Capacity of the Southwest Forest Products Industry to Support Small-Diameter Timber Utilization and Restoration: A Synthesis

By Shay Levine

Northern Arizona University

School of Forestry

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Advisor:

Han-Sup Han, Ph.D.

Readers:

David Auty, Ph.D.

Dipita Ghosh, Ph.D.

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Abstract

The forest products industry in the southwestern US has experienced substantial changes over the past two decades, including fluctuations in processing capacity and production efficiency. Current land management practices focus on restoration and the utilization of small-diameter timber. However, implementing effective management treatments presents several challenges. Climate-driven issues, federal policy, and operational restrictions (e.g., weather and site conditions), along with low infrastructure capacity for forest products, have all contributed to low utilization rates of small-diameter timber. This review synthesizes existing literature on past and current forest product processing capacity in Arizona and New Mexico, with a focus on utilization trends, infrastructure limitations, and emerging opportunities in the forest products sector. Despite some yearly variability, findings indicate a steady increase in utilization rates relative to total processing capacity. Although findings indicate increased utilization, there is room for future growth as processing capacity continues to remain underutilized. Key challenges facing forest product production include limited product diversity in select markets and a lack of industry infrastructure across the Southwest. Our results suggest that the development and innovation of alternative products (biochar, mass timber, etc.) could help fill capacity gaps. The literature and data show that adequate processing capacity exists. Which could allow for increased industry production and the ability to recover additional value from forest residuals. Increasing utilization of small-diameter trees and the development of alternative value-added products could help expand forest restoration efforts and stimulate forest industry growth in the Southwest.

Keywords: small-diameter timber (SDT), Southwest, utilization, forest products

Abbreviations:

SDT - Small-Diameter Timber

SED - Small End Diameter

4FRI - Four Forest Restoration Initiative

TPO - Timber Product Output

BBER - Bureau of Business and Economic Research

WMSP - White Mountain Stewardship Project

USFS - United States Forest Service

USDA - United States Department of Agriculture

MBF - Thousand Board Feet

NGO - Non-Governmental Organization

CFLRP - Collaborative Forest Landscape Restoration Project

DBH - Diameter at Breast Height

EWP - Engineered Wood Product

MOE - Modulus of Elasticity

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1. Introduction

Challenges in the capacity and utilization of timber in the forest products industry of the Southwestern United States (U.S.) have been a prevailing obstacle for many decades and have undergone many ebbs and flows since logging was established in the southwest in the mid to late 1800s. Over the last 100 years, forests in the western United States have undergone large ecological and structural changes, largely driven by fire suppression, historically unsustainable logging practices, and ongoing climate change patterns and stressors (Hagmann et al. 2021; Covington et al. 1997; Allen et al. 2002). The current forest landscape of the southwest faces three key challenges: high-density and over-stocked forest structures, high catastrophic wildfire risk, and a decline in forest health and biodiversity. Historically, frequent low-intensity fire maintained open, heterogeneous ponderosa pine (*Pinus ponderosa)* and mixed-conifer forests across much of the region (Covington & Moore 1994; Fulé et al. 1997). However, federal fire suppression policies initiated in the early 20th century combined with extensive grazing and the decline of Indigenous cultural burning practices, have contributed to the development of denser forest structures and increased surface fuel accumulation across the landscape (Allen et al. 2002; Hessburg et al. 2021). These landscapes are now more vulnerable than ever in the face of climate change and the challenges it presents.

Persistent climate trends play a critical role in creating undesirable forest structures and in shaping how management treatments are applied across the Southwestern landscape. Several recent studies indicate that over the past two decades, increasingly frequent droughts have placed additional stress on vegetation, including trees and other plant life (Hagmann et al. 2021; Clark et al. 2016). Hanson and Weltzin (2000), reported that drought conditions in forested systems of arid regions such as the Southwest and the Western U.S pose inherent challenges, with potentially detrimental effects on water availability, landscape biodiversity and other ecosystem aspects. Over the past decade, climate change models for the U.S Southwest project higher temperatures, increased plant water demand, and longer

dry seasons. By promoting more frequent and severe droughts and increasing the prevalence of insect outbreaks, these conditions indirectly drive higher wildfire frequency and intensity, ultimately leading to extensive tree mortality across the landscape (Archer and Predick 2008; Ayres and Lombardero 2000; Allen et al. 2010). Forested systems characterized by large amounts of down-woody debris, standing dead timber, and compromised stands create ideal conditions and breeding grounds for various pests (e.g., bark beetles, *Dendroctonus spp*.) and pathogens (e.g., dwarf mistletoes, *Arceuthobium spp.*) (Klutsch et al. 2014). These conditions which facilitate the emergence of pests and pathogens further exacerbate fuel accumulation and the risk of more frequent wildfires.

Historical land use practices, poor management and climate change factors, modern wildfires in the western US, including Arizona (AZ) and New Mexico (NM), now burn with much higher severity and size, and cause much higher ecological disturbance than their historical fire regime behaviors (Singleton et al. 2019; Kreider et al. 2024; Singleton et al. 2019) Longer periods of non-frequent fire cause forests to grow denser and promote more condensed conditions. Resulting in the expansive forest network of highly dense small-diameter timber stands that we see in today's forest structures (Covington and Moore 1994; Hagmann et al. 2021). These stands crowd landscapes and promote higher intensity catastrophic wildfires.

Over-stocked stands primarily composed of small-diameter timber (SDT) dominate the landscape and bring with them a multitude of challenges. The utilization of small-diameter trees often highlights a gap between forest restoration needs and the existing industrial capacity to process them (Wagner et al. 1998). Sizes classes for SDT can range anywhere between 5 to 11 inches in diameter. A couple of studies have noted that processing trees under five inches in diameter significantly increases harvesting and handling costs, often requiring integrated systems to generate break-even profit margins (Han et al. 2004; Pan et al. 2008). Additionally, Larson and Mirth (1998) and Fight et al. (2004) discuss that without long-term supply guarantees, such as 20-year stewardship commitments, promoted by land

management agencies, and advanced decision support tools to mitigate market changes, the conversion of small-diameter ponderosa pine into value-added products remains a difficult enterprise for the Southwest's forest products industry.

This said, the economic feasibility of landscape-scale forest restoration in the Southwest is heavily dictated by the high costs of transporting low-value biomass and small-diameter timber utilization rates (Fight et al. 2004). Research indicates that transportation often represents the primary expense in forest thinning operations, particularly for material under 5 inches in diameter generally utilized for bioenergy production (Pan et al. 2008). When local infrastructure, particularly processing facilities within a 50-mile-radius, is lacking, haul distances often become non-feasible, as the market value of the material cannot offset the rising logistics costs (Nicholls 2014). Chang et al. (2023) and Nicholls (2014) further discuss this, which is supported by modeling, and confirm that transportation costs and associated distance constraints create significant barriers, effectively limiting which restoration projects can be implemented based on their proximity to appropriate processing facilities.

Operational windows for forest management in the Southwest are often also constrained by a combination of weather conditions, regulatory restrictions, and wildlife protections. Although data is limited for the southwest, factors such as winter snowfall and melt events, high winds, and seasonal monsoons, fire restrictions during periods of elevated fire danger, and protections for species like Mexican Spotted Owl (*Strix occidentalis lucida)* may reduce or shorten logging operational windows. These trends and forest conditions have created an urgent need for large-scale forest restoration treatments, including mechanical thinning and prescribed burning treatments (Allen et al. 2002; Hjerpe and Kim 2008). Active restoration management is now recognized as a key principle strategy for mitigating wildfire risk, protecting communities and timber, and restoring forest resilience under a changing regional climate (Hessburg et al. 2019; Stephens et al. 2013; Millar et al. 2007). However,

restoration treatments are getting increasingly more difficult to implement due to economic, social, and logistical challenges, especially the limited ability of local mills to process small, low-value material produced from thinning and restoration projects (Wu et al. 2011; Keegan et al. 2006; Simmons et al. 2020). Without addressing these operational and market barriers, the scale of restoration implementation across the landscape will continue to hold back further growth.

Understanding that the capacity and infrastructure of the forest-products industry in the Southwest plays a huge role in further growth and establishment of more effective forest restoration and management across nearly 7.3 million acres of non-reserved timberland in the region is critical to scaling up restoration efforts across the landscape (Simmons et al. 2020). Two types of capacity are of most interest to this study, production capacity, the amount of finished product produced from a facility in a given time metric (year, quarter, etc.) and timber processing capacity, the total amount of potential production that could take place considering all raw materials (timber) are used at their fullest potential with limited residual waste (Beagles et al. 2024) (Table 1). Understanding the two types of capacity and why they should be used as a metric for restoration is particularly important in Arizona and New Mexico, where restoration, thinning, and hazard-fuel reduction treatments are essential to supporting community wildfire protection, improving forest health, and enabling land management agencies to achieve long-term restoration goals.

Throughout the western US, regional timber processing capacity, which is generally understood as the volume of timber reported in thousand board feet (MBF) that could be processed by a specific business, state or region as a whole, is in decline (Keegan et al. 2006). Meanwhile, many forest management projects in Northern Arizona generate non-traditional products from small-diameter logs and biomass material. For example, instead of producing traditional structural dimension lumber making stud and small dimension products (i.e., pallets and 1x (one by) materials), creating a mismatch

between what the forest needs ecologically (restoration treatments) and what products and volume amounts of timber the industry can profitably process (Hampton et al. 2011). This is exacerbated by a limited diversity of forest products being produced from wood residuals and biomass material, while dimension lumber for stud and pallet production continues to be the primary focus for current product utilization (Simmons et al. 2020a; Nicholls 2014). As we continue to utilize 100% of our sawlog timber (10" + DBH) and heavily underutilize non-sawlog (smaller-diameter timber, 5-10" DBH) and biomass materials, this gap between ecological necessity and industrial capacity will continue to create critical bottlenecks limiting large-scale implementation of restoration treatments.

This research examines whether the forest products industry in the southwestern US possesses sufficient capacity to meet regional forest restoration needs. Understanding existing mill capacity and realistic production volumes enables better alignment of timber sale volumes and timing with processing constraints, supporting restoration goals and implementation timelines. Finding the correlation between the capacity that federal partners like the USDA Forest Service (Forest Service) and other agencies can offer through timber sales, stewardship and service contracts, like collaborative efforts such as the Good Neighbor Authority (GNA) program and the Four Forest Restoration Initiative (4FRI) projects, as well as increasing wood utilization for processing facilities to maximize production rates, could be the key to addressing many of the gaps present in today's industry.

The goal of this study is to identify well-established literature on the forest products industry in the Southwest, with a focus on its modern history and current state of affairs, challenges in the utilization of small-diameter timber, and trends in products and timber processing capacity over time. To better understand this issue in the specific context of the Southwest, this study attempts to analyze three main objectives. (1) Analyze and develop an understanding of the modern history of the forest products industry in the Southwest (New Mexico and Arizona), focusing on challenges with small-diameter

timber utilization. (2) Analyze supply and demand trends for forest products coming out of Arizona and New Mexico-based timber processing facilities over time. (3) Interpret current uses for forest product deliverables being utilized for a diversity of forest products to better inform areas of strength in current utilization and highlight innovative and alternative products to potentially be developed.

2. Methods and Data

2.1. Forest Products Industry Literature Search and Selection

This literature review implemented a structured approach to identify and evaluate scholarly and technical sources related to timber industry capacity, forest restoration outputs, and forest product utilization in the southwestern United States. The literature found through this search process was analyzed around the three primary sections: (1) Modern history and changes in industry capacity in the U.S Southwest, (2) Challenges in the utilization of small-diameter, low-value timber, and (3) Trends in forest products and opportunities for innovation and development.

The review was conducted using clearly defined selection criteria, including targeted keyword selection, literature database selection, a specific timeframe, and a well-defined regional scope. These criteria were applied consistently to ensure the relevance and focus of the sources included in the analysis. A combination of single keywords and combined search criteria was used to select and screen literature on specific topics such as capacity, supply, production, and forest product utilization. Due to significant regional variation in timber supply, industrial capacity, and restoration outputs, the analysis was restricted to the southwestern United States, with a particular focus on Arizona and New Mexico. Individual keywords included in the search criteria included "*capacity"; "supply"; "production volume"; "production"; "forest products"; "timber products"; "utilization"; "small-diameter timber"; "low-value timber"; "southwest"; "Arizona"; "New Mexico"; and "Western United States".*

Other phrases and combined search terms included “capacity and Arizona,” “forest products and production volume,” and “small-diameter timber and utilization challenges” were also used to narrow our results.

To make sure credible and peer-reviewed materials were utilized, searches were conducted using the following academic databases and journals: Google Scholar, Journal of Forestry, Forest Products Journal, Science Direct, and Web of Science. Technical reports and other regional assessments from the US Forest Service, statewide agencies, and Non-Governmental Organizations (NGO’s) were assessed and reviewed when they provided helpful context, relevant data, or a good analysis of the topics.

To perform a literature search with the best and most relevant information, search results were limited to publications from the date range of 1990 to 2025. This time period showcases the start of modern forest restoration initiatives, gives opportunities for more advanced alternative and innovative wood products markets, and showcases the current understanding and processing challenges of small-diameter timber utilization across the western United States. Resources and other articles produced before this timeframe were used only when they offered critical background knowledge and added significance to the analysis.

Studies with solid data and a regional focus were prioritized to better understand Arizona and New Mexico’s abilities to meet forest management needs and allow for a more centralized focus on the challenges and opportunities of the Southwest’s timber industry. All other literature from additional Western states was only used when it offered solid insights that were important to the analysis for context and comparison, specifically to forest conditions or similar industries in the Southwest. Older sources than the criteria mentioned (1990-2025) were included only to provide critical historical

context or relevant background information. A summary of the key definitions found in the literature search is provided to give the reader a better context and understanding of specific industry terms used throughout the literature review.

Table 1. Primary terms and associated definitions used to help describe and explain aspects of the literature review.

Term	Description
Timber Processing Capacity	The volume of timber reported in (MBF) thousand board feet that could be processed, given sufficient supplies of raw material, firm market demand for products, and ordinary downtime for maintenance, is the volume of timber that could be used annually if a facility operated at its self-reported production capacity.
Production Capacity	The potential volume of output a facility can produce on a shift or annual basis, assuming firm market demand for products, sufficient supply of raw materials, and ordinary downtime for maintenance.
Small-Diameter Timber	The timber that encompasses the size ranges below and above the classification for sawtimber, which includes: "sawlogs timber" (10" + DBH), "non-sawlog timber" (5" – 10" DBH) and biomass material (timber residuals).
Engineered Wood Products	Any structural product made from roundwood that has been reduced into smaller pieces of wood, or a structural product that is made from residue materials from wood processing operations
Mass Timber	The classification of a group of technologies and products that are a distinct class of engineered wood products, which use various methods of joining smaller pieces of lumber or paneling to create one solid structural product.
Ecological Restoration	The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.
Cellulose Nanocrystal Impregnation	The modification process forces highly crystalline, rod-like cellulose particles into the porous structure of wood to increase the value of non-structural wood species by enhancing its mechanical properties for advanced engineering and architectural applications.
Juvenile Wood	The zone of wood extending outward from the pith (center) is commonly grown in the first three years of a tree's life.

Definitions acquired by (Beagles et al. 2024, Sorenson et al. 2016, Guss 1995, Clewell et al. 2004, Larson et al. 2001, Tsai 2023, Burrill et al. 2023, Poshtiri et al. 2024, Atkins et al. 2023)

2.3. Data Collection and Analysis

Data collection for this study was conducted independently from the literature review and gathered from 3 primary sources: USFS Cut and Sold Reports, USFS Timber Product Output (TPO) Data, and the University of Montana's Bureau of Business and Economic Research (BBER) forest industry reports. A forest product industry inventory was also created to collect information around current operating facilities and the products they produce for the forest products industry in Arizona and New Mexico. These databases and reports were analyzed, and quantitative data was collected to highlight a few key trends and patterns. A summary of the data sources, reports, and variables utilized in this study is provided in Table 2.

Table 2. Primary databases and reports of Arizona and New Mexico, over the years, and the summary of variables used to assess the capacity of the forest products industry.

Database/ Report	Region/ State	Years	Variables
USFS TPO Database	Region 3	2012, 2016, 2019, 2020	Product Type & Number of Facilities
USFS Cut and Sold Reports	Region 3	2000-2025	Volume Cut (MBF)
BBER Reports	AZ, NM	1997, 1998, 2002, 2007, 2012, 2016, 2021	Processing & Production Capacity (MBF)
Southwest Forest Product Industry Inventory	AZ, NM	2025	Current Forest Product Industry Breakdown

(MBF) = Thousand Board Feet

Data for the Southwest Forest Product Industry Inventory was compiled and organized using a few key variables. Information on current products from active processing facilities was collected through targeted internet searches. Facilities were categorized into three primary product types: Dimension Wood Products and Lumber, Secondary Wood Products and Millworks, and Wood Fiber Residuals and Byproducts. In addition, each facility was classified by state-level designation (Arizona or New Mexico). Data was collected by recording the presence of the specific product produced by an Arizona or New Mexico-based processing facility. This data was expressed as percentages by dividing the number of specific product types by the total number of products within each primary forest product category (e.g., secondary wood products). The operational status of facilities was verified through direct communication; facilities with unknown status were contacted via phone. If no confirmation was obtained after two attempts, a third call was made, followed by a brief email inquiry. Facilities that did not respond to these efforts were classified as non-operational. Data was processed using Microsoft Excel.

USFS Cut and Sold reports were analyzed and organized to evaluate three key variables: (1) Quarterly harvest volumes in thousand board feet (MBF) by state, which included both Arizona and New Mexico (USFS Region 3), (2) Cumulative totals of all quarterly reports for each year analyzed by state, and (3) Cumulative total for all of Region 3 (Arizona and New Mexico) by year. Data was collected using harvest (cut) volume data from the year 2000 to 2025. Graphs and figures were created to showcase the fluctuations of timber harvested from the Southwest's landscape over time, as well as to assess current outputs and potential capacities for the Southwest’s timber industry.

USFS TPO data was organized by using core table 1 (Figure 1) from within the TPO

database, for Arizona and New Mexico, which describes the number of mills by species and product type, as well as by state designation. The table is represented by using available data during specific years for analysis; these years included 2012, 2016, 2019, and 2020. Three variables were collected and analyzed from the TPO dataset: (1) The change in processing capacity, based on the number of processing facilities; (2) Forest product type, and (3) Year. Forest product type was further classified using categories adapted from core Table 1 from the TPO database referenced above. Each product category was consolidated into two to three product types to simplify analysis and graphical representation. In Dimension Wood Products and Lumber, log home mills and sawmills were combined. In Secondary Wood Products and Millworks, miscellaneous, pole, and post mills were grouped together. Within Wood Fiber Residuals and Byproducts, biomass/energy plants, misc. bark/mulch mills, and residential fuelwood operations were combined. Although species type was included in the original TPO dataset, it was excluded from analysis because it was not analytically relevant to the study objectives.

Core Table 1. Number of Mills by Species and Product Type,Arizona & New Mexico

		Survey Year / State Name							
		2012		2016		2019		2020	
Major Species	MEANING	Arizona	New M..	Arizona	New M..	Arizona	New M..	Arizona	New M..
Softwood	Biomass/energy plant	1		1		7	4	4	7
	Log home mill (include Vig..	2	5	2	7	1	8	1	11
	Misc - Bark/mulch mill	1		1		3	1	3	2
	Miscellaneous mill		1		1		1		
	Pole mill	1			1				
	Post mill					2	2		3
	Pulp/Paper mill								
	Residential Fuelwood Stu..	3		3	2				
	Saw mill (includes cooper..	10	14	13	21	12	17	10	18
	Total	**18**	**20**	**20**	**32**	**25**	**33**	**18**	**41**
Hardwood/Softwood	Biomass/energy plant							2	1
	Misc - Bark/mulch mill								1
	Miscellaneous mill				1				
	Pole mill			1					
	Post mill							1	
	Residential Fuelwood Stu..	1		1					
	Saw mill (includes cooper..	1			2				2
	Total	**2**		**2**	**3**			**3**	**4**
Hardwood	Miscellaneous mill		1		1				
	Saw mill (includes cooper..	1		2				2	
	Total	**1**	**1**	**2**	**1**			**2**	
Grand Total		**21**	**21**	**24**	**36**	**25**	**33**	**23**	**45**

Figure 1. Core Table 1 from USDA Forest Service Timber Product Output (TPO) database, representing the number of mills by species and product type in AZ and NM.

Using BBER forest industry reports, we compiled data for seven primary attributes in Arizona and New Mexico: total timber processing capacity (MBF), total timber production (MBF), timber processing capacity utilization rate, sawmill production capacity, lumber production (MBF), and the associated utilization rate from sawmill production capacity and lumber production. Data was collected at approximately five-year intervals (±1 year) from 1998 to 2021 for Arizona and from 1997 to 2021 for New Mexico. Starting dates for the data collection differed due to the availability of reports provided by BBER.

Professional interviews and discussions were additionally utilized to gain a deeper understanding and provide relevant and unique forest industry perspectives from leading industry professionals. Interviews were conducted with two senior-level individuals involved in Arizona's private forestry sector to provide additional context and insight into this study. Tabi Bolton, Regional Area Supervisor at Campbell Global, an international investment asset management company for timberlands operating under J.P. Morgan; provided a perspective on regional forest management and industry trends. Kevin Ordean, Director of Forest Operations at Restoration Forest Products (RFOR), Arizona's largest high-capacity sawmill, contributed expertise on small-diameter ponderosa pine production, restoration-focused forestry operations, and strategies for reducing wildfire fuel loads. Both professionals were provided with a series of nine questions surrounding the primary three themes of the literature review, discussed above at the beginning of subsection 2.1.

3 & 4. Results

3. Literature Review

3.1. Modern History of the Forest Products Industry in the Southwest

3.1.1. Restoration-Focused Management

Historically, the forest products industry in the southwest has been closely connected to forest species composition, management practices, and continuous market demands. The US Southwest, encompassing parts of Arizona, New Mexico, Colorado, and Utah, has experienced fluctuations in timber harvesting due to shifts in forest policies, environmental constraints, and industrial capacity, immediately preceding the 1990s (Sorenson et al. 2016). Specifically in Arizona and New Mexico, large decreases in total harvested volumes were recorded following the 1990s (Figure 2). Some earlier research by Betters (1984) indicates that commercial timber infrastructure and workforce availability have historically limited the scale and extent of timber harvesting in mixed conifer and ponderosa pine forests. Over the last two decades, an increase in restoration-focused management, which is often referred to as ecological restoration management (Allen et al. 2002), has shifted the conversation and objectives of management from maximum timber production to wildfire and landscape restoration uses. Much of this forestry perspective shift included collaborative forest landscape restoration projects (CFLRPs), such as the Four Forests Restoration Initiative (4FRI) and the White Mountain Stewardship Project (WMSP). Hjerpe et al. (2021) indicated that these projects and initiatives increased demand and treatment for small-diameter timber and the acres they sit on, while also showcasing some existing industry and agency capacity limitations.

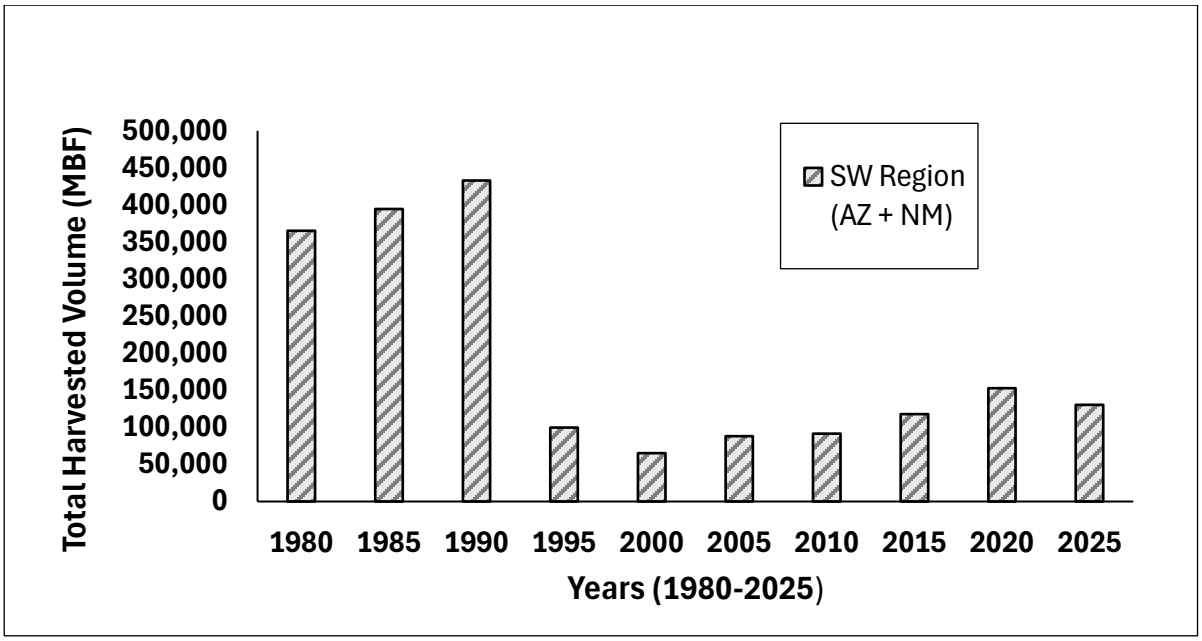


Figure 2. Trends in total harvested volume (MBF) and years from 1980-2025 for the Southwest region (Arizona and New Mexico).

Early collaborative efforts, such as the Greater Flagstaff Forest Partnership and the White Mountain Stewardship Project (WMSP), provided the foundational proof-of-concept for utilizing long-term stewardship contracts to achieve restoration goals (Egan and Nielsen 2014). The WSMP was created in 2004 as one of the first restoration initiatives in the county at the time, creating a platform for future initiatives to take off from. Following the occurrence of a few significant wildfires in the region and large-scale forest destruction, 4FRI was established in 2009, the successor to the WMSP (Devenport and Colavito 2026). 4FRI at the time of its beginning, was one of the largest restoration projects in the US and by far the largest in the state of Arizona. The initiative is a collaborative effort that spans 2.4 million acres across the Coconino, Apache-Sitgreaves, Kaibab, and Tonto national forests, with its vision being to support natural fire regimes and local economies (Devenport and Colavito 2026). With the creation of 4FRI, restoration-based projects and ecological restoration were put front and center. 4FRI foundational documents called for thinning up to one million acres over 20 years, ramping up to 50,000 acres per year (Hjerpe and Mottek-Lucas 2024). The primary goal of

4FRI was to accelerate the pace of treatment from 20,000 acres to approximately 50,000 acres per year through mechanical thinning and prescribed burning (Four Forest Restoration Initiative 2011). This objective gave land managers the ability to scale up operations once appropriate infrastructure and resources were established.

Between 2010 and 2023, the initiative made significant strides, with cumulative restoration activities supporting hundreds of regional jobs and generating millions in economic output. In 2023 alone, 4FRI activities supported 564 direct jobs and $148.5 million in regional economic output (Hjerpe and Mottek-Lucas 2024). These initiatives demonstrated that forest health could be improved by thinning small-diameter trees, while also highlighting the necessity of a productive and financially stable wood products industry to help offset the high costs of these treatments and logistics associated (Nicholls 2014). Despite these economic contributions, the implementation of these initiatives has faced substantial logistical and socioeconomic limitations. Creating a critical bottleneck of high costs to remove low-value restoration byproducts while also having limited regional processing capacity. This was evidenced by the 2022 termination of the Phase 1 integrated stewardship contract, which resulted in 48,000 acres being returned to the government untreated due to the contractor's inability to secure financing and industrial capacity (Devenport and Colavito 2026; USDA 2022c). Additionally, Nicholls (2014) notes that the lack of diverse markets for biomass and the challenges of high road maintenance and transportation costs have historically restricted the scale of operations in the forest.

To address these persistent hurdles and the escalating threat of catastrophic fire, the U.S. Forest Service introduced the Wildfire Crisis Strategy (WCS) in 2022. The WCS represents a national pivot toward landscape-scale management, identifying 4FRI as a priority landscape for

accelerated funding through the Infrastructure Investment and Jobs Act and the Inflation Reduction Act (Devenport and Colavito 2026). This strategy seeks to bypass previous limitations by providing the funding necessary to bridge the gap between treatment costs and industry viability. By identifying 4FRI as one of the Initial Landscape Investments, the USFS has committed significant resources from the Bipartisan Infrastructure Law to accelerate thinning on high-risk acres (USFS 2022b). This large amount of funding is specifically intended to help scale up treatments to a level that matches the pace of the wildfire crisis, aiming to treat an additional 20 million acres on National Forest System lands over the next decade (USFS 2022a). The USFS (2022a) acknowledges that current market conditions often make the removal of small-diameter timber and forest residuals economically unfeasible for traditional timber operators.

3.1.2. Changes In Timber Harvest and Utilization

Changes in milling capacity and processing capabilities over time have been documented extensively. Studies by Keegan et al. (2006) and Simmons et al. (2020) indicate that western U.S. mills have varying degrees of capability to handle small-diameter timber and restoration-based material. Analyses comparing anticipated fuel reduction and thinning project outputs to facility intake suggest that regular discrepancies between available harvestable timber and the capacity of processing facilities often misalign on projects (Hampton et al. 2011). Prior studies throughout the western US also seem to indicate a substantial decline in timber-processing capacity over the past several decades. Specifically, Keegan et al. (2006) reported a regional decline in capacity from roughly 5.0 billion cubic feet (CF) in 1986 to 3.2 billion CF in 2002, with most facilities optimized for logs greater than 10 inches in diameter at breast high (DBH). Only about 20% of remaining mills were equipped to efficiently process logs under 10 inches DBH, the size class most prevalent in restoration treatments. In the four corner states (Arizona,

Colorado, New Mexico, Utah), Sorenson et al. (2016) found that dimension lumber and studs accounted for 63% of sawmill sales in 2012, showcasing the limited diversity of non-traditional markets. Further, Stewart et al. (2004) noted that large volumes of small-diameter material can often remain unprocessed and can be left to rot or burn in the woods, due to poor local infrastructure. Ultimately, this continued misalignment between the mechanical requirements of restoration thinning and existing industrial infrastructure creates significant challenges, hindering the economic viability of forest health initiatives.

3.1.3 Restoration Modeling to Support Management Goals

Several restoration modeling efforts to determine desired restoration output goals have estimated regional wood supply while also assessing the economic impacts of forest restoration treatments. For example, Hjerpe et al. (2021) modeled the economic impact of the Four Forest Restoration Initiative (4FRI), showing how increased restoration activities can improve local employment, increase mill utilization, and aid in forest health efforts. Similarly, Hampton et al. (2011) used a stakeholder consensus approach to estimate sustainable wood supply from Northern Arizona restoration treatments, highlighting how coordinated planning between land managers and industry can help address capacity constraints. Nicholls (2014) showed that with the development of forest products clusters in Arizona, the industry can take better advantage of restoration project wood residuals and quality timber resources that are closer in proximity to lessen the impact of additional transportation and operational costs. These findings suggest that although restoration activities have increased harvest volumes, mismatches still exist between the volume of material removed from project sites and volumes the mill can process, creating an ongoing constraint with restoration efforts.

3.2. Challenges In Utilization of Small-Diameter Timber

3.2.1 Overview and Definition of Small-Diameter Timber

Small-diameter timber (SDT), a common output of fuel reduction, thinning and restoration treatments, presents unique utilization challenges due to constraints around its physical characteristics, lower market value, and associated high processing costs (Chang et al. 2023; Hjerpe & Kim 2008; Mackes et al. 2005). As stated by Tsai (2023), SDT is not simply explained under one specific definition; in fact, the definition varies publication to publication depending on utilization methods and initial measurements used. The study goes on to state that SDT in many studies was primarily gathered from two main measurements, which can be determined by the small end diameter (SED) and diameter at breast height (DBH) measurements. Small-diameter timber is commonly referred to as the timber that encompasses the size ranges below the classification for "sawtimber" which, according to forest service reports, is timber that exceeds a DBH of at least 9 inches for softwood species and a DBH of at least 11 inches for hardwood species (Tsai 2023; Burrill et al. 2023). For the purposes of this study, after analyzing various publications and discussing conceptual models that best describe the Southwest's forest structures, we are classifying small-diameter timber as a broader definition describing it as the trees and size ranges within the Southwest's current forest structures that can be appropriately used for timber production markets, which generally occur from size classes between 5" and 18" DBH. To better emphasize this concept, we used three main categories to classify the raw materials, consisting of the definition of small-diameter timber. (1) Sawlogs, (2) Non-sawlog material, and (3) Biomass and wood residuals. Seen here in Figure 3 below.

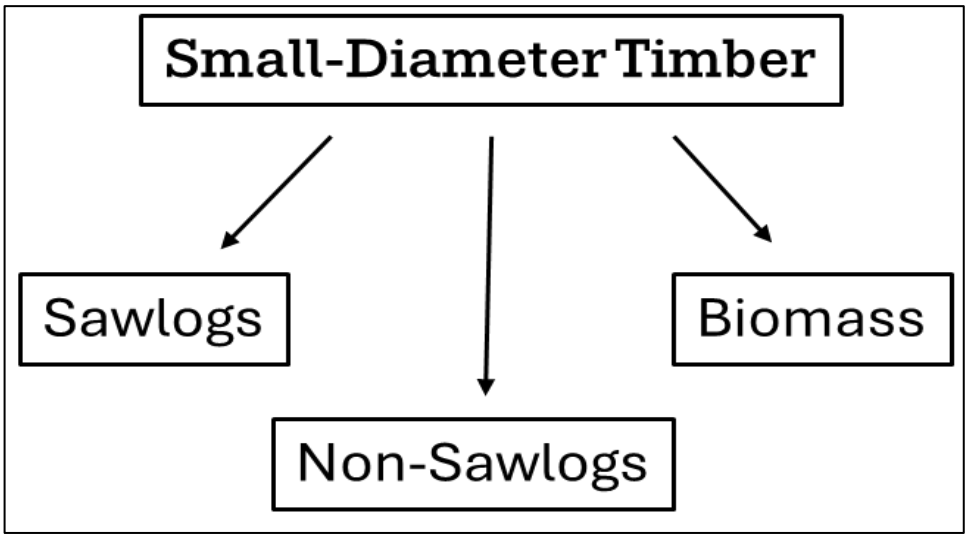


Figure 3. Simplified conceptual model of small-diameter timber (SDT) classification and breakdown of raw materials included in SDT.

3.2.2. Utilization Challenges

Utilization of small-diameter timber presents persistent challenges that complicate efficient use and operational logistics. A few studies suggest that SDT's physical characteristics showcase that its fundamental morphology creates barriers for further utilization and product value (Hjerpe & Kim 2008). Understanding the characterization of SDT within its wood structure is key, as SDT is characterized by having higher proportions of juvenile wood, which, in the context of wood product production, significantly compromises its structural utility and lowers market value for associated products.

The successful management of these stands is historically constrained by a mismatch between forest restoration requirements and existing industrial capacity. Much of the current infrastructure in western North America remains optimized for larger diameter sawtimber, leaving a significant gap in the ability to process the smaller trees removed during thinning operations (Wagner et al. 1998). Processing trees under five inches in diameter significantly inflates harvesting and handling costs, often requiring the implementation of complex,

integrated systems to achieve results that sometimes barely break even on profits (Han et al. 2004; Pan et al. 2008). In addition, the high financial risk associated with re-equipping and re-structuring existing facilities for small-diameter log lines remains a disincentive to private investment (Stewart et al. 2004). Without long-term supply guarantees such as 20-year stewardship commitments and comprehensive decision support tools to help manage unpredictable wood prices, the conversion of small-diameter ponderosa pine into value-added products remains a bottleneck for the Southwest's forest products industry (Larson and Mirth 1998; Fight et al. 2004).

These economic barriers are further compounded by the high costs of logistics, and transportation, often representing the single largest expense in forest thinning operations (Pan et al. 2008; Chang et al. 2023). Because small-diameter timber and its associated biomass have low market values and low bulk density, the financial margin for these projects is extremely narrow. Research by Nicholls (2014) suggests that for a wood products industry to effectively support landscape-scale restoration, processing "clusters" or networks must be located within a relatively local radius. Ideally, within a 50-mile radius of the treatment area.

Consequently, long-haul distances create large distance barriers that can limit the scope of feasible restoration to areas immediately adjacent to the few remaining industrial hubs in Arizona and New Mexico (Nicholls 2014; Chang et al. 2023). This leads to underutilization of forest biomass and timber resources, where high-priority restoration zones remain untreated due to their distance from appropriate processing facilities. Additionally, the lack of local markets for wood chips and sawmill residuals forces many contractors to absorb the cost of disposing of large volumes of biomass generated by these treatments. Without strategic investment aimed at reducing these transportation challenges and improving local

infrastructure, the gap between regional restoration goals and industrial production rates is likely to widen. Economic studies suggest that high production and transport costs relative to potential revenue create a barrier to widespread utilization (Fight et al. 2004; Pan et al. 2008). Becker et al. (2008) introduced the HCR Estimator 2.0 software as a tool to model cost and revenue thresholds for harvesting small-diameter ponderosa pine, creating a platform for logging contractors and forest planners to help lower their costs for performing fuel reduction treatments.

3.2.3 Additional Barriers to Use

Despite methods for finding new ways to efficiently transport, use and make logistics more feasible, barriers still remain that threaten effective utilization (Hjerpe et al. 2009). Limited local processing capacity, a lack of productive infrastructure, as well as high operational costs, slow down the momentum of converting small-diameter material into profitable marketable products (Keegan et al. 2006; Simmons et al. 2020b; Hampton et al. 2011). Other challenges, including policy and other management rules, including environmental permitting and high restoration standards, can place additional limits on harvest volumes or can slow materials flow from the forest to the mill (Sorenson et al. 2016). Public and industry willingness to accept the use of small-diameter timber also continues to be a barrier to further production, as small-diameter timber is often perceived as low quality, which in some markets limits demand for traditional products and is a deterrent to adopting alternative materials (Wagner et al. 1998; Stewart et al. 2004).

3.3 Forest Product Trends, Innovations and Opportunities for Expansion

3.3.1. Value-Added Products Utilizing Small-Diameter Timber

Regional forest products markets are changing, reflecting changing demand patterns, new technologies, and policy-driven restoration priorities. Alderman (2022) reports that traditional product streams, including lumber, chips, pellets, mulch, and biomass, continue to dominate production, but demand for engineered wood and alternative materials is increasing. New forest product technologies aim to improve resource efficiency, expand utilization pathways, and add value to small-diameter timber. A study by Larson and Mirth (1998) projected that a large portion of small-diameter ponderosa pine could be converted into value-added products with the right processing methods. One of the largest barriers to feasible and profitable operations surrounding small-diameter, low-value timber is finding ways to add value by creating alternative and residual biomass products. For example, a few emerging products that have hit the market and have great potential for use in biomass and timber residual markets, including wood wool cement panels and carbon casting wood fiber blocks. Currently a few companies have jump-started the use of these products, including Woodsyn and Graphyte. Lowell and Green (2001) observed that manufacturing appearance-grade products from low-value timber can provide greater economic returns compared to most conventional dimension lumber products. Additionally, the study noted that small-diameter ponderosa pine from densely stocked stands holds sufficient value for use in both primary wood products and specialized secondary products, such as moulding and millwork. Some of these techniques are now being implemented in mills around Arizona and New Mexico. For example, several facilities produce tongue-and-groove pattern stock for value-added applications such as flooring, interior and exterior wall paneling, and ceiling finishes. Additional high-value alternative products have been identified in the literature. Kelkar et al. (2006) report that essential oils and resins can be extracted from small-diameter pine through steam distillation, highlighting viable revenue streams in both domestic and international

markets. The study also states that the residual material produced from distillation can further be utilized in bioenergy markets or converted into cleaner (i.e., leaner) facility-generated emissions.

Innovation and development in forest products is not new, as products including engineered wood products (EWP's), biofuel, and bioenergy alternatives have been around for the better half of the century. One good example of innovation taking place in the industry is the use of mass timber products, including cross-laminated timber (CLT) and glulam, which, according to a study by Ellrich et al. (2025), are expanding the range of applications and products for smaller-diameter material. These new opportunities for innovation, as well as improved harvesting and processing strategies, suggest that small-diameter timber can contribute meaningfully to both our economic and ecological goals if the right technology and markets are in place. Additionally, specialized processing technologies with CLT production and cellulose nanocrystal impregnation require a large investment upfront, skilled labor, and specialized equipment that, many times, is not accessible to smaller mills or other local processing facilities (Bajwa et al. 2024 and Ellrich et al. 2025). Specifically, in glulam applications, the high proportion of juvenile wood in small-diameter timber is a key consideration. However, Hernandez et al. (2005) found that, based on modulus of elasticity (MOE) and other bending properties, small-diameter ponderosa pine can achieve sufficient stiffness to be classified into E-rated grades, indicating its feasibility for structural applications.

This, combined with advanced engineering techniques like cellulose nanocrystal impregnation and engineered wood products, allows low-value timber to meet structural performance standards previously achievable only with large-diameter logs. At the same time,

bio-based products such as lignin composites, biochar, and cellulosic biofuels are currently under development, providing more alternative markets that could support circular economy models and encourage collaborative resource utilization (Huang and Bagdon 2018; Kelkar et al. 2006).

3.3.2. Production of Diversified Forest Products

Beyond traditional wood products, biomass utilization for energy production has emerged as a growing and much-needed industry niche. Biomass recovery is inherently one of the largest challenges in finding further value in forest residuals, and if utilized effectively, it can offer feasible and beneficial outputs to communities and facilities. These outputs can take the form of bioenergy, emerging products like biochar, and others. A few studies suggest that integrating fuel reduction treatments with local bioenergy enterprises can help recover economic values from harvest residues and promote local economies and employment (Nicholls et al. 2008; Iversen and Van Demark 2006). Another study in the Lake State region of the US emphasized that without sufficient processing infrastructure, particularly for small-diameter timber, the cost of forest restoration increases, utilization declines, and treatment timelines slow considerably (Pokharel et al. 2023). Blatner et al. (2012) found that although processing facilities are increasingly utilizing small-diameter timber in place of traditional larger, more desirable logs for dimension lumber, the volume of wood residuals and byproducts has declined significantly. They also state that due to technological advancements in sawmill operations (e.g., computer sensing log optimization, curve sawing technology, and thinner kerf saw blades, etc.), lesser amounts of mill residue like sawdust and planner shavings are produced, allowing for better optimization of the log, regardless of diameter size. This could give facilities the ability to utilize smaller and less valuable logs to make available timber

resources increasingly financially feasible for lumber and alternative product production (Blatner et al. 2012).

The integration of forest restoration with local economic development and renewable energy production shows the diverse potential of forest products. In a study showcasing biomass utilization from bioenergy in the western U.S., they noted that federal legislation incentives heavily emerged in the early to mid-2000's to stimulate biomass utilization (e.g., the national fire plan, the Healthy Forest Restoration Act of 2003, and the billion-ton initiative). These incentives jump-started the push for bioenergy production in the western U.S., with the intended use of utilization of dense small-diameter forest residuals (Nicholls et al. 2008). Additionally, Pokharel et al. (2023) note that according to the U.S. Energy Information Administration, electricity produced from biomass material accounted for 6.7% of the total electricity produced in the United States in 2021 (EIA 2022), with a majority of the volume coming from the utilization of woody biomass. Similarly, Iversen and Van Demark (2006) highlighted the role of bioenergy in utilizing forest biomass while supporting local employment, demonstrating how community-oriented bioenergy operations can reduce wildfire risk and create economic opportunities.

Though the product industries could benefit greatly from biomass utilization and recover value from forest residuals, the Southwest region faces a unique set of socioeconomic and infrastructural hurdles that require a more integrated approach to residual recovery (Nicholls et al. 2018). While historical incentives (4FRI, WMSP, etc.) jump-started the industry, the long-term viability of restoration efforts in southwestern ponderosa pine forests depends on overcoming the value gap created by high treatment costs and low-value outputs. Hjerpe et al. (2009) argue that the socioeconomic success of these restoration projects is inherently linked to

the development of well-developed local biomass markets that can absorb small-diameter timber. Without these markets, the high costs of thinning dense stands become unfeasible, therefore stalling the ecological goals set by federal mandates. This challenge was further intensified by the collapse of the housing market and the Great Recession, which depleted the regional timber processing infrastructure, leaving a void in the processing capacity needed to handle forest residuals (Keegan et al., 2012). With this said, the most reliable path forward for the Southwest forest products industry lies in diversifying beyond traditional lumber toward a multi-product stream that includes bioenergy and high-value bioproducts.

Utilizing woody biomass for electricity generation in the Southwest provides a strategic alternative to open-pile burning or leaving fuels to decay, both of which contribute to poor air quality and carbon emissions. Huang and Bagdon (2018) demonstrate that the environmental and health benefits of using woody biomass for power, specifically through the reduction of particulate matter, create a net positive impact on regional healthcare costs and air quality. This aligns with broader strategic assessments of the Western U.S., which identify forest residuals as a primary feedstock for a sustainable biofuels industry capable of meeting modern energy demands (Patton-Mallory et al. 2008).

Emerging biochar markets provide an even more advanced pathway for high-value recovery, converting forest slash from waste material into a value-added product. Biochar production represents a frontier for the Southwest, where its application in arid soils can enhance water retention and long-term carbon sequestration. However, as Peirson et al. (2024) note, scaling biochar production requires moving beyond basic pilot programs to address the logistical barriers of transporting low-density forest waste. They suggest that by deploying mobile pyrolysis units or establishing localized bio-hubs, the industry can reduce transportation

overhead and produce a stable, value-added commodity that appeals to both the agricultural and carbon-credit sectors (Peirson et al. 2024). This shift from treating biomass as a waste residual of timber processing to advanced manufacturing methods can allow the regional industry to capture the full value recovery from these operations, ensuring that every ton of extracted biomass contributes to a higher-value output.

3.3.3. Expanding Timber Production and Infrastructure Networks

The development of value-added products is an emerging market, and research indicates that there could be practical applications for utilization, industry network expansion, and production methods have some promising outcomes if implemented efficiently. Regional analyses from a couple of studies by Nicholls (2014, 2022) indicate that cluster-based industrial networks can grow both economic and ecological benefits by centering production capacity on available forest fiber. Additionally, Nicholls notes that the use of cluster-based industrial networks has the potential to establish well if the correct measures are put in place. This includes scaling the emerging industry appropriately and gathering support and cooperation from local, state, and federal governments in the form of subsidies and initiative programs. A few studies emphasized that improvements in wood product processing and residual management are enhancing material efficiency and resource recovery (Blatner et al. 2012; Pramreiter et al. 2023). Pramreiter et al. (2023) specifically state that resource efficiency and resource recovery around engineered wood products (EWP's) are needed to keep up with the demand of urban growth and a push toward sustainable cities.

With incentives and the recent push for increased harvest volumes from National Forest (NF) lands, a recent study by Morgan et al. (2025) with the Bureau of Business and Economic Research (BBER) showcased potential industry responses to increased restoration-

related wood supplies and industries, to identify more opportunities for new processing capacity, product market expansion, and innovation in material streams. Additionally, they found that with a new executive order, mandated from the White House, put into place in March of 2025, it called for a 25% increase in National Forest timber harvests over the next 4–5 years. As well as stating from deeper internal analysis gathered from Cut and Sold reports from the US Forest Service, indicate that each western state has the available timber processing capacity to establish a 25% increase in harvested wood production. Stating that the existing timber processing industry could immediately utilize additional timber resources from National Forests.

4. Forest Products Industry Capacity in Arizona and New Mexico

4.1. Industry Evolution and Restoration Gaps

The literature shows a pattern of change in overall size (operating facilities) and lower infrastructure capacity within the southwest's forest products industry. Declines in mill numbers, workforce capacity, and infrastructure since the early 1990s have reduced total timber-processing capability in the region (Sorenson et al. 2012; Hayes et al. 2021). As restoration-oriented policies have increased the volume of material generated from public lands, initiatives in the Southwest, such as the Four Forests Restoration Initiative (4FRI) and the White Mountain Stewardship Project (WMSP), have piloted the effort to expand opportunities and funding for thinning and fuel-reduction treatments (Nicholls 2014). A common pattern throughout the literature is the ongoing challenge between available wood supply and the existing configuration of infrastructure and scale of processing capacity represented in the current state of the forest products industry in the Southwest. Regional capacity declined substantially from the 1990s through the early 2000s (Figure 2), and at the time, only a small proportion of mills were

optimized to process logs under 10 inches in diameter (Keegan et al. 2006). This shift from higher value, larger timber size classes to low-value small-diameter timber presented inevitable challenges to utilization and value recovery. Although product diversity (EWP's and bioenergy) has converged into emerging and alternative product markets (wood fiber and residual markets), sawmills and other processing facility outputs remain concentrated in traditional dimensional wood product markets (one and two-by lumber and pallet stock), with limited diversification into higher-value or alternative products. Economic modeling efforts demonstrate that although restoration activities can increase employment and mill utilization, facility intake capacity, current infrastructure gaps, and high transportation and logistics costs limit how much harvestable material can be utilized (Chang et al. 2023; Iversen and Van Demark 2006). Due to these barriers, large volumes of small-diameter timber remain underutilized or pushed towards low-value alternatives like wood chips and other residuals from harvesting and sawmill operations. This is a continuous cycle in which restoration objectives tend to outpace industrial capacity and existing infrastructure.

4.2. Forest Product Market Trends

Over the 25-year period, Arizona (AZ) consistently recorded higher harvest volumes than New Mexico (NM), reflecting its comparatively larger industrial capacity and the presence of large-scale restoration initiatives (Figure 4). AZ also exhibits greater year-to-year variability, with noticeable fluctuations, which a few studies found show that these ebbs and flows in the overall trend imply these could be the result of fluctuations in market conditions, processing facility openings or closures, and changing policy directives (Sorenson et al. 2016; Hayes et al. 2021). Additionally, NM exhibited lower overall harvest volumes, but recent years show moderate yet upward trends.

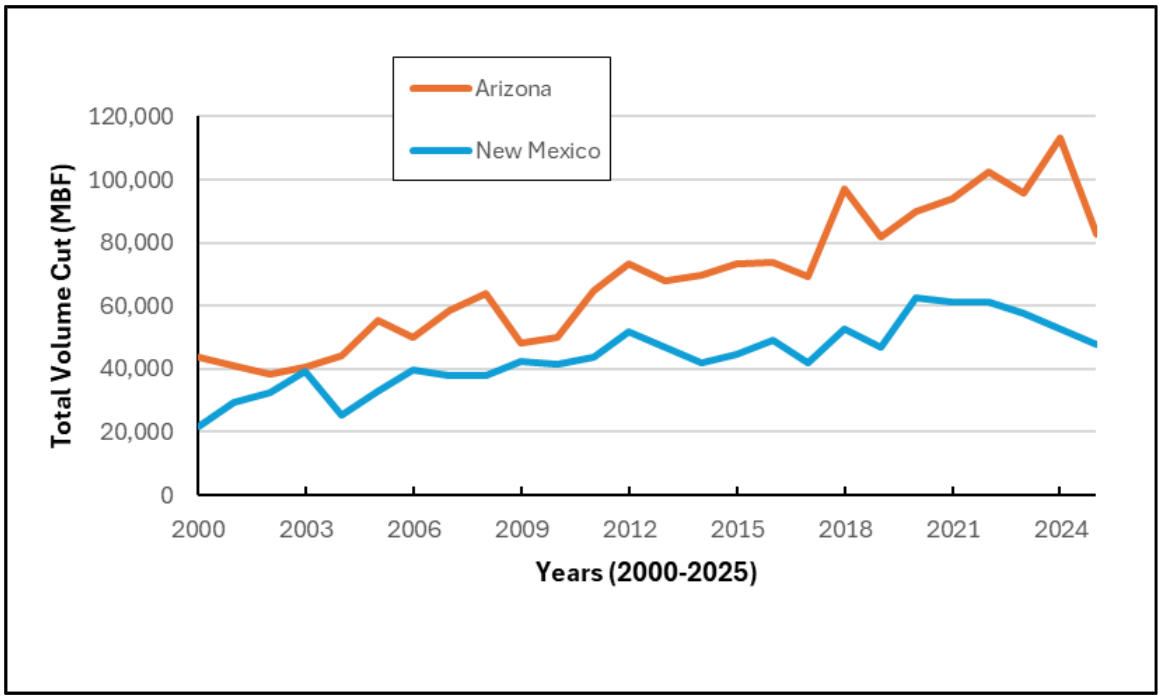


Figure 4. Trends in total timber harvest volume for Arizona (AZ) and New Mexico (NM) from 2000 to 2024.

Both states demonstrate an overall increasing trend in harvest volume over time, particularly in the past decade. This upward movement aligns with expanded restoration-focused management and increased federal emphasis on active forest treatments in the Southwest. The significance of this trend lies in its implication for industry capacity. Rising harvest levels suggest that the existing forest products infrastructure has been able to absorb greater volumes of material over time, at least incrementally. However, the variability in annual harvest totals also indicates that capacity utilization is sensitive to policy, funding, and market conditions (Sorenson et al. 2016). Collectively, the cut and sold data suggest that while harvest output is trending upward, indicating growing alignment between restoration supply and processing demand, the system remains dynamic and potentially constrained by operational and market factors that influence year-to-year stability.

4.3. Processing Capacity vs Volume Produced

The comparison of total timber processing capacity with actual production reveals a persistent gap between available industrial infrastructure and realized output in both Arizona (AZ) and New Mexico (NM) from the late 1990s through 2016. In AZ (Figure 5), processing capacity consistently exceeds realized production volumes across all years shown (1998–2016), indicating large volumes of underutilization as much as 22%, with a utilization rate in 2016 of 78%, within the existing milling infrastructure. Although both capacity and production fluctuate over time, with capacity declining in the early 2000s and partially rebounding by 2012, actual production remains well below maximum potential output. With that, 22% of unutilized in 2016 came from unused or underutilized non-sawlog (smaller-diameter timber) and biomass residuals being produced from restoration thinning treatments.

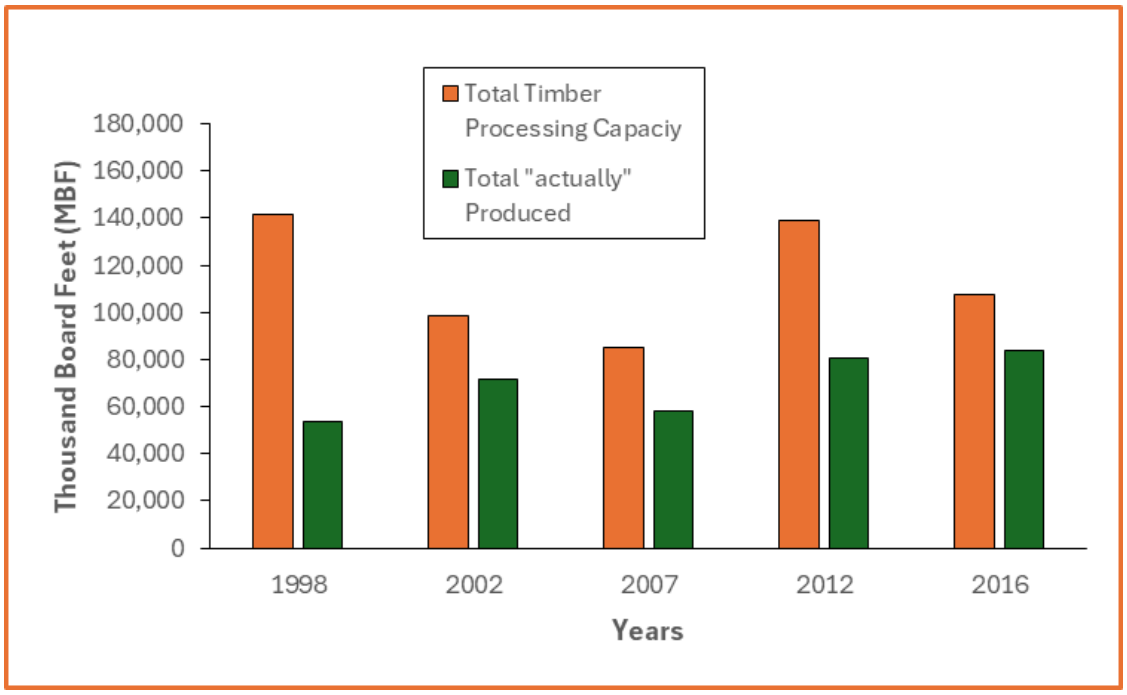


Figure 5. Comparison of total timber processing capacity and actual timber production (thousand board feet, MBF) by year, showcasing gaps for underutilized volumes for Arizona (AZ).

NM (Figure 6) shows a more pronounced long-term decline in total processing capacity between 1997 and 2016, accompanied by consistently lower production levels. While production remains below available capacity in all years, demonstrating underutilization, generally referred to as the difference between processing capacity and actual production, according to a few studies, these trends could be the result of reported mill closures and overall infrastructure loss within the state's forest products sector (Hayes et al. 2021; Simmons et al. 2020a). The widening gap between processing capacity and actual production in later years highlights both reduced industrial scale and smaller output volumes relative to potential processing capacity. With last recorded utilization rates of only 55% and an underutilization rate of 45%. Collectively, these figures are significant as they demonstrate, while a surplus in underutilized capacity exists in both AZ and NM, this gap could suggest that constraints on timber supply, market demand, or even operational factors (e.g., wood supply or transportation), rather than from just physical infrastructure alone, could limit the industry's ability to operate at full capacity (Sorenson et al. 2021; Hampton et al. 2011). The industry in both states continues to underutilize potential forest wood resources, stemming from an oversupply of sawlog timber (10" + DBH) and an undersupply of non-sawlog (5" - 10" DBH) and biomass material into current wood markets. From a restoration perspective, this underutilized capacity could suggest and represent an opportunity to increase output without immediately requiring major investments in infrastructure up front.

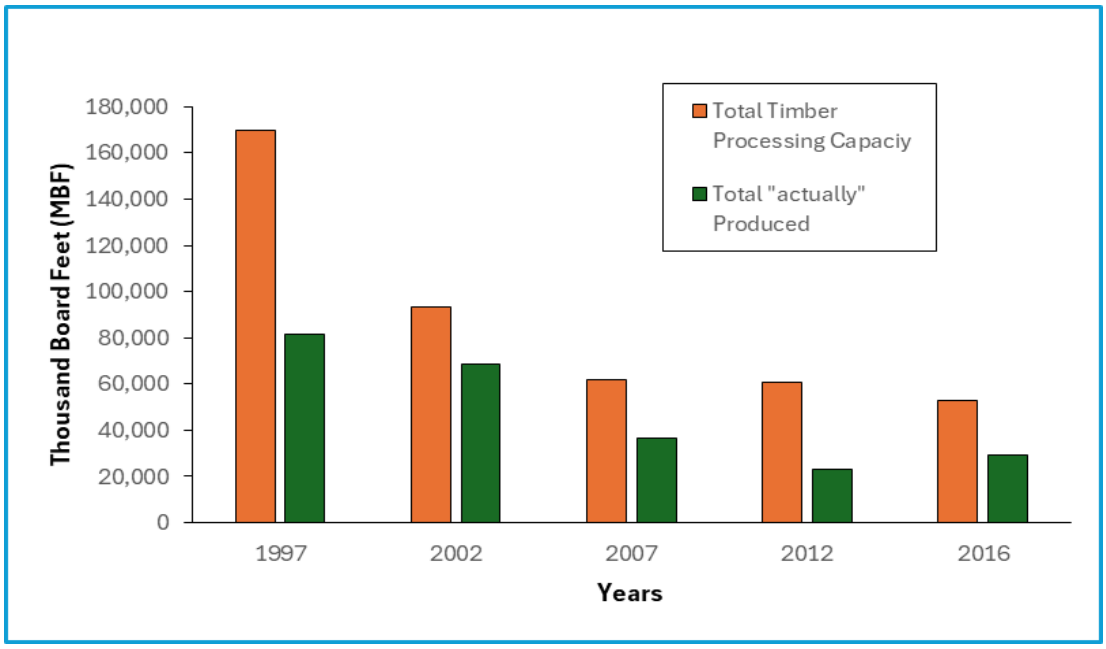


Figure 6. Total timber processing capacity and actual timber production (thousand board feet, MBF) by year, showcasing gaps for underutilized volumes for New Mexico (NM).

4.4. Product Diversity and Frequency Comparison

Across both AZ (Figure 7) and NM (Figure 8), the data collectively show that dimension wood products and lumber facilities consistently represent the largest share of total facilities, reinforcing the dominance of traditional sawmill production within the regional industry.

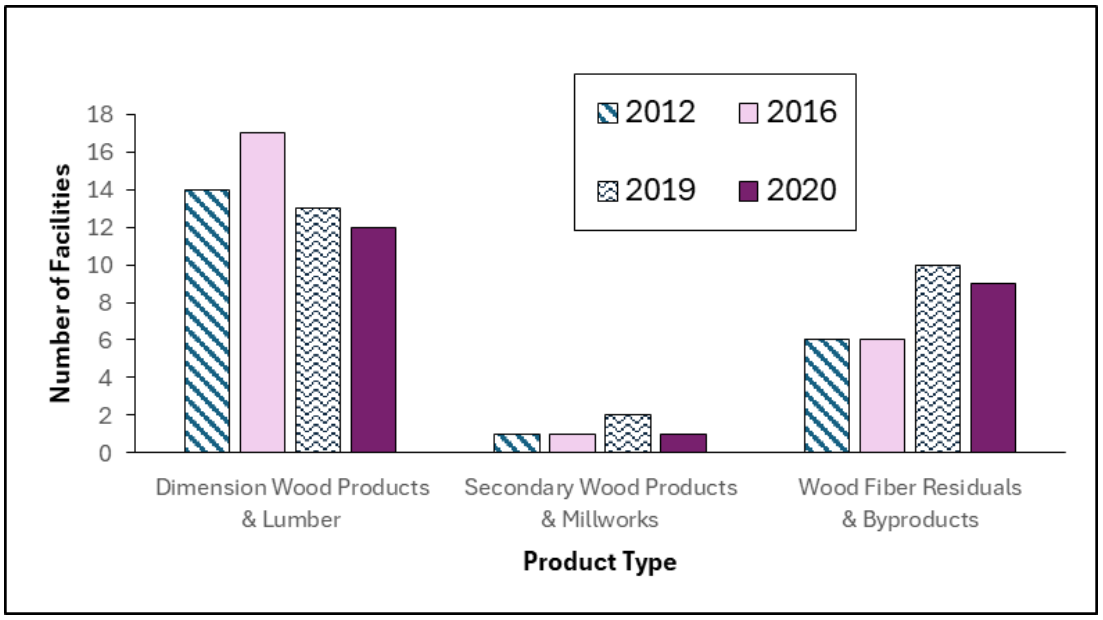


Figure 7. Number of processing facilities represented by product type category in **Arizona** across selected years (2012, 2016, 2019, and 2020).

AZ shows moderate fluctuation over time, with a peak around 2016 followed by slight declines by 2020, while NM exhibits an overall increase in dimension lumber facilities between 2012 and 2020. This pattern suggests that, despite historical industry contraction, the core sawmill sector has remained relatively stable and, in some cases, expanded modestly in recent years. The continued concentration in dimension lumber production indicates that much of the region's processing infrastructure remains aligned with conventional product streams rather than diversified manufacturing.

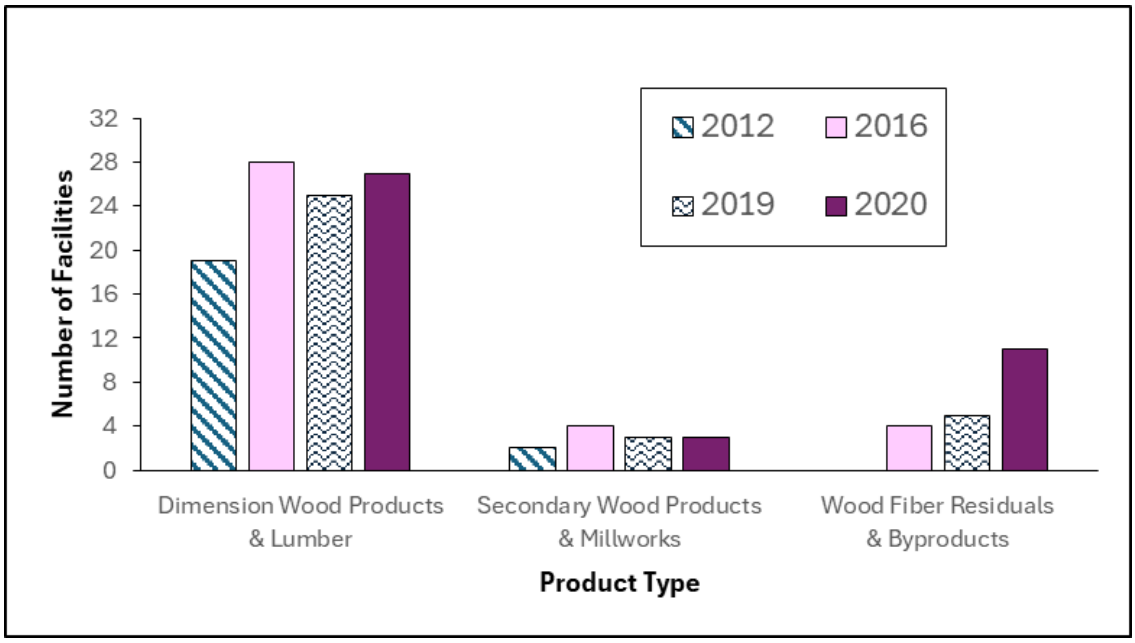


Figure 8. Number of processing facilities represented by product type category in **New Mexico** across selected years (2012, 2016, 2019, and 2020).

A notable trend in both states is the gradual increase in facilities producing wood fiber residuals and byproducts, particularly evident in New Mexico by 2020. This growth signals expanding utilization of biomass, chips, pellets, and other secondary outputs, which are critical for absorbing low-value and small-diameter material generated through restoration treatments. In contrast, secondary wood products and millworks facilities remain comparatively limited across all years in both states, reflecting a relatively small value-added manufacturing sector. Overall, the TPO data suggests incremental diversification and improved fiber utilization, but continued reliance on primary dimension lumber and pallet production.

Additionally, data from the Southwest Forest Product Inventory for AZ (Figure 9a) and NM (Figure 9b) reveal a regional market dominated by dimension wood materials, though the two states differ significantly in their production of value-added and specialty wood products. As stated above, both states show production is heavily concentrated in rough/dimension lumber (48%) and beams (24%), making up more than 70% for AZ and 85% for NM of the entire market base. Although with small shares (10%) from mass timber products and (5%) in

pattern stock products like tongue and groove boards, AZ is showing signs of involvement in emerging markets, which could suggest further development in these areas is promising. The presence of wood panels and mass timber components suggests there is evidence of emerging diversification in product utilization, though it remains secondary to traditional lumber markets.

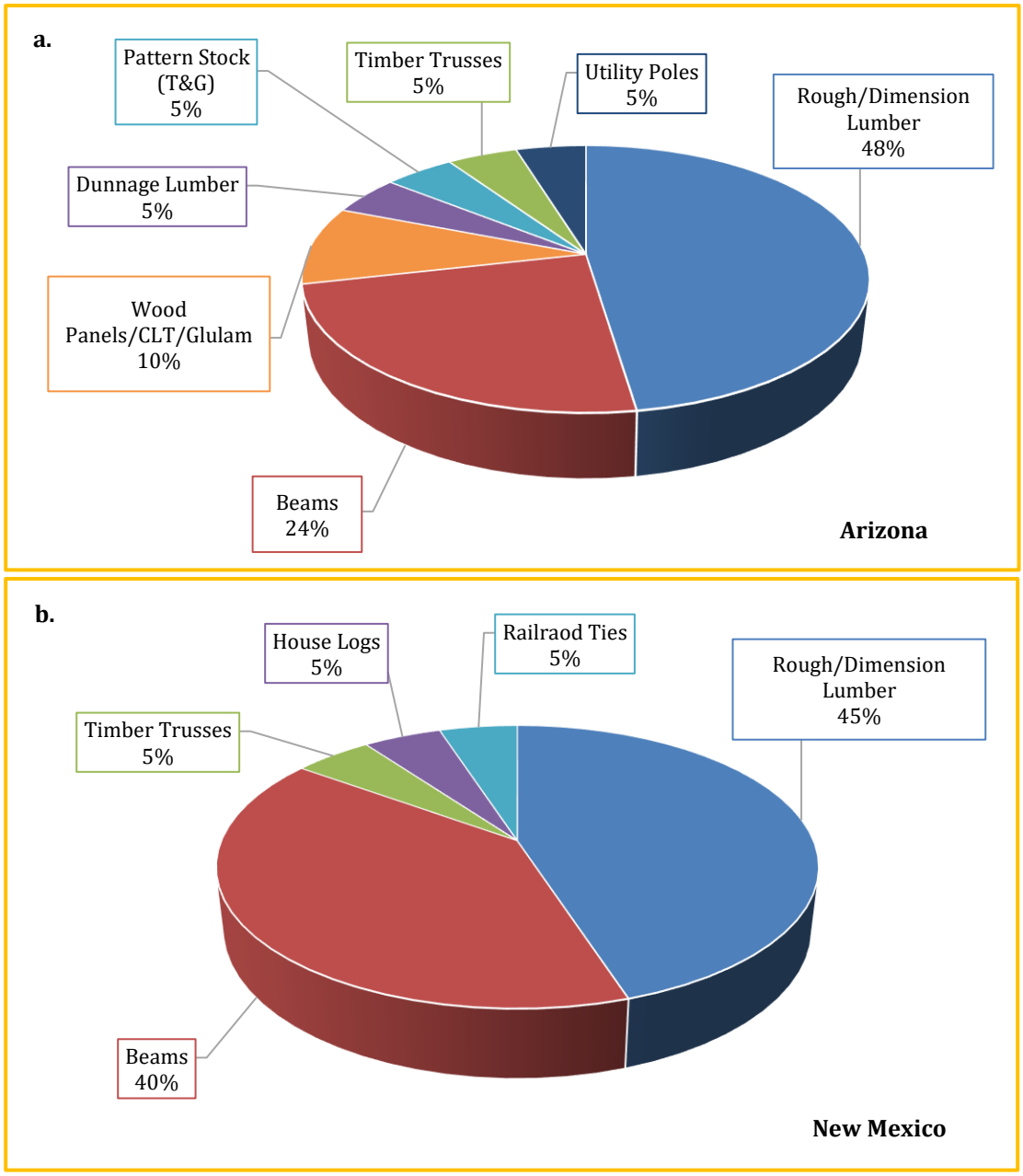
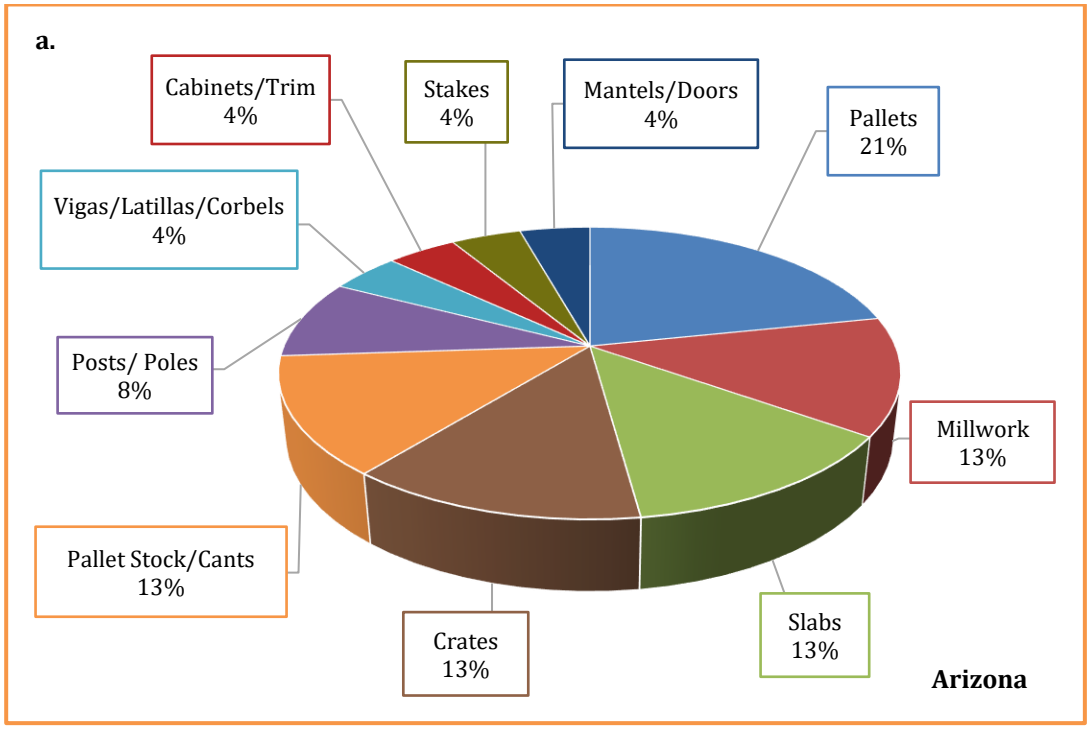


Figure 9. Percentage breakdown of dimensional wood products and lumber for (a) Arizona and (b) New Mexico.

While secondary wood products for AZ markets seem to show a relatively diversified foundation (Figure 10a), the distribution of products from the figure could suggest a strong market product diversity and infer that AZ is playing to its strengths of finding emerging opportunities for higher value-added products. Although with smaller shares (4%) in four of the eleven secondary products produced, it could indicate that a lack of continued investment in those high-value products markets could be present. Overall, Arizona's industry identity appears tied to broad-based, utilitarian wood manufacturing with balanced output across multiple product lines, which may reduce economic vulnerability by avoiding overreliance on a single product category.



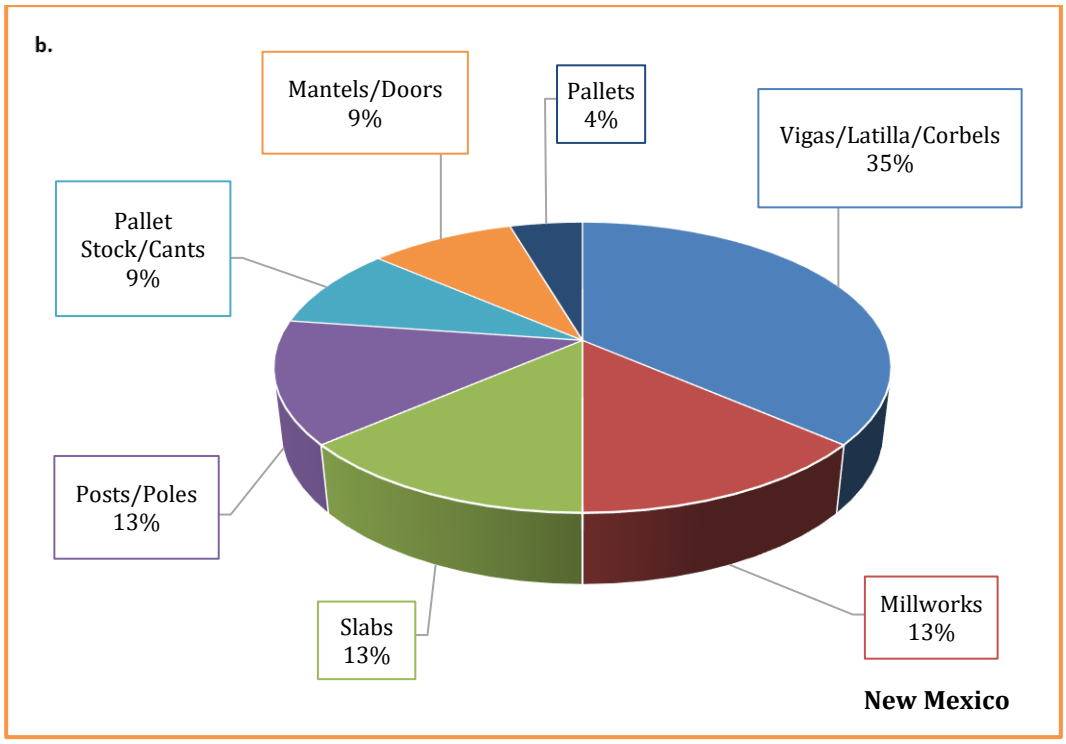


Figure 10. Percentage breakdown of secondary wood products and millworks for (a) Arizona and (b) New Mexico.

New Mexico's production profile (Figure 10b) is highly specialized, with vigas/latillas/corbels accounting for 35% of output. This reflects the strong cultural and architectural influence of Southwestern and Native American influences on product streams, making these products central to the state's forest industry identity. Notably, pallet production is much smaller (4%) compared to Arizona, indicating less focus on large-scale industrial shipping and packaging markets. The figure highlights a key pattern: Arizona showcases product diversification, while NM demonstrates its cultural products' significance, which is rooted in New Mexico's preservation of regional architecture and culturally significant products.

Notable differences from the figures in how AZ (Figure 11a) and NM (Figure 11b) utilize wood fiber residuals and byproducts are evident in both states. AZ and NM both seem to have a primary focus on traditional uses for biomass and wood residuals, while higher utilization of

alternative and/or emerging residual products in AZ showcases more prominence in niche markets (Figure 11a). The presence of biochar and bioenergy, along with a more than twofold share of the woodchip market in Arizona (23%) compared to New Mexico, indicates a faster growth trajectory into emerging markets such as bioenergy. Ultimately, helping to recover lost opportunities from residual waste. The presence of relatively niche markets like biochar and energy production in AZ, although small, corroborates the literature, stating that methods of biomass utilization from biochar and bioenergy could be a way to increase investment and add value recovery to forest operation and restoration projects (Patton-Mallory et al. 2008; Peirson et al. 2024)

Although Arizona's distribution, shown in Figure 11a is fairly diversified, indicating multiple end uses for mill residues and a balanced approach to byproduct recovery, current utilization patterns show the industry is more oriented toward traditional fuel and raw fiber markets than higher-value specialty products and outputs.

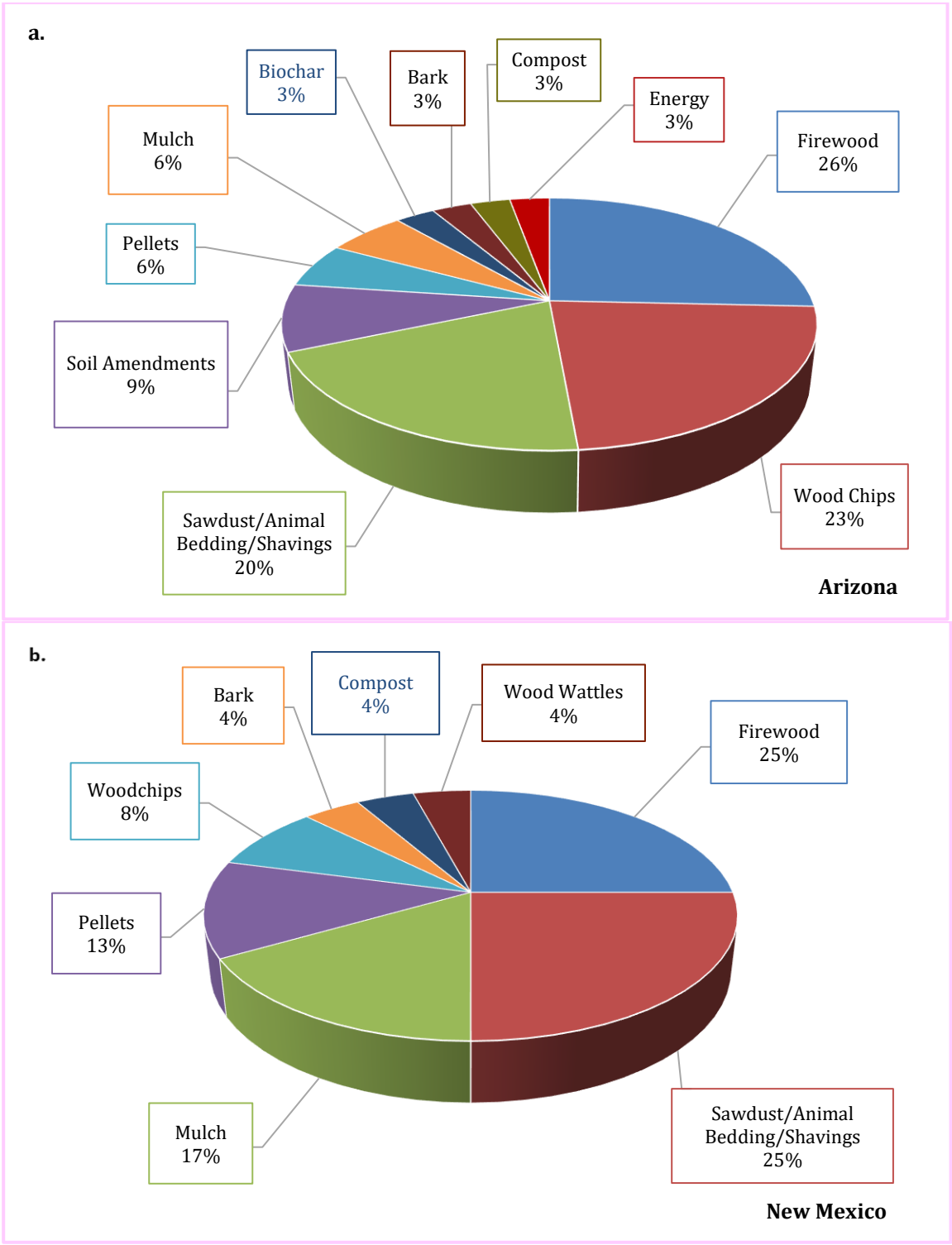


Figure 11. Percentage breakdown of wood fiber residuals and byproducts for (a) Arizona and (b) New Mexico.

The higher utilization of pellet production in NM (13%) compared to AZ (6%) may also signal additional engagement in value-added bioenergy markets. While both states rely heavily on fuelwood and bedding products, AZ's byproduct sector is more diversified and chip-oriented due to existing infrastructure for woodchip and biomass-fueled energy production, whereas NM shows limited growth in current and more diverse byproduct markets. These patterns showcase differences in market demand, infrastructure, and potential biomass utilization strategies. Understanding these models and snapshots and implementing strategies into current residual and biomass markets help to showcase individual states' weaknesses and opportunities for growth.

5. Discussion

5.1. Key Trends in Supply and Demand Factors

This literature review synthesis and accompanying data analysis show a continuously growing gap between forest restoration objectives in the southwestern United States and the ability of the regional forest products industry to support management goals. Across Arizona (AZ) and New Mexico (NM), restoration-driven management has increased the volume of timber harvested, particularly small-diameter, low-value material, yet the industry remains largely oriented toward traditional lumber production and constrained by limited infrastructure and forest product diversification. What this means in Lamins terms is that restoration efforts across AZ and NM are producing an oversupply of sawlog materials for traditional wood markets and an undersupply of non-sawlog and biomass materials being produced from wood product markets. Although analysis of USFS Cut and Sold reports demonstrates a clear upward trend in harvest volumes over the past decade, particularly in AZ, reflecting expanded restoration initiatives and increased federal emphasis on active forest management. TPO and BBER data generally indicate that this increased supply has not translated or encouraged proportional

increases in capacity utilization or product diversification (Keegan et al. 2006; Simmons et al. 2020b; Sorenson et al. 2016).

A major finding of this study is that production capacity continues to remain underutilized (Figures 5 & 6), specifically for non-sawlog timber and biomass materials, while other external operational challenges continue. BBER data shows that total processing capacity consistently surpasses actual production in both AZ (Figure 5) and NM (Figure 6). Especially in Arizona, where much of the literature suggests that infrastructure by itself is not the only limiting factor. This aligns with findings by Hampton et al. (2011) and Hjerpe et al. (2021), that unstable supply, high transportation costs, and market uncertainty all limit mill operations more than available infrastructure capacity. The situation that persists is not just from contributing external factors but from internal harvesting operations and utilizing volumes of raw materials being produced from restoration treatments. We found that a further contributing factor limiting higher utilization rates, which were around 78% for AZ and 55% for NM, was the dominance in the use of sawlog grade timber, and the lack of further utilization of non-sawlog and biomass materials coming out of the woods. We understand that the forest products industry here in the Southwest is utilizing 100% of the sawlog material coming out of restoration treatments, while we see the gaps in utilization is focused around limited markets and infrastructure surrounding non-sawlog timber and biomass materials. Other limiting factors that forest industry professionals seem to agree with include further internal challenges facing the industry, such as lower access to public funding and economic market fluctuations. Tabi Bolton, a senior-level professional working as a regional area supervisor with Campbell Global in Flagstaff, AZ, discussed this idea in our interview. He noted that for the Southwest's forest products industry to sustain itself and continue to employ logging contractors to implement restoration projects, three primary factors need to change. (1) The lack of consistency in offerings of Forest Service sales and projects, (2) the need for more government subsidized opportunities and funding, and (3) a need for lower interest rates

for equipment loans (Bolton, T., Campbell Global, Flagstaff, USA, personal communication). These limiting factors, if addressed appropriately, could help to stimulate underutilized capacity and help to sustain the industry further into the future. While the industry has seen recent increases in utilized harvesting volumes, general trends suggest that there is improved alignment between restoration supply and industry demand. The year-to-year variability observed in USFS cut and sold data (Figure 4) supports the literature correlating that fluctuations in harvesting volumes showcase the system's dependence on policy decisions, funding availability, and market conditions (Sorenson et al. 2016). Understanding that these factors, as well as a low diversity of forest products, help to explain why "extra" capacity (22% for AZ and 45% for NM) that is underutilized has not consistently led to higher production rates or steady uses within the industry.

The dominance of dimension lumber facilities observed in the TPO data (Figures 7 & 8) reinforces a second key pattern identified in the literature, limited diversity of forest products and associated markets present in the Southwest products industry. Both Arizona and New Mexico remain heavily reliant on traditional low-value lumber applications, despite decades of producing restoration treatment material that is poorly suited to traditional dimension lumber markets. This finding mirrors earlier regional assessments showing that only a small proportion of mills are optimized to process logs under 10 inches DBH (Keegan et al. 2006; Wagner et al. 1998). These findings matter for restoration-focused management because, although existing sawmills and processing facilities can handle standard lumber and some biomass, limited growth in secondary manufacturing and a lack of product diversity may prevent the industry from fully capturing value from small-diameter timber.

While steady growth in wood fiber residual and byproduct facilities, particularly biomass, pellets, and fuelwood, has been observed from various databases and reports, studies also suggest

that utilization of low-value (non-sawlog) material, secondary wood products, and higher-value products (e.g., cross-laminated timber and glue-laminated timber) remains underrepresented in available markets. Many professionals, including Kevin Orden, the Director of Forest Operations at the Restoration Forest Products (RFOR) sawmill in Bellemont, Arizona, discussed the idea that underutilization and lack of presence of secondary wood products is mainly due to lack of specialized facilities and the challenge of procuring investments and funding for those facilities (Ordean, K., Restoration Forest Products, Bellemont, USA, personal communication). This reliance on traditional products such as dimension lumber and pallets limits the industry's ability to capture economic value from additional restoration outputs, a challenge consistently highlighted in studies of small-diameter timber utilization (Stewart et al. 2004; Fight et al. 2004).

5.2. Development of Innovative Products and Business Infrastructure

Despite the constraints, the results from the literature and additional data collectively demonstrate technical and economic potential for improved utilization, provided appropriate improvements to industry infrastructure, diversification of forest products, and market conditions align (Han et al. 2004; Hjerpe et al. 2009; Nicholls et al. 2018). Advancements in engineered wood products, sawmill optimization technologies, and biomass utilization approaches suggest that small-diameter ponderosa pine could be introduced to meet both structural and value-added standards for alternative products (Hernandez et al. 2005; Blatner et al. 2012; Ellrich et al. 2025). The presence of emerging engineered wood and residual markets in Arizona, although limited, indicates that diversification of product types and uses is possible. New Mexico's efforts in specialized culturally distinctive products such as vigas and latillas continue to demonstrate how smaller niche markets can help support regional identity and local economy, consistent with findings by Lowell and Green (2001) and Nicholls (2014).

While capacity gaps are often attributed to insufficient infrastructure, our study's findings suggest that transportation costs, suboptimal geographical disconnect between wood supply and corresponding facilities, and operational uncertainty (e.g., weather patterns, market prices, etc.), all play equally important roles (Chang et al. 2023; Nicholls 2014; Sorenson et al. 2016; Keegan et al. 2006). Long haul distances to processing facilities, limited local infrastructure within economically feasible ranges, and seasonal or regulatory constraints can all restrict the flow of material from the woods to the mill (Chang et al. 2023; Nicholls 2014; Keegan et al. 2006). These factors can help to explain why increased harvest volumes do not always result in increased production, even when limited capacity exists. Additionally, persistent market perceptions of small-diameter timber as low quality continue to suppress demand for both traditional and alternative products, reinforcing barriers identified by Wagner et al. (1998) and Stewart et al. (2004).

The relevance of these findings directly reflects our study's central research question: whether the Southwest's forest products industry has sufficient capacity to support current and future restoration needs. The synthesized information suggests that, although the industry historically operated at a larger and more prominent scale, today's forest products sector lacks the processing capacity and infrastructure necessary to achieve restoration output goals at the scale needed for long-term ecological management objectives. Although existing capacity may accommodate some short-term increases in harvest volumes, as supported by recent BBER analyses (Morgan et al. 2025), ensuring long-term alignment between restoration supply and industrial demand is critical for the sustainability and success of the industry. Prerequisites for industry expansion to meet desired management objectives will require strategic investments in infrastructure, expanded product diversity with involvement in emerging and/or alternative markets, stronger coordination efforts between land managers and industry entities, as well as

ongoing policy support. Without these changes, restoration timelines may be driven more by utilization barriers rather than by projected management necessity.

5.3. Study Limitations and Areas for Future Research

This study was limited to specific research aspects; however, since the paper is a synthesis of information and data within a broader context, most challenges arose from gaps in the existing literature on niche areas of the Southwest forest products and logging industry. As a result, published information on transportation costs, contract structures, and operational constraints specific to the Southwest's landscape and forestry industry practices, while referenced in the literature as barriers to utilization, was limited in abundance if not also lacking publishable resources at all. These topics were not quantitatively modeled in this analysis due to data source limitations and the inability to obtain contract documentation and resources.

Limitations were present in our original research surrounding current forest product inventories for AZ and NM. Due to time constraints, unverified data, and university research permissions for additional study implementation. Further research into our original inventory is needed to verify operational status and current product production breakdowns of regional private businesses that meet the criteria for contributing to the Southwest's forest products industry. Since this data revolves around private businesses, as they are subject to closures and starting up previous or initial business endeavors, the collection of survey data would be most beneficial to verify operating status, current product production breakdowns, and diversity. Additionally, since the collection of information and business presence was based on preliminary online searches, information such as specific facility product types, addresses, and contact information (phone and email) remained unverified and is an essential piece to creating the most accurate example of product and processing facility breakdowns.

As stated in Chang et al. (2023), studies surrounding traditional operations research that provide high-quality data and in-depth analysis of specific aspects of the industry are generally not common in abundance. Traditional forest operations research is usually very time-consuming, labor-intensive, and expensive to implement. Because of this, research is often limited in amount and is primarily focused on commercial timber production, rather than in restoration material production. Future research could build upon this study in several crucial ways. More studies surrounding modeling haul distances, estimating region-specific transportation costs, and processing facility proximity to timberland would significantly improve understanding of operational feasibility for restoration projects. Further research into market development for engineered wood products, biomass-based materials, and emerging bio-based technologies could also help to inform avenues for wood product diversification.

6. Conclusion

This literature review demonstrates recurring mismatches between forest restoration needs in the southwestern United States and the capacity and structure of the regional forest products industry. As restoration treatments increasingly produce small-diameter, low-value material, while existing infrastructure remains largely configured around traditional lumber production, product diversity and the need for value-added products from wood residuals present an ongoing challenge. Focusing on the further utilization of smaller-diameter timber (non-sawlog and biomass materials) and addressing the challenges surrounding forest product diversity and barriers with industry infrastructure could provide a pathway to elevate the Southwest's forest products industry into more productive and lucrative markets.

Currently, product capacity exists but remains at smaller scales than historically observed, with utilization constrained by limited product diversification, high transportation costs, market

uncertainty, and operational inefficiencies. As a result, increased harvest volumes alone have not been sufficient to ensure that restoration material can be effectively and feasibly processed at the scale required to meet forest management objectives. Overall, current trends indicate that the Southwest's forest products industry is gradually moving toward greater efficiency, some needed value recovery, and diversification of products for best utilization. By utilizing innovative engineering techniques, promoting biomass utilization, and the use of collaborative industrial networks like 4FRI and others, small-diameter timber and restoration-produced materials and residuals can further add to both the regional economy's resilience and sustainable forest management.

The significance of these findings lies in clarifying that restoration challenges are not solely ecological or supply-driven, but operationally and economically reliant. Aligning restoration goals with industrial capacity will require strategic investments in facilities capable of processing small-diameter material, expanded markets for biomass and value-added wood products, as well as continued collaboration and cooperation between local, state, and federal agencies, as well as the forest products industry sector. By increasing the utilization of small-diameter trees and the development of alternative value-added products, we should expect to see expanded forest restoration efforts and forest industry growth across the landscapes of the Southwest.

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