Appropriate Technology Biomass Collection and Handling Systems for Smallwood Utilization

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Forest Concepts, LLC

SBIR Phase I Project Final Report

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Executive Summary

The continuum of forests and natural areas in need of fuel reduction thinning ranges from wilderness and working industrial forests to urban neighborhood greenbelts and overgrown residential lots. An object of this project is to characterize the problems associated with projects in the true wildland-urban intermix of residential lots to open spaces containing 20 acres or less. Our problem can be further decomposed into those properties that are wholly within urban areas – e.g., Berkeley and Santa Cruz, California; and those areas that border expansive public and private forests – e.g., Auburn, California and Pendleton, Oregon. Our goal is to synthesize optimal or at least more appropriate biomass collection and handling systems for these situations. In particular, we seek to specify functional objectives and design parameters for biomass handling systems that enable value-added utilization of biomass removed in the process of reducing fire risk and improving forest health.

The stimuli for the present project are the combined national priorities established by the National Fire Plan, the Healthy Forests Restoration Act, and the Energy Policy Act of 2005, with specific emphasis on their biomass provisions.

Community forests, greenbelts, and other urban natural areas are challenging the public with dual, yet interconnected problems of declining forest health and uncontrollable wildfires. Simple solutions are particularly impractical in the wildland-urban intermix of residential lots, public spaces and a patchwork of forestland / brushland. While traditional logging, macerating and thinning is practical in contiguous forests with established forestry infrastructure, the "front yard-back yard" nature of the intermix requires more appropriate systems and methods. A national focus on fire prevention and forest health in the intermix is less than a decade old, thus methods, equipment and strategies are at a very early stage of development. Costs are unacceptably high, and frustrations among landowners and contractors mount as inappropriate systems and equipment are used.

Forest fragmentation due to subdivision of land near rural communities results in high-hazard zones surrounding traditionally agricultural and timber towns. Private and industrial timberland owners typically cease active management of lands that are slated for subdivision, resulting in missed thinning and commercial harvests. Buyers of suburban lots typically seek the visual shelter of dense vegetation, and ambiance of "living in the woods." Further, naïve urbanites rarely appreciate the need to manage their newly acquired properties in order to maintain or improve forest health and sustainability. We are now facing thousands properties that are undergoing intervention as a result of insurance company pressure, local fire protection regulations, or incentives from federal agencies. In some cases, existing logging contractors and infrastructure is sufficient to execute projects, but more frequently no ready solution exists to conduct thinning and biomass removal.

We characterized methods used and biomass utilization destinations for communities across the West through surveys, interviews and site visits. The first survey collected general information about the amount of biomass/smallwood collected, current destinations for woody biomass, and the nature of programs in each community. Follow-up surveys collected additional information about utilization opportunities and more detailed information about how projects are executed.

The original work plan called for a few multi-day site visits. Very early in the interviews, we learned that the kinds of in-depth data we were seeking were not available. We also found that the variety of situations was very broad, both geographically and by community type. Thus, we decided to visit many

communities in a series of regional trips. Some sites were visited prior to receiving SBIR funding. Areas visited to assess fuel reduction thinning methods and biomass utilization include:

- Methow Valley, WA – second-home communities and subdivision of working forest lands
- Pendleton/LaGrande, OR – mixed non-industrial forests and suburban properties
- Snoqualmie, WA – community of executive homes on 20 acre lots comprised of former industrial timberland
- Sierra foothills from Susanville to Sacramento, CA – mixture of working forests and rapid suburban development
- Coastal range from Santa Cruz to Yreka, CA – urban greenbelts, parkland areas, suburban development on wildland interface
- Missoula, MT- rapidly expanding urban center encroaching on industrial and public working forests
- Central Oregon from Prineville to LaPine, OR – intermix of public recreational forests and suburban development
- Warm Lake, ID – Resort lots and in-holdings entirely surrounded by the Boise National Forest

We found projects in the Sierra foothills and near other timber communities that were generating more than enough revenue from log sales to cover direct costs. We found projects in other areas, including some near timber towns that operated at a public cost of several thousand dollars per acre. In every community, we found landowners and coordinating councils that would like to increase the value-added utilization of biomass removed during thinning and fire protection brush removal. Although our project team has identified more than 100 potential uses for woody biomass, few community project coordinators or contractors could name more than logs, compost, mulch, and cogeneration energy fuel as potential outlets for their biomass. The vast majority of all woody biomass was either being left on the sites, or hauled to disposal sites.

The short-term opportunity for innovation is to reduce the cost of materials handling, regardless of whether the destination is disposal or value-added utilization. Today, almost all of the woody biomass that is removed is in the form of merchantable logs or commingled whole-plant chips. Where sufficient logs are collected to support loaders and truckload hauls, the revenue supports their handling. Conversion of biomass to commingled chips precludes almost any use except mulch and some cogeneration customers. Additionally, chips are costly to transport since they have a bulk density of only 7-9 pounds per cubic foot compared to solid wood at 28 – 40 pounds per cubic foot.

Tow-behind trailer-mounted chippers are the most common equipment used for biomass preparation. The chippers are more expensive to operate than most fire protection groups realize, and are extremely noisy when operated in residential neighborhoods. Other than hauling materials away in the loose bulk form, we did not learn of other materials handling equipment. However, during the energy crisis of 1975-1983, biomass baling, cubing, pellet mills and related techniques were researched. Baling was the most promising technique, in part because it consumes relatively low energy and is mechanically simple. Unfortunately, the technology was never commercialized.

As noted above, we identified over one hundred potential uses for woody biomass. We also found that many of the communities interviewed or visited would prefer to see more value-added utilization. Thus, the synthesis objective for this Phase I project is to specify collection and handling systems that are appropriate to the context of wildland-urban intermix programs, AND that preserve utilization potential of the recovered biomass.

The most promising equipment systems include:

- Baling into high density bales that are easy to transport on highway trucks, rail cars and barges – take advantage of existing transportation infrastructure for intermediate and long hauls

- Transportable feedstock preparation equipment and centers that can process biomass into poles, cants, fiber fractions, and wood strands in the communities where biomass originates – deliver what each customer/user needs and in a form that reduces their subsequent costs
- Intermodal bunks, bins or other unitization that reduces the handling costs associated with transfer of materials between transport vehicles – avoid dumping stuff into piles and then reloading

In addition to collection and handling systems, community-based fire protection groups and contractors need logistical and marketing support. They do not know what the outlets for their biomass are, what the feedstock specifications are, and how to ship the material cost effectively. There are many parallels in the recycling industry that apply to the biomass situation. Creation of small quantities of old corrugated cartons, newsprint, aluminum, plastics and metals is highly dispersed across the landscape and community. Producers (homeowners, offices and shops) do not need to know where to take each material, or even allow time to haul the recyclables themselves. Today, highly efficient collection, sorting and transport logistics companies take care of all the details. We envision that similar logistics companies will develop in the future for biomass collection and handling.

Phase I Conclusions by Research Question

What are the individual piece characteristics of fuel-reduction biomass that map to potential value-added uses?

- We expected the material from any particular site to be fairly homogeneous, and dominated by conifer poles. However, our survey results and site visits demonstrated that the woody biomass removed from fire protection thinning sites is dominated by brush and limbs, with relatively few pole-size stems.
- Most programs surveyed either piled for on-site burning or pulled to the roadside for chipping. Solid wood conifer poles are often piled for the landowner to cut into firewood. Merchantable, saw-log size stems are sometimes yarded to the road and loaded on conventional log trucks. More often the logs are cut into firewood and left for the landowner to use.
- In part, due to lack of knowledge about utilization options, most non-merchantable biomass is cut, chopped or otherwise reduce to piece sizes that preclude value-added use.

What are the piece size and characteristics wanted by primary users of each biomass fraction?

- We have developed a catalog of potential uses. The list of 108 uses in our current catalog ranges from charcoal for barbeques, to commodity fiber and paper chips. We have identified one or more value-added uses for all fractions of the biomass, except poison oak.
- Value-added users of woody biomass almost universally want material that is in larger pieces and cleaner than the commingled “arborist” chips that are produced today. Even cogeneration energy facilities would prefer coarser material.
- We heard from potential users that once the woody biomass is chipped into commingled green chips, including bark, needles, multiple species and dirt, it is of little value.
- Most engineered wood products firms prefer to receive whole logs today so they can control the production of their own feedstock. Specifications for wood strands to be used for engineered lumber and wood flour for composites are under development. There is an emerging opportunity for intermediary firms to produce commodity feedstocks.

What are the characteristics of a representative sample of biomass and stems from three or more geographically disperse locations in the West?

- In the Methow Valley of north-central Washington, the roundwood stems range from 3-inches to 12-inches diameter and are mixed pine species. Most of the volume consists of conifer branches, understory brush and bitterbrush from open areas.
- In the Snoqualmie suburban neighborhoods of the Puget Sound region, the roundwood is former timber plantation Douglas fir of small to merchantable diameters. The brushy material and limbs are not presently removed for disposal or use. However, the King County Economic Development group is keenly interested in the potential for value-added uses.
- In the Pendleton and LaGrande area of northeastern Oregon, the roundwood is primarily merchantable pine and fir. Pole-size material is sent to a post and pole plant. Brush and limbs are ground on-site and spread over the land.
- In the coast range of California, the roundwood is a mix of eucalyptus, pinus radiata, and pine, depending on the watershed. Most of the volume is brush species including chaparral, manzanita, poison oak and scrub oak.
- In the northern Sierra foothills, the roundwood is mostly low-value pine and oak. As with other sites, most of the volume is brush and limbs.

What are effective and efficient equipment and logistics systems for preparing, transporting and handling the biomass fractions identified in objective 1?

- Current methods for materials collection and handling are admittedly inefficient and costly, except for the merchantable logs that fit conventional logging trucks.
- More appropriate materials handling would be to bale or otherwise densify whole-plant biomass and fiber to preserve value and decrease transport cost. Smallwood utilization with wood bunks would reduce the cost of handling pole stock.
- We conducted baling tests with bitterbrush and photinia. The material before baling had a bulk density of approximately one pound per cubic foot. After baling, the density was ten - fifteen pounds per cubic foot. There were no technical problems with baling in a recycling baler. This material would not be able to be baled in a conventional agricultural baler. We subsequently processed a bale of photinia through a tub grinder to produce hog fuel and compost feedstock.

What are the operational characteristics of wildland-urban interface fuel reduction contractor businesses?

- The contracting business in more urban areas is dominated by very small contractors and is highly fragmented. Contractors entered the fire protection market from existing bases in landscaping, grading, or tree trimming. Equipment and methods often reflect the roots of each business. The only new equipment purchased for use in the interface projects appears to be chippers and powered pole saws. In many cases the contractor provides labor only. The local fire department, community or landowner association often purchases a chipper or other special equipment with grant funds from state or federal programs.
- The contracting business in rural and forest areas is shared by logging and forest operations/wildfire contractors. Where a project is framed as a timber sale and the site is amenable to traditional logging equipment, logging contractors assume the lead. Where the merchantable volume is low or site conditions are difficult, forest operations contractors, and marginal loggers are involved.

- In residential areas, individual homeowners and neighborhood groups provide most of the labor. They pile brush on the street for waste disposal, or in advance of "chipper days" where the local agency chips on site. Some community programs employ inmate crews for labor.
- We found no examples of centralized collection, sorting, and reselling such as is practiced by woodlot operators in timber towns and recycling firms in urban centers.

What are appropriate existing and to-be-developed equipment systems for the contractors and for their customers?

- On-site materials handling is in need of labor aids and agile, small forwarders
- Our historical review of equipment systems developed in the U.S., Canada and Europe during the last energy crisis of 1975-1983 found that baling for efficient transport held the most promise.
- Lower energy, low noise size reduction equipment such as slicers and shears may be more efficient and acceptable than chippers used today.

What are the capital, operating and other costs likely to be with new systems versus existing methods for handling and transporting biomass and stems?

- Capital costs should be similar to existing systems. We propose to substitute balers and self-loaders for a chippers and tractor-loaders.
- Operating costs should be substantially lower since we will eliminate the hand-feeding labor and expensive repair and maintenance of a chipper.
- We adapted the USDA Forest Service Southern Research Station FORTSv4 Biomass Trucking Simulator to analyze costs for existing and proposed methods. Chipping urban biomass and delivering it 200 miles to a cogeneration plant should cost approximately $135 per bone dry unit (bdu). An optimized biomass baler system has a projected cost of only $62 per bdu.
- Unitized collection and handling of small diameter roundwood and chunkwood should reduce the operating costs from approximately $100 per ton today, to approximately $40 per ton in the future.

What are the likely system economic benefits of implementing an improved biomass collection and transport system?

- The fuel value of biomass is approximately $40 per bdu, and the federal subsidy is expected to be $15 per bdu ($20 per green ton). Thus, the baler option is nearly break-even while the chipper base case requires large public subsidies.
- Reducing the handling cost of smallwood brings the material cost in line with post and pole plants. The potential exists to re-establish one or more post and pole plants in the north-central California region.

For each of at least three communities, what is the expected outcome of implementing a new system with respect to volume of biomass converted to higher value uses, potential increased economic activity, and number of interested contractors and biomass customers?

- None of the communities we studied have anything approximating a vibrant timber economy. Most of the forestry and wood products infrastructure is long-gone, except in the Susanville-Burney Falls area of California. In most cases, biomass will need to be transported a hundred miles or more to any significant user.

- A fledgling compressed wood fuel producer in Watsonville, CA may grow to become a significant user of woody biomass from the Bay area. However, their local markets are eroding due to fireplace regulation, air quality restrictions and lifestyle changes among their customers.
- No post and pole firms are left in California, yet the state is a significant market for poles produced in Canada, Montana and Idaho. Therefore, an opportunity exists for a regional post and pole operation, most likely along the Interstate 80 corridor.

SBIR Phase I Project Team:

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Responsibility: Value-added uses, Feedstock Specifications, Systems
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Handling equipment, Energy Optimization, Field Studies
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Surveys and interview design, conduct, analysis. Community group relationships
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Primary Agency Cooperators:

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Biomass collection and utilization – historical perspective and resources
Bill Elliot – USDS FS Rocky Mountain Research Station
Materials size reduction and energy estimates
Craig Rawlings – Montana State Technology Development Center, Missoula
Biomass collection and utilization programs

Comprehensive Report of Activities and Results

Our objective:
Improve the utilization of biomass removed from fuel reduction thinning projects in the wildland-urban intermix zone (residential lots to 20 acre units)

> Specifically, this project proposes to design and develop biomass handling systems that enable collection and handling of the various fractions of thinned forest biomass such that the materials can be allocated to their highest and best use in surrounding communities.

Expected outcome:
The end result of the project will be new knowledge and performance data that will enable more cost-effective recovery of forest biomass from fuel reduction and forest health thinning projects. Improved cost effectiveness will enable treatment of additional acres. Lower wood and biomass cost will enable job creation and improve business sustainability in rural communities throughout the forested regions of the nation. At the end of Phase II research (summer 2007), new equipment systems will be demonstrated to contractors and landowners.

Introduction to the problem:
Prior to the creation of the National Fire Plan, fire protection around homes and communities was the responsibility of individual landowners. Local regulations typically required mowing of dry grass and clearing of dead brush to reduce the risk and magnitude of wildfires around homes and public buildings. Projects were executed by landscape and arborist contractors or individual landowners. As such, the materials removed were piled and burned, hauled away or chipped at the discretion of the landowner.

The advent of the National Fire Plan and subsequent legislation requires half of the federal funds (approximately $300 million per year in FY05) to be spent in the wildland-urban interface. The federal program also funded the creation of local coordinating and contracting bodies that are variously named FireWise, FireSafe or other forms of fire prevention councils. There are approximately 150 local FireSafe Councils in the state of California, and probably 300 related councils across the West. The graphic below provides insight into how the money and responsibilities flow from the Federal program to the execution of projects on the ground.

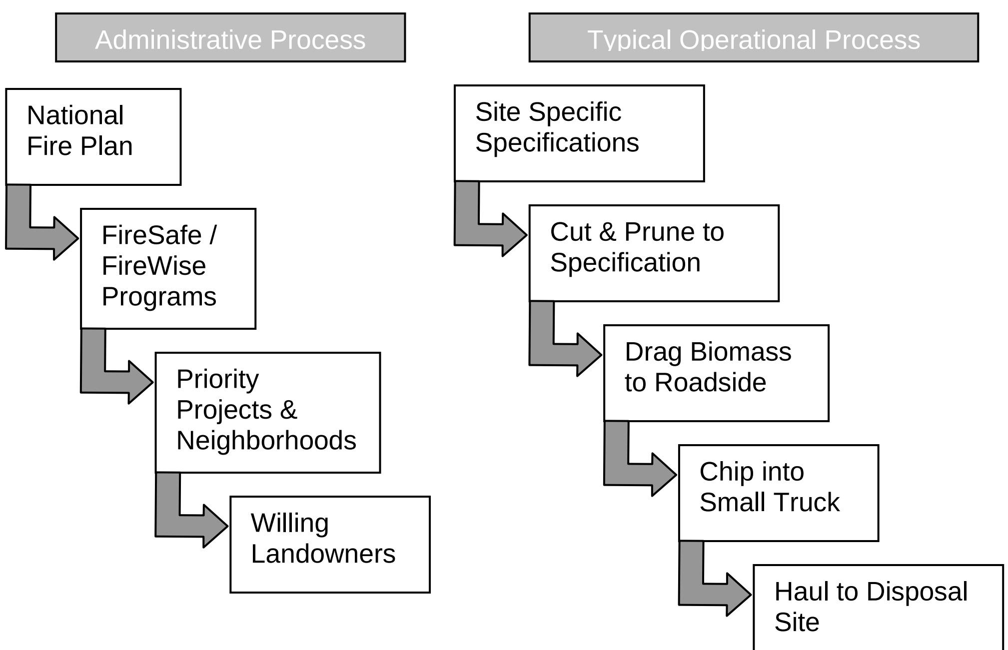


Figure 1. Graphical overview of typical administrative and operational processes that apply to wildland-urban intermix fuel reduction projects.

To help provide a visual context for the current situation and end result of fuels reduction projects we present two photos below from the Methow Valley of North-Central Washington State. The photo at left includes very high density of standing trees, dead understory and dead branches down to the ground level (aka ladder fuels). Many rural homeowners value the visual screening that high density forests provide. They typically have been reluctant to remove fuels on their own since it would open up their home and activities to viewing by neighbors and others – and thus compromise one of the benefits of "living in the woods." The photo at right shows a neighboring property that was thinned and pruned under National Fire Plan funding to meet the regional FireWise recommendations for tree spacing and fuels removal. The site has more of a park-like look and feel, including native grass vegetation that had previously been shaded out by the dense canopy above.


Figure 2. Photographs of two suburban sites visited in the Methow Valley of eastern Washington. Left photo is of a site just before thinning. Right photo is of nearby recently completed site.

The on-the-ground thinning activities involve two stages in most cases. The first shown in the photo sequence below is the cutting, piling, skidding or dragging and pruning of vegetation around homes. The crew shown in figure 3 is a forestry contractor who uses small skidders to move materials and a chainsaw crew to cut materials.


a.


b.


c.

Figure 3. Photos from visit to Methow Valley projects. Small diameter stems are bunched for skidding (a) by as small cable-skidder (b) to roadside. Branches are pruned from standing large trees to eliminate "ladder fuels" (c).

In some cases the biomass is piled in small piles around the property for burning in the fall or winter. Where equipment can drive onto the property, some landowners allow the crew to chip the material and spread the chips back across the ground. More often, the landowner requires that the biomass be removed from the property. In that case the biomass is either dragged or skidded to the edge of the street and piled for subsequent handling.

The photo series below shows a typical on-street operation from two projects on the Central Coast of California. Brush is accumulated into piles at the property itself (fig. 4b) or collected in neighborhood piles (fig. 4a). Daily or weekly a crew brings chippers and chip trucks to the site and disposes of the accumulated piles. The crew in figure 4b is an inmate crew using equipment owned by the Morepark FireSafe Council. The equipment was purchased by the council with funds from a National Fire Plan grant.

a. b. c.

Figure 4. Photos from visit to central coast of California. “Front and backyard” projects yield piles of brush alongside the road (a). Chipper crews gather material (b) and chip it into small trucks (c) for disposal.

Characterizing “the problem”

The fundamental problem for us is to find a better way to handle the “stuff” that comes off the landscape as a potential co-product of fuel reduction projects. We can better understand the problem by characterizing biomass from our area of interest (residential lots to 20 acre suburban properties) against relevant scale factors.

The first factor we will consider is that of characteristic piece size. The figure below shows a range of piece sizes from grinder dust to whole-tree logs. Once material is ground into chips, fibers and dust, there are relatively few utilization opportunities. Certainly all of the solid wood options are precluded. In order to upgrade the value, much capital and energy must be expended. For example, sawdust can be converted to fuel logs and pellets that replace firewood, but at a cost of more than $100 per ton.

Characteristic Piece Size (feet long)

0.002 ← 0.02 — 0.2 — 2.0 → 20

Dust	Fibers	Chips	Blocks	Posts	Poles	Logs
Plastic lumber	MDF	Paper	Firewood			

Utilization Options Remaining

Few ← Many → All

The second metric that we will consider is that of invested energy. It is axiomatic that bigger pieces take less energy to make. Capturing a whole log takes only two cuts of a saw – one at the butt and one at the top of a useful log. As we further reduce the cut length to pole segments, firewood and chips, we increase the number of cuts and the cumulative cross-sectional area of cut surfaces. Thus, we can craft a scale of invested energy for various piece sizes. We also know that energy produced by a chainsaw is more expensive than energy produced by an engine chopper at roadside, and that in-turn is more expensive energy than an electric or steam powered processor at a fixed factory location. Thus, we can conclude that it is more energy efficient to transport larger and more intact pieces to a final destination – provided that the cost of transportation is not piece-size dependent.

Invested Energy versus processed piece size

0.002 | 0.02 | 0.2 | 2.0 | 20

Extreme | High | Modest | Low

Piece size also drives our choice of handling methods. Sawdust and fibers are best handled with pneumatic conveyors, while wood chips and firewood chunks are best handled with belt conveyors. Once the piece size exceeds approximately four feet in length, the pieces no longer can turn corners or be easily conveyed, except in straight lines. Longer stems are best handled in bunks, banded bundles or as individual pieces.

Materials Handling Methods

0.002 | 0.02 | 0.2 | 2.0 | 20

Pneumatic | Conveyors | Bunks | Pieces

In a like manner, we can explore the optimal container for transporting and handling materials across a range of characteristic sizes.

Container Preferences

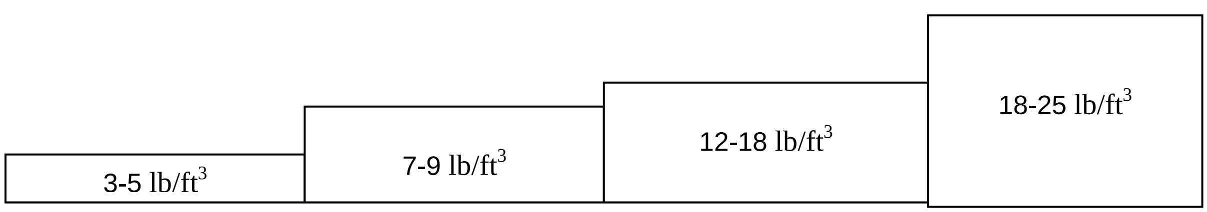
0.002 | 0.02 | 0.2 | 2.0 | 20

Bins & bags | Chip vans | Pallets | Log trucks

As a companion to container preferences, we can map bulk density to the materials in typical transport containers. Fine powders such as used for plastic lumber cannot be compressed into bricks. Wood chips cannot be baled to high density.

Bulk Density in Transport Container (lb/ft^3)

0.002 | 0.02 | 0.2 | 2.0 | 20



It is readily apparent that higher bulk density will result in lower unit transportation cost for densities in the range that we find for biomass. Truck and trailer hauling is limited either by cubic capacity of payload mass. According the Bob Rummer of the USFS Southern Research Station, trucks are limited to approximately 4,000 ft^3 of volumetric capacity and 42,000 pounds of payload capacity, whichever is limiting. Thus, any payload that has a bulk density of less than 10.5 lb/ft^3 will be limited by cubic capacity. Higher densities will enable a truck or trailer to hit the legal weight capacity before “cubing out.”

Our experiments with baling are consistent with earlier studies that result in bale densities of 13 – 18 lb/ft^3. Bales can also be readily transported on common trucks and flatbed trailers, while logs and chips require specialized transport vehicles.

Opportunity

We believe that the benefits of chippers are grossly oversold. Chipping biomass is promoted as an "easy solution," by makers of chipping machinery and many biomass combustion energy producers, but their motives are suspect. Chipping firms expanded into biomass from a base in the pulp and paper market. Pulp chips are tightly specified and must be from clean wood. The North American pulp and paper industry peaked in capacity about thirty years ago. The chipper industry grew with that of their primary customers. During the decline in the pulp and paper industry, chipper manufacturers sought to promote adaptations of their technological paradigm to other customers. Arborists embraced the chipping technology since it reduced their cost of transport and disposal of woody tree trimmings and brush. The cost savings more than offset the relatively high cost of owning chippers. Customers of woody biomass, particularly compost facilities and biomass combustion energy plants promote chipping as a preferred raw material since it benefits them to shift that cost and operation to their suppliers. We did not find any biomass customers who provided a price premium for chipped material. Thus, in a buyer's market it made good business sense for these dominant customer groups to promote on-site chipping.

Although baling was successfully researched during the 1975-1983 era, adoption would have required a paradigm shift for both equipment makers and customers for woody biomass. Many logging companies already had chippers that they had previously acquired to supply whole-tree chips to the pulp and paper industry. Thus, the cost of switching to a new paradigm prevented baling and associated materials handling to move forward.

Today, the woody biomass industry is dividing into three sectors. One sector is aligned with agricultural crop residues and agricultural materials handling paradigms – primarily baled materials. A second sector is aligned with large-scale forest restoration and fuels reduction on vast public land areas. This sector is rooted in traditional logging and chipper systems. They have huge amounts of sunk capital, fully depreciated equipment systems, and longstanding customer-supplier relationships. The third segment is just now being created to work in the wildland-urban intermix and capture urban green-waste for value-added markets.

The WUI sector is struggling to discover and develop methods and business systems that are optimal for the conditions and markets they serve. We are at a moment in time where many contractors and community fire plan groups are learning that existing logging infrastructure and landscape/tree service infrastructure are not appropriate to the task. Our site visits were greeted with great optimism that we might be bearers of a magic bullet that would simultaneously reduce the cost of fire protection programs, and increase the potential for utilization and local economic activity. Perhaps we may be able to deliver in the long term, but in the short term we probably can offer better ways to handle what biomass is being collected and preserve the options for value-added utilization.

The potential for value-added utilization depends on the availability of local and regional markets for woody biomass, poles and logs. Different fractions of the material removed during fuel reduction thinning have different market values as shown earlier in the scale discussion. In addition to piece size, the quality attributes of individual pieces affects value. An important objective of biomass collection and handling is to preserve the opportunity to direct materials to their highest value markets.

Table 1. Hierarchy of value for small diameter roundwood depending on end-market use (based on 4-inch diameter x 8-foot length)

Grade Name	Desig.			**$ / Ton**	**Grade**	**$/ Piece**	**$/ft^3**
Appearance Peeled	A-P			200	1	3.00	3.51
Appearance Bark On	A-B			175	2	2.63	3.07
Character Peeled	C-P			115	3	1.73	2.02
Character Bark On	C-B			100	4	1.50	1.76
Rustic Bark On	R-B			100	5	1.50	1.76
Utility - Bark On	U-B			60	6	0.84	0.98
Utility - Dowel Stock	U-P			50	7	0.70	0.82
Small Diameter Saw Logs	U-B			45	8	0.63	0.74
Strand & Flake	S			35	9	0.47	0.55
Pulpwood	C			30	10	0.39	0.46
Fuel	F			15	11	0.19	0.22
Mulch	M			5	12	0.06	0.07

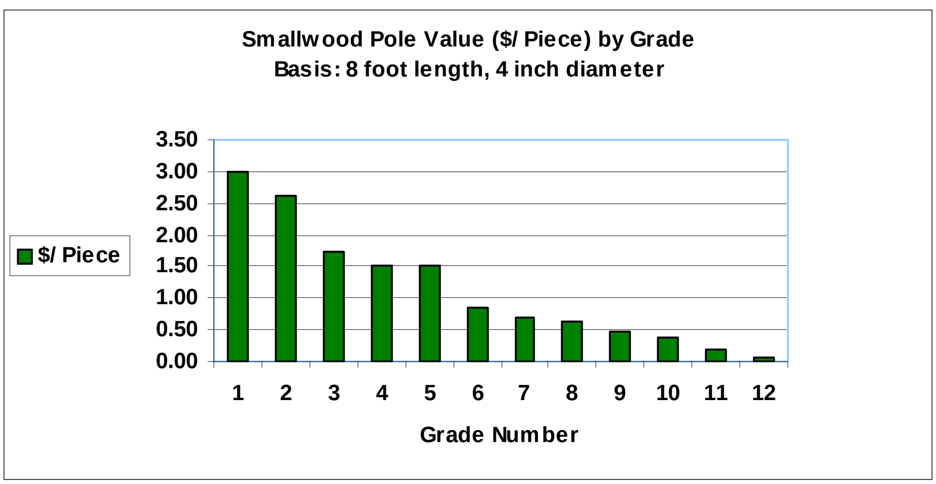


Figure 5. Graphical representation of the values of smallwood pieces based on market values. Data from Table 1 above.

As a part of a previous project with the Boise National Forest and Idaho Department of Commerce, we developed a conceptual plan for community-based business parks that utilize small diameter roundwood and other biomass from local forests (Dooley 2002). We demonstrated that the only viable community-business development model would be to stimulate the creation of multiple interdependent businesses, each using a fraction of the available biomass. Energy fiber is one outlet, but the current energy market cannot pay the full cost of harvesting and transporting fuel reduction thinnings. However, by allocating even 15-20 percent of the available tonnage to higher value uses, the system economics turn positive.

Roundwood materials offer a potentially important outlet for small diameter timber – particularly the lower bole. The price of small diameter bark-on (aka barky) roundwood delivered to mills in Montana is tracked by the Montana State University Extension Service. Their fall 2004 quarterly report indicated that lodgepole pine posts with 4-inch small end diameter and 8-foot length were being purchased by mills for

$0.80 each (Montana BBER 2004). If we accept that the selling price, f.o.b. manufacturer for products is approximately 2-3 times the raw materials price, then the value of small diameter roundwood continues to be among the more attractive value-added outlets for forest biomass.

New and adapted biomass collection and handling equipment systems

We started our exploration of alternative materials handling methods by benchmarking industries that face similar problems of geographically dispersed source locations, and bulky materials to handle.

Paper recycling – Post-consumer paper, newsprint and corrugated containers are collected from communities and point sources for delivery back to pulp and paper mills for recycling. Material is either baled at the source in the case of large producers, or collected from producer-site bins and baled at regionally central locations. Bales are accumulated into truckload or railcar quantities and then shipped as efficient units to mill customers. Baling is accomplished with specialized recycling balers. The baler industry is fairly mature with approximately 20 significant competitors. Once paper is baled it is easily handled with forklifts and shipped via conventional transportation networks.

Metal Recycling – Machine and welding shops, fabricators, and metals recovery facilities all produce quantities of scrap metal (aluminum, iron, steel, etc.). Regional metals recyclers deploy roll-off containers to scrap metal producers and haul filled containers back to their reload yards. At regional reload yards the metal is sorted and shredded or baled for long-haul shipping by rail, barge or ocean ship.

Construction & Demolition Materials Collection & Recycling – Construction and demolition (C&D) debris, including a high fraction of recoverable wood, are collected in specialized refuse containers and end-dump trucks. C&D containers are typically larger volume than waste containers due to the low bulk density of C&D debris. Otherwise, roll-off containers are handled with the same trucks and central facility handling methods as other waste.

Logging - Wood chipping and specialized chip hauling is a mature industry with many manufacturers and sizes of machinery. Morbark, a leading manufacturer of chippers and whole tree harvesters, currently sells 18 models of chippers. The product line ranges from tow-behind 25-hp models to 860-hp whole tree chippers.

In the early 1970's there was considerable interest in whole-tree chipping to capture all of the standing biomass for pulp chips, energy and other bioproducts. Several methods were developed for sorting commingled chips through beneficiation. Mattson at the USDA Forest Service North Central Research Station used a spinning wheel compression system to separate bark chips from solid wood chips (Mattson 1975). Through a combination of methods he was able to reduce the bark content to 3.5 to 7.5 percent depending on wood species. John Sturos explored air suspension systems to separate commingled chips (Sturos 1972). He determined that the terminal velocity of various fractions could be used as a separation technique. The method was particularly effective to separate large pulp chips (1.5cm) from bark, and less effective to separate small wood pieces and sawdust from bark.

Small poles and pulpwood logs are handled as individuals and transported on trucks that have forked racks to contain the poles. Most haulers use modified flatbed trucks and trailers. Larger logs are handled as individual pieces and transported on specialized log trucks and trailers. Loading is with separate equipment, or by truck-tractors that are equipped with onboard log loaders.

Mining and Gravel – The mining industry relies upon specialized haulers and loaders. Bulk crushed materials can be conveyed on belts for long distances – sometimes for several miles. Trucks and loaders are typically of special construction to maximize payload with very high density materials. Ore may weigh from 100-200 lb/ft^3 as compared to green wood at 50 lb/ft^3 and bulk biomass at less than 10 lb/ft^3.

Municipal trash & Waste hauling – The waste management industry uses extremely specialized equipment that maximizes the number of customers that can be serviced in any day, and minimizes the cost of collection and handling waste materials. The industry has technology cycles that have a live of about 20 years, and advances are continuous.

The trash collection industry must accommodate the needs of large and small producers, thus has a range of technological solutions to fit the customer bases. Curbside pickup is trending to more automated and semi-automated systems that only require one truck driver/operator. Today single operators can service as many households as a truck with crew of three could just 20 years ago. Larger waste generators are provided with various bins, roll-off containers, and compactor containers.

The lesson for our project is that if we package the biomass on site for automated collection, we should be able to make dramatic improvements in the labor required for handling and loading. For example, if we baled smaller biomass into “hay-bale” size bales, tied them with a wrap-around band, and stood them on end at the curbside, they could be captured and loaded with the same kind of equipment that picks up and unloads toter waste bins today.

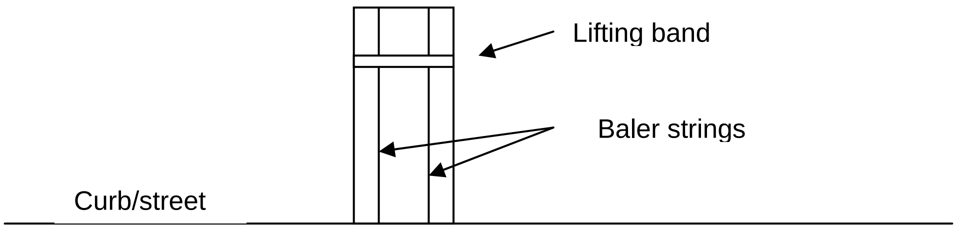


Figure 6. Sketch of a small bale of biomass made to the scale of a residential waste toter, with the addition of a lifting band to accommodate automated loading.

Early in the project, engineer David Lanning attended the waste industry national conference and exposition to benchmark technology and meet with equipment manufacturers. His trip report documents many opportunities to learn from the waste industry and adapt their materials handling systems to collection and handling of woody biomass from fuel reduction projects.

<u>Tree Trimming</u> – Arborists and pole-line maintenance firms almost universally handle materials by hand and then chip the woody biomass to reduce its volume for hauling. In non-public areas they are increasingly adopting masticating equipment manufactured by Fecon and others to shred, chop and disperse the material on-site. In either case there are no, or at most relatively few attempts to capture biomass in a form that enable value-added utilization.

<u>Fruit and Vegetables</u> – The fruit and vegetable industries have developed highly specialized totes, bins and containers for unitizing and efficiently handling valuable produce. Whether it be plastic lug boxes, wooden fruit bins, or whole truck tomato bins, the container and handling methods are matched to the commodity, means of harvest and destination customers.

Figure 7. Tomato haulers in Central California with specialized fiberglass bins mounted on standard flatbed trailers.

The fruit and vegetable industry uses a combination of specialized in-field vehicles and standard on-road vehicles. The on-road vehicles (e.g. highway trucks) are equipped with specialized bins and other attachments when needed.

The lesson for our project is to only design and build the equipment that is specific to our needs, and then rely on common carriers for all other transportation.

Hay – Sometime in pre-history, gatherers started hauling hay in wheelbarrows and wagons. Hay wagons were used until the industrial revolution of the mid-1800s. Bulk density was low and labor content was high. The invention of the stationary baler in 1813 and field baler in 1870 greatly reduced the labor content, and more importantly quadrupled the bulk density of hay for transport and storage. Hay bales have evolved since then to three types today. Small square bales are typically 14 x18x48 inches and weigh 60-120 pounds. Large square bales are typically 42x48x96 inches and weigh 1000-1500 pounds. Round bales are typically 42 inches long by 42-48 inches diameter and weigh 700 – 900 pounds. Hay handling equipment has continuously evolved to reduce the labor content and increase payload. Loose hay has a bulk density of 1-2 lb/ft^3 while baled hay has a bulk density of 12-18 lb/ft^3.

Of particular relevance to our project is that chopped straw and hay are typically produced at the destination from field-baled hay because chopped hay will not form a stable bale, and hauling of chopped hay has an even lower bulk density than that of loose hay.

Cotton – Following a similar path as the hay industry, cotton was originally collected and transported loose in carts and bins. Stationary balers baled cotton delivered from fields in large volume loose-filled trailers up to the present time. Beginning in the 1970s, cotton module builders began to produce truckload sized compressed modules that could be lifted onto tilt-bed conveyor-bottom trailers for transport from the field to a gin. Preference for loose hauling or modules typically depends upon distance from the grower to the gin which contracts for the crop.

Lessons Learned from Benchmarking Exercise

- Maximize the bulk density at the point of production for materials. The most common technique is baling or other compressed unit.
- Minimize the labor content for handling through automation, unitization and other techniques
- Preserve utilization options until materials arrive at a central processing point or customer's location.

Characterization of Organizations, Projects, and Processes - Current Situation Analysis

Our characterization milestones were executed in Phase I through a combination of structured surveys, telephone interviews, and site visits. Summaries of the surveys are attached as appendices.

Surveys: We conducted two rounds of surveys/telephone interviews with community-based wildfire protection organizations. The first survey was provided on our web site, as an email attachment, or as a structured telephone interview, depending on the preference of participants. As a result, we achieved an exceptionally high response of 66 completed surveys from a target audience of 150 people. The response rate is a function of both our multi-vehicle method that made it easy for participants, PLUS the high level of interest in what we are doing and the potential benefit of our project. The first round survey collected general information about the amount of biomass/smallwood collected, current destinations for woody biomass, and the nature of programs in each community.

The second survey was sent via e-mail to the 66 respondents of the first survey, of which 19 responded. This second questionnaire aimed at clarifying data obtained from the first survey and gaining an understanding of the potential of fuels reduction activities, both in terms of scope – the acreage that has been specified for fuels reduction – and the volume of materials produced. Additionally, we sought to:

- Identify and quantify the relative weight of the key factors that determine the amount of fuels reduction that is being carried out;
- Document access to value-added uses for these materials and how this effects the amount of fuels reduction work;
- Document the per-acre cost of fuels reduction under varying conditions;
- Identify the sources of funding for fuels reduction initiatives;
- Identify the methods and equipment that have been found to be most effective in carrying out small-scale fuels reduction projects;
- Document equipment and methodological needs and innovations; and
- Assess the best arrangement for providing equipment tailored to small-scale fuels reduction projects to the users.

In short, the first survey afforded a sense of the current trends of fuels reduction initiatives in WUI zones and the second survey provided an outline of their potential scope and productivity (in the absence of budget and equipment constraints).

The second survey responses suggested that access to funds (be they from grants or value-added uses) is a central factor in determining the amount of fuels reduction that is carried out. In turn, the cost of transportation is central to accessing value-added venues. The surveys and site visits (discussed below), suggested a number of possible inroads for linking fuels reduction materials to conventional commercial uses and the equipment, methodology and infrastructure that would be needed to realize this linkage, thereby laying the groundwork for, at least in part, a self-funding cycle of fuels reduction via value-added uses.

Site Visits: The original work plan called for a few multi-day site visits. Very early in the interviews, we learned that the kinds of in-depth data we were seeking were not available. We also found that the variety of situations was very broad, both geographically and by community type. Thus, we decided to visit many communities in a series of regional trips. Trips included: Methow Valley, WA; Pendleton/LaGrande, OR; Snoqualmie, WA; the Sierra Foothills near Sacramento, CA; and to the Coastal range from Santa Cruz to Yreka, CA.

Figure 8. Map of fuel reduction projects visited for data collection. Red flags mark the sites visited under this SBIR Phase I project. Blue flags mark sites visited prior to this project.

Each site visit documented the way thinning is done, how the contractors work, what equipment is used today, and the characteristics of the woody biomass that is removed. The site visit provides a somewhat informal venue to discuss the potential for improved handling systems to reduce cost and improve utilization. To date there is great support for our project and interest in our goal of enabling higher utilization. Each visit was documented by a trip report and photographic record.

Zen & the Anatomy of Fuels Reduction

Our project team created a graphical method to integrate the nature of fuels reduction projects across the scales of piece size and parcel size. These two factors appear to dominate how projects are approached, contracted, and executed.

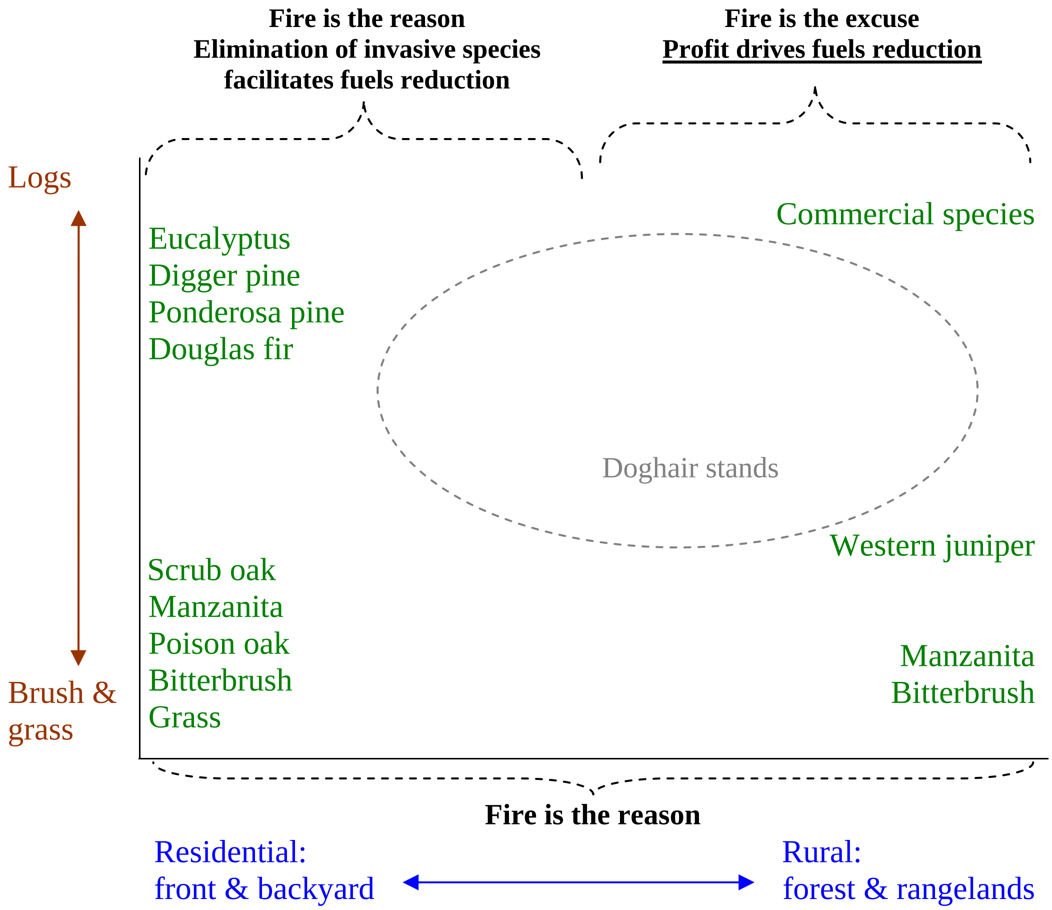


Figure 9. The "Zen & the Anatomy of Fuels Reduction" showing the effects of scale (x-axis) and size of materials removed (y-axis).

We found that two kinds of scale affect the choice of contractors, methods and biomass utilization options. As we listened to program coordinators and contractors, the scale factors led to a sort of zen that guides how people think (aka problem framing), while the complex interaction of scales define the anatomy of individual projects. As we develop recommended solutions for materials collection and handling, our solutions must be consistent with both how people think about the problem and the scale factors.

As you consider the above diagram, the lower axis is a continuum of project size from individual residential lots to large rural landscapes. The residential lot problem is defined by and constrained by having to work in homeowner's front and back yards – and aesthetic and landscaping values dominate decisions about methods to use, and the kind of contractors who can do the work. Rural forest and rangeland projects are approached much more like powerline and right-of-way clearing projects where the objective is to get the materials on the ground and there are few operational constraints. In most residential frontyard-and-backyard projects all the biomass must be removed from the site. As the property size increases to suburban lot scale, more landowners are willing to have the biomass shredded and left on the ground. At the wildland scale, the finer materials are typically lopped and spread or piled and burned. Only merchantable materials are removed from the site.

The other scale factor is the size of biomass materials. On the vertical axis you can see that the materials range from fine fuels (grass, forbs, small brush) to larger brush (manzanita, bitterbrush, poison oak) and large trees (hardwood and softwood). At the upper end of size are huge ancient conifers that overhang the homes and hundred year old eucalyptus trees that are 3-4 feet in diameter. Interestingly, the fine fuels are easier to handle at the residential lot scale while the large trees are easier to handle in the large projects, particularly since at that scale logging contractors and equipment are practical. We found that large trees on residential lots are frequently cut into firewood size chunks for handling, effectively precluding any value-added use.

Poison oak was mentioned by most community coordinators as a plant that must be removed during fuel-reduction projects, but causes major problems for contractors. Not the least of the problems is incidental contact with the toxic plant during field work. Also, the material must be kept out of chipper piles since the toxic oils become aerosols during chipping, and the shredded plant parts contaminate the entire batch of chips with toxic oils. We expect that sumac, poison ivy and other toxic plants are problems in other parts of the country.

Noise and dust is an issue for residential landowners and urban areas, while not a problem for rural communities and forestland owners. In some residential neighborhoods the noise from chippers was deemed unacceptable.

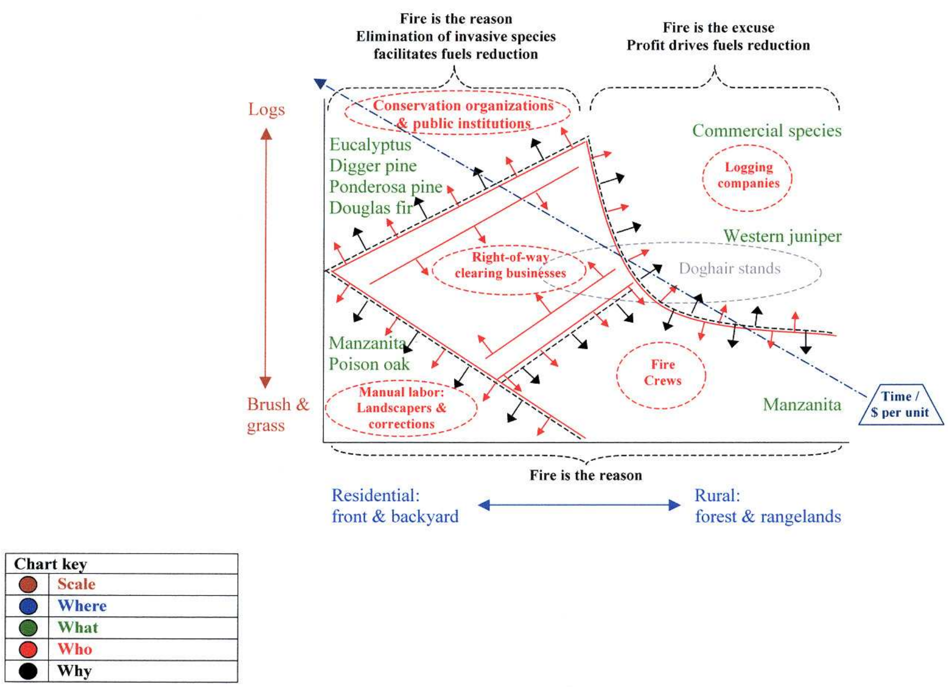


Figure 9. The "Zen & the Anatomy of Fuels Reduction" showing the kinds of organizations and contractors who are most appropriate to execute fuels reduction projects (red color layer).

In Figure 9 above, we add a layer that maps the contractors and project crews to the materials and properties. In the lower left corner of the diagram are landscape contractors and inmate crews who provide manual labor to cut weeds and brush around homes on small lots. This is classic front-and-backyard work where all materials must be carried to curbside for disposal. Most of the material is grass, brush, dead branches, and sapling trees. As we move up the left side of the chart, the tree size increases but the property size stays small. Removing big, dead and danger trees from residential lots requires specialized equipment and crews. In some areas, the trees are lifted out by large crane.

On the right edge of the diagram are large rural parcels. As we found in the Methow Valley and Ukiah, much of the landscape is covered with brush and forbs rather than trees. The appropriate contractors and crews are forest operations contractors, fire-fighting crews and environmental restoration contractors. Work consists of cutting and piling brush, or cutting and chipping brush. At the top right of the diagram are forested landscapes where the dominant material is timber. The projects consist of thinning the standing forest to remove dead trees and open the spacing to reduce the risk of crown fires. Most or all of the logs removed can either be sold as saw logs, shredded into boiler fuel, or chipped for paper. Traditional logging contractors are the preferred service providers. In the Susanville, California and LaGrande, Oregon areas we found that many fuels reduction projects were actually profitable for the contractor, landowner, and FireSafe Council.

In between the brush projects and the logging projects is a “no man’s land” of dog hair stands and intermediate parcel sizes that are uneconomical for anyone to clear. Lot sizes of 2-20 acres are a problem for hand crews due to the distance from roads to the interior, and problems for logging contractors since the cost of mobilization is high and the lots are too small for efficient mechanized operations. Dog hair stands are forested areas that typically have more than 800 stems per acre, and each stem is only 2-5 inches diameter. These stands are very difficult for both hand crews and mechanized operators to work in. Fortunately, a new class of masticator equipment such as the Fecon brand horizontal axis shredder mounted on skid-steer tractors is becoming available. While the Fecon type shredder leaves all biomass on the site, it can be an effective tool for fuels reduction on intermediate sites.

Methods and Equipment used for On-Site Work

Typical tools and equipment list for a fuels reduction hand crew include:

- Chainsaw and personal protective equipment
- Pole pruner – either hand saw type or power saw on end of pole
- Brush hook, Pulaski or similar grubbing tools
- Trailerable chipper pulled by one-ton truck
- Some crews have an ATV or small farm tractor-loader to help move materials

Typical tools and equipment list for logging contractors doing fuels projects

- Log skidder – small articulated skidder and large skidders
- Masticator – either skid-steer mounted or loader mounted
- Feller-buncher
- Forwarder
- Log trucks
- In-woods whole tree processor/chipper
- Chip vans or contract chip haulers

A hand crew operations contractor with a 3-5 person crew might have only a few thousand dollars in owned equipment, and a rented chipper. A logging contractor, on the other hand, typically has more than one million dollars worth of equipment.

Opportunities for New and Improved Equipment

The need is to develop better methods and equipment for collecting and transporting smaller woody biomass – both trees and shrubs. Cost savings in labor can accrue from investment in more appropriate small-scale equipment. We completed a number of brainstorming exercises to seek better systems for on-property cutting, gathering and transporting. We also sought better methods for on-street processing and transport to disposal sites or markets.

Objectives for screening ideas include:

- Reduce the noise – better solutions produce no more noise than garbage trucks do today
- Reduce the dust – better solutions do not produce dust
- Preserve downstream value as much as practical – better solutions leave the materials more intact and in bigger pieces
- Minimize hand labor once the biomass is cut – better solutions do not have to be hand fed
- Minimize the invested energy – better solutions use smaller engines per ton processed
- Maximize the bulk density for transport – better solutions result in bulk density approaching that of solid wood
- Minimize the capital investment for small contractors and FireSafe Councils – better solutions can be bought or leased for costs similar to chippers and chip vans
- Convert materials into packages that can be transported and handled with well-established methods and equipment – better solutions yield biomass that can be hauled by standard trucks, railroad cars and barges

Two general concepts scored highest from among the many ideas we considered. We propose to bale branches, brush, tree tops and other loose biomass. We also propose to use multimodal wood bunks for unitizing logs and poles.

Baling may be done at any of several locations by different versions of the same technology.

- Small portable balers can be mounted on ATV trailers or small prime movers (e.g. Gator) and taken onto the property where they can be fed by the same crews that cut the material. In this situation, the baling operation is closely coupled to the cutting and fuels reduction crew. Such a baler would necessarily produce a relatively small bale that could be handled by the hand crew.

- Trailer and truck mounted balers that produce large or small bales would have a grapple-loader to pick up piles along the street and bale the material into bales for subsequent hauling to a central reload location.

- Central fixed balers much like recycling balers that bale materials delivered by other contractors and crews. Central balers may be engine or electric powered depending on the site. Central balers would be high capacity to process many truckloads of biomass bales per day.

Wood bunks of two types are contemplated. Small pallet-sized wood bunks were previously developed by Forest Concepts for handling firewood logs and pole stock. Larger multimodal wood bunks built on roll-off frames were jointly developed by the USFS Southern Research Station and SBS Wood Shavings for collecting and handling logs of up to 24 feet long and 18 inches diameter.

We will further describe each of these solutions later in this report.

Customers and Markets for Woody Biomass and Small Diameter TImber

We will start with the bottom line first. In most areas of the West, the problem is one of disposal rather than satisfying existing markets. There simply are not customers clamoring for woody biomass. Whether the biomass producer is a FireSafe Council, Conservation District, contractor or municipality, the daily challenge is to find an outlet that charges less than landfills to take the biomass collected that day. In a previous project, we developed a list of 34 alternative outlets and values for small diameter timber and biomass.

Table 2. Products and Markets for Woody Biomass and Small Diameter Timber

•Christmas trees – *natural look* •Mine props •Firewood •Posts and Poles •Furniture Poles •Log Home & Trail Railings •ProjectPoles™ •Cabin Logs •Utility Poles •Pilings •Biomass Energy Fuel – aka hog fuel •Pulp & Paper Chips •Landscape Mulch •Compost •Veneer blocks •Craft, Promotional & Gift Items •ELWd® Bioengineering Structures	•Rough Sawn Lumber & Timbers •Planed, Dried & Graded Lumber •Pallet lumber •Veneer pallet stacking sheets •Shavings for Animal Bedding •Sawdust & Granules for Bedding •Wood Excelsior – Packaging •Wood Excelsior – Erosion Control •Wood Strand – Erosion Control •OSB / Engineered Wood Panels •Wood Energy Pellets •Cement-Wood Composite •RTA Fencing Kits •RTA Landscape Products •RTA Roundwood Structures •Flooring – T&G boards •Character Wood Boards & Molding

In this project, we expanded the list to more than 100 potential products/uses. Many uses on the expanded list are sub-categories of the above table. Our new list used raw material specifications as the primary criteria for segregation, while the former list used economic end-uses as the criteria. For example, the above table lists Engineered Wood Panels. Different types of panels require different feedstocks. Medium density fiberboard uses ground wood fibers that are less than 1mm thick and 10mm long. Flakeboard panels use flakes that are 2-3mm thick and 30-60mm long. If a woody biomass business was providing feedstocks to each of these engineered wood panels sub-markets they would have to produce different feedstock products.

We discovered that technical feedstock specifications do not exist, except for paper chips and select biomass combustion energy plants. We expected that the feedstock requirements for ethanol plants, fuel pellet manufacturing, veneer blocks, etc. would be well documented and used for a basis of commerce. During the latter portions of Phase I, we contacted a number of experts from around the country to contribute heuristics and experience to the definition of feedstock specifications. Contributors included:

- Vikram (Vik) Yadama, Washington State University
- Klein E. Ileleji, Purdue University
- Dr. Jerrold E. Winandy, USDA FS Forest Products Laboratory
- Bryce Stokes, USDA FS WO
- K.C. Das, University of Georgia
- Sue Nokes, University of Kentucky
- Oladiran Fasina, Auburn University
- Bryan Jenkins, UC Davis
- Bruce Hartsough, UC Davis
- Tad Mason, TSS Consultants
- Tom Richards, Pennsylvania State University

Although our compilation of feedstock specifications is somewhat crude and obviously incomplete, we may have the most extensive compilation in existence. The data we have enables us to evaluate biomass utilization and handling options. We will address further development of our compilation in our Phase II proposal.

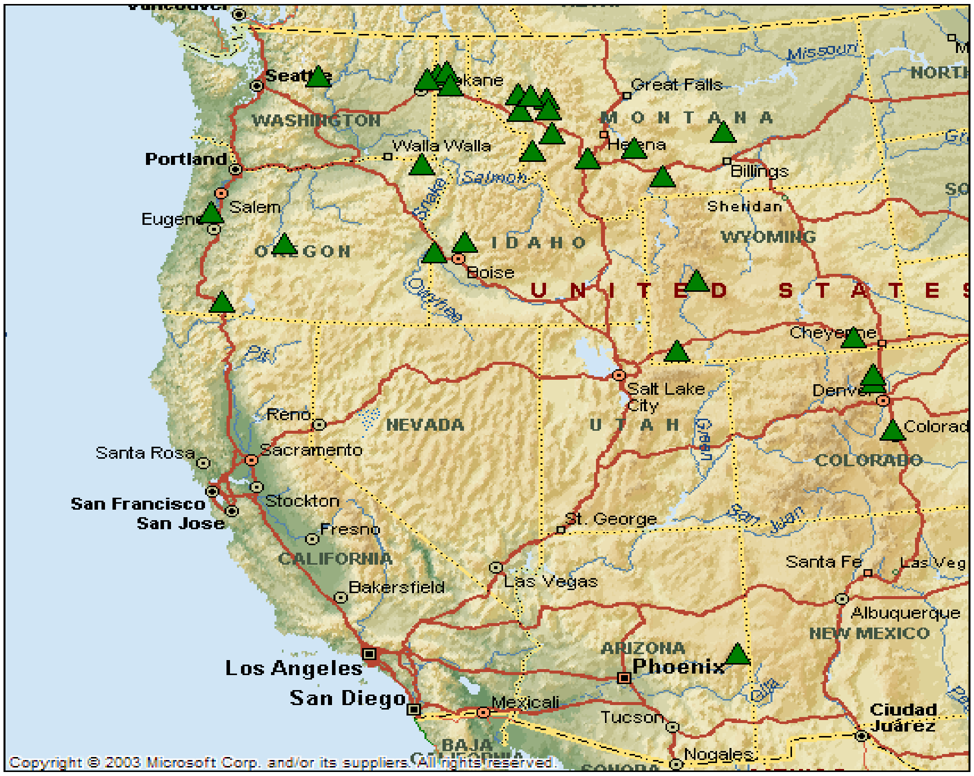


Figure 10. Location of post and pole plants in the western United States. Note the lack of plants in California, Utah, and Nevada.

Post and pole plants are generally considered to be the outlet of choice for small diameter timber. A vibrant post and pole industry is often willing to pay $30 - $45 per green ($60-75 per bone dry ton) ton for small diameter pole stock. This is double what the biomass is worth for energy. In the conifer regions, substantial volumes of the fuel reduction materials is in the post and pole size class. The figure above shows several things of note. There are no post and pole plants within reasonable hauling distance from fuel reduction thinning projects anywhere in California and Nevada. Thus, the regional outlets are limited to disposal sites or biomass energy facilities. In the Pacific Northwest and Intermountain regions, there are a number of post and pole plants, but those we surveyed told us that they are buried in low-cost supply from private lands, commercial logging operations and local landowners. The implication is that new capacity will need to be built before existing producers can accommodate fuel reduction thinning smallwood. In the high wildfire risk areas of coastal and Sierra Nevada range of California, the are no markets for smallwood. Substantial investment in facilities, equipment and marketing will be required to create a regional post and pole industry from scratch.

Lacking a post and pole market, the next choice for utilization is biomass combustion energy facilities. Again, the installed capacity in the West, particularly in California, Nevada and Arizona is limited. Biomass-to-energy plants in Burney and Anderson California are aggressively contracting for biomass from fuels reduction programs. The Burney Falls plant pays between $30 and $45 per bone dry ton (bdt) for hog fuel delivered to their plant east of Redding, CA. Other facilities pay between $25 and $35 per bdt for shredded biomass. The implication is that biomass energy is a viable market only where the cost of transportation is sufficiently low.

Our Phase I Solution

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 to improve value
- Woody biomass marketing and logistics support to match materials with users
- Central woodyard and reload center to minimize first-mile costs

Earlier we introduced the notion of baling and smallwood unitizing. These two equipment solutions are within the scope of completing under Phase II support. 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. 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 11. Bales of branches and forest residuals. (P. Schiess photo)

Figure 12a, 12b. 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.

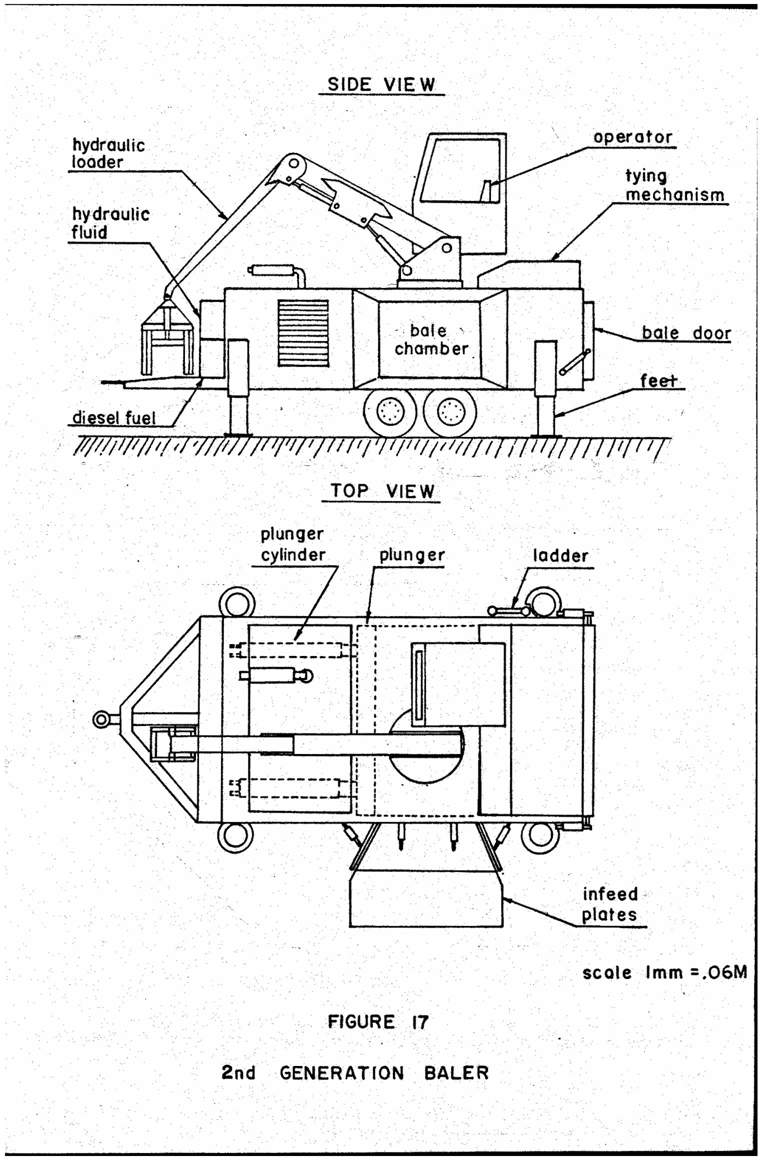


Figure 13. Concept sketch for VPI second generation baler. (P. Schiess)

We expect to include development and testing of a current technology biomass baler as part of our Phase II proposal. Our prototype baler will probably be smaller than the VPI 2nd generation concept in order to be more appropriately scaled to fuel reduction projects at the wildland urban intermix.

Baling Experiments

We conducted two baling experiments during Phase I 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 14. Fifteen pound 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 500 pound 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 1.5 inches 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 15. 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.

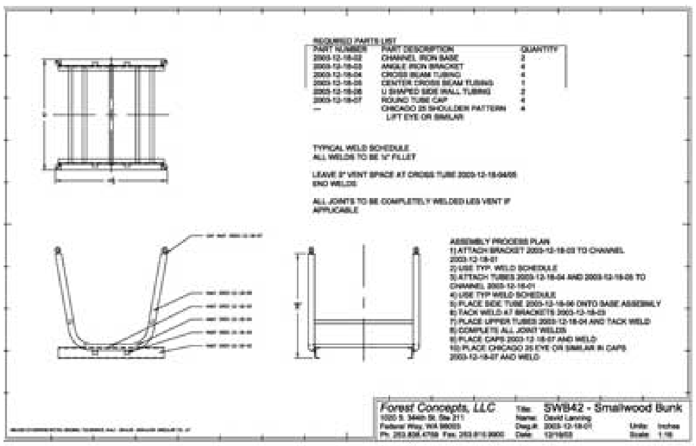
We then took the baled woody biomass to Cedar Grove Compost Company and had them feed it into the greenwaste grinder as shown below. The operator reported that the bale fed very well and that he would not resist delivery of biomass in baled form.

Figure 16. 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.

Wood Bunks

Solid roundwood posts, poles and small sawlogs have value as either firewood or raw material for smallwood businesses. In both cases it is preferable to unitize the material for transport. In a previous project funded by the National Fire Plan, we designed smallwood bunks for collection and handling of poles.



a.

b.

Figure 17. Engineering drawing of smallwood bunks for unitizing small diameter poles for value-added use (a). Field test of wood bunks on the Cascade Ranger District of the Boise National Forest.

During the present SBIR Phase I project, we evaluated the utility of our current wood bunk design against the materials being removed from fuel reduction projects. We determined that the wood bunks would work well. However, very little small diameter poles are actually removed from residential lots and other small parcels. Nearly all of the smallwood that is felled for fuel reduction is cut to short lengths and left as firewood for the landowner. If there was a local smallwood market, we might expect that more of the small diameter poles would find there way into the marketplace.

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.

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 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.

Research and development questions for a Phase II program include:

- What are the measurable benefits of baling versus chipping of WUI biomass in urban and suburban areas? We expect the benefits to include lower cost of handling and transport, increased resident satisfaction due to lower noise and dust, and post-processing benefits to customers of the bales.
- What is the willingness of biomass customers to pay a premium for baled biomass versus chipped biomass?
- What are the measurable benefits of unitizing poles and other larger woody biomass for handling and delivery to customers?
- How big is the market for biomass balers? How broadly can a biomass baler be applied to supply feedstocks to the emerging bio-economy and billion-ton vision?

Our SWOT analysis did not identify any fatal obstacles to commercial success. The technology for baling woody biomass was extensively researched during the 1978-1983. Although the results were not commercialized, most of our important technical questions about baler compression forces, densities, spontaneous combustion risk, etc. were addressed. Three key participants in the earlier research – Bryce Stokes, Peter Schiess, and Jim Fridley – have offered to advise us during the Phase II development project.

Recommendation to Proceed or Stop

The project team recommended to the Forest Concepts management that we proceed to a Phase II proposal. We believe that our proposed solution will be well received by organizations and contractors doing fuel reduction thinning in the wildland-urban intermix. Further, we believe that there are many spin-off and related applications of the technology to help the United States fulfill its vision for reducing our dependence on imported oil. The wildfire protection market will provide a launch portal, and the bio-based economy and bio-energy markets will develop to provide long-term sustainability.

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Contacts – persons aware of or involved in the project and results

Literally hundreds of persons are aware of the project and the support from USDA CSREES SBIR. The project and surveys are featured on our company website www.forestconcepts.com. We conducted telephone and electronic surveys with more than 150 individuals. We presented project overviews at:

- County council meeting in Susanville, CA
- FireSafe council meeting in Berkeley, CA
- Small-group meeting at USFS Research office in Roslyn, VA
- Montana Fuels Reduction Workshop at Missoula, MT

Primary cooperators in the Phase I project included

- Dr. James Fridley – University of Washington
- Dr. Peter Schiess – University of Washington
- Bryce Stokes – USDA FS WO
- Bob Rummer – USDA FS Southern Research Station, Auburn
- Arne Arnesson- Cascade Woodlands, Wenatchee, WA
- Mark Knabe – USDA FS Forest Products Laboratory
- Bill Elliot – USDS FS Rocky Mountain Research Station
- Craig Rawlings – Montana State Technology Development Center, Missoula