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Innovative Solutions for Bioenergy and the Environment

August 10, 2015 (latest update: September 24, 2015)

Conceptual Specification of Forest Utility Balers for Woody Biomass

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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.

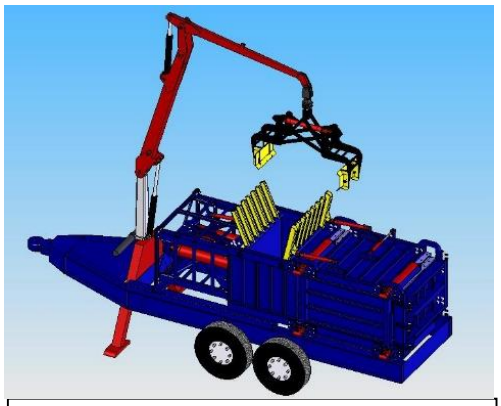

Figure 1. Concept rendering of forest utility baler on straight trailer and with 17-ft reach self-loader.

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.

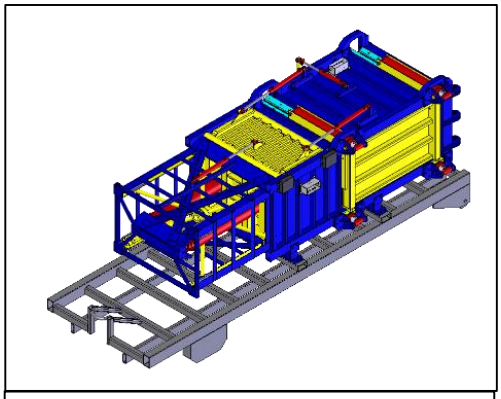

Figure 2. Concept rendering of forest utility baler module for installation on forwarder, truck chassis, hook lift skid, etc.

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 small piles, roadside debris windrows, and large piles that contain woody biomass that must be removed from the forest.

Figures 3. 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 large-bale track-mounted self-propelled 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 general-purpose modular baler most suitable for baling of dispersed woody biomass along roads and in small piles. The modular baler may be mounted on a forwarder for off-road use within units to collect excess forest residuals.

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

Overview of Conceptual Forest Utility, High-Biomass-Recovery Baler

The forest utility modular woody biomass baler is designed to maximize recovery of forest residuals from small/remote/stranded landings, scattered roadside windrows and piles, thinnings from hand crews, and forest management prunings.

The baler module is designed to be incorporated onto a wide range of undercarriages and prime movers. The baler module can be mounted on (and powered by) a forestry log forwarder when in-woods mobility is needed. Such configuration takes advantage of the forwarder's mobility, onboard log crane, and hydraulic power capacity.

In other configurations, the baler module can be paired with an optional engine/hydraulic power-pack and a small-log loader for stand-alone use on a trailer frame or truck chassis as shown in Figure 3.

Figure 3. Forest Concepts' engineering prototype forest utility baler collecting forest residuals from roadside windrows on Snoqualmie National Forest.

Modularity particularly enables users to minimize capital by mounting the baler on existing forwarders, truck chassis, or trailers. When use is seasonal due to markets, fire, snow, etc., the baler can be removed to free the prime mover for other uses.

The 32x48x56-inch high density bale produced by the forest utility baler is designed to maximize trucking payload, minimize bale yard requirements, and be handled by lightweight skid-steer loaders as well as conventional agricultural bale handling equipment. Each bale is expected to weigh between 900 and 1,200 pounds depending on moisture content. The bale weight specification is constrained in-part by lifting limits for skid-steer loaders used in the forestry and vegetation management industries.

Figure 3. Forest residuals bales produced by utility baler from roadside windrows on Snoqualmie National Forest.

The baler infeed is approximately 48-inches (4-feet) wide to maximize piece length that can be loaded without slashing. The compression direction is parallel to the 56-inch bale dimension to maximize bale density. Productivity will be enhanced by inclusion of an automated wire-tie system that will reduce the tying time to approximately 30 seconds compared to five minutes for manual tying.

An on-board hydraulic chain-type slashing saw eliminates the need for chainsaw operators on the ground and to minimize the need for slashing of residuals during the harvesting operation. 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 saw can be deleted.

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

- Regenerative hydraulic system to reduce fuel consumption.
- 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 when a self-contained engine and hydraulic power pack is incorporated into the baler system.

Design Data for Conceptual Forest Utility Woody 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. Although the base baler module is intended to be incorporate into a wide range of prime movers, loader configurations, power supply, etc., we are presenting one case in this BRDI project that is trailer mounted, has an on-board loader, has one slashing saw, and has a self-contained hydraulic power unit. (This is essentially the configuration of our engineering prototype.)

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
  - Make: Kubota Tier 4 emissions control engine approximately 47 HP
  - Flow: 25-30 gpm –enables 50 second no-load full stroke cycle time
  - Our goal is to minimize fuel consumption and maximize the loader productivity which is the limiting factor for baler production rates.
- Running Gear/Base
  - We include a pintle hitch straight heavy duty trailer in this conceptual design. This type of trailer can be pulled by a 4wd truck, agricultural tractor, or lightweight skidder.
  - Option for skid mount with hook-lift skid base
  - Option for mounting the baler module on a forwarder and using its grapple and hydraulic power systems
- Slashing Saw
  - Hydraulic slashing saw with harvester bar chainsaw is standard
  - Our base design includes a standard hydraulic chainsaw from Danzco, Inc.
  - Option to include two slashing saws – one on each side of the baler
  - Option to delete
- Bale Tying system
  - The conceptual baler will include an automated wire tying system that will place 5-7 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.
  - Manual tying with 440 poly baler twine is an option for sites with very low productivity.

Baler Module Basic Engineering Data

The forest utility baler module is specified as a commercial version of the engineering prototype currently in use by Forest Concepts. The performance and components included in this section of the design report represent the engineering team's current thinking about commercially available components and configurations.

The baler will be designed with side-eject and auto-tie around the 32 x 56 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: 42-inches by 48-inches
    - Infeed grates are of the patented Forest Concepts design
- Platen dimensions: 32-inches tall by 48-inches +/- wide
- Platen hydraulic force: 140,000 pounds (100+ psi at platen)
- Platen and ejection hydraulic cylinders: double acting telescoping cylinders
- Baler module estimated weight: 12,000 lbs (Transport weight of the baler module itself excluding power pack, grapple loader, trailer, 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's 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: 5
- Feet of wire consumed per bale: 77 linear feet per bale, 2.28 pounds per bale.
- Wire cost per bale: $1.25 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: 36 inches Chain: .404 Harvester Chain

Hydraulic Power Pack – 47 hp

- Engine: Kubota 48 HP liquid cooled D1803-CR-T-E4B Tier 4 Emissions
- Horsepower: 49.6 @ 2700 RPM
- Fuel: Diesel Fuel Tank Capacity: 20 gallons
- Fuel consumption estimates are based upon 47 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 1.41 gallons of diesel per machine-hour.
- Primary Hydraulic Pump: 25 gpm variable displacement pressure compensated
- Hydraulic oil tank capacity: 50 gallons

- Hydraulic power pack weight: 3,800 lb

Small-log Grapple Loader

- Make: Kesla Model: 204T telescoping
- Maximum Reach: 22 ft retracted, 27 ft extended
- Lifting capacity: 1,800 pounds @ 10 ft. reach
- Grapple opening width: 54 inches with custom biomass grapple
- Loader weight: 2,400 lb

Transport Dimensions

- Length: 20 feet
- Width: 8-ft 0-inches
- Transport Weight: 21,000 lb (including baler, 47 HP hydraulic power pack, trailer, and loader)

Data for Operations, Economics, and LCA Teams

To this point, the baling discussion and design has focused solely on the baler itself. We will continue with the trailer-mounted, self-loading baler that is operated by a single operator who drives the towing truck and then sits in an operator's seat on the baler to operate the baler. The towing truck in this scenario is used to bring the baler to the forest and move it from point to point within the forest. Daily movements within the forest are expected to be no more than a mile or two per day, thus fuel consumption for the truck is excluded from this data. If a truck is desired in economic analyses, we would suggest that a Ford F450 4wd flatbed truck with 25,000 lb. towing capacity be used.

A complete logistics-based scenario will necessarily include equipment and trucks needed for gathering and hauling bales from the baling sites to centralized storage and processing sites.

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 where large piles need to be baled at stranded landings. However, lower productivity is to be expected at roadside small piles and windrows due to higher biomass handling time and additional in-unit moving time. Even lower productivity will occur when baling dispersed small piles in a harvest unit due to high moving and biomass gathering time requirements compared to actual baling time.

Dimensions		**Power**	
Transport Width (ft.- in.)	8'-0"	Peak Horsepower	49.6 hp @ 2700 rpm
Transport Weight (lb)	21,000 lb	Operating Horsepower	47 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 (mph)	Highway	Fuel Consumption rate	1.41 gal./machine-hr
		Fuel Cost per Gallon ($/gal)	*
		Fuel Tank Capacity (gal)	20 gal

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

Ownership (Baler Only)		Consumables	
Purchase Price ($)	$135,000.00	Lubricants (% fuel cost)	20%
Economic Life (Years from new)	7 years	Repair & Maint. (% depreciation)	50%
Salvage Value (% purchase)	5%	Baling wire cost/bale ($)	$1.25 /bale
Interest Rate	*	Slashing Saw Bar & Chain($/PMH)	$5.00/PMH
Insurance	*		
Taxes	*		

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

The estimated purchase price (manufacturer's list price) assumes there is a market for a minimum of 100 balers of this type per year.

Operational (Baler Only)		System Operations Data	
Bale dry weight (wet basis)	700 lb	Baler Operator	1 person
Bale size (HxLxW) (inches)	32x48x56	Loader Operator Base Wage	*
Baler Utilization % (PMH/SMH)	85%	Labor Benefits & Fringe	*
Baler Capacity (bales/PMH)	10 bales/hr	Other wage costs (L&I, etc.)	*
Loader Efficiency (% Filling Baler) (pile sorting & biomass arranging)	40%	Paid Hours per day (hrs)	*
Baler Production Rate (bales/hr)	4 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 60% 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 “forest utility woody biomass baler” is intended to enable cost-effective collection and transport of currently stranded biomass sources at remote/small 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.

Acknowledgments:

This material is based upon work supported by a grant from the U.S. Department of Energy under the Biomass Research and Development Initiative program: Award Number DE-EE0006297.

Earlier development of woody biomass baling technology and construction of the Forest Concepts engineering prototype baler was supported in-part by U.S. Department of Agriculture under the NIFA SBIR program: Award Numbers 2005-33610-15483 and 2006-3361-17595.

Innovative designs, engineering data, and inventions disclosed in this report are the subject of provisional US Patent Application(s) filed by Forest Concepts, LLC under provisions of the Bayh-Dole Act of 1980 and other federal regulations.

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
- Arsiero Logging / Northwest Renewable Energy Group – Mike Malgarini
- 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 forest utility balers for woody biomass. Auburn, WA, Forest Concepts, LLC**:** 9.

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