Appendix A-2

Detailed Supply Chain Summary and Waste Assessment

1. Approach

The detailed supply chain reviews focus on characterizing some of Washington's most intriguing ag goods. These include apples, Washington's most valuable crop; potatoes, the crop processed in the largest quantity; and grapes, a crop that has experienced rapid growth for processing and cultivation in the recent past. Focus is placed on biomass, energy, and water along each of these supply chains with the goal of identifying opportunities to implement symbiosis as well as the likely barriers that would limit its adoption. The Following were questions we used to describe each supply chain:

Flow of Material between farms, storage, and processors

- How are crops used, are they sold fresh or processed?
- What types of facilities are used in the supply chain?
- What is the balance between quantity and quality in determining crop value?

Farm level trends

- Where are crops grown?
- How large are individual farms?
- How have farms changed in the recent past?

Storage

- Is storage on-farm, owned by cooperatives, or at processors?
- Does storage result in waste biomass, water or energy?
- When are crops available throughout the year?

Processing

- How much waste, residual biomass, water, and energy are generated?
- Is the waste sold to other markets already?
- How does scale impact operations?

Symbiosis Examples

- Are there existing examples of symbiosis within the supply chain?

2. Key Findings

Each supply chain is significantly different, so studying three supply chains with one methodology provided useful insights into opportunities to implement agricultural-industrial symbiosis. The list below describes key observations:

- Seasonality is an important consideration for all elements of supply chains. Some crops, like potatoes, can be stored and processed throughout the year, while others, like grapes, have a short processing season.
- The number and scale of processors is variable across industries. There are hundreds of wineries in Washington, while there are just a handful of tree fruit and potato processors. Depending on the approach being used for symbiosis, either type of facility may be preferable.
- Efficiency is an emphasis for most companies already. High value food waste is typically sold as cattle feed and wastewater is often used for irrigation. Exceptions to this observation are typically at storage facilities and smaller processors.
- The location of supply chain elements is also an important consideration. Tree Fruit processors are all in cities in the Yakima Valley, and are often located near other industrial facilities. Some wine and potato processors are in cities, like Pasco, Richland, and Quincy, which have other types of industry nearby, while others are relatively isolated from potential symbiosis partners.

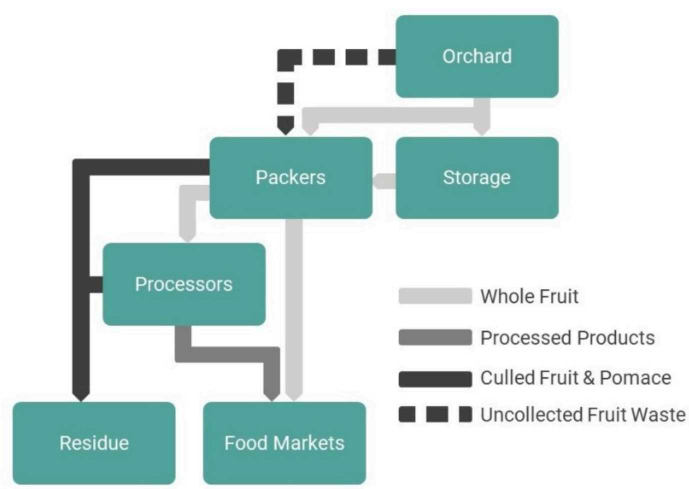

Figure A-2.1: General tree fruit supply chain

3. Tree Fruit Supply Chain

3.1 Supply Chain Overview

The supply chain for tree fruit is a multi-stepped process that results in both fresh fruit and processed foods that are available to consumers throughout the year. As shown in Figure A-2.1, the supply chain begins at the orchard. Following harvest, fruit is delivered to warehouses that store and pack fruit. The roles of individual warehouses can vary as some packing houses also have fruit storage capacity, with the ability to store some or all of the fruit they pack in a year. The supply chain also varies depending on the type of fruit. Pome fruit, which include apples and pears, can be stored for several months after harvest in a controlled atmosphere environment. Cherries, which are a type of stone fruit, begin to spoil quickly after harvest, and are rushed directly to packing houses.

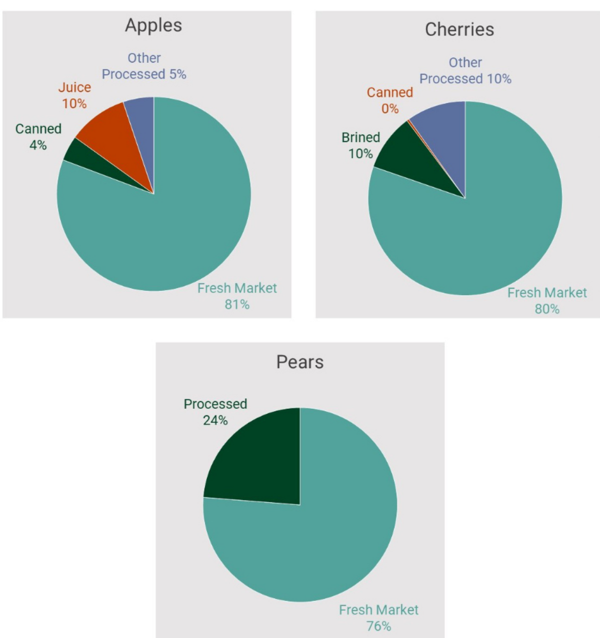

Figure A-2.2: Usage rates for tree fruit grown in Washington, 2016

One of the key functions of packing houses is fruit sorting, which determines whether fruit is suitable for the fresh market or processing. As shown in figure A-2.2, depending on the species, between 81 and 76 percent of fruit is sold fresh [1].

In this context, the term “fresh” refers to any whole, unprocessed fruit, regardless of the length of the time the fruit has been held in storage. The storage lifespan of pome fruits can vary from a few months to a year depending on the variety. Fresh market fruit is sold to a wide variety of clients, with most fruit going to either export or domestic wholesale for uses in restaurants and sales in grocery stores [2]. Some lower quality fruit is suitable for processors. Several in-state companies make an array of products including juice, sauce, dehydrated fruit, fruit essence, and fresh-sliced packaged fruit.

3.1 Orchard trends

As shown in figure 3, the tree fruit industry is mostly limited to a strip of Washington that runs north and south along the east side of the Cascade Mountains [3]. The USDA has divided this region into three areas: the Yakima Valley which includes Benton, Kittitas and Yakima Counties; the Columbia Basin which includes Adams, Franklin and Grant counties; and Wenatchee which includes Chelan, Douglas, and Okanogan counties [4]. Apples have always been the dominant tree fruit in Washington and comprised 74% of the total tree fruit acreage during the last Census of Agriculture in 2017 [5]. Sweet cherries came second with 17% and pears third with 9%. Small amounts of other stone fruit like apricots, nectarines, plums, sour cherries, and peaches are also grown in Washington. The Yakima Valley contained 38% of total tree fruit acreage in the state, the Columbia Basin 32% and Wenatchee 23%. Most of the remaining 7% of acreage was in Klickitat and Walla Walla counties.

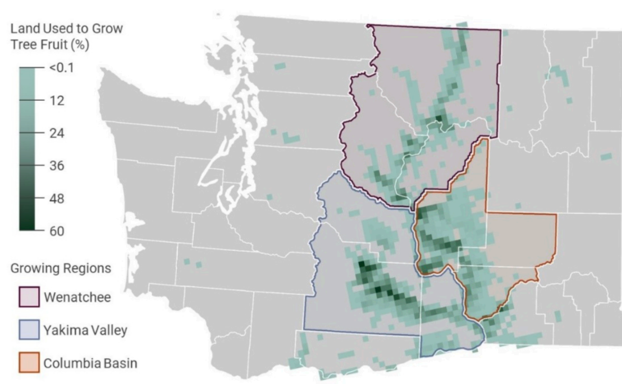

Figure A-2.3: The tree fruit growing region in Washington

As shown in figure A-2.3, the tree fruit industry is mostly limited to a strip of Washington that runs north and south along the east side of the Cascade Mountains [3]. The USDA has divided this region into three areas: the Yakima Valley which includes Benton, Kittitas and Yakima Counties; the Columbia Basin which includes Adams, Franklin and Grant counties; and Wenatchee which includes Chelan, Douglas, and Okanogan counties [4]. Apples have always been the dominant tree fruit in Washington and comprised 74% of the total tree fruit acreage during the last Census of Agriculture in 2017 [5]. Sweet cherries came second with 17% and pears third with 9%. Small amounts of other stone fruit like apricots, nectarines, plums, sour cherries, and peaches are also grown in Washington. The Yakima Valley contained 38% of total tree fruit acreage in the state, the Columbia Basin 32% and Wenatchee 23%. Most of the remaining 7% of acreage was in Klickitat and Walla Walla counties.

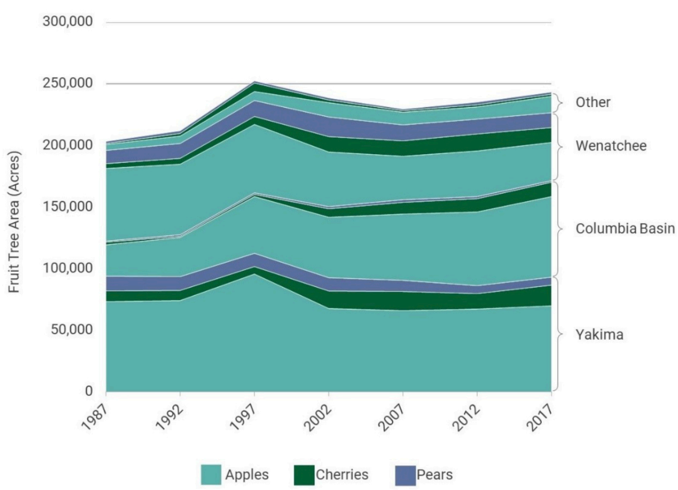

Figure A-2.4: Tree Fruit Acreage in Washington

Figure A-2.4 uses data from 7 consecutive agriculture censes [5]–[10] to show trends in overall acreage. Across the state, total acreage increased 19% between 1987 and 2017 from 203,000 to 243,000 acres. Cherry acreage almost tripled with a 173% increase, apple acreage increased 10% and pear acreage fell 17%.

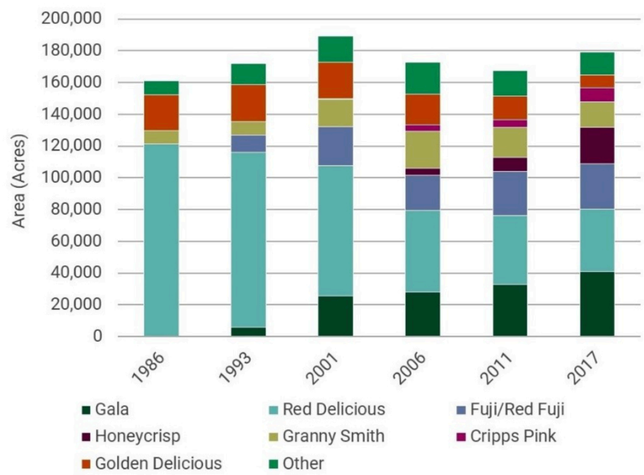

Figure A-2.5: Washington Apple Varieties

In 1997, total apple acreage peaked, in what would be a temporary bubble, as farmers were faced with reduced demand for red delicious apples. As shown in Figure A-2.5, this bubble was followed by a large number of orchards being replaced with new varieties [4]. As of 2017, 69% of apple acreage in Washington had been planted since 1996. Other orchards either went out of business or changed fruit species altogether [2], so that only 27% of apple trees in production in 1996 were still in production in 2017.

The decline in pear acreage has mostly been due to a halving of acreage in the Yakima Valley. But this trend was not consistent throughout the state. In 2017, Wenatchee contained 57% of the state's pears after an increase in acreage of 12% over the past 30 years.

The Columbia Basin experienced an overall 173% increase in acreage between 1987 and 2017.

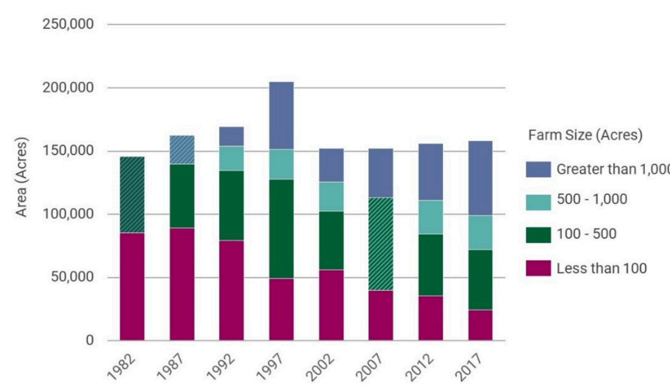

Figure A-2.6: Orchard Acreage held by Farm Size

Unlike the Yakima and Wenatchee areas, it was not subject to the “apple bubble” acreage decrease in the late 90’s, likely because the Columbia Basin was an area that was newer to the fruit industry at the time and had fewer established orchards with out-of-fashion varieties.

As shown in figure A-2.6 [11]–[17], another ongoing and significant trend is the consolidation of the orchard sector [2], [18]. Since 2002, total acreage has stabilized and is easier to analyze. Over the period of these censuses, an increase in orchard land held by large landholders has increased at a rate greater than 8% than the preceding census. Land held by small size operations has also consistently decreased at a rate of 4% per census.

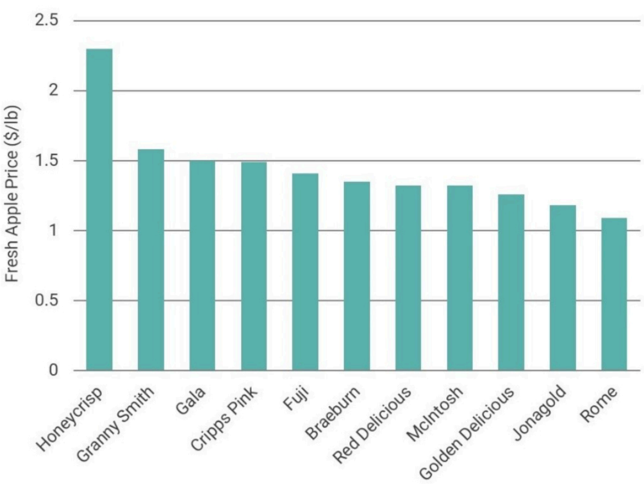

Figure A-2.7: 2022 US Apple Prices

Variety selection for fruit is based on orchard expected return, so farmers are continuously working to modernize their orchards with new varieties that offer improved flavor, appearance, easier management and hardiness. Particularly the apple industry has seen a major shift towards newer varieties. As one example, the Honeycrisp variety began to experience a rapid rise in popularity in the mid 2000’s [4] following its release by the University of Minnesota in 1992 [19]. Farmers have mostly been attracted to Honeycrisp by its industry-leading prices, as shown in Figure A-2.7, as average non-organic Honeycrisp apples sold for 40% more than the classics red delicious and golden delicious [20]. But the price of fresh market fruit is not the only metric that farmers use. Honeycrisp has one of the lowest fresh-use rates of any variety due to a relatively high rate of defects, particularly bitter pit [19], in the fruit and a relatively short storage lifes [21]. As shown in figure A-2.8, despite being the 3rd most-produced variety in 2022, more Honeycrisp apples were sent to processors than the first and second most-produced varieties. Figure A-2.8 was calculated using tables 7 & 11 in the 2022 Apple Outlook Report [20].

This means that not all farmers have determined that purchasing Honeycrisp saplings is the most economical decision, and other varieties like Gala and Fuji, which sell for less than Honeycrisp, but still have a higher value than the once dominant Red Delicious, have also seen an increase in acreage throughout the 2000s. Even as the market shares of these newer varieties continue to grow, more new varieties are also beginning to enter the market. For instance, two varieties on the rise, Cosmic Crisp and SweeTango, were both crossbred from Honeycrisp [22], [23].

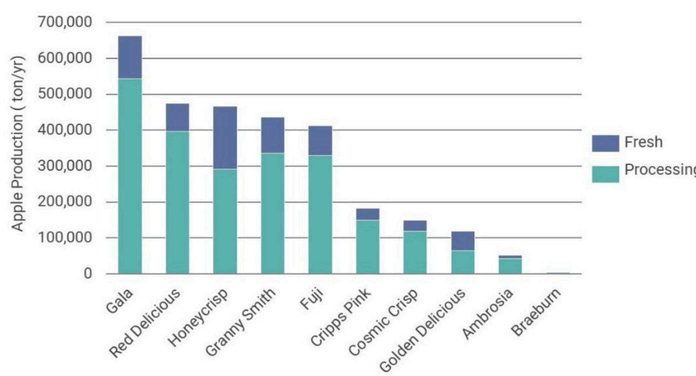

Figure A-2.8: Production and use of apple varieties, Washington, 2022 (Calculated)

Different fruit varieties are harvested at different points throughout the season, as the harvest window for each variety is typically just a couple weeks. Orchards grow multiple varieties of one type of fruit so that the harvest can be staggered over a longer period, requiring a smaller number of laborers for a longer period of time [2]. The apple harvest begins in the late summer and continues through late fall. Harvest dates are also dependent on weather, so year-to-year variations and local climates can shift harvest windows by weeks. The major varieties picked early in the season include Gala, Honeycrisp, and Golden Delicious; mid-season varieties include Red Delicious, Granny Smith, and Cosmic Crisp; and late season varieties include Fuji and Cripps Pink (Pink Lady). Pear season roughly coincides with apple season. Summer pears, which are primarily Bartlett pears, are harvested in August. Winter pears, include Anjou and Bosc pears, and are harvested in late August and September [24].

Cherry season begins several months earlier than pome fruit harvest. It runs from mid spring to late summer, depending on the variety and climate. Bing cherries are frequently used as a benchmark to compare other varieties because they account for half of the state's total acreage [25]. Harvest for Bing cherries starts in the early-to-mid season at roughly the same time as Rainier cherries; Chelan cherries are harvested one to two weeks earlier; and Lapin, Skeena, and Sweetheart cherries are harvested one to three weeks later.

3.2 Fruit Packing and Storage

As shown in figure A-2.9, there are more than 60 active fruit packing and storage companies in Washington, and the industry is disaggregated. As is shown in figure A-2.10, no company reported handling more than 7% of the state's total packing or storage capacity over the last three years. Data was collected from permits [26]. Consolidation has been a long-term trend in the packing industry, as there were 154 packing houses in 1985 [2]. Some areas have been more affected by this trend, like Brewster where several companies have consolidated and Waitsburg where the largest packer in the state handles a significant amount of fruit from Franklin and Walla Walla counties. Areas where the fruit growing industry has existed the longest, particularly Yakima and Wenatchee, have more established infrastructure, while the Columbia Basin has relatively few packing and storage facilities. Pome fruit can be stored for months after harvest. A survey of Washington fruit packers found that most storage facilities use controlled atmosphere storage, which holds fruit at specific set points for oxygen, carbon dioxide, and temperature among other variables to maximize the storage life [27], [28]. Some facilities also use a dynamically controlled atmosphere, which is more intensively managed and varies storage set points throughout the year [29]. Depending on the variety and storage technique, apples can typically be stored for 10 – 12 months. Honeycrisp is the most notable exception with its relatively short six-month storage life [21]. Most pears have a shorter storage life than apples, as Bartlett pears last approximately 6 months, Bosc last 8 months, and Anjou last 10 months.

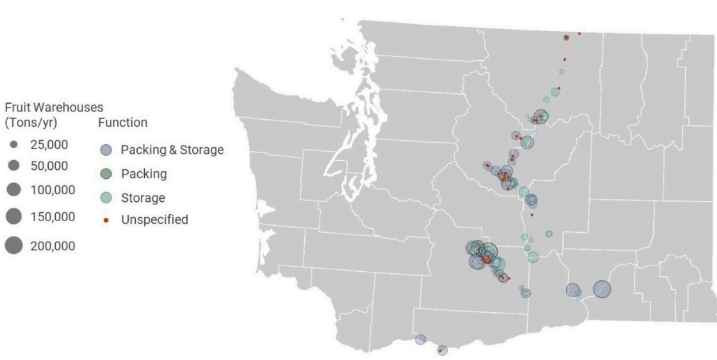

Figure A-2.9: Locations of fruit packers

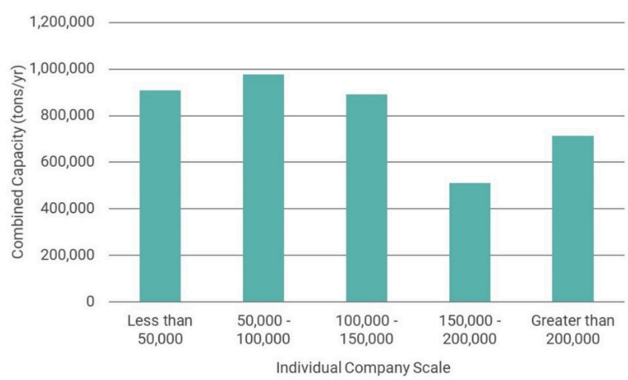

Figure A-2.10: Most fruit packers are mid-sized companies

Cherries have a much shorter storage life than pome fruit. Following harvest, packers rush to cool cherries. After picking, each hour that the internal temperature of cherries are over 40 degrees is equivalent to one less day of shelf life at stores [30]. Immediate measures to jump-start the packing process even before arrival to the packing house may be taken. Stemilt uses mobile equipment that begins the cooling process at the orchard [30]. Once cherries are cooled, they are sent to markets as soon as possible.

3.2 Fruit Processing

The distribution of fruit is dependent on grading. The highest quality fruit are sold for the fresh market, while lower quality fruit are either sold to secondary fresh markets, processors, or culled. The differences between the higher quality grades is based solely on appearance, like whether an apple has the specified amount of red color on its skin [31]. In lower quality grades, a variety of other defects that affect taste and texture may also be present. Fruit with rot is not sold for human consumption. These different grades result in a price hierarchy for apples and pears. As shown in Figure A-2.11, fresh fruit sell for significantly more than any other grade [32]. Next fresh slices, frozen, canned, dried, and juice markets offer the best prices in that order. In general, the uses that modify the fruit the least pay the most for the fruit.

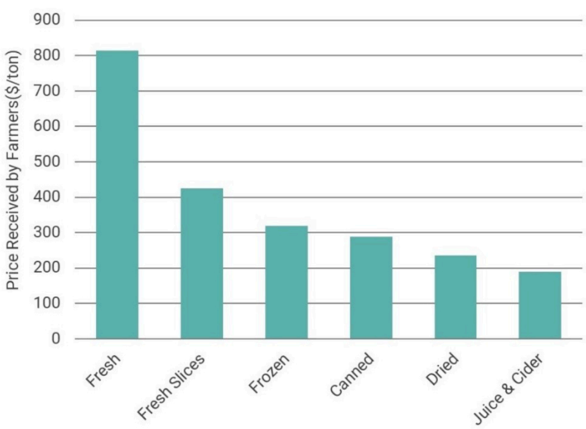

Figure A-2.11: Apple Prices by use, 2017, United States

Fruit processors are located in four areas: Wenatchee, Yakima, Prosser/Sunnyside/Grandview, and Royal City. While there are many companies that use tree fruit in their products, the focus of this work is directed towards companies that process larger quantities. Figure A-2.12 shows fruit processors in Washington. Processors were identified through the water permit database [26].

There are seven juice processors in Washington. Key processes for fruit juice canning include washing, juice extraction (crushing), steam pasteurization, and packaging. Some plants also concentrate fruit juices using steam, replacing the need to pasteurize later. The residuals from juicing consist of pomace from whole the crushed fruit. The largest apple processor is Tree Top, which primarily makes apple juice. Tree Top is a cooperative [33] owned by farmers throughout the region and has existing relationships with an adjacent winery owned by Zirkle Fruit [34].

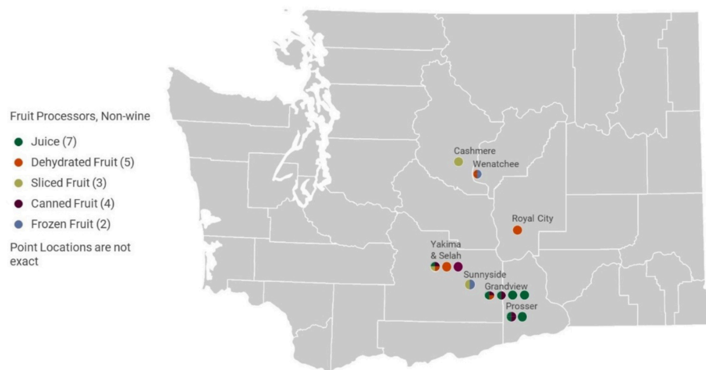

Figure A-2.12: Fruit Processors, by output type

There are four sauce processors in Washington, which are located in the Yakima Valley. Most fruit sauces consist of apples, although other fruit like grapes may be used. Key processes consist of washing, coring and peeling, slicing or crushing, filling, and heat sterilization.

Two sliced apple plants operate in Washington. Sliced fruit processing is relatively simple, as fruit is sliced, sprayed with agents to inhibit browning, and packaged.

Other fruit processing primarily serves to make intermediary ingredients for other foods like fruited breads and snacks. The processes to make these products vary from plant to plant, depending on the specifications that are demanded at different locations.

3.2 Waste Biomass Inventory

Waste biomass from the fruit industry can be generated from a variety of sources, like annual orchard thinning waste, or periodic orchard tearout when aging trees are replaced. The most valuable waste is culled fruit. At the orchard level, waste fruit can either fall on the ground prior to harvest or be rejected and dropped on the ground by fruit pickers. While this is a potentially a significant source of fruit, it is typically not collected. Especially fruit that falls on the ground can harbor pathogens, so it needs to be collected separately from regular fruit picking [35], although waste fruit can also cause issues for orchard management [36], [37]. Fruit lost in orchards can sometimes be mulched along with other waste like thinned branches and then spread over the trunks of trees to fertilize following crops [37]. At packing houses, fruit that is not deemed suitable for the fresh market are then graded for the processing market, or as a last resort, culled. The waste generated by fruit processors is dependent on partially dependent on the type of processor, but generally this waste is called pomace and consists of skins, peels, stems, seeds, and cores of fruit [38].

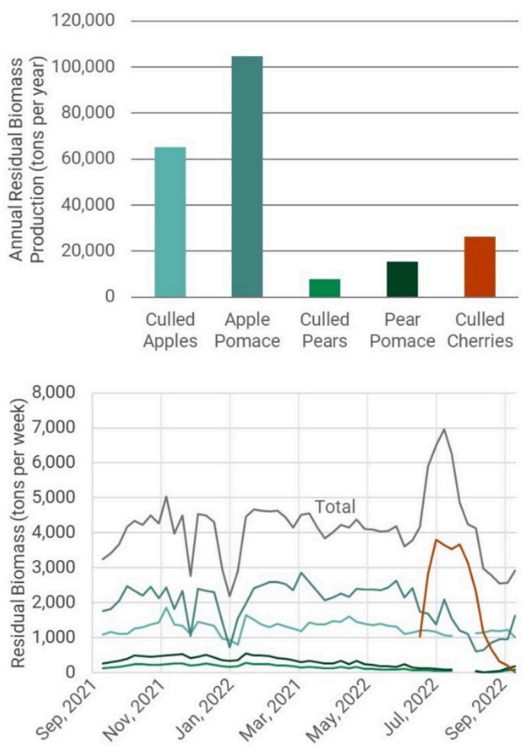

Figure A-2.13: Fruit Waste Seasonality during the 2021 season

As shown in figure A-2.13, shipments of fruit throughout the year can be used as an indicator for when waste fruit is available [39]–[41]. For pome fruit, shipments to fresh markets and processors are continuous throughout the year, but not at a constant rate. At the start of the harvest season, shipments are in a lull, which begin to ramp-up following the harvest of the first major varieties in mid-September. For the next several months, shipments occur at a steady rate, with the exception of interruptions around the major winter holidays. By late May, apple shipments begin to decline until the end of summer when the next season’s apples begin to ship. The drop in shipment quantities in May is likely due to a combination of factors, as the storage lifespan of most major apple varieties begin to expire over the summer and packers are also likely trying to clear space for the cherry harvest and then the next year’s apple harvest. Pear shipments begin to decrease by mid-winter as some varieties run out of stock due to the shorter storage lifespan of pears. Cherry shipments begin immediately after the start of cherry harvest and mirror the rate of harvest. Once the cherry season is over, shipment quickly comes to an end.

For pome fruit, the cull rate makes up a relatively small percent of the total fruit because there are several secondary processing markets with purchasers located throughout the growing region. No explicit information about cull rates is available, but between 2017 and 2021 3% of apples in the US were listed as unsold [20]. In Washington, the unsold rate was 4.6% over the same period [42].

Cherries have a much higher cull rate than the other fruit because there are fewer secondary markets for damaged fruit. While processed cherries make up a significant amount of the overall market, these cherries are often purpose grown with a variety that lends itself to brining [43]. Some sorted-out fruit may also be used, but many cherries are processed whole, so it should be assumed that all rejected fruit is suitable for processing. According to the WSU enterprise budget, typical cull rates are 20% and farmers should expect to receive a price for culls that is between 10% and 2.5% of fresh market cherries [44].

Pomace generation rates can be difficult to find on a company by company basis, but have been reported to vary between 9-45% in water permits. Waste is highest for products where the fruit is kept whole, or in large pieces, like sliced apples. A "general rate" of 25% is used for fruit pomace generation in Figure A-2.12 [38], [45].

3.3 Biomass Uses

Waste fruit currently has several uses. Most processors and some fruit packers sell fruit for cattle feed. As shown in Figure A-2.14, a significant amount of waste fruit from fruit packing facilities is also landfilled, representing a significant opportunity.

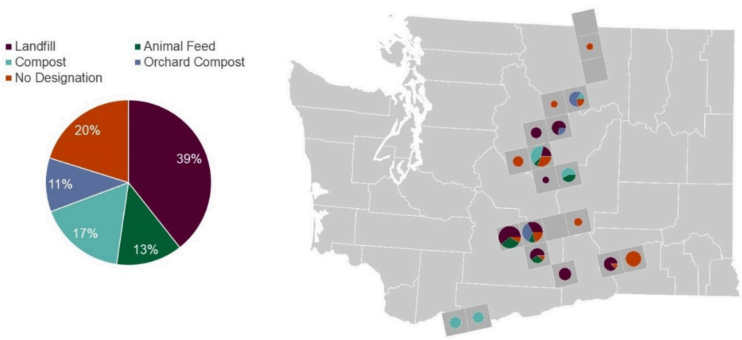

Figure A-2.14: Reported waste fruit uses by fruit packers

Residual fruit can be used as a forage replacement in animal feed for cattle and hogs [46]. It is a succulent feed, meaning animals like to eat it, and it is particularly high in fiber [47]. In diet formulations, residual fruit is fed as a forage component, working in a similar function as corn silage. Feeding rates for residual fruit can vary depending on diet formulations, but typical feeding rates for both growing cattle and milking heifers are near 18 pounds per day [47]. One potential challenge is whether or not culled cherries can be fed to cattle. The flesh of cherries is non-toxic, but the pits and leaves are poisonous [48].

Fruit waste has been widely researched as a potential component for anaerobic digestors that produce biogas. At least one study has been conducted to determine biogas potential from an apple and manure slurry [49].

Some packing companies also own orchards. One option for these companies is to recycle their own residuals by composting. For instance, Stemilt composts fruit waste, thinned branches and leaves, locally procured manure, and lime at a composting facility near their orchards [50]. This approach reduces fertilizer demand in addition to reducing fruit waste. Milne Fruit also sells waste fruit to wineries that use it to compost in their vineyards.

3.4 Water

Water is consumed at each level of the supply chain, but some water is difficult to collect, particularly irrigation water. Water from storage, packing, and processing is easier to collect and reuse. Based on estimates derived from water consumption reports from water permits, fruit storage requires approximately 0.1 gallons per ton and fruit packing requires approximately 2 gallons per ton. Water consumption is highly variable by plant. Part of the variability is due to the different products lines that each plant has, although some procedures, like washing, are universal. But the variability is also dependent on the design of the facility. Some have equipment that either uses less water or collects and recycles water [51].

The wastewater quality from fruit depends on the processes the water has been used for. Water used for cooling, or non-contact cooling water (NCCW) has higher temperatures and softening agents that can foul the water. Fruit washing water and evaporated water from juice concentration contains organics. Water used for drenching fruit before storage has pesticide chemicals [52].

3.5 Energy Consumption

Energy consumption values are not available on a plant-by-plant basis in the state of Washington, but several broad industry assessments have been conducted that identify sources that can be recycled. Fruit processors produce steam to concentrate fruit juice and sterilize containers [53]. The hot water used for refrigeration at storage facilities may also be a source of energy.

Tree Fruit References

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4. Potatoes Supply Chain Overview

The Washington potato supply chain includes farmers, packers, processors, and multiple markets for an array of products. As shown in Figure A-2.15, the supply chain begins by harvesting potatoes on farms. After harvest, potatoes are stored in sheds located near farms for up to one year. Fresh potato packers typically operate as an extension onto storage sheds, so they are also located near farms. As shown in Figure A-2.16, most potatoes are sent to processing plants [1]. Primary potato products from Washington processors include frozen French fries, dehydrated potatoes, chilled ready-to-eat dishes and IQF (individually-quick-frozen) potato pieces. Starch slurries, which are a byproduct of processing, can also be sold to make food ingredients and industrial supplies.

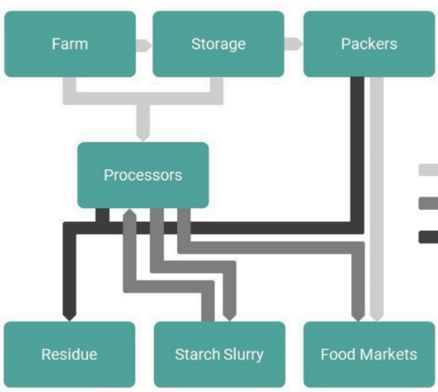

Figure A-2.15: Potato Supply Chain

The Washington potato supply chain includes farmers, packers, processors, and multiple markets for an array of products. As shown in Figure A-2.15, the supply chain begins by harvesting potatoes on farms. After harvest, potatoes are stored in sheds located near farms for up to one year. Fresh potato packers typically operate as an extension onto storage sheds, so they are also located near farms. As shown in Figure A-2.16, most potatoes are sent to processing plants [1]. Primary potato products from Washington processors include frozen French fries, dehydrated potatoes, chilled ready-to-eat dishes and IQF (individually-quick-frozen) potato pieces. Starch slurries, which are a byproduct of processing, can also be sold to make food ingredients and industrial supplies.

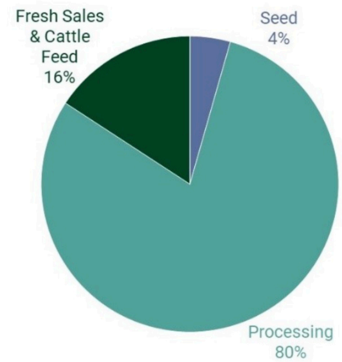

Figure A-2.16: Potato Sales in Washington and Oregon by Volume, 2019 – 2021

Agricultural practices for potatoes vary across Washington. As shown in Figure A-2.17, most Washington potatoes are grown in Eastern Washington [2]. Potatoes in this area are typically grown in 3- or 4-year rotations with a variety of grains, vegetable, and hay crops that often include alfalfa, field corn, sweet corn, beans, onions, carrots, and wheat [3]. Rotations in Northwest Washington are typically three years and may include field corn, vegetables, and berries.

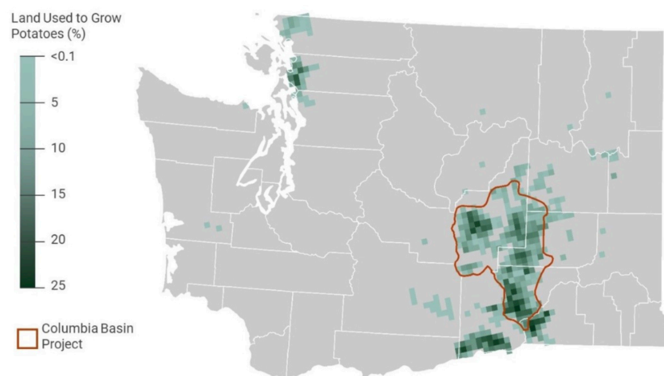

Figure A-2.17: Potato cultivation in Washington, 2021

Several types of potatoes are grown in Washington, but the most important varieties are Russet potatoes which are preferred by the state's potato processing industry due to their high specific gravity and large size [4]. Between 2016 and 2022, 80% of all potatoes grown in Washington were Russets, while white potatoes accounted for just 12%, red and blue potatoes 5%, and yellow potatoes 3% . Russet potatoes can be further divided into several varieties including Burbank, Nortkotah, Umatilla, Ranger, and several others [1]. In 1991, 83% of potatoes were planted to Russet Burbank, but by 2016 just 31% were planted to Burbank [5], as other varieties have recently become more popular for several reasons including appearance, storage characteristics, and resistance to diseases and pests. Farms in the south Columbia Basin typically grow potato varieties that are delivered fresh to processors, instead of stored [3]. Farms in Northwest Washington specialize in growing potatoes for the fresh market, with about half of the acreage being planted to red potatoes [3]. Potato varieties are also susceptible to rapid changes in market conditions. The widespread outbreak of covid-19 in 2020 resulted in a reduced demand for French fries from restaurants [6]. Between 2019 and 2021, the percentage of acres planted to Russet for all of Washington fell from 84% to 75%.

Major irrigation works, like the Columbia Basin Project shown in Figure A-2.17, make potato farming feasible in the arid shrub steppe environment of Eastern Washington [7]. The Columbia Basin Project distributes water from the Columbia River through a series of canals and reservoirs from the Grand Coulee Dam to Pasco [8]. It is particularly significant, as it supplied water to 62% of the state's potato acres in 2021. Another 31% of potato acreage was grown in a combination of state and privately-operated irrigation projects in Eastern Washington. Some areas, like the Horse Heaven Hills, along the Columbia River in Benton County have at least partially used ground water for irrigation in the past although the historic usage is not considered sustainable over the long term [9]. While not on the scale of the Columbia Basin Project, private projects that draw water from the Columbia, Snake, and Yakima Rivers supply a significant

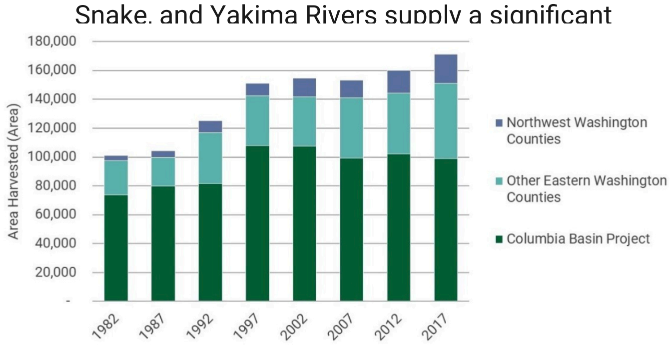

Figure A-2.18: Potato Acreage over time

Over the last 40 years, the area used to grow potatoes has changed significantly. As shown in Figure A-2.18, acreage increased in areas throughout the state between 1982 and 1997 [11]–[14] [15]–[18]. Since 1997, acreage in the Columbia Basin has decreased slightly while acreage has increased in other parts of Eastern Washington and Western Washington. Over this same period, yields have also increased substantially. Between 1957 and 2007, the average Washington Potato yield increased by an average of 7% per year [3].

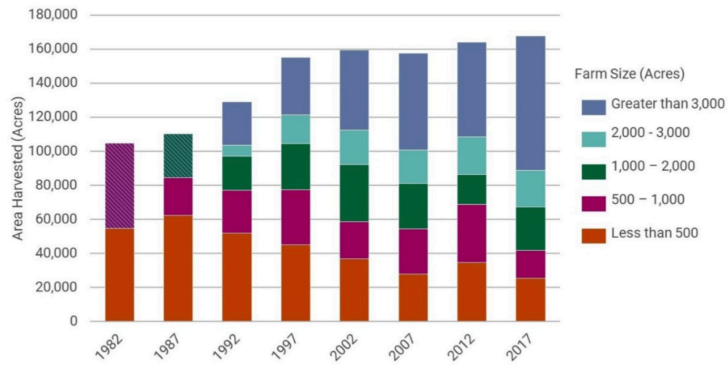

Figure A-2.19: Potato acres by farm size

One consistent trend in potato cultivation has been the increasing size of farms. As shown in Figure A-2.19, even as total potato acreage increased, the amount of acreage in farms greater than 3,000 acres has increased [19]–[22] [23]–[26]. In 1982, approximately half of total potato acres were grown in farms with less than 500 acres. While total acreage grew rapidly until 1997, the total amount of acres in the less than 500 acres category fell. In 2017, acreage in farms with less than 500 acres was less than half that of 1982, despite total acreage increasing 60%.

4.1 Potato Packers & Storage

For up to a year, potatoes are stored in sheds, which regulate temperature, humidity and airflow to prevent spoilage, moisture loss, and conversion of starches to sugars in the potatoes [27]–[30]. A representative from Lamb Weston described the objective of storage as tricking potatoes into thinking they're dormant during winter in the ground and waiting to sprout in the spring. Depending on the specifications of end users and the type of potato, they are stored between 38-50 degrees Fahrenheit [27]. There are no databases that track the locations of storage sheds, but it can generally be understood that sheds are close to farms. It is not uncommon for farms to own their own storage sheds, although some potatoes are stored at on-site storage owned by processors.

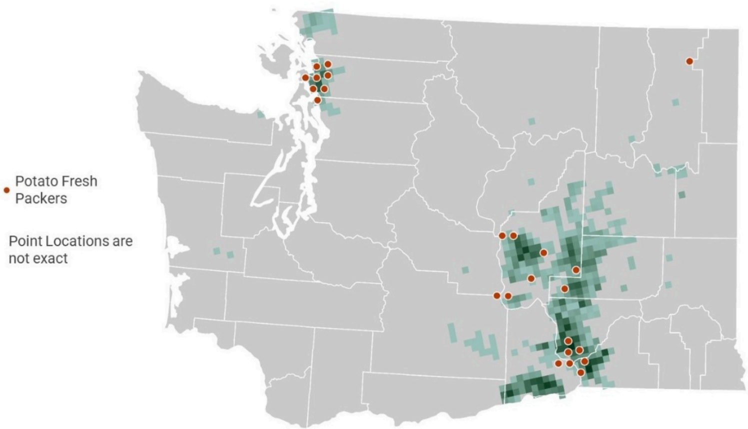

Figure A-2.20: Potato fresh packers in Washington

As shown in Figure A-2.20, potato packers are located throughout the Columbia Basin and the smaller potato growing region in Western Washington. The packers list may not be comprehensive, as it was from an industry trade organization [31]. Similar to storage sheds, fresh pack facilities are located near potato farms. Packing includes washing with water and often fumigants, sorting potatoes by size, optically inspecting them for quality issues, and packing [32]. Depending on the defect, culled potatoes from fresh pack facilities may still be sold for the processing market.

4.2 Potato Processors

Washington has twelve primary potato processing plants and two plants that process the waste starch slurry from processors into value added products. As shown in figure Figure A-2.21, all Potato processors are located in the Columbia Basin with clusters around the Tri-Cities (Richland and Pasco), Quincy, and Moses Lake/Warden/Othello and a lone facility in Connell.

Figure A-2.21: Washington Potato Processors

Most processors make French fries, and account for a large majority of the state's total capacity. Key processes include grading and washing, peeling, slicing, blanching, frying, freezing, and packing [33]. Water permit data from the Washington Department of Ecology was used to identify facilities and their characteristics [34]. Three companies operate fry plants: Lamb Weston operates 5, JR Simplot operates 2, and McCain Foods operates 1. Lamb Weston also has the largest total capacity, as all the fry plants have relatively similar capacities that range between 231,000 and 413,000 tons per year. Optical sorters are used to find defects in the potatoes. Instead of culling an entire defective potato, typically just a small section of the potato is removed and the pieces that are not large enough to make fries are sent to a secondary line that makes "formed" products like hash browns. After potatoes are washed and peeled, potatoes are sprayed as they go through slicing. The water recovered from this step can be sold to other companies as a starch slurry.

Two processors primarily produce dehydrated potatoes. Key processes include washing, peeling, precooking and cooking, mashing, and drum drying. The manufacture of dehydrated potatoes is relatively energy intensive, as the energy input to process one ton of potatoes is almost triple the amount required for frozen French fries. Because dehydrated potatoes are made into small flakes, they are not dependent on sourcing potatoes that produce large slices, allowing them to receive culled potatoes from the fresh pack industry.

Starch processors upgrade the slurry received from other plants. The processor in Richland produces a wide variety of food ingredients. Notably, the Lamb Weston in Richland purchases a French fry batter to make extra-crispy “stealth fries”, meaning the starch is returned to its origin [35]. The plant in Moses Lake manufactures chemicals for the paper industry [36]. Ingredion currently owns both facilities.

4.3 Waste Biomass Inventory

Waste biomass is generated at several points along the supply chain and includes culled potatoes and rejected potato pieces from processors. No use cases were found for the above ground biomass of the plants. Potatoes are harvested mechanically from the ground and transported to storage sheds where they are sorted before being stacked in piles. Sorting is repeated before either packing or processing. Fresh packers only market the most-desirable looking potatoes, as it is expected that customers can individually inspect each tuber. Rejected potatoes may be sent to processors or culled. Processors work to minimize rejected biomass by selectively cutting out bad spots in potatoes and using an efficient peeling technique that uses steam and pressure to remove the skin. Small potato pieces that are too small for French fries or other larger cuts are used to make formed potato products like hash browns. No data on cull rates of potatoes was found for potato fresh packers. Processors can be expected to reject 15-40% of all incoming biomass depending on their process technology [37].

Figure A-2.21: Washington Potato Processors

Relative to other fruits and vegetables, the supply of potatoes throughout the year is relatively stable due to their long storage life. As shown in Figure A-2.22, there is a jump in potato shipments near harvest, as farmers deliver some of their potatoes to commercial facilities with storage capacity [38]. For most of the year, weekly potato shipments from Washington range from 7,000 tons during the months following harvest to approximately 4,000 tons during the summer.

4.4 Biomass Uses

While a complete inventory of potato biomass is not available, it is likely that it is almost exclusively sold for cattle feed. Potatoes are high in starch, and can function similar to grains in cattle diets, although their high moisture content can limit cattle performance and are expensive to transport [39]–[42]. Potatoes are also low in necessary nutrients like protein, calcium, and fiber, so farmers would need to supplement with other foods. At a feed rate of 3lbs of potatoes per 100lbs of animal weight, a typical cow could consume approximately 48lbs pounds of potato culls per day in a healthy diet [40]. Several potato companies are also involved in the cattle and dairy industries. These cross-industry ties suggest that feeding cattle potatoes is partly a matter of convenience. J.R. Simplot, known for pioneering frozen French fries, also owns a cattle feedlot in Burbank. Lamb Weston, the largest potato processing company in the state, owns a dairy in Paterson.

Potatoes can be fermented and used to produce fuels like biogas [43].

4.5 Energy

Potato processing is energy-intensive and typically includes high-heat applications for steam, drying, and frying. Energy consumption values are not available on a plant basis, although air permit records for the Lamb Weston French fry plant in Hermiston, OR, the Oregon Potato dehydrated potato plant in Boardman, OR and other studies can be used to inform initial assessments [33], [44], [45]. In both Hermiston and Boardman, natural-gas fired plants supply food processors with thermal energy via steam. The Lamb Weston plant in Hermiston has steam delivered by the adjacent Hermiston Generating Plant, owned by Perennial Power [46]. The Coyote Springs Natural Gas Cogeneration Facility in Boardman supplies steam to several industrial customers [47].

4.6 Water

Water use and output varies by plant, as potato processing plants manage different water streams throughout their plants. Some plants, like Lamb Weston in Richland, operate their own wastewater treatment plants [48]. Most wastewater treatment plants dispose of at least some of their water via land application.

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5. Grapes Supply Chain Overview

The supply chain for grapes in Washington results in either juice or wine depending on the type of grape. As shown in Figure A-2.23, the supply chain begins during harvest at vineyards during the fall. Following harvest, grapes are quickly crushed and processed. Washington grape products are available to consumers throughout the year. Grape juice is pasteurized, so it can last until the next harvest season and wines are typically aged several years.

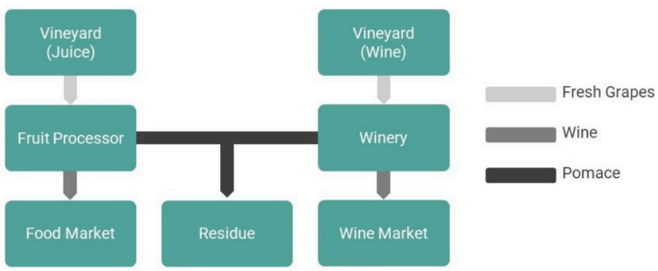

Figure A-2.23: Grape supply chain

4.4 Vineyards

As shown in Figure A-2.24, almost all commercial vineyards in Washington are grown east of the Cascade Mountain range, particularly in the Horse Heaven Hills, Yakima Valley, and Walla Walla areas [1]. According to the 2017 census, Benton County had the most acres of grapes followed by Yakima County [2]. Together, those two counties comprise the entire Yakima Valley. Southern Benton County and Klickitat County have a significant amount of grapes in the Horse Heaven Hills near Paterson.

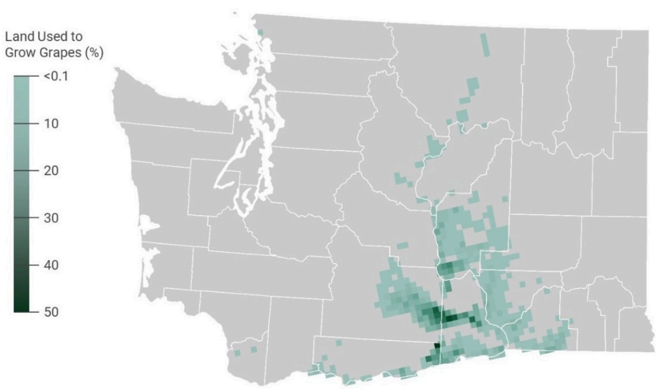

Figure A-2.24: Washington Vineyards in 2021

Most of the grapes in Grant County are in the Wahluke Slope area, near Mattawa. The Grapes in Franklin County are dispersed over the Columbia Plateau, largely in the White Bluffs area. Most grapes in Walla County are near the city of Walla Walla.

Over the last 40 years, the total area used to grow grapes in Washington has increased substantially. As shown in Figure A-2.25, Washington had 27,000 acres of vineyards in 1982. By 2017, that area had nearly tripled to a total acreage of 78,000 acres [3]–[6]. Over that period, land held in small vineyards, with less than 100 acres, has remained stable, while most growth has been from mid-sized and large vineyards.In 1982, vineyards with more than 100 acres had 12,000 total acres, by 2017 that acreage had more than quintupled to 64,000 acres. Compared to other types of farms in Washington, vineyards are typically operated as relatively small farms. For instance, less than 20% of potatoes are grown on

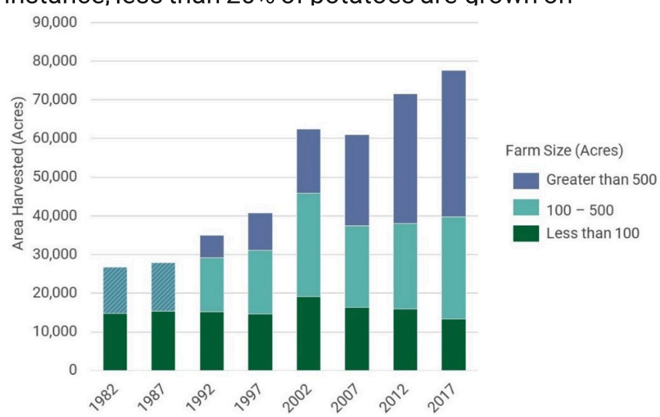

Figure A-2.25: Grape harvest by Farm Size

4.5 Varieties

Grapes within Washington fall into two main categories: juice and wine. These categories are distinct, and each consists of several varieties. While crop outcomes are dependent on an array of factors including variety, management practices, climate, and soil, wine grapes typically have lower yields but greater gross returns because of their higher value [8]–[10]. Wine grapes can be further divided into red and white subcategories. Each type of wine grape is grown throughout Washington, although some areas or vineyards tend to specialize in one or the other [11]. Processing can also be variable depending on the grape variety. During early fermentation, grape skins are used to impart tannins in red wines. White wines are fermented without the skins. Rosé wines are a subcategory of red wines [12]. They use red wine grapes but are fermented similarly to white wines with little to no contact from the grape skins. The longer rose wines are in contact with the grape skins, the darker they become.

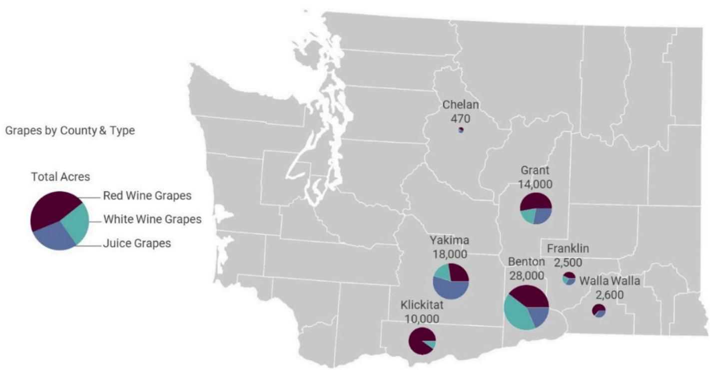

Figure A-2.26: Grapes by Types and County

Most grape acreage in Washington is used to grow wine grapes, but the distribution of grapes is not consistent throughout the state. As shown in Figure A-2.26, most juice grapes are grown in the Yakima Valley, which includes the grapes in Yakima County and some of the grapes in Benton County [11]. Red wine grapes are the most prominent type of wine grape, especially in Walla Walla and Klickitat counties, which have almost no white wine grapes. The distribution of grape types is dependent on several factors. For instance, the facility database establishes that Yakima Valley is home to all the state's grape juice processors, so it is likely that it is

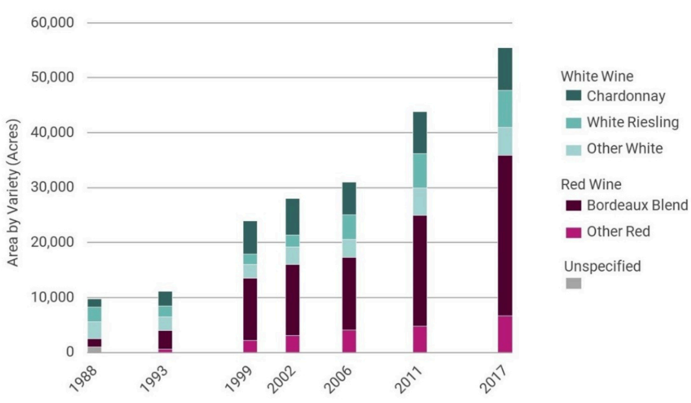

Figure A-2.27: Wine Grape Varieties by Year

most convenient to contract with more local growers. Climate is a major factor for wine grapes. It is generally considered that warmer climates are suited for red wines in Washington, so areas like the Horse Heaven Hills and Walla Walla Valley grow predominantly red wine grapes [13].

The Washington grape industry is relatively immature compared to other parts of the world with large production capacities. It is valuable to consider how the industry has changed as it has matured over the last 40 years, and to consider whether we should expect significant changes to the industry in the near future. Figure A-2.27 shows the distribution of red and white wine grape acreage by year [11], [14]. In 1988, most wine grapes in Washington were white wine grapes, and the most popular variety was white Riesling [14]. By 1999, total red wine grapes had overtaken whites, and Chardonnay had become the most popular variety. By 2011, segment growth of red wine grapes had continued to outpace white wine grapes and Cabernet Sauvignon, a Bordeaux variety, had become the most popular variety in the state. Current projects suggest that the pace of the growth over the last several decades is likely slowdown in coming years as wine has lost market share to other alcohol [15].

The impact of variety selection on the grape industry may be important relative to symbiosis. Wine grapes are smaller than juice grapes but have a higher sugar content and thicker skins [16]. And because red wines are aged on their skins, grapes that produce especially thick skins can be favored in certain applications [17]. All these factors impact the amount and quality of excess biomass produced by the grape industry. Energy inputs may also be variable. Some grape juice is concentrated, which demands a large amount of heat [18]. Wine is often stored by wineries for several years before it is released, and during that period it must be stored in a climate-controlled warehouse [19], [20].

4.5 Varieties

Figure A-2.28 shows the locations of large grape processors in Washington in the facility database. All of them are in Eastern Washington, and the locations of most can be further defined as falling within the Yakima Valley. Four Juice processors are all located near the line between Yakima and Benton Counties in either Grandview or Prosser. In total, Washington has more than 1,000 wineries licensed by the state Liquor and Cannabis Board [21]. Not all of these are considered relevant for symbiosis. 20 large wineries, those that process more than 50,000 cases per year, are spread across Eastern Washington. The major clusters are in Prosser/ Grandview and the Tri Cities. The Horse Heaven Hills, Mattawa, George, and Walla Walla also have large wineries.

Figure A-2.28: Major Grape Processors in Washington

After harvest grapes are crushed and juiced, grape juice is sterilized and then packaged in sterilized and sealed bottles [10], [18]. In some instances, juice may be concentrated which requires heat to drive moisture from the juice. Depending on the plant and specific product, grape juice may be mixed with other ingredients. At wineries, crushing is followed by fermentation, ageing, and packaging [22].

Below are some useful terms that can be used to classify wineries and wines [23], [24]:

- **Estate**: wines in which all processes in the supply chain, from the vineyard to bottling, are executed by one company. Estate wines are made by wineries of all sizes. A winery may produce both estate wine and non-estate wines.
- **Custom Crush**: winery that executes parts of the wine production process for another company. Services may include crushing, fermenting, aging, and packaging, but vary by customer. All custom crush wineries are considered large wineries in Washington.
- **Label**: One company may produce wines under multiple labels, even when production is executed at one facility. The purpose for using multiple labels is often for one company to appeal to a broader spectrum of wine consumers. In other cases, a custom crush winery may produce wine for a customer under one label and their own wine under another.

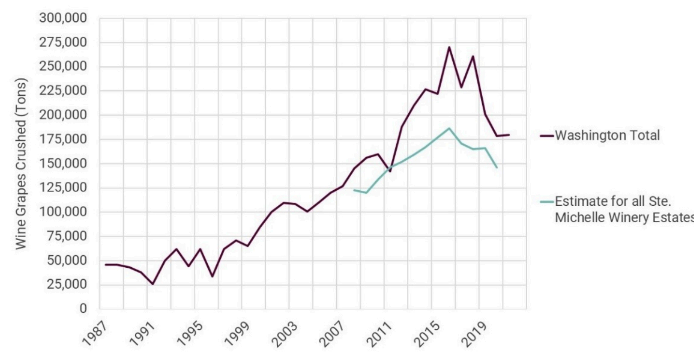

Figure A-2.29: Capacity of Ste. Michelle Winery estates relative to total capacity in Washington.

The largest wine company based in Washington is Ste. Michelle Estates [25]. Within Washington Ste. Michelle labels include Chateau Ste. Michelle, Columbia Crest, 14 Hands, Snoqualmie, and Col Solare but they also own several other wineries in the United States and one in Italy [26], [27]. As one of the older wineries in Washington, they have long utilized much of the state's total grape production, peaking near 70% [28]–[36]. As shown in Figure A-2.29, total production from Ste. Michelle had closely mirrored overall Washington wine production until 2014. This has coincided with a shift in sentiment within the industry that Ste. Michelle's successes and failures are no longer indicative of the state's industry as a whole [37]–[39]. Despite recent woes, Ste. Michelle will likely continue to be Washington's largest wine company for the foreseeable future.

4.6 Wine Value and Scale

Instead of seeking to maximize yields or total alcohol production, wineries may choose to emphasize subjective qualitative characteristics to maximize value. An advantage of this approach relative to symbiosis is that smaller facilities are not only commercial, but competitive with many other similar facilities. This competition leads to an environment that seeks innovation and is also flexible enough to implement new ideas quickly. In most other industries, the scale of many Washington wineries would be considered a pilot or demo scale, meaning that wineries are at a scale advantageous for experimentation [40].

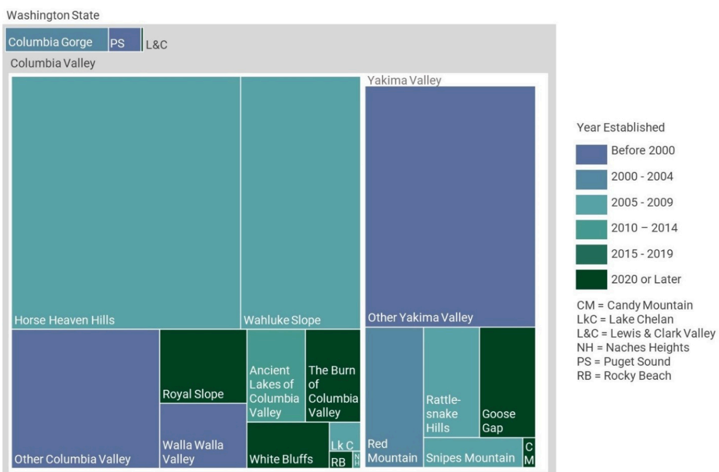

Figure A-2.30: Washington AVAs by the year they were founded and their current grape acreage

The establishment of Washington as a high-quality wine producing region has been the utmost priority of organizations like the Washington Wine Commission [41]. Historically, Washington has been recognized for producing low-priced premium quality wine [15], [42]. As the wineries within the region have become better established and consumers have become better educated, this perception has begun to change to a higher opinion. One indicator of this change is the recent establishment of small American Viticulture Areas (AVAs). AVAs are geographic areas that are used to specify the origin of wine. As shown in Figure A-2.30, the older AVAs within the state are large, for instance the Columbia Valley AVA encompasses almost all wine grapes within the state. Newer AVAs are smaller, and typically sub-AVAs of the Columbia Valley [43]. Often, they encompass a small area. For instance, Candy Mountain contains a single south-facing hillside. Wines from these AVAs are scarcer, meaning that their rarity can lead to higher value. This proliferation of small AVAs especially serves to benefit small estate vineyards and wineries who can monetize the sense of their connection to the land. This shift toward higher-value wines suggests that Washington's diverse wineries will continue to persist, and that it is unlikely that consolidation will heavily impact the industry in the foreseeable future.

4.6 Biomass

Grape biomass includes seeds, stems, and skins discarded after juice or wine processing. Relative to other types of agricultural biomass, grape waste is produced in small quantities. As noted in the water permit fact sheet for the Welch's plant in Grandview, approximately 90 pounds of waste is produced for every ton of grapes processed, just 4.5% of total incoming biomass [44]. At Welch's waste generation rate, total grape biomass in 2021 would have been 13,000 tons. This value is likely slightly low, as wine grapes often have thicker skins than juice grapes.

The seasonal availability of grape biomass is based around harvest in the fall. Grapes are crushed soon after harvest, and most of the biomass is available after crushing. Red wines are fermented on grape skins for approximately one month, depending on the maker's preferences, so much of the red wine biomass becomes available later.

According to water permits indexed for the facility database, most grape biomass is either landfilled, used for cattle feed, or mulched and used as compost. Limited information is available about the specific qualities of grape biomass.

4.6 Water

According to Washington's general permit for wineries, on average wineries use approximately 6 gallons of water for each gallon of wine produced [45]. Wastewater from grape processing can be handled by local wastewater plants in some cases, as Washington does not require wineries that produce less than 7,000 cases to have water permits. But larger wineries often have their own wastewater treatment plants. Several projects they may be considered examples of symbiosis have already been undertaken by the industry. Northstar Winery in Walla Walla is a small winery with an annual production capacity of 10,000 cases. In 2019, they became the first winery in Washington to use BioFiltro's worm bedsin its water treatment plant [46]. West Richland and Kennewick both have wine wastewater pretreatment plants [47]. These plants help attract new businesses by reducing the capital costs necessary for new wineries near the treatment plants.

4.6 Energy

Energy inputs for processing grapes depend on whether the grapes are used for juice or wine. For grape juice processing, the juice must be sterilized, which is typically accomplished using steam [18]. If the juice is concentrated, additional heat will be required. At wineries, just the packaging is sterilized for most types of wine. Atmospheric temperature control at wineries is important throughout fermentation and aging [48], [49]. Aging is done in large warehouses and is an important component of the wine industry. Wines typically aged a minimum of 1 year, and often more, before release. Outside of Washington, wineries have used alternative energy sources to heat their facilities, like geothermal [50].

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