Rob and Melani Walton Sustainability Solutions Initiatives

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The Nature Conservancy

Modeling the Economic Viability of Restorative Thinning

December 2013

Initial Assessment Report

This project was completed by the Sustainability Solutions Services, a program within the Walton Sustainability Solutions Initiatives at Arizona State University, under contract with The Nature Conservancy in Arizona. Additional funding was provided by the Dorrance Family Foundation through The Nature Conservancy in Arizona.

ASU Global Institute of Sustainability

Walton Sustainability Solutions Initiatives

Dan O'Neill
General Manager
Sustainability Solutions Services
dan.oneill@asu.edu
(480) 965-9666

sustainabilitysolutions.asu.edu

Acknowledgements

This report was prepared by (in alphabetical order):

Olga Epshtein, Research Aide, Sustainability Solutions Services, Walton Sustainability Solutions Initiatives
Karen Kao, Project Manager, Sustainability Solutions Services, Walton Sustainability Solutions Initiatives

Additionally, the authors wish to acknowledge and thank the following whose support and input in this project and report were invaluable:

<u>The Nature Conservancy in Arizona:</u>
Patrick Graham, State Director
Rob Marshall, Director, Center for Science & Public Policy

<u>Arizona State University:</u>
Dr. Rajesh Buch, Practice Lead, Sustainability Solutions Services, Walton Sustainability Solutions Initiatives; Senior Sustainability Scientist, Global Institute of Sustainability
Dr. Craig Carter, Professor of Supply Chain Management, W.P. Carey School of Business
Hannah Laluzerne, Research Aide, Sustainability Solutions Services, Walton Sustainability Solutions Initiatives
Yuri Luzanau, Research Aide, Sustainability Solutions Services, Walton Sustainability Solutions Initiatives
Dan O'Neill, General Manager, Sustainability Solutions Services, Walton Sustainability Solutions Initiatives
Dr. Thomas Seager, Associate Professor, School of Sustainable Engineering and the Built Environment, Ira A. Fulton Schools of Engineering; Senior Sustainability Scientist, Global Institute of Sustainability

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Abbreviations, Units, and Conversion Factors

Abbreviations

4FRI	Four Forest Restoration Initiative
ANSI	American National Standards Institute
ASU	Arizona State University
ASTM	American Society for Testing and Materials
CHP	Combined Heat and Power
CLT	Cross Laminated Timber
DOE	U.S. Department of Energy
HUD	U.S. Department of Housing and Urban Development
FPL	USDA Forest Service – Forest Products Laboratory
LVL	Laminated Veneer Lumber
MC	Moisture Content
MDF	Medium Density Fiberboard
(Prescott) NF	(Prescott) National Forest
NFC	Nano-Fibrillated Cellulose
OSB	Oriented Strand Board
PSL	Parallel Strand Lumber
SDW	Small-Diameter Wood
TNC	The Nature Conservancy
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service

Units

BDT	Bone dry ton (MC = 0%)
BF	Board-foot (12” x 1” thick)
Btu	British thermal unit
GT	Green ton (MC = 50%)
kg	Kilogram
kJ	Kilojoule
kW	Kilowatt
kWh	Kilowatt hour
lb	U.S. pound
MBF	1 thousand board-feet
MMBF	1 million board-feet
MW	Megawatt
MWh	Megawatt hour
psf	Pound (force) per square foot

Conversion Factors

1 green ton (GT) of chips	=	2,000 pounds (not adjusted for moisture)
1 bone-dry ton (BDT) of chips	=	2,000 dry pounds (MC = 0%)
1 BDT chips	=	2.0 GT (MC = 50%)
6 GT logs	=	1 MBF
1 GT logs	=	160 BF of lumber
1 Chord	=	128 cubic feet or 500 board-feet
1 Chord	=	2.6 tons
2 Chords	=	1 MBF
1 MBF	=	7.5 tons

Executive Summary

About

The Nature Conservancy (TNC), one of the world's largest environmental nonprofit organizations, is helping to make a positive impact in more than 30 countries, and all 50 of the United States. TNC in Arizona works with local communities, businesses, and individuals to pioneer solutions that save the lands and waters that sustain Arizona's iconic beauty, healthy economy, and rich quality of life. For this study, TNC teamed with the Sustainability Solutions Services (S^3), one of eight Rob and Melani Walton Sustainability Solutions Initiatives of the Global Institute of Sustainability at Arizona State University. S^3 utilizes expert teams to collaborate with clients on real, practical, and effective sustainability solutions.

Research Agenda

The loss of a quarter of Arizona's Ponderosa pine forests in the last decade as a result of catastrophic fires, the reduced government funds for thinning, and the lack of a robust wood products industry in recent years has heightened the sense of urgency to restore forest health at a faster pace and a larger scale. Consequently, the key objective of this study was to identify economically viable scenarios for restoring forest health by accelerating harvesting small diameter wood (SDW), which is critical to the maintenance of fire-adapted ecosystems. This study has been developed for use by the US Forest Service, local governments, and businesses in making decisions related to increasing investment in wood products businesses. These scenarios examined pathways that integrate the maintenance of these sustainable ecosystems with long-term economic success in the region. Three questions were examined, which are followed by the conclusions of this study:

On ecology: Is there a portfolio of businesses able to consume woody biomass generated by restorative thinning that is based on small to intermediate-sized capital investments, in addition to, or in place of, the major (hundreds of millions of dollars) previously considered?

On technology: What capital, technological, and supply chain assumptions are required for an economically viable scenario, including reducing or eliminating the need for U.S. Forest Service (USFS) subsidies?

On economics: If no economically viable scenario exists, what subsidy is required to proceed with restoration?

Study Background and Methodology

SDW is characterized by an average growth of 8-12 inches and no larger than 16 inches. The study area includes the Four Forest Restoration Initiative (4FRI; Kaibab, Coconino, Apache-Sitgreaves, and Tonto National Forests) and Prescott National Forest. A majority of growth found in this region is Ponderosa Pine, characterized by quick growth, low decay rate, and ease of workability. The physical geography and ecology of Arizona ecoregions play a critical role in the economic viability of restorative thinning.

The study methodology consisted of four parts:

1. **Technology Inventory**. Understand current and emerging enabling technologies for wood processing, including emerging technologies (for instance, biomass-to-energy).
2. **Business Inventory.** Develop an inventory of possible large, medium, and small business possibilities that could utilize SDW.
3. **Industry Viability Assessment.** Conduct an initial industry viability assessment, based on analyzing a variety of business combination and configuration scenarios.
4. **Initial Assessment Report & Presentation.** Provide an initial assessment report and presentation.

Additionally, a team from S^3 traveled to the 4FRI area to observe the forest supply chain and interview harvesters and manufacturers. The team toured the Four Corner Forest Products Sawmill and the Forest Energy Pellet Mill to observe small diameter wood processing.

Wood Products Supply Chain & Business/Technology Assessment Viability

The wood products supply chain, as defined by a result of the study's business inventory and onsite visits, is the basis for the model and scenario development of this project. The wood products supply chain typically involves three stages – harvesting, processing, and manufacturing. Small diameter Ponderosa Pine is most commonly used in energy production and small wood products.

Economic viability of the forest industry was analyzed based on the supply chain model developed by the S^3 team of existing forest industry businesses and technologies. Modeling examined current trends in the SDW supply chain, business operations (e.g. capital, operating costs), technology assessments (current, emerging, and next-generation technologies), and cost-benefit analyses of potential national-level or state-level forest service subsidies for viable restoration efforts. Assumptions in this model include a steady profit over time and stable market prices, that everything produced is sold, and that there is no interruption in wood supply or limits on thinning rates.

Five scenarios of forest-thinning projects were explored. In Scenario A, the economic viability of harvesting 900,000 acres of SDW from the 4FRI region over 20 years is shown. Here the modeled combination of businesses, technologies, acreage of land, and time span shows promising results in that approximately $378 million of capital investment could potentially generate $607 million of annual net sales and 235 jobs at full cluster build out. Scenario A could be deployed in the 4FRI area to deliver economically viable solutions to the region that restore forest health while developing local economies. The approach would assemble a few clusters of complementary businesses. Each cluster would serve log harvesting within a 150-mile diameter, processing SDW into valuable products, such as lumber, pellets and chips.

Key to the viability of this cluster approach would be local uses of slash, which includes trees less than five inches in diameter, as well as trimmings from in-field log processing and other brush/understory. A general rule of thumb is that such biomass cannot be economically transported a distance greater than 50 miles. A viable local use of the slash could be generation of power, and possibly heat, in local generation equipment, such as boiler or gasification units.

One such cluster is well under development as a result of the White Mountain Stewardship Program, a predecessor to the 4FRI. Located in the Show Low-Springerville area, it includes logging operations, a pellet mill, a biomass-to-energy plant and, most recently, a small diameter lumber mill. Local uses of slash are not in place in this existing cluster.

Final results suggest promising pathways for the use of SDW as lumber, in combination with woody biomass for biomass-to-energy technologies. A major finding point to a viable scenario is one in which the forest industry may thrive by operating several businesses that are modularly built with reasonable capital investments, in contrast to an approach of a few businesses requiring large capital investments.

The scenario further suggests that federal subsidies for thinning could potentially be eliminated. A current market price for small diameter logs that appears to be profitable for both the harvester and the manufacturer is $35 per ton. The total optimized administrative cost of $177 per acre represents $7 per ton. Such cost optimization could result from economies of scale and application of new technologies and practices. In this scenario, a log price greater than $42 per ton could eliminate the need for subsidies. Higher log prices could result from local, national, and international market development for small diameter wood products.

Discussion

Federal and state-level budgets are inadequate to proceed with subsidized restorative thinning across the western United States. For this work to be economically viable, therefore, it must occur at profit and require little to no government subsidy. Businesses must be diverse in their trade and roles as well as utilize a variety of technologies to ensure market stability and innovation. For long-term economic and ecological success, key considerations must be made for the viability of the northern Arizona forest region. Additional sources of value creation for SDW are possible as shown schematically in Figure 1, further enhancing economic viability.

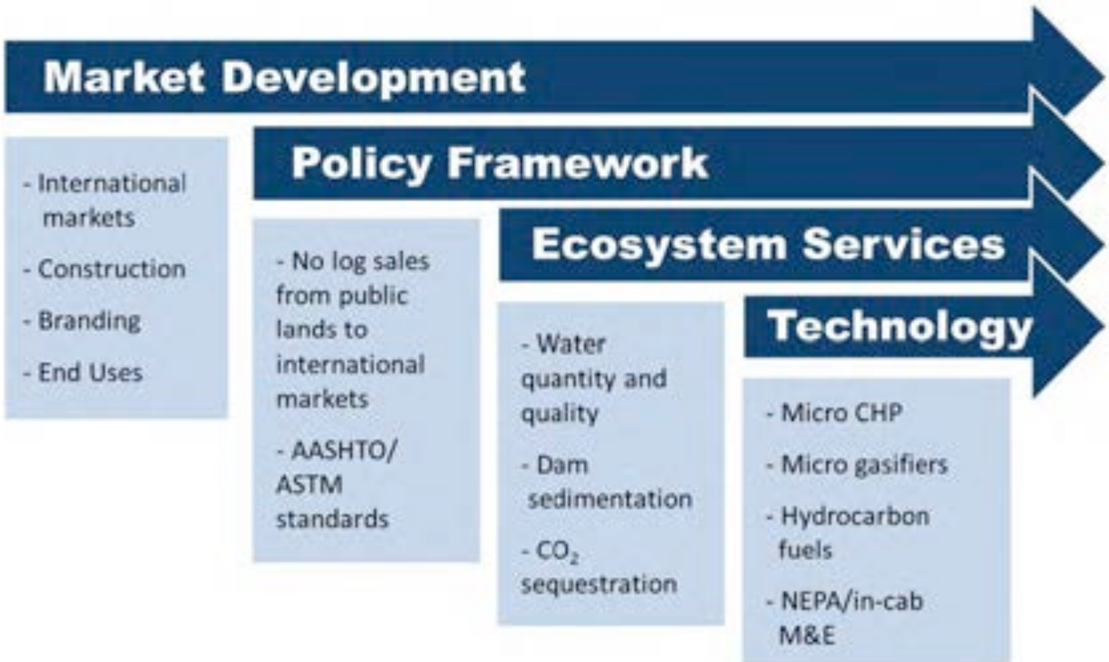


Figure 1. Value Creation

First, a *systems-focused* view of the forest and role of fire-adapted ecosystems is critical to consistency and stability of the market. Market development through market branding, diverse end uses of SDW logs and further exploration of international markets are critical to creating demand and supporting a stronger price for SDW as a raw material. Second, to maintain the successful interplay between economics and ecology, adaptive management and governance frameworks will need to be implemented to oversee relevant policy creation and implementation. This includes factors such as considering rules on international markets, product standards (e.g. ASTM), and the use of life-cycle assessment methodologies. Third, the possibility of monetizing the ecosystem services provided by harvesting SDW should be considered. Lastly, growth models and advancements in market development and technologies must be kept current in order to ensure a healthy balance between economics and ecology. This includes explorations into and employment of underutilized technologies, such as micro-gasifiers and hydrocarbon fuels. Emerging technologies should also result in lower costs of wood processing and creation of higher value products. .

Each of these considerations could play a significant role in further contributing to the economic viability of the scenarios explored above. Furthermore, these considerations could advance the success of SDW harvesting, which will in turn decrease the need for subsidies and allow for much needed market transformations in the forest products industry.

1. Research Agenda

The loss of a quarter of Arizona's Ponderosa pine forests in the last decade as a result of catastrophic fires, the reduced government funds for thinning, and the lack of a robust wood products industry in recent years has heightened the sense of urgency to restore forest health at a faster pace and a larger scale. Consequently, the key objective of this study was to identify economically viable scenarios for restoring forest health by accelerating harvesting small diameter wood, which is critical to the maintenance of fire-adapted ecosystems. This study has been developed for use by the US Forest Service, local governments, and businesses in making decisions related to increasing investment in wood products businesses. At present, heightened fire hazard as a result of forest management history, projections of increasing aridity, and heightened potential exposure of human populations and critical ecosystems results in increased risk (Figure 2).

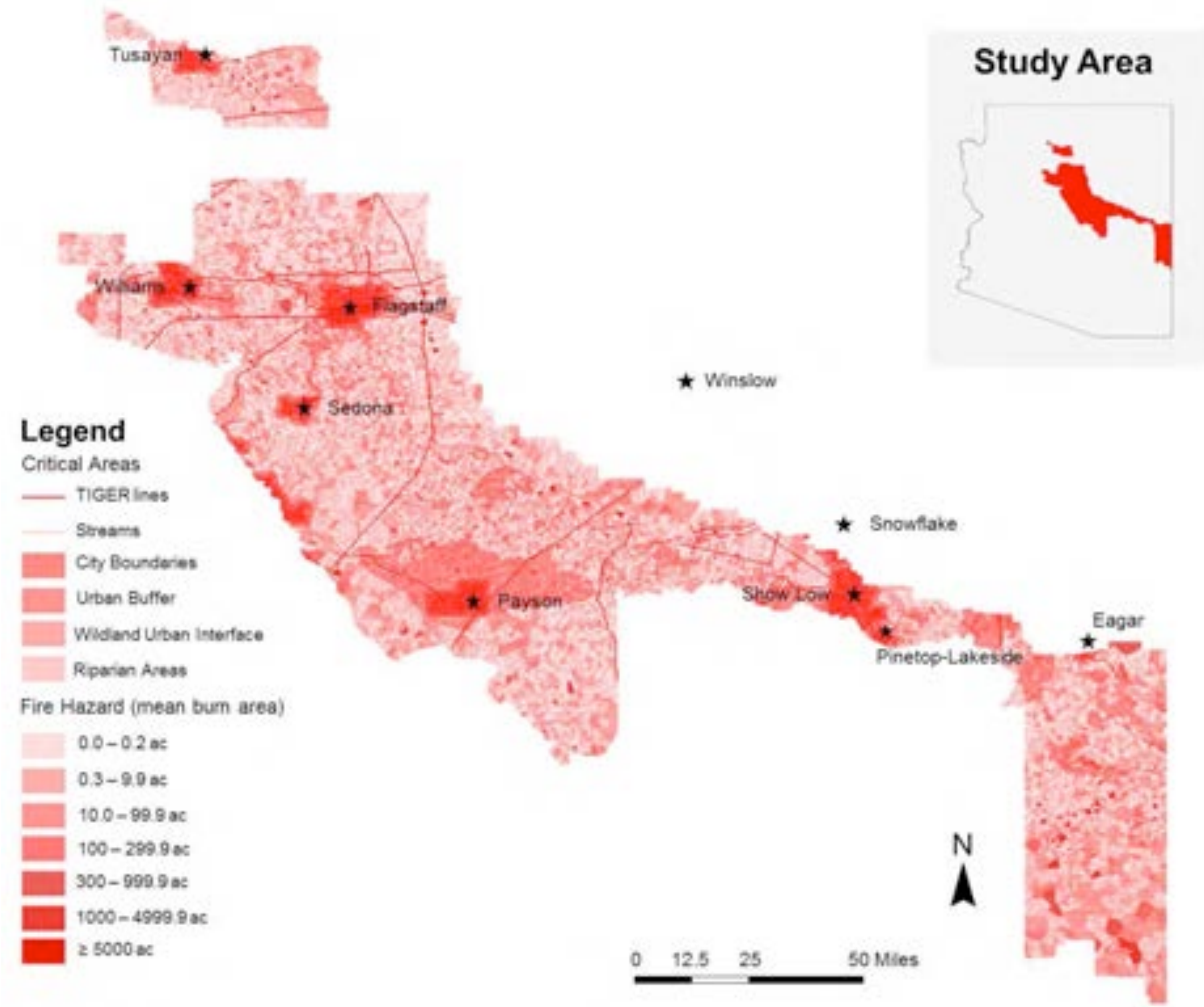


Figure 2. Fire hazard in the 4FRI area as computed from Forest Service fire occurrence data, overlaid over critical infrastructure and areas of ecological importance

These scenarios aimed to examine pathways that integrate the maintenance of these sustainable ecosystems with long-term economic success in the region. Three questions were examined:

On ecology: Is there a portfolio of businesses able to consume woody biomass generated by restorative thinning that is based on small to intermediate-sized capital investments, in addition to, or in place of, the major (hundreds of millions of dollars) previously considered?

On technology: What capital, technological, and supply chain assumptions are required for an economically viable scenario, including reducing or eliminating the need for U.S. Forest Service (USFS) subsidies?

On economics: If no economically viable scenario exists, what subsidy is required to proceed with restoration?

2. Study Background and Introduction

Healthy forests are critical to maintaining local and regional ecosystems. For years, the federal and state government agencies have been working to thin Arizona forests via prescribed burns or mechanical thinning in order to reduce the risk or large-scale, damaging wildfires. Working with local loggers, sawmills, and manufacturers to process these large amounts of harvested wood have historically been successful. However, the loss of a quarter of Arizona's Ponderosa pine forests in the last decade as a result of catastrophic fires, the reduced government funds for thinning, and the lack of a robust wood products industry in recent years has heightened the sense of urgency to restore health at a faster pace and a larger scale. Additionally, recent trends in the Southwestern US, and nationally, show that SDW that was once considered more for use as pulpwood is now being used for lumber and other purposes. An economically viable forest industry will need to consider this transition.

Small diameter wood (SDW) is characterized by an average growth of 8-12" and no larger than 16" in diameter. Harvesting SDW is critical to restoring the structure, pattern, and composition of fire-adapted ecosystems, and will also provide for fuels reduction, forest health, and wildlife and plant diversity. The study area includes the Four Forest Restoration Initiative (4FRI; Kaibab, Coconino, Apache-Sitgreaves, and Tonto National Forests) and Prescott National Forest, as shown in Figure 3 (next page).

The study area included a paired comparison of the Four Forest Restoration Initiative (red in inset) and the Prescott National Forest (blue in inset). The central image shows the vegetation distribution in the study area. The higher elevation and more abundant rainfall in the Four Forest Restoration Initiative region result in a more dense distribution of Ponderosa Pine and other lumber-grade timber. Ponderosa Pine is characterized by quick growth, a low decay rate, and ease of workability, which has historically made it commonly utilized for timber. By contrast, along and below the Mogollon Rim, the Prescott National Forest has a greater abundance of grasses, shrubs, forbs, and non-lumber grade trees. The physical geography and ecology of Arizona ecoregions play a critical role in the economic viability of restorative thinning.

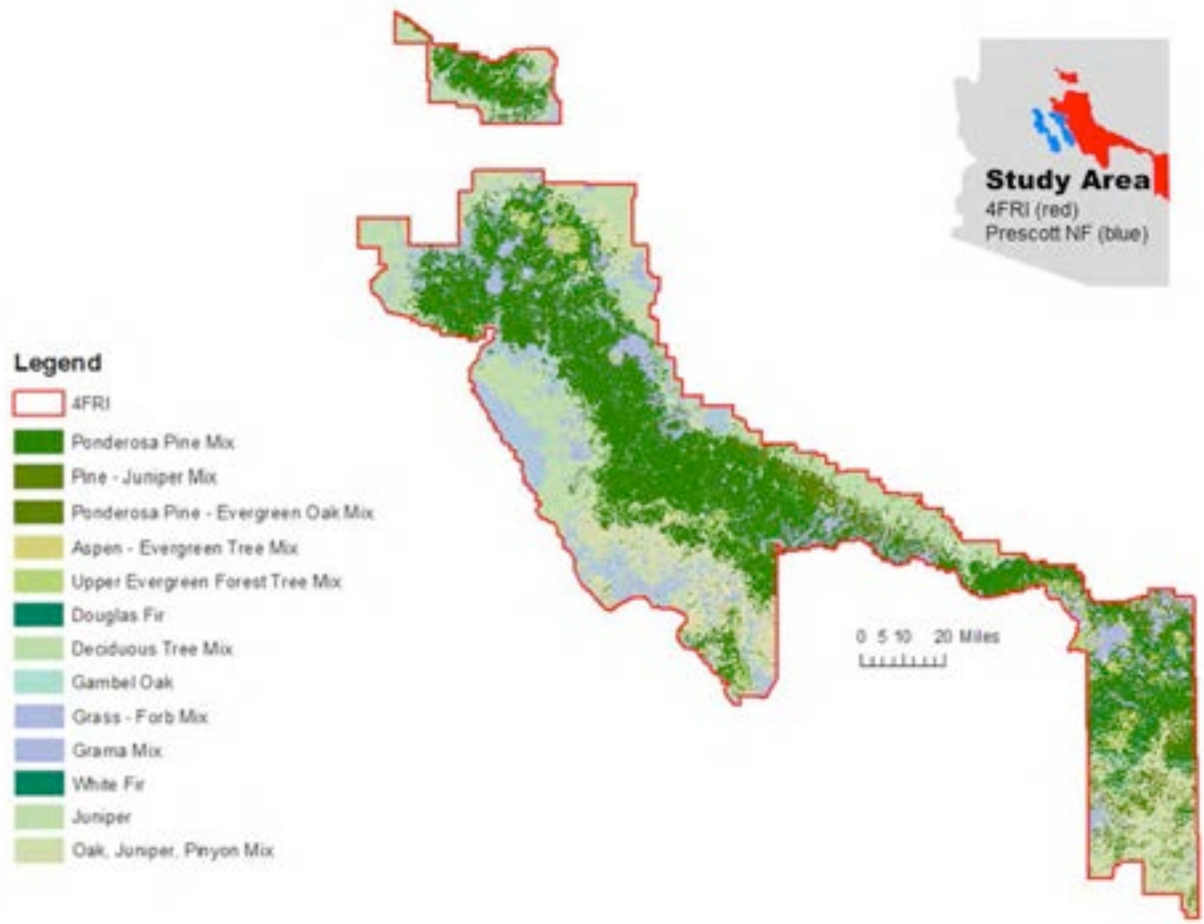


Figure 3. Four Forest Restoration Initiative (4FRI; Kaibab, Coconino, Apache-Sitgreaves, and Tonto National Forests) and Prescott National Forest Study area

In 2006, the United States Forest Service (USFS) launched the White Mountain Stewardship Contract, a pilot program that offered businesses the opportunity to bid for a thinning contract of 100,000 acres of forest over a period of 10 years. Even with the 10 year contracts, the USFS has to subsidize a portion of the harvesting costs in order to attract business investment in small scale mills and plants. With increasing pressure to mitigate the occurrence of wildfires, the USFS began making plans to increase the offer to 900,000 acres over 20 years, with the first contract for 300,000 acres over 10 years. These 900,000 acres will be selected from within the 2.4 million Four Forest planning areas. The first 300,000 acre contract was awarded in May 2012 to Pioneer Associates, but has since been transferred to Good Earth Power AZ LLC.

Success of this initial effort could lead to restoration treatment of over one million acres of Ponderosa Pine forest in the northern Arizona region at approximately 50,000 acres per year over a period of 20 years. Appropriately scaled businesses will play a key role in the effort by harvesting, processing, and selling wood products created from SDW. Restoration-based work opportunities could create jobs across northern Arizona and throughout the West.

3. Wood Products Supply Chain

The wood products supply chain typically entails three stages – harvesting, processing, and manufacturing, as shown in Figure 4. In the first stage, SDW is harvested in the form of slash (woody debris, such as branches or leaves) or timber and can be cut manually or by machinery. In the second stage, SDW slash or timber can be utilized by a diverse set of processing plants based on the desired manufactured product. Here, small diameter Ponderosa Pine is most commonly run through pulp mills, sawmills, or engineered wood plants. These result in wood products such as pulp for paper manufacturing, chips and pellets for energy production at biomass to energy plants, lumber for a variety of construction and other uses, and panels for OSB manufacturing. The wood industry supply chain is illustrated here for a standard "industry cluster." This representation, though simplified, has been demonstrated to work in the White Mountain region.

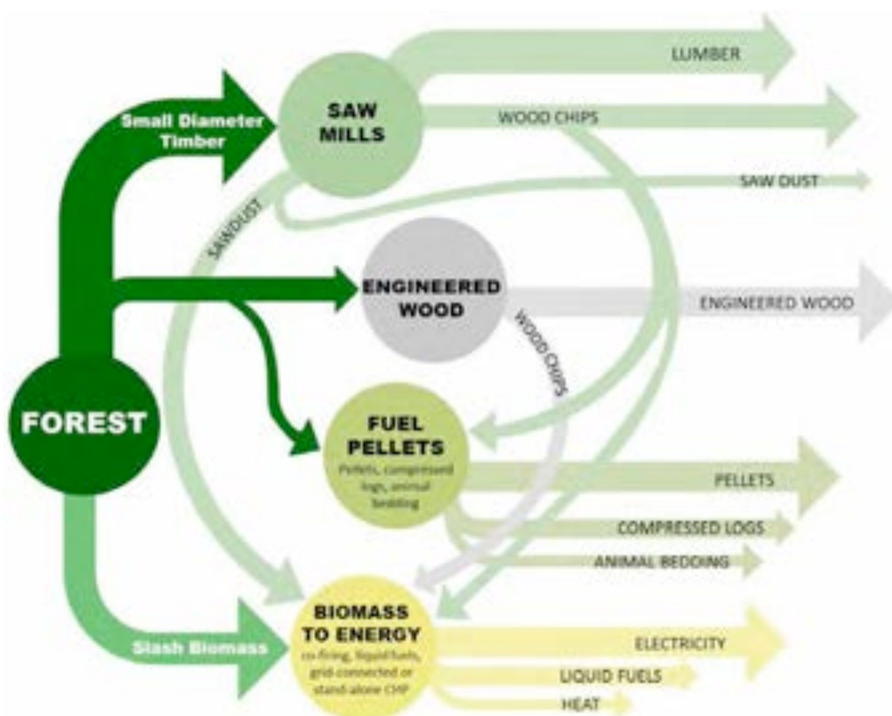


Figure 4. Wood products supply chain

3.1. Research Methodology

The study methodology consisted of four parts:

1. **Technology Inventory**. Understand current and emerging enabling technologies for wood processing, including emerging technologies, for instance biomass-to-energy.

2. **Business Inventory.** Develop an inventory of possible large, medium and small business possibilities that could utilize SDW.
3. **Industry Viability Assessment.** Conduct an initial industry viability assessment, based on analyzing a variety of business combination and configuration scenarios.
4. **Initial Assessment Report & Presentation.** Provide an initial assessment report and presentation.

Additionally, a site visit for field research was conducted. This included traveling to the White Mountain Stewardship Area to observe the forest supply chain, interview foresters, and tour the Four Corner Forest Products Sawmill and Forest Energy Pellet Mill to observe small diameter wood processing. The field research site visit is further discussed below.

4. Current Status of Subsidies

The restorative thinning work under White Mountain Stewardship contract was undertaken primarily to reduce fire risk around mountain communities. The contract was subsidized by the USFS at a rate roughly equivalent to $7 per acre of mechanical treatment. This subsidy was paid directly to logging crews involved in the thinning. A certain fraction of large diameter (greater than 16 inches in diameter at breast height) Ponderosa Pine was marked for harvest. Larger-diameter logs are, generally speaking, more valuable. Permitting the harvest of a select number of larger trees allowed the USFS to limit direct expenditures in the form of a cash subsidy while providing an incentive for bids. By contrast, the larger 4FRI contract was accepted with a subsidy equivalent $1.00 per acre with the primary purposes of restoring ecological health to the forest and reducing the risk of catastrophic fires. However, the 4FRI contract stipulated all slash biomass (log residues and underbrush) be removed from the forest. In the White Mountain Stewardship contract, slash removal was left to the discretion of the logger. If viable and profitable uses for the slash biomass were available, such as biomass energy facilities within a reasonable transportation radius, the loggers could exercise their right of removal and generate a profit. Alternatively, if recovery was not profitable, the loggers could exercise their right to pile the residues and leave them for the USFS to burn in place.

The transition to a lower subsidy with less operational flexibility between the White Mountain Stewardship and 4FRI contracts suggests that (1) SDW harvest and utilization in the region is perceived as a potentially profitable venture, such that the USFS has been able to attract bids with lower implied subsidy rates, and (2) operating strategically located biomass energy and fuels facilities - in the absence of alternative slash processing methods - is vital to the feasibility of such contracts.

5. Business Inventory

An inventory for existing business assets was conducted across multiple companies in Arizona to assess the economic viability of SDW. A copy of the full business inventory can be found in Appendix A. These businesses were identified as users (previous, current, or potential) of SDW.

For a more comprehensive inventory of wood products in general, please refer to Hunt [1], though many businesses have closed since the report was issued in 2011. Businesses were categorized as logging, sawmill, manufacturing, pulp sawmill, or energy-to-biomass sectors. In general, most were located in northern Arizona, particularly around the Flagstaff and Pinetop region. Businesses were surveyed for their capital investment, operating costs, and transportation costs. External SDW market opportunities were explored with potential options for international export and online trading.

5.1. Existing Business Assets

5.1.1. Logging

Of the 14 logging businesses that were identified, S^3 was able to reach approximately half for data, and at least one was identified as recently gone out of business. From this data, capital expenses ranged from approximately $200,000 to almost $2 million dollars, with operating costs between approximately $500,000 and $750,000 dollars per year. Both capital and operating costs depended on factors such as type and quantity of machinery, project size, and length of operating season.

5.1.2. Sawmill

S^3 identified 16 sawmill businesses. However, a handful of these businesses are multi-trade (e.g. were also considered logging businesses). Given this, of approximately 7 that were identified as mainly sawmill companies; we were only able to contact four owners, one of which stated he does not use SDW. The first two businesses were of a smaller nature, with one investing total capital of approximately $100,000 and utilizing an intake of approximately 300,000 board feet/year and 750 tons/year of mulch and firewood, half of the supply coming from SDW. The second business operates with an annual operating cost of approximately $40,000 and has an intake of approximately a semi-truck-load/month, and employs fewer than 10 people.

The fourth is the newly opened Four Corner Forest Products Sawmill in Eager, Arizona, which became a fully-operational sawmill in May 2013. The sawmill is owned and operated by the Vaagen Brothers, who started their first sawmill business in the early 1950s, and includes a high-speed mobile HewSaw, which gets its feedstock from forests in northeast Arizona and northwest New Mexico. The mill costs approximately $7 million dollars/year to operate and has a capacity of 20 log loads/shift with a product volume of 100,000 board feet/shift. Additionally, the sawmill requires approximately 15-30 employees directly and an additional 25-50 employees in the forest logging industry.

5.1.3. Biomass to Energy

In the Arizona region two main biomass to energy companies: Forest Energy Corporation and Snowflake Mountain Biomass Power Plant (also Snowflake Power, LLC), have been influential in the regional forest industry.

Snowflake Power LLC closed in March 2013 as a result of the Catalyst Paper mill closure in late 2012, and was recently acquired by Nova Power LLC. The plant reopened in August 2013. The plant has a total capacity of 24 MW with 18 MW coming from biomass and wood feedstock and would employ 35 people directly and 60-70 indirect jobs in the larger forest industry.

Forest Energy Corporation, located in Show Low, Arizona was originally built in 1992. It has since been modified and would cost approximately $9-10 million dollars in the current market to build a facility with similar capabilities. The plant is capable of producing approximately 64,000 tons of finished wood product annually, which is mostly comprised of pellets (for fuel, bedding, barbecues, etc.) and densified logs.

5.1.4. Manufacturing

Twelve (12) businesses were identified as potential utilizers of SDW in manufacturing of wood products. Two were available for further information. Research shows that these companies range in manufacturing wood products from pallets to shade structures to moulding. More specifically, SDW could be used for fuelwood, with an intake of approximately 4,000 chords/season for one business. Another business stated that if the wood was large enough to create 2x4 lumber (which SDW often can be) then the wood would be utilized to create pallets.

5.1.5. Pulp Mills

As of September 2012, the Catalyst Paper mill in Snowflake, Arizona that co-operated with the Snowflake Power, LLC biomass to energy plant, closed down. The pulp mill was the only business of its type in Arizona and supplied fuel resources to Snowflake Power, LLC. The business employed 308 individuals.

5.2. Emerging Business Opportunities

Emerging business opportunities through international export or online trading may provide as an alternative market for SDW.

5.2.1. International Export

International export can provide opportunities for Arizona forest businesses to take advantage of new markets for SDW. This opportunity is especially relevant when considering which countries provide the largest markets for both supply and demand for desired species and qualities of wood. However, since international export often entails higher transportation costs, SDW harvesting volumes must be sufficient enough to develop an adequate return on investment. For this assessment, we have identified Asian markets as an upcoming market for SDW as well as potential businesses interested in wood intake (Appendix A).

5.2.2. Online Trading

Considering options in online trading for the SDW industry may provide an additional business market, especially given its capacity for global reach. Preliminary research has yielded several sites, such as www.alibaba.com, which currently feature approximately 35 suppliers across Asia, North America, and South America selling wood products. Additionally, www.ebay.com also provides similar services. These online platforms could provide Arizona forest industry businesses with a market outlet for supply or products that are not utilized locally.

6. Technology Inventory

An inventory of small diameter wood processing technologies was analyzed to support the assessment of the economic viability of small diameter wood utilization over different time scales. The complete inventory can be found in Appendix B. The technologies are categorized by technical maturity and commercial feasibility. Based on these coupled criteria, technology options are grouped into current, emergent (0-5 years years), and next-generation (5+ years) categories, as shown in Figure 5. In this context, the terms emergent and next-generation refer to the prevalence of commercial-grade applications of a given technology. However, within the scope of this report, we disaggregate the concepts of technology and economic maturity. By doing so, we aim to decrease the amount of uncertainty associated with projections of economic viability for projects which have not yet been market-tested. Consequently, pilot plants and successful small-scale proof of concept operations are not considered to be current technologies until there has been at least one commercial-scale application. Moreover, we define feasibility in terms of economic viability at scales consistent with current forest restoration practices.

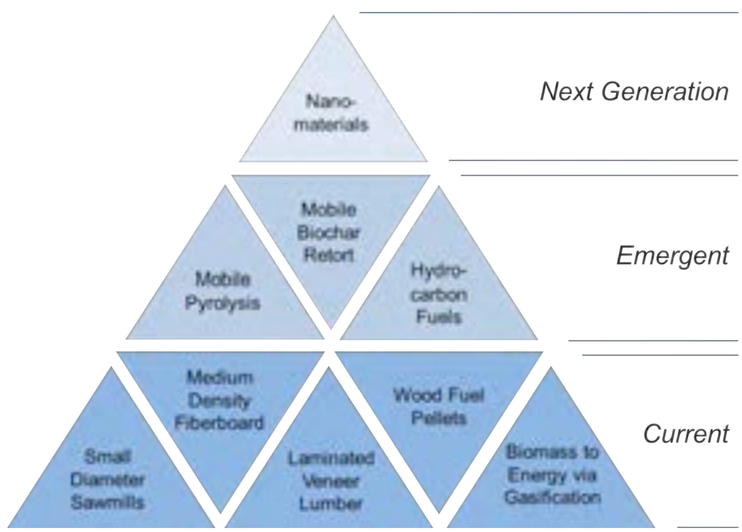


Figure 5. Overview of technologies

6.1. Current SDW Processing Technologies

Currently, viable processing methods for small diameter Ponderosa Pine include:

- The production of lumber and lumber products from lumber-grade tree boles via small-diameter sawmills,

- The production of pellets, briquettes, and compressed wood logs from various grades of wood chips,
- The conversion of chipped or torrefied wood chips or slash biomass into energy through combustion or gasification,
- The utilization of chips for pulp, paper, or mulch, and
- Application in a number of engineered or processed wood products.

Despite the variety of outlets, actual demand can be limited by end products tied to the performance of cyclical markets. One such dependency exists between the lumber or engineered wood and construction industries. In addition to the role of market downturns, industry perception of small diameter Ponderosa Pine as an inferior material limits demand. Conversion to energy, particularly electric power, represents the most stable outlet for woody biomass – yet at current wholesale electricity rates, this pathway cannot support unsubsidized restorative thinning. Generally speaking, biomass energy is more economically viable when environmental regulations and various economic incentives are in place [2]. Overall, while wood biomass fuels have lower carbon content and negligible fossil fuel carbon intensity (Table 1), their heat content is substantially less than conventional fossil fuels (Table 2, next page) [3]. Although low-value woody biomass is considered an attractive biomass source since it does not compete with food production, it tends to be difficult and expensive to extract.

Table 1. Carbon intensity of fuels. Adapted from: Welling and Shaw, Energy from Wood Biomass Combustion in Rural Alberta Applications.

Fuel	kg-C/kg	lb-C/MBtu	kg-C/MJ
Coal	0.78	56.9	24.5
Oil	0.85	47.2	20.3
Natural Gas	0.76	31.9	13.8
Wood (dry)	0.45	zero	zero

Source: Global Emission Model for Integrated Systems (GEMIS), 2006

Table 2. Comparisons of fuel lower heating values. Adapted from: Welling and Shaw, Energy from Wood Biomass Combustion in Rural Alberta Applications.

Fuel	Btu/lb	GJ/T
Natural Gas	22,865	53.18
Propane	19,940	46.37
Gasoline	18,831	43.8
Diesel #2	18,401	42.8
Biodiesel	16,251	37.8
Fuel Oil #1	15,910	37
Ethanol	11,479	26.7
Bituminous Coal	10,318	24
Sub-Bituminous Coal	9,000	20.93
Flax straw (dry)	8,587	19.97
Wood Pellets	8,512	19.8
Wheat straw (dry)	7,680	17.86
Wood (15% moisture)	6,450	15
Biogas	7,159	17.25

Source: Global Emission Model for Integrated Systems (GEMIS), 2006

Wood residues, such as the wood chips, tree bark, and sawdust generated during timber processing are currently allocated to a variety of end uses which remain more profitable than conversion to energy [4]. The recovery of under-utilized slash biomass (canopies, limbs, and brush) and its transport to suitable processing facilities is not yet economically viable. While some forest thinning contracts require the removal of all residues, the costs are borne either by the USFS as a direct subsidy, or by permitting the logger to remove a certain fraction of large diameter timber as indirect compensation. In almost all cases, the production of electricity from biomass is more economical when the resulting heat is captured and used as thermal energy in combined heat and power (CHP) systems. Economies of scale suggest that electricity generation is more feasible at larger scales. At smaller scales, biomass energy can be made viable when co-located locally near the harvest area. If biomass energy facilities are co-located, the heat and power may be used to power kiln dryers at sawmills or fuel pellet plants. The economics of construction and utilization of new biomass energy facilities is more favorable in remote, grid-unconnected areas.

Commercially viable and profitable end uses exist for lumber-grade SDW. However, because nationwide, the forest management scheme is shifting in advance of complementary shifts in markets and industries, there remains the perception that SDW is an inferior product, and unless it can demonstrate the same properties as large diameter logs, has no viable uses. Simultaneously, although there are technologically viable end uses for slash biomass (i.e., conversion to energy), the structure of energy markets and infrastructure policy make this an emergent market player. There have been success stories, but adoption of district heat and power systems run on woody biomass, or large-scale bioenergy power plants remain perceived as experimental "case studies." Because these are viable from a technological standpoint, however, more time and proactive regulations, incentives, and policies may be all that is required to realize a stable and economically sustainable demand for slash biomass in the region.

6.2. Emergent SDW Processing Technologies

Improved recovery efficiencies and scales are driving the emergence of viable new small diameter Ponderosa Pine processing technologies. These include continued testing, ANSI/ASTM/AASHTO certification, and increased commercialization of new and existing engineered wood products and modular and/or mobile bioenergy systems. Although timber sales and forest management policies are shifting all over the nation, small diameter Ponderosa Pine is still considered a lower grade and lower value material. In terms of structural characteristics such as strength and hardness, Ponderosa pine rates less favorably than Douglas fir and hemlock, as well as the more desirable southern pines, such as shortleaf pine, loblolly pine, and longleaf pine. Additionally, the smaller diameter tends to correlate to a higher rate of defects such as knots and juvenile wood [4]. These factors, which limit the economic viability of small diameter Ponderosa Pine as lumber, can be mitigated during the production of various processed and engineered wood products. In cases where electrical generation from woody biomass may not provide a sufficient return on investment to warrant the capital requirement, emergent liquid biofuel (diesel and ethanol) technologies may provide an attractive alternative for the utilization of all forest thinning residues - including slash biomass unsuitable for engineered wood products or lumber. While the testing and certification of these biofuels is ongoing, several have already passed ASTM testing (ASTM D75 military aviation JP-8 fuel; ASTM R100 economy and mid-octane fuel; ASTM R50+ high quality blendstock), certifying them as viable "drop in" fuels. Currently, some of these technologies are nearing full-scale commercialization. As they emerge in the marketplace over the next 5 years, they will aid in providing an economically valuable outlet for thinning residues. Finally, near-term advances in mobile biochar retort and pyrolysis units promise to increase the economic viability of restorative thinning.

6.3. Next-Generation SDW Processing Technologies

In the mid- to long-term, the next generation of technologies suitable for processing small diameter Ponderosa Pine may come from the chemical industry via the production of plastics, organic compounds, solvents, and acids; integration into fuel cell systems via coupled woody biomass gasification and filtration systems; and in coupled utilization for ethanol recovery and nanomaterial production. Woody biomass is composed of a number of organic and inorganic constituents. In the future, better recovery of these "building blocks" via biological or chemical conversion could increase the number of end uses for woody biomass in the pharmaceutical, fuel, and chemical industries.

Currently, most of the reviewed next-generation technologies have been successful at the laboratory (bench) scale. Their true commercial potential, therefore, is difficult to gage. In the chemical industry in particular, recovery (or efficiency) varies widely between bench scale at which most research and development efforts occur, and the commercial batch scale at which technologies must operate to be economically viable. Consequently, although the cited efficiencies for nanofiber recovery or ethanol production are relatively high, it is too early to tell whether these methods can remain sufficiently efficient during commercial translation. Nevertheless, these and other next-generation technologies have the potential to transform an under-utilized and low-value material into a stock for the production of high-value end products in a sustainable manner.

7. Field Research

In July 2013, the S^3 team conducted a site visit to the White Mountain Stewardship area. The purpose of the site visit was to follow up on prior business inventory research efforts and to better assess the situation through collaboration with local industry players and stakeholders. The team toured a logging operation, meeting with a crew harvesting small diameter Ponderosa Pine under the White Mountain Stewardship contract, as well as work orders to remove burned logs from the Wallow Fire area. Following the logging operation, the team toured the newly operational Four Corners Forest Products small diameter sawmill, the Forest Energy Corporation wood fuel pellet plant, the Moulding Accents plant, and met with regional stakeholders.

The site visit and the collaborations established as a result of the trip have led to a more realistic understanding of the forest products industry, particularly as it applies to the study area. A viable solution for lumber-grade small diameter Ponderosa Pine is beginning to play out in the White Mountain Stewardship area. This involves high-recovery automated small diameter sawmills, and provides a profitable outlet for SDW without the need for emergent or next-generation technologies. Conversely, utilization of slash biomass has not yet had a long-term record of success. While there is buy-in from key industry players, such as Ameresco, the idea of small-scale, modular, distributed heat and power generation or gasification units has not yet been implemented. Previous attempts at community buy-in for wood fuel pellet district heating had not met with success, suggesting that further work is required before local biomass energy generation can compete with the convenience of grid-based power. Decisions about local sales of co-products (such as wood chips, sawdust, or tree bark generated during sawmill operation) versus sales to external markets depend on market prices and how those compare to the transportation costs.

Finally, the visit led to the conclusion that a cluster approach, wherein modular, co-located or proximate industries may utilize each other’s byproducts and/or co-products, has the potential to work well. This is perhaps a more viable and sustainable alternative to a central hub approach, based on one or a few large-scale investments. The approaches could also be combined effectively.

Based on these findings, a supply chain was developed to represent the current state of an operational industry cluster. This cluster currently exists, although it is spread out across the White Mountain Stewardship region. This approach depends on a number of incremental capital investments that can be made over time in any number of configurations. Each cluster is supplied with slash biomass and small-diameter wood by a number of logging crews. The logging capacity is a function of the contract time frame and thinning acreage; both parameters are set by the Forest Service. The recovered material can then be allocated to various processing units within the industry cluster; products, co-products, and by-products may be recycled within the cluster, or sent to an external market. This representation of material flows and accumulation of costs and revenues was used as the basis for the development of an economic assessment model.

8. Model Development

An economic viability model was developed based on field research and the results of the technology and business inventories. This Excel model was intended for rapid scenario development and assessment of various industry configurations. Two stand-alone sub-models were included for additional specificity of scenarios and are discussed in their own respective sections below. The primary sub-model was supply-driven and carried out a hierarchical set of calculations whereby material flow through the supply chain was tracked alongside the accumulation of costs and revenues. The secondary sub-model explored profitability thresholds. This sub-model was built to provide the user with the means to explore the effect of scale (volume processed) and fetch (transportation radius) on a given technology's bottom line. Ultimately, the model provided a conceptual and quantitative platform for further integration of collaborative environmental, economic, and social scenario development. An overview of the model is shown in Figure 6.

Figure 6. Model overview

8.1. Model Objectives

The primary purpose of the model was to serve as a platform for scenario development and the optimization of small diameter wood restoration and utilization strategies. Subsequently, the model was designed to:

1. Synthesize the various supply chain links and nodes as they transform a raw product into a value-added commodity.
2. Inform S^3's understanding of the feedbacks between restoration (via thinning contract acreage and duration), and utilization (via required economic development).

Additionally, the model was tasked with answering the following three questions relating to the industry viability of current, emergent, and new-generation harvesting and processing options:

1. Is there a viable mix of businesses that will economically consume the output of forest restoration at a number of restoration volumes/speeds, that is based on small- to medium-sized, modular capital investments?
2. What is the capital, business formation, and technology assumptions required to make a scenario economically viable?
3. If no viable scenario can be found, at what rate would the USFS need to subsidize forest restoration?

The modeling results, as they pertain to these questions, are presented in the next section and are further discussed in subsequent sections.

8.2. Input Data

Data used to parameterize the model originated from market research and direct stakeholder responses, peer-reviewed literature, and technical reports. Because the model was built to be a generalizable tool that could be broadly applied across different ecologic and economic landscapes, the initial parameterization could be modified to reflect different biomass availabilities, operating conditions, or available technologies. In addition to this extra option, the model was built on the default premise that certain parameters – notably, thinning rates and material allocations, would be user-defined.

8.3. Assumptions

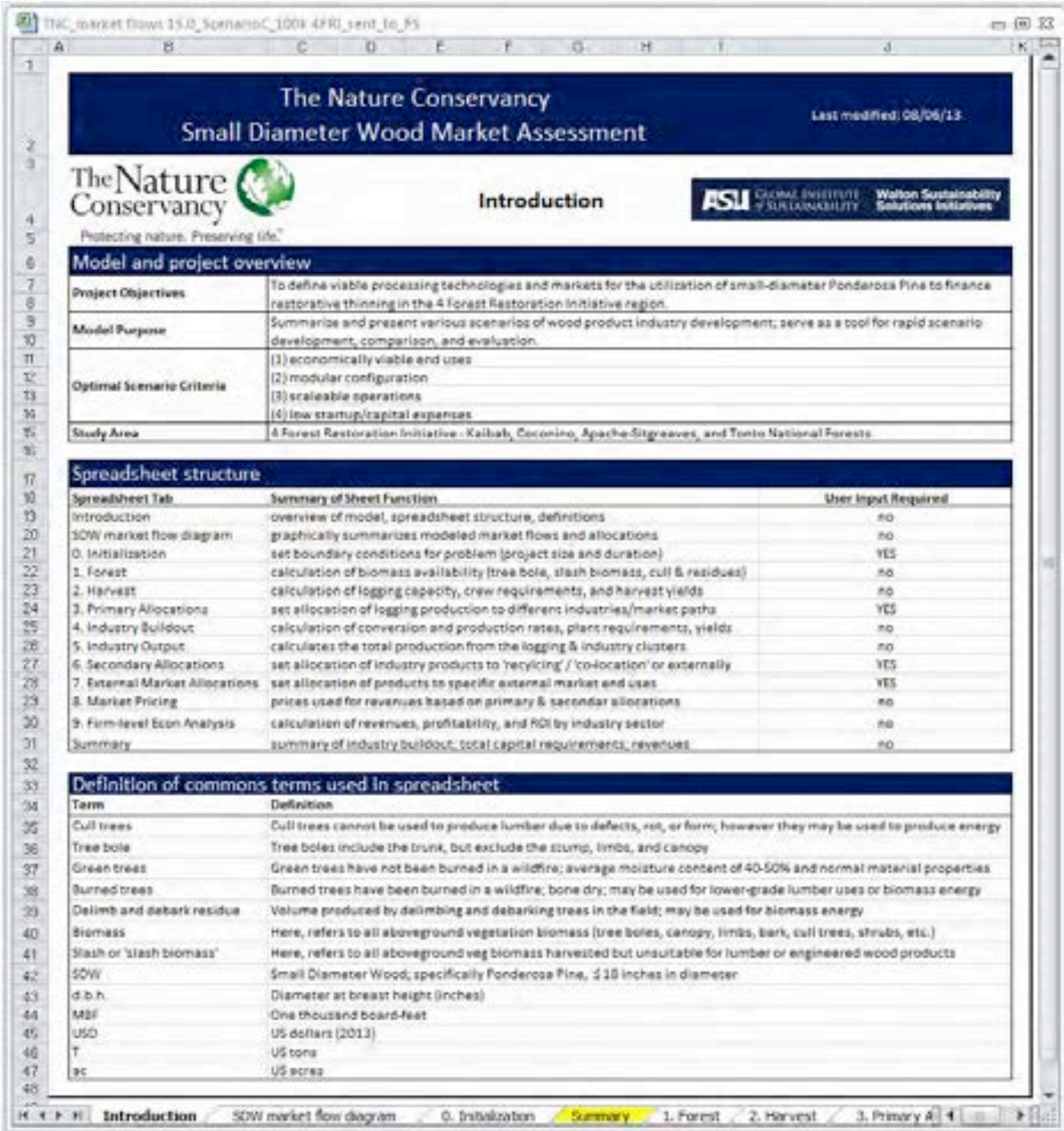
The model structure was based on a set of simplifying assumptions. These assumptions presume that:

1. Profitability remains steady throughout the entire duration of the model run
2. Economic viability is driven by supply rather than demand (i.e., everything produced is sold)
3. Market pricing remains stable across the entire duration of the model run
4. There is no interruption in wood supply due to wildfires or other calamities

Many factors go into the long-term feasibility of on-the-ground investments. Consequently, the model was developed as a screening-level tool, or a test of infeasibility rather than guaranteed feasibility.

8.4. Primary Model Structure – Cluster Development

Two overview tabs within the Excel model, *'Introduction'* (Figure 7, next page) and *'SDW market flow diagram,'* provide the user with a high-level introduction to the model. The Introduction tab reviews model and project objectives and defines the study area for which the initial data is applicable. This tab also provides a summary of the model structure and defines terms, units, and abbreviations used elsewhere in the model. The *SDW market flow diagram* tab contains a conceptual market flow diagram illustrating the various supply-chain pathways for small diameter logs and slash biomass.



The Nature Conservancy
Small Diameter Wood Market Assessment

Last modified: 08/06/13

The Nature Conservancy
Protecting nature. Preserving life.

Introduction

ASU Global Institute of Sustainability — Walton Sustainability Solutions Initiatives

Model and project overview

Project Objectives	To define viable processing technologies and markets for the utilization of small-diameter Ponderosa Pine to finance restorative thinning in the 4 Forest Restoration Initiative region.
Model Purpose	Summarize and present various scenarios of wood product industry development; serve as a tool for rapid scenario development, comparison, and evaluation.
Optimal Scenario Criteria	(1) economically viable end uses (2) modular configuration (3) scaleable operations (4) low startup/capital expenses
Study Area	4 Forest Restoration Initiative - Kaibab, Coconino, Apache-Sitgreaves, and Tonto National Forests

Spreadsheet structure

Spreadsheet Tab	Summary of Sheet Function	User Input Required
Introduction	overview of model, spreadsheet structure, definitions	no
SDW market flow diagram	graphically summarizes modeled market flows and allocations	no
0. Initialization	set boundary conditions for problem (project size and duration)	YES
1. Forest	calculation of biomass availability (tree bole, slash biomass, cull & residues)	no
2. Harvest	calculation of logging capacity, crew requirements, and harvest yields	no
3. Primary Allocations	set allocation of logging production to different industries/market paths	YES
4. Industry Buildout	calculation of conversion and production rates, plant requirements, yields	no
5. Industry Output	calculates the total production from the logging & industry clusters	no
6. Secondary Allocations	set allocation of industry products to 'recycling' / 'co-location' or externally	YES
7. External Market Allocations	set allocation of products to specific external market end uses	YES
8. Market Pricing	prices used for revenues based on primary & secondar allocations	no
9. Firm-level Econ Analysis	calculation of revenues, profitability, and ROI by industry sector	no
Summary	summary of industry buildout; total capital requirements; revenues	no

Definition of commons terms used in spreadsheet

Term	Definition
Cull trees	Cull trees cannot be used to produce lumber due to defects, rot, or form; however they may be used to produce energy
Tree bole	Tree boles include the trunk, but exclude the stump, limbs, and canopy
Green trees	Green trees have not been burned in a wildfire; average moisture content of 40-50% and normal material properties
Burned trees	Burned trees have been burned in a wildfire; bone dry; may be used for lower-grade lumber uses or biomass energy
Delimb and debark residue	Volume produced by delimbing and debarking trees in the field; may be used for biomass energy
Biomass	Here, refers to all aboveground vegetation biomass (tree boles, canopy, limbs, bark, cull trees, shrubs, etc.)
Slash or 'slash biomass'	Here, refers to all aboveground veg biomass harvested but unsuitable for lumber or engineered wood products
SDW	Small Diameter Wood; specifically Ponderosa Pine, ≤ 18 inches in diameter
d.b.h.	Diameter at breast height (inches)
MBF	One thousand board-feet
USD	US dollars (2013)
T	US tons
ac	US acres

Introduction | SDW market flow diagram | 0. Initialization | Summary | 1. Forest | 2. Harvest | 3. Primary A

Figure 7. Introduction tab of the spreadsheet model

Starting with the first tab *'0. Initialization'*, the model requires the user to specify a set of parameters. The mechanical thinning area (contract acreage) may be specified in any increment with no upper or lower bound. The corresponding time frame (contract duration, in years) must also be input by the user. Here too, there is no restriction on the maximum or minimum values. This flexibility is built into the model both to develop a more generalizable and broadly-applicable product, and to provide the user with the means to carry out smaller, more focused, scenario analyses if required. This tab produces the required harvest rate (acres per year) that is fed into all subsequent model steps and drives the calculation of required capacities, costs, and revenues.

In the next tab, *'1. Forest,'* the user may specify the biomass characteristics that are applicable to a given study area. Biomass densities are parameterized as tons of material per acre of contract area. The initial acreage is converted into discrete volumes of small diameter timber and slash biomass. Understory herbaceous biomass (grass and forb material) may be included in the total slash volume. Alternatively, the user may elect to define slash biomass as exclusively the residues of logging operations. In order to model the effect of historic or projected wildfires on the viability of thinning projects, this tab asks the user to allocate a certain fraction of tree boles (lumber-grade small-diameter timber) to "burned" or "green" – i.e., unburned.

In tab *'2. Harvest',* logging capacities, capital investments, and workers are calculated based on known parameters for a single (baseline) operation, scaled to the user-defined required harvest rate. Logging yields are calculated as a function of the user-specified biomass characteristics and harvest rate. These yields are shown at a daily time-step (daily operations) and a yearly time-step (yearly operations). Generally speaking, the model parameters are based on a yearly time-step. This is done to normalize the production of industries that operate on different schedules. For this reason, outputs such as ROI calculations and revenues are provided exclusively on a per-year basis. However, these yearly variables are based on per-day productivity and number of operating days per year. These two parameters (days per year and daily capacity) can be changed, and the yearly calculations would update and reflect those changes.

Allocations are controlled by the user and can be specified in tabs 3 (primary allocations) and 6 (secondary allocations). Tab *'3. Primary Allocations'* requires the user to define how tree boles and other biomass volumes will be distributed between the industry cluster (composed of saw mills, pellet plants, central biomass to energy facilities, local distribution heat and power generation, and processed wood products), and/or an external market. Raw material prices in the primary allocations tab are linked to logging revenues. These can be modified by the user.

Based on the user's decision regarding primary allocations, an industry cluster is developed to accommodate the rates and volumes generated by the thinning project. Tab *'4. Industry Buildout'* calculates these capacities, capital investments, manpower requirements, conversion factors, throughputs, and estimates yields on daily and yearly timescales. Similar to the calculation of required logging capacity, the industry requirements are scaled to the ratio of total material inflow to the intake capacity of a single baseline operation. Allocating less material to an industry will reduce the required capacity. Increasing the allocation will result in higher required capacity.

The next tab, *'5. Industry Output,'* summarizes the total yield of logging operations and all subsequent processing and production. This information is aggregated across all industries and summarized by commodity (s.a. lumber or electricity). Processing residuals (s.a. wood chips or sawdust produces as a by-product of saw mill operations) are also included. Again, this data is presented both at yearly and daily time-steps.

A feedback loop is built into the model. In tab *'6. Secondary Allocations,'* the user is asked to specify the desired allocation of industry production (pulled from *5. Industry Output*) to internal 'recycling' within the industry cluster, or its allocation to external markets. Allocating material within the industry cluster will increase the required capacity proportionally to the influx volume, and update the volumes in *5. Industry Output.*

In the event that external market allocation is desired, tab *'7. External Market Allocations'* allows the user to select from a list of possible end-uses. Similarly to all other allocations within the model, the user is allowed the flexibility to specify fractional allocations. In other words, the total volume produced may be split in any number of configurations between the end uses available.

Tab *'8. Market Pricing'* is used in conjunction with *5. Industry Output, 6. Secondary Allocations,* and *7. External Market Allocations*, to calculate the revenues in tab *'9. Firm-Scale Econ Models'*. Return on assets (ROA), and indirectly, operating costs, are based on estimates of annual profitability and model-calculated revenues. These are simple firm models that estimate economic development and firm outcomes based on simple profitability and capital investment assumptions.

The *'Summary'* tab, highlighted in yellow, provides a broad overview of the developed scenario. In addition to summarizing the required capital investment, employment potential, and operating capacities, the Summary tab plots the capital investment density, total capital investment, net income, and return on investment by industry. No parameters should be modified in this sheet.

8.5. Secondary Model Structure – Thresholds

Alongside the primary material flow model, a secondary sub-model explores economically viable thresholds for thinning projects. Focusing on the same collection of industries as the primary material flow model (see SDW market flow diagram), the *'Thresholds'* tab provides the user with the means to test out different transportation radii and market pricing to understand how the required contract area varies between industries and changes as markets and contract conditions change.

9. Economic Viability Assessment: Scenarios

A total of five scenarios of forest-thinning projects were explored. These scenarios compared the economic viability of restorative thinning at scales ranging from 70,000 to 900,000 acres and different regions of the Four Forest Restoration Initiative and Prescott National Forest. Here, we discuss the results from one of the scenarios and summarize major conclusions. The full results of all scenarios can be found in Appendix D.

9.1. Scenario A: Four Forest Restoration Initiative – 900,000 acres

Scenario A explored the potential for creating a set of modular industry clusters capable of processing the output of thinning operations at rates compatible with Forest Service contract requirements. These clusters could be distributed throughout an area of interest, thereby reducing the transportation distance from the forest to suitable processing facilities, and/or taking advantage of existing infrastructure and ongoing investments. The model provides a measure of the required processing capacity to match the throughput of harvest operations. However, it remains generalizable in that it assumes no specific set optimization criteria a priori, allowing the user to test out and compare various industry configurations. The results of Scenario A are presented below in Table 3.

Table 3. Scenario A

Thinning area and harvest timeframe					
Restorative Thinning Area			900,000		acres
Harvest Timeframe			20		years
Summary of industry build-out					
Industry	**Capital**	**No.**	**∑ Capital**	**Net Sales**	**Jobs**
Logging	$ 2M	12	$ 24M	$ 51M	72
Small-diameter sawmill	$ 10M	5	$ 50M	$ 430M	90
Wood Fuel Pellets	$ 20M	2	$ 40M	$ 15M	16
Central Biomass Energy	$ 60M	2	$ 120M	$ 59M	19
Distributed Generation	$ 12M	12	$ 144M	$ 52M	38
		TOTAL	**$ 378M**	**$ 607M**	**235**

Restorative thinning 900,000 acres over the course of 20 years in the 4FRI area will require about 12 logging crews working simultaneously. These crews are expected to require about $24 million worth of capital investment to outfit, and generate about twice that, resulting in $51 million in net sales over the 20-year period.

It should be noted that logging capacity, as well as all other industry recommendations, can be covered in whole or in part by existing investments and existing businesses currently operating in the area. In other words, a portion of the capital investment may very well have already been made years ago. In such a case, the actual amount of new capital to be raised would decrease.

Due to the relative abundance of Ponderosa Pine in the 4FRI region, a viable case for the utilization of small diameter sawmills exists. These mills have high rates of recovery and provide a profitable end product. As a result, given a total capital investment of $50 million, the saw mills are expected to generate $430 million worth of sales over the course of the 20 year contract period. Wood fuel pellet plants, central biomass energy facilities, and combined heat and power units for distributed generation do not recover their capital investments through net sales over the course of the contract time frame. Therefore, while the overall scenario suggests over $200 million in profit may be possible, the majority of net sales are generated by saw mill production. Biomass energy capital investments amount to 3 times the capital required for a single sawmill, yet result in a fraction of the revenues. It should be noted, however, that this represents the necessity of removing all slash biomass from the forest. Given current biomass prices, a more economically viable option may be burning these low-value residues. Overall, such a configuration of businesses could generate 235 jobs.

10. Discussion

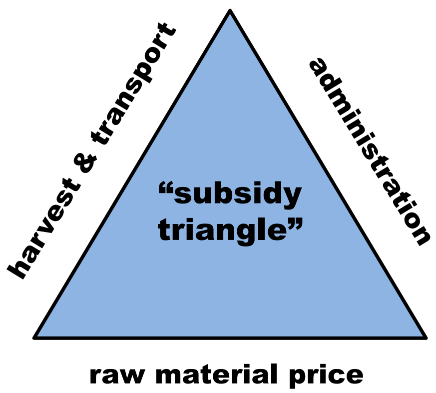
Final results suggest promising pathways for the use of SDW as lumber or engineered wood and woody biomass for biomass-to-energy technologies. Strategically, a major finding suggests a viable scenario in which the forest industry may thrive off of operating several businesses that are modularly built with smaller capital investments, rather than, or in combination with, a few businesses requiring larger capital investments.

International markets were also examined as a potential extended market, though its viability is yet to be determined. Long-term success for SDW harvesting and healthy forest restoration must incorporate a comprehensive systems approach that operates on a smart, dynamic relationship between policies, emerging technologies, ecosystem services, and balanced market development.

10.1. Subsidies

Due to changes in fire and forest management policies, the USFS began to transition from the timber sale of saw logs (above 16 inches diameter at breast height) to restorative thinning contracts targeted at the removal of what had formerly been considered pulpwood (16 inches d.b.h. and less). Because SDW is considered less profitable to harvest, the USFS has been subsidizing the process to help offset the costs of harvest and transportation incurred by loggers. The subsidy is meant to cover the difference between the true cost of thinning and the revenue which can be generated by the sale of harvested biomass. The scale of the undertaking is immense, however. Federal and state-level budgets are inadequate to proceed with subsidized restorative thinning across the western United States. For this work to be economically viable, therefore, it must occur at profit and require little to no government subsidy.

The rate of required subsidy is determined by three factors (Figure 8). Administrative costs, incurred by the USFS during the environmental planning, preparation, and monitoring stages of the project, are currently partially subsidized. Harvest and transportation costs are covered by the logger and are not subsidized. If the costs of mechanical thinning are considered too high, however, acreage may be treated with private subsidies or left untreated. Finally, the market prices of harvested biomass factors in the calculation of subsidies because it determines the revenue which can be generated by the harvest of a given acre of forest. The subsidy is the difference between costs and revenues, such that a sufficiently profitable balance is struck.



Per Acre Administrative Costs of Restorative Thinning Projects in the Southwest*

Category	Current Cost	Optimized Cost
Planning	$65	$15 NFMA | $42 NEPA
Preparation	$200	$74
Administration	$75 | $20 monitoring	$48
Total	**$360 / acre**	**$177 / acre**

**Preliminary analysis of the average administrative costs per acre for forest restoration projects implemented in Region 3 of the U.S. Forest Service:* adapted from SW Region Restoration Task Group, 2008

Figure 8. Market subsidies

The rate of required subsidy is a function of the administrative, harvest, and transportation costs, as well as the raw material price.

Harvest and transportation costs are highly variable, and depend on the terrain and infrastructure (road and processing facility) density in a given region. While more strategic investment in smaller-scale distributed industry clusters may help decrease transportation costs by decreasing the required transportation radius, these costs are largely functions of the geographic and economic landscape and are difficult to vary. Increased efficiencies and improved methods for the harvest of small diameter timber may drive these costs down, but they can be expected to retain a high degree of variability.

Figure 8 also presents a summary of per acre administrative costs for restorative thinning in the southwest region. Currently, restorative thinning projects require an average of $360 per acre in planning, preparation, and administrative overhead costs. If these costs can be reduced, the optimized per acre costs is estimated to be roughly half the original amount, at $177 per acre. Although this difference is less than the variance between the highest and lowest possible harvest and transportation costs, the subsidy pertains specifically to this cost category. Optimizing and streamlining the administrative process could be expected to slash the subsidy in half, with no additional efforts at market development or innovations in harvest and processing technologies.

Based on analysis of current market conditions, at current administrative, harvest, & transportation costs, a profitable price point exists at $35 per ton with a $7 per acre subsidy. At lowest administrative, harvest, & transportation costs, this profitable price point would be expected to move to roughly $42 per ton. This raw material price would result in no subsidy being required of the USFS, while providing a sufficiently profitable return for loggers. To demonstrate the importance of optimizing administrative costs and the high degree of variability in harvest and transportation, for these same calculations at the highest administrative, harvest, and transportation costs, the profitable price point moves to roughly $74/ton with no subsidy.

10.2. Systems Considerations

Federal and state-level budgets are inadequate to proceed with subsidized restorative thinning across the western United States. For this work to be economically viable, therefore, it must occur at profit and require little to no government subsidy. The above analysis of a subsidy-free market price shows that this possibility is within sight.

Businesses must be diverse in their trade and roles as well as utilize a variety of technologies to ensure market stability and innovation. For long-term economic and ecological success, key considerations must be made for the viability of the northern Arizona forest region. Additional sources of value creation for SDW are possible as schematically shown in Figure 9, further enhancing economic viability.

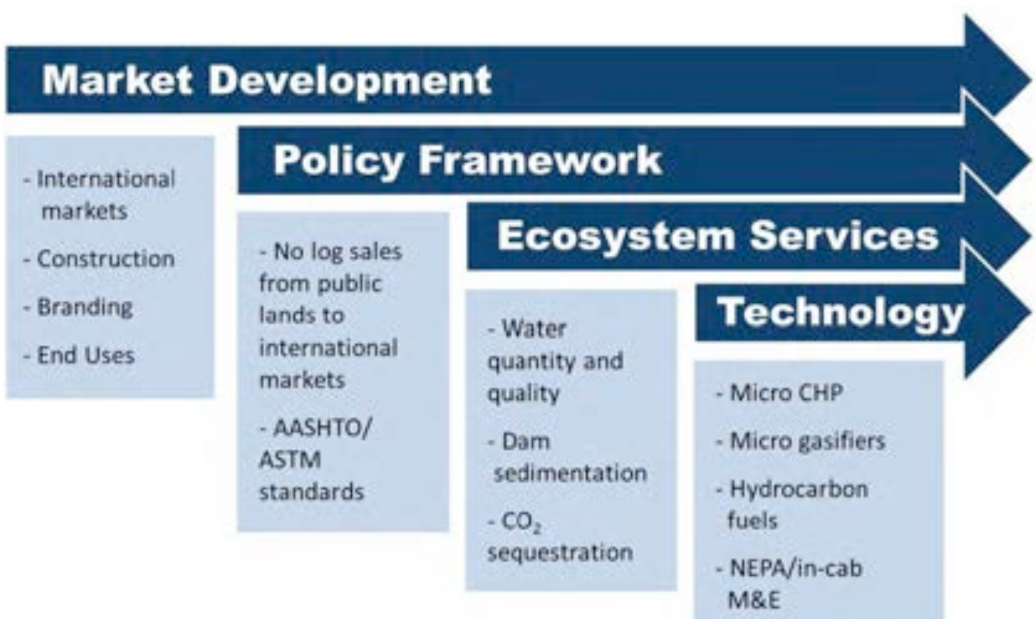


Figure 9. Value Creation

Achieving the $42 per ton raw material price for SDW logs might be achieved by finding/creating additional value through other system elements, including market development, policy modifications, monetization of ecosystem services provided by a healthier forest and continued improvements in efficiency of value chain operations through the employment of new technologies as they emerge. This project did not analyze these factors in depth, but encountered them during our research and analysis. They represent a potential future research agenda for both enhancing the research data, analysis and model development. A continued systems-focused view of the forest and role of fire-adapted ecosystems is critical to consistency and stability of the market. All aspects of the SDW value network must be analyzed, modeled and explored in more detail to understand realistic value creation opportunities.

One of the most critical success factors is market development, which can occur in a number of ways. Finding new, profitable end uses for the wood is probably the most important of those. Current market players are finding some success in niche markets, such as post and pole for the southwest region. New markets must be constantly explored to build demand in a robust overall market that can withstand the ups and downs of individual market segments. One that might be especially critical is the international marketplace, both for chipped logs and whole logs. The ability to use SDW in construction market segments would be an important way to build demand.

To complement these efforts, the USFS and involved states should consider a broad-based branding and marketing plan that encourages businesses and consumers to utilize products made from SDW, because of the multiple benefits to them and to the larger society. One can envision a campaign focused on SDW similar to the "Water, Use It Wisely" campaign that resulted in a greater consciousness of water use in American society. The "Made in America" campaign is another such example.

To maintain the successful interplay between economics and ecology, adaptive management and governance frameworks will need to be implemented to oversee relevant policy creation and implementation. One of these factors related to market develoment is the current rules regarding the shiplent of logs from public lands to international markets. Consideration should be given to an exception for SDW logs, as international buyers might pay more for whole logs than for wood chips, which is the SDW product most commonly sold internationally.

Some amount of SDW testing to product standards (e.g. ASTM) for markets such as construction have been done and/or are ongoing. Accelerating this testing and certification, if possible, could result in additional market segments for SDW. To support both market and regulatory initiative Life Cycle Assessment (LCA) methodologies for analysis and assessment of the environmental tradeoffs of SDW compared to substitute products could be employed. The authors are unaware of any such application of LCA to SDW products, though such application could exist.

The ecosystem services provided by harvesting SDW must also be considered. These services include reduced risk of dam sedimentation, increased water yield, increased CO_2 sequestration, and improved water quality control. Stakeholders who have a major interest in the health of the watershed represented by the forests analyzed in this report, have initiated research into many of these areas. The impacts of large scale fire, and the potential benefits from restoration of forest health, are becoming better known. The pathways to monetization of these services are not generally clear. For instance, it is possible that the carbon footprint reductions represented by a healthy forest could result in tradable carbon credits. How this might be made possible, and who in the value chain might benefit, is under consideration.

It is equally unclear how an increase in water quality and availability, as well as the avoidance of reservoir sedimentation, might be monetized. As an example of one pathway, The Nature Conservancy has worked with cities across Latin America and in Santa Fe to establish water funds, where communities invest in projects to improve the watershed to reduce water pollution and increase water supply [5][6]. Monetization of some or all of these services could significantly contribute to the goal of creating a profitable, subsidy-free price for SDW as raw materials.

Finally, growth models and advancements in market development and technologies must be kept current in order to ensure a healthy balance between economics and ecology. This includes explorations into underutilized technologies, such as micro-gasifiers and hydrocarbon fuels. Emerging technologies should also result in lower costs of wood processing and creation of higher value products. This report concluded that employment of new technologies might not be necessary to achieve a subsidy-free price. However, new technologies historically have created both new efficiencies to reduce costs, as well as new product possibilities that create new market segments and new demand. One particularly important potential for the employment of new technologies is the processing of forest biomass (i.e., slash) for the creation of power and/or heat on a local basis that is near the harvesting point. While there are many current technologies that can be employed to do this, others are emerging that will make the process more economically viable.

Each of these considerations could play a significant role in contributing to the economic viability of the scenarios explored above and must be kept in mind as industry moves forward. Furthermore, these considerations will advance the success of SDW harvesting, which will in turn decrease the need for subsidies, and allow for much needed market transformations in the forest industry.

11. Next Steps

Of the system considerations mentioned previously, the most promising ones include monetizing ecosystem services provided by healthy forests. CO_2 credits, collected either by the logger or the USFS, are a promising option for increasing the value of each thinned acre. Markets for CO_2 credits already exist: what is required is aligning USFS operations with CO_2

sequestration and credit methodologies. This is being worked on by key forest health stakeholders.

Similarly, healthy forests help to maintain and improve water quality through filtration of rainfall and snowmelt and increase the water yield as it is transferred to groundwater and surface waters. Preventing the occurrence of catastrophic fires will decrease soil erosion, in turn preventing excessive sediment transport. Dam sedimentation, and the costs associated with its mitigation, are of significant concern for Arizona water supplies. Recognizing these services provided by timely and adequate forest management through restorative thinning, and monetizing them to add value to the thinning process, could result in restorative thinning being a more profitable proposition and to attract investment in accelerating forest thinning.

These issues, along with market development factors, should be explored in future research and iterations of the model.

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Appendix A: Business Inventory

Table 4 below shows a listing of Arizona businesses identified in this initial assessment report. An asterisk (*) denotes a business that is involved in multiple stages of the forest supply chain (e.g. logging and processing).

Table 4. Arizona Business Listing

Name	Location (AZ)	Contact Phone
LOGGING		
Authentic Southwest Building Materials*	Tucson	(520) 296-4689
Canyon Country Mills & Resources	Fredonia	(928) 643-7007
Canyon Creek Logging Inc.	Pinetop	(928) 242-2713
Ethelbah Enterprises, LLC*	Pinetop	(928) 369-2149
Future Forests	Pinetop	(928) 245-7007
High Desert Investment Co.*	Flagstaff	(928) 774-9111
Holl Logging Inc.	Lakeside	(928) 368-2272
Holliday Timber	Alpine	(928) 245-1895
Mountain Top Wood Products*	Show Low	(928) 537-2884
Old Santa Fe Lumber*	Prescott	(928) 445-3456
Perkins Timber Harvesting	Williams	(928) 607-3860
Simpson Contract Cutting LLC	Alpine	(928) 699-4870
TriSar Logging	Snowflake	(928) 536-7848
W.B. Contracting	Eagar	(928) 333-4491
SAWMILL		
AP Sawmill and Lumber Products LLC*	Flagstaff	(928) 607-2084
APC Lumber Inc.	Eagar	(928) 333-3055
Authentic Southwest Building Materials*	Tucson	(520) 296-4689
Canyon Wood Supply	Camp Verde	(928) 567-3481
Cheyenne Log Homes*	Eagar	(928) 333-2751
Four Corner Forest Products Sawmill	Eagar	(928) 333-5535
Ethelbah Enterprises*	Pinetop	(928) 369-2149
High Desert Investment*	Flagstaff	(928) 774-9111
Idaho Forest Products*	Surprise	(623) 842-0650
Imperial Laminators	Eagar	(928) 333 5501
Mountain Top Wood Products*	Show Low	(928) 537-2884
Old Santa Fe Lumber*	Prescott	(928) 445-3456
Reidhead Brothers Lumber Mill	Nutrioso	(928) 339-4542

Round Valley Wholesale Lumber Lnc.	Eagar	(928) 339-4542
San Carlos Apache Timber Product	San Carlos	(928) 475-4334
Western Moulding Company	Snowflake	(928) 536-2131
SW Forest Products	Phoenix	(602) 278-1009
MANUFACTURING		
AAA Pallet and Lumber Co	Phoenix	(602) 278-1450
AP Sawmill and Lumber Products LLC*	Flagstaff	(928) 607-2084
APC Lumber Inc.	Eagar	(928) 333-3055
Arizona Log and Timberworks	Eagar	(928) 333 2751
Arizona Log Homes	Payson	(480) 861-8434
Arizona Wholesale Fuelwood	Laveen	(602) 237-2365
Cheyenne Log Homes*	Eagar	(928) 333-2751
Idaho Forest Products*	Surprise	(623) 842-0650
Moulding Accents	Snowflake	(928) 536-2131
Mountain View Log Homes	Tucson	(520) 818-2944
Nutrioso Log Works	Nutrioso	(928) 339-4657
Winners Circle Soil Products	Taylor	(928) 536-7398
PULP SAWMILL		
Catalyst Paper	Snowflake	closed
BIOMASS TO ENERGY		
Forest Energy Corporation	Show Low	(928) 537-1647
Nova Power, LLC (Formerly Snowflake Power, LLC)	Snowflake	(602) 476-0631
Pinal Power	Scottsdale	(480) 889-7006

Table 5 shows potential international markets for SDW wood.

Table 5. Potential International Markets

Name	Intake Market
Shanghai Zhengshan Wood Co., Ltd	US Southern Pine
Shanghai Timber Trading Association, Softwood Professional Committee	White Pine
Chongqing Zhongnuo Timber Development Co., Ltd.	Dimensional lumber, pine and softwoods for paneling, and architectural lumber
Taewon Lumber Co., Ltd.	Raw wood (with or without bark), wood chips
Tianjin Jiayu Industrial & Trade Co., Ltd	SPF KD HT LUMBER (Spruce-Pine-Fur Kiln-Dried Heat-Treated Lumber)
Shanghai Anresion Wood Industry Co., Ltd	Kiln-dried ash lumber
Shenzhen Rainbowwood Co., Ltd	General wood products
Shanghai YuTo Wood Co., Ltd	Timber (unsure if Pine)

Adapted from https://www.forestbusinessnetwork.com/our-events/slc/agenda/wood-exports-at-the-small-log-conference-meet-the-asian-wood-product-buyers/.

Appendix B: Technology Inventory

1. Current SDW Processing Technologies

1.1. Small Diameter Round Timber

Round timber is a minimally processed product that can be made from small-diameter Ponderosa Pine. Typically, round timber utilizes trees as small as 4 to 9 inches in diameter. Tree boles must pass certain criteria for straightness, knot size, grain angle, and defect distribution. Although not all small diameter wood is suitable for structural (construction-grade) applications, round wood is generally stronger and more stable than mill lumber. Due to its geometry and grain orientation, small diameter round timber has 2-3 times the moment capacity, 3-4.5 times the allowable load under deflection, and 1.57 times the axial load capacity of dimensional saw lumber [1]. Despite these advantages, however, round timber is more difficult to dry than sawed lumber, and more prone to cracking. Additionally, joints between round timbers are more difficult to construct and require the expertise of specially-trained technicians and workers. Building codes may pose another challenge. Though these obstacles can be overcome, round timber will most likely remain a specialty construction material [2].

1.2. Stationary Small Diameter Sawmills

The processing of small diameter timber for lumber is complicated by conventional mills which are not equipped to process what traditionally have been considered “pulp logs.” European manufacturers have led the development of dimensional lumber mills designed for the processing of small diameter plantation-harvested timber ranging from 5 to 24 inches, although 9 to 13.5 inch models are more common. In addition to thinner blades and equipment designed to accommodate shorter and thinner logs, the small diameter mills are highly automated machines. Logs are fed in by a conveyer and scanned to created three-dimensional models of the distribution of defects, grain orientation, and other characteristics. These models interface directly with the saw controller, which adjusts the blades and determines the optimal configuration of lumber sections that can be recovered from a given log. The import of these mills into the North American market has made possible the processing of smaller diameter wood into high-value lumber. To be economically viable, small diameter sawmills require substantial automation, high efficiency/recovery rates, and maximizing throughput to cover capital and operating expenses. Such mills currently exist, but the requisite operator expertise and technological capital are clustered more densely in regions where the wood products industry has remained vibrant. Until very recently, this has not been the case in northern Arizona.

1.3. Mobile Small Diameter Sawmills

In contrast to stationary small diameter sawmills, mobile mills are better equipped to provide a return on investment with low volume production. These mills require a smaller initial capital investment in equipment, infrastructure, and land. If powered by a diesel-powered generator, mobile saw mills can operate on location, substantially reducing transportation costs of logs to remote processing facilities. Mobile milling is particularly attractive in situations where the wood supply is inconsistent or distributed across a large area. Mobile mill manufacturers such as Wood-Mizer®, Mobile Dimension®, LumberSmith®, Lumbermate®, Economizer®, and Timberking® design these mills with narrower band, swing, or circular saw blades, increasing recovery. Mobile small diameter sawmills can process 4 to 13 inch diameter timber at lengths between 4 and 20 feet. In addition to their record of on-the-ground performance, portable sawmills have been formally reviewed by the USDA Forest Service and the Forest Products Laboratory. In December 2004, the USDA Forest Service Pacific Northwest Research Station completed an economic assessment of a mobile Micromill® unit for processing small-diameter Ponderosa Pine [3]. The SLP5000D Micromill® requires 3-4 operators, and is able to process 3,250 board feet per hour at a total lifetime equipment cost of $426,185 and $150,476 in annual operating and maintenance (2003 US dollars). The mill produces 0.28 tons of dirty wood chips per MBF lumber. The authors conclude that mobile milling of small diameter Ponderosa Pine can be economically viable when markets are strong, but revenues are inadequate to cover capital, operating, and labor costs in average to poor markets.

1.4. Engineered Wood Products - Particleboard Manufacturing

Particleboard is produced by binding cellulosic fibers with a synthetic resin or binder under heat and pressure. The cellulosic fibers originate from wood chips, sawdust, or planer shavings. This material is dried to a moisture content of 2 to 8 percent. After drying, the material is screened by size and mixed with urea-formaldehyde or phenol-formaldehyde resins and waxes. The mixture is deposited as a continuous mat on a conveyor belt. Three or five layers are bonded together to form composite panels. The panels are pressed, finished, and cut to size. Finished particleboard is typically composed of 90% wood fiber, 9.2% urea-formaldehyde resin, 0.3% wax, 0.1% ammonium-sulfate catalyst, and 0.4% urea scavenger [4]. The finished product can be used for the production of countertops, kitchen cabinets, shelving, door cores, manufactured home decking, stair treads, flood underlayment, and office and residential furniture [5]. Particleboard is typically manufactured to densities ranging from 28 to 55 psf and varies in thickness from 1/8 to 2-1.4 inches [6]. The production of particleboard must comply with voluntary standard ANSI A208.1, as well as additional regulations issued by the U.S. Department of Housing and Urban Development (HUD). The production of particleboard is an energy-intensive process, requiring 569 MJ of electricity per cubic meter produced [4]. Table 6 (next page) presents a summary of a recent life cycle assessment (LCA) carried out by Wilson (2010) for particleboard production [4].

Table 6. Process requirements for one cubic meter of particleboard.

Products	Value	Unit/m^3
Particleboard	1.00 (746)	m^3 (kg)
Bark mulch sold	12.9	kg
Wood waste to landfill	0.4	kg
Boiler fly ash to landfill	0.1	kg
Resources	**Value**	**Unit/m^3**
Municipal water	304	L
Materials/fuels	**Value**	**Unit/m^3**
Total wood residue	672	kg
Urea formaldehyde resin	68	kg
Wax	2.5	kg
Ammonium sulfate catalyst	0.72	kg
Urea scavenger	2.9	kg
Electricity	569	MJ
Natural gas	30	m^3
In-mill generated wood fuel	2.1	kg
Air Emissions	**Value**	**Unit/m^3**
CO_2 (fossil)	57	kg
VOC	0.36	kg
Methanol	0.02	kg
Formaldehyde	0.06	kg
Acetaldehyde	0.0006	kg
Acrolein	0.00004	kg
Phenol	0.005	kg

Adapted from: Wilson (2010) http://www.corrim.org/pubs/reports/2010/phase2/Module_F.pdf

1.5. Engineered Wood Products - Medium Density Fiberboard (MDF) Manufacturing

Similar to particleboard, medium density fiberboard (MDF – ANSI A208.2) is a composite panel product manufactured from wood fibers and a binding agent, most commonly a synthetic resin. The wood fibers are produced by heating and vat-softening clean wood chips. The softened wood chips are then pulped and dried. Once dry, the fibers are blended with a mixture of resin and/or wax. Although urea-formaldehyde resins are the most common, phenolic resins, melamine resins, and isocyanates may also be used. The resinated material is formed into a mat and undergoes hot pressing to a thickness ranging from 1/2 to 3/4 inches and a density of 30 to 50 pounds per cubic foot. Its more uniform density distribution makes it a more structurally stable product than particleboard, as well as better suited for machining and finishing. When finished and smoothed, MDF requires no veneer or laminates, unlike particleboard. MDF may be used to make furniture, cabinets, door parts, molding, millwork, laminate flooring, and paneling. Because MDF utilizes wood fibers, rather than flakes (as is the case with oriented strandboard), there is no size restriction on the diameter of trees which can be utilized in its production. Capture systems for volatile organic compounds (VOCs) are required for controlling the emission of dryer and press exhaust. Technologies such as regenerative thermal oxidizers (RTOs), regenerative catalytic oxidizers (RCOs), and thermal catalytic oxidizers (TCOs) are among the more commonly used. These systems capture and combust the recovered gases, thereby destroying VOCs and reducing CO emissions [7]. Table 7 presents a summary of a recent life cycle assessment (LCA) carried out by Wilson (2010) for medium density particleboard production [8].

Table 7. Process requirements for one cubic meter of MDF.

Products	Value	Unit/m^3
Medium Density Fiberboard	1.00 (741)	m^3 (kg)
Wood boiler fuel sold	0.06	kg
Bark mulch sold	12.9	kg
Wood waste to landfill	2.21	kg
Boiler fly ash to landfill	1.94	kg
Resources	**Value**	**Unit/m^3**
Municipal water	935	L
Well water	452	L
Materials/fuels	**Value**	**Unit/m^3**
Total wood residue	793	kg
Urea-formaldehyde resin	83.3	kg
Wax	5.21	kg
Urea scavenger	1.28	kg
Electricity	1494	MJ
Natural gas	43	m^3
In-mill generated wood fuel	54	kg
Air Emissions	**Value**	**Unit/m^3**
CO_2 (fossil)	83.4	kg
VOC	0.84	kg
Methanol	0.22	kg
Formaldehyde	0.16	kg

Acetaldehyde	Not reported	kg
Acrolein	Not reported	kg
Phenol	Not reported	kg
Methylene diphenyl diisocyanate	Not reported	kg

Adapted from: Wilson (2010) Life-cycle inventory of medium density fiberboard in terms of resources, emissions, energy and carbon. Wood and Fiber Science, 42(CORRIM Special Issue):107–124.

1.6. Engineered Wood Products - Oriented Strandboard (OSB) Manufacturing

During production of oriented strandboard (OSB), logs are debarked, conditioned for 4-6 hours in hot water, and flaked using a disk-type flaker. The flakes are dried and conveyed to a screener, where the flakes are separated by size. After sorting, a resin binder (most commonly, in the form of powdered or liquid phenolics and diphenyl methane di-isocyanates) is sprayed on the flakes inside a rotary blender. The resinated flakes are aligned and deposited in layers, forming a mat. The mat is pressed and cut to size. Finished OSB is composed of roughly 85-97% wood, 0-15% phenol formaldehyde or polymeric diphenylmethane diisocyanate, and 0-2% paraffin wax [9]. Unlike particleboard and medium density fiberboard, OSB is made of wood flakes rather than fibers. This distinction is important in that it constrains the utilization of smaller (shorter) small-diameter wood. Although Ponderosa Pine is not the preferred softwood specie for the manufacture of OSB, it can be used, particularly if mixed with other soft or hardwoods with better material properties. Despite these limitations, OSB has an important advantage in that it is a performance-rated structural panel. Because OSB has been widely used in construction, technical feasibility and compliance with building codes is all but assured. All building codes in the U.S. and Canada recognize OSB as a direct equivalent of plywood [10]. Despite its advantages, OSB plants produce substantial emissions and are capital-intensive enterprises [11]. Table 8, adapted from Puettmann *et al*. (2012) [10] shows the inputs and outputs associated with producing one cubic meter of OSB. Table 8 (next page) summarizes the results of the LCA analysis conducted by the authors. It should be noted that the environmental performance values presented in Table 9 (page 34) correspond to the direct (on-site) production only, and do not account for transportation or prior processing.

Table 8. Process requirements for one cubic meter of OSB.

Products	Value	Unit/m^3	Allocation (%)
Oriented strandboard	1	m^3	72.75
Wood fuel (produced)	199.4	kg	23.36
Bark mulch sold	23.07	kg	2.7
Fines sold	9.23	kg	1.08
Dust/scrap sold	5.13	kg	0.6
Resources	**Value**	**Unit/m^3**	
Water, cooling, surface	36.28	L	
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at grid	205.67	kWh	
Natural gas, combusted in industrial boiler	23.9	m^3	
Wood waste, combusted in industrial boiler	199.4	kg	
Phenol formaldehyde resin	21.73	kg	
Methylene diphenyl diisocyanate resin	4.18	kg	
Wax	9.89	kg	
Air Emissions	**Value**	**Unit/m^3**	
CO_2 (from VOC combustion)	12.3022	kg	
VOC	1.1174	kg	
Methanol	0.2035	kg	
Formaldehyde	0.0574	kg	
Acetaldehyde	0.0671	kg	
Acrolein	0.0241	kg	
Phenol	0.0124	kg	
Methylene diphenyl diisocyanate	0.0001	kg	

Adapted from: Puettmann et al. (2012) Cradle to gate life cycle assessment of oriented strandboard production from the southeast.

Table 9. Environmental performance of one cubic meter of OSB in the SE region.

Impact Category	Unit	OSB Production/m^3
Global warming potential	kg CO_2 equivalent	274.76
Acidification potential	H+ moles equivalent	140.01
Eutrophication potential	kg N equivalent	0.0777
Ozone depletion potential	kg CFC-11 equivalent	0
Smog potential	kg O_3 equivalent	33.08
Total Primary Energy Consumption	**Value**	**OSB Production/m^3**
Non-renewable fossil	MJ	4846.86
Non-renewable nuclear	MJ	663.11
Renewable – non biomass	MJ	19.4
Renewable - biomass	MJ	3991.14
Material Resources Consumption (non-fuel)	**Value**	**OSB Production/m^3**
Non-renewable materials	kg	2.84
Renewable materials	kg	656.07
Fresh water	L	465.99
Waste Generated	**Unit**	**OSB Production/m^3**
Solid waste	kg	39.35

Adapted from: Puettmann et al. (2012) Cradle to gate life cycle assessment of oriented strandboard production from the southeast

1.7. Engineered Wood Products - Laminated Veneer Lumber (LVL) Manufacturing

Laminated veneer lumber (LVL) is a composite wood product which can be substituted for structural lumber in headers, beams, rafters, joists, and composite I-joist flanges [12]. Similar to other composites, LVL is better suited for the utilization of small diameter Ponderosa Pine than dimensional lumber, because warping, twisting, bowing, and shrinking can be minimized during production. Major defects in the original timber can be avoided, thus guaranteeing a more uniform and stronger end product. Logs are debarked, cut, and steamed. Veneers about 0.125 inches thick are cut from the preconditioned logs. The green are then veneers are dried and graded using ultrasonic graders to increase stiffness and strength. The graded veneers are coated in phenol-formaldehyde resin and arranged manually. The stack of resinated veneers is hot pressed, cured, and cut to length. Table 10 (next page) summarizes the results of the LCA analysis conducted by the authors. It should be noted that the environmental performance values presented in Table 11 (page 36) correspond to the direct (on-site) production only, and do not account for transportation or prior processing.

Table 10. Process requirements for 1 cubic meter of LVL.

Products	Value	Unit/m^3
Laminated veneer lumber	1	m^3
Co-products (waste, scrap, trim, sawdust)	21.25	kg
Resources	**Value**	**Unit/m^3**
Water, cooling, surface	35.23	L
Materials/fuels	**Value**	**Unit/m^3**
Electricity, at grid	59.51	kWh
Diesel	0.17	L
Natural gas	3.38	m^3
Phenol formaldehyde resin	8.2	kg
Phenol resorcinol formaldehyde resin	0.59	kg
Parallel Laminated Veneer	430.87	kg
Veneer, dry	122.32	kg
Air Emissions	**Value**	**Unit/m^3**
CO_2 (fossil)	60.0324	kg
VOC	0.0154	kg
Methanol	0.0094	kg
Formaldehyde	0.0002	kg
Acetaldehyde	0.0005	kg
Acrolein	0	kg
Phenol	0	kg

Adapted from: Puettmann et al. (2013) Cradle to gate life cycle assessment of laminated veneer lumber production from the Pacific Northwest

Table 11. Environmental performance of one cubic meter of laminated veneer lumber in the Pacific Northwest region.

Impact Category	Unit	LVL Production/m^3
Global warming potential	kg CO_2 equivalent	66.02
Acidification potential	H+ moles equivalent	30.44
Eutrophication potential	kg N equivalent	0.025
Ozone depletion potential	kg CFC-11 equivalent	0
Smog potential	kg O_3 equivalent	4.98
Total Primary Energy Consumption	**Value**	**LVL Production/m^3**
Non-renewable fossil	MJ	1184.15
Non-renewable nuclear	MJ	83.95
Renewable – non biomass	MJ	56.81
Renewable - biomass	MJ	23.74
Material Resources Consumption (non-fuel)	**Value**	**LVL Production/m^3**
Non-renewable materials	kg	0.86
Renewable materials	kg	5.78
Fresh water	L	275.13
Waste Generated	**Unit**	**LVL Production/m^3**
Solid waste	kg	3.98

Adapted from: Table 13 in Puettmann et al. (2013) Cradle to gate life cycle assessment of laminated veneer lumber production from the Pacific North

1.8. Bioenergy - Biomass Cofiring

Co-firing woody biomass in conventional coal-powered power plants is considered a near term, low-cost option for converting biomass to electricity. As of 2010, more than 40 U.S. power plants have conducted test burns [13]. Currently, 89 U.S. power plants are co-firing coal with biomass [14]. Although there is not a clear consensus on the net life-cycle impacts of co-firing, supplementing coal with woody biomass results in demonstrated reductions in sulfur dioxide (SO_2) and nitrous oxide (NO_x) emissions [13]. These alone can make co-firing an economically viable option in the face of increasingly stringent emission standards and the requisite retrofit or decommissioning. During co-firing, coal is supplemented with woody biomass which is pre-ground to a particle size smaller than 1/4 inch. Although this approach requires minimal processing, pilot tests have demonstrated mixed results when the biomass exceeded anywhere from 3-8% total energy value. Torrefaction prior to co-firing, while more expensive than pulverizing alone, has been more successful. Likewise, the use of wood fuel pellets in place of raw pulverized biomass can increase the technical viability of co-firing at higher rates. Wood fuel pellets and coal have comparable bulk densities (45 lb/ft^3 vs. 43-50 lb/ft^3, respectively). While the heat content of bituminous coal is higher, wood fuel pellets fall within a reasonable range (16.7-26.9 MMBTU/ton vs. 15.8-17.0 MMBTU/ton, respectively) [15]. Further technical challenges arise when the fuel source is co-mingled with debris such as foliage or bark, rather than co-fired exclusively with clean wood chips [16]. This suggests that unless significant modifications are made to boilers and operating systems, co-firing may not be a viable outlet for the majority of low-value forest residues (i.e., the brush, limbs, and canopies). The costs of necessary modifications can range from borderline negligible when wood is co-fired at low rates (3% of lower) to around $300 per kW of installed capacity at 5-8%. Higher co-firing rates (10%) require substantial retrofits and separate wood fuel storage, handling, and injection systems [17].

1.9. Bioenergy - Direct Combustion

Conversion of woody biomass to energy through direct combustion is the oldest form of energy production. In the present day, direct combustion systems vary in size and operating system [18-20]. They range from residential wood burning stoves to multi-MW combined heat and power plants, and can utilize a variety of feedstocks including wood residues, agricultural or waste biomass, and/or torrefied wood and pellets. During the process of combustion, heat is generated directly from the exothermic reaction. This can be used directly to provide central or district heating or it may be used to boil water, produce steam, and power a steam turbine to generate electricity. During primary combustion, solid biomass is burned, releasing gases, and volatilizing various organic and inorganic compounds. Secondary combustion occurs simultaneously. In secondary combustion, the gases which are volatilized during primary combustion are burned. If “complete” combustion is achieved, the process releases only carbon dioxide and water vapor in addition to heat. In the combustion is not carried to completion, however, tars, carbon monoxide, particulate matter, and hydrocarbons are also released. This is problematic from an air quality standpoint, and reduces the overall conversion efficiency of the system. Incomplete combustion can be minimized by designing systems such that all of the feedstock spends sufficient time in the high temperature zone (2-4 seconds), is combusted at a sufficiently high temperatures (1100-1500°F), and an adequate air flow is maintained to oxygenate the combustible gases (10-12 lb-air per lb-feedstock) [21]. Although raw wood and wood residues can be combusted directly, this is usually done only at the micro scale (ratings less than 1MW). At larger scales, greater efficiency and emission compliance measures justify more costly feedstocks, such as wood chips, pellets, briquettes, and torrefied wood. The cost of combustion systems is very variable. For small to medium-scale systems, estimates are $50,000 to $150,000 for 0.6MWs, $100,000 to $350,000 for 0.6-1.5MWs, and $250,000 to $500,000 for 1.5-3MWs [22]. The efficiency rates of wood and other forms of fuel stocks are presented in Table 12 (next page).

Table 12. Overall efficiency of wood and other competing fuels.

Fuel	Power Plants (%)	Other Uses (%)
Coal	33 – 35	45 – 60
Gas	40 – 50	85
Wood	22 – 25	65 – 80
Nuclear	32	NA
Oil	NA	80
Propane	NA	80

Adapted from: Table 1 in http://dof.sitevision.com/econ/resources/pub-usda-fs-primer-on-wood-biomass-for-energy.pdf

1.10. Bioenergy - Gasification

Although gasification has been used for power generation for more than 35 years, woody biomass has not been the feedstock of choice due to its complex chemistry and lower energy content compared with fossil fuel feedstocks such as coal [23]. Similarly to direct combustion, gasification relies on the conversion of solid biomass into combustible gases. When the feedstock is heated by hot steam and air injection to 133-2200°F, synthetic gas or "syngas" is released, alongside ash and particulate matter. The syngas can be oxygenated and combusted to generate heat and power turbines for electrical generation. Alternatively, it can be allowed to cool and condense, and used as a liquid fuel substitute. Since syngas is composed of 85% hydrogen and carbon monoxide (as well as carbon dioxide, nitrogen, methane, and trace gases), the molecular structure of the condensed liquid fuels resembles that of conventional hydrocarbon fuels. Although both syngas and the resulting liquid fuels are valuable products, the particulate matter in syngas and the naturally low hydrogen content of woody biomass mean that neither syngas nor the liquid fuel can be used directly without processing to make them better resemble their conventional counterparts. Syngas must be "scrubbed" to remove impurities before it can be used to power turbines. Updraft gasifiers are typically used for direct heat applications at a small or medium scale. These systems are the simplest and can operate with variable moisture contents (up to 60%), but produce a large amount of tars. Downdraft gasifiers are better suited for small-scale systems (200-500 kW). Although small-scale gasifiers for community or district heat and power exist, economics currently favor large scale applications. Larger units tend to have more uniform temperature gradients, reaction rates, resulting in more consistent operation and higher throughput. At largest scales, gasifiers are also used in conjunction with direct combustion systems.

1.11. Bioenergy - Pyrolysis

Whereas gasification produces primarily syngas, during pyrolysis solid biomass undergoes thermochemical degradation into oil (variously referred to pyrolysis oil, syn-oil, bio-oil, or synfuel). Biochar and syngas are also generated. Because the process is anaerobic, negligible ash is produced. The process can be optimized for the recovery of biochar, syngas, or synfuel. When pyrolysis systems are operated at the lower temperature range (800°C), biochar recovery is increased. At higher temperatures (over 1000°C), more volatilization generates a greater volume of syngas and synfuel, but a correspondingly smaller fraction of biochar. Biochar can be utilized as a soil amendment for agriculture, as a microbiologic substrate and filtration system in soil and groundwater remediation, and as an alternative to conventional activated granular carbon filters for drinking water treatment. As a structural soil amendment, biochar increases overall porosity and permeability, aerating the soil. Additionally, the open lattice structure and carbon content provide a substrate for microbial activity and increases root nutrient availability and uptake. As a medium for groundwater remediation, biochar provides a carbon stock for anaerobic bioremediation of chlorinated solvents and other hydrocarbon spills.

1.12. Bioenergy - Torrefaction

Torrefaction does not directly produce heat or energy. Rather, it is used to improve the characteristics of woody biomass as a feedstock for energy production [24]. Torrefaction is a form of anaerobic low temperature (392-608°F) pyrolysis. At these temperatures, water is evaporated and cellulose, hemicellulose, and lignin are partially broken down. This results in a mass reduction of 20-30% and a heating value loss of 10%. Torrefaction increases the energy density of woody biomass, though not as substantially as densification. Consequently, torrefaction and densification are sometimes combined for maximum energy density. Once woody biomass has been torrefied, it becomes easier to grind. Torrefied wood can be processed into fuel pellets or briquettes alongside raw woody biomass. When wood has been both torrefied and densified into pellets, transportation costs can be decreased by 40% based on the water and mass reduction. The end product has a higher energy density (16-25 GJ/ton) than raw wood (10-11 GJ/ton), making it a more economically profitable material (Tables 13-14). The low moisture content and consistency also make torrefied biomass more suitable than untreated wood for co-firing with coal [24]. The use of torrefied wood, rather than raw wood chips can increase the percent (by volume) of biomass which can be co-fired with coal. Additionally, torrefied wood (either densified or not) can be used in conventional residential pellet stoves, direct combustion systems, or entrained-flow gasification systems.

Table 13. Bulk and energy density changes during torrefaction.

Stock	Bulk Density	Energy Density
Wood chips	400 kg/m^3	6.5 GJ/ton
Torrefied wood chips	300 kg/m^3	7.5 GJ/ton
Wood pellets	700 kg/m^3	11 GJ/ton
Torrefied pellets	800 kg/m^3	16 GJ/ton

Adapted from:
http://www.agrireseau.qc.ca/references/32/presentations_guelph/2Torrefaction%20-%20Pros%20and%20Cons%20By%20Mathias%20Leon%20UoG.pdf

Table 14. Torrefied wood pellets compared to coal.

Parameter	Coal	Torrefied Pellets
Heating value	25 GJ/ton	22 GJ/ton
Ash	10%	3%
Sulfur	3%	0.10%
Nitrogen	1.50%	0.20%
Chlorine	0.05%	0.01%

Adapted from:
http://www.agrireseau.qc.ca/references/32/presentations_guelph/2Torrefaction%20-%20Pros%20and%20Cons%20By%20Mathias%20Leon%20UoG.pdf

1.13. Bioenergy - Wood Fuel Pellets and Compressed Logs

In the process of pelletizing and compression, woody biomass is densified. This process increases the energy density of the woody biomass. Because the biomass is pre-dried in kiln dryers beforehand, water and some portion of the total VOC content are volatilized. Consequently, the pellets release fewer particulates, ash, and soot when burned and comply with indoor air quality regulations. During production, the raw logs are processed into wood chips. The chips are kiln-dried, and processed again into coarse sawdust. The sawdust is fed into a hydraulic press where it is compressed without the addition of adhesives or other chemicals. The compressed sawdust is then extruded into various molds to produce pellets. Alternatively, it may be formed into continuous logs and cut to a desired length. Because the material is formed using only compressive force, any defective products can be broken down and recompressed. Due in part to this ability to recycle all by-products and in part to the purely mechanical production, densification of woody biomass into fuel pellets is a very efficient process. If starting with bone-dry wood chips, the loss rate is around 10%.

2. Emergent (0-5 years) SDW Processing Technologies

2.1. Engineered Wood Products - Wood-thermoplastic Composite Manufacturing

Wood-thermoplastic composites are made from a mixture of wood fibers and polymers. The woody biomass is chipped, pulped, dried, and mixed with thermoplastic resins such as polyprolyne, polyethylene or polystyrene [25-30]. The composite material retains many of the characteristics of thermoplastic polymers, but can incorporate up to 70% cellulose content. Structurally, they have mechanical behavior similar to polymers. They have a lower strength and stiffness than wood, and they experience time and temperature-dependent behavior (they are viscoelastic materials). However, since the wood-thermoplastic composites are extruded, they have the advantage of being easier to form. Additionally, though they are less strong than lumber, they are capable of utilizing defective (cull) logs and small diameter growth with no adverse effects to the quality or mechanical behavior of the finished product. In addition to being viable end uses for small diameter wood, wood-thermoplastic composites can also incorporate post-consumer recycled plastics. Wood-thermoplastic composites are frequently used in outdoor applications where moisture and sunlight would negatively impact traditional lumber products. The composites are made into outdoor decks, railings, fences, cladding and siding, molding and trim, window and door frames, and furniture. They can also be used for signage, although ASTM and AASHTO standards do not permit these signs to be used along roadways.

2.2. Engineered Wood Products - Laminated I-beam and I-joist Manufacturing

Laminated I-beams and I-joists are a specific application of wood composites. Typically, wood I-beams and I-joists are made from plywood, oriented strandboard (OSB), sawn lumber, or laminated veneer lumber (LVL). Because different parts of an I-beam (or I-joist) carry different loads and experience loading at different rates, the web and flange components are formed separately and connected with an adhesive. The web is manufactured from plywood or OSB, whereas the flanges are made from lumber or LVL. This is a particularly valuable end-use for small diameter wood because wood I-beams and I-joists have been certified as structural members and are currently being used in residential and commercial construction. Higher grade (higher load rating for industrial or heavy commercial construction) I-joists are usually custom made by hand, whereas regular grade I-joists more typically used for small commercial or residential construction are made on automated production lines. The demand for I-beams and I-joists is very intimately tied to the construction industry; as a result, it can be highly variable.

2.3. Engineered Wood Products - Glued-Laminated Wood Trusses Manufacturing

Glued-laminated wood (Glulam) is a composite product made by joining sheets of lumber with adhesive to form larger, continuous structural-grade wood members [31-32]. One advantage of utilizing small diameter wood for Glulam production is that the process can utilize smaller lengths and smaller diameters to produce a valuable end product with a multitude of structural applications. Rather than representing planes of weakness, discontinuities (breaks between one lumber face and the next) are actually stronger due to the wood-adhesive bond. Glulam is used for large, generally heavier, structural applications such as for floor beams, arches, and garage door headers. During production, lumber is kiln-dried and graded. Each lumber piece is connected to the next with end-joints to increase the overall length of the member. Finger joints are most common. These are machined into the lumber ends and the two lumber pieces are saturated with a resin such as melamine-formaldehyde. The resin is allowed to cure under pressure. Once one Glulam member is made to the required length, it is used as a template for other members. The successive pieces are similarly joined with adhesive, cured under pressure, and finished.

2.4. Liquid and Gaseous "Drop In" Biofuels - Catalytic Hydropyrolysis

Catalytic Hydropyrolysis (or hydroconversion) differs from conventional pyrolysis in that it uses catalysts and hydrogen, in addition to heat, to convert biomass into synfuel [33]. Without the addition of hydrogen, the synfuel produced by conventional pyrolysis methods has a low hydrogen/carbon ratio, making the product less desirable as a "drop in" fuel (R100) or a high quality blend stock (R50 and above). Although woody biomass is rich in carbon, it has little hydrogen. Water evaporation (H_2O) during heating further reduces the availability of hydrogen [34]. When this hydrogen deficiency is overcome by the injection of supplementary hydrogen gas during pyrolysis, hydrocarbon production is improved. The possibility of converting woody biomass (lignin) to organic carbon – particularly as a surrogate for hydrocarbon fuels – has been studied at length. Lautsch and Freudenberg, in 1943, were the first to successfully demonstrate that lignin in an aqueous alkaline solution could be converted to produce phenolic components [35]. Currently, a typical high-end conversion rate is on the order of 86-92 gallons of synfuel per ton of woody biomass. For wood, the estimated efficiency is about 26-46%. The high cost of required machinery and the relatively low conversion efficiency continue to make small-scale catalytic hydropyrolsysis uneconomical.

2.5. Liquid and Gaseous "Drop In" Biofuels - Mobile Pyrolysis

Mobile pyrolysis units are promising technologies in the sense that they promise to overcome a critical limitation in the economic viability of restorative thinning projects. High transportation costs of low-value slash biomass are frequently a limiting factor in subsidized restoration. Mobile pyrolysis not only offers an outlet for this low-value biomass, but brings the conversion process directly on-site. Mobile pyrolysis units currently on the market typically have a modified chain flail dryer which can be used to pulverize the biomass as well as to dry it to the required moisture content. Once the biomass has been prepared, it can be fed into an auger pyrolysis fluid bed system or into a combination fluid bed/retort combustion system and biochar retort. The choice of systems and operating temperatures determines whether the biomass is converted primarily into synthetic gas and biochar, or whether bio oil is extracted. The estimated efficiency of this process is on the order of 50%.

2.6. Liquid and Gaseous "Drop In" Biofuels - Fischer-Tropsch Processing for Liquid Fuels

The Fischer-Tropsch process relies on a sequential conversion of a carbon source (s.a. woody biomass) into synthetic liquid fuel via preliminary conversion to synthetic gas. Transition metals, such as cobalt and iron, are most commonly used as catalysts. While the Fischer-Tropsch process is not in itself an emergent technology, its application for biomass-generated liquid fuels is relatively novel. As with most forms of "biogas", syngas produced from wood-powered systems must be 'scrubbed' of impurities. If left untreated, the particulate matter present in biogas reduces the useful life of turbines and capture efficiencies. This process has arrived at maturity from a technical standpoint, but commercialization at a scale appropriate for wide-spread application in forest restoration projects remains a challenge. Similarly to other energy technologies, capture efficiency is increased by direct utilization of thermal output, rather than by cycling exhaust heat back through the system. Depending on the scale of operation, demand for local heat generation may not be sufficient to justify investments in a combined heat and power system. However, co-location with other wood product business – s.a. kiln dryers at sawmills or pellet plants – may decrease transportation costs and drive up the economic viability of both processing options. An average conversion rate is 50 gallons of synfuel to each ton of woody biomass. The efficiency of this process is about 50-60% when thermal output is used in a combined heat and power application. Efficiency is lower for all-electric units.

3. Next-Generation (5+ years) SDW Processing Technologies

3.1. Bioenergy - Fuel Cells

As R&D efforts into the commercialization of fuel cell technology continue to advance, woody biomass may have a role to play in powering the next generation of fuel cells [36-37]. Fuel cells demonstrate a high sensitivity to sulfur. Because syngas generated from woody biomass via pyrolysis or gasification contains negligible sulfur content, it could be a viable alternative to coal-powered gasification. Syngas produced from woody biomass is also more highly volatile and reactive than that produced from coal. Whereas wood's low energy density is a drawback for direct combustion and other current or emerging bioenergy processing methods, the lower temperatures and pressures are a definitive advantage for powering fuel cells [38]. Although the syngas will need to be purified before it can be used to power fuel cell systems, the additional processing is not substantially more resource-intensive than that required currently for electric production. Recent efforts by Jain *et al*., Ahn *et al*., and others have focused on studying the feasibility of utilization of various woody biomass feedstocks in direct carbon fuel cell systems. Jain *et al*. analyzed the performance of hybrid direct carbon fuel cells powered by waste medium density fiberboard (MDF). The authors find that although limitations remain, the technology is sufficiently promising to pursue further.

3.2. Integrated Nanomaterial and Energy Production

A major obstacle in the conversion of woody biomass to various types of biofuels is the difficulty of degrading lignin [39]. This limitation could be turned into an opportunity by the integrated co-production of nano-fibrillated cellulose (NFC) and ethanol. In the process of converting woody biomass to ethanol, the cellulose and hemicellulose fraction is hydrolyzed into sugar and fermented into ethanol. This degradation can be accomplished physically (mechanically), chemically, or biologically (using bacteria or enzymes as biological catalysts). Lignin makes up the remaining 10-35% of the woody biomass fraction, and is not convertible to ethanol. However, the residues of ethanol production contain a large fraction of cellulose, lignin, and other extractives which currently remain largely unused despite having intrinsic value. Recent research into the integrated production/recovery of ethanol and nanomaterials has shown that efficiency increases because a substantially smaller fraction of the biomass is discarded, and the microbial/ enzymatic activity predigests the cellulose to a more appropriate scale for nanofiber recovery. Several studies have been successful as a bench-scale proof of concept, though no pilot-scale tests have been accomplished to date [40-41]. More generally, a new generation of lignocellulosic materials may open up many doors for valuable end uses for woody biomass [42].

3.3. Biobased Products

Lately, there has been much interest in research concerning the transformation of lignoocellulosic biomass into a variety of biobased products [43-49]. In 2004, the DOE identified 12 building block chemicals that can be produced from sugars via biological or chemical conversions. The 12 building blocks can be subsequently converted to a number of high-value bio-based chemicals or materials. Building block chemicals, as considered in that analysis, are molecules with multiple functional groups that possess the potential to be transformed into new families of useful molecules. The 12 sugar-based building blocks are 1,4-diacids (succinic, fumaric, and malic), 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, asparatic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol [50].

3.4. Chemicals

Woody biomass can be used to extract many organic chemicals [42, 51-57]. In addition to the syngas, synfuel, and bio-oils mentioned earlier, woody biomass can be processed into charcoal, phenolic oils, and methanol using pyrolysis. Hydrolysis can be used to create levulinic and lactic acid. Both can be used as building blocks for multiple other end uses. Levulinic acid can be used in the manufacturing of some pharmaceuticals, plastics, and biofuels.

Table 15. Chemical Production – Composition.

Component	Softwoods	Hardwoods
Cellulose	40 – 44%	43 – 47%
Hemicellulose	25 – 29%	25 – 35%
Lignin	25 – 31%	16 – 24%
Extractives	1 – 5%	2 – 8%
Ash	< 1%	< 1%

* Adapted from: John Shelly, UC Berkeley Cooperative Extension, Presented Bioenergy Conf. 3MAR06 at Denver.

Appendix B Citations

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Appendix C: Economic Viability Model Scenarios (B-E)

Scenario B: Four Forest Restoration Initiative – 300,000 acres

Table 16. Model output for a 300,000 acre Four Forest Restoration Initiative project scenario

Thinning area and harvest timeframe					
Restorative Thinning Area		**300,000**		**acres**	
Harvest Timeframe		**20**		**years**	
Summary of industry build-out					
Industry	**Capital**	**No.**	**∑ Capital**	**Net Sales**	**Jobs**
Logging	$ 2M	4.0	$ 8M	$ 17M	48
Small-diameter sawmill	$ 10M	1.5	$ 15M	$ 145M	60
Wood Fuel Pellets	$ 20M	0.5	$ 10M	$ 4.9M	11
Central Biomass Energy	$ 60M	0.6	$ 36M	$ 19.7M	12
Distributed Generation	$ 12M	4.0	$ 48M	$ 17.5M	24
		TOTAL	**$ 117M**	**$ 204M**	**155**

Restorative thinning of 300,000 acres over the course of 20 years in the 4FRI area will require about 4 logging crews working simultaneously. These crews are expected to require about $8 million worth of capital investment to outfit, and generate about twice that, resulting in $17 million in net sales over the 20-year period.

Given a total capital investment of $15 million, small-diameter saw mills are expected to generate $145 million worth of sales over the course of the 20 year contract period. Wood fuel pellet plants, central biomass energy facilities, and combined heat and power units for distributed generation do not recover their capital investments through net sales over the course of the contract time frame. Therefore, while the overall scenario suggests over $204 million in sales may be possible, the majority of net sales are generated by saw mill production. Biomass energy capital investments amount to 3 times the capital required for a single sawmill, yet result in a fraction of the revenues. It should be noted, however, that this represents the necessity of removing all slash biomass from the forest. Given current biomass prices, a more economically viable option may be burning these low-value residues. Overall, such a configuration of businesses could generate 155 jobs.

Scenario C: Four Forest Restoration Initiative – 100,000 acres

Table 17. Model output for a 100,000 acre Four Forest Restoration Initiative project scenario

Thinning area and harvest timeframe					
Restorative Thinning Area			**100,000**		**acres**
Harvest Timeframe			**10**		**years**
Summary of industry build-out					
Industry	**Capital**	**No.**	**∑ Capital**	**Net Sales**	**Jobs**
Logging	$ 2M	3.0	$ 6M	$ 12.7M	18
Small-diameter sawmill	$ 10M	1.1	$ 11.3M	$ 109M	23
Wood Fuel Pellets	$ 20M	0.4	$ 7.7M	$ 3.7M	4
Central Biomass Energy	$ 60M	0.5	$ 27M	$ 14.7M	5
Distributed Generation	$ 12M	3.0	$ 36M	$ 13.1M	9
		TOTAL	**$ 88 M**	**$ 153 M**	**59**

Restorative thinning of 100,000 acres over the course of 10 years in the 4FRI area will require about 3 logging crews working simultaneously. These crews are expected to require about $6 million worth of capital investment to outfit, and generate about twice that, resulting in $13 million in net sales over the 10-year period.

Given a total capital investment of $11.3 million, small-diameter saw mills are expected to generate $109 million worth of sales over the course of the 10 year contract period. Wood fuel pellet plants, central biomass energy facilities, and combined heat and power units for distributed generation do not recover their capital investments through net sales over the course of the contract time frame. Therefore, while the overall scenario suggests over $153 million in sales may be possible, the majority of net sales are generated by saw mill production. Biomass energy capital investments amount to 3 times the capital required for a single sawmill, yet result in a fraction of the revenues. It should be noted, however, that this represents the necessity of removing all slash biomass from the forest. Given current biomass prices, a more economically viable option may be burning these low-value residues. Overall, such a configuration of businesses could generate 59 jobs.

Scenario D: Prescott National Forest – Ponderosa Pine

Table 18. Model output for a Ponderosa Pine thinning Prescott National Forest project scenario

Thinning area and harvest timeframe					
Restorative Thinning Area			**71,609**		**acres**
Harvest Timeframe			**10**		**years**
Summary of industry build-out					
Industry	**Capital**	**No.**	**∑ Capital**	**Net Sales**	**Jobs**
Logging	$ 2M	2	$ 4.0M	$ 8 M	12
Small-diameter sawmill	$ 10M	0.8	$ 7.5M	$ 72M	15
Wood Fuel Pellets	$ 20M	0.3	$ 5.1M	$ 2.4M	3
Central Biomass Energy	$ 60M	0.3	$ 18M	$ 10M	3
Distributed Generation	$ 12M	2	$ 24M	$ 9M	6
		TOTAL	**$ 58.6M**	**$ 101M**	**39**

Restorative thinning of 71,609 Ponderosa Pine-dominated acres over the course of 10 years in the Prescott National Forest area will require about 2 logging crews working simultaneously. These crews are expected to require about $4 million worth of capital investment to outfit, and generate about twice that, resulting in $8 million in net sales over the 10-year period. Given a total capital investment of $7.5 million, small-diameter saw mills are expected to generate $72 million worth of sales over the course of the 10 year contract period. Overall, such a configuration of businesses could generate 39 jobs.

Scenario E: Prescott National Forest – All Biomass

Table 19. Model output for an all-biomass thinning Prescott National Forest project scenario

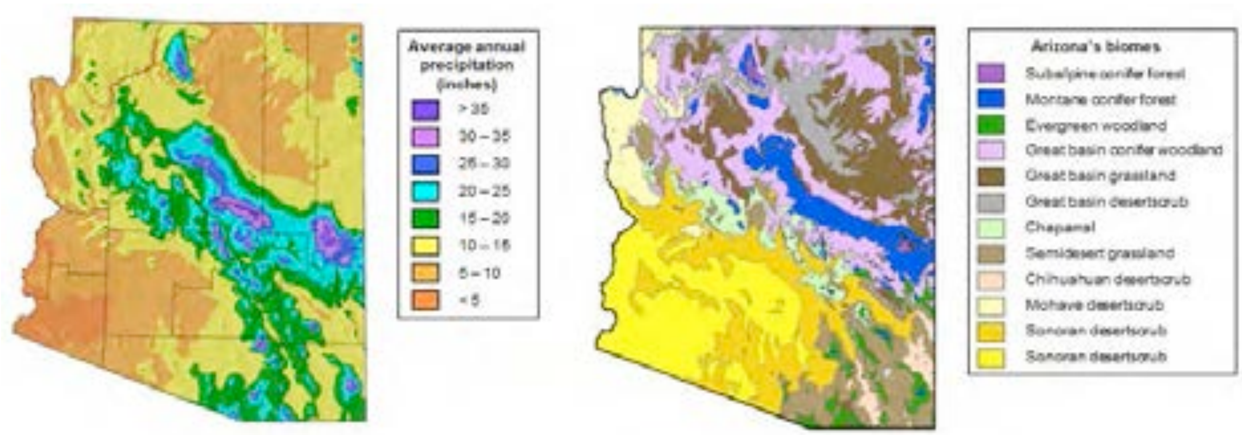
Thinning area and harvest timeframe					
Restorative Thinning Area			141,000		acres
Harvest Timeframe			10		years
Summary of industry build-out					
Industry	**Capital**	**No.**	**∑ Capital**	**Net Sales**	**Jobs**
Logging	$ 2M	4	$ 8M	$ 12M	24
Small-diameter sawmill	$ 10M	1	$ 5M	$ 24M	18
Wood Fuel Pellets	$ 20M	0	$ 0M	$ 0M	0
Central Biomass Energy	$ 60M	1	$ 60M	$ 29M	8
Distributed Generation	$ 12M	6	$ 72M	$ 25M	18
		TOTAL	**$ 145M**	**$ 90M**	**68**

Restorative thinning of 141,033 acres over the course of 10 years in the Prescott National Forest area will require about 4 logging crews working simultaneously. These crews are expected to require about $8 million worth of capital investment to outfit, and generate less than twice that, resulting in $12 million in net sales over the 10-year period. Restorative thinning of all biomass assumes that the area targeted for restoration will be analogous to the percentage of the 4FRI area targeted by mechanical thinning contracts.

Although restorative thinning in the Prescott National Forest can be accomplished with a smaller total expenditure of capital, because the biomass has lower value end uses, the net sales are also lower. The contribution of lumber sales which helped to drive up the total net sales in previous scenarios is dampened because we the abundance of Ponderosa Pine is much lower. Overall, such a configuration of businesses could generate 68 jobs, but result in a net loss.

Scenario Discussion

Differences in physical geography (Figure 10) map to differences in biomes. In turn, these correlate to differences in vegetation distribution, and in the context of a restorative thinning study, to material availability (Figure 11).



Credit: Jeremy Weiss, University of Arizona, Adapted from Brown DE (1994) Biotic Communities: Southwestern United States and Northwestern Mexico, University of Utah Press, Salt Lake City, UT. Source for average annual precipitation, 1971-2000: PRISM Group, Oregon State University (2006).

Figure 10. What role do physical geography and ecology play in the economic viability of restorative thinning?

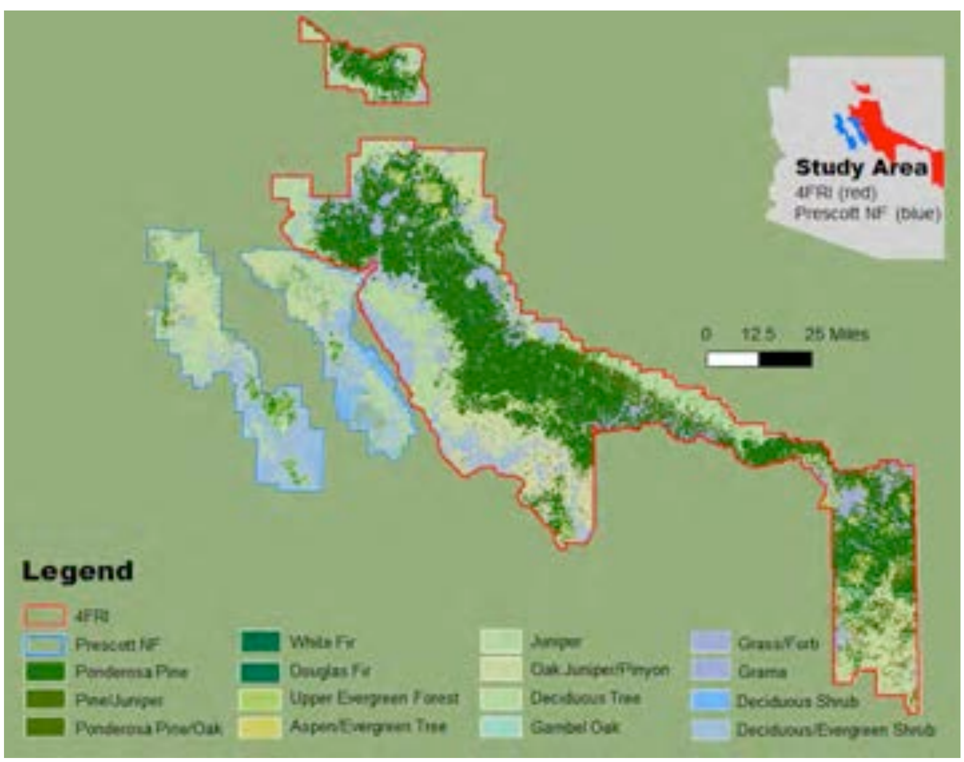


Figure 11. Comparison of vegetation distributions in Prescott National Forest and 4FRI

The generalizable model developed over the course of this project is capable of resolving these differences, by providing the means to parameterize timber and slash biomass availabilities accordingly. Using Scenario A (900,000 acres in the Four Forest Restoration Initiative region) and Scenario E (all biomass in the Prescott National Forest), we present a comparison to illustrate the manner in which observed differences in vegetation distribution within the two study areas (Figure 11) may be expected to translate to the economic viability of restorative thinning projects in each region.

In Figure 12, total required capital investment is plotted by industry type (logging crews, small-diameter sawmills, pellet plants, central biomass to energy plants (B2E), and distributed generation combined heat and power (CHP). These numbers, in million USD, show the capital required for outfitting the logging crews, and building sawmills, pellet plants, biomass to energy, and local combined heat and power unit.

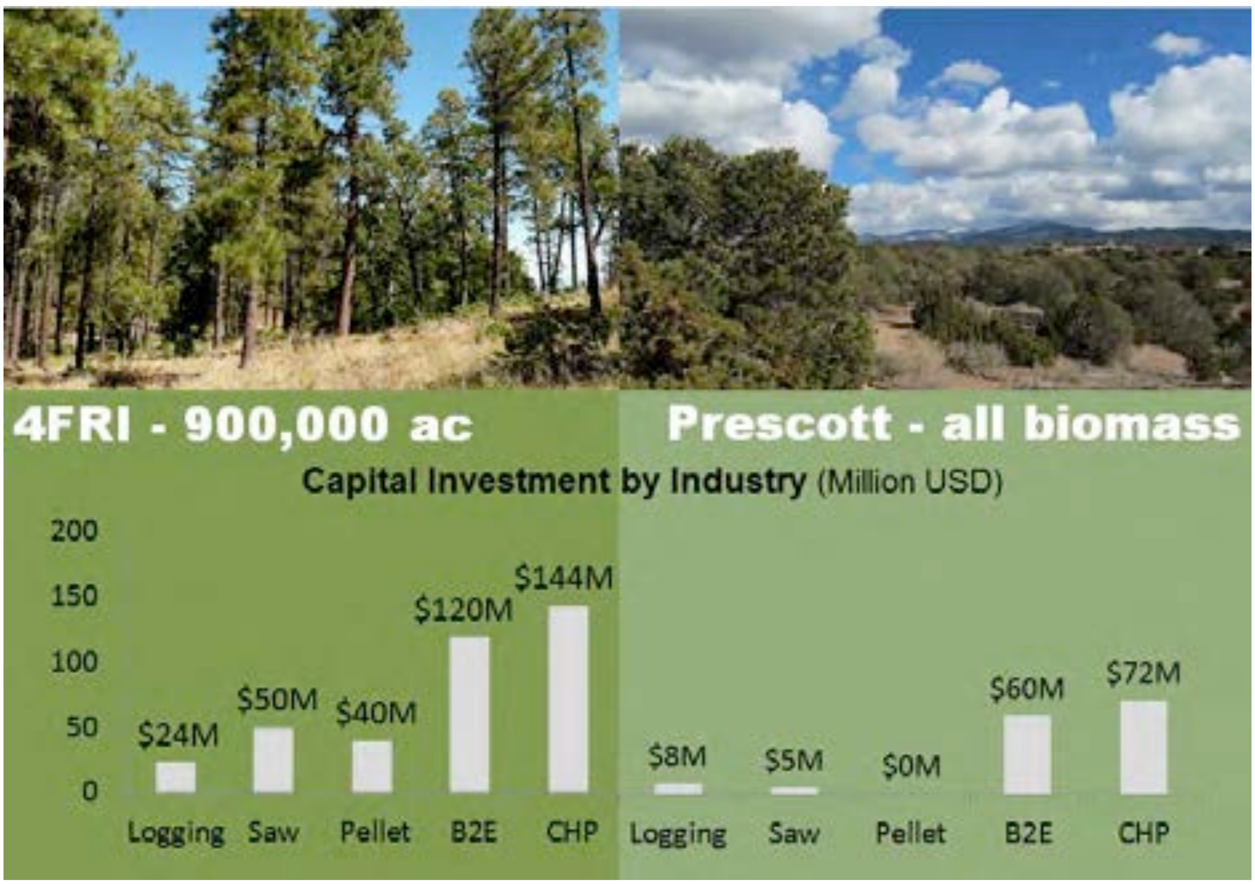


Figure 12. Model-output capital investment requirements by industry sector

In Figure 13, projected net sales (over equal project periods) are plotted in a similar manner. This figure, in particular, makes evident the role site-specific characteristics (i.e., vegetation distribution – see Figure 11) play in driving or impeding an economically viable route to unsubsidized restorative thinning. Prescott National Forest requires less capital investment to restore due to its substantially smaller acreage (Figure 11). However, because the vast majority of Prescott NF biomass is composed of grasses, shrubs, and forbs, it has lower-value end uses. Consequently, net sales are substantially lower than in the Four Forest Restoration Initiative study area, dominated by Ponderosa Pine (Figure 11). The strength of a viable unsubsidized scenario in the later is driven by the high value of lumber and lumber products.

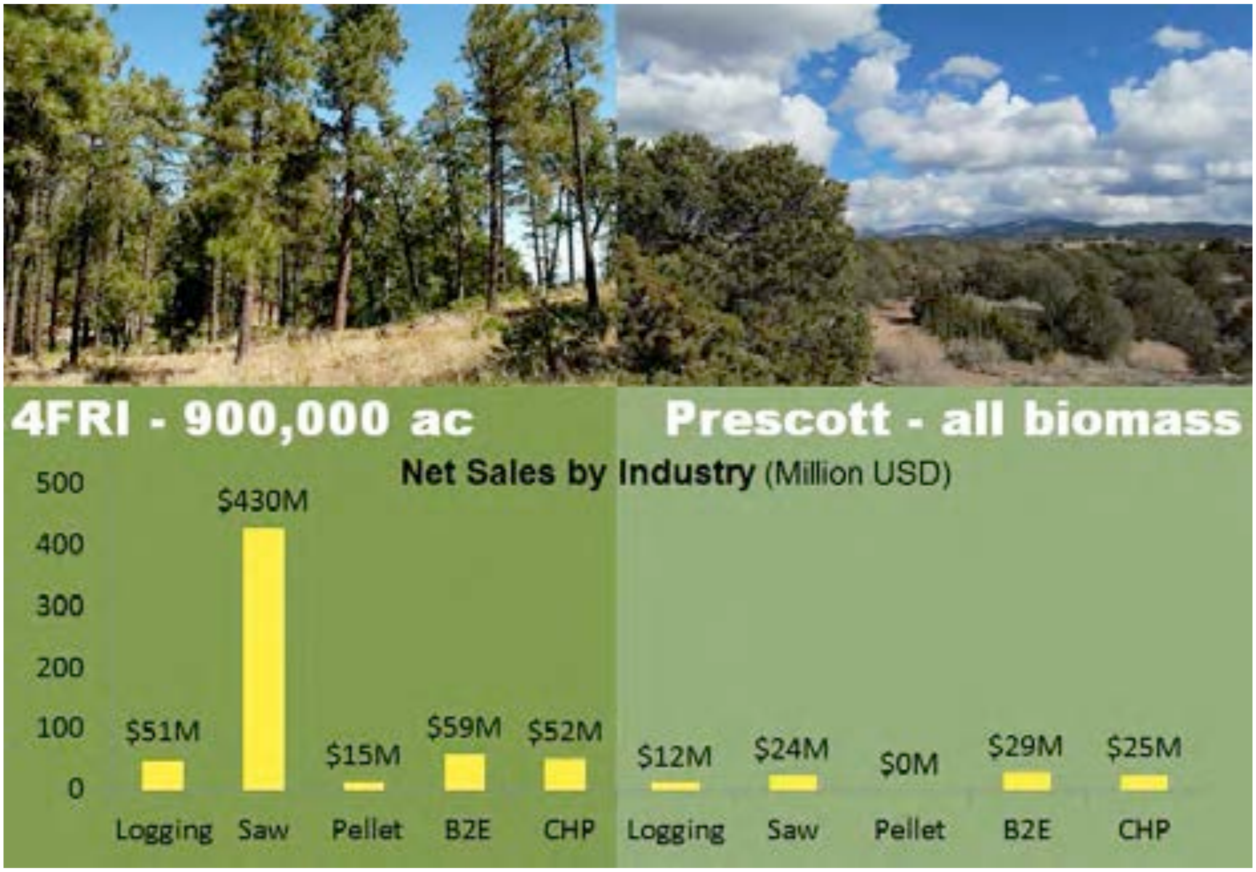


Figure 13. Model-output net sale estimates by industry sector