Opportunities and Barriers for Arizona to Supply Wood Fiber to South Korean Renewable Energy Markets

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Executive Summary

Across northern Arizona, forests are over-stocked with small-diameter, low value trees. Due to the unhealthy nature of these forests, communities are in danger of extremely destructive wildfires, and need restoration to pre-European settlement conditions. Restoration projects can reduce wildfire risk and restore forest health. Over 400,000 acres of federal lands have been approved for restoration treatments across northern Arizona through the National Environmental Policy Act (NEPA). An overabundance of wood fiber is being generated through these forest restoration projects. Markets for biomass wood fiber from restoration activities in Arizona are often located long distances from treatment units. Transportation costs are a hurdle to increasing the pace of restoration across Arizona's forests. This study identified opportunities and barriers for exporting wood fiber from Arizona to renewable energy markets in South Korea. Objectives of the project were to:

(1) Ascertain the desirable specifications (wood chip size, moisture content) of the wood fiber that is being procured by the renewable energy markets in South Korea,

(2) Determine chain-of-custody requirements for wood fiber being imported into South Korea,

(3) Identify costs associated with the transportation of wood fiber from northern Arizona to the Port of Long Beach in California, and

(4) Perform a SWOT analysis, to examine the strengths, weakness, opportunities, and threats (SWOT) of the wood fiber market in South Korea that primarily focuses on the renewable energy sector.

The South Korean government has set mandates for offsetting coal in energy generation with renewable fuel sources, which includes woody biomass and wood heating pellets. The mandates parallel policies implemented in the European Union, which is now a significant export market for wood heating pellets manufactured in the southeastern U.S. Anticipated demand for wood fiber would exceed the capacity of South Korea's natural resources to sustainably supply the raw material. Beneficiaries of the project include the businesses that process wood fiber and the agricultural producers that depend upon federal lands for grazing.

In South Korea, the National Forest Research Institute provides specifications and quality standards for wood product imports. Wood fiber importers for renewable energy markets are most concerned with specifications of fuel wood chips and pellets. These specifications are applied to foreign imported wood fiber from all regions of the world.

Research on chain-of-custody requirements identified the United States Department of Agriculture (USDA) as a monitor of international trade in animal and plant products, including forest products and biomass. International phytosanitary standards provide for a safe and predictable trade system. The United States participates in international standard-setting organizations to promote safe and sustainable trade as well as protection from introduced exotic invasive pests. The specifications for pine wood chips mandate that a Phytosanitary Certificate (PC) and an Import Permit (IP) are required and that imports without required documentation will be refused.

Transportation logistics and costs are a key component in the export of wood fiber to South Korea. Many transportation cost variables exist, and accurately defining these costs is difficult. Instead, transportation methods were ranked based on results from pilot projects and input from subject matter experts. Based on the results, we have identified that direct loading of wood chips into containers at a railhead, will likely be

the least expensive transportation method. However, functioning railhead capacity in northern Arizona is limited at this time. Transporting the biomass material by tractor-trailer to Phoenix, Arizona or Snowflake, Arizona, followed by loading onto railcars is the only option in the near-term.

Highlights of the SWOT analysis showed significant uncertainty as well as opportunity. The key strength to the South Korean biomass fuel market is that it is large and growing. Fuel wood pellet demand in South Korea has been increasing since Renewable Portfolio Standards were introduced in 2012. Industry analysts project consumption of six million metric tons of biomass in 2021. Government support through renewable energy production mandates make the market attractive to suppliers and investors. Wood chip prices in South Korea can be double the price in the U.S. Opportunities exist for new suppliers to enter the marketplace, due to the relatively relaxed wood fiber quality standards.

In South Korea, market weaknesses include the immature market fundamentals and volatile prices of fuel wood chips and wood pellets. RPS are reviewed and revised every three years. Policy uncertainty and a lack of guarantees and long-term offtake agreements discourage investment in supply chains. Potential policy changes to wood fiber specifications and statutory requirements could add costs and regulatory hurdles. In Arizona, potential changes to federal land management policy and forest products industry competition represent obstacles.

In addition to South Korea, Japan is also a potential target for an Arizona business supplying wood fiber to Asian markets. From a logistics standpoint, the transportation methods would be very similar to reaching the export markets in South Korea. Like South Korea, government leaders in Japan also support the use of woody biomass to produce renewable energy. Japanese renewable energy policy is akin to a Feed-in Tariff program that provides for extended guarantees to producers and suppliers entering into long-term offtake agreements. This policy can be more attractive to wood fiber suppliers than South Korea's RPS, because of the price guarantees. The wood pellet prices in the Japanese market are significantly higher as well. The premium price paid by Japanese producers is due to reliable partners and sustainable product supply chains. Expansion of the Asian biomass fuel market as it matures will open significant opportunities for international suppliers.

The size and projected growth of the biomass energy markets in South Korea are enticing to U.S. suppliers, despite the market uncertainties. With economically efficient transportation options and strong stable partners, Arizona could supply wood fiber to Asian markets. Finding utilization outlets for the by-products of forest restoration activities is increasingly important. With planned increases in forest restoration across northern Arizona, this importance will grow.

Shipping woody fiber via railroad and marine transport to South Korea can be an economically viable solution to Arizona's forest restoration biomass issues. Arizona could supply wood fiber to renewable energy markets in South Korea or Japan in an economically efficient and sustainable manner, by developing long-term offtake agreements with Asian buyers.

The South Korean renewable energy market is immature but expanding and showing potential for future growth. Wood fiber prices in South Korea can be more than double the price in the U.S., on a per ton basis. The size, government policy support and market potential make shipping Arizona wood fiber to South Korea an attractive option. However, the instability of the market and insecurity of South Korean policy makes significant investment into this market risky. Based on our research, there are opportunities

for Arizona to supply wood fiber to South Korean renewable energy markets, but logistical hurdles exist with current infrastructure in northern Arizona.

Introduction

In 2012, South Korea implemented a renewable energy portfolio standard that mandates power plants with generating capacity of 500 megawatts (MW) and greater to incorporate renewable energy into their portfolios (International Energy Agency 2019). The mandated target is 10 percent replacement of coal with renewable fuels by 2023. Based upon strategies implemented by electrical generating facilities in the European Union, South Korea has sought to replace coal with raw wood chips and wood fiber that has been extruded into wood pellets. For 2018, the value of wood pellets imported into South Korea, from all global partners was $522 million (M) (USDA 2020D). Vietnam led in export sales of wood pellets, to South Korea, at $333M followed by Malaysia and Thailand with export values of $87.1M and $45.7M, respectively. The 2018 value of wood pellets exported from the United States to South Korea was $2.2M. This is a significant drop from the highest export value of $10.2M in 2014, however exports from the U.S. to South Korea have been slowly increasing since a low point in 2016. Industry analysts identified the biggest cause of this steep decline in U.S. exports was due to increasingly lower-cost wood pellets from other Asian trading partners and competition from other types of biomass such as palm kernel shells (Campilho 2017). However, mounting pressure from environmental groups regarding sustainability is pushing South Korea to implement chain-of-custody requirements on imported wood fiber to ensure the material is not originating from environmentally sensitive regions. Much of the increased concern regarding sustainability is that Asian markets are projected to surpass the European Union in the annual volume of imported wood fiber for energy generation (Parton 2019). Given that forest and grassland restoration treatments on federal lands must go through the National Environmental Policy Act (NEPA) process in the U.S. and that all exported forest products are monitored by the USDA Animal and Plant Health Inspection Service, validating the sustainability of exported wood fiber from Arizona should be straightforward.

Wood fiber brokers from South Korea did visit Arizona in 2014, but unfortunately were not able to solidify contracts for woody biomass or wood pellets with in-state producers. During this period, producers were barely able to supply their domestic customers and were hesitant to take additional orders due to the lack of long-term timber sale agreements with the U.S. Forest Service.

This paradigm changed in 2015 with the completion of several Environmental Impact Statements (EIS) for landscape scale forest and grassland restoration projects across northern Arizona. Forest harvesting capacity and businesses have since increased. In federal fiscal year 2017 a total of 13,108 acres were treated which was a 33-percent increase from the number of acres treated in 2012 when South Korea first implemented a renewable energy portfolio standard (USDA 2018).

Currently, in northern Arizona, there are 430,261 acres with NEPA approval for the mechanical removal of small-diameter ponderosa pine (*Pinus ponderosa)*, to restore timber stand densities towards pre-settlement conditions (USDA 2015A). In woodland areas, 158,000 acres of juniper reduction treatments have been approved for the purpose of grassland restoration (USDA 2015B). The location of the NEPA approved acres and wood processing facilities are presented in Figure 1.

With the increased forest harvesting capacity and available raw wood materials, Arizona is poised to become a significant producer of wood fiber. A significant volume of wood fiber needs to be available in

order to move the economies of scale so that exporting wood fiber from Arizona to South Korea becomes economically feasible.

Arizona's forest products sector consists of two mulch producers, numerous sawmills and fuelwood manufacturers, a single wood heating pellet manufacturer, and one biomass fueled electrical generating plant. Collectively these businesses are the main utilization outlets for the by-products of the forest and grassland restoration projects. Up until late 2017, there had been two wood pellet manufacturers in Arizona. The second facility curtailed operations due to a softening of local markets attributed to mild winters and a subsequent reduced demand from residential pellet stove owners.

The average yield of woody biomass from forest restoration projects in Arizona is 25 tons per acre treated (Rappold 2019). Woody biomass is defined as the small-diameter logs from trees less than 6 inches diameter at breast height, branches and tops of trees. Grassland restoration projects on average yield four to five tons of biomass per acre, mostly from juniper species (*Juniperus spp.*). The by-products of the forest and grassland restoration projects are ideal products for direct firing in boilers for electricity generation. Businesses have also successfully used these whole-tree chips to produce industrial wood heating pellets, which offer some handling benefits over raw wood chips (Dogwood 2012). The smaller residential heating pellets are typically manufactured using white wood chips that are generated from the processing of debarked logs into lumber at sawmill facilities.

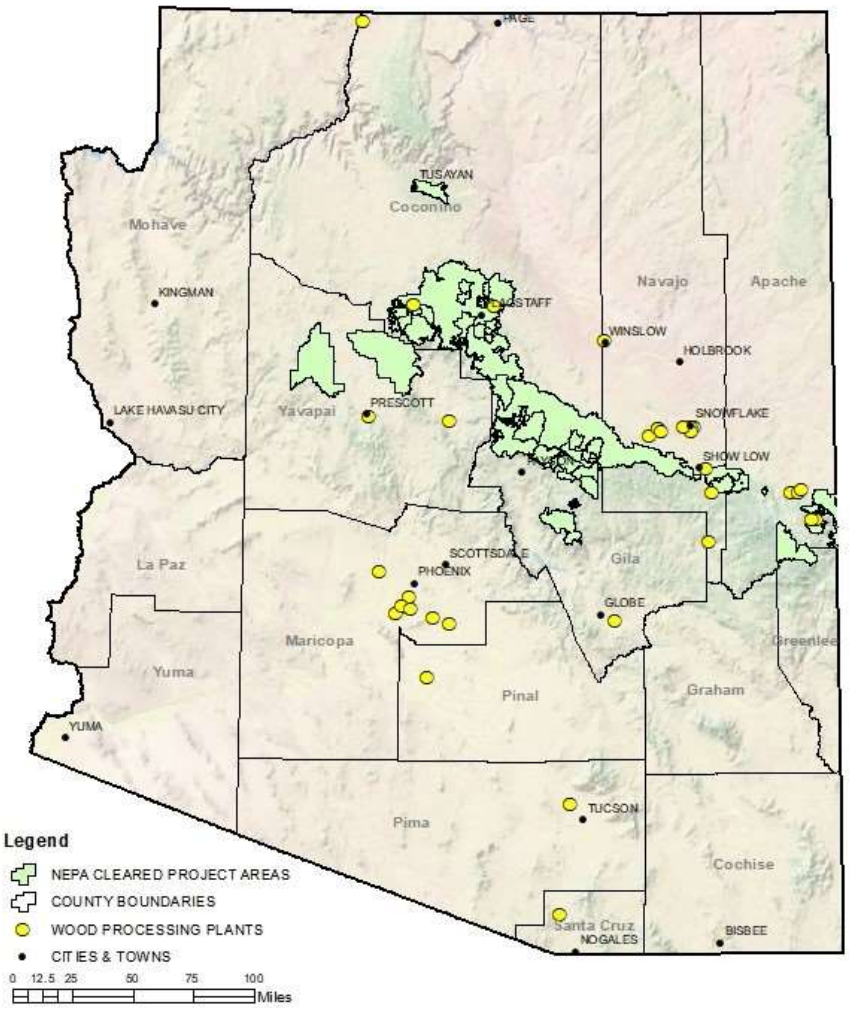

Figure 1. Identification of NEPA cleared project areas, planned project areas, and wood processing plants in Arizona. Source: The University of Arizona

Arizona is home to the world's largest contiguous ponderosa pine forest that extends from the border of New Mexico to north of the Grand Canyon. In terms of exports of forest products, Mexico is Arizona's biggest trade partner. In 2018, the value of solid sawn lumber processed in Arizona and exported to Mexico was $3.7M, down from a high of $13M in 2016 (USDA 2020D). For the year 2018, wooden pallets accounted for $1.2M and exports of wood heating pellets to Mexico were negligible. Expanded export markets will mutually benefit Arizona's forest industries and

the numerous agricultural producers that depend upon healthy forests and grasslands for cattle grazing. In federal fiscal year 2016, Arizona's national forests and grasslands supported a livestock count of 158,393 that included cattle, horses, sheep, and goats (USDA 2017A). Current statistics maintained by the University of Arizona's Extension Forestry program identifies there are eleven sawmills in Arizona and ten logging companies. Regarding employment, agriculture supports 33,975 jobs in Arizona and the timber sector accounts for 7,315 (Headwaters 2018).

Biomass as a renewable fuel source has advantages over fossil fuel energy production. Many nations have set a goal to reduce carbon dioxide emissions from power production. Emissions from the use of biomass as fuel are considered to be minimal or zero due to the carbon dioxide recycled and captured during the photosynthetic process of the tree (Qian et al. 2014). Carbon neutrality can be achieved when harvested forests are replanted or regenerate and return to original levels of biomass (Schlesinger 2018). Energy production from sustainably produced biofuels produces less atmospheric pollution than fossil fuel energy production (Murray 2017). Biomass as fuel produces significantly less nitrous oxide and sulfur dioxide than most fossil fuels (Qian et al. 2014). In most instances, wood pellets can be burned in coal fired plants with only slight modifications, and output losses from switching from coal to biomass are low (Strauss 2017). Fuel wood pellets produce a lower energy output on a fuel-weight basis, than coal. Most countries that are using biomass as a renewable fuel have policies supporting coal to wood pellet conversion (Strauss 2017). In some instances, due to the higher price of biomass as a fuel source, government policy intervention is necessary to encourage compliance with renewable energy production mandates.

The goals of the project are to examine ways to expand markets for wood fiber to foreign markets, which will support the increased pace and scale of forest and grassland restoration treatments in Arizona. Specific project objectives include: (1) ascertain the desirable specifications (wood chip size, moisture content) of the wood fiber that is being procured by the renewable energy markets in South Korea, (2) determine chain-of-custody requirements for wood fiber being imported into South Korea, (3) identify costs associated with the transportation of wood fiber from northern Arizona to the Port of Long Beach in California, and (4) perform a SWOT analysis, to examine the strengths, weakness, opportunities, and threats (SWOT) of the wood fiber market in South Korea that primarily focuses on the renewable energy sector.

Biomass Resulting from Restoration Treatments in Arizona

The world's largest contiguous area of ponderosa pine forest pans Arizona and New Mexico. This forest stretches from central New Mexico in the east to beyond the north rim of the Grand Canyon and is more than 4 million acres in size. Ponderosa pine forests across the western United States are dense, unhealthy and susceptible to severe wildfires, and insect and disease outbreaks (Covington et al. 1997).

Public land management practices in the past have reduced the resiliency of national forests to natural and anthropogenic disturbances. Changes in fire suppression, logging and grazing practices have resulted in unusually dense forests, overstocked with small-diameter trees (Larson 2001). Research by Covington and Moore (1994), demonstrated that forest restoration thinning treatments can effectively restore forest ecosystem health. Increasing the scale of restoration is essential to restore the health of forests in the southwestern U.S. (Hjerpe et al. 2009.). A key hurdle to increasing the pace and scale of forest restoration is a lack of markets for the low-value small-diameter wood by-products of restoration treatments. A

common explanation for the slow pace of restoration activities is a lack of adequate markets to utilize the woody biomass residues (Ruggirello 2017).

Completing forest restoration treatments is fiscally challenging (Lynch 2001, Nicholls et al. 2018). In addition to traditional logging slash, restoration treatments are primarily producing small-diameter ponderosa pine logs. Traditional forest product markets and sawmills have difficulty utilizing and marketing these by-products because of their low value. Large-diameter ponderosa pine logs yield significantly greater market value than the small-diameter logs from mechanical thinning restoration treatments. The low value impacts profitability of forest product firms as well as the efficiency of restoration operations. A challenging environment exists where lack of markets and low-value wood intersect, creating obstacles to economic viability.

In the 1990s, the primary focus of forest management shifted away from timber production and a greater emphasis was placed on environmental concerns (AZ State Forestry 2010). As a result, the forest industry across northern Arizona contracted and today, the forestry business and the forest products industry are only a fraction of their former size. The capacity to handle the wood by-products of large-scale restoration treatments does not currently exist across the entire ponderosa pine landscape.

Arizona is home to the Four Forest Restoration Initiative (4FRI), the largest landscape-scale restoration project selected by the U.S. Forest Service Collaborative Forest Landscape Restoration Program, covering portions of four national forests (Tonto, Coconino, Kaibab, and Apache-Sitgreaves). A stated goal of this project is to reduce hazardous forest fuels through mechanical treatment of 50,000 acres per year (USDA 2017B). Treatment of this scale is expected to produce 1 million tons of small-diameter logs and woody biomass in excess of the market demand (Fleishman 2019). The 4FRI was created under the premise that a landscape-scale project would enable significant treatment acres, such that an appropriately scaled cluster of forest industries would develop to support the restoration project without financial support of the government. In 2012, the first forest restoration treatment contract was awarded. To date, the pace of annual mechanical treatments has not met the U.S. Forest Service goal of treating 50,000 acres per year.

In the footprint of the first 4FRI contract, a majority of small-diameter logs are hauled to markets in Phoenix, Arizona to be processed into lumber or chipped for landscape and mulch products. Transportation costs from forest harvesting locations in northern Arizona to Phoenix markets can be prohibitive. Without support through government subsidies, the costs of mechanical thinning and transportation of wood residues is often not economically feasible.

Due to the lack of wood products industry in northern Arizona and the difficult economics associated with transportation, woody biomass, including small-diameter logs, limbs and branches, is often burned on site after harvesting. High transportation costs make hauling to markets economically infeasible. Piling and burning biomass in the forest is an alternative, but this wastes a resource and creates unhealthy smoke in addition to the implementation costs. Pile burning is expensive and days with appropriate weather conditions for burning are limited. In addition, many current thinning project contracts require removal of woody biomass. 4FRI task orders stipulated that all post-harvest forest residues must be removed, instead of burning onsite.

A solution is needed to address the high transportation cost associated with hauling low-value woody biomass over long distances when local markets are not available. Selling a large volume (e.g., >500,000

tons/year) of wood chips internationally may be an option, if these markets are willing to purchase the chips at higher prices than domestic markets will sustain (Halbrook and Han 2019).

South Korean Renewable Energy Markets

Renewable Energy Policy History in South Korea

The South Korean government has supported renewable energy initiatives through a diversified energy portfolio since the 1970s. Policy action began with the passage of the Promotion Act for New and Renewable Energy Development, Utilization and Deployment in 1972. Through the 1980s, renewable energy production was focused on waste-to-energy and solar thermal heating devices (Chen et al. 2014).

Two popular and effective policies for expanding energy production from renewable sources are Feed-in Tariffs (FIT) and Renewable Portfolio Standards (RPS). The fixed tariffs, a form of economic policy that promotes investment in renewable energy production, guarantee selling prices above the market price of electricity. Government fiscal support allowed for investment in renewable energy technologies that would likely have been excluded from a market-based energy production mix. In 2002, South Korea introduced a FIT policy to encourage renewable energy production from wind, solar, solid recovered fuel (SRF), and biomass (Kwon 2015). The FIT policy was effective and South Korea saw increased renewable energy businesses and renewable energy production as a result of this policy. By 2008, a third version of the New and Renewable Energy plan was published, with a goal to increase renewable energy production to 11% of total energy production by 2030 (Chen et al. 2014). Due to policy success and increased government spending on fixed tariffs, by 2009, upper limits were created for FITs on certain renewable sectors including solar, wind and biomass, based on budget limitations.

In this environment of increased expenditures on FITs, the South Korean government replaced the FIT policy with RPS in 2012. RPS mandate that energy production from renewable sources meet a required minimum proportion (KEA 2020). Annual percentage targets increased from 2% in 2012, to 8% in 2020, and will increase to 10% in 2023 and beyond (Table 1). As part of the initial RPS policy implementation, RPS are reviewed and can be adjusted every three years.

Table 1: South Korean annual Renewable Portfolio Standards targets. Source: Korea Energy Agency, 2020

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
	%											
Original	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0	
Revised	2.0	2.5	3.0	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0

** South Korean renewable energy production as a percentage of total energy production*

As part of the RPS scheme, energy producers can meet renewable energy production requirements in two ways, through their own production, or by purchasing renewable energy certificates on the open market from other producers (KEA 2020 & Kwon 2015). Sources of renewable energy are weighted, based on a renewable energy certificate (REC) weighting scheme, so that 1 megawatt-hour (MWh) of production multiplied by REC multiplier will calculate the REC quantity based on that production. In 2020, the woody biomass REC multiplier is 1.5, meaning for every MWh of production from biomass, energy producers are getting 1.5 RECs (KEA 2020). Those RECs can then be sold at market rates to other energy suppliers.

Renewable energy production has continued growth under the RPS scheme in South Korea. The use of biomass for energy production significantly increased at the outset of RPS. Energy production from biomass increased 500% from 2011 to 2013 (Kwon 2015). Kwon (2015) also states that switching from coal to biomass energy production is considered a low technology cost venture in South Korea. In South Korea, biomass can be co-fired in existing coal power plants with limited reduction in power production. Coal imported to South Korea for use in power generating facilities is classified as lignite. This type of coal has a low heat content, like wood pellets, meaning similar volumes of pellets would be needed to replace coal (Roni et al. 2017). Co-firing has been controversial and policy changes have reflected a favorable REC multiplier for dedicated biomass energy production over co-firings. As of October 2019, dedicated wood pellet energy generation was receiving REC multipliers ranging from 0.5 - 1.5 depending on fuel origination location and plant type. Dedicated conversion and co-firing plants were allocated a 1.0 REC multiplier with anticipated reductions in the future (Strauss 2019A).

South Korean Market Demand for Biomass as a Renewable Fuel Source

By 2018, South Korea became one of the top three wood pellet markets in the world. Requirements for RPS in South Korea have promoted that growth as utilities are mandated to produce increased amounts of renewable energy. Demand for wood pellets in South Korea is the main driver of increased wood pellet production and capacity across southeast Asia, particularly Vietnam and Malaysia, and Thailand and Indonesia to a lesser extent (Walker 2018). Consumption of wood pellets in South Korea has run between 1.5-2.5 million tons annually (F2M 2018), since the inception of RPS. Market demand will continue to increase as plants are converted from coal burning to full biomass production and other dedicated biomass energy production plants are commissioned.

Market Supply of Biomass in South Korea

The United States Department of Agriculture's Global Agriculture Trade Systems tracks international trade in many commodities, including wood products. In 2018, the latest figures available, South Korea imported 3.44 million metric tons of wood pellets, 193,192 metric tons of sawdust and waste wood, and 21,178 metric tons of wood chips (USDA 2020D). Vietnam was the main supplier in each commodity category, due to geographical proximity and favorable pricing.

Over a five-year period, wood pellet imports into South Korea increased 86.3% from 2014 levels, and 41.7% from 2017 to 2018. Vietnam supplied 63%, or 2.2 million metric tons, of the 3.44 million metric tons of wood pellets imported in 2018. Wood pellet imports from Vietnam increased 44% from 2017 to 2018. Vietnam has been the main supplier of wood pellets across the most recent five-year period. Malaysia supplied 585,615 metric tons of wood pellets, or 17% of all pellet imports in 2018. The United States supplied just 12,256 tons, or 0.4% of the total import volume for 2018 (USDA 2020D).

Import volumes of wood waste and sawdust into South Korea grew 10.7% from 2014 to 2018, with most of the growth occurring in 2017. Vietnam supplied nearly the entire market in 2018, with a 97% share equivalent to 186,744 metric tons of waste wood and sawdust. These numbers increased 8.2% from 2017. Vietnam has been the majority supplier of waste wood and sawdust across the most recent five-year period. The United States supplied just 216 metric tons, or 0.1% of the total import volumes in 2018 (USDA 2020D).

Wood chip imports increased 54.4% from 2017 to 2018, but decreased 66.2% from 2014 to 2018, a five-year period. Market demand for wood chips in South Korea fluctuated significantly during this period.

Wood chip imports had been decreasing between 2014 and 2017, before an uptick in 2018. Vietnam supplied 70% of the imported wood chip market in 2018. This represents a decrease from 95% market share in 2017. Vietnam and Russia have been the majority suppliers of wood chips across the most recent five-year period. For the period 2014-2017, the United States supplied less than 1% of total wood chip imports to South Korea (USDA 2020D), but in 2018, the United States became the second largest supplier of wood chips to South Korea, supplying 14.5% of the total for that year.

Market Price of Fuel Wood Pellets and Other Biomass Fuels

In September 2019, the three-month weighted moving average of pellet prices delivered to South Korea was USD$115/metric ton based on International Trade Data (Strauss 2019B). Pellet prices for delivery from Vietnam were significantly lower at USD$92/metric ton. In the preceding year, pellet prices have moved from a high of USD$158 in September 2018 to a low of USD$115 in September 2019 due to decreased market demand.

The South Korean RPS encourage short-term spot rate, market rate, contracts for wood pellet imports (Strauss 2017). South Korean REC prices and spot rate prices of wood pellets are directly and highly correlated. A drop in REC prices will lead to a depressed demand for wood pellets and a subsequent decline in spot rates prices. REC prices reached all-time highs in May 2017 but have been falling since. That downward trend continued through the first quarter of 2020. Spot rate prices for delivered wood pellets from Vietnam fell to an all-time low in September 2019. Vietnam is supplying 60-70% of the South Korean market, so this price decline is significant to overall supply and demand (Strauss 2019C). This uncertainty drives the short-term outlook of the South Korean wood pellet market. Lower prices in the REC markets, make purchasing RECs in the marketplace cheaper than wood pellet electricity production, causing a shift away from wood pellet imports.

The RPS policy does not guarantee biomass price stability like the FIT. As a result, South Korean buyers have shown a reluctance to enter into long-term supply agreements. In the absence of long-term offtake agreements, South Korean utilities engage in a short-term wood fiber buying strategy. In addition to price, biomass wood fiber quality and specifications are important.

Objective 1 – Wood Fiber Specifications

Ascertained the desirable specifications (wood chip size, moisture content) of the wood fiber that is being procured by the renewable energy markets in South Korea. Identification of the specifications for the wood fiber will provide information that is relevant to harvesting, processing, and transportation operations. The major output of this objective was a summarized list of the wood specifications that are being procured by wood buyers in South Korea for use in energy production. Relevant wood specifications that were identified include; moisture content, ash content, chip or pellet sizing, and target BTU output.

The South Korean National Forest Research Institute provides specifications and quality standards for wood products (NFRI 2020). These product specification standards define the requirements for all wood products, and cover everything from dimensional lumber to engineered wood products, including oriented strand board (OSB), particle board, and wood composites, to wood chips, pellets, charcoal and biochar. Renewable energy markets are concerned with wood fiber specifications of wood chips and pellets, and to a lesser degree charcoal and biochar. The quality standards provide guidance to both residential, small-

scale use and industrial needs. The standards and specifications are applied to both domestic and imported wood fiber.

Fuel Wood Pellet Specifications

The South Korean National Forest Research Institute provides twenty categories of quality standards for wood pellets. These standards include specifications on pellet size, moisture content, ash content, net caloric value or energy content, density, as well as content standards for inclusion of many elements including; nitrogen, sulfur, chlorine, arsenic, cadmium, copper, lead, mercury, nickel, and zinc (Table 2). South Korean biomass energy industry sources confirm that pellet size, moisture content, ash content and energy content are the most important requirements.

Per the South Korean standards, there are three classes or grades of wood pellets for industrial uses. The differences in specifications are in the size of the pellet and the ash content. Class 1 wood pellets have desired lengths between 3.15 mm and 40 mm, with a diameter or thickness up to 8 mm. Class 2 pellets consist of the same length specifications but include diameters up to 10 mm, and Class 3 includes diameters up to 12 mm. As with the size specifications, the ash content requirements are more precise for Class 1 pellets, which specify an ash content below 1.5%. Class 2 and Class 3 pellet specifications are 3.0% or less and 5.0% or less respectively. For all classes of wood pellets, specifications require a moisture content of 10% or less on a green weight basis.

The requirement for wood pellet energy content is greater than 16.5 megajoules per kilogram (MJ/kg) for all classes. Converted to British Thermal Units (BTUs) per pound, 16.5 MJ/kg is equivalent to 7,094 BTUs per pound. These values are as-received values, not oven-dry. The oven-dry value equivalent would be greater. This energy content is the low heating value or net caloric value. Low heating value excludes the heat generated from water vapor during combustion. The high heating value or gross caloric value or gross energy is not identified in wood pellet specifications.

Forest Energy Corporation in Show Low, Arizona produces residential fuel wood pellets utilizing small-diameter whole trees, including bark. Forest Energy produces three grades of pellets that meet or exceed all specifications from the South Korean National Forest Research Institute. The three grades align with the ash content specifications outlined in Table 2 (Forest Energy Corporation 2020). Today, Forest Energy lacks the capacity to produce wood pellets on the scale of South Korean demand. Current production supplies the residential fuel wood pellet market in the southwestern U.S. at a higher margin than would be attainable in South Korea.

Wood Chips Specifications

South Korean standards for wood chips separate chips into six grades based on chip size (Table 3). Grade sizes have low end sizes of 3.15 mm and range from 16 mm to 200 mm on the high end. Maximum chip length can be as high as 400 mm in small amounts (less than 6%) in the highest grade. The highest-grade wood chips should be between 3.15 mm and 16 mm in length with less than 15% of the chips smaller than 3.15 mm. Less than 6% of highest-grade chips should exceed 31.5 mm with a maximum length of any single wood chip no greater than 45mm.

The South Korean National Forest Research Institute provides thirteen categories of quality standards for wood chips. These standards include specifications on chip size, moisture content, ash content, net caloric value, density, as well as content standards for inclusion of many elements including; nitrogen, sulfur, chlorine, arsenic, cadmium, lead, mercury, and the ash melting point (Table 4). South Korean biomass

energy industry sources confirm that chip size, moisture content, ash content and energy content are the most important requirements.

Table 2. Quality specification of industrial wood pellets in South Korea. Source: National Forest Research Institute, South Korea, 2019

Property	Unit	I1	I2	I3
Diameter/Length	mm	D06, 6 ± 1 3.15 < L ≤ 40 D08, 8 ± 1 3.15, < L ≤ 40	D06, 6 ± 1 3.15 < L ≤ 40 D08, 8 ± 1 3.15, < L ≤ 40 D10, 10 ± 1 3.15, < L ≤ 40	D06, 6 ± 1 3.15 < L ≤ 40 D08, 8 ± 1 3.15, < L ≤ 40 D10, 10 ± 1 3.15, < L ≤ 40 D12, 12 ± 1 3.15, < L ≤ 40
Moisture Content	%	≤ 10	≤ 10	≤ 10
Ash Content	% dry	≤ 1.5	≤ 3.0	≤ 5.0
Durability	%	≥ 97.5	≥ 96.5	≥ 95.0
Fine Powder	%	≤ 4.0	≤ 5.0	≤ 6.0
Additive	%	< 3	< 3	< 3
Net Caloric Value	MJ / kg	≥ 16.5	≥ 16.5	≥ 16.5
Density	kg / m^2	≥ 600	≥ 550	≥ 500
Nitrogen (N)	%	≤ 0.5	≤ 0.7	≤ 0.7
Sulfur (S)	%	≤ 0.05	≤ 0.05	≤ 0.05
Chlorine (Cl)	%	≤ 0.03	≤ 0.05	≤ 0.1
Arsenic (As)	mg / kg	≤ 1	≤ 1	≤ 1
Cadmium (Cd)	mg / kg	≤ 0.5	≤ 0.5	≤ 0.5
Chromium (Cr)	mg / kg	≤ 10	≤ 10	≤ 10
Copper (Cu)	mg / kg	≤ 10	≤ 10	≤ 10
Lead (Pb)	mg / kg	≤ 10	≤ 10	≤ 10
Mercury (Hg)	mg / kg	≤ 0.1	≤ 0.1	≤ 0.1
Nickel (Ni)	mg / kg	≤ 10	≤ 10	≤ 10
Zinc (Zn)	mg / kg	≤ 100	≤ 100	≤ 100

Table 3. Size classification of wood chips in South Korea. Source: National Forest Research Institute, South Korea, 2019

Class	Wood Chip Size (mm)	Length % ≤ 3.15mm	Length % Large Chips (mm)	Max Length (mm)	Cross-Section Area (cm2)
P16S	3.15 < P ≤ 16	≤ 15%	≤ 6% (>31.5)	≤ 45	≤ 2
P31S	3.15 < P ≤ 31.5	≤ 10%	≤ 6% (>45)	≤ 150	≤ 4
P45S	3.15 < P ≤ 45	≤ 10%	≤ 6% (>63)	≤ 200	≤ 6
P63	3.15 < P ≤ 63	≤ 10%	≤ 6% (>100)	≤ 300	≤ 6
P100	3.15 < P ≤ 100	≤ 10%	≤ 6% (>200)	≤ 350	≤ 6
P200	3.15 < P ≤ 200	≤ 10%	≤ 6% (>250)	≤ 400	≤ 6

** P represents wood chip size classifications*

Table 4. Wood chip classification and specification in South Korea. Source: National Forest Research Institute, South Korea, 2019

Property	Unit	Wood Fuel Chips		Hog Fuel
		1	2	
Diameter/Length	mm	Select from Table		
Moisture Content	%	≤ 25	≤ 35	≤ 35
Ash Content	% dry	≤ 1.5	≤ 3.0	≤ 5.0
Density	kg / m^2	≥ 200	≥ 150	≥ 150
Nitrogen (N)	%	≤ 1.0		≤ 1.5
Sulfur (S)	%	≤ 0.1		≤ 0.15
Chlorine (Cl)	%	≤ 0.05		≤ 0.1
Arsenic (As)	mg / kg	≤ 1		≤ 2
Cadmium (Cd)	mg / kg	≤ 1.0		≤ 2.0
Chromium (Cr)	mg / kg	≤ 10		≤ 20.0
Lead (Pb)	mg / kg	≤ 10		≤ 20.0
Mercury (Hg)	mg / kg	≤ 0.1		≤ 0.1
Ash Melting Point	°C	Measurement		

Per the South Korean standards, there are two classes of wood fuel chips and a single grade of hog fuel. Wood fuel chips are produced from chipping with a blade and produce more consistent size chips. Wood fuel chips are a cleaner fuel compared with hog fuel. Hog fuel is produced from blunt force grinding from hammers, producing a stringy and uneven-sized wood fiber (Drax 2020). Hog fuel can include limbs, bark, shavings and sawdust.

Moisture content specifications for wood fuel chips should be less than 25% for Class 1 and less than 35% for Class 2. Ash content requirements for Class 1 and 2 wood fuel chips should be less than 1.5% and 3.0%, respectively. Hog fuel has both higher allowable moisture and ash content resulting from the nature of hog fuel production. Specifications for hog fuel moisture content is less than 35% and ash content is less than 5%. No specifications for energy content requirements are identified in the documentation. However, in communication with South Korean buyers, ponderosa pine wood chips are highly preferred for their energy content, along with price and availability (Han 2018). A 2018 review of biomass feedstock available in the Camp Navajo area of Arizona showed ponderosa pine high heat values of 8,000-8,8000 BTUs per dry pound (TSS Consultants 2018). An energy analysis has shown that ponderosa pine wood chips could produce up to 10,800 BTUs per pound (Han 2018).

Other Wood Fiber Products Specifications

In South Korea, several other biomass forest products are regulated by National Forest Resource Institute standards and specifications. Those products include wood briquettes, biochar and charcoal. Specifications for these products are listed in Appendix B-D. Wood fuel briquettes are densified biomass energy products, much larger in size than wood heating pellets. The briquettes allow for use of biomass residues in a uniform shape and size (Felfi et al. 2005). As stated by the International Biochar Initiative (IBI 2015), biochar is solid material created from a thermochemical conversion of biomass that takes place in a limited oxygen environment. Biochar is charred organic matter than can be used as a biofuel.

Charcoal or charred wood can be used as a partial substitute in co-firing power plants that burn coal and biomass. These three biomass fuel products have specifications and quality standards under the National Forest Resource Institute, available as part of the Wood Product Standards and Quality Standards (NFRI 2019).

Objective 2 – Chain-of-Custody Requirements

Determined chain-of-custody requirements for wood fiber being imported into South Korea. The important output of this objective was identifying what paperwork during the US Forest Service contracting process needs to part of the chain-of-custody paper trail during the export process. In general, federal lands are not able to be certified by traditional third-party audits such as the Forest Stewardship Council's protocols. This is due largely to the fact that federal lands are managed for multiple use that includes recreation, water, forage, and forest products.

Federal lands in Arizona cannot be certified by traditional third-party audits such as the Forest Stewardship Council (FSC)'s protocols or the Sustainable Forestry Initiative (SFI). This is mainly due to the fact that federal lands are managed for multiple use that includes recreation, water, forage, and forest products (Rappold 2020). The Forest Service and Pinchot Institute for Conservation studied and evaluated forest management on five national forest units to determine if management was meeting forest certification standards. The results were mixed, but no changes to the applicability of forest certification standards on National Forest land and forest products were changed. The South Korean biomass market does not require third-party forest certification, but stricter regulations on transparency of imports are being considered (USAID 2018). Therefore, no forest certification documentation is required for wood products export to South Korea at this time.

The United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) monitors and controls international trade in animal and plant products, including forest products and biomass. International phytosanitary standards allow for global rules governing a safe and predictable trade system (USDA 2020A). The United States participates in international standard setting organizations including the International Plant Protection Convention (IPCC) and the North American Plant Protection Organization (NAPPO) to promote safe and sustainable trade as well as protection from introduced exotic invasive pests.

APHIS provides plant and plant product requirements by country and plant species. Specific regulations for pine (*Pinus spp.)* wood products export to South Korea are detailed by product type. The APHIS export database states all wood with bark, including, logs, lumber, branches, and wood chips must list the county and state of origin on the Phytosanitary Certificate. The Phytosanitary Certificate indicates that plant and plant products meet the specified phytosanitary requirements.

An import permit is required for wood products import into South Korea; wood products cannot be certified without a permit (USDA 2020B). The Phytosanitary Certificate indicates that plant and plant products meet the specified phytosanitary requirements. Certificates are issued to ensure conformity to the regulated articles. Importing countries require certificates with wood products because there is a potential for exotic pest introduction in the process. Import shipments that do not have the required certification upon arrival will be refused, destroyed or delayed.

The specifications for pine wood chips state that Phytosanitary Certificate (PC) and Import Permit (IP) are required. Imports without required documentation will be refused. Additionally, all wood with bark, including wood chips, must list the state and county of origin on the PC.

The specifications for pine wood shavings state that a Phytosanitary Certificate (PC) is required. Additionally, wood shavings require inoculating treatments via heat treatment or methyl bromide fumigation programs. Heat treated wood must reach a core temperature of 56°C for 30 minutes. An industry certificate documenting a treatment process consistent with the regulations is an acceptable replacement.

The exporter has the responsibilities to meet the specifications outlined in the APHIS Export Certification Manual (USDA 2020C). These specifications cover the entire process and include requirements for application, inspection, sampling, testing, and certification for export. The exporter or shipper must safeguard the certified shipment from any infestation beyond the date of certification. United States export control regulations must always be met.

Objective 3 – Wood Procurement and Transportation Costs

Identified costs associated with the transportation of wood fiber from northern Arizona to the Port of Long Beach in California. Outputs from this objective quantified the transportation costs of transporting wood fiber (woody biomass or heating pellets) by tractor-trailers and by rail cars to the Port of Long Beach. The minimum number of railcars and associated wood volumes to cost-effectively utilize BNSF railcars was determined. Available railheads will be identified for subsequent analysis of tractor-trailer haul distances from timber processing centers.

Due to the lack of small-diameter log and woody biomass utilization capacity in certain areas of Arizona, additional outlets for woody biomass, beyond domestic markets, need to be identified. However, the high cost of transportation is a significant limiting factor when transporting low-value woody biomass over long distances. One potential solution to address this problem is the use of rail transportation to reach other domestic or international markets, particularly if these new markets pay higher prices (Halbrook & Han 2019). Shipping via rail has many benefits over road transport. Moving freight via rail produces approximately 75% less greenhouse gas emissions (Lee 2019). Railroads can be more than 400% more efficient than trucks and a single train can replace hundreds of trucks on the road (Lee 2019).

Currently in Arizona, trucking is the major mode of transportation for moving wood chips from forest to market. In the U.S. Southwest, railroad transportation is infrequently used to deliver wood chips over long distances (>500 miles). Because interest in exporting woody biomass internationally via rail lines has only recently been considered, much is not known or well understood about the logistics, costs, and infrastructure of railheads in northern Arizona.

Transportation costs can be one of the most significant expenses in the wood procurement process. For example, Pan et al. (2008) studied harvesting and transportation costs associated with removing forest biomass. They showed that hauling costs comprised the largest share of total expenditure. A pilot study in Colorado showed that using rail to ship woody biomass could reduce the barrier of high transportation costs (Valley Courier 2018).

Several modes exist for transport of wood fiber from Arizona to the Port of Long Beach. Transportation by tractor-trailer is an option but can be less efficient and more costly than other transportation methods

due to the inherent volume limitations. The distance to destination is too long (>700 miles) to make this a feasible solution. Another option is trucking wood chips in freight containers to Phoenix with a transfer to rail cars, and then railroad transportation to the Port of Long Beach. This option reduces hauling distance with tractor-trailers and maximizes the hauling capacity of rail lines. A third option is rail transport from northern Arizona to the Port of Long Beach. However, available railhead capacity in northern Arizona is minimal.

Several railheads exist in northern Arizona, but at the time of producing this report, most of the railheads would require significant upgrades to the infrastructure in order to transport wood chips to the Port of Long Beach. There is a railhead at the Arizona National Guard Camp Navajo Ordinance Facility in Bellemont, Arizona that is currently being used to transport items for strategic defense purposes. A second railhead is located in Winslow, Arizona. Based upon conversations with rail line representatives, the railhead facilities in Bellemont and Winslow would both need infrastructure upgrades to be completed before the facilities could be used for intermodal transport. It is unclear at this time if private enterprises are committed to investing in the upgrades needed to make these railhead facilities an option for transporting woody biomass. The Apache Railway in Snowflake, Arizona along with a railhead operated by Burlington Northern Santa Fe (BNSF) in Phoenix are also options but do have inherent logistical and economic tradeoffs that must be considered. The main tradeoff with the BNSF facility in Phoenix is that the biomass must be transported from northern Arizona by tractor-trailer. Depending on where the tractor-trailers are being loaded with biomass, this can equate to a one-way haul distance of over 150 miles. While there are significant forest resources near to the Apache Railway, there are regional market issues that must be considered. The complexity of the woody biomass market near the Apache Railway is detailed below. Both the Camp Navajo and Winslow railheads lack adequate length of spur lines and track switches to accommodate a full-unit train carrying 220 shipping containers (double-stacked). Significant investment would be required to lengthen the spur track and strengthen bridges, as well as upgrade track switches with current technology to allow for wood fiber transport to west coast ports.

The Apache Railway begins in Snowflake, Arizona and connects to a main transcontinental rail line in Holbrook, Arizona. Adjacent to the railway in Snowflake, there are two sawmills and a woody biomass-fueled electrical generating facility. The woody biomass facility needs approximately 400,000 green tons of biomass annually to operate at full capacity. Feedstock for this facility is comprised of whole-tree chips from the unmerchantable portions of trees stems generated during forest restoration activities on the Apache-Sitgreaves National Forest and the Fort Apache Indian Reservation. Depending upon market conditions, the biomass facility may also procure white wood chips from the two nearby sawmills. White wood chips generated by the sawmills are often sought after by a residential wood heating pellet manufacturer in Show Low, Arizona. Overall there is greater market demand for woody biomass in the Snowflake area compared to the Bellemont or Winslow areas. Without a comprehensive wood supply analysis of the Apache-Sitgreaves National Forest, it is unclear if this one National Forest can alone meet regional wood supply needs in addition to export markets in South Korea. Most likely if the Apache Railway was to be used as a railhead for exporting biomass, the material would likely need to originate from other National Forests and transported over highway to Snowflake for loading onto rail.

Camp Navajo and Winslow railheads exist in an area with limited utilization of biomass. A recent wood supply study by the Ecological Restoration Institute indicates that there is more than 300,000 tons of small-diameter wood available within a one-hour one-way hauling distance. The Apache Railway in eastern Arizona has sufficient rail infrastructure, but market dynamics require a strong coordinated effort

to build a sizable volume of wood products. Eastern Arizona has significant industry and greater competition for wood chips from wood products facilities. Current utilization options exist in that part of the state. Long transportation distance (>250 miles) is a limiting factor for woody biomass from the western portion of Arizona forests. The high costs and distance involved in trucking wood fiber to the Apache Railway makes this option untenable for western Arizona forests.

In 2019, researchers at the Ecological Restoration Institute at Northern Arizona University completed a proof of concept, pilot project to deliver wood chips from Arizona to the South Korean market. The pilot study tested the logistics and efficiency of using railroad transportation to expand delivery range and open new markets to Arizona wood fiber suppliers. The pilot study identified loading and chipping times, and weights to fill intermodal shipping containers with wood chips.

Researchers partnered with BNSF railroad on a concept to ship woody biomass using intermodal containers. Full-unit intermodal trains typically carry 220 containers and are point-to-point transportation, without intermediate stops. The scale of the pilot study was below the full-unit train threshold and thus extraordinary business for BNSF. With support from the community and assistance from Hyundai Merchant Marine (HMM), the study moved forward with 58 intermodal shipping containers. Containers from Memphis, Tennessee, were delivered to Camp Navajo on eight railcars totaling 1,891 feet in length, with a mix of single and double-stack containers (Halbrook and Han 2019). Researchers filled the containers with wood chips at the Camp Navajo facility west of Flagstaff, Arizona. Wood chip filled shipping containers were transported via BNSF railroad to the Port of Long Beach to await transpacific marine transportation to South Korea. Throughout the pilot study, researchers analyzed the efficiency and logistics associated with, log loading, hauling, log offloading/piling, equipment mobilization requirements, intermodal container delivery, container offloading, placement, chipping/filling containers, and reloading filled containers onto railcars (Halbrook and Han 2019).

Results of the pilot study showed that railroad transportation may be a viable solution for supplying woody biomass long distances and to international markets. Forest restoration activities in northern Arizona will continue to produce woody biomass as a by-product. Additional demand for wood fiber would help increase the pace of forest restoration in Arizona and help the U.S. Forest Service meet the treatment goals need to address forest health issues (Halbrook & Han 2019).

The pilot project identified that the chipping and material handling equipment utilized during the trial run, may not be practical to cost effectively meet the high-volume needs of South Korea. Additional research is needed to model the efficiencies of a dedicated chipping facility which would be a central staging area for logs and chipped material to be dried and function as a primary wood terminal for small-diameter and low-grade logs from forest restoration projects. The centralized wood terminal concept would ideally facilitate increased efficiencies in loading rail containers through the use of multiple feed conveyors and automated container handling. Scaling up a chipping facility to higher volume output levels would reduce operational costs.

The 2019 pilot project also identified needed infrastructure improvements, if a full-scale industrial chip export operation was to be developed at the Camp Navajo facility. Rail infrastructure, including 8,000 feet of new track and electronic rail switches, would need to be completed in order to meet intermodal shipping standards set by the BNSF rail company, which services the Camp Navajo railhead. Other needed site improvements include reinforcing concrete pad loading areas to damage by container loading

equipment and minimize ground disturbance. Additionally, since Camp Navajo is located on U.S. Department of Defense lands additional approvals will need to be obtained before a full-scale industrial operation could begin (Halbrook & Han 2019). The timeframe for approval and specific agreements that would be needed between a private enterprise and the U.S. Department of Defense was not identified in this study.

The economic challenge of shipping wood fiber via railroad transportation is a significant obstacle to its implementation, in addition to the operational logistic challenges. The market price of wood fiber in South Korea is significantly higher than the price in the southwestern U.S., but transportation and handling costs to South Korea's market must be minimized for the operation to be financially profitable. During the 2019 pilot study, the market price of wood chips free-along-side (FAS) at the Port of Long Beach was approximately USD$80 per ton at an average moisture content of 25%.

Prices of wood chips in South Korea were recently USD$116 per green ton. Transpacific marine transport via shipping containers, from the Port of Long Beach to South Korea is estimated to cost approximately USD$23 per metric ton (Halbrook and Han, 2019). Operating expenses associated with chipping, loading and hauling wood chips from the forest to the railhead vary between a low estimate of USD$40 per ton and a high estimate of USD$63 per ton (TSS Consultants 2018). Included in these operational expenditures is USD$25-36 per ton to harvest, merchandise, and load the logs onto a tractor-trailer. Transportation of logs using standard tractor-trailers is estimated to add an additional expense of USD$100 per hour of travel. To ensure an economically viable solution, the cost to chip and load containers plus railroad transportation costs must stay below USD$80 per ton. To remain economically feasible, rail transportation costs must remain below USD$30-40 per ton or USD$700-900 per shipping container depending on margin goals (Figure 2) (Halbrook & Han 2019). Transportation costs are a major component of exporting biomass to overseas markets and thus need to be minimized to make marketing wood fiber to the South Korean market financially viable.

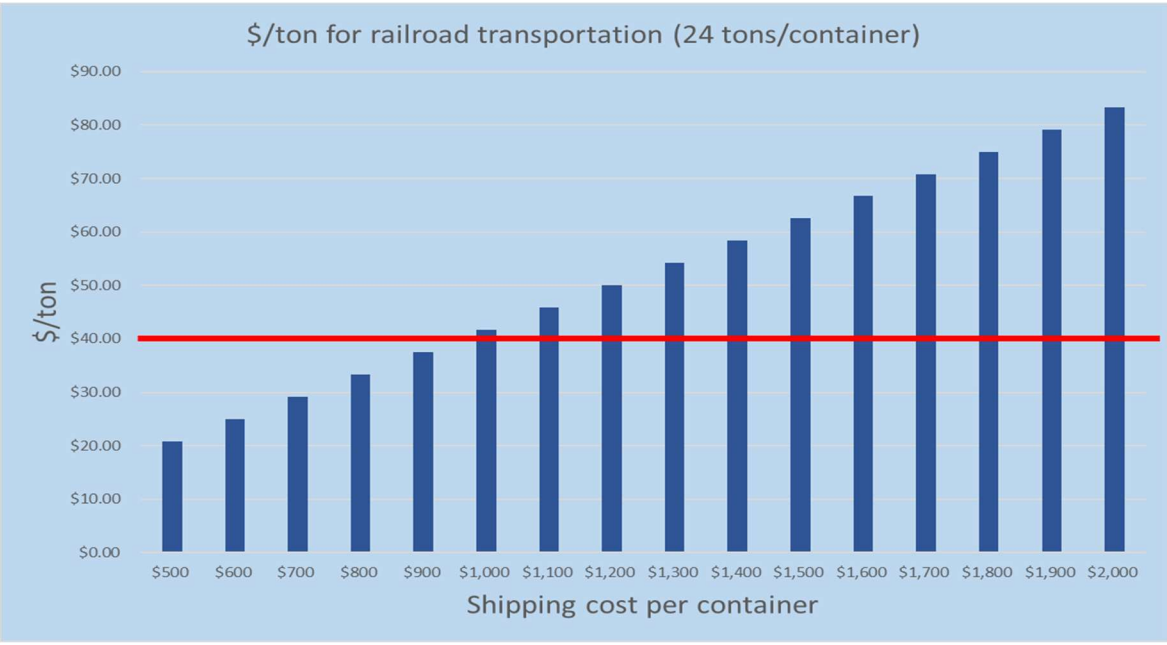

Figure 2. Relationship between shipping cost per container and the unit cost per ton of wood chips filling those containers. Source: Halbrook and Han, 2019

In researching this section of the study, it became evident that simply too many variables exist to accurately define transportation costs. Instead we chose to rank transportation methods by cost, using results from pilot projects and subject matter experts.

Based upon the analyzes done for this report we have identified that the most expensive transportation method to export woody biomass to South Korea would be direct transportation of the biomass to the Port of Long Beach using tractor trailers. The high cost of using tractor trailers as the sole transportation method is a function of the limited volume of biomass one tractor trailer can transport, in comparison to rail cars. To maximize volume transported, containers on rail cars or rail gondolas need to be utilized for delivery to the Port of Long Beach. Direct loading of wood chips into containers or gondolas, at a railhead, will likely be the least expensive transportation method, based upon volume transported. However, as stated above, functioning railhead capacity is limited at this time. Therefore, transporting the biomass material by tractor trailer followed by loading onto railcar at either the Phoenix or Snowflake railheads is the only option in the short term.

Objective 4 – SWOT Analysis

Performed a SWOT analysis of the wood fiber market in South Korea primarily focused on the renewable energy sector. The outputs and information gathered for the above three project objectives have identified critical components that are part of the SWOT analysis.

SWOT Background

The SWOT analysis has been used in the corporate business environment for many years. The purpose of a SWOT analysis is to identify existing, internal, strengths and weaknesses, and potential, external, opportunities and threats. With this knowledge, strengths can be leveraged and weaknesses mitigated through proactive strategies. Opportunities can be exploited, and threats avoided. When used appropriately, this analysis can form the basis for a successful strategy (Chang and Huang, 2006).

A standard SWOT analysis identifies strengths and weaknesses as existing characteristics or factors. Typically, these would be internal to the organization or market. In this study, strengths and weaknesses are existing conditions, both in South Korean renewable energy markets as well as wood fiber supply and supply chain infrastructure in Arizona, and between Arizona and South Korea.

In a traditional SWOT analysis, opportunities and threats are external to the organization or market conducting the analysis. These factors are often related to market opportunities and threats from competition or regulation. Opportunities and threats have the potential to occur in the future. In this study, factors were identified that could positively or negatively affect the proposition of shipping biomass from Arizona to South Korea.

Strengths

The market demand for fuel wood pellets in South Korea is large and still growing. Many strengths exist in the South Korean biomass market, most notably the size of the energy market demand. South Korea ranks 28th in the world in population with more than 51 million people, but when reviewing national energy consumption, the country is ranked in the top ten (WPR 2020). As RPS continue to ramp-up to 10% requirement in 2023, demand for wood pellets will likely mirror that increase. Between 2016 and 2017, wood pellet imports to South Korea increased by 42% (F2M 2018) and the total South Korean market consumed between 1.5 – 2.5 million tons per year.

Industry analysts estimate that by 2021, South Korea will consume more than 6 million tons of biomass annually (Kim 2019 and F2M 2018). Due to the small domestic fuel wood pellet supply, South Korea will need to import 75-80% of the supply needed to meet energy production demand.

The RPS in South Korea and the FIT in Japan provide promising revenue streams for co-firing and dedicated biomass power stations, giving these producers higher fuel wood pellet paying capabilities than energy producers in the U.S. or Europe (Poyry 2019). The FIT scheme in Japan offers a price guarantee through long-term agreements. Both policy schemes are encouraging biomass energy production through price assistance beyond what the free market would bear for biomass energy production. South Korean biomass market prices on a per ton basis can be more than double the price in the United States.

South Korean policy currently mandates RPS percentages through 2024. RPS are scheduled to increase through 2024. Biomass as a segment of the market continues to have support through REC multipliers for energy production. Expectations are that biomass energy production, as a percentage of total RPS production, will continue to increase in the coming years.

Biomass quality standards in the South Korean market are easily achieved and open to feedstock supply markets across the globe. South Korean biomass fuel requirements for quality and sustainability are not as stringent compared to wood fuel specifications in Japan or the European Union. Although the South Korean market has less stringent quality standards, buyers still require consistent and reliable supplies of material. The more relaxed quality standards however do open the market to more suppliers and offer international suppliers the opportunity to compete for market share outside of industry certification standards. These relaxed requirements present a clear opportunity for fast growth in biomass demand and production in South Korea.

Other market strengths include Korea's advanced technology in dedicated biomass plants currently under construction. Increased capabilities should decrease cost per MWh of biomass production. Future biomass production beyond the RPS scheme will be required to meet free market supply and demand conditions. Further technological advances can help achieve that goal.

Development of additional dedicated biomass power capacity, both completed and planned, will contribute to increased demand in the market for wood chips and pellets from international markets. This demand makes investment in the South Korean market attractive to wood chip and pellet producers in the U.S.

Weaknesses

Weaknesses in South Korean Market - The South Korean biomass energy market is immature but growing. At present, weaknesses exist in terms of both supply and demand in the market. Demand side weaknesses are a result of instability in the market price for fuel wood chips and RECs from producing renewable energy.

Renewable energy certificate prices and spot rates, the current point-in-time market price for wood pellets, are directly and highly correlated in the South Korean market. The South Korean RPS encourage short-term spot rate contracts for wood pellet imports (Strauss 2017). This leads to supply uncertainty, lack of market stability and reduced incentives for fuel wood chip and pellet producers to invest in production. South Korean REC prices and spot rates prices of wood pellets are highly volatile in the current market. A drop in REC prices will lead to depressed demand for wood pellets and a decline in

spot rates prices. REC prices reached all-time highs in May 2017 but have since been falling. Spot rate prices for delivered wood pellets from Vietnam fell to an all-time low in September 2019. Vietnam is supplying 60-70% of the South Korean market, so this price decline is significant to overall supply and demand (Strauss 2019C). This uncertainty drives the short-term outlook of the South Korea wood pellet market. Lower prices in the REC markets make purchasing REC in the marketplace cheaper than wood pellet production, causing a shift away from wood pellet imports for fiscal reasons.

The South Korean market lacks sufficient suppliers and producers to insulate the market from volatile swings. The small scale of Asian fuel wood pellet markets is a weakness. The Asian renewable energy wood pellet market is relatively new on the global scene. South Korea and Japan are the main markets currently. There is a lack of liquidity in the marketplace, with too few suppliers and customers. Market growth will eliminate this weakness, but today, a limited number of suppliers and producers restricts flexibility and impacts the long-term outlook (Meth 2019).

The Asian biomass markets lack a single large company in the supply market. The European Union and United Kingdom markets have Drax as the main supplier. Pinnacle is a large wood pellet manufacturer in North America. Synergies of scale produced by a single large market player could make expansion to new markets, like Asia, easier and more cost effective. Most pellet producers find it difficult to commit to capital expenditures on plant, equipment and logistics without long-term commitment. Without this type of agreement, financing can be a key hurdle for producers (Strauss 2017).

One major weakness of the South Korean renewable energy market is the reliance on RECs and REC multipliers to encourage production from renewable sources. Renewable energy production, including with biomass, is more expensive than coal energy production. Without government policy mandates and quotas on production, energy generation would likely revert to coal production. A lot of uncertainty exists about the market if the support schemes were to suddenly end. Technological advances are needed to make biomass power generation cost-effective in the marketplace. Alternatively, the price of biomass may drop enough that replacing coal with biomass suddenly becomes an economically feasible solution. Neither of these scenarios exist today, but future use of biomass as fuel may depend on shifts in these directions.

Supply side weakness is again driven by volatility, due to the immaturity of the biomass fuel market, but other factors also affect the weakness in the market for international supply of fuel wood pellets to South Korea. Vietnam is the number one supplier of wood pellets to South Korea, with more than 50% market share. South Korea needs a diversification of wood fiber suppliers from new international markets.

As South Korean demand for wood pellets has increased, production in Vietnam has fulfilled the market demand. It is foreseeable that future demand will exceed Vietnam’s supply capacity. Vietnam currently has an oversupply of wood pellets, which has the potential to flood the market, and ultimately would reduce prices to a point where North American suppliers would no longer be able to compete on price alone. As of 2018, Vietnam is providing 800,000 tons of wood pellets to South Korea annually. But Vietnam is nearing a threshold of maximum sustainable production from current plantations. Collectively these factors may signal that the market is close to being maxed out and further demand will likely need to be met from other markets.

There are two issues that negatively affect demand for international wood pellet supply and are directly related to domestic infrastructure. These concerns are recent increases in domestic wood pellet production

capacity in South Korea, and an undersupply of deep-water port facilities capable of receiving large cargo ships from transpacific trips.

South Korean domestic wood pellets are a direct competitor to international delivery of woody biomass. The South Korean wood pellets are cheaper and easier to procure. As of 2019, South Korea is favoring domestic biomass with higher REC multipliers. While policy changes have reduced REC multipliers for biomass production in most instances, domestic wood pellet production has found increased support in the RPS and REC environment. Dedicated biomass power plant production is now receiving 2.0 multiplier while plants co-firing with domestic wood pellet supply are seeing increases in REC multiplier from 1.0 to 1.5 (Strauss 2019A). The domestic supply of wood pellets is a small segment of the market, but any increase in domestic production will directly reduce the need for imported wood products. Some estimates expect as much as one third of total wood pellet market demand to be sourced from domestic supply in the near term (F2M 2017).

Increased sourcing from North American wood suppliers will require more deep-water port facilities. South Korea currently has the capacity and facilities, but Japan is a different situation. Japan's port infrastructure is a weakness to the market. The country cannot handle larger capacity ships coming from North American markets. Additional deep-water ports are needed if biomass imports are to increase at scale.

Capacity and Infrastructure Issues in Arizona - Several weaknesses exist for Arizona to supply woody biomass to South Korea and other Asian markets. The most significant is the near total reliance on U.S. National Forests for wood fiber supply. There are few privately-owned forests in Arizona. One major concern is the possibility for injunctions or closures on federal lands, which would quickly restrict the supply chain unless sufficient material was in storage.

Only 17% of land in Arizona is privately held. An even smaller fraction is privately owned lands that are forested and are accessible to logging equipment. The majority of forested lands in Arizona are on public lands across six national forests. In contrast, private forested land in Arizona is minimal. A result of this ownership mix is that woody biomass supply from Arizona relies almost entirely on public forests. Significantly more rules and regulations exist for forest management and wood acquisition on federal lands. One threat to biomass supplied from public lands is changing USDA Forest Service policy and federal court intervention. As recently as 2019, federal courts halted all forest operations across several national forests in New Mexico and Arizona due to an environmental activist group challenge (Fonseca 2019). This injunction affected one of the four forests associated with the Forest Service's Four Forest Restoration Initiative (4FRI) but the majority of restoration activity in Arizona was unaffected. A similar injunction on all Arizona public lands could significantly stop or delay wood supplies from Arizona. Phase 2 of the 4FRI project offering has the potential to allow a forest products business a twenty-year contract for wood supply from federal lands in Arizona.

Supply disruptions can have significant impact on transpacific international delivery to South Korea. Disruptions from severe weather, natural disturbances, rail or shipping impacts could interrupt trade and negatively impact the market. The logistics of shipping woody biomass from Arizona via rail to the Port of Long Beach and then by cargo ship across the Pacific Ocean to South Korea are significant. Both distance and time can affect the probability, severity and impact of disruptions in the supply chain. Weather and natural disturbances also have the possibility of negatively impacting feedstock deliveries.

Due to the distance and shipping time, small disruptions in the supply chain could significantly impact market energy producers. These impacts can be mitigated by maintaining adequate supplies on-hand. Excess biomass supply in storage, a common practice, would mitigate this issue in the short-term.

Additional weaknesses resulting from Arizona supply to South Korea are the limited transportation partners and narrow access to rail spurs. Railroads in the United States are a near oligopoly. BNSF controls the rail line running across northern Arizona. This lack of competition for railroad business limits a supplier's capacity to negotiate lower transportation costs. The near monopolistic nature of this environment introduces a variable that would be beyond control of a business in this marketplace. The Ecological Restoration Institute showed in a pilot study that shipping wood chips via rail on BNSF lines from Camp Navajo, Arizona to the Port of Long Beach is possible and could be made efficient, if sufficient upgrades to the rail system are implemented (Halbrook & Han 2019).

One of the hurdles to increasing the scale of woody biomass shipment via rail is the lack of railheads in northcentral Arizona; railhead capacity is minimal in this region. The Ecological Restoration Institute pilot study showed that significant capital improvements would be necessary to scale to full-train shipments in this area. The Apache Railway has the infrastructure and track length, but the location in eastern Arizona, near existing forest product industry make this option less than ideal. Today, wood waste in this region is utilized by the biomass plant in Snowflake, however historical fluctuation in state and federal policy make this complementary utilization of resources nonpermanent. The lack of rail infrastructure remains a weakness in northcentral Arizona markets today. Appropriate railheads and railroad infrastructure exist to transport wood fiber from Phoenix to the Port of Long Beach. However, this option involves significant tractor trailer transportation from northern Arizona to Phoenix and is thus less than ideal.

The last weakness is related to supply of ponderosa pine chips from Arizona forests. High initial moisture content of northern Arizona ponderosa pine is at the upper limit of South Korean specifications for woody biomass. Options to reduce moisture content include waiting for logs to air-dry, chipping logs and air-drying chips, or debarking logs and then chipping. All methods are options to lower the moisture content before delivery. Each method would add either time, cost or both to the final product. Clean chips would be preferable to South Korean buyers over whole tree chips.

Opportunities

Similar to South Korea, Japanese biomass energy markets have support through government policy. And the logistical operations needed for a U.S. based supplier to deliver wood fiber to Japan are similar to those for delivery to South Korea. Significant opportunities exist in both the South Korean biomass energy market and the same market in Japan, and those opportunities are detailed here in concurrence. Asian markets are predicting significant growth in the near-term, with possibilities for expansion beyond government policy terms. As this market matures, there will be an opportunity for new suppliers with increased capacity.

Long-term supply agreements are the exception in South Korea today, most supply agreements are short-term in length. A lack of guarantee in the RPS scheme means long-term contracts and investment is hard to come by. There is progress being made in South Korea. In 2017, Pinnacle Renewable Holdings, a Canadian firm, announced a long-term commitment to provide Korean energy supplier CGN Daesan

Power with 315,000 tons of biomass annually starting in 2021 (F2M 2017). Agreements like this demonstrate that long-term off-take agreements are possible but are currently not standard.

The opportunity for woody biomass is expanding with the recent policy changes to phase out SRF as part of the REC policy. SRF wood pellets are a wood product produced from woody construction debris. The pellets produced from construction and demolition debris are a lower cost and lower quality alterative to standard wood pellets. As of 2019, SRF pellet RECs have been eliminated. As a result, standard wood pellets may see increased demand.

The Japanese market is the largest opportunity for suppliers of woody biomass from Arizona. The market is growing, producers are looking for reliable suppliers and willing to pay a premium price. By 2030, analysts expect Japan will consume 15 – 20 million tons of biomass annually (F2M 2017). According to 2017 data from the Economic Co-operation and Development (OECD 2017), Japan has the third largest economy, and the second largest electricity production among member states.

The Japanese wood pellet market has several advantages over the South Korean market. Revenue generated from FIT projects are fixed across a 20-year generation period. The FIT subsidy supporting the renewable energy market allows for producers to enter into long term contracts. That stability is attractive to large partners in Canada and the United States. Wood pellet imports in Japan exceeded one million tons in 2018. The majority of Japan's wood pellet market was supplied by Canada (63%) and Vietnam (31%) (Walker 2018). The Japanese wood pellet market is expected to increase to 5 million tons annually by 2024 and 15-20 million tons annually by 2030 (Strauss 2019B). Exporting supply to Japan, in addition to South Korea, is a significant opportunity. Higher standards for quality, sustainability and consistency exist in the Japanese wood pellet import marketplace, but competition may be reduced as producers in Vietnam find it difficult to meet the higher specifications.

Since the Fukushima Daiichi nuclear disaster in 2011, Japan has approved 3.4 giga-watts of biomass-fired power plant capacity (F2M 2018). Additional demand for wood pellets will be met by international supply markets. Demand for wood pellets in Japan is estimated to increase to 15-20M tons by 2030 (F2M 2018).

Japan is paying premium prices for wood pellets. Reliable, sustainable sourcing is the goal of Japanese electricity producers and woody biomass buyers. Increases in market prices may create price competition across the Asian markets, which would be a benefit to Arizona suppliers.

In contrast to South Korea, biomass demand in Japan is stable due to the certainty provided by the FIT policy. Japanese producers are showing preference to reliable suppliers with a stable track record over suppliers that are attempting to sell their wood fiber at lower prices. The Japanese FIT program provides substantial revenue guarantees to allow producers to contract long term for supply. Long-term off-take agreements benefit both producer and buyer and contribute to success in the biomass as fuel marketplace (Strauss 2019C).

A maturation of Asian biomass markets in South Korea and Japan poses a tremendous opportunity for new producers and suppliers. Increased competition could lead to increased prices, benefiting suppliers both in demand and price.

Vietnam currently supplies more than 60% of the South Korean wood pellet market. The sustainability of Vietnam's forest resources is nearly exhausted at this level and additional supplies from tree plantations

are limited. Additional South Korean market demand must be met through imports from new markets. Arizona is primed to meet that market need. Compared to Vietnam and Malaysia, wood fiber from Arizona's forest resources are much more sustainable and likely be a higher quality fiber product.

Vietnam and Malaysia are supplying the majority of imported fuel wood pellet supply to South Korea. Arizona's wood supply has the potential to take market share based on factors of reliability and sustainability. Although wood products from U.S. National Forests cannot attain forest industry sustainability accreditation, documented environmental impact statements are in place to ensure the forest resources are not depleted. Cargo transportation infrastructure via roads, rail and west coast ports in the U.S. are significant, mature and reliable. In terms of quality, ponderosa pine wood chips have a greater energy content over other wood fiber sources. An energy analysis showed that wood chips from Arizona have a greater energy content over other international supplies (Han 2018).

There is an opportunity for a large pellet producer, such as Enviva or Pinnacle, to produce significant quantities of wood pellets from U.S. forest restoration activities to supply Asian biomass markets. A partnership with a high-volume pellet producer could lower current hurdles to implementing a supply chain of woody biomass from Arizona to South Korea or Japan.

Threats

Policy and Regulations - Changes to South Korean RPS policy is the number one threat to market stability. Renewable Portfolios Standards in South Korea were implemented in 2012 but are reviewed and changes can be made every three years. This uncertainty is precluding producers from entering into long-term offtake agreements with international suppliers. Policy changes from the South Korean government could address this issue if it persists.

A lack of long-term supply contracts introduces volatility into the South Korean fuel wood pellet market. As discussed in a previous section, South Korea's fuel wood chip and wood pellet demand has largely driven the increase in wood pellet industry capacity across southeast Asia, and Vietnam in particular. Without long-term agreements, Vietnamese wood pellet producers have increased investment and supply. As prices and demand fell throughout 2019 due to weather and other factors, these producers were negatively impacted (Strauss 2019A). Future investment will likely look for long-term price guarantees to hedge against this sort of negative situation. The ability for energy producers to locate affordable and reliable feedstock supplies is crucial to continued growth in the market.

South Korean renewable energy policy is fluid, from the FIT programs of the 2000s, to the RPS scheme in 2012, and the three-year review and policy updates. Policy, timing and REC multipliers per MWh production are subject to change and regulatory uncertainty.

Potential South Korean policy changes to REC multipliers significantly affect market demand and renewable energy fuel mix. When RPS policy was initiated in 2012, REC multipliers for production from biomass were 2.0 for both dedicated and co-firing biomass plants. This support led to an increase in renewable energy production from biomass fuels. Uncertainty surrounding the REC multipliers is a hazard to a stable market. Reductions in REC multipliers have the effect of dampening demand for woody biomass. Lower REC multipliers coupled with a decrease in REC prices could impact future wood pellet market demand. This impact could be reflected in both lower prices and reduced demand from South Korean buyers (Strauss 2019A).

Likewise, the loss of RECs for co-firing coal and biomass has shifted demand and encouraged production of dedicated biomass facilities. Growth in South Korean wood pellet markets has been driven by Korean energy producers co-firing wood pellets and coal in the same power plants. As of 2019, REC multipliers for co-firing operations have been eliminated. SRF pellets support has been reduced in dedicated plants and eliminated entirely in co-firing operations (Strauss 2019A).

One negative policy change that would specifically affect Arizona woody biomass supply would be a change to require sustainable certification. Arizona producers can provide strong chain-of-custody certification and environmental impact statements for harvesting on federal lands, but forest industry certification cannot be attained for wood products from U.S. National Forests because of a policy to manage the forest for multiple objectives. Potential South Korean policy changes to require third-party sustainability certification could jeopardize nearly all Arizona supplies. Sustainability certification is difficult, if not impossible, on national forest lands today.

Similarly, any changes in phytosanitary regulations could disrupt supply from Arizona. In 2013, Mexico made changes to phytosanitary requirements for lumber exported from the U.S. to Mexico (USDA 2013). The regulatory changes introduced a requirement for inspection and certification in the U.S. for all lumber imports to Mexico. This additional measure complicated exports from Arizona and increased costs for suppliers. The issue of federal versus private land regulatory requirements has the potential to create economic disruptions in any international trade.

On the supply side, legal injunctions on National Forest lands can affect consistent and reliable supply. Most forests across Arizona are on public lands. Forest restoration activities on the Coconino, Kaibab, Apache-Sitgreaves and Tonto National Forests are producing woody biomass and wood products. Because these national forests are subject to changing federal policies, it can pose a significant threat when timber harvesting activities are disrupted. For example, in September 2019, United States District Court ordered an injunction across six national forest in the U.S. southwest. The injunction indefinitely halted all operations on the forest until monitoring of an endangered species, the Mexican Spotted Owl, improved (Fonseca 2019). The court injunction based on an environmental group filing demonstrates the policy and regulatory difficulties of relying on public land to supply wood products exclusively.

Competition – Renewable Portfolio Standards requirements are production mandates at the producer level. RPS do not dictate production from specific renewable fuels. Wind or solar could take a larger share of RPS production in the future resulting from increases in battery technology. Increases in wind and solar technologies have the potential to crowd out biomass as a renewable fuel source in South Korea. RPS do not allocate production quotas per renewable fuel source. Shifts in the energy production mix may negatively impact the biomass market. Technical energy potential, or the theoretical potential for technology gains to increase market share are largest for solar, geothermal and wind production (Chen et al. 2014). Battery technology is currently the limiting factor for solar production. Technological improvements and lower production prices would negatively impact the share of energy production from biomass. Likewise, nuclear power or shale gas production are a threat to biomass as a renewable fuel in South Korea.

Competition also exists for U.S. and Arizona wood supplies. An analysis of 4FRI phase 1 task orders showed that 17.2 green tons of biomass per acre were created during mechanical restoration activity. Increasing supply of biomass is driving expansion of the forest industry in northern Arizona (Fleishman

2020). New forest products businesses are being created to match the supply. In 2019, a groundbreaking was held for the opening of a new sawmill in Williams, Arizona (Howell 2019). This sawmill is expected to have capacity to produce 100 million board feet of lumber. Competition also exists for use of biomass in other industries, including landscaping, animal bedding, domestic renewable energy, and wood heating pellets.

While the idea of supplying wood fiber from Arizona to South Korea is novel, this activity is not unprecedented on the global scene. The southeastern U.S. has been supplying wood fiber to renewable energy markets in Europe for years.

Annual U.S. wood pellet exports have grown from 200,000 tons in 2008 to more than 5 million tons in 2017. The growth in market demand is driven by European biomass markets (Parton 2019). Much of this production is in the southeastern U.S. Increasing demand in Asia and a maturation of the bioenergy markets will be appealing to stable forest products business. There is a legitimate concern that suppliers already in the market will pull increased demand. The southeastern U.S. has feedstock supplies tied to private lands and the infrastructure to meet market demands. In comparison with Arizona, the southeastern U.S. has a more robust forest industry sector and an established biomass supply chain infrastructure. With abundant access to wood and high-value logs bearing most of the costs, biomass markets are an attractive secondary market for the wood products industries already in place. The question will be whether the closer and more mature European markets will continue to grow. Estimates suggest that demand in the United Kingdom and Netherlands will begin to decline by 2026 (Canadian Biomass 2020). Supply from the southeastern U.S. could shift to meet Asian market demand.

Other western states could replicate Arizona's forest restoration on public lands. Forests across the western United States are unhealthy and are in need of restoration. West coast states could provide the same quality wood with potentially cheaper transportation costs to ports than Arizona. New suppliers could price wood fiber below break-even points available to Arizona suppliers of woody biomass. A threat remains that the southeastern U.S. or other states like California could step in with a similar approach, possibly at a lower price.

There are other biomass fuels that compete with woody biomass for renewable production. Palm kernel shells, rice husks, bamboo and other waste-to-energy biofuels are currently being utilized in energy and heating pellet production. Palm kernel shells (PKS) are a waste product of palm oil production. Palm kernel shells can be used as a biofuel in renewable energy production. Current pulverized coal boilers are not suitable for use with PKS and are thus not a current piece of the renewable energy market in South Korea (Strauss 2019A). South Korean policy is shifting away from SRF to cleaner sources with a higher energy content. Additionally, shells from coconut, walnut, pistachio, almond, and sunflower plants can be used as biofuel. Future developments may make waste shell products attractive alternatives.

Weather and other Forest Health Issues in Arizona – Threats to supply and demand can negatively impact the market. On the demand side, climate and weather can impact demand for heating and electricity. An unseasonably warm winter in 2019 was associated with decreased demand. A difference exists between summer and winter demand for heating and electricity in South Korea. South Korean market demand for electricity and heating in winter fluctuates. Warm winters are associated with a decline in demand for electricity. Fluctuations in demand can create an imbalance in supply and demand.

An oversupply of wood fuel will lead to lower prices in the market. Potential seasonal impacts are a threat to continued stable demand and production

Bark beetle outbreaks in Arizona pose a serious threat to supply of woody biomass. Dry, hot weather has been increasingly common in the southwestern U.S., leaving trees vulnerable to bark beetle attack. Drought conditions can exacerbate this situation. In recent years, mountain pine beetle infestations in British Columbia have severely impacted available wood fiber for pellet producers like Pinnacle. Pinnacle has been forced to halt wood pellet production at some facilities due to lack of wood residues. Raw materials are usually sourced from local sawmills, but the region's sawmill industry reduced sawing operations on account of the increasingly restricted availability of fresh roundwood caused by the mountain pine beetle infestation (Greene 2016). Dry, hot weather also increases the risk for wildfire. The impacts of wildfires could significantly disrupt the supply chain in Arizona. Like bark beetle outbreaks, drought conditions can exacerbate wildfire risks.

Other threats, potential disruptions and issues include woody biomass storage capacity, both in the southwestern U.S. and in South Korea. Locations for dry storage do not currently exist, like they do in the southeastern U.S. and British Columbia, Canada. Prices in the global markets for electricity, and energy producing fuels are highly volatile. Extended periods of low-priced oil or natural gas may affect market demand for biomass as fuel. Lower consumer electricity prices make using more expensive alternative fuels less cost-effective. Threats to the market exist with varying degrees of realistic probability of occurrence.

Discussion and Conclusions

This study lays out the opportunities and barriers for Arizona to supply woody biomass to South Korean, and to a lesser extent Japanese, renewable energy markets. There are few statutory or regulatory barriers to entry for a supplier to begin serving the South Korean biomass markets. Economies of scale and barriers to entry can be low for forest industry firms handling only transportation or small-scale chipping. Financial barriers, in the form of upfront costs, increase if a single firm implements a more sophisticated and multi-layered solution. Chain-of-custody and phytosanitary requirements can be easily met by Arizona’s suppliers.

The strengths and opportunities in the market are large and numerous. The key strength to the South Korean biomass fuel market is that it is large and growing. Demand for fuel wood pellets has been increasing since RPS were introduced in South Korea in 2012. The strength of the market is that government support through renewable energy production mandates makes it attractive to suppliers and investors. Due to the relatively relaxed wood fiber quality standards, opportunities exist for many new suppliers in the marketplace.

In addition to the South Korean market, an Arizona business could potentially service wood fiber markets in Japan. From a logistics standpoint the transportation methods would be very similar to those used for reaching the export markets in South Korea. Like South Korea, government leaders in Japan also support the use of woody biomass to produce renewable energy. Japanese renewable energy policy is akin to a FIT program that provides for extended guarantees to producers and suppliers entering into long-term offtake agreements. This policy can be more attractive to wood fiber suppliers than South Korea’s RPS. The price of wood pellets in Japan is significantly higher as well. Japanese producers are paying a

premium for stable, reliable partners and sustainable product. As the Asian biomass fuel market matures, further expansion will open significant opportunities on the supply side.

The South Korean biomass market is not all upside growth and expansion. There are legitimate concerns about weaknesses that exist in the current market and threats to the market in the future. The weaknesses result from both sides of the market; wood fiber suppliers and energy producers.

In South Korea, market weaknesses include the immature market fundamentals, the volatile REC prices and spot rate prices of fuel wood chips and wood pellets. The market lacks the stability to attract a single large pellet producer to meet the demand. Additionally, the market relies on RECs to support renewable biomass fuel production. Without these mandates, producing electricity with biomass would not be cost-effective. The lack of guarantees and long-term offtake agreements discourages investment in supply chains.

Threats to Arizona supplying wood fiber to South Korean markets come in two forms, threats to policy and threats from competition. RPS are reviewed and revised every three years. Changes to RECs, RPS percentages, and energy production mix through REC multipliers can all impact the demand for biomass fuel. Without stability, supply lines are threatened with disruption. Policy changes to wood fiber specifications and statutory requirements could add costs and regulatory hurdles to an already complex logistical initiative.

Competition exists for wood fiber in Arizona and amongst biomass suppliers in the global market. Arizona wood fiber from National Forests will always be subject to Forest Service multiple use objectives and federal policy changes. Consequently, there will be potential for forest shutdowns, restrictions and court injunctions that may disrupt supply. Growth in the Arizona forest products sector related to the Forest Service 4FRI project would introduce competition for forest resources. The operational costs to supply wood fiber to wood product manufacturers in northern Arizona would be significantly cheaper than international freight shipments.

Despite the uncertainties, the size and growth of the woody biomass markets in South Korea are enticing to U.S. suppliers. With appropriate partners and economically efficient transportation options, Arizona could supply wood fiber to Asian markets. With planned increases in forest restoration across northern Arizona, the importance of finding utilization outlets for the by-products of forest restoration activities are increasingly important.

Even without long-term agreements from South Korean wood buyers, suppliers of biomass in the southeastern U.S. currently have the infrastructure and wood supply to start shipping biomass. This competition from the southeastern U.S. or other western states could potentially marginalize any suppliers in Arizona that attempt to enter the market.

Other strengths, weaknesses, opportunities and threats may exist between the Arizona to South Korea supply chain and within the South Korean market. This study examined the most relevant and pertinent issues which were identified from a combination of consulting with subject matter experts and knowledge of regional issues. Due to the uncertain nature of South Korean renewable energy policy, additional research will be needed to update these findings in the future.

Shipping woody biomass via rail and marine transport to South Korea can be an economically viable solution to Arizona’s biomass restoration issues. By developing long-term offtake agreements with Asian

buyers, Arizona could supply wood fiber to renewable energy markets in South Korea or Japan in an economically efficient and sustainable manner.

Opportunities and threats to the market must be weighed against the probabilities of those outcomes occurring. The SWOT diagram (Figure 3) is a visual representation of all the strengths, weakness, opportunities and threats for Arizona suppliers to deliver wood fiber to South Korean renewable energy markets. Detailed SWOT factor relative rankings are included in Appendix A.

SWOT Factor Scoring

Strengths, weakness, opportunities and threats were evaluated and scored on a relative scale, in comparison to every other key factor. An expert evaluation group assessed and scored each factor on a scale of 1 -10, with a score of 10 being the strongest. Factors deemed extremely strong to the proposition of shipping wood fiber to South Korea were given the highest rating, including the large market size and high price of wood chips in South Korea.

Factor scores for opportunities and threats recognized the probability that the factors would impact the proposition; that opportunities would be exploited, and threats avoided. The factor scores are scaled with a score of 10 having the highest probability of impacting the proposition, and a score of one having the lowest probability.

A weighting factor was assigned to each strength, weakness, opportunity and threat based on the relative importance and scale of impact with regard to the proposition of shipping wood fiber from Arizona to South Korean renewable energy markets. The weightings were scaled 1 – 10, with a rating of 10 having the greatest importance or largest impact, and a rating of one having the least importance.

Finally, a strategic impact score was calculated by multiplying the two ratings. This strategic impact score encompasses both strength of the SWOT factor or probability of occurrence, in combination with the weighting factor reflecting its importance. This calculation highlights the key SWOT factors in the analysis.

An example - The threat of supply disruption on national forest lands has a factor score of 3, reflecting the relatively low probability that an injunction would disrupt the wood supply from national forest thinning operations. However, the weight factor assigned to the importance and scale of impact is scored as an 8. With limited alternatives for wood supply in Arizona on private lands, an injunction or other disruption would have serious impacts on the project. Combining those two scores, the strategic impact score of 24 is relatively ordinary when comparing all SWOT factors. The probability of disruption is low, but the impact would have serious consequences.

Two strength factors, the large size of the wood fiber market in South Korea and the high price of the wood fiber paid by South Korean buyers, were specifically identified. These factors are relevant, effect the entire market, and have significant strategic impact. Two threat factors, the lack of long-term offtake agreements and the reliance on national forest lands for supply in Arizona, are specifically identified as well. The lack of long-term agreements is a significant issue today, has the potential to impact continued growth and the size of future markets. The reliance of national forest land for wood supply and potential for disruption is a significant threat. The probability of disruption is ranked low, but the impact would be large and limited options exist to mitigate those circumstances. Other significant opportunities and weaknesses are identified in similar fashion.

Arizona National Forests are unhealthy and overstocked with small-diameter trees. The Forest Service has initiated a project to restore more than one million acres of forests across Arizona, where a significant by-product will be small-diameter logs and woody biomass. At the current time, Arizona lacks the manufacturing infrastructure to sufficiently utilize all of the unmerchantable wood and biomass in a cost-effective manner. But international markets for biomass as a renewable fuel source do exist in both South Korea and Japan. Policies of the South Korean and Japanese governments encourage the use of woody biomass in generating renewable energy, which currently has the effect of increasing the value of biomass imports.

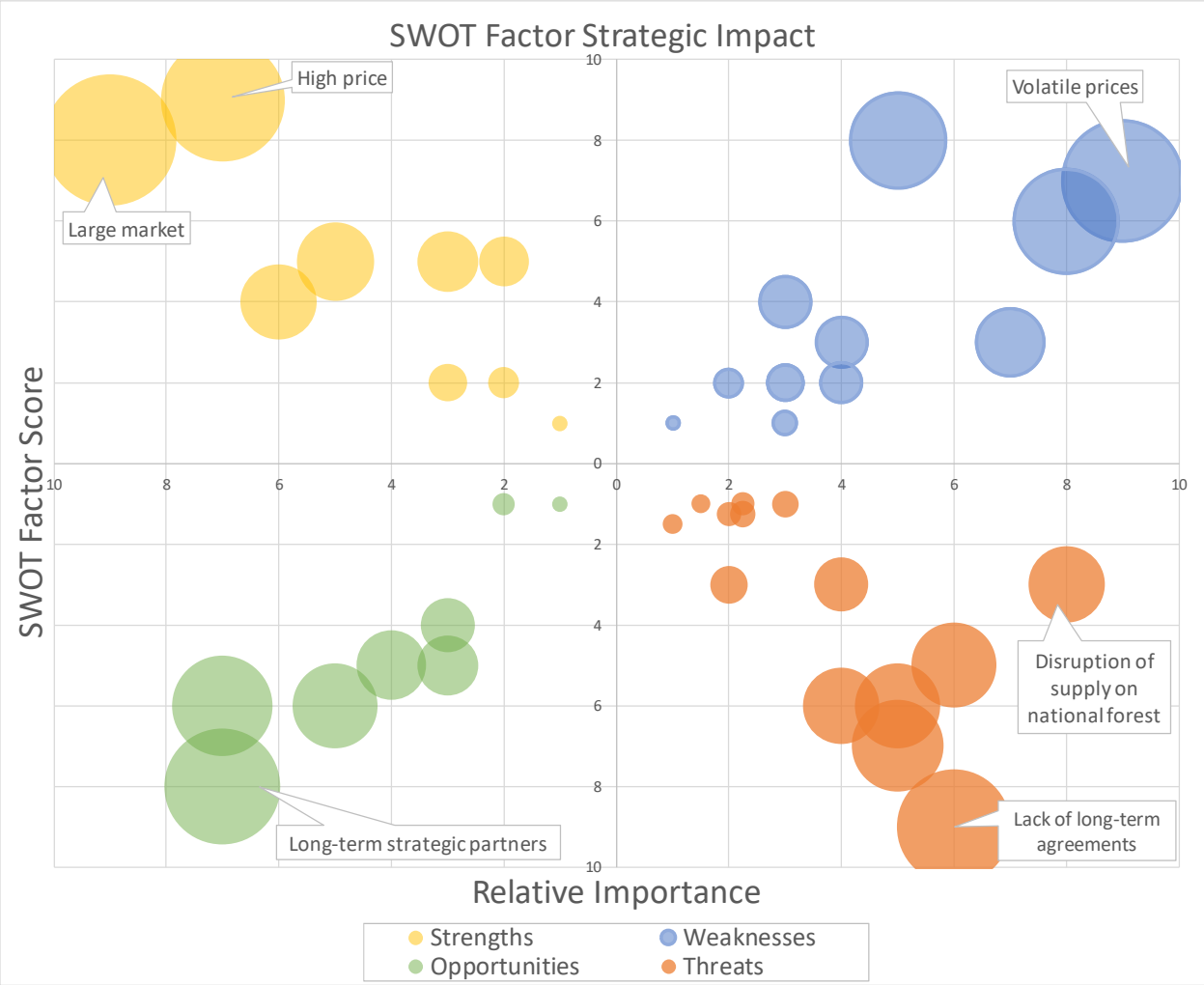

Figure 3. SWOT diagram representing strategic impact of various factors affecting the proposition of shipping wood fiber from Arizona to renewable energy markets in South Korea. SWOT Factors were evaluated and assigned a score by a panel of experts. The relative importance, or weighting factor, acknowledges the importance of the individual factors. Strategic impact, a calculation of SWOT factor rating and the weighting factor, is represented by bubble size. Individual factor scores are included in Appendix E.

Transportation costs are the largest cost associated with forest products. Transportation of woody biomass by tractor-trailer can become cost-prohibitive over long distances. Utilizing unique combinations of trucks, rail, and marine transport could extend supply chain boundaries. With integrated partners,

shipping woody biomass via rail from northern Arizona to the Port of Long Beach can be an economically feasible solution.

The South Korean renewable energy market is immature but expanding. Prices are more than double the price per ton as in the U.S. The size, policy support and future potential make shipping Arizona wood fiber to South Korea an attractive proposition. However, the stability of the market and insecurity of South Korean policy are risks that should be mitigated before investment into this market. Given everything we researched, there is good potential and opportunity for Arizona to supply wood fiber to South Korean renewable energy markets, with some limitations currently with infrastructure in northern Arizona.

Professional Ethics

Ethics is a guiding philosophy of what is morally important. As a member of the Society of American Foresters (SAF), I hold true, the principles laid out in the SAF Code of Ethics. Two principles which I find to be at the heart of my own ethics are; a forester's responsibility to manage forests for current and future generations, and sound science is the foundation upon which the forestry profession is built. These two principles were top-of-mind as this project was completed. This research may positively impact the future forest restoration landscape in Arizona. But that impact will only be realized if the research methods are sound and the management implications are appropriate.

The United States Forest Service motto sums up my feelings on forestry. The motto is, "Caring for the Land and Serving People." Becoming a professional forester is more than satisfying a self-interest; it is about protecting the environment, our forests, and working for the greater good. With this research, I provide open, honest and accurate information that will be publicly available for all.

Before coming to forestry, I spent more than fifteen years as a finance professional, and I understand professional business ethics. I have learned the importance of personal integrity and earning the trust of colleagues, clients and contemporaries. This fundamental understanding of the moral principles that I believe in and espouse is a key part of what makes me who I am. Ethics are about conviction and doing what is right, even when that is difficult.

In the words of conservationist Martin Litton, "It doesn't take many voices to make things right, just strong voices."

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Appendix

Appendix A. Listing of abbreviations and explanations used in the paper

Abbreviation	Explanation
4FRI	Four Forest Restoration Initiative
APHIS	Animal and Plant Health Inspection Service
BNSF	Burlington Northern Santa Fe
BTU	British Thermal Unit
EIS	Environmental Impact Statement
FAS	Free-along-side
FIT	Feed-in Tariff
FSC	Forest Stewardship Council
HMM	Hyundai Merchant Marine
IP	Import Permit
IPCC	International Plant Protection Convention
M	Million
MJ/kg	Megajoules per kilogram
MW	Megawatt
MWh	Megawatt-hour
NAPPO	North American Plant Protection Organization
NEPA	National Environmental Policy Act
OSB	Oriented Strand Board
PC	Phytosanitary Certificate
PKS	Palm Kernel Shell
REC	Renewable Energy Certificate
RPS	Renewable Portforlio Standards
SFI	Sustainable Forestry Initiative
SRF	Solid Recovered Fuel
SWOT	Strengths, weakness, opportunities & threats
USDA	United States Department of Agriculture

Appendix B. South Korean softwood charcoal specifications. Source: National Forest Research Institute, South Korea

Property	Wood Charcoal
Size	7% less than 3cm
Moisture Content	below 10%
Ash Content	5.5% or less
High Heat Content	6,200 kcal / kg or more
Arsenic (As)	1.0 mg / gk or less
Cadmium (Cd)	1.5 mg / gk or less
Lead (Pb)	30.0 mg / gk or less
Mercury (Hg)	0.15 mg / gk or less

Appendix C. South Korean wood briquette specifications. Source: National Forest Research Institute, South Korea

Property	Unit	Class		
		A1	A2	B
Moisture Content	%	≤ 12	≤ 15	≤ 15
Ash Content	% dry	≤ 0.7	≤ 1.5	≤ 3.0
Density	g / cm^2	≥ 1.0	≥ 1.0	≥ 0.9
Additive	%	≤ 2	≤ 2	≤ 2
Net Caloric Value	MJ / kg	≥ 15.5	≥ 15.3	≥ 14.9
Nitrogen (N)	%	≤ 0.3	≤ 0.5	≤ 1.0
Sulfur (S)	%	≤ 0.03	≤ 0.03	≤ 0.04
Chlorine (Cl)	%	≤ 0.02	≤ 0.02	≤ 0.03
Arsenic (As)	mg / kg	≤ 1	≤ 1	≤ 1
Cadmium (Cd)	mg / kg	≤ 0.5	≤ 0.5	≤ 0.5
Chromium (Cr)	mg / kg	≤ 10	≤ 10	≤ 10
Copper (Cu)	mg / kg	≤ 10	≤ 10	≤ 10
Lead (Pb)	mg / kg	≤ 10	≤ 10	≤ 10
Mercury (Hg)	mg / kg	≤ 0.1	≤ 0.1	≤ 0.1
Nickel (Ni)	mg / kg	≤ 10	≤ 10	≤ 10
Zinc (Zn)	mg / kg	≤ 100	≤ 100	≤ 100

Appendix D. South Korean biochar specifications. Source: National Forest Research Institute, South Korea

Property	Unit	Residential Grade				Industrial Grade	Ignition Grade
		1		2			
		Without Ignition Agent	With Ignition Agent	Without Ignition Agent	With Ignition Agent		
Moisture Content	%	≤ 10	≤ 10	≤ 10	≤ 10	≤ 10	≤ 10
Ash Content	% dry	≤ 5.5	≤ 25	≤ 10	≤ 40	≤ 25	≤ 40
Fixed Carbon	%	≥ 65	≥ 30	≥ 50	≥ 20	≥ 35	≥ 20
Net Caloric Value	kcal / kg	≥ 6,200	≥ 4,800	≥ 5,400	≥ 3,000	≥ 5,000	≥ 3,000
Barium (Ba)	%	0	≤ 10.5	0	≤ 10.5	≤ 10.5	≤ 10.5
Arsenic (As)	mg / kg	≤ 1.0				≤ 5.0	
Cadmium (Cd)	mg / kg	≤ 1.5				≤ 5.0	
Lead (Pb)	mg / kg	≤ 30				≤ 50	
Mercury (Hg)	mg / kg	≤ 1.5				≤ 0.25	
Sulfur (S)	%	≤ 1.5				≤ 0.25	

Appendix E. SWOT factors affecting the proposition of shipping wood fiber from Arizona to renewable energy markets in South Korea. SWOT Factor Scores were assigned after an evaluation by a panel of experts. The Relative Importance, or weighting factor, acknowledges the importance of the individual factors. Strategic impact is a calculation of the SWOT factor rating and the weighting factor.

	SWOT Factor	Factor Score	Relative Importance	Strategic Impact
Strength	Large market (top 10 energy consumer)	8	9	72
	High price - Can be more than double US price	9	7	63
	Korea will need to import 75-80% of biomass fuel	5	5	25
	RPS scheme support in South Korea	4	6	24
	Increasing Renewable Portfolio Standards % through 2024	5	3	15
	Strong demand - estimate of 6 M metric tons/year by 2021	5	2	10
	Low quality and sustainability requirements for biomass fuel	2	3	6
	Development of additional dedicated biomass production capacity	2	2	4
	Advanced technology in dedicated biomass plants	1	1	1
Weakness	REC prices and spot rate are directly and highly correlated	7	9	63
	Uncertain future beyond RPS scheme	6	8	48
	Reliance on National Forests for wood fiber in AZ	8	5	40
	Limited transportation partners and limited access to rail (railroad oligopoly)	3	7	21
	Vietnam has current oversupply of pellets	3	4	12
	Single market and lack of liquidity - too few suppliers & customers	4	3	12
	Supply disruptions can have significant impact	2	4	8
	Lack of a single large company in the supply market	2	3	6
	High initial moisture content of northern Arizona ponderosa pine	2	3	6
	South Korea is favoring domestic biomass with higher RECs	2	2	4
	Whole tree chips versus clean chips - moisture content (MC%)	1	3	3
	Lack ofdeep water port facilities	1	1	1
Opportunity	Long term supply agreements	8	7	56
	Japan is paying premium price	6	7	42
	Large Japanese market	6	5	30
	Greater BTUs over Vietnam & Malaysia supplies	5	4	20
	Vietnam holds >60% of market; sustainably tapped at this level	5	3	15
	Sustainability and quality, opportunity over Vietnam & Malaysia	4	3	12
	Phasing out solid recovered fuel (SRF) as part of REC	1	2	2
	Pinnacle or large pellet maker to open a facility in Southwestern US	1	1	1
Threat	No long-term offtake agreements in Korea	9	6	54
	Fluid policy; timing & RECs per MWH decreasing, regulatory uncertainty	7	5	35
	Potential South Korean policy changes - phytosanitation requirements	6	5	30
	Sustainable certification is difficult/impossible on national forest lands	5	6	30
	Potential South Korean policy changes - 3rd party sustainability certification	6	4	24
	Legal action; injunctions on NF lands; lack of private land (supply issues)	3	8	24
	Wind / solar take a larger share of RPS	3	4	12
	Domestic competition for wood supply	3	2	6
	Competition from within US, possibly at lower price	3	2	6
	Electricity prices	1	3	3
	Bark beetle or other infectious disease epidemic in SW	1	2	2
	Nuclear power, shale gas	1	2	2
	Loss of co-firing RECs	1	2	2
	Wildfire	1	2	2
	Storage: in country or in US SW; storage exists in US SE & BC CA	1	2	2
	Oil prices	2	1	2