, and 8925451) directly related to baling of woody biomass. An objective of the BRDI project is to conceptualize new versions of the Forest Concepts baling technology that would be more optimal for use on large-scale logging operations in the western United States.

Fine forest residuals are in three levels of concentration across a harvest unit (aka logging site). Some of the material is distributed across the landscape where it fell during harvest operations. Other material is concentrated within the unit or along roadsides either as small piles or low windrows. Very large piles (aka haystacks) and windrows are common at large centralized landings and processing sites within an active harvest unit. In most situations, the dispersed fine branches are left on-site to protect the soil, provide habitat values and decay to release nutrients for the next generation of the forest. Excess biomass is gathered by the logging crew into in-unit piles, roadside debris, and large piles that contain woody biomass that must be removed from the forest.

Figures 2. Forest residuals dispersed across ground and collected into in-unit piles (left); along roadsides (center), and at central landings/processing sites (right).

Forest Concepts uses the Appreciative Design Method to guide the development and specification of new products, processes, and equipment (Dooley and Fridley 1996; Dooley and Fridley 1998; Dooley and Fridley 1998). The Appreciative Design Method merges elements of soft systems and social network analysis with traditional engineering design to establish functional requirements, operational objectives, and constraint sets that limit selection of design attributes and features.

We applied the design process to the problem of baling forest residuals during the first year of the BRDI project. We identified key stakeholders and documented what was important to them about biomass removal, forest operations, safety, logistics, and other criteria that resulted in a set of high-level requirements and specifications for forest residue balers (Dooley, Lanning et al. 2015). That work also resulted in design and specification of bale sizes, densities, and weights (Dooley 2015). The result of those analyses was that two substantially different baler “families” were needed to satisfy a bimodal distribution of forest operations constraints and centralized processing system constraints. A small-bale modular baler was defined and is detailed in a companion document (Dooley, Lanning et al. 2015). This document details the conceptual specification and design elements of a large-bale production machine most suitable for baling of concentrated woody biomass along roads and in piles.

This report is one in a series developed under the BRDI project to explore the viability of baling forest residual biomass and associated equipment systems. Related reports include:

1. Dooley, J. H., C. J. Lanning, et al. (2015). Conceptual specification of forest residue balers using the Appreciative Design Method. ASABE Paper No. 152189213. St. Joseph, MI, American Society of Agricultural and Biological Engineers.
2. Dooley, J. H. (2015). Specification of Bale Dimensions. Design of a Forest Residue Baler - BRDI Task 2.2. Auburn, WA, Forest Concepts, LLC**:** 8.
3. Dooley, J. H., C. J. Lanning, et al. (2015). Conceptual specification of forest utility balers for woody biomass. Auburn, WA, Forest Concepts, LLC**:** 9.
4. Dooley, J. H., C. J. Lanning, et al. (2015). Conceptual specification of large-bale forest residuals balers. Auburn, WA, Forest Concepts, LLC**:** 9. (This report)

Overview of Conceptual Large-Bale, High-Production Baler

The large-bale modular woody biomass baler is designed to maximize daily production while baling previously piled logging slash, forest residuals, thinnings from hand crews, and forest management prunings. The baler is intended to be supported by an excavator-type grapple loader to feed biomass into the baler and handle bales produced much like a grinder and loader combination interact today. The base-model conceptual baler is mounted on a self-propelled tracked undercarriage and is tele-operated by the loader operator via wireless controls (also, much like mobile grinders are today).

Figure 3. Overlay of conceptual track-mounted self-propelled baler on a logging site with an actual forest woody biomass loader. The baler is approximately to scale with the loader.

The 34x48x96-inch high density bale produced by the baler is designed to maximize trucking payload, minimize bale yard requirements, and be handled at bale yards by conventional agricultural bale equipment. Each bale is expected to weigh between 2,000 and 2,500 pounds depending on moisture content.

The baler infeed is approximately 96-inches (8-feet) wide to maximize piece length that can be loaded without slashing. The compression direction is parallel to the 48-inch bale dimension to minimize baler cycle time between loadings.

An on-board hydraulic chain-type slashing saw eliminates the need for chainsaw operators on the ground or to employ an excavator that has its own slashing saw on the grapple. Although we believe the base-model will have one slashing saw, saws on both sides of the baler infeed opening may be a preferred option for some firms. For those users that have and/or prefer grapple loaders with slashing saws, the baler's on-board baler saw can be deleted.

The baler is integrated onto a tracked undercarriage and engine/power unit that is common to self-propelled biomass grinders. Similarly, the wireless remote control is envisioned to be of the same type as used for mobile grinders. Each of these features minimize the need for operators to learn new systems to use and maintain.

The concept rendering (figure 1) shows a baler module that is scaled from the Forest Concepts' engineering prototype street-legal woody biomass baler, an engine/hydraulic power unit module, and a commercially available tracked undercarriage. Other baler models and options in this "large bale family" may include:

- Decks on at the end of the baler or on top to carry finished bales produced within harvest units or along roads to more accessible aggregation locations.
- An optional bale handler/stacker may reduce the demand on the loader operator.

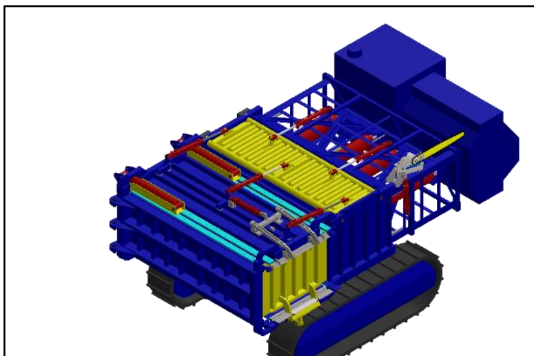

Figure 1 (repeated). Concept rendering of track-mounted self-propelled large bale machine for forest applications.

- Tow hitches at one or both ends to pull a flatbed trailer for collecting bales. The trailer may be used to facilitate forwarding of finished bales, or may be used for longer distance delivery to centralized processing yards.
- Automated bale property sensing, data logging, and tagging devices to measure bale moisture content, bale weight, GPS location of material baled, landowner, and other useful chain-of-custody information.
- Self-leveling for use on steeper, but machine-operable harvest units.
- Although we included a self-propelled tracked undercarriage in the base machine, options would include rubber tires, non-self-propelled, and the like.

Environmental and sustainablility features that can be incorporated into the baler include:

- Regenerative hydraulic system to reduce fuel consumption.
- Heat recovery thermal-electric generation system to reduce demands on alternators.
- Bio-based hydraulic oil that has low environmental footprint and non-hazardous spill risk.
- Tier-4 engine and emissions control system to anticipate future air quality regulations.
- Pressurized and automated fire suppression system, and onboard pressurized water tank with hose for wildfire containment. (Water tank may provide ballast in self-leveling versions)

Design Data for Conceptual Large-Bale Biomass Baler

This section details the major elements of the proposed conceptual baler. These elements and components were used to establish fuel consumption, maintenance expectations, weights, and other relevant performance information.

Identification of specific manufacturers, product names, brands, model numbers, etc. in this document does not constitute an endorsement nor recommendation by the authors, project managers, or sponsors. All tradenames and trademarks are the property of their owners. Specific brands, models and the like are included in this document to: a) provide readers with the sources of design and performance data; b) demonstrate the commercial availability of key components and subsystems; and c) provide a starting point for more detailed and disciplined specification and selection of components for designers of commercial versions of the equipment described.

Standard Elements Used in the Conceptual Design and Primary Options Expected in Commercial Models

- Diesel Engine Hydraulic Power Pack – peak flow goes to platen cylinders
    - A 100 gpm – 250 hp enables 30 second no-load full stroke cycle time
    - In our conceptual baler, we used a Cummins C-Series C8.3-260 diesel engine. This engine generates 260 hp at 2200 rpm and weighs approximately 1,200 pounds.
- Running Gear/Base
    - We include a Self-propelled track undercarriage is the base case to enable mobility at landing. The conceptual machine envisions a CAT OEM Solutions tracked undercarriage with appropriate track length, capacity, and track width.
    - Option for skid mount with hook-lift skid base
    - Option for trailer mounted on highway legal semi-trailer running gear
- Slashing Saw
    - Hydraulic slashing saw with harvester bar chainsaw is standard

- Our base design includes a standard hydraulic chainsaw from Danzco, Inc. that is similar to the commercially produced Danzco saw used on Forest Concepts' engineering prototype baler.
    - Option to include two slashing saws – one on each side of the baler
    - Option to delete
- Wireless remote control
    - Can be operated from ground or cab of support equipment.
    - Every existing biomass grinding manufacturer has this capability as a feature or option on their standard equipment. Numerous control vendors exist.
- Bale Tying system
    - The conceptual baler will include an automated wire tying system that will place 9-11 ties per bale.
    - Our design assumption is an Accent Wire Model 470 tier that uses 12 gauge black annealed baling wire. The wire has a load strength of approximately 600 pounds per strand.
        - Similar wire tie systems are commercially available from Leggett & Platt, and Cranston Machinery.
    - Alternative bale strapping methods include polyester and steel strap from commercial vendors such as Signode, etc.

Baler Module Basic Engineering Data

The baler module is arranged to have a wide opening (tentatively 42 x 96 inches) to the maximum allowable and still have the overall baler transport-width less than 120 inches. The width should be constrained to enable transport on conventional forestry equipment trailers with over-width placards.

The platen will move in the 48-inch direction to minimize platen cycle time. This assumes that the loader operator alternates placing biomass into the baler toward one end and the other of the baler infeed opening to balance bale density from side to side.

Three or four platen compression cylinders spaced across the platen may have 84-inch telescoping cylinder stroke and 8-inch diameter each to achieve the desired compression force plus "over-pressure" at finished bale time. An open design question is whether the cylinders are double-acting (as in the prototype) or single-acting with a chain-winch return.

The baler will be designed with side-eject and auto-tie around the 44 x 48 inch direction similar to the engineering prototype. The baler module will include mounting plates to enable commercially available auto-tie or strapping systems to be installed from Signode, Cranston, L&P, Accent, etc. The side ejection will release the finished bale on the same side as the loader operates to enable rapid handling of bales by the loader. In operation, the loader will be picking and placing a finished bale onto a trailer or stack while the baler ejection door is closing and the platen is recycling to start the next bale cycle.

- Infeed opening: 45-inches by 96-inches
    - Infeed grates are of the patented Forest Concepts design
- Platen dimensions: 34-inches tall by 96-inches +/- wide
- Platen hydraulic force: 300,000 pounds (100+ psi at platen)
- Baler module estimated weight: <u>18,000</u> lbs (Transport weight excluding power pack, undercarriage, etc. estimated below)

Auto-Tie System

Auto-tie systems using wire, steel strapping, or polyester strapping can be installed on the baler using equipment from several manufacturers. For the purposes of this BRDI conceptual design, we will use steel wire that is the same system as used on cardboard recycling balers. The wire can be cut and removed on the infeed to a grinder, or can be ground into small pieces and removed by magnetic pulleys on the grinder outfeed conveyor.

- Make: Accent Wire   Model: 470
- Wire diameter: 12 gauge, Tensile Strength: 1,600 pounds, weight: 33.62 feet per pound
- Number of wraps per bale: 9
- Feet of wire consumed per bale: 130 linear feet per bale, 3.9 pounds per bale.
- Wire cost per bale: $2.13 per bale ($0.55 per pound)

Slashing Saw System

The on-board slashing saw is located at one end of the baler infeed opening. It is controlled by the loader operator who positions a grapple-full of over-length biomass in position and then cycles the saw.

- Make: Danzco   Model: 404 grapple saw
- Bar length: 48 inches   Chain: .404 Harvester Chain

Hydraulic Power Pack – 250 hp

- Engine: Cummings C8.3-260
- Horsepower: 260 @ 2200 rpm
- Fuel: Diesel   Fuel Tank Capacity: 130 gallons
- Fuel consumption estimates are based upon 250 hp and a fuel consumption rate of 0.11 l/hp-hr (0.03 gal/hp-hr) (Per. Comm. John Sessions). This would result in a fuel consumption of 7.65 gallons of diesel per machine-hour.
- Primary Hydraulic Pump: 110 gpm variable displacement pressure compensated
- Hydraulic oil tank capacity: 90 gallons
- Hydraulic power pack weight: 5,500 lbs

Tracked Undercarriage

- Make: CAT   Model: 312 Series
- Track dimensions: plate width: 14 inches, track length: 109 inches
- Weight: 7,000 lb

Remote Control System

- Undefined model from: Magnetek, Cooper Bussman, etc.

Transport Dimensions

- Length: 20 feet
- Width: 9-ft 6-inches
- Transport Weight: 34,000 lbs (250 hp version)

Data for Operations, Economics, and LCA Teams

To this point, the baling discussion and design has focused solely on the baler itself. It is assumed that a baler is part of a baler system that includes a tracked loader as shown Figure 3. The operator of the loader also controls the movement and actions of the baler. The baling process onboard the baler is highly automated to enable tele-operation. Thus, there is no direct labor cost for a baler operator.

We are aware that the BRDI project is evaluating multiple operating scales, work days per year, etc. We endeavor to provide the following data in a format that can be used to estimate the number of baler/loader systems needed to achieve annual production targets within the scheduled operating days.

We are simplifying productivity data to a single production rate to avoid adding complexity to the already many operating scenarios facing the economics team. Our production estimates assume that the baler/loader are essentially fully occupied making bales during scheduled machine hours. This will be the case in the centralized grinder replacement scenario. However, lower productivity is to be expected at roadside small piles and windrows due to higher biomass handling time and addition in-unit moving time. Even lower productivity will occur when baling dispersed small piles in a harvest unit due to high moving time requirements compared to actual baling time.

Dimensions				**Power**		
	Transport Width (ft.- in.)	9'-10"			Peak Horsepower	260 hp @ 2200 rpm
	Transport Weight (lb)	34,000 lb			Operating Horsepower	250 hp
	Transport Height (ft.- in.)	8'-0"			Fuel Type	Diesel
	Transport Length (ft.- in.)	20' -0"			Fuel Consumption basis	0.03 gal/hp-hr
	Travel Speed on Tracks(mph)	0.8/1.5 mph			Fuel Consumption rate	7.65 gal./machine-hr
					Fuel Cost per Gallon ($/gal)	*
					Fuel Tank Capacity (gal)	100 gal

* Rates are set by others in the project to be consistent across all equipment systems

Ownership (Baler Only)				**Consumables**		
	Purchase Price ($)	$350,000.00			Lubricants (% fuel cost)	20%
	Economic Life (Years from new)	7 years			Repair & Maint. (% depreciation)	50%
	Salvage Value (% purchase)	5%			Baling wire cost/bale ($)	$2.13/bale
	Interest Rate	*			Slashing Saw Bar & Chain($/PMH)	$8.00/PMH
	Insurance	*				
	Taxes	*				

* Rates are set by others in the project to be consistent across all equipment systems

It is important to note that the baler must be supported by a grapple loader similar to those used to sort biomass and to support horizontal grinders. The costs for the loader is not included here. It must be selected from the equipment data sets of other Task 2 teams.

The purchase price is the expected list price of the machine as configured in the discussion and from a full-line manufacturer producing at least 26 similar machines per year.

Operational (Baler Only)			System Operations Data	
Bale dry weight (wet basis)	1,400 lb		Baler Operator	None
Bale size (HxLxW) (inches)	34x48x96		Loader Operator Base Wage	*
Baler Utilization % (PMH/SMH)	85%		Labor Benefits & Fringe	*
Baler Capacity (bales/PMH)	18 bales/hr		Other wage costs (L&I, etc.)	*
Loader Efficiency (% Filling Baler) (pile sorting & biomass arranging)	60%		Paid Hours per day (hrs)	*
Baler Production Rate (bales/hr)	10 bales/hr		Loader cost burden ($/SMH)	*
Bale stacking for transport	2 - high		Scheduled Days/year	*
Bale average moisture (% wb)	*		Scheduled Hours/year (SMH)	*
			Scheduled hours / day (SMH)	*
			Operating hours / day (PMH)	*

* Rates are set by others in the project to be consistent across all equipment systems and scenarios.

Bale weight is stated on a dry weight basis and must be adjusted for as-baled moisture content to calculate hauling payloads.

Operational data used in these tables is our current best estimate based on field testing of the engineering prototype, work-elements analyses, and engineering judgement. These values are subject to change as new field data is collected and analyzed.

The difference between baler productive capacity and estimated baler production rate is due to loader inefficiencies. Field studies observing loaders filling forwarder trucks and Forest Concepts' field studies of woody biomass baling with a self-loading baler suggest that approximately 40% of productive time is lost due to the loader arranging or gathering biomass to prepare it for pick-up.

Summary:

This report is one in a series of documents that detail the conceptual design and specification of forest residuals balers. The "large forest biomass baler" is intended to replace mobile in-woods grinders used to process piles at landings, roadside windrows, and in-unit slash piles. Bales produced by the baler may be left for forwarding using a conventional log forwarder or accumulated on trailers or hook-lift decks for hauling.

This report endeavors to provide other BRDI Project teams with basic data necessary to model logistics, economics, and LCA/Carbon burdens for baling as an alternative method for collection, transport, and storage of forest residuals.

Engineering content in this report endeavors to provide prospective baler manufacturers and product design engineers with a starting point for their own work to assess commercial potential or design commercially relevant forest residuals balers.

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Development of specifications for forest residuals balers was influenced by discussions with:

- Humboldt State University – Han-Sup Han, Joel Bisson, Anil Kizha
- Oregon State University – John Sessions
- Peterson Pacific Corporation – Larry Cumming
- Danzco – Ed Danzer
- Accent Wire – Janice Allem

Citation:

(Dooley, Lanning et al. 2015) - Dooley, J. H., C. J. Lanning, et al. (2015). Conceptual specification of large-bale forest residuals balers. Auburn, WA, Forest Concepts, LLC**:** 9.

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