Wood Wool Cement & Wood Fiber Insulation Feasibility Analysis

Completed For:

Council of Western State Foresters

Completed by:

THE BECK GROUP

February 2023

TABLE OF CONTENTS

The work upon which this project is based was funded in whole or in part through a cooperative agreement with the USDA Forest Service, Wood Innovation Program (22-CA-11111169-046).

CHAPTER 1 – EXECUTIVE SUMMARY

1.1 INTRODUCTION

The Council of Western State Foresters (CWSF) Forest Products Committee (FPC), a collaboration of state forestry professionals across the Western United States and Pacific Islands, is working to maintain and enhance markets for traditional and non-traditional forest products. As part of those efforts, CWSF commissioned this "Emergent Market" report to develop a better understanding of the feasibility of Wood Wool Cement (WWC) and Wood Fiber Insulation (WFI). Both products have been commercialized in Europe, but are much less common in North America, both in terms of market use and domestic manufacturing capacity.

This report provides an overview of key feasibility considerations for businesses developed around these technologies, including factors such as raw material requirements and costs; equipment needs and costs; process considerations (e.g., labor, plant scale, etc.); market size and product values; and regulatory and/or policy issues affecting commercialization of these technologies.

1.2 WOOD WOOL CEMENT

The following sections describe the main findings about Wood Wool Cement. See Chapter 2 for more detailed information.

1.2.1 Products and Markets

WWC is a panel product made from a combination of wood wool (also known as excelsior), Portland cement, and water. The main product type made from this mixture of materials is Wood Wool Cement Board (WWCB), an acoustic panel used mainly as decorative finish on ceilings and walls. WWCB's key properties are excellent sound absorption, good thermal insulation, fire resistance, and ease of design (i.e., available in many colors and machinable to different shapes/sizes). Those attributes afford architects and designers an excellent balance of performance and flexibility in creative design.

WWCB is also recognized for its sustainability as it contains wood – a renewable resource. Also, some producers manufacture WWCB using less energy-intensive cement. This has allowed one manufacturer to win a German Sustainability award[1], achieve cradle-to-cradle Gold Level certification for the product, and proclaim the product carbon negative. Annual European demand for WWCB is estimated at 215 million square feet, of which decorative acoustic panels represent about 90%. There is also production in countries such as China and Japan; though information about production volumes/market size for those regions is unavailable, it is believed to be small. WWCB is currently produced in 2' wide by 8' long sheets in thicknesses ranging between 1/2" to nearly 4". Product sales prices are not published, but industry contacts report that they range between about \$0.90 and \$1.40 per square foot (FOB plant).

Tectum is a similar, US-manufactured brand-name product made from wood wool. However, Tectum is made using Magnesite (magnesium carbonate – $MgCO_3$) as a binding agent instead of Portland cement. As a result, Tectum is only suitable for indoor applications, whereas WWCB can be used both indoors and outdoors as it resists decay. WWCB used in exterior applications in Europe is still in service after more than 70 years. For example, WWCB is used in sound barrier walls along highways and railroads, and as exterior cladding on homes and commercial buildings.

[1] https://www.kingspan.com/group/news-insights/kingspan-news/troldtekt-wins-prestigious-german-sustainability-a

Two other WWC products include Wood Strand Cement Board (WSCB) and Wood Wool Cement Large Wall Element (WWC–LWE). Both products can be used as structural elements (e.g., as a wall system) in buildings. The WWC–LWE product is produced as a whole wall section (i.e., a panel between 1' to 1.25' feet thick by 9' to 10' wide (the wall height when the panel is placed in use) by up to 20' long). Those large pieces form whole walls, leading to fast and labor-efficient construction. The markets for both products are much smaller than WWCB and are still developing in Europe. However, given the increasing interest in off-site manufacturing and modular housing construction, it appears that there is significant market potential for the WWC–LWE product in North America as it can be used as a prefabricated wall element in modular homes. Both products, however, face the obstacle of gaining recognition in US building codes.

1.2.2 WWCB Manufacturing Considerations

A high-level estimate of the all-in capital cost for a turnkey WWCB manufacturing plant is $35 million. This includes all manufacturing equipment, its installation, a site, buildings, delivery and installation of the equipment, and soft development costs such as project planning, engineering, financing, permitting, etc. Such a plant can produce about 4.2 million cubic feet of WWCB annually and employ about 17 hourly laborers per shift. Nearly all currently operating facilities in Europe run 3 shifts per day, 5 days per week, 50 weeks per year. In addition to the hourly staff, the plant would require a total of 8 salaried staff including a general manager, accountant, and office manager, with salespeople making up the balance.

The largest ongoing operating expense is Portland cement, which is estimated at 28% of operating cost, followed by 23% for hourly labor, 20% for depreciation, and 9% for wood raw material. A plant of the scale just described would consume about 12,500 bone dry tons of small-diameter trees per year. All three products described in the preceding markets section are manufactured from small-diameter trees. In fact, the largest diameter stem that can pass through the wood wool shredders is 12". In Europe, the most commonly used species are spruce, pine, and aspen. The same species could be used in the US, as well as true firs and Douglas fir.

1.2.3 Conclusions & Recommendations

Based on the information gathered and analyzed for this report, it appears that WWC technology can be used to develop viable businesses that utilize small-diameter trees to create a variety of wood-based building materials. The following reasons support this conclusion:

- WWC technology utilizes trees less than 12" in diameter from a variety of the tree species commonly found in the Western US.
- WWC manufacturing technology is more than 100 years old and has been proven many times over in industrial-scale facilities around the world. Additionally, a European company that has been in business for more than 65 years can provide a turnkey solution for the main components of a WWC manufacturing facility.
- WWC products placed in use have demonstrated key attributes, including durability (even in applications exposed to weather), fire resistance, excellent thermal (insulative) properties, excellent sound absorption properties, and strength properties for use in structural applications.
- From a sustainability perspective, WWC products do not emit gases or chemicals that are harmful to human health; they utilize wood, which is a renewable resource. Recent developments in cement manufacturing have contributed to a lower carbon footprint for WWC products, with one manufacturer claiming the product is carbon negative. Note that cradle-to-grave Environmental Product Declarations (EPDs) per EN 15804 are available from most European manufacturers.

- A full financial analysis was not completed for a WWC business, since important details about site acquisition costs, financing assumptions, localized raw material costs, etc. can all vary significantly from project to project. Nevertheless, it appears that a WWC business would generate more than enough revenue to offset operating costs and amortize the investment made in the business.
- A key caveat in viability is that, given the currently small market share of these products in the US and lack of recognition for several WWC products in building codes, the first US-based manufacturers face significant market development risk. It follows that market development should be a key focus for any entrepreneur entering this space.
- Regarding the previous point about market growth, the following recommendations all relate to potential means of growing the market for WWC products:
    - A group or committee should be organized to advocate for the acceptance of WWC products into US building codes. CWSF may be able to work with US-based entrepreneurs who are planning to develop WWC manufacturing abilities, to help facilitate building code acceptance through organizations such as the American Wood Council.
    - There is the possibility that organizations such as AWC and SLB (both listed above) view WWC as not falling under the umbrella of wood products. However, since WWC products use a considerable amount of cement and a lesser amount of steel (for large wall elements), there may be avenues for approaching these other industries for promoting WWC. For example, it is recommended that any WWC advocates (e.g., WCSF, entrepreneurs, etc.) approach the Portland Cement Association, an industry association serving America's cement manufacturers (www.cement.org), to explore whether the association is willing to assist in developing North American markets for WWC products.
    - WWC advocates should approach the Softwood Lumber Board (SLB), an industry-funded initiative formed to promote the benefits and uses of softwood lumber products. While WWC does not directly contribute to use of softwood lumber, it's use may help promote softwood lumber's use. This would be true so long as WWC products are used in conjunction with mass timber construction, which is expected to be a major use of softwood lumber.
    - The US Forest Service has a long track record of supporting research for utilizing small-diameter trees and businesses aimed at using them. The existence of businesses that can utilize small-diameter trees helps increase the pace and scale of forest restoration – a key US Forest Service initiative. WWC advocates should position the technology to harmonize with this initiative as a viable means of utilizing small-diameter trees.
    - Human health represents another potential advocacy tool for WWC products. Research has shown that noise pollution is detrimental to human health. To the extent WWC panels reduce noise pollution in homes, businesses, and other structures occupied by humans, they can contribute to improved human health.

1.4 WOOD FIBER INSULATION

The following sections describe the main findings about Wood Fiber Insulation (WFI). See Chapter 3 for more detailed information.

1.4.1 Products and Markets

WFI is a family of insulation products that includes:

- Rigid panels that are typically applied in roof, wall, and floor systems to provide thermal and sound insulation in a structure.
- Batts that are typically applied between studs in a wall system, or joists in a floor system, to provide thermal and sound insulation in a structure.
- Loose fill that is typically applied in areas not readily covered by panels or batts (e.g., an attic) to provide thermal and sound insulation in a structure.

Regardless of the product type, WFI materials' key properties are excellent thermal insulation and sound absorption characteristics. They are fire resistant through the addition of borates during the manufacturing process, which retard fire and inhibit decay from insects and fungus. They also have the advantage of containing large amounts of carbon that the natural process of tree growth has extracted from the atmosphere. In contrast, many other insulation materials are made from petrochemical by-products. As those raw materials are extracted from the earth, they have a significantly larger carbon footprint than WFI products.

The US market for insulation materials is currently estimated at $7 billion annually. TimberHP is a startup company that is about to begin manufacturing WFI products in Maine. The company anticipates annual sales will total about $100 million when the plant is fully operational. Thus, they are seeking to capture only about 1.5% of the total US market.

1.4.2 WFI Manufacturing Considerations

A high-level estimate of the all-in capital cost for a greenfield WFI manufacturing plant that uses all new equipment is $200 to $250 million. TimberHP, the Maine startup WFI manufacturer, repurposed a shutdown paper mill and purchased used manufacturing equipment. Their reported capital expense was about $130 million for a plant that can produce about 115,000 bone dry tons of insulation annually. There is virtually no yield loss between raw material and finished product when wood chips are the feedstock. Thus, TimberHP's plant will consume about 115,000 bone dry tons of wood fiber per year. Note that if pulpwood is the feedstock, the bark on the pulp logs cannot be used and would therefore be a loss in the yield between raw material purchased and finished product sold. However, the plant could combust the bark to produce thermal energy for the manufacturing process, electricity for the manufacturing process, or both. A facility of the scale just described requires a workforce of about 120 hourly laborers.

While there are different approaches to WFI manufacturing, most involve the use of disc refiners to convert solid wood fiber into a pulp. This process is energy-intensive, requiring significant electrical power supplies. Thus, a strategic approach to siting a WFI facility would involve optimizing the combination of proximity to market, access to plentiful low-cost fiber, access to inexpensive power costs, and a pool of available labor.

1.4.3 Conclusions & Recommendations

Based on the information gathered and analyzed for this report, it appears viable to produce WFI products from mill residuals and/or small-diameter trees to create wood-based building insulation materials that perform as well or better than insulation made from other non-wood materials. Manufacturing wood-based insulation products also provides the benefits of being less energy intensive than other insulation materials while sequestering carbon for the life of the building or structure. The reasons supporting this conclusion include:

- WFI technology has been proven among existing manufacturers in Europe to be able to utilize mill residues (i.e., wood chips) and small-diameter trees with little restriction among suitability of trees species.
- WFI manufacturing technology is nearly 100 years old and has been proven many times over in industrial-scale facilities in Europe. Additionally, TimberHP is a US-based startup company that is on the verge of beginning WFI production in the US. Should their venture prove successful, their experience may prove helpful for establishing WFI manufacturing in other North American regions.
- There are European companies with long track records of manufacturing the major equipment items needed for manufacturing WFI panels (e.g., wood dryers, disc refiners, wood pulp and adhesive blending equipment, presses for forming panels, and dryers to dry finished panels).
- From a sustainability perspective, WFI products do not emit gases or chemicals that are harmful to human health; they utilize wood, which is a renewable resource; and while in use they sequester significant amounts of carbon.
- A full financial analysis was not completed for a WFI business since important details about site acquisition costs, financing assumptions, localized raw material costs, etc. can all vary significantly from project to project. Nevertheless, it appears that a WFI business would generate more than enough revenue to offset operating costs and amortize the investment made in the business.
- A key caveat in viability is that wood insulation currently has only a very small share of the US market. Thus, any WFI manufacturer seeking to establish a US-based business can expect to expend significant market development effort in the early years following startup.
    - Another market-related caveat is that insulation is almost by definition mostly air per unit of volume. This makes it cost-ineffective to ship long distances, requiring a manufacturer who has developed brand awareness of their product to establish multiple manufacturing facilities so as to serve a nationwide market in profitable fashion.

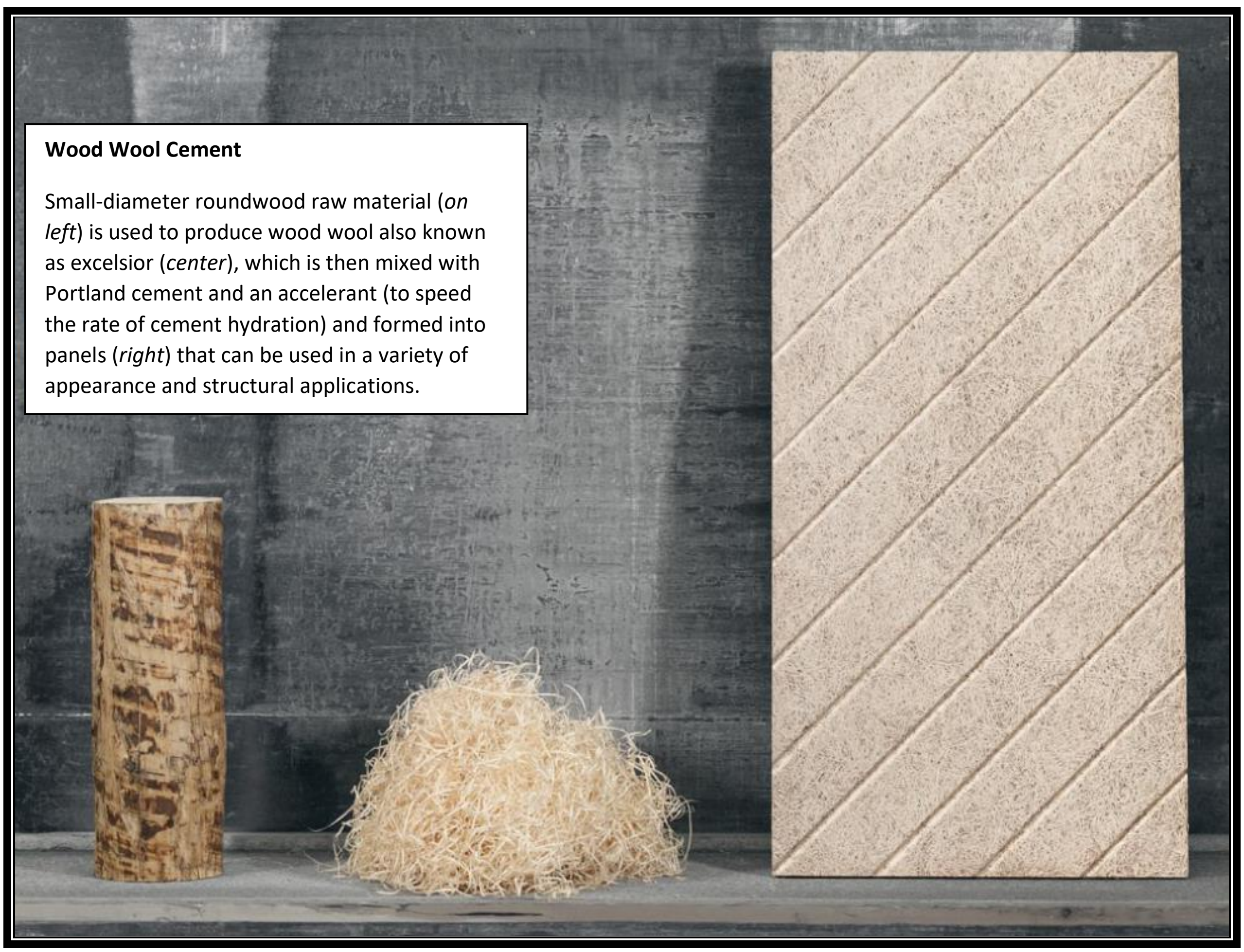
CHAPTER 2 – WOOD WOOL CEMENT

2.1 OVERVIEW

As shown in **Figure 2.1**, Wood Wool Cement (WWC) is a product that uses small-diameter roundwood as a raw material to form long, narrow strands of wood wool (also known in North America as excelsior). The wood wool is coated with a mixture of Portland cement and curing accelerator (e.g., sodium silicate or liquid glass, calcium chloride, or potassium silicate) and formed into a panel. After the combination of wood wool and cement cures, the panels are used in a variety of applications.

According to product literature produced by Nordeco[2], WWC is 60% wood, 39.5% cement, and 0.5% curing accelerator on a volumetric basis. On a weight basis, panel composition at the time of manufacture is 1 part water, 1 part wood, and 2 parts cement/curing accelerator. Finished panel density typically ranges between 17 and 30 pounds per cubic foot depending on the manufacturer, species, and specific type of WWC product. Other key properties of the panels include excellent sound absorption. The material does not emit any toxic substances while in use, and its cement coating resists fire and decay. The material is also a good moisture-regulating thermal insulator, and can thereby improve the energy performance and indoor climate of a building.

Figure 2.1 – Wood Wool Cement Board



Wood Wool Cement

Small-diameter roundwood raw material (*on left*) is used to produce wood wool also known as excelsior (*center*), which is then mixed with Portland cement and an accelerant (to speed the rate of cement hydration) and formed into panels (*right*) that can be used in a variety of appearance and structural applications.

Image credit: Baux

2 https://nordecowcb.com/albom_teh_resheniy.pdf

2.2 HISTORICAL PERSPECTIVE

The technology for manufacturing WWC boards dates as far back as the 1880s, when patents were filed in Germany for making slabs from wood wool (excelsior, gypsum, and water). In 1908, a patent was filed in Austria for technology using Magnesite as a binding agent. In the late 1920s, more innovation occurred as Portland cement was introduced as the binding agent; this method remains in use today, and permits outdoor use. In 1938, wood wool board standards were accepted by the Deutsches Institute for Normung (DIN). Standards development followed in other countries including Austria, Britain, India, Sweden, and the Netherlands. In 2002 a broader European Standard, EN 13168, was adopted to govern WWC use in thermal applications.

2.3 PRODUCTS & MARKETS

This report section provides information about common types of WWC products and the associated market information, such as market size and product sales values. Note that little published information exists about these aspects of WWC. Thus, the information is derived by combining the few published sources of information with insights from key members of the WWC industry.

As shown in the list below, at the current time there are three main types of WWC products. Note there are product variations within each main category to serve different end-use applications. The sections following the list describe the key aspects of each main product type.

1. Wood Wool Cement Board (WWCB)
2. Wood Strand Cement Board (WSCB)
3. Wood Wool Cement Large Wall Elements (WWC–LWE)

2.3.1 Wood Wool Cement Board (WWCB)

WWCB is by far the most common type of WWC product. It is typically produced as panels with density averaging about 20 pounds per cubic foot. Typical production dimensions involve thicknesses ranging between 0.5” and 4”, in 2’ widths by 8’ long. Other sizes can be produced (e.g., up to 10’ lengths), but panel sizes are dictated by the sizes of the molds used to form the panels and cure the cement. Thus, the ability to produce a range of sizes requires significant upfront manufacturing process planning. The panels have excellent sound absorption, high fire resistance, high wet and dry rot resistance, freeze/thaw resistance, are resistant to insect damage, and have good thermal insulation properties.

Given the preceding characteristics, the largest applications for WWCB are acoustic ceiling panels and as a decorative element on interior walls (e.g., offices, bars/restaurants, stores, theaters, etc.). The ability to produce low-density boards in a variety of colors, sizes, and shapes has contributed to rapid recent growth in this market sector. Also, modern building designs often feature hard-surfaced floors, walls, and ceilings, which all decrease sound quality. Thus, acoustic panels added to the design can help mitigate sound-related issues associated with modern design. Another factor contributing to market development is that composites are now available where a WWCB panel is adhered to an adjoining layer of mineral wool, polystyrene, or expanded polystyrene (EPS) panel.

The current global market size for WWCB is estimated at 20 million square meters per year (215 million square feet).[3] Product values vary depending on region, board characteristics, and by manufacturer, but industry contacts reported that current prices range between about US$10 per square meter and $16 per square meter with average panel thickness equaling about 1”. Expressed differently, current sales prices in Europe range between a low of about US$8 per cubic foot and a high of about $12 per cubic foot, prices

3 Proceedings of the Innovative Production Technologies and Applications in the Field of Wood Cement Products. Bert van Elten. International Inorganic-Bonded Fiber Composite Conference, 2022. Hamburg, Germany.

FOB the manufacturing facility. Similar FOB mill pricing is not available in North America, as there are currently no WWCB manufacturers operating in the region.

Currently there are about 20 existing WWCB production lines in Western Europe. Examples include Celenit (Italy), Isolith (Austria), Dietrich (Switzerland), Baux/Traullit (Sweden), Knauf/Heraklith[4] (Germany, Hungary, Netherlands), CE Wood (Latvia), Troldtekt (Denmark), and Fibrolith (Germany). There are also producers in Russia where it is reported that three lines have been installed in recent years. There are also Chinese companies producing WWCB with an estimated eight lines installed in recent years.

There is one company currently pursuing development of WWCB manufacturing capacity in North America: Troy Acoustics in Georgia. There is also Tectum, an acoustic panel brand-name product made from aspen wood wool and magnesium carbonate (rather than Portland cement) as the binder. This important distinction limits Tectum to indoor uses. Armstrong World Industries (AWI), a leading designer and manufacturer of commercial and residential ceiling and wall solutions in the US, owns Tectum. In 2021 AWI generated $1.1 billion in revenue, making it a well-capitalized producer of a similar product.

Figure 2.2 illustrates WWCB product applications. In the picture on the left, wood wool cement board manufactured by Heraklith is used as a decorative and acoustic panel on a vertical wall application. In the picture on the right, ceiling panels manufactured by Troldtekt are used as residential ceiling acoustic panels in a horizontal application.

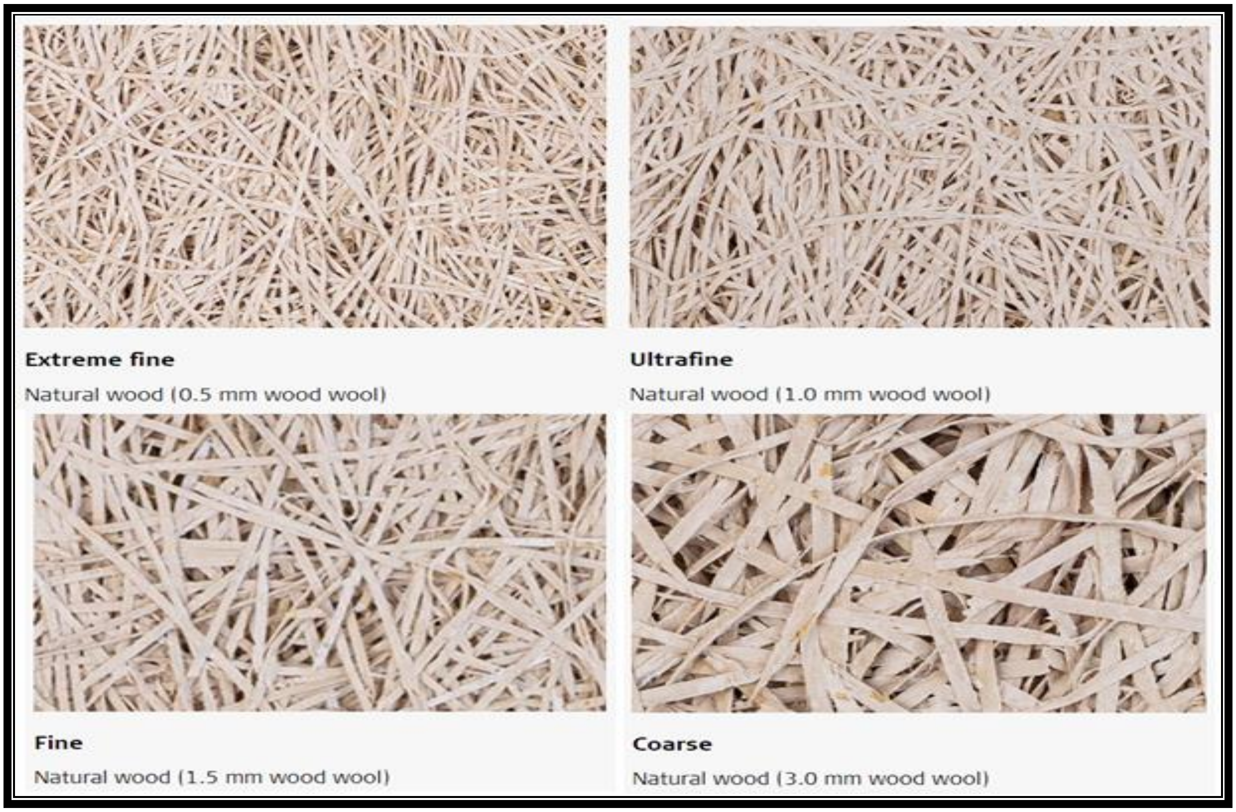
Figure 2.2 – Examples of WWCB Products in Acoustic Applications

Source: Heraklith and Troldtekt

Another aspect of WWCB products is the size of the wood wool fiber used to make the material. This has led to manufacturers offering WWCB panels made from various size wood wool strands. Designs and aesthetics vary, but in general consumers view panels made with smaller (i.e., finer) wood wool strands as more appealing. Thus, as shown in **Figure 2.3** manufacturers typically offer panels made from differing sizes of wood wool. As the figure shows, the wood wool used can range in size from 0.5 millimeters wide (extreme fine) to 3.0 millimeters wide (coarse).

[4] Knauf Insulation (parent of Heraklith) acquired US manufacturer USG Corp. and its distribution network. Thus, there is a pathway for Heraklith WWC products to be stocked in the US. Similarly, BAUX has a US-wide distribution network and a facility in Savage, MD where imported panels are machined before shipping to customers. Yet another example of infiltration into US markets is that Troldtekt was purchased by the Kingspan Group, which manufactures rigid insulation panels in California. Thereby creating a potential pathway into the US.

Figure 2.3 – Example of Differently Sized Wood Wool Raw Material for WWCB Panels



Source: Troldtekt

Figure 2.4 – Example of WWCB in Use as a Reinforced Roofing Panel (source Eltomation)

As shown in **Figure 2.4** on the preceding page, thicker WWCB panels (e.g., up to 3–4” thick) are made with approximately 3” diameter wood dowels embedded within the panel to provide increased strength (see the inset picture in the figure). The panels are then placed over the horizontal beams/rafters in a roof structure. Up to this point this product has only been used in Scandinavia, where it helps to reinforce roof panels to endure heavy snow loads common in the region. Other applications for the thicker WWCB panels include exposed interior surfaces in buildings such as libraries, swimming pools, sport arenas, and livestock barns where noise abatement is desired.

WWCB panels have also been used in outdoor applications where sound reduction is needed. Examples include sports stadiums, sound-reducing walls adjacent to railroads (see **Figure 2.5**), and highways. Such applications expose the WWCB panels to outdoor elements such as sun, extreme heating/cooling cycles, rain, and snow. Since there is a wood element in the panels, there is the risk of decay and or insect attack, but decades of use in many settings have proven WWCB panels durable in outdoor applications. Also, although not typically an outdoor application, WWCB is commonly used to deaden noise at gun ranges.

Figure 2.5 – WWCB In Use as a Sound Barrier Along a Train Track (source Eltomation)

2.3.2 Wood Strand Cement Board (WSCB)

Another WWC product is called Wood Strand Cement Board (see **Figure 2.6**). The production process and typical product sizes (length and width) are similar to those of WWCB. However, a key difference is that in the pressing stage of the manufacturing process, a hydraulic press is added which enables compressing the boards to a much higher density during curing (i.e., density of WSCB is nearly 70 pounds per cubic foot). Also, as a result of the higher pressure applied during curing, the resulting panels are thinner (i.e., 1/4” to 1” thickness) and have increased structural properties including bending strength up to 2,900 psi.

Common applications for WSCB include flooring and underlayment, exterior and partition walls, and sound barrier walls. According to Eltomation, WSCB’s inventor, the product can be a substitute for cement bonded particleboard, backerboard, oriented strandboard, gypsum, and medium density fiberboard. This is because of the product's improved strength characteristics relative to WWCB, but also because the material resists fire, weathering, decay, termites, and other insects. WSCB can also accept nails, screws, and staples with ease, and it requires no special tools for cutting, profiling, drilling, etc. No information was available about market size or market values for this product type. These products are not currently accepted as structural components in national, state, and local building codes. However, they have been used in structural applications in countries such as Japan, where the products are applied in structures to cope with seismic applications and codes. Thus, the products have been proven in other jurisdictions and could likely be accepted for use in the US – but building code acceptance is currently a serious obstacle to US market development.

Figure 2.6 – Example Wood Strand Cement Board (WSCB) Used in Wall and Roof Applications (source Eltomation)

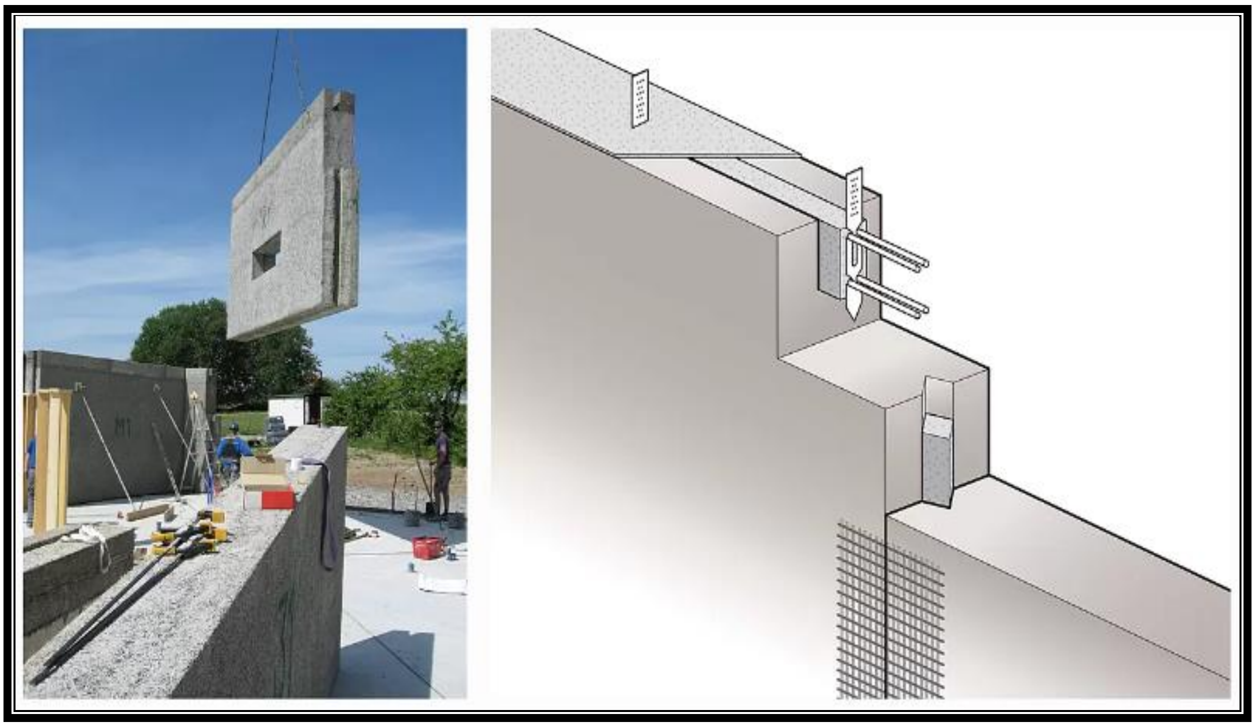
2.3.3 Wood Wool Cement Large Wall Elements (WWC-LWE)

Another developing product is Wood Wool Cement Large Wall Elements (WWC–LWE). This product is made from wood wool cement, but unlike the previously described products, WWC–LWE is a building system in which the WWC–LWE elements constitute entire wall sections. As with newly developing construction methods in North America that use mass timber, the WWC–LWE elements are manufactured in a factory and machined to their final dimensions (i.e., including cut-outs for windows, doors, electrical, etc.). The elements are then transported to the building site, where cranes position them a prepared foundation. The elements are connected by pouring fresh concrete in already prepared vertical cavities at the ends of adjoining elements. Additionally, a reinforced concrete ring-beam is poured in a prepared groove on the top of each element to further secure adjoining elements to each other (see **Figure 2.7** for illustration of the process).

WWC–LWE wall elements are currently produced in Sweden by Traullit. They produce elements up to 20' long by 8.5' tall. The elements' thicknesses vary depending on application, but can be up to 1.3' thick. WoodSyn, an Arizona-based company, is researching development of a WWC–LWE product.

Like other WWC products, the WWC–LWE products have excellent acoustical properties, are good insulators, and resist fire, weathering, and fungal or insect-related decay. The material is also machinable. A bonus for construction is that the large elements permit very efficient construction; this reduces waste, costs less, and minimizes potential damage to building elements that are exposed to weather when construction using conventional wood materials drags on for an extended period. Information about market size and product values was not available for this product type. Also, as with WSCB, US building codes do not currently allow for use of this material without obtaining a permitting variance.

Figure 2.7 – Wood Wool Cement Large Wall Element (WWC–LWE)



Source: Traullit

2.3.4 Sustainability

Sustainability is a key consideration for each of the three WWC product types just described. With regard to the wood raw material, wood's renewability means that companies making WWC products can utilize wood that has been certified by various third-party organizations as sourced from well-managed forests (e.g., Forest Stewardship Council, Sustainable Forestry Initiative, American Tree Farm System, and Programme for the Endorsement of Forest Certification). Additionally, the ingredients in wood wool cement only include wood, water, and cement. No resins are used to bind the material together, which avoids the potential for off-gassing of chemicals (e.g., formaldehyde) when resin-bonded materials are in use.

Another sustainability consideration is that the European WWC manufacturer, Troldtekt, has started using a less carbon-intensive cement called FUTURECEM. According to Troldtekt, the material is made from a process patented by Aalborg Portland: it synergizes calcined clay with lime filler, substitutes a large portion of the fired clinker in the cement, and reduces cement's carbon footprint by 30 percent. Using this cement in their products along with raw material from well-managed forests, combined with renewable manufacturing power sources and other considerations such as material health and social fairness, has allowed Troldtekt to achieve cradle-to-cradle Gold Level standard. They now claim that their panels absorb more carbon dioxide than is produced by their manufacture.[5]

2.4 RAW MATERIAL

2.4.1 Density & Chemical Composition

A variety of tree species and sizes are suitable for manufacturing WWC. However, in general practice in the regions of the world where WWC manufacturing is prevalent (e.g., Western Europe and Russia), the commonly used species are spruce, pine, and aspen. This is because all these species possess two key characteristics that make them desirable for use in WWC manufacturing. First, they are low-density woods, which makes them easier to machine into strands. Second, their chemical composition (they contain low levels of tannins and sugars) is conducive to full and fast curing of the Portland cement, water, and wood mixture, which in turn creates strong panels.

The second key raw material issue is the wood's chemical composition. Hydration is a chemical reaction by which the cement's main compounds (e.g., Alite, Belite, and Aluminate) form chemical bonds with water molecules to become hydrates and other compounds that give cement its characteristic strength. In WWC production, wood is added to the mix of cement and water. Adding wood affects the cement's curing in WWC because wood's tannins and sugars are soluble in water. This is important because when wood, water, and cement are mixed, the dissolved tannins and sugars inhibit cement's hydration reaction. According to Alpar et al.[6] this is because the cement compounds (e.g., Alite, Belite, etc.) form a gel on their surface when the tannins and sugars are present. That gel inhibits or prevents the hydration of the cement (i.e., the gel inhibits the formation of strong hydrates). Thus, WWC made with wood high in tannins and sugars can have poor strength properties because the cement does not fully cure.

Regarding the density issue, **Table 2.1** illustrates the typical density of the commonly used species. Note that the densities differ significantly from a low of about 20.5 bone dry pounds per cubic foot to a high of nearly 34 bone dry pounds per cubic foot. Except for the southern pine species in the list, all of the densities are relatively low compared to other softwood species such as Douglas fir and western larch, and much lower than most hardwood species. Wood wool is produced by a modern high-capacity Wood Wool Machine, which operates with a 16-knife disc at up to 900 rpm. A single such machine (referred to as Eltomatic CVS-16, as supplied by Eltomation), replaces as many as eight older-style manually fed reciprocating sledge machines. The older machines are no longer allowed in the European market due to poor safety and no CE (a marking on products on Europe to show that the product meets EU safety and health standards). Also note: Not shown on the table are Douglas fir and true firs, common western US species which are also acceptable for use in WWCB manufacturing.

5 https://www.troldtekt.com/news-press/press/2021/futurecem/

6 Tibor L. Alpar et al. Wood Wool Cement Boards Produced with Nano Materials. Proceedings of the 3rd International Scientific Conference on Hardwood Processing. 2011. Blacksburg, VA. Note this research focused on hybrid poplar. The interactions between wood compounds, cement, and water during hydration depend on a variety of factors including species, time since harvest, season of harvest, etc. Thus, research specific to a species of intended use is strongly encouraged.

Table 2.1 – Density of Tree Species Commonly Used for WWC Manufacturing

Tree Species	Specific Gravity	Bone Dry Pounds/Cubic Foot
Engelmann spruce	0.33	20.6
White spruce	0.33	20.6
Black spruce	0.33	20.6
Eastern white pine	0.34	21.2
Jack pine	0.37	23.1
Sitka spruce	0.38	23.7
Lodgepole pine	0.38	23.7
Ponderosa pine	0.38	23.7
Aspen	0.39	24.3
Red pine	0.41	25.6
Shortleaf pine	0.47	29.3
Loblolly pine	0.47	29.3
Slash pine	0.54	33.7
Longleaf pine	0.54	33.7

2.4.2 Size

Physical piece size is another raw material consideration. **Figure 2.8** provides an illustration of how the wood wool manufacturing process affects the physical size of the raw material. In the foreground of the left picture is a chop saw. It is fed pieces that are about 2’ long that have been precut from longer log sections. When the 2’ long blocks reach the stops on the chop saw line, the machines in the back move out and secure each end of the 2’ long block (as shown in the right-hand picture). The chop saw then cuts the 2’ long block in half, and the two resulting pieces are moved to the position in the background of the picture on the left where the shredding machine will convert the blocks into wood wool. The physical size limitation of the machinery means that pieces cannot be greater than 12” in diameter. The machines can process pieces as small as 3” diameter; however, machine productivity falls dramatically with decreasing block diameter. Therefore, most operations specify the minimum acceptable raw material diameter as 4” to 5”.

Figure 2.8 — Wood Wool Processing

Source: www.Eltomation.com

2.4.3 Log Length

Log length is another consideration. Most logging operations in the Western US use whole-tree harvesting and yarding with whole tree stems processed into long-log lengths on landings. Depending on the tree size, utilization standards, and logging/trucking equipment configurations, these long-log lengths can range anywhere between 20' and 50' or more when they are transported to a mill. At a WWCB facility, those long-length logs would have to be bucked to shorter lengths prior to entering the wood wool manufacturing process. Ideally those shorter long-length logs are 2' multiples, which is the bucked length of the pieces just prior to shredding into wood wool. Therefore, a WWC manufacturer in the Western US will need equipment for cutting the "as-received" long-log stems into lengths appropriate for entry into the wood wool manufacturing equipment line. The most likely point in the operation for this function is after the "as received" long logs are processed through a debarker. This is because the longer lengths are processed more efficiently in a debarker.

2.4.4 Log Quality

Raw material quality is another consideration. Optimal finished WWC panel properties are achieved when the wood wool strands are as long as possible. The closer the overall average strand length is to the maximum possible length of 12", the better the panels' strength properties and the more flexibility the manufacturer has for making panels of varying density. Therefore, raw material containing rot and decay is not acceptable. Similarly, very large knots can also affect the shredding process and the average length of the wood wool strands. Thus, generally excluding raw materials containing rot/decay and very large knots are prudent operating procedures, but no published information exists about the actual specifications for allowable knot size.

2.4.5 Seasoning

As previously described tannins and sugars affect the cement hydration process. Thus, one part of seasoning is allowing those compounds to cure. Moisture content is another aspect of seasoning and another raw material consideration. When fed into the wood wool manufacturing process, the raw material should be about 20 percent moisture[7]. The current industry practice is for wood raw material received at a WWC factory to first be debarked. Removal of the bark increases the rate of air drying, mitigates the formation of fungus and decay processes, and reduces the likelihood of insect-related problems that can occur when moisture is confined to the area where bark and wood fiber join. The air drying process can take 3 to 6 months depending on ambient climate conditions.

Air drying avoids the capital and operating expenses of raw material dry kilns and the need to handle and stack logs multiple times. However, it also ties up working capital in the large inventory of raw material that must be held on site. Completing a cost/benefit analysis of log drying equipment versus air drying is beyond the scope of this study. However, it is recommended that any entrepreneur considering investing in a WWC business should analyze kiln drying versus air drying of raw material. Also, the effectiveness of kiln-drying in "curing" the sugars and tannins is an open question where more research is needed.

One potential workaround could entail leaving logs on landings to dry, rather than occupying space and consuming working capital at the WWC facility. However, several factors affect the ability to implement this practice. For example, intact-bark on logs drying on landings may experience significant degradation from insects and fungus/decay. The regional climate might impact both seasoning and accessibility to log

[7] In this report, references to moisture content are on a wet basis, which is the convention of expressing the portion of the material's total weight that is moisture as opposed to expressing water's weight relative to the dry weight of the wood, which is called oven-dry basis.

decks on landings. The willingness of landowners and logging/trucking contractors to let log decks season might vary; this despite the fact that transporting seasoned logs should allow more wood fiber per truckload, since water is a lower percentage of the material's weight.

2.5 PROCESS AND PRODUCTION

The report section provides an overview of the manufacturing process and describes various key aspects including capital costs, operating costs, plant scale, etc.

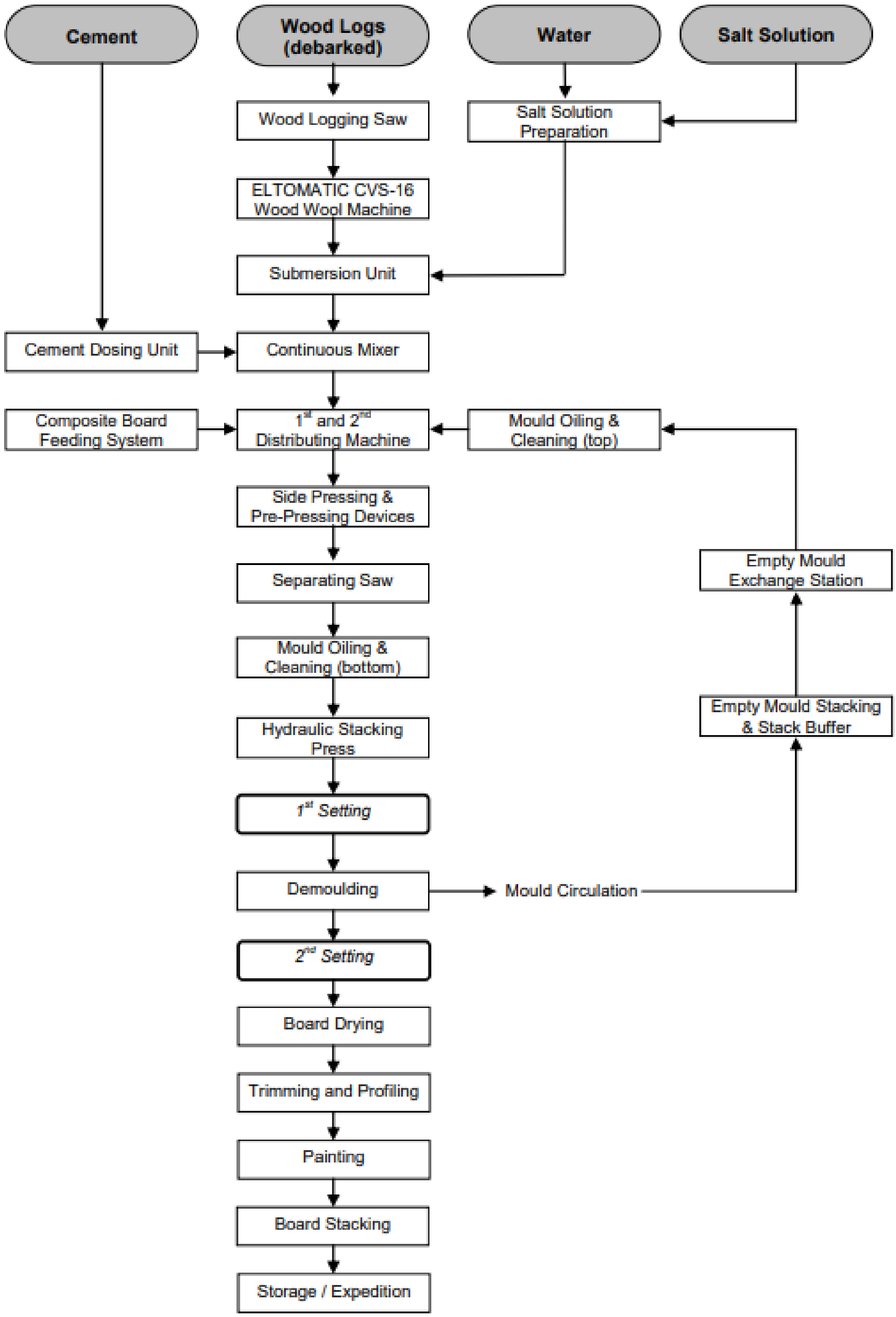
2.5.1 General Process Overview

Figure 2.9 (from Eltomation) provides a basic overview of the key steps in manufacturing WWC products. As the figure indicates, air-dried and debarked long logs are received at the plant from the wood yard. They are cut to 2' lengths and then converted into wood wool. Dust and fines are removed from the wood wool, which is dipped in a water solution that also contains an accelerator (e.g., sodium silicate) to enhance the cement hydration process.

Next the wood wool is mixed with cement in a continuous mixer. That mixture is then passed through machine centers which distribute the wood wool and cement mixture. Formation into molds is done by having plywood molds, which have only rims on the long sides pass underneath forming stations with the line moving at about 65 feet per minute. This creates a continuous mat of fresh mixture, which is then cut by a flying saw at the proper length for each mold. This creates about one new panel every 7 seconds. The molds, now filled with the wood wool and cement mixture, are then prepared for pressing. Then the filled molds are stacked and allowed to cure for 24 hours, in what is called the first setting. Next the panels are demolded (i.e., the mold is removed from the panel). Note that empty molds are reused by circulating them back to an earlier stage in the process. They are automatically cleaned and oiled between uses to avoid buildup of unwanted residues.

After the first setting and demolding, the panels are then stacked and moved into a climate-controlled warehouse space where they are allowed to cure for approximately 10 more days. This second curing stage is called the second setting. After the second setting, the panels are typically dried in a kiln and then moved to a finishing line. There they are trimmed to final dimensions and may have other finishing done such as profiling edges, cutting to different sizes, making cut-out areas, coloring, etc. Finally, panels are moved to an area where they are packaged, strapped, banded, etc. in preparation for shipping to customers.

Figure 2.9 – Overview of Key Steps in the WCE Manufacturing Process (Source Eltomation)



The pictures on the following pages provide a visual illustration of the equipment used in selected key steps from the preceding figure. Like the preceding figure, all pictures are used courtesy of the Eltomation website.

Figure 2.10 – Sorting and Buffering System for Blocks that Have Been Cut to 2' Lengths

Figure 2.11 – Wood Wool Feeding and Dosing System Ahead of the Station Where Wood Wool is Mixed with Cement and Accelerator

Figure 2.12 – Mixing Station Where Wood Wool, Cement, and Accelerator are Combined

Figure 2.13 – The Main Forming Line Where the Wood Wool, Cement, and Accelerator Mixture is Formed into Panels

Figure 2.14 – Panels About to Exit Stacking Press and Panels in Molds After Exiting Stacking Press; Stacked Panels are Then Moved into Storage for First Setting

Figure 2.15 – After First Setting Panels are Demolded in Preparation for Second Setting, Which Takes About 10 - 12 Days

Figure 2.16 – After Second Setting Panels Are Cut, Profiled, Trimmed to Final Dimensions Using CNC Machines, In Final State (not shown) Finished Panels are Packaged for Shipment to Customer

2.5.2 Plant Scale

According to industry contacts, almost all WWCB panels are currently produced as 2' wide by 8' long panels. Thus, the surface area of each panel produced is essentially constant; however, panel thickness varies from the thinnest panels being about 5/8" thick up to the thickest being about 4" thick. Since the amount of time to form each panel only slows down a little as the panel gets thicker, the plant's output is dramatically affected by the average thickness of the panels produced. In other words, the line for panel forming runs at the speed of about 65 feet per minute when forming thin panels. It only slows down slightly when thicker panels are formed. Thus, panel thickness is a key determinant affecting total plant output.

Another factor affecting production is the amount of uptime, which according to industry contacts averages about 87.5% at well-managed, well-maintained plants. This means that during every 8-hour shift, one hour's production is lost to minor unplanned downtime events and recurring downtime events for cleaning and servicing machines. Another factor is the number of shifts. Industry contacts indicated that most plants run 3 shifts (8 hours/day per shift) for 5 days per week. The 2 off days per week allow for scheduling regular maintenance of machine centers to assure steady production during scheduled operating hours.

Given the information in the preceding paragraph, **Table 2.2** illustrates how annual plant production varies with average panel thickness. All values in the table assume the plant is operating on a 3-shift basis. As the data in the table illustrates, plant output ranges between about 1.9 million cubic feet and 4.8 million cubic feet per year depending on average panel thickness. Thus, plant output increases by a factor of about 2.5 when going from production of 0.49" thick panels to production of 3.28" thick panels. Note that the various production rates are all achieved with the same equipment; note also that the thicknesses in the table are converted from common thicknesses used in European markets. A plant developed in the US would likely produce panels to slightly different thicknesses (e.g., 0.5”, 1”, 1.5”, etc.).

Another significant consideration is that panel thickness affects the amount of raw material consumed annually. For example, the plant would consume about 5,900 bone dry tons of raw material per year when producing all 0.49” thick panels. It would consume about 15,000 bone dry tons of raw material per year when producing 3.28” thick panels.

In summary, WWC plants are small relative to other, more conventional forest products businesses such as sawmills, veneer/plywood mills, etc. However, this technology does represent a meaningful localized market for utilizing small-diameter trees. For example, if a plant were to consume an average of 12,500 bone dry tons of raw material per year, that would equate to about 1,000 truckloads of raw material annually (for most Western US species). Or if an average of 12.5 bone dry tons is removed per acre of forest management thinning treatment, a WWC plant would support thinning 1,000 acres/year. A WWC-LWE manufacturing plant would consume about the same amount of raw material per year as the thickest panel in the table below.

Table 2.2 – Impact of Panel Thickness on Plant Output and Raw Material Consumption

Production Metric	Header on Each Column is Panel Thickness (in Inches)					
	0.49	0.82	1.15	1.64	2.46	3.28
Annual Plant Finished Product Output (square feet/year)	38,167,860	38,167,860	36,229,387	26,938,087	18,649,445	14,638,811
Annual Plant Finished Product Output (cubic feet/year)	1,878,340	3,130,566	4,160,199	4,418,978	4,588,938	4,802,760
Annual Raw Material Consumed (Green Tons at 50% MC)	11,740	19,566	26,001	27,619	28,681	30,017
Annual Raw Material Consumed (Bone Dry Tons)	5,870	9,783	13,001	13,809	14,340	15,009

2.5.3 Capital Costs

As previously described, Eltomation is the only manufacturer of wood wool manufacturing equipment that provides a turnkey solution. In other words, there are other equipment manufacturers that can provide wood wool manufacturing equipment, wood/cement mixing equipment, panel pressing equipment, etc., but as of late 2022, Eltomation is the only company in the world that can supply all of this equipment in a single package. According to their website and to industry contacts interviewed as part of this study, Eltomation is currently quoting (for budgetary purposes) a capital cost of about $16 to $18 million for a fully automated WWCB plant. **Table 2.3** shows the list of main equipment items that would be included in the turnkey facility.

Included in the costs are the cost of equipment itself, estimates for shipping the equipment to a customer, installing the equipment at the customer's site, and commissioning the equipment. Also, note that prices for individual items are not available other than by obtaining a project-specific quote after working with Eltomation to specify project needs more precisely. Note that for Eltomation to supply a full-scale WWCB plant to an offshore customer (i.e., a North American customer), between 40 and 70 forty-foot containers would be needed to ship all the equipment. The variance depends on whether some finishing equipment would be sourced locally instead of from Eltomation's plant in Europe.

Several other required items and services are not included in the cost quote, beginning with land and a manufacturing plant. Enough land is needed for a facility with adequate space to store up to six months of raw material inventory, as well as a building with a minimum size of 180' by 700' and an eave height of 20'. Also needed at the site are adequate space for parking for employees, space for trucks to maneuver while loading, unloading, and carrying inbound raw material and outbound finished product, and a truck scale for weighing raw material deliveries. The site also needs electrical service with the capacity to supply about 0.5 MW of power. The turnkey quote also does not include costs for items such as cement storage silos, rolling stock for moving raw materials and products, waste and dust recovery systems, etc. Also not included are soft costs such as permit acquisition, business planning, overall project management, etc. When all other costs are included, it is estimated that an "all-in" price for a WWCB plant will likely be in the range of $32.5 to $37.5 million. Note, however, that all of the preceding can vary significantly given the characteristics of any potential project. Thus, the "all-in" estimate should be considered for budgetary purposes only. The capital cost for a WWC-LWE plant is roughly estimated at $15 million, but again it is for budgetary purposes only.

Table 2.3 – Major Equipment Items Included in Turnkey Wood Wool Cement Board Manufacturing Plant

Major Equipment Item	Budgetary Capital Cost*
Wood Block - Cutting, Sorting, & Buffering System	
Rotating Wood Wool Machine	
System Controls	
Wood Wool Feeding & Dosing System	
Cement Feeding & Storage System	
Main Forming Line	
Panel Stacking System	
Panel Separating Saw System	
Demolding Equipment	
Board Drying & Finishing Line	
Board Stacking and Strapping System	
Total	**$16 to $18 USD in Millions**

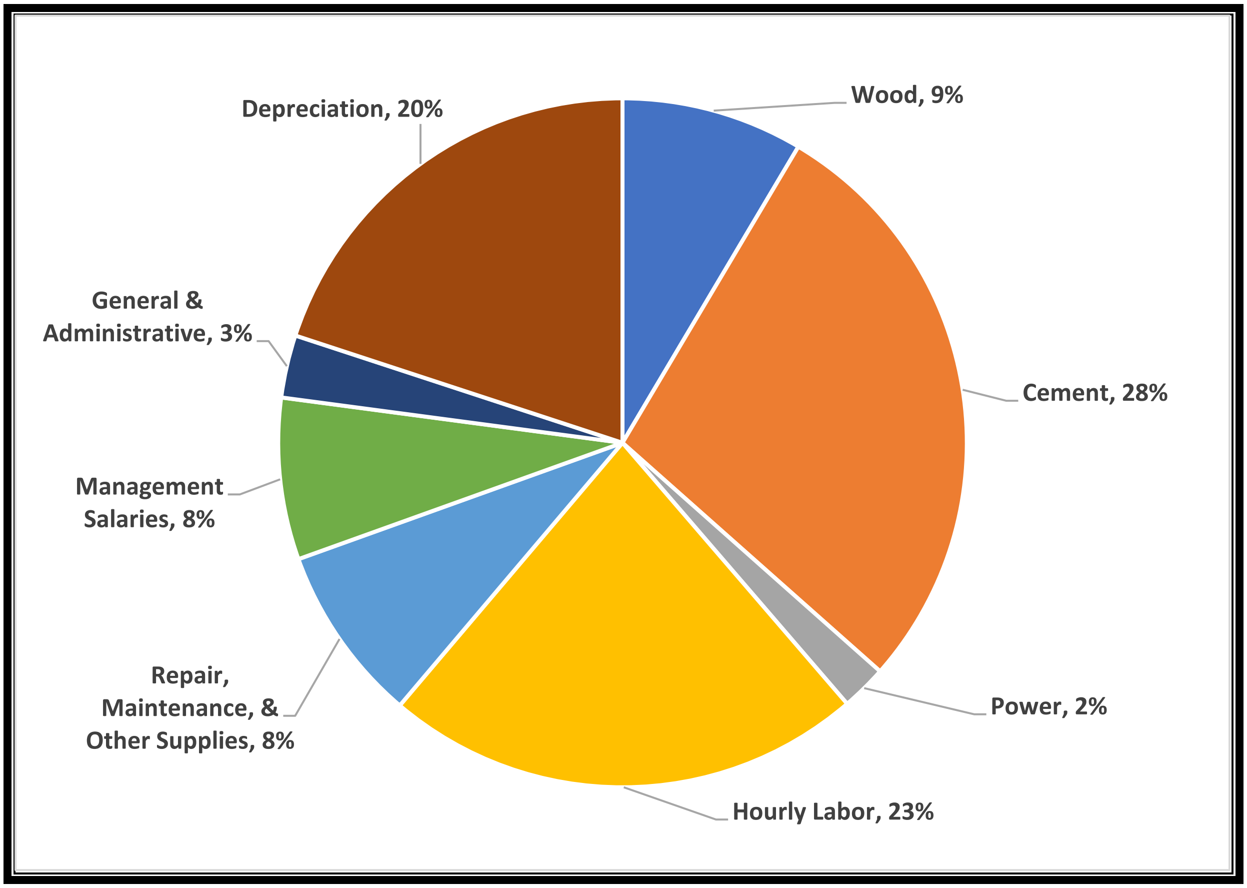
*Note values are not shown in the rows because a capital cost estimate with that level of detail was not available

2.5.4 Ongoing Operating Costs

Figure 2.17 summarizes the operating costs for running a WWC manufacturing operation modeled as operating on a 3-shift basis (5 days/week for 50 weeks per year) and producing 4.4 million cubic feet of finished panels annually.

As the data in the figure show, wood comprises about 9% of raw material cost (based on an assumed delivered price of $95 per bone dry ton including bark and wood being received at an average moisture content of 50%). Cement is the largest percentage of total cost at 28%, and is based on a cement cost of $150 per ton for white cement delivered to the plant. Hourly labor is another relatively large proportion of total cost at 22% and is based on a total of 17 hourly employees per shift (includes forklift drivers, log yard, debarker, machine center operators, and maintenance and electrical staff). Management salaries account for 8% of total cost and were assumed to include a general manager, accountant, office manager, sales manager, and five salespeople. Depreciation was calculated based on an all-in capital cost of $35 million and 10-year straight-line depreciation. The remaining cost categories are all small relative to those already described and are estimated based on averages from other similar sizes and types of businesses.

Figure 2.17 – Natural Operating Cost Categories as a Percentage of Total Operating Cost



2.6 POLICY & REGULATORY

There are two policy and regulatory issues that directly affect the development of WWC manufacturing businesses in the Western US and market development in the US. A key recent policy-related development involves the passage of the Inflation Reduction Act in the early fall of 2022. The Act contained several forestry-related provisions; key among them for development of WWC manufacturing businesses is the continued funding of the Wood Innovation Grant (WIG) program that is administered by the US Forest Service's State and Private Forestry Division. The exact amount varies in differing published reports, but it appears that the WIG program was funded with $100 million. The intent of the grant program is to stimulate and expand wood products and wood energy markets. Historically the program has focused on mass timber, renewable wood energy, and technological development that supports fuel reduction and sustainable forest management. USFS Wood Innovation Grant leaders contacted as part of this study indicated that supporting planning and development of a WWC business is consistent with the goals of the program. Thus, an entity seeking to develop a WWC business could apply to the WIG program for assistance.

The other key policy area is that the WWSB and WWC – LWE products are intended for use in structural applications. However, neither product group is approved for use in any local, state, or national building codes. Thus, any architect, engineer, or building developer that wants to use these products would have to navigate a lengthy, costly, and uncertain process for obtaining a variance that would allow use of these materials for a specific project. Since these WWC products appear viable based on their performance in regions where their use has already been established, it is recommended that the WCSF (and other groups as appropriate) begin pursuing acceptance of these products into local, state, and national building codes. The American Wood Council (AWC) is an organization whose mission is ensuring a resilient, safe, and sustainably built environment. AWC accomplishes this mission by contributing to the development of sound public policies, codes, and regulations which allow for the appropriate and responsible manufacture and use of wood products. This work is further carried out by AWC through developing and disseminating consensus standards, comprehensive technical guidelines, and tools for wood design and construction. AWC also provides technical education programs to facilitate proper use of various wood products. Thus, AWC will be a key resource in any efforts to gain acceptance of WWC products into US building codes. For applications in the transportation sector, e.g., for noise abatement along highways and railroad tracks, the recognition of WWC products in state-specific AMLs (Authorized Materials List) / QPLs (Qualified Products List) will be necessary.

2.7 CONCLUSIONS ABOUT WWC'S GENERAL VIABILITY AND RECOMMENDATIONS

Based on the information in this report, it appears that WWC technology can be viably used to develop businesses that utilize small-diameter trees to create a variety of wood-based building materials. The reasons supporting this conclusion include:

- WWC technology utilizes trees less than 12" in diameter from a variety of the tree species commonly found in the Western US.
- WWC manufacturing technology is more than 100 years old and has been proven many times over in industrial-scale facilities around the world. Additionally, a European company that has been in business for more than 65 years can provide a turnkey solution for the main components of a WWC manufacturing facility.
- WWC products placed in use have demonstrated key attributes including durability (even in applications exposed to weather), fire resistance, excellent thermal (insulative) properties, excellent sound absorption properties, and strength properties for use in structural applications.
- From a sustainability perspective, WWC products do not emit gases or chemicals that are harmful to human health; they utilize wood, which is a renewable resource. Recent developments in cement manufacturing have contributed to a lower carbon footprint for WWC products, with one manufacturer claiming the product is carbon negative.
- A full financial analysis was not completed for a WWC business since important details about site acquisition costs, financing assumptions, localized raw material costs, etc. can all vary significantly from project to project. Nevertheless, it appears that a WWC business would generate more than enough revenue to offset operating costs and amortize the investment made in the business.

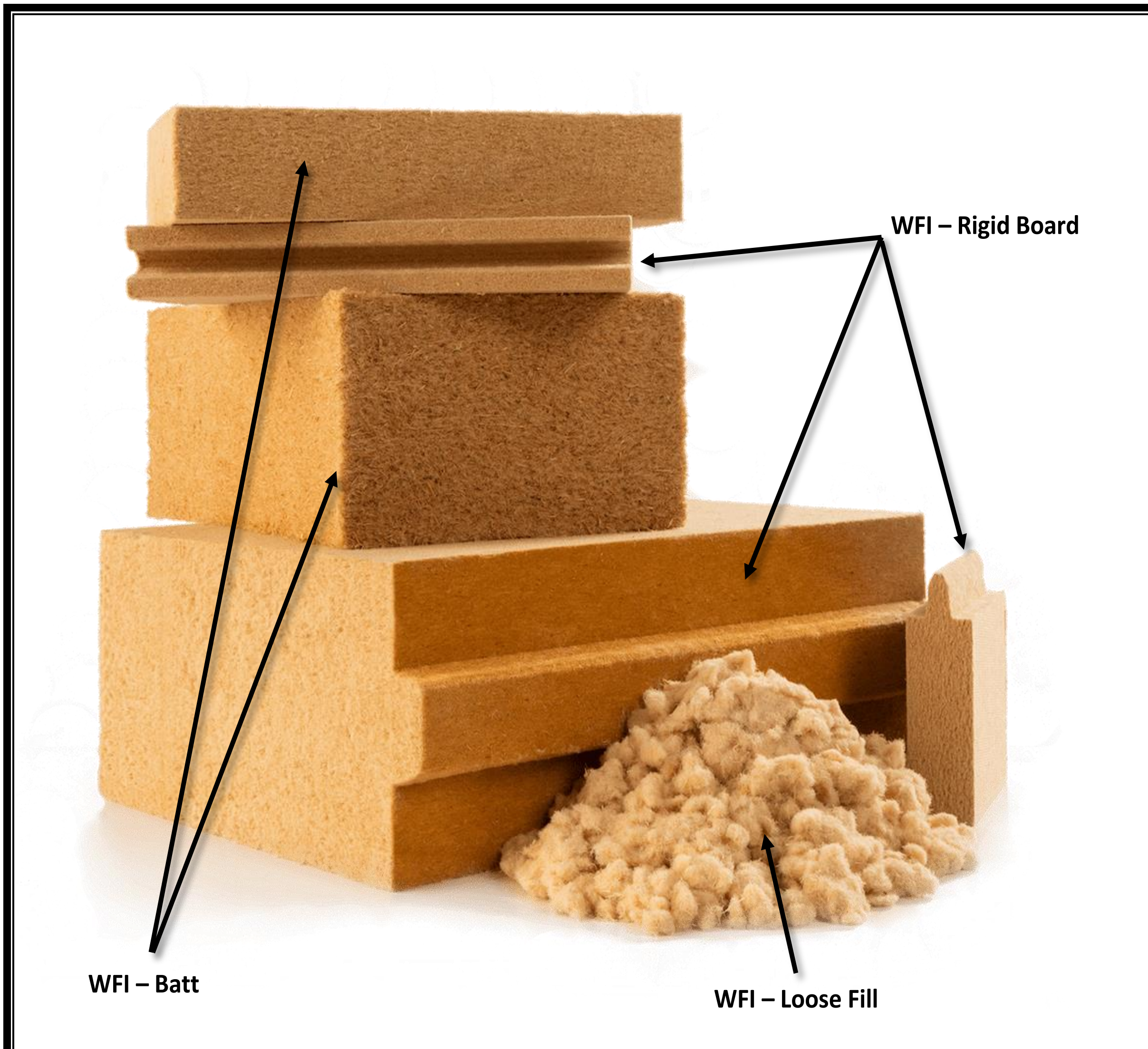
- A key caveat in viability is that, given the currently small market share of these products in the US and lack of recognition for several WWC products in building codes, there is a significant risk in market development for the first US-based manufacturers. Market development should be a key focus for any entrepreneur entering this space.
- Regarding the previous point about market growth, the following recommendations all relate to potential means of growing the market for WWC products:
    - It is recommended that a group or committee be organized to advocate for the acceptance of WWC products into US building codes. CWSF may be able to work with US-based entrepreneurs who are planning to develop WWC manufacturing abilities, helping facilitate building code acceptance through organizations such as the American Wood Council.
    - WWC products use a considerable amount of cement. It is recommended that any WWC advocates (e.g., WCSF, entrepreneurs, etc.) approach the Portland Cement Association, an industry association serving America's cement manufacturers (www.cement.org), to explore whether the association is willing to provide any assistance in developing markets for WWC products in North America.
    - It is recommended that any WWC advocates approach the Softwood Lumber Board (SLB), which is an industry-funded initiative to promote the benefits and uses of softwood lumber products. While WWC does not directly contribute to use of softwood lumber, it may help promote softwood lumber's use if WWC products are used in conjunction with mass timber construction, which is expected to be a major use of softwood lumber.
    - The US Forest Service has a long track record of supporting research for utilizing small-diameter trees and businesses aimed at using them. This is because the existence of businesses that can utilize small-diameter trees helps increase the pace and scale of forest restoration, which is a key US Forest Service initiative. Any WWC advocates should work to position this technology favorably as a viable means of utilizing small-diameter trees.
    - Finally, it is recommended that another potential means of advocating for WWC products is by emphasizing the material's positive impact on human health. Research has shown that noise pollution adversely affects human health. To the extent WWC panels reduce noise pollution in homes, businesses, and other structures occupied by humans, they can contribute to better health.

CHAPTER 3 – WOOD FIBER INSULATION

3.1 OVERVIEW

As shown in **Figure 3.1**, Wood Fiber Insulation (WFI) is a family of products designed to provide thermal and sound insulation for buildings. The manufacturing process first reduces wood to individual cellulose fibers, then reforms the material into a WFI product in a secondary part of the manufacturing process. As the figure shows, there are three generic WFI product types: *rigid boards*, *flexible batts*, and *loose fill*. The rigid board and batt products are produced in a variety of thicknesses. The rigid board product is typically applied as an insulating layer in an exterior wall over plywood or OSB sheathing, but underneath exterior siding. The flexible batt product is also typically used as an exterior insulator, but the batts are fitted between wall studs or roof joists. Finally, loose fill is also used to fill in spaces between wall and roof joists, but (unlike a batt that fits snugly between the studs or joists) is blown into place.

Figure 3.1 – Wood Fiber Insulation Products



Source: TimberHP by Go Lab

3.2 HISTORICAL PERSPECTIVE

Wood in various forms has been used to build and insulate homes for millennia. Starting in the early 1930s, a "wet process" for manufacturing rigid insulation panels was developed in Germany. As suggested by the name, the wet process involves grinding wood down to cellulose fibers, mixing the ground material with hot water, and forming it into a panel. Initially water is removed by a combination of a vacuum and pressing; later, heat is applied to fully dry the material. The lignin naturally present in wood allows the material to bind together without the need for additional adhesives. The final step involves cutting the matte to the desired width and length. The wet process is still used by some manufacturers today. However, about 20 years ago, a "dry process" was developed for manufacturing WFI rigid insulation panels. Like the wet process, the dry process starts with grinding wood material down to cellulose fibers. From there, it differs in that the next step is drying the ground material. After drying it is mixed with an adhesive (usually polymeric methyl diphenyl diisocyanate, abbreviated pMDI) and a small amount of paraffin wax to enhance water resistance. The material is then formed into a matte and placed in a press, where air and steam are used to cure it. The cured panels are then cut to final dimensions. The development of the dry process has coincided with significant market growth in Europe for WFI products.

3.3 PRODUCTS & MARKETS

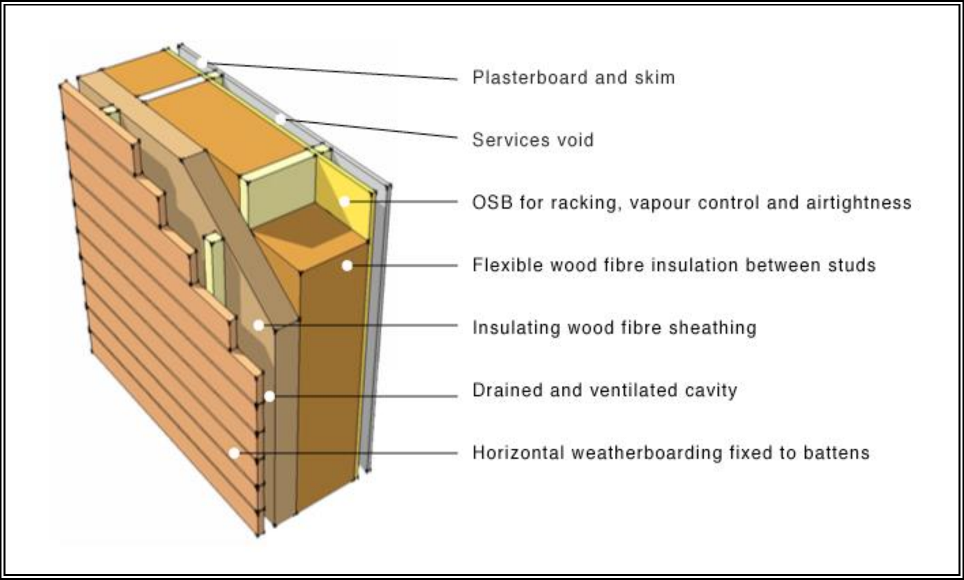
This report section provides information about common types of WFI products and the associated market information such as market size and product sales values. Little published information exists about these aspects of WFI products. Thus, the information is derived from personal communication with key members of the WFI industry, combined with the few published sources of information. At the current time there are three main types of WFI products as shown in the list below. Note there are product variations within each main category to serve different end-use applications. The sections following the list describe the key aspects of each main product type.

1. WFI Rigid Panels
2. WFI Batt
3. WFI Loose Fill

It is worth noting that these three distinct types of WFI products are often used together as a "system" in a wall, roof, or floor as shown in **Figure 3.2**. As the figure illustrates, the light yellow pieces are wall studs. Between the studs, the brownish orange substance represents flexible WFI batts. These fit snugly between the studs and require no adhesive to stay in place. Note that the figure shows batts used between the studs, but WFI loose fill could also be used in the cavity between studs. On the exterior side of the studs is a layer of WFI rigid panels. These panels can vary significantly in thickness, but nearly always have a tongue and groove built into the edges so that panels can fit together securely. Next, furring strips are applied to the outside of the WFI rigid panels, followed by exterior siding. Not shown in this example is that there is often an air and vapor barrier applied to the outside of the WFI rigid panel. Also not shown in this example is that some designs finish the exterior of the wall with render (typically a cement mixture) instead of siding. In such cases, a wire mesh is first affixed to the exterior of the WFI rigid panel to provide better adhesion of the render material.

On the interior of the wall, in this example, is an OSB (or could be plywood) sheathing affixed to the studs to provide structural stability and to create an air and vapor barrier. The figure also shows the interior wall as plasterboard (also known as drywall) but it could be numerous other types of materials (e.g., paneling, tile, stucco, etc.).

Figure 3.2 – Example of Wood Fiber Insulation Products Used in a Wall System



Source: GreenSpec

3.3.1 WFI – Rigid Panels

As previously described, WFI rigid panels are commonly used to help insulate a wall system. However, they can also be used as rain-tight sarking boards in roof systems, and as a subfloor in flooring systems to provide insulation and deaden sound. **Figure 3.3** provides an illustration of a typical WFI rigid panel being applied to a roof. Note in this particular example, the panels do not have the characteristic tongue-and-groove configuration.

Figure 3.3 – Example of WFI Rigid Board Product in Use

Source: Beton Wood

3.3.2 WFI – Batt

Batt is a blanket of insulation that is installed between wall studs, floor joists, or roof rafters. For many years it has been mostly associated with fiberglass, but recent interest in sustainable, renewable, and less carbon-intensive building materials has spurred renewed interest in WFI batt. The material provides excellent thermal performance; it is vapor-permeable, which more easily allows water vapor to pass through the material without condensing into water and potentially causing mold problems. It is also easy to install, and while it is flexible, it is stiffer than most other batting and therefore resists slumping while in use due to gravity or when it gets heavier after absorbing moisture. This is especially true when it is sized to fit snugly between studs, joists, or rafters without use of adhesives or fasteners. Another benefit of WFI batt is that it provides excellent soundproofing when used in walls, floors, or roofs. **Figure 3.4** illustrates WFI batt used between floor joists. Note that in this example the batt is not fitted as snugly between joists as might be expected in a wall or roof application.

Figure 3.4 – Example of WFI Batt in Use

Source: Beton Wood

3.3.3 WFI – Loose Fill

WFI loose fill is a third type of wood insulation product. As the name implies, the wood material is not formed into a panel before use, but rather used as a loose material that fills oddly shaped cavities not easily filled with a rectangular panel, or to fill attic and wall spaces as part of a renovation project. Like other WFI products, it is made from wood chips that have been reduced in size to individual cellulose fibers. No adhesives are used in the product, but it is treated with borates to reduce its susceptibility to insects, decay, and combustibility.

Figure 3.5 – Example of WFI Loose Fill In Use

Source: Beton Wood

Table 3.1 summarizes key product characteristics for the three WFI product types. As the data in the table shows, all three of the WFI product types have R-Values ranging between about 3.5 to 4.0 per inch of thickness. Note that R-value is the measure of a material's capacity to resist heat flow. The higher a material's R-value, the greater its capacity to serve as a thermal insulator. In the US, the recommended R-values for walls range from R13 in the south to R21 in the north and between R30 and R60 for attics in the south and north respectively. The table also shows that the materials are typically produced to a range of sizes and thicknesses, for ease of adaptation to different insulative needs given a region's climate and to differing housing construction systems. Also note that each product is bound in its final form in various ways. The rigid panels are made with pMDI, a chemical adhesive commonly used in wood products because it has weather-resistant properties. The table also shows that the various WFI products have very low density with the rigid panels averaging about 10 pounds per cubic foot. In contrast, bone dry solid softwood averages about 26.5 pounds per cubic foot (at 6% moisture). Thus, WFI manufacturing yields products that are 2.6 times less dense than solid wood (relative to rigid panels) and more than 17 times less dense than solid wood (loose fill). The de-densification of wood fiber is the driving mechanism in what allows WFI products to have their characteristic insulating and acoustic properties. However, a disadvantage of low density is that WFI products cannot be cost-effectively shipped more than about 400 miles.

Table 3.1 – Summary of Typical WFI Product Specifications

Product Characteristic	WFI – Product Type		
	WFI – Rigid Panel	**WFI – Batt**	**WFI – Loose Fill**
R-Value	• 3.4 to 3.7 per inch of thickness	• 4.0 per inch of thickness	• 3.8 per inch of thickness
Size	• 1” to 9.25” thick • 24” wide • 4’ and 8’ lengths	• 3”, 3.5”, 5.5”, 6”, and 7.25” thicknesses • 15” and 23” widths for wood studs and 16” and 24” widths for steel studs • 47” length for wood studs and 48” length for steel studs	• R60 attic occupies ~ 12 square feet per 25# bag • 2x6 wall (R21) occupies about 18.4 square feet of wall space per 25# bag
Composition	• Wood fiber, pMDI adhesive, paraffin	• Wood fiber, polyamide binding fiber, borate	• Wood fiber and borate
Density	• ~10 pounds per cubic foot	• ~3 pounds per cubic foot	• ~1.5 pounds per cubic foot
Fire Ratings	• ASTM E84 Class B <75 Flame and <450 Smoke Spread	• ASTM E84 Class A Flame and Smoke Spread rating	• ASTM E84 Class A <25 Flame <450 Smoke Spread
Other	• 10 to 20 PSI compressive strength • Industry-leading acoustic performance (relative to other insulation materials)	• In addition to fire mitigation, borate also inhibits mold, mildew, and insects • Industry-leading acoustic performance (relative to other insulation materials)	• In addition to fire mitigation, borate also inhibits mold, mildew, and insects • Industry-leading acoustic performance (relative to other insulation materials) • Product packed in 25-pound bags with 48 bags/pallet

Source: TimberHP

3.3.4 Market Size

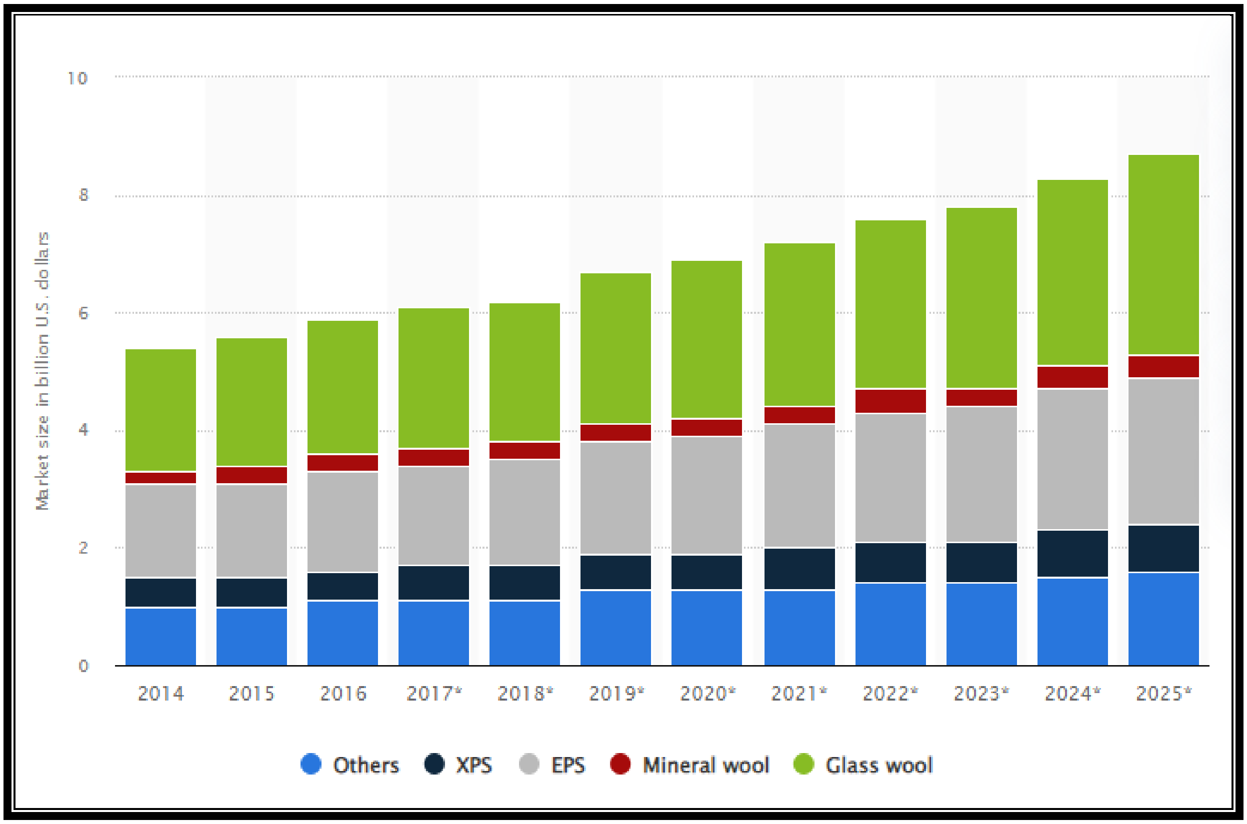
The US market for insulation materials is estimated to currently be about $7 billion dollars per year as shown in **Figure 3.6**. Glass wool is the most used material (on a dollar basis) followed by expanded polystyrene (EPS). Other materials such as extruded polystyrene and mineral wool are much smaller segments of the market. Wood fiber insulation is lumped into the category called “Others,” which in total is estimated about at $1 billion in 2022. TimberHP, a company that will start WFI manufacturing in Maine in 2023, is anticipating annual revenues of about $100 million when fully operational (about 10% of the “Others” insulation market segment). The year-over-year growth shown in the figure is driven by rising energy costs which cause consumers to seek lower energy use, and by regulations incentivizing homeowner investments in energy efficiency (e.g., insulation). As will be described in a later section of the report, the capital costs for developing an insulation manufacturing facility are significant. Therefore, production tends to be concentrated among several well-capitalized manufacturers who operate multiple manufacturing facilities distributed throughout the country.

The European market is growing even faster. For example, Steico, a publicly owned German company that makes WFI products, reports year-over-year sales growth more than 22% in WFI products and very strong growth in the US market.[8] Wooden Haus Supply is a Montana-based company that has been importing and installing WFI products (produced by Steico) for several years. A number of other European

[8] https://www.steico.com/fileadmin/user_upload/Investor_Relations/2022_Veroeffentlichungen/2022_Finanzberichte/EN_STEICO_Half-Year-Report_2022.pdf

companies (Gutex, Schneider, etc.) are exporting WFI products to the US, but the volumes are small due to high transportation costs.

Figure 3.6 – Estimated Size of US Insulation Market



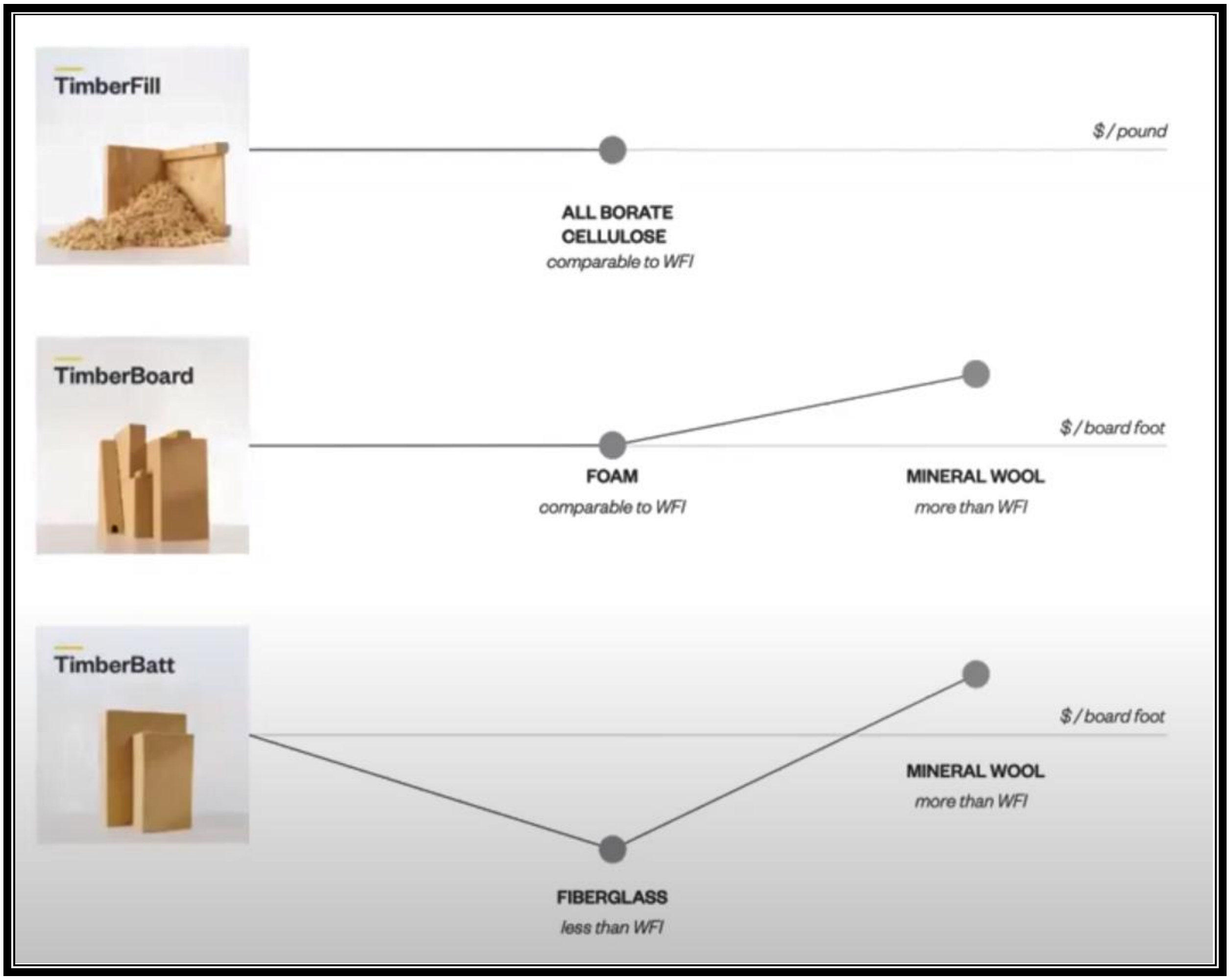
Source: Statista.com

3.3.5 Market Prices

There are no published prices for WFI products. However, Internet searching reveals that current retail prices for WFI products are about $0.70 per pound (assuming products among all manufacturers have densities similar to those shown in Table 3.1), or nearly $1,400 per ton. Given those retail level prices, it is estimated that sales values FOB the manufacturing facility are approximately $0.40 to $0.45 per pound or $800 to $900 per ton. An important characteristic of WFI products is that they are very lightweight relative to their cubic volume. As a result, relatively little material (on a weight basis) can be shipped per truckload; this makes shipping very expensive on a dollars per unit of weight basis. This characteristic of WFI products (and all insulation products in general) is that manufacturing tends to be distributed geographically with points of manufacture located near major market areas.

Figure 3.7 illustrates how TimberHP, the new WFI manufacturing startup in Maine, intends to take their products to market regarding pricing relative to other types of insulation materials. As the figure illustrates, the WFI loose fill product treated with borate will be comparable in cost to loose fill cellulose product (i.e., recycled paper that has been manufactured into a loose fill insulation material). TimberHP's TimberBoard product will be priced at the same level as EPS and XPS (polystyrene foam insulating products), but lower cost than mineral wool (insulation formed from molten rock). Finally, TimberHP's TimberBatt product will be priced between fiberglass insulation batt and mineral wool batt products.

Figure 3.7 – WFI Price Comparison Relative to Other Insulation Materials



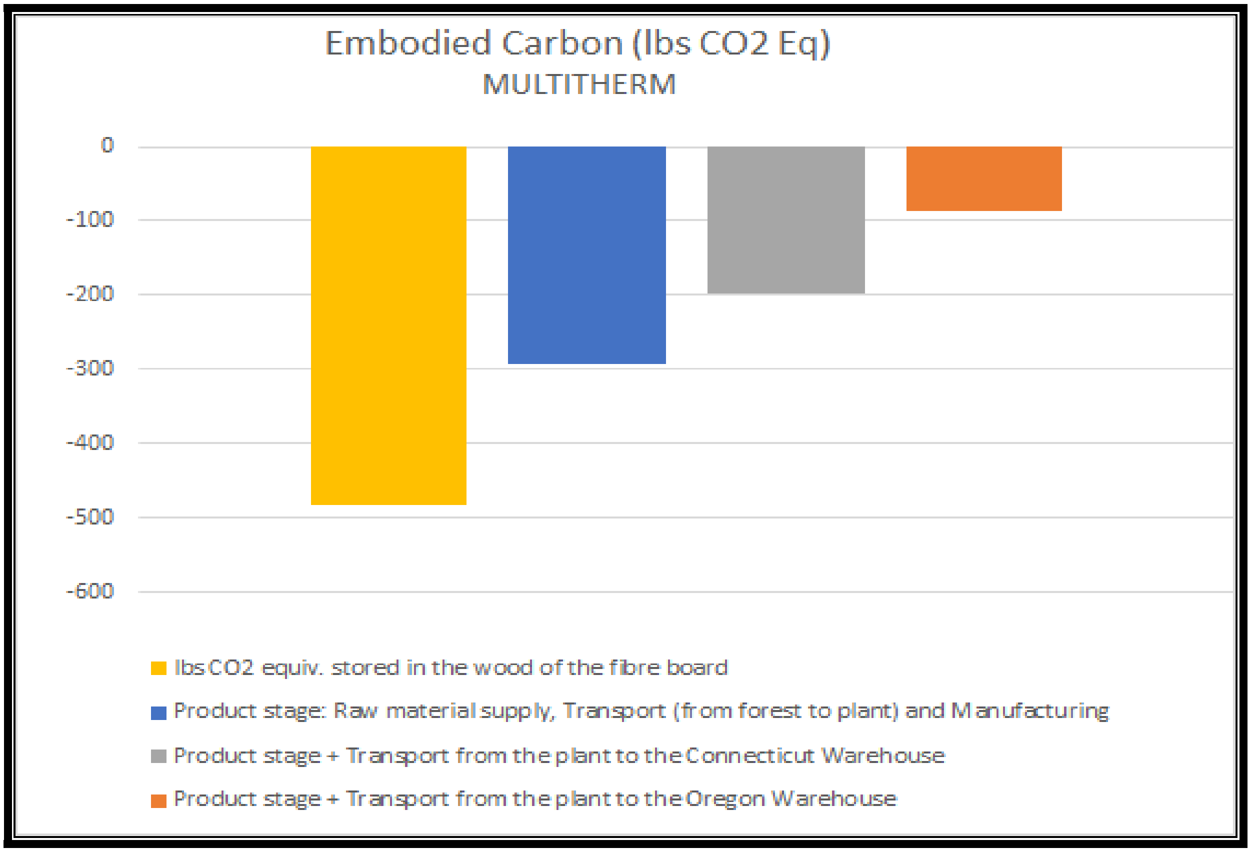
3.4 SUSTAINABILITY

WFI products are widely viewed as sustainable and environmentally friendly. The reasons for this are many.

First, wood is a renewable material. In other words, wood fiber used in WFI (and other forest products) is replaced by new forests that replace harvested lands through planting and natural regeneration. In the United States, according to the US Forest Inventory and Analysis database, more fiber is grown each year than is harvested for manufacture into forest products and that is lost to natural mortality (e.g., insects, disease, fire, etc.). The same is true of Canada. Thus, at current timber harvest and natural mortality levels in North American forests, wood use is well within sustainable levels. Additionally, some WFI producers elect to use only wood sourced from forests that are third-party certified as being sustainably managed (e.g., FSC, SFI, etc.).

Wood used in the form of wood fiber insulation is about 50% carbon on a weight basis. Thus, while WFI products are in service – which is often for long periods equal to the life of a building – the carbon taken from the atmosphere during tree growth is sequestered in the WFI material. Perhaps the biggest arguments in favor of WFI products are associated with its carbon footprint. As shown in **Figure 3.8**, a square meter of WFI material with R29 equivalent thermal resistance (or a little more than 8” thick assuming 3.5 R-value per inch of thickness) contains nearly 500 pounds of sequestered carbon dioxide equivalent (the yellow bar in graph). Since the carbon in the insulation is sequestered the graph values are shown as negative. However, when the material is harvested, transported to a manufacturing facility, and manufactured into a WFI product, carbon is released. Thus, the same square meter by ~8 inch thick WFI material now contains a net of about 300 pounds of sequestered carbon (i.e., some carbon was released back to the atmosphere in the process of converting the material into a WFI product). Similarly, the grey and orange bars in the graph represent the net pounds of carbon dioxide equivalent remaining in the material after transporting the WFI product from Europe to the US East Coast and then ultimately to the US West Coast. In the end, the square meter of WFI material about 8" thick is estimated to be sequestering a net volume of just under 100 pounds of carbon dioxide equivalent. Note the values in the figure are provided by Gutex, a German manufacturer of WFI products.[9]

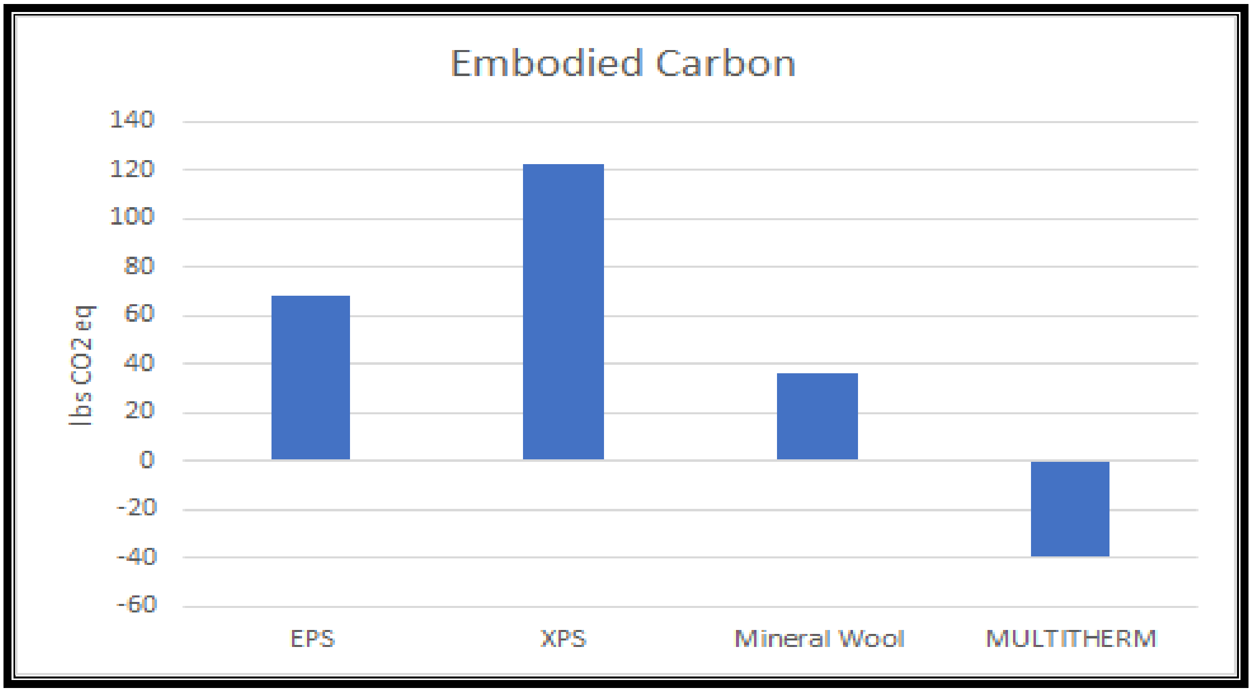
Figure 3.8 – Estimated Embodied Carbon in WFI Products When In Use



Not only are WFI materials carbon negative when placed into service, they also perform considerably better than other types of insulation materials, which as shown in **Figure 3.9** are net carbon emitters during their production. Note that EPS and XPS are two types of polystyrene insulation, with EPS being expanded polystyrene and XPS being extruded polystyrene. Both are made from aromatic hydrocarbons, which are by-products of crude oil. Mineral wool is another form of insulation made by converting molten rock into fine fibers that resemble a natural wool material. Mineral wool production is energy intensive because the rock must be heated to molten levels before being rapidly cooled with an air stream to create the mineral wool material. Thus, the material is carbon intensive due to the high energy needed for heating.

[9] https://cphba.com/gutex-wood-fiber-insultation-a-carbon-solution-on-day-one/

Figure 3.9 – Estimated Embodied Carbon Among Insulation Products Made From Other Materials



3.5 RAW MATERIAL

Most existing WFI manufacturers purchase their raw material in the form of wood chips and sawdust, which are produced as by-products of other processes such as sawmilling and veneer/plywood manufacturing. A variety of softwoods are the main raw material used for WFI products. Softwood is generally preferred since those species typically have longer cellulose fibers, which translates into stronger WFI products. However, some plants use hardwood species. Regardless of whether the raw material is hardwood or softwood, there are relatively few specifications for the raw materials used to make WFI products other than it must be clean wood fiber and must not contain contaminants such as metal, dirt, bark, etc. **Table 3.2** provides more detail on typical quality specifications for the fiber received at a low-density fiberboard plant (i.e., a WFI facility).

Table 3.2 – Generic Quality Specifications for WFI Facility Raw Material Received in Chip Form

Products shall be produced from bark-free, dirt-free, sound wood and shall conform to the following specifications:
• Average chip size target of 3/4" to 1 1/2" and ¼" thickness. Maximum allowable size is 2" and ½" thickness. • Deliveries shall be free from foreign material, including but not limited to pieces of plywood, construction/demolition waste, painted wood, preservative-treated wood, stones, sand, insulation, gypsum, asphalt, metal, rubber, belting, and plastic. • The presence of bark shall be tolerated to the extent of up to 1% of the load by weight of shipment. • The presence of grit shall be tolerated up to the extent of 0.1% of the load by weight of shipment. • The presence of rot shall be tolerated up to the extent of 2% of the load by weight of shipment. • Alternative species are allowed up to a maximum of 5% of by weight by shipment. • Dry and green fiber shall not be delivered in mixed loads. • No evidence of added water.

The ability of a WFI manufacturing plant to utilize mill residues is important for development of WFI manufacturing capacity in North America for several reasons. First, there has been a long and steady decline in paper manufacturing capacity throughout North America. As a result, sawmills and veneer/plywood mills in many parts of North America today have fewer options for selling their by-products than in the past. This is an encouraging finding for a prospective WFI manufacturer, since they may be able to locate a facility in a region where there are a number of existing sawmills, but where there is limited market for sawmill by-products (chips, sawdust, and planer shavings). In other words, they may be able to provide a market for an otherwise underutilized or unutilized material.

The scenario described in the preceding paragraph should provide a WFI manufacturer with access to mill residual raw materials during most market conditions. However, as a point of reference, in the fourth quarter of 2022 mill residual chips in North America were trading at values ranging from a low of $45 per bone dry ton (delivered) in the US South to a max of nearly $200 per bone dry ton (delivered) in the Pacific Northwest. Prices in the Pacific Northwest, Lake States, Northeast, and British Columbia were all at record highs at the end of 2022. This was due to several factors, such as strong demand for paper combining with a period when sawmill production is declining due to weak market conditions. A labor strike in the Pacific Northwest also lowered mill output, which in turn limited chip supply; limited logging capacity in the Northeast also constrained supply. Thus, a WFI manufacturer may experience periods where high demand for mill residuals and limited supply combine to dramatically increase their raw material prices.

While a WFI manufacturer may plan to mainly rely on mill residues as raw material, they also have the option to include debarking and whole log chipping capability at their facility. This would enable a WFI manufacturer to purchase small-diameter trees (i.e., pulpwood) and convert them into chips, which can then be used as WFI raw material. Thus, during times when mill residual chip prices are high, mill residual chip supply is low, or both, the WFI producer would have an alternate supply source in the form of whole log chips sourced from pulpwood.

However, note that including whole log chipping capability at a WFI facility also forces the WFI producer to incur several costs. First is the capital cost for purchasing and installing the required equipment (e.g., a debarker, a chipper, sizing screens, storage bins, etc.). Second is the ongoing operating and maintenance costs (e.g., labor, power, supplies and repair, etc.) that are required to operate the equipment. The third type of cost is less obvious, but involves underutilizing equipment. By designing a facility to be able to utilize both mill residuals and roundwood, it is likely that during periods when mill residuals are the main source of raw material, the whole-log chipping equipment will be underutilized or even unutilized – an inefficient use of the invested capital.

A final cost is that when mill residuals are utilized, the cost of gathering the material at a single location and processing it into chips is borne by the sawmill (or veneer/plywood mill) that produces them as a by-product. In other words, a significant amount of raw material each year accumulates at a sawmill and typically no cost is assigned to its production since it develops as a by-product of sawmilling (or veneer/plywood manufacturing). In such a scenario, the value of the material is determined by market forces. If a WFI facility is sited where mill residual supply is plentiful and demand for mill residuals is weak, the plant should enjoy low raw material costs. In contrast, for small-diameter roundwood, the value of the raw material is driven by the costs incurred delivering it to a facility (i.e., the costs of buying stumpage rights; the costs for harvesting, yarding, processing into pulpwood, and trucking to a WFI plant; the costs at the WFI plant involved in processing into chips, accounting for yield loss of bark, etc.). All of those costs must be assigned to the delivered cost of roundwood raw material. Thus, utilizing roundwood as a raw material may be more costly than using mill residuals in a region where there is low existing demand for mill residuals. In summary, each prospective WFI operation will have to carefully analyze options for utilizing roundwood, mill residuals, or both.

3.6 PROCESS AND PRODUCTION

The following sections provide a description of existing and planned WFI manufacturers, an overview of the general WFI manufacturing processes, and capital/operating expenses for WFI facilities.

3.6.1 Existing Manufacturers

Currently there are no operating WFI manufacturers in North America. However, TimberHP is a startup that is about to begin operation in Madison, Maine at the site of a former paper mill in the process of being converted to WFI manufacturing. The plant will produce about 115,000 bone dry tons of WFI products annually when fully operational. It is also reported that TimberHP is in the process of evaluating other sites in the US for opening a second WFI manufacturing facility.

In Europe there are four major WFI producers including Pavatex, which operates a plant in Golbey, France. Pavatex has also commissioned construction of a new plant in Chavelot, France that is expected to be operational by the end of 2023. When finished, both plants will have a combined annual capacity of about 110,000 tons per year. There are also Gutex and Schneider Best Wood in Germany. Additionally, Steico is a publicly owned company based in Germany which has multiple WFI manufacturing operations including Czarnków, Poland, with what is claimed as the world's largest WFI production facility. The plant has four lines for producing wet process WFI rigid panel products, two lines for producing dry process WFI rigid panel products, two lines for producing WFI batt, and one line for producing WFI loose fill. Steico also operates a plant in Czarna Woda, Poland, that has four wet process lines for manufacturing WFI rigid panels. In Gromadka, Poland, the company is currently constructing a new WFI manufacturing plant. When complete, the plant will have two production lines for WFI batt and one for dry process WFI rigid panels. Finally, in Casteljaloux, France, Steico operates a plant that has two production lines for WFI batt and one for dry process WFI rigid panels. In total, Steico is estimated to have about 350,000 tons per year of annual production capacity of various WFI materials. Well-established European based equipment manufacturers such as Siempelkamp and Dieffenbacher have long track records of supplying the major equipment items needed for WFI manufacturing.

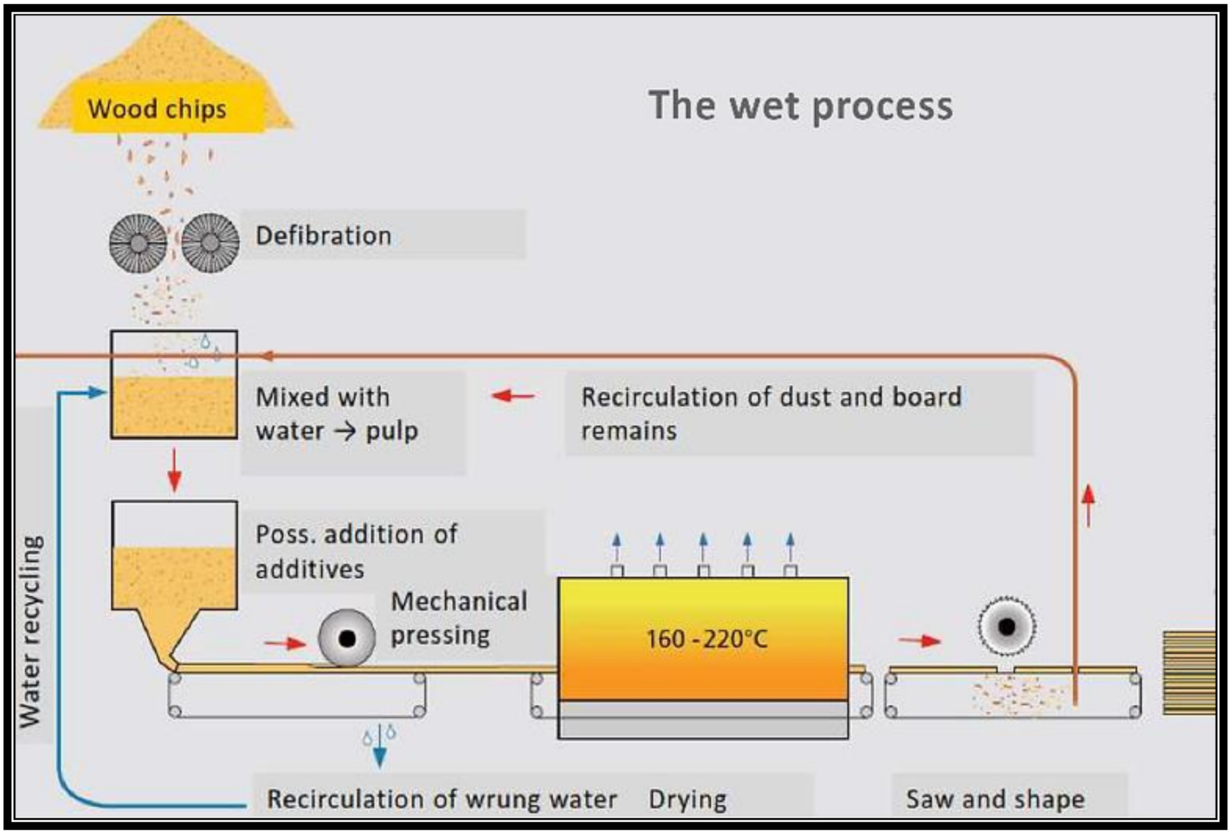
3.6.2 General Process Overview

The WFI panel products fall within the general category of Low Density Fiberboard (LDF). While LDF products can be made from a variety of materials (e.g., hemp, bagasse, etc.), most are made from wood. There are two types of processes used to manufacture LDF panel materials: the wet process and the dry process. As previously described, the wet process was developed nearly 100 years ago in Germany.

Wet Process Description – The general steps are illustrated in **Figure 3.10**. The first step is pulping the wood fiber. While there are a variety of ways to convert wood into pulp (e.g., chemical, mechanical, and various combinations of both), most WFI manufacturing operations use a refiner to create pulp mechanically. A refiner consists of two large, heavy metal disks that are spaced very closely together (i.e., so that the large faces of the disc are close together). One or both of the discs rotate and wood chips are forced between the discs, which grind them into a pulp. In the figure, this process is called *defibration*. In most operations, the wood chips are steamed or heated in hot water before entering the refiner to ease the process. The resulting pulp from the refiner is then mixed with water (and additives such as borate). That mixture is then formed into a panel, compressed to the desired thickness, and dried.

The wet process is energy intensive, including electrical energy to operate the refining discs and thermal energy to dry the panels. An advantage of the wet process is that lignin, a naturally occurring compound in wood, acts as a natural binding agent, thus no adhesive is required for the panels to maintain their shape and integrity after drying. Another potential drawback is that wet process panels have a higher tendency to absorb water when placed into service. Thus, if the panels should come into contact with moisture, the wet process panels will absorb the water. Sometimes paraffin wax is added to the process to provide the panels with resistance to moisture absorption. Steico, one of the leading European WFI producers operates several plants that use the wet process to manufacture WFI panels.

Figure 3.10 – Overview of Wet Process for WFI Manufacturing



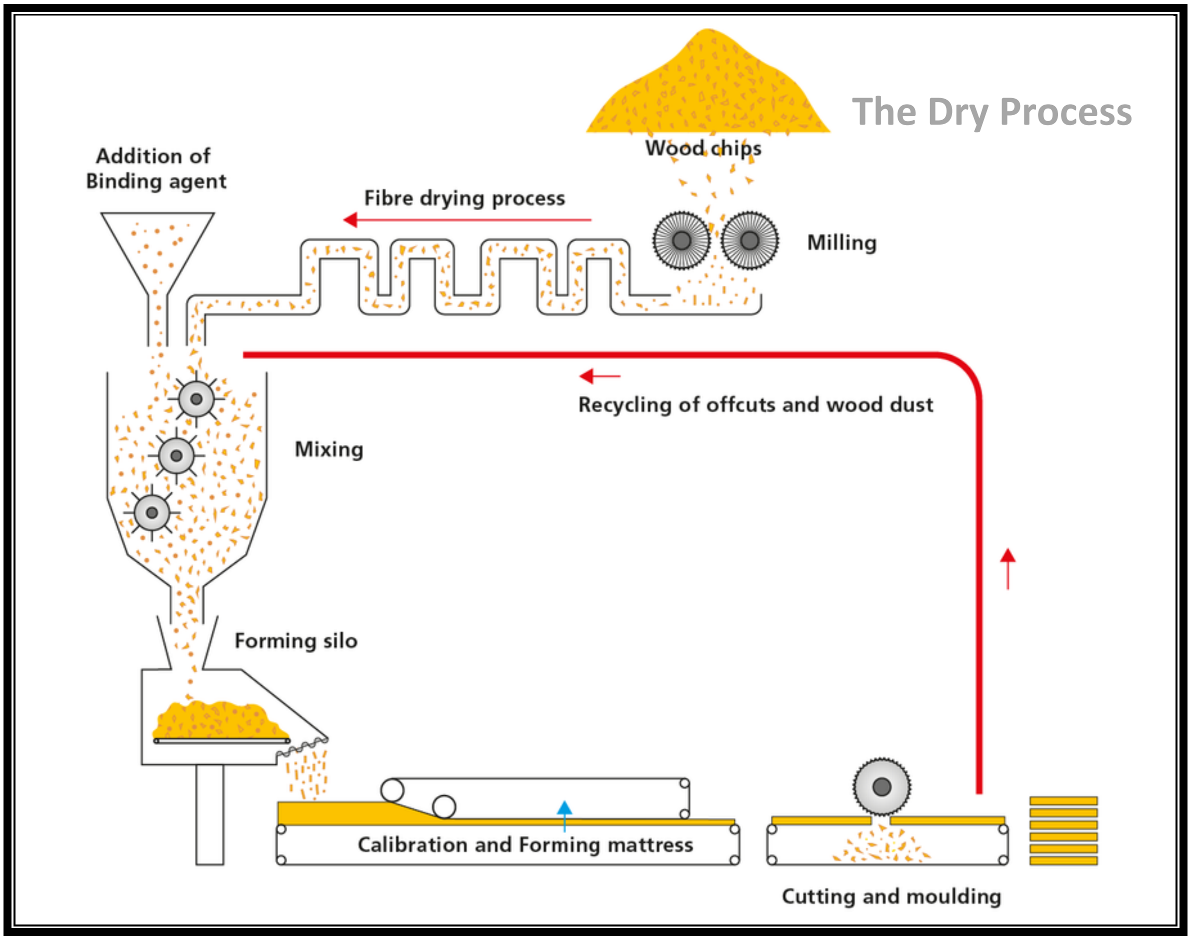
Source: Steico

Dry Process Description – The general steps are illustrated in **Figure 3.11**. As the figure shows, like the wet process, the first step in WFI dry process manufacturing is refining solid wood chips into pulp (i.e., wood chips heated with water or steam are refined into pulp). Next the refined fibers are dried, typically in a rotary dryer. Then the dried pulp material is mixed with resin (pMDI in the case of TimberHP's process) and paraffin wax. That mixture is then formed into a matte. The matte is then hot pressed to cure the adhesive, wood fiber, and wax mixture. Finally, the dry and cured matte is cut to its final dimensions.

Several things are noteworthy about the wet and dry processes. For product sold as loose fill material, the dry process is conducive to serving this market since the dry, pulped material can be diverted from the remaining steps of the manufacturing process. The material sold as loose fill is compacted, bagged, and palletized.

The wet and dry processes described are for the formation of WFI rigid panel products. For WFI batt products, the dry process is used – up to a point. Instead of mixing the pulp with wax and polyurethane adhesive, the material is mixed with polyamide binding fiber and borates. Polyamides are a generic term to describe a group of chemicals that act as a binder. The polyamide, borate, and pulp mixture is then formed into batts that typically range between 3" and 7.5" in thickness and 16" to 24" in width. A widely perceived advantage of the dry process is that paraffin wax is added to the mixture of polyamide binder and wood. This addition makes the material highly resistant to water.

Table 3.11 – Overview of Dry Process for WFI Manufacturing



Source: Steico

Finally, in either the wet process or the dry process, the material is dried before it is considered a finished product. Depending on the process, the drying occurs in rotary dryers, board conveyors, hot presses, etc. Drying wood means that emissions controls are an important consideration in the manufacturing process. Typical emissions include wood dust and particulate matter, volatile organic compounds, nitrogen oxides, and carbon monoxide. The interactions of wood and heat that drive these emissions are well understood and a variety of equipment is available to mitigate and control the emissions. Nevertheless, the emissions associated with wood drying must be considered as part of the due diligence and will likely require a permitting process for any new facility developed.

3.6.3 Plant Scale & Capital Expense

As previously described, there are many types of insulation materials. Many are made from by-products of the petrochemical industry or from recycled products. This means that competing insulation products often have a lower cost structure than might otherwise be the case, since the raw materials are by-products of other processes. Also, the competing materials are produced in large quantities at industrial-scale facilities.

Given these circumstances, WFI manufacturing facilities are also large-scale operations that typically operate on a 24/7 schedule. WFI facilities also typically use sawmill by-products as their raw material, although as previously described in the raw materials section, some may also utilize small-diameter trees. Another characteristic of WFI facilities is that since the process involves converting wood fiber into pulp, the front end of the manufacturing operation is similar to a pulp mill. This means that the plants typically require a large amount of equipment (and associated capital expense) for processing. Additionally, as previously described, the refining equipment is energy intensive, which also ramps up the scale of WFI manufacturing operations (e.g., larger more robust electrical service, the need for a thermal energy source, heated presses for forming the panels, etc.). All of the preceding factors combine with the fact that finished product cannot be cost-effectively shipped long distances. This limits the scale of a plant. Given all of these factors, it is estimated that the average plant consumes 100,000 to 150,000 bone dry tons of raw material annually.

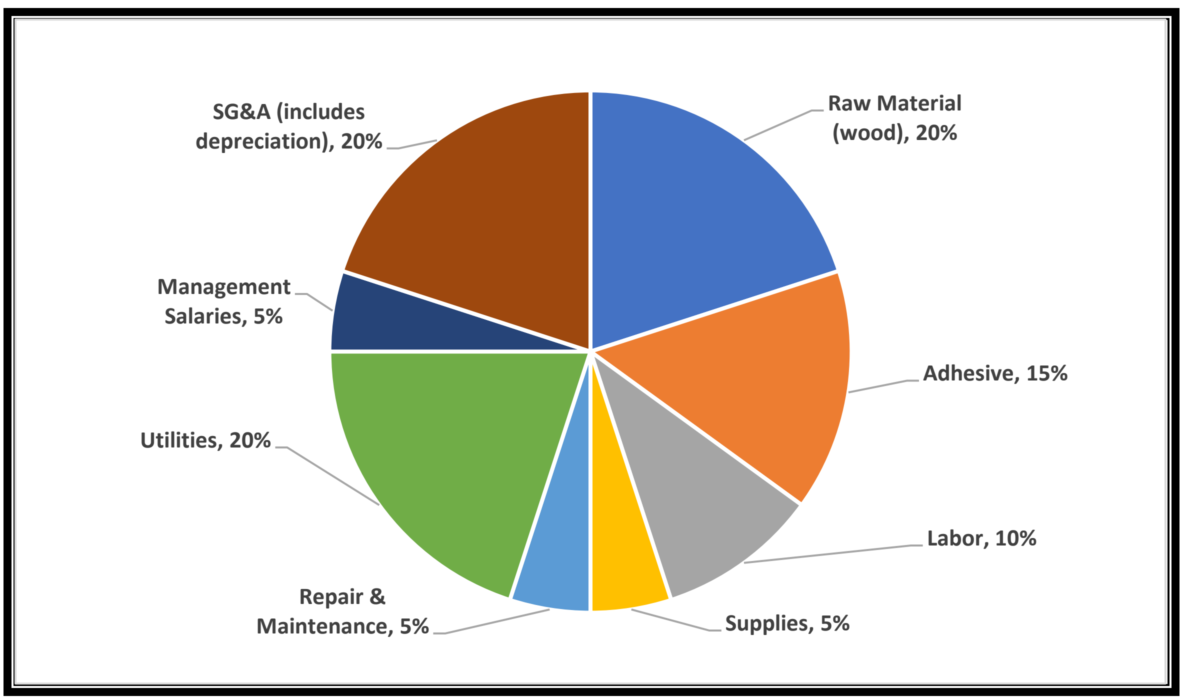
With regard to capital cost, the TimberHP project in Central Maine is reported to have a capital cost of approximately $130 million. Importantly, that project was sited at a mothballed paper mill that was acquired for a reported $1.9 million dollars. Additionally, the fiber board forming machines and presses were purchased used from a company in Germany. Interviews with TimberHP staff revealed that the estimated capital cost for a WFI facility using all new equipment and at a greenfield site will range between $200 and $250 million.

3.6.4 Operating Expense

Figure 3.12 summarizes the operating costs for running a WFI manufacturing operation modeled as operating on a 3-shift basis (7 days/week for 50 weeks per year) and producing about 115 million dry tons of finished WFI products annually.

As the data in the figure show, wood constitutes about 20% of raw material cost (based on an assumed delivered price of $90 per bone dry ton and wood being received at an average moisture content of 50%). Utilities and SG&A (Sales, General & Administrative including depreciation) also account for an estimated 20% of operating costs each. The cost of purchasing the various adhesives used in the process is estimated at 15% of the operating cost. Hourly labor is another relatively large proportion of total cost at 10%, and is based on the facility having 120 hourly employees. Please note these costs have been modeled based on a comparison to similar forest products manufacturing operations.

Figure 3.12 – Natural Operating Cost Categories as a Percentage of Total Operating Cost



3.7 POLICY & REGULATORY

A WFI manufacturer will encounter several key policy and regulatory issues in establishing and operating a manufacturing facility in the US. The first involves manufacturing the products, and revolves around the issue of obtaining air quality permits related to the emissions of materials such as VOCs, NOx, particulate matter, etc., which occurs when wood materials are dried. Obtaining the necessary permits is not expected to be insurmountable, given that there exists a variety of emissions control equipment to keep emissions within acceptable levels. Nevertheless, the equipment is typically costly and the permitting process extends the development timeline for a project.

The second issue involves obtaining key certifications for the WFI products. More specifically, controlling the flammability of WFI products is a key issue since wood is inherently combustible. WFI manufacturers have addressed this issue by adding chemicals (borates) to the wood fiber to reduce combustibility. However, the effectiveness of these treatments must be certified by an independent organization; for example, Underwriters Laboratory (UL) handles this type of certification. According to TimberHP contacts interviewed as part of this study, there is a long track record of WFI products manufactured in Europe meeting UL standards to achieve various fire ratings, which enable the materials to be used in building construction and to comply with building codes. TimberHP fully anticipates that their operation will obtain the same certifications once their plant is operational and their products can undergo testing.

A third market-related policy issue is that there is increasing value placed on sequestering carbon for long periods. WFI products clearly fill this role. An example of how groups are trying to incentivize that process is the recent construction of Founders Hall in Seattle, Washington. This is a six-story mass timber building on the University of Washington campus totaling 96,000 square feet, and it is estimated to store more than 1,000 tons of carbon dioxide for decades. Aureus Earth is a company that linked carbon offset buyers with the building developers so that the developers were compensated for selecting wood as the primary material used in Founders Hall. Additionally, the Softwood Lumber Board is an entity funded by a check-off on every thousand board feet of softwood lumber sold in the US. The SLB directs how funds collected from the check-off are used to promote the use of softwood lumber. A key initiative for the SLB is positioning the use of wood materials as a solution to climate change issues. WFI producers can piggyback on these efforts, since using wood-based insulation products increases the amount of carbon sequestered for long periods in association with building construction.

3.8 CONCLUSIONS ABOUT WFI'S GENERAL VIABILITY AND RECOMMENDATIONS

Based on the information gathered and analyzed for this report, it appears that WFI products can be viably produced from mill residuals and/or small-diameter trees to create wood-based building insulation materials that perform as well or better than insulation made from other non-wood materials. Additionally, making wood-based insulation products has the benefits of being less energy intensive than other insulation materials and sequestering carbon for the life of the building or structure. The reasons supporting this conclusion include:

- WFI technology has been proven among existing manufacturers in Europe to be able to utilize mill residues (i.e., wood chips) and small-diameter trees with little restriction among suitability of trees species.
- WFI manufacturing technology is nearly 100 years old and has been proven many times over in industrial-scale facilities in Europe. Additionally, TimberHP is a US-based startup company that is on the verge of beginning WFI production in the US.
- Multiple European companies have long track records of manufacturing the major equipment items needed for manufacturing WFI panels (e.g., wood dryers, disc refiners, wood pulp and adhesive blending equipment, presses for forming panels, and dryers to dry finished panels).

- From a sustainability perspective, WFI products do not emit gases or chemicals that are harmful to human health; they utilize wood, which is a renewable resource; and while in use, they sequester significant amounts of carbon.
- A full financial analysis was not completed for a WFI business since important details about site acquisition costs, financing assumptions, localized raw material costs, etc. can all vary significantly from project to project. Nevertheless, it appears that a WFI business would generate more than enough revenue to offset operating costs and amortize the investment made in the business.
- A key caveat in viability is that wood insulation currently has only a very small share of the US market. Thus, any WFI manufacturer seeking to establish a US-based business can expect to undergo a significant market development effort in the early years following startup.
- Another market-related caveat is that insulation is almost by definition mostly air per unit of volume. Therefore, the material cannot be cost-effectively shipped long distances. This necessitates that a manufacturer who has developed brand awareness of their product must develop multiple manufacturing facilities to be able to serve a nationwide market.