COLORADO STATE FOREST SERVICE
COLORADO STATE UNIVERSITY

Woody Biomass in Colorado:
Quantification, Assessment and Opportunities

Section 4 - Biomass Harvesting, Transportation and Delivery Systems

4.1 Introduction

Biomass utilization requires the harvest and transportation of biomass from the source to the utilization facility. To protect biomass resources and do an efficient job of providing forest products to markets, it is essential to understand harvest systems. In areas where there might be more than one market for harvested material, one must understand the values and related specifications associated with each product. Product markets might also dictate the type of transportation required, as markets might desire harvested materials in different forms and/or lengths or have other limitations.

4.2 Biomass supply chains

Developing sufficient and sustainable raw material supply chains is a critical element of operating a facility that utilizes biomass. A forest biomass supply chain typically includes harvesting, pretreatment (processing and conversion), transportation and storage (World Bioenergy Association, 2018). Biomass utilization facilities can either harvest biomass with their own crews, contract with others or buy on the open market from those who harvest and have biomass to sell. Each method has its own risks related to securing a sustainable and economical supply to operate a facility.

In Colorado, forest biomass can be sourced from urban and community forests as well as public and private forestlands. Both areas may include the wildland-urban interface (WUI), defined as an area where structures and other human developments meet or intermingle with wildland vegetation (Colorado State Forest Service [CSFS], 2024). Urban and community forests often include non-native tree species, and residential areas are managed differently from wildland forests. For example, in core urban areas of Fort Collins that are not considered WUI, post-weather tree debris removal is more important than forest fuels reduction. Conversely, the Black Forest northeast of Colorado Springs is zoned residential but is managed primarily as WUI, and forest fuels reduction is a priority.

Fuels reduction has been a priority for public and private forests. The USDA Forest Service (USFS) manages nearly half of the forestlands in the state, and it has been concentrating on fuels reduction projects to reduce the impacts of wildfire, particularly near homes and private properties. As the largest forestland manager, the USFS has historically been the largest source of forest biomass.

Although some elements of these two sources of biomass function similarly, there are distinct differences between them. While utilization is an option for both, treatment scale and objectives are usually different for wildland versus urban and community forests. As a result, the practices and harvesting systems used to harvest trees from wildland forests (normally performed using industrial amounts of sawtimber) are different from those used to remove urban and community trees.

Biomass can be utilized in log form, as chips or as other processed material. Some municipalities collect urban wood waste that can come from trees or clean wood related to construction. Often these facilities grind wood waste for mulch so local citizens can use it, but it can be used in other biomass utilization facilities.

There are other forms of biomass, such as residual biomass from milling logs: bark, sawdust and planer shavings. These are usually less expensive than forest-derived biomass. Other potential sources of biomass, such as wood construction debris, wood in the municipal solid waste stream, agricultural residues, algae cultivation and animal manure, are not considered in this section.

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COVER: *A log truck arriving at Blanca Forestry Products mill in the San Luis Valley.* ***Credit: CSFS***

4.3 Harvesting

Methods and systems used to harvest trees depend on the topography, tree sizes, volumes to be harvested and desired products from the harvest. Ground-based harvesting — where all the harvesting equipment is on the ground, as opposed to involving aircraft — is most common in Colorado and is the primary focus of this discussion. Such systems are generally less expensive than other methods of harvesting.

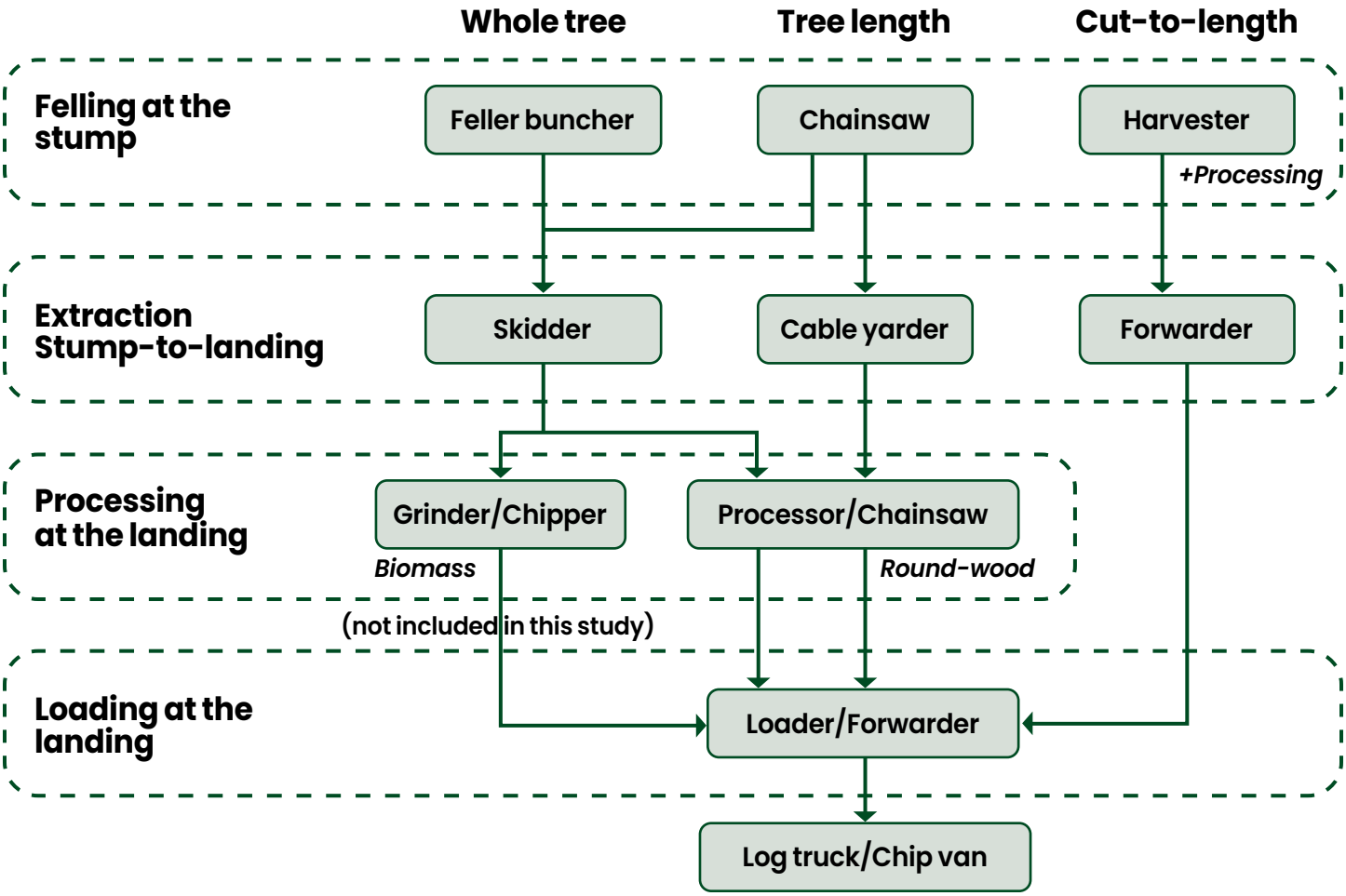
4.3.1 Timber harvesting in wildland and WUI forests

A variety of methods and systems are used to harvest timber in Colorado, a state famous for its topography. The essential flow entails felling (harvesting), consolidating (skidding or yarding the cut trees), processing (removing undesired biomass such as limbs and tops) and transporting (sending all the material to its next step, typically a mill). The harvest system used for removing trees depends on the silvicultural prescription, ecological impact and utilization standards for the harvested timber. Harvest systems in Colorado are predominantly ground-based because harvest units are on shallow slopes. On steeper slopes, some ground-based systems use a tethering method where a winch is used to assist equipment movement. Other harvesting systems used on steep slopes include yarding with cables and the use of helicopters to fly logs to an accessible location.

Gautam et al. (2010) characterized harvesting methods based on the form in which trees are delivered to a landing. The level of preprocessing the tree undergoes prior to arrival at the landing defines the method. Four principal methods were identified: cut-to-length (CTL), tree length (TL), full tree (FT) and whole tree (WT). FT and WT are often used interchangeably.

In CTL the main stems of trees are felled by a processor, limbed and bucked to length in the forest. This leaves limbs and tops in the forest for nutrient recycling, but large amounts of residuals can increase fuel loads and

Figure 4.1 – *Harvesting equipment used for WT, TL and CTL methods. From Chang et al. (2022)*



In woods cut-to-length processor. ***Credit: CSFS***

A feller buncher. ***Credit: Steve Rudolph, CSFS***

A skidder. ***Credit: Amy Bulger, CSFS***

A delimber. ***Credit: Pierce Pacific Manufacturing***

therefore fire risk. Desired logs are moved to a landing by a forwarder or skidder, where they are loaded and sent where they will be utilized. The CTL system is used where the silvicultural prescription calls for thinning a forest stand, as it allows operators to select trees for harvest and remove them with limited damage to the residual stand. Forest thinning is a common prescription used to reduce vegetation in forest stands, intended to reduce the impact of wildfire.

In other ground-based harvesting systems such as TL, FT and WT, trees are felled by hand with chainsaws or by machines such as a feller buncher. Depending on resource objectives, trees can be delimbed and topped in the forest and brought in TL to be made into logs. If residual biomass is to be utilized, trees are brought to the landing as FT or WT with limbs and tops attached; they are then delimbed and cut to log lengths with residuals piled for use as biomass.

Skidders and/or dozers are common machines used for bringing logs to the landing, although other options are available. Delimbing can be done by hand or by machine, such as a delimber or processor. This method can be used to meet silvicultural prescriptions for thinning or to conduct a more intensive harvest. Depending on stand conditions, bringing the full tree to the landing can increase the damage to residual trees as longer trees require more room to maneuver through the residual forest.

Cable and helicopter yarding systems are more expensive to operate than ground-based methods. Harvesting operations in Colorado rarely use cable operations. Helicopter operations are highly transitory and can be used if terrain, resource objectives and harvested volume justify it. Due to the expense, most helicopter-logging operations in Colorado have received grants to offset the cost of implementing forest management prescriptions.

Log loader loading a truck with yarder and delimber in the background. ***Credit: John Gold***

In **Table 4.1** a variety of equipment that can be used to harvest trees is subdivided into harvesting, skidding/yarding, processing and transportation subgroups depending on function and capability, including approximate capital costs for the equipment. These costs represent the initial capital cost of the equipment such as interest, insurance and depreciation or operating costs. Mean costs per ton are shown for the various equipment types based on studies cited and experience. Actual costs will vary depending on the volume per acre, tree size, terrain and distance to landings and destinations. The cost of fuel to operate machines also influences harvest costs.

Choosing the systems that best meet resource objectives can require the assistance of those with harvesting experience and will often determine the success of implementation.

In addition to cost, the environmental, economic and social aspects of the project should be considered. Included in this is how harvested biomass will be utilized — such as whether the wood will be used for logs, chips, woods fuel, separated into several products or left on the landscape.

Table 4.1 – Harvesting systems

Harvesting equipment type	Capital cost - average (range)		Harvesting method[d]	Mean production rate (tons/PH)	Mean cost per ton ($/ton)
	New ($1000)	Used ($1000)			
Felling					
Feller buncher	$610 ($340 - $780)	$180 ($20 - $650)	FT/WT	36.72[b]	$5.7[b]
Felling and preprocessing					
Harvester/Processor	$755 ($440 - $950)	$255 ($30 - $820)	CTL	16.06[b]	$17.7[b]
Chainsaw	$1.13.5 ($0.500 - $2.875)	$0.685 ($0.200 - $1.820)	TL	11.74[b]	$8.08[b]
Skidding/Forwarding					
Skidder	$415 ($275 - $475)	$155 ($20 - $475)	TL & FT/WT	23.47[b]	$8.17[b]
Cable yarder	$2,290 ($1,700 - $3,000)	$225 ($50 - $725)	TL	16.01[b]	$37.88[b]
Forwarder	$605 ($450 - $775)	$185 ($20 - $520)	CTL	16.31[b]	$13.13[b]
Helicopter	$7,000 - $30,000	$300 - $25,000	TL & FT/WT	36	$167.00
Log processing					
Log processor	$620 ($440 - $860)	$260 ($55 - $635)	TL	24.69[b]	$8.52[b]
			FT/WT	26.65[b]	$8.47[b]
Log loading					
Log loader	$425 ($325 - $615)	$155 ($20 - $500)	CTL	27.83[b]	$6.64[b]
			TL	46.02[b]	$4.70[b]
			FT/WT	48.55[b]	$4.24[b]
Chip processing					
Whole tree chipper[c]	$425 ($135 - $685)	$235 ($50 - $585)	FT/WT	40[d]	$7.50[c]
Horizontal grinder	$935 ($635 - $1,200)	$440 ($100 - $990)	FT/WT	30[d]	$18.33[f]
Hauling equipment type	**Capital cost - average (range)**		**Loaded haul distance**	**Cost per loaded mile[g] ($/mile)**	**Cost per ton[h] ($/ton)**
	New ($1000)	**Used ($1000)**			
Log truck	$230 ($195 - $290)	$110 ($40 - $195)	75 miles	$7.53	$20.92
Chip trailer/van[i]	$48 ($15 - $60)	$38 ($15 - $60)	40 miles	$5.63	$8.34

Notes to Table 4.1:

a. CTL = Cut-to-length; TL = Tree length; FT = Full tree; WT = Whole tree (Note: In practice WT is used interchangeably with FT)
b. Taken from Chang et al. (2022) - converted to English units and 2023 dollars
c. Includes both towable and self-propelled chippers capable of processing full/whole trees
d. Smidt & Mitchell (2014)
e. Based on a machine rate of $300 per hour determined using method outlined by Miyata (1980)
f. Based on a machine rate of $550 per hour determined using method outlined by Miyata (1980)
g. Estimated using cost data taken from Hayes et al. (2022)
h. Based on a load of 27 tons
i. Chip trailer/van only, does not include cost of truck

4.4 Urban and community forest tree removals

Strategies for removing urban and community trees can vary considerably from trees harvested in wildland forests. While in some cases multiple trees are removed at once, often individual trees are removed. Frequently the trees being removed are either dead or in a serious state of decline, causing a risk to surrounding infrastructure. Urban trees are usually removed with chainsaws, to fell trees or portions of them. Depending on tree size and complexity, a bucket truck may be used to assist with removing upper portions of the tree. Where trees are close to infrastructure, a cable or crane may be used for safety reasons.

The potential for utilizing the main bole of a tree can affect how it is handled and processed. Tree characteristics often dictate whether utilization is an option. For example, straight larger diameter logs from black walnut trees killed by thousand cankers disease in Boulder County and the Denver Metropolitan Area were transported to a local sawmill and processed. The lumber sawn from the logs was evaluated, and after being adequately heat-treated, proved suitable for a variety of value-added products (Mackes et al., 2015).

There are currently several small sawmills located in Front Range counties that process higher-quality logs from species such as black walnut, ash, elm, oak and maple. The biomass remaining after production is often chipped or ground; unless there is a utilization option for the material such as mulch, compost or bioenergy, it is usually deposited in a landfill. For example, in 2008 the tree care industry in the Tri-City Area (Fort Collins, Greeley and Loveland) generated 36,742 tons of urban forest residues (Nash, 2009). Around 40% of this biomass went to a landfill.

4.5 Processing biomass

How biomass is processed prior to transport is usually dictated by how the biomass will be utilized. Woody biomass is commonly processed into logs, chips or woods fuel prior to leaving the forest. It is important to determine the most efficient location and method for processing as this is a significant cost in utilizing biomass. Common choices for processing locations include the landing, a sort yard or the biomass utilization facility.

4.5.1 Log processing

Logs are normally delimbed and topped prior to transporting them to a mill or facility for further processing. Depending on the tree's length, its main bole can be bucked to specified log lengths or hauled full tree length. If non-merchantable biomass is to be utilized, trees are brought to the landing with limbs and tops attached. Trees are then delimbed and bucked, then sorted into product types. Non-merchantable volume is piled and might be chipped or ground — either on-site or at a central location, as depicted in **Figure 4.2.**

4.5.2 Non-merchantable biomass utilization

There are multiple methods of utilizing non-merchantable biomass, each with requisite raw material specifications. These range from blocks of wood to ground woods fuel. The low margins associated with utilizing non-merchantable biomass require efficient raw material processing into a usable form. In determining the most efficient processing method, the first question concerns where the processing will occur. This can happen at the landing, at the utilization facility or at a separate location. Strategies must balance initial processing costs versus benefits, both in transportation costs and in conversion costs at the biomass conversion facility.

The type of facility utilizing the biomass will dictate how biomass is processed. Some facilities can use small logs without processing. Some, such as wood pulp, require clean chips with no bark; others such as pellets and briquettes can use chips with bark on. Others, for example large boilers, can use ground material from any portion of the tree. Important factors to consider when preprocessing biomass are desired particle size, biomass moisture content, grit contamination and wood quality (Ciolkosz, 2019). In Colorado, processing is often done at the landing prior to transport.

Chippers, grinders and shredders are the most common equipment used in Colorado to process non-merchantable biomass. Chipping machines can process wood as small as 2" with bark, or logs that have been debarked. For use on forest biomass, most equipment has the capacity to chip entire logs. Chips can be used for pulp or boiler systems that require consistent material size for feeding and burning. Grinders produce chips and chunks that are used in larger boiler systems or processed into mulch. Shredders are smaller than grinders but produce similarly sized material.

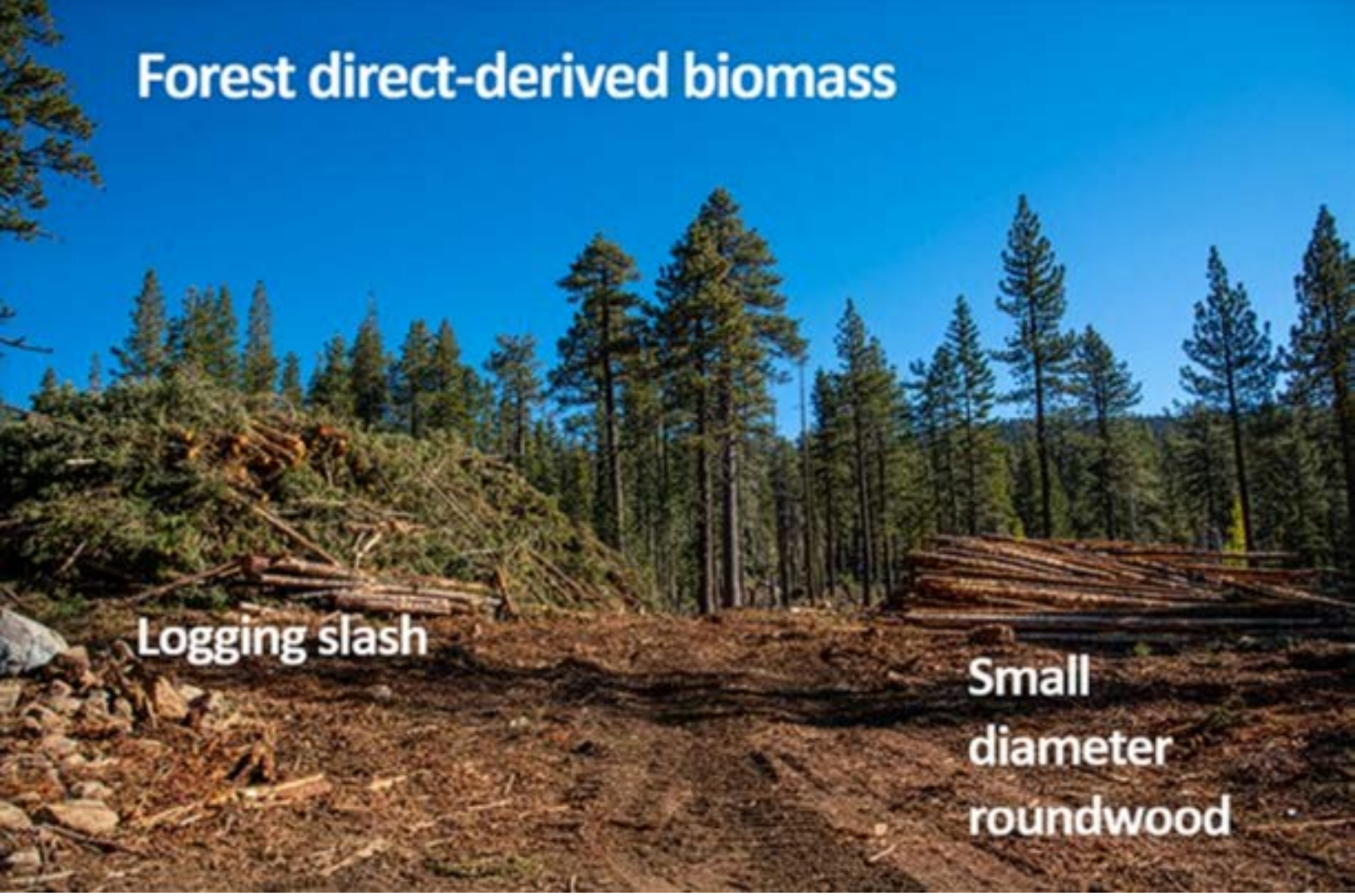


Figure 4.2 – Non-merchantable volume on a landing. ***Credit: Roy Anderson***

Bundlers and composite residue log (CRL) operations collect, compress and bind forest residues into cylindrical bundles (Mitchell, 2011). These bundles can be brought from the forest to a central location to be processed for utilization. While this technology is available, it has not been used much throughout the West. When demonstrated near Nederland in 2005, the bundles remained on site for an extended period (years) after the demonstration because there was no facility nearby to utilize them.

4.5.3 Transportation

Biomass can be transported as logs or, after processing, as chips or woods fuel. Forest residues are often dispersed and have a low bulk density, which increases collection and transportation costs, especially for unprocessed biomass. Therefore, they are typically processed prior to transport, which is normally done by truck or rail. In Colorado, timber operations almost exclusively use trucks to transport logs and preprocessed biomass from forest treatment areas. Colorado sawmills have used rail to transport clean wood chips to pulp and paper mills out of state.

All trucks used are subject to size and weight restrictions on haul roads, including state and interstate highways. Size restrictions are in place for both height and length, as well as limits on how far the load may overhang the truck. Size and weight information for trucks traveling on Colorado roads and highways are published by the Colorado State Patrol (2023). Weight limits are shown in **Table 4.2.**

Most forest biomass is transported using tractor-trailers. A variety of configurations are feasible including conventional log trailers, container trailers designed to hold bulk material and chip vans. Trailers used to transport biomass can have live floors that facilitate unloading. With limited ability to navigate forest roads, containerized tractor-trailer and chip van access can be challenging in Colorado. Weight restrictions on forest roads and bridges must also be considered.

Smaller trucks can also be used to transport biomass. Smaller trucks with attached boxes or beds tend to be shorter than 40’ in length, with accordingly lower capacity. They tend to be more maneuverable, but because of their lower payloads are more suited to

Table 4.2 – Colorado State Patrol size and weight information for trucks. ***Source: Colorado State Patrol (2023)***

	Interstate (I-70, I-25, I-76)	Non-interstate
Single axle limit	20,000 lbs	20,000 lbs
Tandem axle limit	36,000 lbs	40,000 lbs
Gross weight limit	80,000 lbs (Subject to Federal Bridge Weight Formula)	85,000 lbs (Subject to State Bridge Weight Formula)

shorter hauling distances. These types of trucks are used extensively to transport urban forest residues in Colorado. Residues are normally chipped and blown into the back of a truck fitted with a box or bed to contain the biomass, which is either transported to a biomass facility for utilization or disposed of in a landfill. The distance from the biomass source to the final destination, collection yard or utilization facility is a determining factor regarding utilization (Nash, 2009). If the landfill is significantly closer or more convenient, most arbor care companies are unwilling to travel the additional distance to a biomass collection yard.

4.5.4 Storage and handling

Biomass storage is necessary to keep a facility operating when fuel is less abundant due to seasonal availability, or during disruptions in supply (due to factors such as logistical challenges or weather events). A boiler shutdown must be done systematically, costing time and resources; as with other facilities that utilize biomass, an assured fuel supply is important. To determine the required storage, an estimate must be made of potential cubic volume of biomass supply required to operate through disruptions. This cubic volume can then be used to estimate the storage area necessary to operate the facility continuously. Large facilities can require substantial quantities of stored biomass in areas where spring breakup can last two months or longer.

There are different types of storage for biomass: direct (active), on-site and intermediate. Direct storage is automated and is usually linked to the feed system that meters biomass into the facility. On-site storage is not linked directly to the facility but represents a reserve located near the facility. Intermediate storage is located offsite, with biomass brought from there as needed.

Direct storage systems tend to be considerably more expensive than other storage systems. Many facilities have a combination of storage types. Chadron State College in Nebraska has a central steam heating plant that is fired with wood chips. They use an annual average of 8,000 tons of wood chips to fire two Hurst boilers. The facility has a direct storage capacity of 100 tons and maintains a reserve of 1,000 to 1,200 tons stored in piles on site (Hurst Boiler News, 2008).

Biomass can be stored in bins, silos or piles. Bins or silos are often used when biomass is derived from milling activities. Chips, sawdust and shavings can be captured, then directly fed to the biomass facility or trucked to another location. Storage in piles is common when biomass is processed remotely or requires a large space for storage. When biomass is stored outdoors, piles must be maintained to facilitate drying, reduce material degradation and combat heat buildup as the biomass dries. If the latter receives inadequate attention, this buildup can result in spontaneous combustion.

Contamination is an issue for piles stored on the ground, as rocks and other contaminants can be scraped up with biomass and cause damage to the system. For example, the biomass heating system in Nederland was once damaged by rocks running through the feed system. One recommended method entails storing biomass on a paved pad under cover.

4.6 Colorado forest biomass supply infrastructure

Colorado currently has few operations that utilize woody biomass as chips or woods fuel. Biomass collection is rare, and few efforts have even been tried in Colorado. A company owned by JR Ford (based in Pagosa Springs) deployed a state-of-the-art biomass collection system (Quinton, 2018). Although a significant supply of wood chips became available with support of a stewardship contract awarded by the USFS, the markets for them have been slow to develop. Nonetheless, strategies that have been used across the state will be considered in this section for both wildland and urban/community forests. **Figure 4.3** depicts a map of Colorado forest products mills circa 2020.

4.6.1 Wildland forest biomass

The infrastructure used to harvest and collect biomass sourced from Colorado wildland forests relies heavily on conventional logging equipment. Therefore, this section considers biomass collection strategies that use conventional logging systems, reviewing harvesting case studies and a summary of current treatment costs. The logging contractor workforce is characterized, and industry trends are identified.

4.6.1.1 Biomass collection strategies used in Colorado

Strategies used to collect biomass vary based on factors such as the form (logs, chips, etc.), quality and amount available. For larger trees where there is an intent to utilize branches and tops in addition to logs, the full (whole) tree is usually skidded or yarded to a landing, where processing occurs. Higher-value trees are usually delimbed and topped. The logs are then transported to a processing facility such as a sawmill.

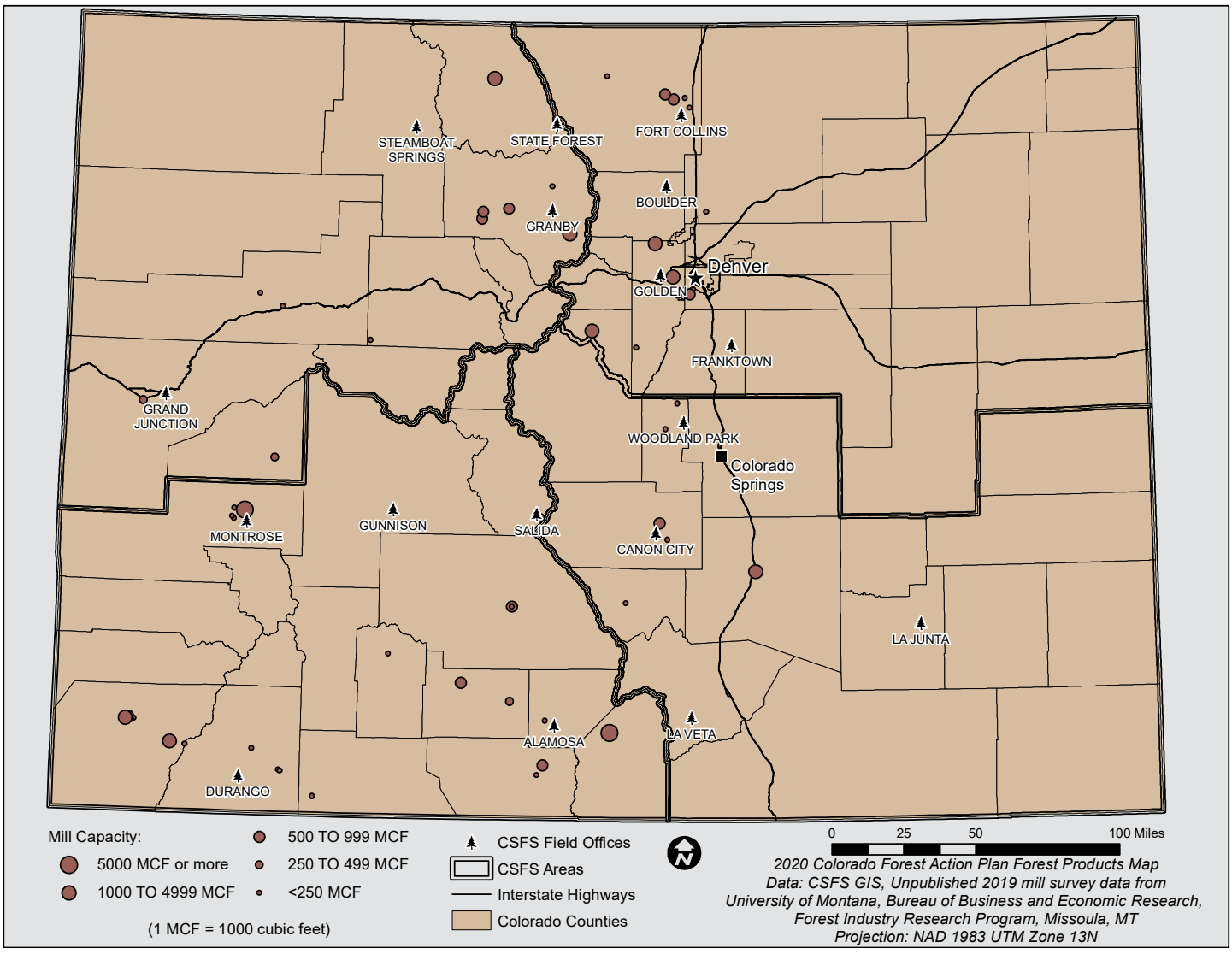


Figure 4.3 – Map of Colorado forest products mills in 2020. ***Credit: 2020 Colorado Forest Action Plan (CSFS, 2020)***

In effect, when using this strategy, the cost of moving the biomass to the landing is subsidized by the value of the logs. The branches and tops are then processed for transport using a chipper or horizontal grinder. The biomass can be blown directly into a chip van or piled on site for later transport. If logs or entire trees are to be chipped or ground, this eliminates the need for delimbing and can either be accomplished at the landing or from decks along a forest road.

Throughout the state, small logs and logs otherwise not suitable for sawtimber are often used as firewood. During planned harvest operations, harvesting contractors or firewood dealers will purchase small logs and firewood from the sale area. Some landowners, such as the Ben Delatour Scout Ranch northwest of Fort Collins, periodically pile logs the public may cut and remove as firewood. Agencies like the CSFS, USFS and Bureau of Land Management as well as some county and municipal forestry departments identify areas where they need to thin trees and then issue permits to the public for removal. This allows reduction of stand density or dead trees (which reduces wildfire risk) in areas where timber sales are not economically feasible.

Peak to Peak Wood was a consortium of Front Range counties cooperating to develop markets as fuel reduction treatments become a consistent source of fiber. Supported by the CSFS, this program helped establish log sort yards and slash collection sites in Boulder, Gilpin, Larimer and Jefferson counties. Although the program ended years ago, Boulder County still operates two forestry sort yards located in Nederland and Meeker Park (Boulder County, 2025). Gilpin and Jefferson counties maintain slash collection sites. Access to these sites is free to area residents. Most residents of mountain counties and communities in Colorado currently have access to slash collection/ disposal sites.

Unfortunately, unsubsidized opportunities for harvesting and removing large quantities of biomass from the landscape exclusively for use at biomass facilities are mostly absent in Colorado. Specifically, costs associated with utilizing biomass as a feedstock are high relative to end-product value. As a result, the feedstock utilized at biomass facilities of scale in Colorado, such as Eagle Valley Clean Energy that formerly operated in Gypsum (Blevins, 2024), was often heavily subsidized — as was construction of the facility (Booth & Lauenberger, 2018).

4.6.1.2 Harvesting case studies and treatment cost summary

A series of studies by Lynch and Mackes (2003) completed through 2001 provided guidance that helped shape current harvesting practices. Studies were divided into two categories: projects where fuels (biomass) were removed from the site and projects where they were left on site; most also examined the economics of restoration treatments. Projects where fuels were removed from the site included the Ponderosa Pine Partnership, Mixed Conifer (Gordon Creek), Cheesman-Trumbull and Air Force Academy Projects. While these projects provide useful insights, market conditions have changed for woody biomass in Colorado since their implementation. Current market conditions should be reviewed prior to implementing biomass harvest.

The Ponderosa Pine Partnership Project conducted in 1996 was located in southwestern Colorado near Dolores. Economic data were collected on five units (492.6 total acres) of land administered by the USFS that were treated using a forest restoration prescription. The harvesting method was tree-length logging, and the systems used were manual felling with chainsaws, mechanical felling with a harvester, rubber-tire skidders, a knuckle-boom loader and conventional log trucks. On average, 29.1 tons per acre of logs were removed from the site. The average revenue per acre was $917.93 compared to harvesting costs that averaged $910.76 per acre, resulting in a small profit to the logger. The stumpage return to the USFS ranged from $1.14 per ton for non-sawlog material to $8.92 per ton for sawlogs. Stumpage rates varied by unit.

This study showed that ecological and fuel reduction objectives could be accomplished at no cost to the landowner in markets that were available at the time. Project implementation required enough timber to keep harvest costs down; it was also essential that the timber be of sufficient quality to sell for favorable prices (Lynch, 2001).

As mentioned earlier, there have been several studies examining the economics of forest restoration treatments in Colorado (Ponderosa Pine Partnership, Gordon Creek, Cheesman-Trumbull, Air Force Academy). These studies thoroughly researched the types of forest products harvested in forest restoration projects, along with the financial results of the work. Markets were available at the time of the studies that are no longer available in Colorado, making it difficult to replicate the results today. A key point that remains relevant is that there must be enough valuable material (sawlogs) to produce enough revenue to remove the less valuable material. If there is not enough valuable material, the project must be subsidized to perform the restoration work, which is currently common throughout the West. Subsidies usually come from public entities with a desire to reduce the impact of wildfire.

An alternative to removing biomass is to leave it in the forest or at the landing. In this scenario, non-merchantable biomass is usually piled to burn or decay over the long term. **Table 4.3** provides a summary of selected projects where fuels were left on site. These projects generally had a lower cost per acre than projects where biomass was removed. Further, although per-acre costs from these studies are dated, the conclusion remains relevant: **Minimizing handling of biomass is essential to reducing project costs.**

Harvesting costs by CSFS region in Colorado, taken from Appendix 7 of the 2020 Colorado Forest Action Plan (CSFS, 2020), are presented in **Table 4.4**. There is considerable variation in harvesting costs across the state, but costs of $3,000 per acre or more are not uncommon, especially in the WUI along the Colorado Front Range. The cost of harvest is influenced by slope, silvicultural prescriptions and treatment requirements.

The Heavens Project near Conifer (Jefferson County) involved treating 359 acres at a cost of $3,370 per acre (CSFS, 2020, Appendix 7). Timber was skidded to a landing and preprocessed, removing limbs and tops. Merchantable logs were then transported to be processed; using a horizontal grinder, tops were processed into chips that were blown into a chip van and transported to a biofuels plant. The basal area of the residual stand was further reduced using a masticator. An evaluation of project costs revealed that they were not excessive given the scope of work.

4.6.1.3 Colorado logging contractor workforce

The logging contractor workforce in Colorado was surveyed in 2002 (Mackes, 2004) and again in 2015 (Vaughan & Mackes, 2015). All companies composing the workforce were small businesses ranging from one employee to more than 20. Findings from the 2015 survey indicate that many businesses transitioned from traditional logging, where timber generates revenue for the landowner, to service contracts where the loggers are paid to implement forest restoration or fuels projects.

The logging contractor pool in Colorado has declined over the last two decades. In 2002 Colorado had 373 contractors engaged in forest management activities. By 2015 there were 236. The primary reason for the decline is the inability of contractors to maintain

Table 4.3 – Project costs where biomass was left on site. ***Source: Lynch and Mackes (2003)***

Project	Form left in woods	Treatment cost per acre
Flickenstein Gulch Project	Lop and scatter	$100.70
Hydro-ax-Projects	Mastication	$124.69 - $402.00
Heil Ranch 2 Project	Chips	$800.00
Genesee Project	Stacked firewood, slash piled and burned	$1,095.95

Table 4.4 – Harvest costs by forest type and CSFS area. ***Source: CSFS (2020)***

Cover type	Treatment cost per acre			
	NE Range (Average)	NW Range (Average)	SW Range (Average)	SE Range (Average)
Piñon-juniper	N/A	$400 - $600 ($500)	$400 - $1,000 ($700)	$500 - $2,300 ($1,600)
Mixed conifer	$1,400 - $3,000 ($2,000)	$1,000 - $3,000 ($1,500)	$2,000 - $3,500 ($2,800)	$800 - $5,000 ($2,050)
Spruce-fir	N/A	$0 - $2,500 ($1,500)	$1,400 - $3,500 ($2,500)	$1,200 - $2,400 ($1,775)
Ponderosa pine	$1,200 - $3,500 ($2,300)	$0 - $2,000 ($1,200)	$800 - $2,000 ($1,200)	$800 - $3,000 ($1,825)
Lodgepole pine	$700 - $4,000 ($1,700)	$0 - $2,400 ($2,200)	$600 - $4,000 ($2,200)	N/A

profitability. Other factors contributing to the decline were company consolidation, difficulty hiring and retaining skilled employees, increased mechanization of operations raising capitalization requirements and reducing employment opportunities, illegitimate contractors and an aging population of business owners — many of whom are approaching retirement.

Further, Vaughan and Mackes' 2015 study concluded that existing workforce capacity was inadequate to meet current and future demand for forest management treatments. A more recent survey of logging, mastication and trucking contractors (Vaughan et al., 2022) found that there is significant need for workforce development and training if this workforce is going to perform the restoration efforts expected in Colorado. In 2023, Colorado passed legislation requiring the CSFS to create a timber, forest health and wildfire mitigation industries workforce development program (Colorado General Assembly, 2023). Efforts to enhance the workforce under this legislation have been implemented through employers and those offering training in the fields related to timber, forest health and wildfire mitigation.

4.6.2 Biomass sourced from urban and community forests

Urban forest residues in Colorado include woody biomass from landscaping and tree care activities, land and utility line clearing, and post-weather debris cleanup. This biomass is delivered to collection sites if established; failing that, it is deposited in landfills. Collection sites have been established by most municipalities and counties along the Colorado Front Range and in other regions of the state to accommodate residues from properties administered by the city or county. Landfills will usually accept yard waste at a reduced tipping fee. Some cities such as Loveland have programs where city residents can drop off yard debris at their recycling center for no charge, while non-residents are charged a tip fee.

4.6.3 Biomass supply chain planning and management

When utilizing biomass, the utilization facility should be constructed for optimum consumption of the anticipated biomass available to the site. Many facilities have failed because the planners did not fully understand the biomass readily available in the area, either in type or volume. In such cases, biomass must be processed to meet the facility's needs or be brought in from outside the area. This leads to inefficiencies that can ruin a business. Therefore, the first step in establishing a supply chain is understanding the supply available. This can be done by analyzing Forest Inventory and Analysis (FIA) data available in Section 3 - Characterizing and Quantifying Forest Biomass in Colorado, reviewing harvest data for the area and conversing with land managers in the area.

4.6.4 Biomass supply chain efficiency

Biomass supply chain efficiency begins with a thorough understanding of how different types of biomass affect the utilization facility. Size, species and quality can all impact the operation. Understanding the tradeoffs between different types of biomass and the related cost is critical for ensuring a facility's profitable operation. For many biomass utilization facilities, procuring raw material represents the largest operating cost.

Different types of biomass might have different costs depending on markets and availability. To determine the most profitable type, it is essential to understand how the type of biomass affects the utilization facility's production. If a biomass type is more expensive but makes the facility more efficient, it might be the most profitable. Conversely, if a biomass type is significantly less expensive than others, it might overcome the inefficiency of the facility for a larger profit.

At the source of the biomass, where harvest or collection operations occur, using the proper equipment to get the biomass into a desired form is critical. Whether it is ensuring logs are the correct length, or that fuel chip sizes match the feed system, it is key to ensure efficient processing of biomass into the correct form. Operators require education on the quality and type of biomass used at the facilities where they send it. These specifications require reinforcement as the project progresses, and the operators must be updated as markets change. Communication through the supply chain is a must.

The next step of the supply chain is transportation. Efficient loading of biomass on trucks or other transportation methods, with products going to the correct location, avoids the self-inflicted inefficiency of extra handling. Once at the utilization facility, unloading must be done expeditiously to avoid the wasteful cost of paying the driver to wait to unload. When loads arrive, storage locations should be known to the driver and ready to accept the biomass, thus reducing waiting time and handling of material.

Storage should be planned before the biomass arrives. Knowing the amount of biomass to be delivered in a given time period is necessary to ensure that storage and unloading equipment are adequate for the expected volume. Having a space for incoming biomass

ensures that extra handling and improper storage will not affect the quality and economy of biomass received. Orderly storage ensures the efficient feeding of biomass to the utilization facility.

If there are different types of biomass to be stored (such as multiple species), this can complicate the storage process, particularly in small storage areas. Sorting the biomass requires storage areas for each sort, requiring partitions in the storage area. In this case the sum of the part is less than the whole, to ensure that biomass types do not mix.

There are classic optimization models for biomass supply chains that consider network design, scheduling, facility location, vehicle routing and technology selection (Sun & Fan, 2020). They can also consider factors such as sustainability, transportation modes, byproducts, types of biomass feedstock and government influences (Mottaghi et al., 2022). The use of such models could help supply chain efficiency.

Biomass Development Opportunity Zones (BDO Zones™) have been analyzed in Colorado. These zones are created using standards for assessing biomass supply chain risks to entice investments in biomass opportunities. The concept was developed by Ecostrat, Idaho National Laboratory and Los Alamos National Laboratory based on six risk categories: Supplier risk, competitor risk, supply chain risk, feedstock quality risk, feedstock scale-up risk and internal organizational risk (Biofuel Development Opportunity Zone Initiative, 2021). Risk factors that fall within these categories have been used to develop a risk rating system for biomass businesses. The benefits of incorporating standards into the rating system include minimizing capital risk and exposure, increasing availability of less expensive capital for biomass projects and decreasing the incidence of project failures. These BDO Zones illustrate opportunities for biomass investment in Colorado. A BDO Zone rating has recently been completed for wood biomass feedstock within a 75-mile radius of Mancos (Biofuel Development Opportunity Zone Initiative, 2021). The 'BBB' rating issued for this analysis represents low-moderate risk of investing in the region. While the workforce capacity and infrastructure were seen as sufficient to provide the study's rated biomass quantities, community opposition to forest restoration and biomass utilization activities was seen as the most significant risk.

4.6.5 Colorado biomass supply assessments

The supply of biomass is influenced by forest ownership within the supply area, biomass markets and disturbances affecting growth. In Colorado, approximately 65% of the forestland is managed by federal agencies — mostly by the USFS. Therefore, USFS policy and direction can influence supply. Agreements with state or private entities, such as Good Neighbor Authority and Master Stewardship Agreements, help facilitate work on USFS and neighboring lands.

When biomass facilities are proposed, the initial step is to complete a business assessment of the proposed operation. Included in that assessment must be an analysis of biomass supply that evaluates potential sources and the related costs.

A supply assessment was conducted for a potential pellet mill in Jackson County in 2007. The project moved forward even though the assessment indicated that the long-term biomass supply was uncertain. Supply and feedstock quality issues coupled with high costs of shipping finished products to market made it difficult for the company to compete in established pellet markets. As a result, it failed and the plant was sold. It currently operates intermittently with extended idle periods. Other biomass facilities that shut down at least in part due to supply issues include a plant located in Nederland in 2005 and more recently the wood-fired heating system at Fairplay High School in Park County. There are success stories in Colorado, such as the Boulder County Open Space Facility in 2003 and the Gilpin County Road and Bridge Facility (CSFS, 2011), so there could be value in analyzing what made those projects successful.

Hauling logs. ***Credit: Ryan Cox, CSFS***

4.7 Summary

Biomass can be utilized as sawlogs, posts, chips, woods fuel or other forms specific to producers and markets. Utilizing biomass requires that wood be available to supply a biomass facility, either from the forest or via urban collection. A sustainable, long-term supply is essential to entice a utilization facility to an area. By providing a destination for biomass other than burning, a utilization facility can be a partner in forest restoration activities.

Utilizing biomass requires a harvest contractor pool with the proper equipment for extracting the biomass and delivering it to utilization facilities in the form necessary for efficient operations. When a new facility or type of biomass is necessary, the equipment might not be available in the area. In such cases, there must be enough work for harvesting contractors to invest in the proper equipment. Based on data regarding the age of harvesting contractors, attracting younger contractors should be explored.

The type of equipment required for harvesting biomass depends on the site where harvest will occur, the prescription for harvest, and the desired products to be removed. Harvest is usually prescribed to meet objectives in forest stands, and in Colorado, reducing forest fuels and improving forest health are common objectives. Having the proper equipment ensures efficient harvesting that meets the ecological objectives and yields the desired forest products.

The cost of harvesting and delivering biomass varies by project. Volume available, topography, distance to market and type of products hauled all affect the cost. The affordability of utilizing non-merchantable biomass often depends on the ratio of merchantable volume to non-merchantable volume. Removing only non-merchantable volume can be very expensive.

Currently there are few facilities utilizing non-merchantable biomass. Unfortunately, there are examples that have attempted to utilize biomass, but were unsuccessful over the long term. Most of the previous efforts have focused on using non-merchantable biomass for energy, either as pellets or fuel for co-generation. With competition from other less expensive energy sources, such as wind and solar, searching for other types of biomass utilization appears prudent.

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