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Forest Concepts, LLC
3320 West Valley Hwy. N. Ste. D-110
Auburn, WA 98001

Summary Report for Woody Biomass Baling Pilot Project

Field Work: September 13-17, 2021, Lake County, CA

Key Findings

Baling

- All oak, walnut, and other trimmings from two bucket trucks were able to be baled, including some six-inch diameter branches.
- The Forest Concepts engineering prototype baler easily kept up with the two bucket trucks over two days of trials, even with hand-tying of bales.
- The bales weighed 750-800 pounds and were approximately 23% moisture content (wb). If moisture content was a more typical 48%, the weights would have been approx. 1,100 pounds.
- Loggers Unlimited provided a positive and encouraging review of their experience.

Processing & Grinding

- Bale grinding was difficult due to 5/8 grinder grate chosen. It may be impractical to grind bales to 5/8-minus in a single step using the Bandit Beast 750hp grinder.
- Both chipped and baled materials were able to be reprocessed into gasifier feedstocks per the Omni BioEnergy specifications.

Gasification Feedstock Quality

- Omni BioEnergy concluded that all samples of processed chips, bales, and logs would be acceptable for gasification in their Artis systems.
- Omni revised feedstock spec to improve feeding. New spec: Pass ¼ top screen, leave fines in. Reduce long shards.

Cost Comparison

- Total costs from roadside vegetation management debris to gasifier are lower for the baler pathways than for the chipper pathways.
- Relative costs are very sensitive to operating schemes.

Table of Contents

This document is a summary of work conducted by Forest Concepts, LLC for PG&E under Purchase Order: 2700627647 issued to Forest Concepts on June 29, 2021.

Note: This is an abridged version of the full report provided to PG&E.

Overview of Project

This project is the result of a proposal submitted by **Forest Concepts, LLC** to **The Pacific Gas & Electric Company PG&E)**, through the PG&E / ADL Ventures *ProblemSpace* competition. The proposal addresses **Category 2: Next-generation woody biomass densification and transportation technology.**

Next-generation woody biomass densification and transportation technology

Problem
Transportation of woody biomass from a collection site to either a concentration/feedstock yard or to a conversion facility accounts for roughly 25% to 50% of the total delivered cost.
Densification and moisture reduction can be important in reducing transportation costs, and most existing densification technologies are prohibitively expensive.

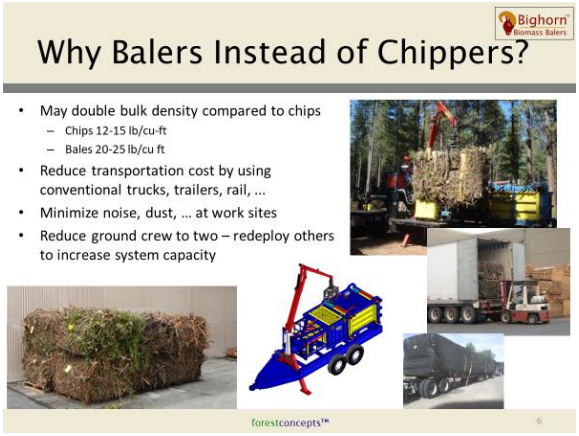
Desired properties
Increases bulk density of woody biomass for transportation
Delivered cost below $5/mmBTU to a location roughly 50 miles away
Reduces moisture content to below 15%

Summary problem statement from *ProblemSpace* website

The competition was sponsored by the gas technology research unit within PG&E. The objective was expanded to include processing and production of feedstocks to be used by distributed-scale gasifiers. The secondary processing may be conducted anywhere between the source and the gasification site.

ADL, PG&E, and a network of expert industry stakeholders assembled by PG&E, jointly evaluated over 100 technologies, choosing eight finalists for a detailed in-person review session on November 14, 2019. Following that session, ADL, PG&E, and other stakeholders chose to move forward with Forest Concepts and its baling technology.

Forest Concepts, LLC is a technology developer based in Auburn, Washington. The company has invented, patented, and developed a woody biomass baling method that has proven effective in other locales to increase the transportation density of woody biomass from vegetation management, wildfire protection projects, and forest management activities. Additionally, Forest Concepts has developed woody biomass size reduction, screening, and drying technologies that enable increased value-added utilization of chipped and baled PG&E vegetation management trimmings.



Slide from Forest Concepts' proposal presentation

The crux of the proposed solution was to substitute woody biomass baling for chipping where applicable across PG&E's vegetation management program. Implementation will entail design and manufacture of a fleet of purpose-specific balers, bale gathering and handling equipment, and developing guidelines for grinding and post-grinding processing of baled woody vegetation into feedstocks appropriate for use in distributed-scale gasifiers.

The current full-scale Forest Concepts engineering prototype baler is mounted on a street-legal trailer and has completed field trials across Washington, Oregon, and northern California. It has neither been extensively evaluated nor optimized for use with powerline vegetation management crews as a direct alternative for tow-behind chippers. A lack of application-specific pilot tests and data limits the willingness of firms to commit to purchase and add baling to their fleets. The current field Pilot study is a first step toward achieving the *ProblemSpace* goals and reducing operational and financial risk for adopting new work methods.

Pilot Study Planning and Contracting

The *ProblemSpace* competition requested comprehensive proposals that were not bounded by time nor dollar constraints. Forest Concepts proposed a multi-year cooperative development program continuing through initial deployment of a final solution by the end of 3-4 years and at a cost of $4-5 million dollars. Each of the four budget periods (phases) were to include defined metrics, milestones, and go/no-go decision points.

Internal constraints at PG&E limited the sponsoring research group to contract for one phase at a time, and to limit the initial contract to Forest Concepts to less than $100,000. Thus, the scope was reworked multiple iterations to reduce the project to a pilot that addresses a narrow set of questions to inform decisions by PG&E whether or not the baling concept has sufficient merit to be of continuing interest. There were no conditional commitments for follow-on funding or to pursue the full original *ProblemSpace* proposal.

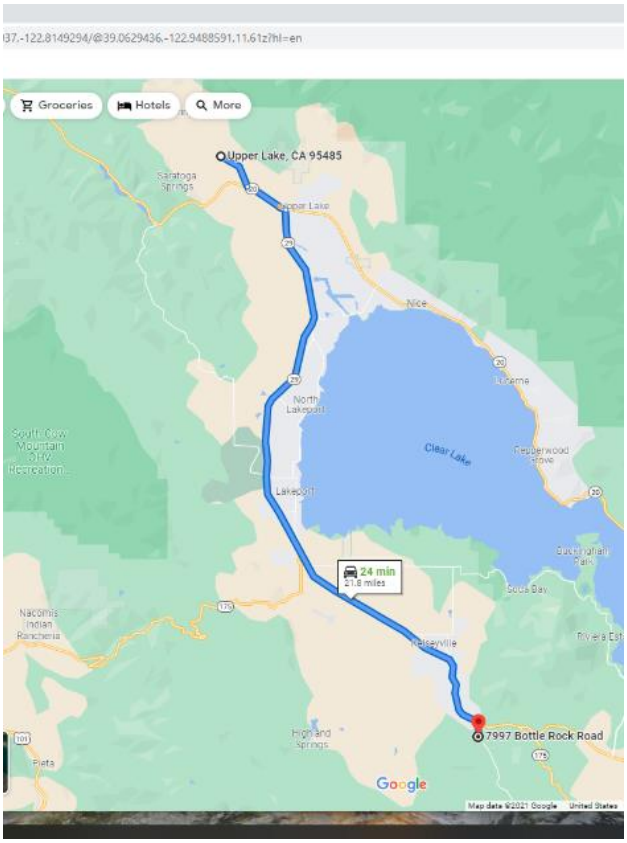
The process of contracting and gaining internal approvals was arduous for all involved, but a contract (Purchase Order: 2700627647) was issued to Forest Concepts on June 29, 2021 to formally launch the Woody Biomass Baling Pilot project. PG&E separately contracted with Loggers Unlimited to be the vegetation management cooperator and with Donahoo, Inc. to be the grinding contractor.

Site Selection

The original project plan was to conduct field trials in the San Jose/Santa Cruz region and deliver biomass to Sierra Energy's gasifier located at Camp Hunter Liggett in southern Monterey County. About 10 months into the planning, Sierra Energy withdrew as they refocused their feedstock supply to solid waste rather than woody biomass.

A search for other gasifiers and gasifier projects under development led to Omni BioEnergy and Scotts Valley Energy (a business of the Scotts Valley Band of Pomo Indians) who were in the process of obtaining construction permits to install a gasifier-generator system in Kelseyville, Lake County. Their participation refocused the field pilot work on Lake County as well.

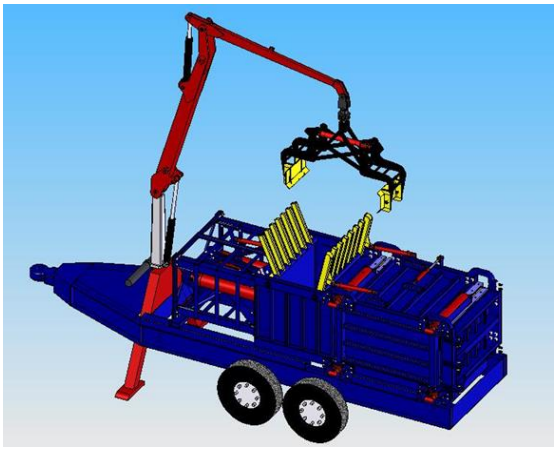
The baling pilot site was chosen by Loggers Unlimited in consultation with PG&E's local coordinators. The site was along Bachelor Valley Road as shown at the top of the map at right. This site was chosen to be on a rural road where traffic would be minimal, where a bucket truck trimming crew was scheduled, and was within a reasonable distance to the grinding site at Donahoo, Inc. The Donahoo biomass processing site is shown at the lower right of the map at a distance of 21 miles from the tree trimming site.



Forest Concepts Baling Technology

Baling of woody biomass from urban and suburban landscape maintenance, wildfire risk reduction, and utility corridor vegetation management may enable lower cost collection, transport, and storage than chipping with tow-behind chippers.

Forest Concepts' development of mobile woody biomass balers has resulted in a "family" of sector-based configurations for small-scale forestry, large-scale forestry, large-scale biomass aggregators, and as a chipper replacement for urban markets. This project focused on street-legal "chipper replacement" balers for use in urban and rural environs as shown in the Figure 1 sketch. The research and development work is documented in a number of publications (J.H. Dooley, Lanning, & Lanning, 2011; J.H. Dooley, Lanning, Lanning, & Fridley, 2008; J.H. Dooley, Lanning, Lanning, Broderick, & Fridley, 2009). 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.



Figures 1. (Left) Conceptual rendering of chipper-replacement woody biomass baler for use by arborists and vegetation management contractors. (Right) Forest Concepts' engineering research prototype baler mounted on 5th-wheel grapple trailer.

The baler is optimized to handle woody debris and trimmings produced by hand crews on the ground or in aerial trucks. Materials that are currently chipped but could be baled are shown in the photos below.

Figures 2. Vegetation management debris that consist of branches, brush, and trimmings are the focus of the Forest Concepts baler.

The challenges of on-site chipping or grinding are well known, even when biomass can be moved to more centralized landings. Baling into rectangular bales with modular baling systems enables baled forest biomass to be handled and hauled just like agricultural hay using flatbed trucks or trailers, and handled with hay squeezes, grapples, or forklifts.


Figures 3. Forest Concepts' engineering prototype baler collecting roadside thinnings in central Oregon from a wildfire protection shaded fuel break project.

Transportation of bales from work sites to central gathering yards uses flatbed trucks or trailers. The chipper-replacement version of the baler would be pulled by a flatbed crew truck having a 10 – 14-ft flatbed so it could collect up to 3-4 tons of bales during its own workday. Where needed, a grapple truck or grapple log trailer could be used to service one or more baling crews to gather bales for delivery to central sites.

Long-haul transportation of bales from large work sites or from central gathering yards can be done using conventional highway-legal flatbed tucks or dry vans as shown below.

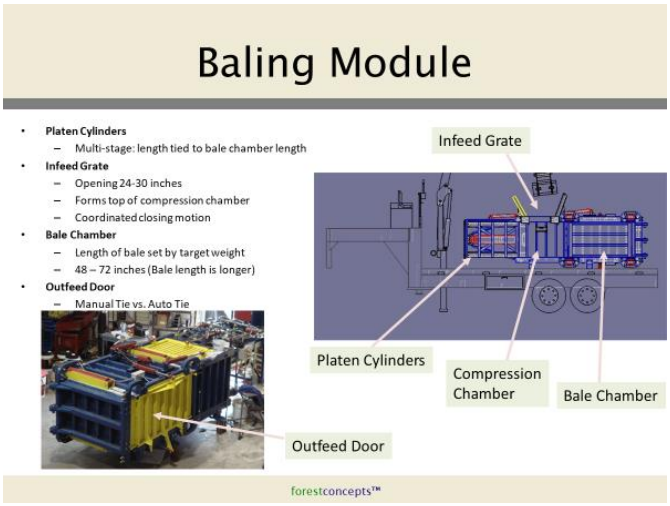

Figures 4. Transportation of baled woody biomass using tarped flatbed trucks or dry vans.

High density bales can be ground to fiber and fuel specifications for a particular use at central sites or at end-user facilities using horizontal or tub grinders.


Figures 5. (Left) Moving bales in grinding yard. (Center) Grinding with horizontal grinder. (Right) Ground bale to produce boiler fuel for use by Avista Power in Kettle Falls Generating Plant.

Modularity – Enables Core Baling Component to be Used Across Platforms

The core of the Forest Concepts baling technology is a baling module that can be mounted on hook-lift skids, flatbed trucks, log forwarders, and straight trailers. Modularity particularly enables users to minimize capital by mounting the baler on existing forwarders, truck chassis, or a variety of on-road and off-road 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 32x48x54-inch high density bale produced by the 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 forest operations and vegetation management industries.

The baler infeed grate is approximately 48-inches (4-feet) wide to maximize piece length that can be loaded without slashing. The compression direction is parallel to the 54-inch bale dimension to maximize bale density. Productivity will be enhanced by inclusion of an automated wire or polyester strap-tie system that will reduce the tying time to approximately 30 seconds compared to five minutes for manual tying.

An optional 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 most customers 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 sustainability 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 or CARB engine and emissions control system to anticipate future air quality regulations.
- Optional pressurized and automated fire suppression system when a self-contained engine and hydraulic power pack is incorporated into the baler system.

The Forest Concepts woody biomass baler has been demonstrated in Washington, Oregon, and California at projects spanning urban to forest conditions. No formal demonstrations or field trials have been conducted related to vegetation management along electrical transmission and distribution corridors.

Baling Technology Commercialization Status

The Forest Concepts woody biomass baling technology is ready for commercialization. Engineering parameters and data is available to manufacturers and licensees. Preliminary design specifications and 3-D solid engineering models are available to greatly reduce the time to production. As shown in Appendix 2, the chipper-replacement family of baler models has been detailed.

There are several companies interested to license the baler technology to integrate into their own vegetation management equipment product lines. They have followed the development closely and attended demonstrations. However, they will not execute a license agreement until they have letters of intent from a significant set of launch customers.

The other approach to commercializing the technology is for Forest Concepts to contract with an equipment design engineering firm to produce complete designs, documentation, etc. necessary for contract manufacturers to build custom balers. One design firm has become familiar with the technology and two prospective contract manufacturers (one in Lodi, CA within the PG&E service area) have obtained drawings of the Forest Concepts prototype and expressed interest to be a manufacturer. This approach will require approximately $3 – 5 million of working capital to complete design, production and testing of manufacturing prototypes, obtaining safety certifications, and launching production at a scale to deliver at least 50 balers in the first year.

PG&E Pilot Project Objectives and Metrics

The objective of the pilot project is a demonstration and confirmation of the conceptual fit of baling as an alternative or compliment to chipping of vegetation management woody biomass. Of particular interest is to evaluate methods that reduce the cost of collection, transportation, and processing of woody vegetation management debris into feedstocks for use in distributed-scale gasifiers. Specifically, this field pilot addresses the following objectives:

- Demonstrate how the baling technology will work for operators (i.e. vegetation management contractors).
- Demonstrate baling's value for transportation (i.e. cost from source to gasifier).
- Demonstrate management of woody biomass at gasifier site (i.e. making chips from bales, unloading, etc.).
- Demonstrate logistically the delivery of the final feedstock product into the gasifier.

The primary metric for success is:

- Baling and utilization of baled woody biomass is judged by PG&E stakeholders to conceptually contribute to the cost, logistics, end-use, crew size, noise, dust, and/or other objectives (e.g. contribution to achieving RNG Roadmap) of the company. The potential benefits warrant continuing development.

Deliverables include:

- Completion of a live demonstration of baling vegetation management debris in support of a PG&E contractor's powerline clearance trimming crew.
- Transportation of bales by the PG&E contractor to a central processing site.
- Processing of baled and chipped vegetation management debris into feedstocks that meet specifications of a gasifier cooperator.
- Preparing a preliminary Excel® comparative economic analysis of the conventional chipping vs baling pathways used during the Pilot.
- Delivering a summary report document and presentation to PG&E.

Report of Activities

Roadside Baling with Tree Trimming Crew

The baling pilot test was conducted along Bachelor Valley Road approximately five miles northwest of Upper Lake in Lake County, CA. The neighborhood was comprised of open woodland grazing lands, mature walnut orchards, and pastures. Traffic was minimal and was comprised of residents and farmworkers. The tree-trimming objective for the crew was described as "routine vegetation work" to establish or maintain the line clearance shown in the PG&E graphic below.

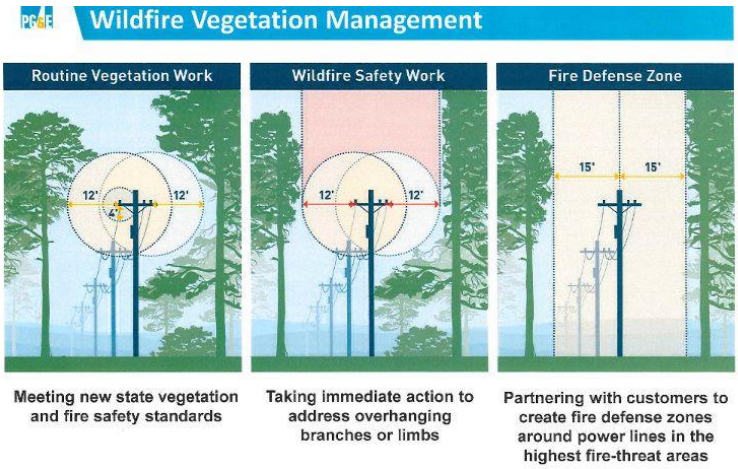


Figure 6. Vegetation management criteria for different levels of clearance.

The vegetation types along the roads were primarily mature oak trees with some walnut and other deciduous trees. Since this distribution line was only being trimmed for line clearance, low brush and vegetation against the lower telephone, cable tv, etc. lines were not trimmed.

The tree trimming crew was comprised to two bucket trucks working together along the road trimming designated trees to establish line clearance. Each truck was staffed by two people – a trimmer and a ground person. The ground personnel from the two trucks also moved traffic cones and performed traffic control when needed. Since the baling was close to the bucket trucks, the trimming crews assisted with traffic control for the baling activity. The trimming ground personnel piled trimmings into organized piles for baling. They used poles to pull down trimmed branches hung up in the trees being trimmed. They occasionally used a leaf blower to clean small vegetation debris and leaves off the roadway. At one point, a truck spent approximately an hour clearing a residential line through a walnut orchard. The general mode of operation was for a trimmer in the bucket to clip or chainsaw branches, accumulate bunches on the bucket, and then drop the clump to

form a roadside pile. They told us that the methods being used were the same as when the trimmings were to be chipped instead of baled.

As can be seen in the photo, the powerlines for most of the demo were on the “oncoming traffic” side of the road. This presented a minor challenge since the Forest Concepts engineering prototype baler is specifically optimized for all materials handling from the “curb” side of the baler.

During the two partial days of work with the bucket crew, Forest Concepts produced four bales having an average weight of 765 pounds. The bale weights were measured in pairs by scaling deliveries to Donahoo, Inc. by a Loggers Unlimited flatbed trailer. The lower-than-expected bale weights may be explained in-part by the fact that the baled material was only 23% moisture content (wet basis). We calculated that the same material at a typical winter/spring moisture content of 48% would weigh an average of 1,030 pounds. The oven dry mass of the bales averaged 536 pounds per bale.

Transporting Bales to Central Grinding Site

Bales were picked up from the roadside by a two-person crew from Loggers Unlimited using a flatbed grapple trailer typically used to haul logs too big for the chipper. The trailer configuration was only able to haul two bales at a time due to a mismatch of bed dimensions with the bale footprint and not trailer payload limitations. The trailer was used to deliver finished bales to the Donahoo, Inc. grinding site where the trailer was scaled to determine average bale weights for the two bales in each load.

Chipping Crew Comparison

The chipper crew normally assigned to work with the trimming crews was tasked with “catching up” with a backlog of accumulated trimmings from recent climbing and other work within about 10 miles of where the baler trial was being conducted. Thus, there was not an opportunity for direct comparison of baling vs chipping along the same section of road. On Wednesday morning, the chipper crew was observed along Scotts Valley Road where the vegetation was mostly oak and pine that was staged in groups and piles. One load of that material was delivered to Donahoo, Inc. for use in the grinding trials (Chipper load 1). On Wednesday afternoon, the chipper crew was observed along Bottle Rock Road where the material was a mix of boxwood, beech, and other shrubby hardwoods. That material was almost continuous along the road which required extensive gathering and feeding of armloads of material into the chipper. One load of that material was delivered to Donahoo, Inc. for use in the grinding trials (Chipper load 2). The two chipper loads had a green weight of 4,620 and 6,200 pounds for loads one and two respectively.

The chipper crew included a driver/lead and ground crew. At the first site, it took the crew 2-5 minutes per pile to gather, drag, and chip the materials, then less than a minute to move to the next pile. Since they were working on a dead-end side road, there was no need for traffic control. Everyone participated in the gathering, occasional chainsawing of large debris, and chipping. Cleanup consisted of blowing debris off the road surface. At the second site which was along an active paved road, two crew members provided full-time traffic control. The rear person also carried a blower to clean the road surface as the chipper advanced. Two other members gathered and fed the chipper. The general scheme was to move the baler 25-50 feet at a time along the road and gather the incremental material behind it each time the driver stopped. Due to the leafy, bulky material being chipped, the truck quickly filled. Our observation ended when the truck had to stop work and deliver its load to a residence about 5 miles away.

The chipper tow vehicle was a Dodge Ram 5500 Crew Cab truck with a chip box on the bed. The chipper was a Morbark Eeger Beever Model 1821 with a CAT 170hp engine and a winch package.

Grinding Chips and Bales at Donahoo, Inc.

A driving objective for the PG&E woody biomass baling pilot study is to determine the feasibility to process powerline trimming vegetation into functional feedstocks for small scale and distributed gasification. The current pilot includes **Omni BioEnergy** as a distributed-scale gasifier company and **Scotts Valley Energy Company** (SVEC) located in Kelseyville, California. Omni BioEnergy's Artis gasification systems are fixed bed co-current gasifiers that are most often directly coupled to internal combustion engine/generators to produce 200-1,000kw of distributed power. The SVEC business plan includes 1) a set of clustered regional bioenergy projects using modular Omni Bioenergy (www.omnibioenergy.com) gasification and electricity generation technology systems, 2) a biochar processing facility, and 3) a wood processing campus. The specification we agreed to for gasifier feedstocks in this pilot study were for the biomass to pass a 3/8-inch screen deck and not pass a 3/32-inch screen deck. Additionally, an objective was to minimize the amount of long shardy particles and sticks that could jamb feeders and augers at the gasifier.

Small-scale gasifiers require feedstock that is uniform, flowable, and has a particle size distribution appropriate for feeders, augers, and the gasifier reactor. Gasifiers such as produced by Omni are sensitive to excessively large and lengthy particles that can cause jamming. It is generally accepted that "arborist chips" have unacceptable size and shape for use in small gasifiers. Bulk vegetation management debris, chipped debris, and baled debris all need to be further milled and screened to produce gasifier feedstocks.

To that end, **Donahoo, Inc.** was enlisted as a central grinding yard cooperator for the pilot study. The company routinely processes woody biomass, including PG&E vegetation management debris, into hog fuel for large-scale biomass boilers using a horizontal grinder and grate with large openings. With support from PG&E, Donahoo replaced the grinding bits with cutter bits and replaced the large grate with a fine grate having 5/8-inch openings. These choices are commonly used in the southeastern U.S. to convert logging slash in to "micro-chips" for use in fluidized bed power boilers and in wood pellet mills. Donahoo wanted to assess the performance of this atypical setup on not only the Forest Concepts biomass bales but on chipped vegetation management debris and roundwood logs from vegetation management and burned sites.

Two chip trucks (one each day) delivered their loads to Donahoo, Inc. The crew unhooked their chipper outside the scale area, weighed the truck on the scale, and dumped the loads next to each other adjacent to the grinder. The truck and crew then scaled out, hitched back to their chipper, and returned to their work sites. The first chip load had a green weight of 4,620 pounds (2.31 green tons), and the second load had a weight of 6,200 pounds (3.1 green tons).

In an operational system, dumped chipper loads would be combined and pushed up into large piles to save space and homogenize the materials. To mimic that, a front-end loader combined the two chipper piles before they were fed into the grinder.

Bales were gathered by a Loggers Unlimited 5th-wheel self-loading grapple trailer at the baling site and delivered to Donahoo, Inc. The truck and trailer scaled into the yard, unloaded the bales using their own grapple, and scaled out of the yard. The combined weight of four bales was 3,060 pounds (1.53 green tons).

Although not documented, delivery time was approximately the same for the chips and bales.

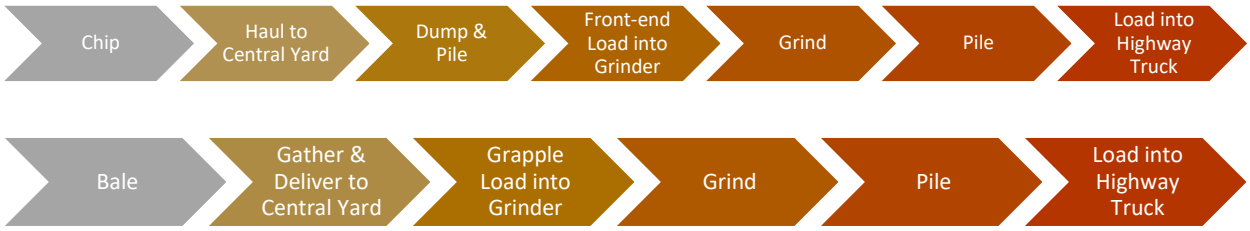


Figure 7: Delivery and processing operations for chips vs bales using a central grinding yard such as Donahoo, Inc.

The figure above shows the sequence of unit operations for a central aggregation and processing yard beginning with chips or bales at a vegetation management site and ending with loading highway trucks for delivery of ground biomass to a gasifier site. This is one of many potential schemes for organizing a supply chain that ends with finished gasifier feedstocks. In this scheme, both raw chips (that contain many long sticks) and bales are ground into a bulk material for transport and subsequent processing at the destination into reactor-ready and user-specific feedstocks.

The economic analysis details two alternative schemes; this one and another where no grinding takes place at the central aggregation and reloading yard.

Processing Chipped and Ground Materials at Forest Concepts

Since Donahoo, Inc. did not have a screening system, samples of ground biomass from each material were brought to Forest Concepts' processing plant in Auburn, Washington for screening through a two-deck orbital screen. The Forest Concepts Model 2448 orbital screen system was used to determine the mass yield of on-spec particles that pass a 3/8-inch top screen and were retained on a 3/32-inch lower deck fines screen.

Since Scotts Valley Energy plans to develop a wood processing campus to directly serve the feedstock needs of their gasifiers, an additional objective was to evaluate the utility of Forest Concepts' Crumbler® rotary shear equipment for processing chipped and shredded vegetation management debris close to the point of use by the gasifier systems. The Crumbler® systems are better scaled to the needs of a gasifier campus, are quiet, produce little dust, and typically have higher yields of on-spec feedstocks than grinders or hammermills. To that end, a portion of the materials brought to Forest Concepts were milled and screened using the Crumbler® system. A select set (seven different materials) of candidate gasifier feedstocks were shipped on September 28, 2021 to Omni BioEnergy for their review.

Baler Pilot Results and Observations

Baler Production Time

Four bales were produced while working in tandem with the two trimmer trucks along Bachelor Valley Road. An observer (Dooley / Lanning) recorded the clock time for the start and end of each baling period and the clock times when the primary work activity began (moving, waiting, baling, …). That data was entered into an Excel® workbook to compute the elapsed time for each activity, total baling time, and elapsed time for each bale. Several hours of video was also collected that may be used for more refined time-studies in the future, but such work is outside the scope of this pilot.

The total work time for each bale is shown in the graphic below. Bales 1 and 2 were produced on the first day of the pilot and bales 3 and 4 were produced on the second day. The "learning curve" was partially due to progressive improvement in the coordination of baling with the trimming crew and partially due to the increase in density of trimmings along the roadside from the first day to the second day. In particular, the trimming crew was able to get ahead of baling on the morning of the second day since they were extensively trimming a couple of very large-bushy mature oak trees. After the crew moved on from those trees, the baler crew could work intensively without moving very much.

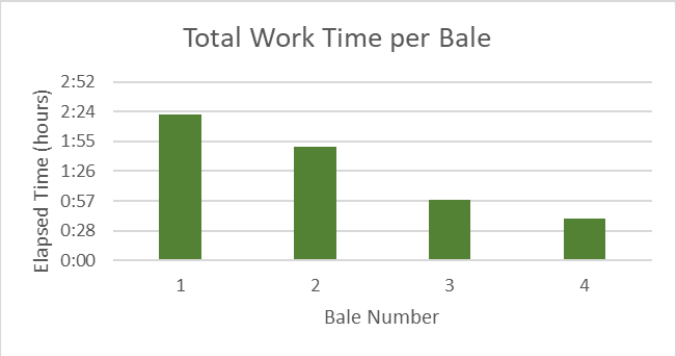


Figure 8. Time in hours to produce each successive bale during the two-day field pilot. Total work time includes moving, waiting, baling, tying, etc. Total time does not include scheduled lunch breaks or maintenance downtime.

The time spent baling at each stop/pile along the road ranged from one minute to fifteen minutes, with most baling times in the 2-3-minute range. This time and frequency appeared to be similar to the observations for the chipper crew. The average percentage of total baling time spent on the baling work activity was 59%. The percent baling time ranged from 47% to 76%.

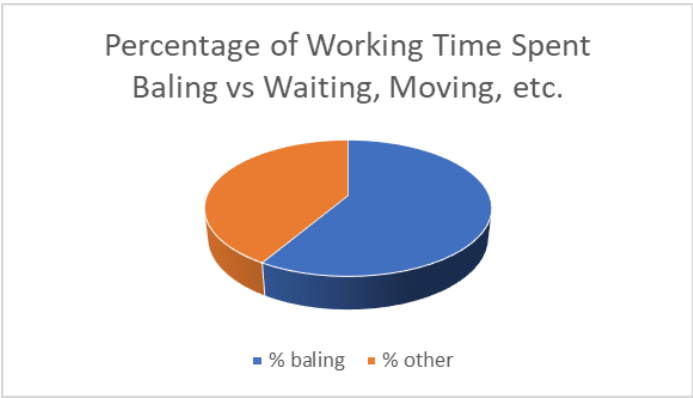


Figure 9. The average percentage of total baling time spent on the baling work activity was 59%.

Sound Level Measurements

Among the proposed benefits of baling versus chipping is the much quieter noise levels for baling. Noise complaints from neighbors is often associated with chipping of woody vegetation debris. Thus, we collected initial sound level measurements around the baling, chipping, and bucket truck equipment.

The general sampling method was to use a digital sound level meter to survey points behind, alongside, and in front of each operating piece of equipment. We did not measure sound level behind the working bucket truck to avoid incursion into the safety zone.

In general, the baler system had similar loudness to that of the bucket truck trimming crew. As expected, the chipper was much louder.

Table 1. Sound level readings at two distances from a bucket truck trimming crew, the Forest Concepts biomass baler, and a chipper.

		Sound Level (dbA)		
Location	distance (ft)	Bucket Truck	Baler	Chipper
Behind	5		94	105
Side	5	87	86	104
Front	5	79	70	90
Behind	30		80	103
Side	30	82	80	100
Front	30	76	69	82

The actual sound intensity for a dbA scale increases with an exponential factor of ten (10x). This means that a meter reading of 90 is ten times louder than a reading of 80 and a reading of 100 is ten times louder than a reading of 90.

It is important to note that our interest in this initial survey was to assess the potential concern for neighbors and nearby workers. Sound level surveys for the purpose of worker safety, personal protective equipment (PPE) specification, and daily average exposure are outside the scope of this project.

Crew Size for Baling vs Chipping

In the Forest Concepts proposal, the baling crew was proposed as two people – an operator/truck driver and a ground person. During the Pilot field trial, due to the high frequency and short distance for most moves (e.g. 2 minutes to bale a pile followed by 1 minute moves of 100 feet or less), the ground person did the driving within a work area and the baler operator/crew lead did the driving between sites. Traffic control was provided by a combination of the Forest Concepts ground person and the Loggers Unlimited trimming truck ground personnel.

As noted earlier, the chipper crew was working several miles away independently of tree trimming operations, so no data was available on how the two crews worked together. However, in the independent chipping sites that Forest Concepts observed, the chipper crew had five personnel when working along a paved active roadway. A front-person focused on traffic control and moving traffic cones to stay in front of the chipper truck. A driver stayed in the truck for the most part due to frequent short moves along the road. Two chipper operators gathered woody debris and fed the chipper. The

fifth person walked behind the crew to provide rear traffic control and to tidy up the road by blowing off leaves and fine twigs.

The main observation made by those who attended the Pilot was that the physical effort for the baler ground person was minimal compared to a chipper ground crew. The person easily had time to do site cleanup and assist with traffic control.

Much more extensive field work across a range of road, vegetation, and other variables will be needed to draw any conclusions about the necessary crew size for baling vs chipping. Had the Forest Concepts baler crew been working independently of the tree trimming crew, additional personnel would have been required for the traffic control duties.

Transportation Bulk Density and Transportation Logistics

One of the *ProblemSpace* objectives was to increase the bulk density and reduce the cost of transportation to users at least 50 miles away from the thinning site. There are two possible current baselines for the transportation challenge. Today, chipping crews stop work when their chip truck is full and drive the truck, chipper, and crew to either a residential site that wants chips or to a central yard/compost facility where they are scaled and allowed to dump. The distance is often within 5-15 miles. The vegetation management company that cooperated with this Pilot commented that the chip-dumping time constituted an important recuperative work break for the chipping crew. The company works hard to maintain a call list of residents, landowners, etc. that will take truckloads of chips for free and are within a short distance of each planned work site. Their cycle time to deliver, unload, and return is often in the range of 30-45 minutes. At the end of the day, the crew often will dump a partial load of chips at their equipment staging yard so they can begin the next work day with an empty truck.

Thus, one interpretation of the 50-mile delivery objective would be for the entire crew to make that delivery on a load-by-load basis. Assuming an average travel time of 2-minutes per mile on urban/suburban/rural roads and a scaling/dumping time of ten minutes, the total time to deliver a load of chips and return to the work site would be approximately 210 minutes (3.5 hours). This would substantially reduce the productive chipping-work time per shift (on an 8-hour day) and would preclude gathering more than one truckload of chips per day unless alternative close sites were available to unload as well as one long-haul 50-mile delivery per day. The reduced daily productivity would likely result in two chipper crews being assigned to each work site so they could keep up with vegetation management production of downed biomass.

The more practical interpretation of the 50-mile delivery objective would be for the vegetation management company (or a subcontractor) to maintain a chip aggregation yard within close proximity to work sites and coordinate the logistics of a two-stage hauling scheme. In this scenario, the chipper crew may follow a routine like they do today. The location of aggregation yards could be carefully choreographed with the working assignments for vegetation management crews with a high value placed on minimizing distance and time for “first-mile” chip delivery and unloading. Large regional chip aggregation yards may substantially increase the average cost for “first-mile” chip delivery versus the current operating scheme.

The two-stage transport and delivery scheme may result in the “first-mile” chip delivery costs being equal to the current situation, but will add costs due to yard site, equipment operations, long-haul truck loading and the cost of trucking to the destination. Since we do not know the direction of the long-haul destination compared to the “first-mile” direction from the work site to the yard, we have to assume that the long-haul distance is still 50 miles. The benefit will be that the long-haul chip trucks can carry the equivalent of seven chipper trucks and the only passenger is the driver. If we further assume the same travel speeds as the chipper crew would have, but with an industry-average 30-minute loading

time and 20-minute unloading time at the destination, the average time per load would be 250 minutes (4.2 hours). Even with sophisticated driver scheduling, this would limit each long-haul truck to making about five trips per day with three shifts of drivers (given additional time for refueling, DOT mandated breaks, etc.).

One way to increase long-haul bulk density and net energy content as desired in the *ProblemSpace* goal would be to add chip processing to the aggregation yard. Milling to smaller particle sizes, screening out undesirable fines, and either natural air drying or heated air drying will increase both the amount of net biomass transported and the value to the user if that user is a thermal process.

Effects of Baling Alternative on Transportation

When we switch to the proposed baling alternative to chipping, much of the chips case directly translates. If we replace the current chip boxes on the chipper trucks with a flatbed, then maximum allowable weight will limit the number of bales that can be carried to five or six depending on moisture content. Thus, the first-mile payload would be the same as for chips. Obviously, replacing the existing chip trucks with more optimized flatbed trucks having larger payload would increase the time for baling vs first-mile transportation.

One opportunity that was included in the Lake County Pilot was to decouple first-mile bale hauling from the baling operation. This is not practical today with chipping crews but might be invented in the future. During the pilot, bales were set along the roadside outside of the fog line as they were produced. A Loggers Unlimited two-person crew with a self-loading flatbed trailer periodically visited the site to gather the completed bales and transport them to a centralized aggregation and grinding yard (Donahoo, Inc.). An optimized light truck and fifth-wheel trailer similar to the photo at right, may be able to gather 10-12 bales per load, which is twice what a chip truck can haul, but may be similar to what an optimized baler crew truck might haul.

Decoupling bale first-mile hauling meant that the baler crew worked full-time which should result in increased daily production. Because the ground crew effort associated with baling is minimal compared to chipper crew work effort, there is probably not a need for the recuperative breaks that chipper crews get while delivering chip loads to residents.

For the long-haul portion of the baled biomass transportation system, bales would be loaded onto flatbed semi-trucks and tarped for the 50-mile delivery. Flatbed trailers are approximately one-fifth the capital cost of chip trailers. The time to load and unload, including tarping, would be similar to loading and unloading chip trucks and the travel time is likely to be the same. Thus, the benefit of baled biomass transport comes down to the bulk density and payload. The bales produced during the Pilot had an average weight of 765 pounds. This computes to a 48-bale truckload having a payload of approximately 37,000 pounds (18.5 tons) of woody biomass at 23% moisture. This is in the same range of the payload for chips in the chip truck case.

Observations from Loggers Unlimited

The following email was received from Loggers Unlimited about their observations:

> *Tuesday, October 12, 2021 6:04:45 PM (*minor edits from FC to improve readability*)*
>
> *As safety manager I could see the immediate safety aspects of the lack of human interaction that goes along with feeding a chipper versus mechanically loading the baler. Not only the obvious but potential injury from lifting, bending, feeding the chipper on uneven terrain, potential of debris being launched out of the chipper. The only thing I can really see* [to improve the baler*] is the safety stops on the grizzly bars covering the hopper if someone needs to physically access the hopper.*
>
> *The noise level was good. You could actually hold a conversation next to the baler and even a couple of customers commented on how quiet it was.*
>
> *The baler would be helpful in overall safety and in the areas the noise dust could be an issue, and possible EVM projects are also a potential due to the amount and proximity of the brush being produced. EVM work would also depend on the baler being on a track chassis. Efficiency would greatly depend on proximity and number of bale drop and processing sites.*
>
> *This overall was a great experience seeing the potential direction and the Forest Concepts Team was great to work with their positive attitudes and professionalism.*
>
> *Thank you*
>
> *Aaron Stanger-Safety Manager*
>
> *Loggers Unlimited inc.*
>
> *(530)446-4690*

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Jeff Durtschi and Steve Owen – OmniBioenergy

Chris Richardson, ADL Ventures

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Appendix 1: Preliminary Baler Family Specifications

August 21, 2009 (updated 11/29/2009, 07/28/2010, 01/20/2020, 9/30/2021)

Biomass Balers – Model 25xx family (direct replacement for small tow-behind contractor chippers)

32x48x56-inch high density bale, 1000-1500 lb. bale

2510 – Entry model street legal baler (one bale per hour) (4-6 bales per day)

- 40 hp gas engine
- Hand loaded
- Hand-tied bales
- Bale dropped on ground for pickup with front end loader

2515 – Entry model ag/off road chassis (one bale per hour) (4-6 bales per day)

- Walking beam axle
- Pintle hitch
- Low ground pressure tires

2540 – Utility baler street legal (three bales per hour) (12-20 bales per day)

- **Two-person crew**
- **45-70 hp diesel engine**
- **Grapple loader (operator seat with hydraulic controls)**
- **Slashing saw**
- **Manual tie**

2540-C - Utility baler street legal (four bales per hour) (12-20 bales per day)

- **Single operator with ground crew**
- **45-70 hp diesel engine (CARB compliant)**
- **Grapple loader (operator seat with direct and teleoperator control)**
- **Slashing Saw**
- **Auto-tie with wire**
- **Teleoperation with RF control**
- **Straight dual axle trailer with 2-5/16 ball hitch**

2540-CT – Utility baler on tracked undercarriage (otherwise same as 2540-C street legal baler)

2545 – Utility baler ag/off road (three bales per hour) (12-20 bales per day)

- **45-70 hp diesel engine**
- **Grapple loader**
- **Slashing saw**
- **Walking beam axle**
- **Low ground pressure tires**
- **Tow with truck or tractor**