The feasibility of recycling and reusing building materials found in single-family homes built after 1970 in Metro Vancouver

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Disclaimer

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Executive Summary

Through a combination of literature review and expert interviews, this study explores the feasibility of recycling and reusing building materials from single-family houses built after 1970 in Metro Vancouver. The study focuses on wood products, which make up the highest proportion of the regional construction and demolition waste stream by weight. Current efforts to divert building materials from the waste stream show high recycling and reuse rates for homes that contain valuable old-growth lumber. Homes built after 1970 have different material compositions that might limit recycling and reuse. The study aims to advance zero waste strategies in Metro Vancouver by asking:

- What are the factors to consider with respect to reusing and recycling building materials from the region's stock of post-1970 homes?
- How do these factors inform future programs and policies to reduce demolition and construction waste in the region?

The study includes:

- A qualitative summary of the composition and diversion potential of materials found in homes built after 1970 in Metro Vancouver, focusing on wood materials.
- A gap analysis that identifies materials that are hard to reuse and recycle. "Hard-to-recycle" and "hard-to-reuse" materials are further distinguished by materials that cannot be recycled easily because of a lack or shortage of facilities in the region, and materials that are nearly impossible to recycle or reuse in all jurisdictions.

Significant findings include:

- Within the post-1970 period, homes built in the 1970s are likely the best candidates for lumber salvage and high diversion rates.
- There are effective options for diversion, such as machine-assisted deconstruction, that could be applied to post-1970 homes to improve recycling and salvage rates. They are not widely adopted in the region due to lack of training, awareness, equipment, and perceptions of costliness.
- Locally accessible markets are not able to absorb all wood materials from post-1970 homes for their best potential uses (i.e. reusing them or upcycling them into new products). Recycling options for lumber and engineered wood that cannot be reused are limited.

Opportunities for future exploration include a demonstration project of a deconstruction on a post-1970 home; the promotion of pre-demolition salvage as a high-value, low-cost diversion

opportunity; further promotion and inquiry into the potential of dimensional lumber for reuse; the pursuit of new markets for recycled lumber and engineered wood to compete with high virgin wood prices; and the exploration and promotion of expanded facilities for wood recycling and reuse.

Introduction

As a building material, wood is typically perceived as more sustainable than asphalt, metals, plastics, and concrete because it is a renewable resource (Howe et al. 2013).[1] Most building materials analyses, however, do not consider end-of-life waste. Within the construction and demolition sector, wood is the largest component of waste going to disposal. In Metro Vancouver, wood forms 60.8% (243,179 tons) of the construction and demolition waste stream sent to landfills (TRI Environmental Consulting 2019). Whereas nonrenewable resources including asphalt, concrete, and metals are readily recyclable, wood has proven more challenging to divert. This is especially true in the residential construction and demolition sector, where conventional demolition practices on one- and two-family homes typically divert less than 50% of building materials from the landfill (City of Vancouver 2018, 3).

The Metro Vancouver Board Strategic Plan acknowledges the need to close the gaps and ensure sufficient capacity in the regional recycling and waste diversion system. Regional and municipal efforts to divert building materials from residential demolitions and promote deconstruction, such as the City of Vancouver's Green Demolition Bylaw, have been successful so far. As the residential building stock continues to age and densify, however, the number of post 1970 homes included in regional demolitions is expected to increase. For that reason, Metro Vancouver is interested in understanding the feasibility of recycling and reusing building materials recovered from single-family homes built after 1970.[2] This report presents the results of a feasibility study into the challenges and opportunities related to the diversion of wood materials from this era of home construction. Wood products from single-family homes are the focus of the study due to

[1] There is debate about the sustainability of wood in new construction, which is outside the scope of this study (see Melton 2018). The consensus is that while wood is renewable, and therefore sustainable, it is not always clear *how* sustainable new wood construction is given a number of factors, including: the ability of certain timber species to sequester carbon, the uncertainty of optimal harvest cycles, and a lack of clarity on how rapidly disposed wood emits greenhouse gases in landfills (Melton 2018). What is clear is that salvaged wood is the more sustainable option compared to new wood because salvaged wood reuses the embodied carbon from the previous structure.

[2] "Houses"/"homes" are defined as detached houses. Multi-unit residential structures, while a significant component of Metro Vancouver's housing stock, were not considered in this study due to their distinct structural properties. For that topic, see a recent study of diversion from 107 LEED-certified multi-unit residential buildings in Canada (Light House 2021).

their incredibly high share of the construction and demolition waste stream by weight in Metro Vancouver.

The results of the study provide insights into four feasibility issues that must be addressed to increase the diversion of wood from single-family demolitions in the region. As such, this study marks a first step towards understanding how deconstruction, recycling, and reuse best practices might apply to more modern homes with harder-to-recycle material compositions.

This report contains:

- A qualitative summary of the composition and recycle/reuse potential of materials found in homes built after 1970 in Metro Vancouver.
- A gap analysis that identifies materials that are hard to reuse and recycle. “Hard-to-recycle” and “hard-to-reuse” materials are further distinguished by materials that cannot be recycled easily because of a lack or shortage of facilities in the region, and materials that are nearly impossible to recycle or reuse anywhere.

Background

Wood remains a versatile, lightweight, and durable option for meeting modern sustainability goals, notably the mitigation of embodied carbon production (Howe et al. 2013). Single-family homes in Canada are predominantly constructed with wooden frames consisting of floor, wall, and roof assemblies held together by individual framing members (e.g. joists, studs, and beams) and sheathing material (Burrows 2013). During the middle of the twentieth century, wood-frame house construction shifted from craft techniques to a more mechanized construction process suited to developing suburban tracts of single-family homes. Across Canada, this led to a reduction in labour hours from an average of 2,400 hours to construct a 1,200 sq. ft. single-family home in the mid-1940s, to an average of 950 labour hours to construct the same home in the mid-1960s (Denhez 2000, 46).[3] The “assembly line” approach to house building, championed by large residential builders, also led to a shift in the materials used in construction. Before the 1940s (and especially before the 1930s), old-growth species of wood were used more widely in areas such as Vancouver where old-growth forests had not yet been depleted (Teshnizi 2015, 9). As Canadian builders pursued cheaper, more efficient building processes, they sought engineered wood products and assemblies that maximized the structural efficiency of wood fibers, and that were amenable to the use of power tools and fasteners (Denhez 2000, 46; see Appendix B for a table of changes). A few examples outlined by Denhez (2000, 38-39) include:

[3] This amounted to a change from about seven months to build a house in the mid-1940s to about seven or eight weeks to build the same house in the mid-1960s (Denhez 2000, 47).

- Engineered roof trusses began to replace site-cut and fitted roof carpentry in the mid-1960s.
- Plywood panels were used in wall and roof sheathing from the mid-1960s forward.
- Nail guns, engineered wood joists, and engineered wood sheathing came to dominate in the mid-1980s.
- A wide variety of plastic-based vapor barriers and insulators came into use during the mid-1980s and mid-1990s.
- High-performance insulation products came into use in the mid-1980s (R20 walls and R30 ceilings), with a wide variety of products available by the mid-1990s.
- While not mentioned by Denhez (2000), stakeholders suggest that the use of construction adhesives in flooring came into prominence in the 1980s.

These advances were made with affordability and efficiency in mind with little consideration for the end-of-life stage of single-family housing. As local governments seek to decrease material going to disposal, the end-of-life stage is of increasing concern. Single-family detached homes form the vast majority of residential demolitions in Metro Vancouver, forming 87% of all residential demolitions between 2009 and 2018 (Statistics Canada, as cited in Metro Vancouver 2019, 41). During this period, 26,118 single-family demolitions took place, which is the equivalent of about seven single-family demolitions per day.[4] There is limited data on the building age of demolitions in Metro Vancouver. The City of Richmond, however, confirms that several post-1970 homes have been demolished based on their demolition permit data. From the data provided by the City of Richmond, the average age for homes that applied for their demolition permits is 1968 (City of Richmond 2021).

Demolitions are typically understood to be driven by the aging of the housing stock, as well as a lack of vacant land to build new homes. Simulation research into demolitions in Residential-Single zones within the City of Vancouver also indicates that rising land values predict the demolition of single-family homes (Dahmen and Bergmann 2021).[5] Land values that increase relative to the appraised value of a building lowers the home's "relative building value." Consequently, a home with a lower relative building value is more likely to be replaced through demolition. This prediction applies not just to older homes, but even homes built in the 1970s and after, when rising land values led more owners to try building to the maximum allowable floor space of their lots (Dahmen and Bergmann 2021). The economic pressure of rising land values has made single-

[4] These two figures were calculated using data on "ground-oriented house demolitions" in the region (Statistics Canada, as cited in Metro Vancouver 2019, 44). Data for the building age of demolitions in Metro Vancouver was not readily available.
[5] The researchers' simulations are stochastic and change slightly each time they are run. The researchers' interactive data story of single-family demolitions in Vancouver can be accessed at: https://mountainmath.ca/teardowns.

family homes of all eras, sizes, and densities (i.e. those equipped with secondary suites and laneway homes) potentially vulnerable to replacement (Dahmen and Bergmann 2021).

Figure 1. Vancouver demolition. Photo by Chung Chow, found via https://www.vancouverisawesome.com/vancouver-news/vancouver-demolition-teardown-study-1938266

Conventionally, single-family houses at the end of their life in North America are demolished with an excavator, with mixed and partially-sorted material sent to public or private waste management facilities to be mostly landfilled (Elliot, Locatelli, and Xu 2020). Governments and sections of the housing industry have responded to the sustainability challenges of residential demolition by promoting a more circular model. This model seeks to maximize the salvage, reuse, and recycling of building material, with landfills becoming not the primary option but the option of last resort in the material recovery process. Deconstruction is especially suited to this model because it enables individuals and communities to reclaim the value and environmental benefits of intact wood products, rather than "downcycling" the materials into lesser products or disposing of them (Elliot, Locatelli, and Xu 2020).

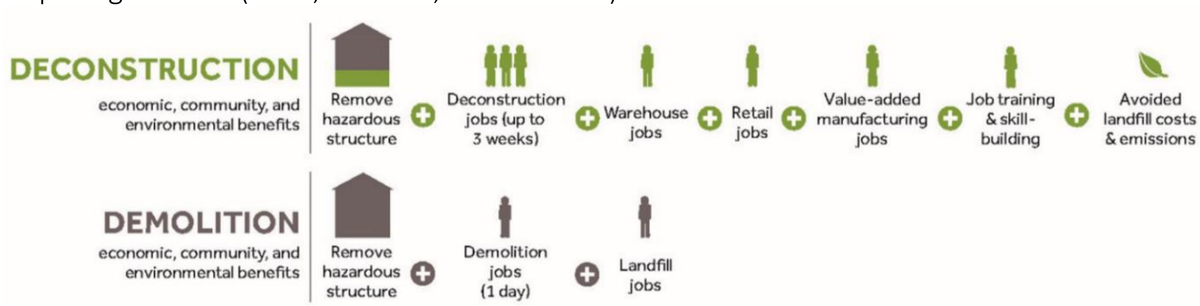

Figure 2. Deconstruction versus demolition. Graphic by Delta Institute (2018).

Whereas conventional demolitions use an excavator to tear down the house and dispose of its contents into a bin (with some on-site sorting), deconstruction typically dismantles the structure by hand and/or by machine to keep as much of the assemblies and individual materials intact for reuse. According to the Delta Institute (2018, 5), the distinction between "demolition" and "deconstruction" is not absolute, forming a spectrum of four practices including:

- Full Demolition: The most expedient but also least sustainable approach, trading low labor costs enabled by heavy machinery for high environmental costs created by landfilling nearly all material (aside from scrap metal and any other material that is required to be sorted).
- Soft-stripping: "Easy-to-capture & high-value material" (e.g. appliances, architectural finishes, cabinetry) is salvaged, but flooring and lumber that is harder to salvage is demolished.
- Hybrid Deconstruction: Flooring, windows, and doors are salvaged in addition to finishes, furniture, and appliances, taking a larger crew and a schedule of three days. The term "hybrid deconstruction" also refers to the use of heavy machinery to dismantle sections of a home's wall and roof assemblies. The intact sections can then be stored and reused in another building project (ReUse Consulting 2021).
- Full Deconstruction: "All wood & valuable material is salvaged" usually within 3 to 10 or more days of labour. Full Deconstruction typically dismantles the structure by hand and prepares re-usable components for reuse, donation, and/or retailing. In Metro Vancouver, the deconstruction company Unbuilders is the main practitioner of this approach, achieving a record diversion rate of 99% on a single-family home built in the 1930s (Metro Vancouver 2020, 15).

To date, policies promoting residential construction and demolition wood diversion target both demolition and deconstruction. Regionally, a clean wood disposal ban encourages diversion, placing a surcharge on unstained, untreated, uncontaminated, and glue-free wood products entering regional facilities. Locally, eight municipalities in Metro Vancouver enforce demolition waste recycling requirements (Metro Vancouver 2020, 7). The City of Vancouver, for example, has become a global exemplar of residential demolition and deconstruction policy (C40 Knowledge Hub 2021). The City of Vancouver introduced the Green Demolition Bylaw in 2014, which initially required the recovery of 75% of demolition materials for reuse or recycling from one- and two-family pre-1940 homes (and 90% for homes with character status). As of 2018, 1,000 pre-1940 homes were demolished under the bylaw, with an average diversion rate of 86% and an overall compliance rate of 98% (City of Vancouver 2018, 4). The success of the bylaw prompted a proposed expansion of diversion requirements towards pre-1950 homes, covering about 70% of one- and two-family demolitions, as well as a deconstruction requirement of three tons of wood for pre-1910 homes (City of Vancouver 2018, 6).

Further expansions of demolition and deconstruction policies in Metro Vancouver will need to consider the distinctive material compositions of post-1970 homes, and their suitability for reuse and recycling. Pre-1950 homes are considered good candidates for deconstruction and wood salvage because they are built with economically and aesthetically valuable materials, namely old-growth lumber, that are conducive to reuse (Delta Institute 2018). Meanwhile, homes built after that period are typically considered poor candidates for both reuse and recycling because they are assumed to contain materials of lesser value that are also more difficult to salvage and recycle (Delta Institute 2018). With respect to wood reuse, post-1970 wood frame homes are potentially problematic because of adhesives, insulation products, and membranes that make framing members difficult to pull apart without damaging the lumber. Furthermore, the modern Spruce-Pine-Fir lumber products typically found in post-1970 homes do not carry the same strength and aesthetic value of old-growth lumber, raising questions about its market value relative to the cost of reclaiming it from a demolition or deconstruction site. With respect to recycling, post-1970 homes contain large volumes of engineered wood products that are designed with adhesives. Plywood, oriented-strand board, and other similar products can technically be recycled but are not accepted in large volumes (i.e. disposal bins full of engineered wood) and are often not accepted at all for recycling by local and regional facilities.

Figure 3. Reclaimed plywood. Photo by Mitchell Reclaim Ltd, via https://www.facebook.com/199522650654025/photos/pcb.286412791965010/286412221965067/?type=3&theater

Little research has been conducted on the feasibility of salvaging, recycling, and reusing materials from homes built after 1970 in North America. This is likely because post-1970 homes are assumed to have little diversion potential. But the planetary urgency of meeting municipal and regional zero waste goals requires exploring all options to divert wood from the landfill, even if these options appear unfeasible at the outset.

Research Approach

In evaluating the feasibility of post-1970 homes as candidates for wood diversion, the study uses the following methods:

- An online literature scan of best practices, lessons learned, and contextual information regarding the demolition and deconstruction of single-family homes in North America. Most of the material consulted was produced by industry and government institutions, with some journalistic and academic sources consulted as well (see References).
- In-depth informational interviews with eighteen stakeholders in government, industry, and the non-profit sector, representing a broad swathe of the construction and demolition sector. Stakeholders include: zero waste program officials, residential builders, demolition and deconstruction contractors, reuse store operators, industry executives, and consultants. Many interviewed stakeholders are located in Metro Vancouver, but others are active on the US West Coast and in the Southwest, and one in London, England. The interviews lasted from twenty-five to ninety minutes, typically lasting about forty-five minutes. Stakeholder names are removed for confidentiality.

Because little published research has been produced about the recyclability and reusability of materials from post-1970 wood-framed homes in North America, the bulk of this study's analysis focuses on the in-depth interviews. Four qualitative criteria were used to synthesize and code the interview findings. These criteria include:

1) *Material feasibility:* does the condition, appearance, and composition of the particular material or assembly warrant recycling or reuse?
2) *Cost feasibility:* is it feasible to recover materials for recycling or reuse given the time, training, equipment, and personnel required?
3) *Market feasibility:* once salvaged and possibly refurbished, are there adequate recycling or reuse markets available to absorb the materials?
4) *Facilities feasibility:* is there an adequate supply of storage and processing facilities for the diverted materials, and are they accessible geographically?

These criteria were determined through stakeholder feedback and online research. Taken together, the criteria are used to identify the most significant barriers to greater reuse and recycling (in that order of priority). They do not exhaust every single criterion that may be considered when mandating or incentivizing diversion.

Feasibility Findings

The research findings are presented in accordance with the study's four-fold approach to feasibility. While findings under each feasibility category are discussed in their own subsection, connections between the categories are often observed.

Material Feasibility: does the condition, appearance, and composition of the particular material or assembly warrant recycling or reuse?

Type	Era	Recyclable?	Reusable?
Clean dimensional lumber (pine, spruce, fir)	1970s+	Yes at 13 locations.	Yes. Donatable to at least 4 used building materials stores. Fir valued highly by contractors and designers. Pine and spruce valued less.
Shiplap sheathing	1970 - 1975	Yes at 13 locations.	Yes. Donatable to at least 4 used building materials stores. Valued highly by contractors and designers.
Fixtures (large appliances, lights, etc.)	1970s+	Yes. Large appliances accepted at 31 locations. Lighting fixtures at 55 locations. Recyclability of other items less clear.	Yes. Donatable to used building materials stores depending on item and its age. Flooring reuse less likely due to glues.
Millwork (doors, trim, wall paneling, etc.)	1970s+	Less likely due to contamination with paints, glues, treatments.	Yes. Donatable to used building materials stores depending on item. Hollow-core doors valued less.
Modular furniture (cabinetry, shelving, etc.)	1980s+	Less likely due to contamination with paints, glues, treatments.	Yes if removable by unscrewing or unfastening. Donatable to used building materials stores depending on item.
Short clean lumber (railings, roof pitch material, etc.)	1970s+	Yes at 13 locations.	Yes for decorative applications. Not usually donatable.
Engineered wood product sheets (oriented-strand board, plywood, particle board)	1980s+	Yes at 1 recycling facility. Variable at others.	Plywood reusable. Plywood over 4 ft. can be donated to used building materials stores. Others harder to salvage and preserve.
Windows	1970s+	Yes at 6 recycling facilities.	Yes. Donatable to used building materials stores depending on age. Lower value pre-1990s.
Polyvinylchloride (PVC) pipes	1970s+	Possibly at 3 recycling facilities.	Donatable for art at 1 location. Reuse for drainage unclear.

Figure 4: Summary table of divertible materials from post-1970 homes

Results from stakeholder interviews indicate the importance of two aspects of wood construction material: the individual building materials themselves, and the flooring, wall, and roof assemblies of which the materials are a part. Figure 4 summarizes the feasibility of recycling and reusing individual materials in Metro Vancouver. The table is arranged by type, focusing on the nine types of materials emphasized by stakeholders during interviews.[6] The summary table captures many individual components but does not exhaust the contingencies associated with problematic construction assemblies. These include the use of adhesives, membranes, and sprayfoam insulation, as well as the possibility of damage in the process of removing the material or due to maintenance issues with the home. The table also does not include concrete and asphalt products, which are readily recyclable in Metro Vancouver and are not analyzed in this report.

The general consensus from interviewees is that the 1970s-era of single-family assemblies in Metro Vancouver offer the most opportunities for diversion, particularly for wood reuse and for the recycling of clean lumber that cannot be reused. Opportunities for 1980s-era homes are less promising due to the presence of large volumes of engineered wood and membranes in the frame. The period during and after the 1990s is regarded as the least feasible for wood reuse and recycling due to the prominence of sprayfoam insulation and construction adhesives.

Two central material barriers raised during stakeholder interviews include the presence of sprayfoam insulation and the use of construction adhesives in the joining of wood members. Meanwhile, clean dimensional lumber, shiplap sheathing, and the fixtures and finishes obtained from an initial salvage are the three most feasible types of items identified. For other materials, stakeholders suggest that recycling, rather than reuse, is the most feasible current option for some home assemblies, specifically those found in the post-1990 period. These findings form a starting point for further analysis, but quantitative data on the material compositions of post-1970 homes is lacking. The material composition of a 1980 “Vancouver Special” case structure is examined briefly to corroborate stakeholder input.

The most significant material feasibility barriers: sprayfoam insulation and plastic-based membranes. An especially concerning material barrier to deconstruction that interviewees identified was the presence of spray polyurethane foam (SPF) insulation, or “sprayfoam,” on the wall and roofing assemblies. Becoming more widely used among a range of insulation options in the 1990s, sprayfoam injected into wall cavities is a potential contaminant, and makes a careful dismantling of the structure nearly impossible. Sprayfoam insulation is “a nightmare” even for experienced deconstruction experts, according to one Metro Vancouver stakeholder. The only feasible option for a wall and roof assembly containing sprayfoam would be to salvage and separate any recoverable and mandated materials (e.g. drywall) and then demolish the structure to be sent to wood recyclers. While the foam could technically be cut and removed from the boards and framing members, one deconstruction stakeholder states that a client demolishing a post-1990 home would not want to pay for that service without a policy directive requiring

[6] Information about the recycling and reuse facilities in Figure 4 was obtained from the Metro Vancouver Recycles database: https://recycling.metrovancouver.org/.

otherwise. Similar concerns are raised regarding plastic-based membranes, such as acoustic seals and vapor barriers on exterior walls. Having been introduced in the mid-to-late 1980s, these plastics are difficult to remove and can render the wood they affect unsalvageable for recycling or reuse according to two industry stakeholders.

Figure 5. Sprayfoam insulation in an attic. Photo by U Value, 2017, via https://uvaluesprayfoam.ie/applications/attic-insulation/.

The second most significant material feasibility barrier: adhesives. Adhesives used on wood flooring and subflooring came into prominence around the late 1980s and increased in the early 1990s. Subfloors were glued to the floor joists to prevent squeaking, which has rendered the floor joist material potentially recyclable but not reusable. The glued material is usually still recyclable because adhesive products from the early 1990s are safer than those used during earlier periods. Wood floors bonded with adhesives, as well as engineered wood products made with adhesives, are still accepted by some recyclers for wood-to-energy applications when blended with clean dimensional lumber. Glues of any kind used for adhering wood members make salvage for reuse difficult, given the risk of damaging the material.

Figure 6. Applying sub-floor adhesive. Photo by Bostik Findley Inc., via https://www.adhesivesandsealants.com/doc/chem-calk-heavy-duty-urethane-construction-ad-0001

Other obstacles that make intact salvage difficult include:

- The use of nail guns starting in the 1970s has made extracting value from otherwise salvageable lumber more difficult, given the labor required to de-nail.
- Engineered wood products such as plywood, particleboard, and oriented-strand board that came into popular use during the 1980s can be difficult to dismantle intact, regardless of the presence of sprayfoam, membranes, and adhesives. Because they are designed for single-use applications, their fragility compared to dimensional lumber and shiplap is not always conducive to salvage. Plywood, however, is considered more durable and less prone to disintegrating in wet and/or hot climates compared to oriented-strand board.
- Exteriors of homes built before the 1990s may contain lead-based paints and need to be tested as lead-free before recycling or reuse.
- Currently, pressure-treated wood cannot usually be diverted for recycling or reuse due to toxicity concerns.

Figure 7. Oriented-strand board sheathing. Photo by NRCan, 2020, via https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/forest-industry-trade/forest-products-applications/taxonomy-wood-products/oriented-strand-board/15851

The most materially feasible opportunities for salvage and reuse are: dimensional lumber, shiplap sheathing, and the fixtures and finishes obtained from an initial salvage. These three categories of building materials were commonly mentioned as the top candidates for salvage, reuse, and recycling in Metro Vancouver. Depending on their quality and condition, dimensional lumber from spruce, pine, and especially fir species can be reused in local construction projects, which is the highest and best use of salvaged lumber. One advantage to lumber from post-1970 homes, particularly from the 1980s and forward, is their adherence to modern dimensions. Dimensional lumber has both “actual” and “nominal” dimensions. Common *nominal* dimensions, such as 2x4, are not *actually* 2 inches by 4 inches in measurement but are 1.5 by 3.5 inches (Canadian Wood Council 2021a). According to one deconstruction stakeholders, the actual dimensions of 2-by boards from more recent homes adhere to the actual dimensions used today. This makes them potentially more useful for structural applications compared to old-growth lumber found in pre-1940 homes, where the actual dimensions of 2-by boards are less standardized. The uniformity of lumber dimensions found from post-1970 homes, assuming they are in good condition, offers a significant opportunity for reuse over recycling.

Figure 8. Shiplap. Photo by Salvage Works, via https://www.salvageworkspdx.com/blogs/news/its-the-word-on-every-designers-mind-shiplap

The quality of dimensional lumber in the post-1970 period is variable, however, with stakeholders citing the common use of engineered wood products and cheaper variations of spruce and pine lumber as a barrier to marketable reuse. The dimensional lumber found in 1970s-period homes was described as occasionally high in quality. One waste management vendor in Metro Vancouver sometimes recovers fir studs from small-scale (not full-house) demolitions on 1970s homes and donates them. A Vancouver housing developer values the spruce lumber found in some 1970s homes for its relative softness, because it is easier to work with and repurpose for reuse compared to old-growth lumber from pre-1940 homes. This developer anticipates that retailers will expand the demand for wood reclaimed from modern homes because of its workability. The presence of shiplap sheathing in homes built before the mid-1970s, when plywood sheathing became more common in Metro Vancouver, presents another opportunity for high-quality salvage.

Fixtures and finishes in post-1970 homes obtained from a pre-demolition/deconstruction salvage were identified as more easily salvageable than lumber by most stakeholders. Lighting, furniture, appliances, millwork, mantles, and other decorative elements are regarded as especially feasible for intact reuse. Compared to the lumber package of pre-1970 homes, fixtures and finishes are generally easier to remove and reuse intact. For instance, modular cabinetry made with engineered wood products that is screwed to the wall can be removed easily, as well as stored easily in a reuse warehouse due to its uniform sizing. Older cabinet sets that are not modular and installed directly to walls are difficult to remove, especially when sixty inches or longer in length. Decking systems that use hidden fasteners, rather than nails, are also conducive to dis- and re-assembly. Hardwood flooring adhered with glues, however, is one finish that is hard to remove because it can become damaged when stripped. Plumbing fixtures can also be challenging to remove because they require more intricate plumbing work and, in the case of large bathtubs, are difficult to lift through the doors of a home. Older electrical appliances such as refrigerators that do not have an Energy Star certification should be recycled rather than reused.

Four stakeholders further suggest that the market value of fixtures and finishes makes them especially feasible candidates for reuse. One deconstruction stakeholder observes that post-1970 kitchens tend to have more valuable fixtures and finishes compared to pre-1970, especially if they have been remodeled. Another deconstruction and reuse sector stakeholder suggests that the main source of value from post-1970 homes will be from fixtures and finishes, not lumber, because of their recently high share of the reuse sector. Overall sales for the stakeholder's reuse warehouses in the US increased in 2020 due to more remodeling activity, becoming higher than ever in twenty-eighty years. Meanwhile, lumber sales declined from their historic 25 to 30% of the organization's annual revenue to 15%, indicating the higher overall value of fixtures and finishes for the organization in 2020.

Recycling is the most feasible diversion opportunity for some wood products. Stakeholders suggest that recycling is the primary option for many wood products from post-1970 homes, especially for:

- Most engineered wood products, particularly oriented-strand board, which are difficult to reclaim and preserve intact.
- Damaged clean wood.
- Short pieces of clean wood (under four feet in length).

Because of the lack of manufacturing facilities interested in construction and demolition wood waste as a feedstock for new wood products, recycling opportunities for nonreusable wood are limited to biofuels primarily. Common engineered wood products, such as oriented-strand board and plywood, can be recycled into biofuels when blended with clean dimensional lumber. Additionally, wood contaminated with paints has been tested in a pilot project as a viable energy source for cement kilns in Metro Vancouver (City of Vancouver 2021). Clean dimensional lumber is often received by a recycling facility in Richmond, BC, and remains the most valuable recyclable wood product the facility receives. That said, a recycling facility stakeholder in Metro Vancouver notes that much of dimensional lumber the facility receives could be recovered for reuse rather than recycling.

The material composition of a 1980 Vancouver Special corroborates stakeholder concerns about materials-related issues. Estimating specific diversion rates for post-1970 homes is a challenge. A regional sample of diversion rates for post-1970 homes was not available for this study. In lieu of diversion data, a life-cycle analysis of a 1980 "Vancouver Special" provides a quantitative glimpse into the composition of an influential post-1970 design (Zhang et al. 2014). The Vancouver Special design came into prominence between 1965 and 1985 in the city of Vancouver, with about 10,000 units produced (Chutter 2016). The design embodies an architectural shift towards cheaper and mass-produced building products, making them representative of a larger trend in housing construction that took place in the post-1970 period. The Specials maximize floor space while minimizing the use of construction materials, making them different in composition compared to pre-1950 homes (Benivolski 2017). The composition of the 1980 case structure corroborates stakeholder concerns regarding the recycling and reuse obstacles associated with the 1980s-and-after period of construction.

The case structure is a 2,542 square-foot two-story home with a low-pitched roof, stone on the ground-floor façades, and stucco on the second-floor façades. A bill of materials was produced by the researchers in the Athena® Impact Estimator version 4.2 (IE) software tool (Zhang et al. 2014; see Appendix C for the full bill of materials). Relevant composition data from the bill of materials includes:

- 41.28 metric tons of concrete were used in the foundation and floor, in addition to 215 concrete blocks in the walls, which are recyclable.[7]
- 7.48 metric tons of ballast (aggregate stone) from the floor and roof were used, which are recyclable.
- 5.02 metric tons of roofing asphalt were used, which are recyclable.

[7] A unit weight of 2400kg/cubic meter was assumed based on Kosmatka and Wilson (2011, 96).

- 7.71 metric tons of engineered wood were used. An estimated 7.31 metric tons of oriented-strand board were used in the flooring, walls, and roof. 0.23 metric tons of softwood plywood were used in the walls and 0.17 metric tons of glued laminated timber was used as columns/beams.[8]
- 12.01 metric tons to 13.17 metric tons of softwood lumber were used in the floors, walls, and roof.[9]
- Fiberglass insulation was used in the walls and roof. Cellulose insulation was used in the roof.
- 3-millimetre polyethylene plastic wrap, a membrane, was used in the walls and roof. An ethylene propylene diene terpolymer (EPDM) membrane was used in the walls.

The bill of materials data corroborates stakeholders' concerns that smaller amounts of salvageable and valuable wood are contained in homes built in the 1980s and after. The presence of membranes in the walls and roof could render the framing lumber and engineered wood difficult, if not impossible, to recover for reuse or recycling. Green demolition compliance reports for pre-1940 homes reviewed by the City of Vancouver in 2016 reveal comparatively more salvageable wood by weight. Homes between 2,500 and 2,600 square feet, which were demolished under the 75% recycling requirement, diverted between fourteen and forty-seven metric tons of wood (City of Vancouver 2017). Meanwhile, the 1980 case structure contains 20.88 metric tons of wood (lumber and engineered wood) that is potentially contaminated by membranes. Most diversion from the 1980 home would likely come from concrete and asphalt recycling and from an initial salvage of fixtures and finishes (which are not listed on the bill of materials).

[8] The tables consulted for the weights are for estimates only. Manufacturing details of the engineered wood, such as species of wood used in production, would be required to make an exact weight calculation. The tables used to convert the volumes into weights for the oriented-strand board and plywood were produced by a roofing consultant in the US (Roof Online 2021). The weight per cubic meters of dried glue-laminated timber is 525.97kg/cubic meter and is listed in American Wood Council and Canadian Wood Council (2013, 4).

[9] The first weight assumes that the lumber is Ponderosa Pine, a common construction material available throughout Western North America. The second weight assumes that the lumber is Douglas Fir, which is among the hardest, heaviest, and most valuable softwoods used in BC (albeit seldom found in houses of the era). The dimensional lumber on the bill of materials is a combination of kiln-dried and green. A weight estimator produced by an ecosystem scientist was used to convert the cubic meters of both kiln-dried and green lumber variations of both species to metric tons (Ray 2014).

Figure 9. 1980 Vancouver Special case structure. Photo by Weiqian Zhang, Shen Tan, Yizhong Lei, and Shoubing Wang, 2014, via DOI 10.1007/s12273-013-0159-y.

Cost Feasibility: is it feasible to recover materials for recycling or reuse given the time, training, equipment, and personnel required?

Deconstruction contractors are often compared to conventional demolition contractors on a cost basis. This is especially the case regarding post-1970 demolitions, where the typical lack of old-growth lumber and the use of engineered wood products, adhesives, and sprayfoam raises questions about the cost-effectiveness of avoiding the landfill through both recycling and salvage for reuse. Most stakeholders suggest that the costs of deconstruction will be slightly higher for post-1970 homes compared to deconstructions of pre-1970 homes, but that post-1970 homes face similar cost-related issues overall. These issues include: perceptions that demolition is cheaper and easier; a lack of ongoing commitment to training for cost-effective deconstruction solutions, such as machine-assisted deconstruction; and planning and equipment to manage the costs of jobsite waste management.

The cost of deconstruction is competitive with full demolition, but the latter is still perceived as cheaper and easier. According to stakeholders, a full demolition with an excavator requires one day; a hybrid deconstruction with a crew of five to six takes roughly three days; a full deconstruction is more variable, taking between three days to three weeks or potentially longer depending on the home's size. Conventional demolition contractors benefit economically from the sheer volume of their yearly operations. Meanwhile, according to one deconstruction consultant, many hand-deconstruction companies in North America work in small volumes and conduct about twenty-five deconstructions per year. In Metro Vancouver and elsewhere, the speed and volume of demolitions creates a widespread perception among homeowners that demolition is cheaper and easier. One deconstruction company in Vancouver challenges this assumption by using federal and provincial tax credits to close the cost difference between deconstruction and demolition. Deconstruction can potentially cost 11,905 CAD less on a referenced 2,400 square foot home when tax credits are accounted for (Unbuilders 2021). The applicability of this calculation to post-1970 homes, however, is unclear because material issues, such as sprayfoam insulation in wall cavities, would require substantial time to deconstruct. Post-1970 homes also contain less valuable lumber to offset costs through donation.

Regardless of home era, one developer in Metro Vancouver suggests that net cost increases resulting from deconstruction over conventional demolition are fairly minor. The main issue is that clients building a new home look at the house removal stage of the project as the first area to reduce costs. Consequently, clients are more hesitant to accept even a small cost increase from the labor required to strip and sort wood framing elements manually after the house's recyclable concrete, asphalt, and drywall has already been salvaged.

Figure 10. Hand deconstruction in Portland. Photo by Construction & Demolition Recycling, 2016, via https://www.cdrecycler.com/article/portland-oregon-deconstruction-ordinance/

One exemplar of cost-effective deconstruction on a city-wide basis is Portland. The city has seen deconstruction costs remain stable since 2015, when its deconstruction program began as a grant system that was transformed into a legal ordinance a year later. The city's deconstruction ordinance expanded to pre-1941 homes in January 2020. Meanwhile, mechanical demolition costs in Portland have increased due to abatement requirements for asbestos, including the hand removal of residential siding. Portland's success is attributable to a combination of public-sector initiative, access to private-sector expertise to train the city's twelve certified deconstruction companies, and the existence of a fairly stable reuse market for old-growth wood.

Portland has not yet begun to regulate wood recovered from homes built after 1970, where the value of the wood relative to the cost of deconstruction is questionable. One transferable lesson learned from Portland is that a city or region's deconstruction sector benefits from policy incentives that make it cost-competitive with demolition. Three stakeholders from the private sector in Metro Vancouver support an expansion of demolition waste and deconstruction policies to post-1970 homes specifically to level the economic playing field between conventional demolition and deconstruction. For a Vancouver housing developer, a mandate to salvage and recycle materials from post-1970 homes would make it easier to justify the costs of a full or partial deconstruction to a client.

The training required to pursue machine methods of deconstruction is not often pursued but can result in cost and time savings. Deconstruction benefits local and regional economies through green employment opportunities, which cultivate valuable construction skills for trades workers and reuse store workers (ReUse People of America 2013). While hand deconstruction is typically the method trained, one North American consultant also promotes "hybrid deconstruction." This involves the machine removal of house sections in panels to be stored for future projects or reused on-site (ReUse Consulting 2021). According to a deconstruction stakeholder, hybrid deconstruction benefits from economies of scale obtained by machine methods, which can help to further close the cost gap between traditional demolition and deconstruction. The consultant suggests that post-1950 homes are prime candidates for hybrid deconstruction due to their uniform framing sizes, which adds to their potential to be reused in a greater range of projects. But an obstacle to this approach, regardless of home era, is the steeper level of training compared to hand deconstruction. The hybrid deconstruction consultant offers to train organizations on two or three buildings, but many only have the financing to commit to one. Without multiple sessions of practical training, few organizations are able to reach a cost-effective stage with hybrid deconstruction.

Figure 11. Hybrid deconstruction. Photo by ReUse Consulting, 2021, via https://reuseconsulting.com/Post_Fab_Panels_ReBuilds.php.

King County, Washington has had success with hybrid deconstruction for cost reduction on county-owned projects, where labour costs are double the market wages for construction labourers. Whereas hand deconstruction normally takes three weeks with a crew of seven to eight workers, the hybrid deconstruction methods practiced by two companies in the county takes five to six days with a crew of three to four. When municipalities within the county eventually adopt municipal ordinances requiring deconstruction, a King County stakeholder suggests that deconstruction could become cheaper than demolition. Whether hand-methods, machine-methods, or a combination of the two are pursued, stakeholders emphasize the need for government and industry commitment to ongoing training to manage costs.

The source-separation of materials enables effective diversion, but it requires careful planning to manage the costs. Two options for sorting deconstructed and demolished materials are: comingled recycling and disposal, where different materials are placed in a single bin as a mixed load for off-site sorting; and source-separation, where materials are sorted into separate bins or bags on the work site. Comingling is often perceived as cheaper and easier, but for the effective diversion of wood, it requires access to Materials Recovery Facilities that can divert items from mixed loads.[10] For divertible materials such as wood, drywall, and metals, source-separation enables higher diversion rates compared to comingling as well as better uses of reclaimed materials (CalRecycle 2018). In Metro Vancouver, source-separation can also potentially reduce overall disposal costs. Lower recycling charges are available for sorted materials in Metro Vancouver compared to mixed loads, notably clean wood, which is banned as mixed waste disposal at regional facilities. Tax deductions obtained from donations of reclaimed materials can also offset project costs. But source-separation is logistically complex and labor-intensive. Three stakeholders suggest that it can potentially add to project time and costs because of the logistics of sorting and transporting materials. Three other stakeholders, however, state that the environmental benefits of source-separation are financially manageable, and possibly less expensive than comingling, with a commitment to jobsite planning.

One waste management vendor in Metro Vancouver works with contractors to facilitate convenient and effective source-separation, working mostly on half-house demolitions and renovations. The vendor supplies jobsite recycling stations that allow for divertible materials to be sorted as they are recovered from the home (Sea to Sky Removal 2021). They supply 36” x 36” x 36” bags for metals, plastics, and cardboard, while clean and dirty wood[11] are separated into piles under signage for reuse/recycling and disposal respectively (Sea to Sky Removal 2021). A developer who works with the vendor stresses the importance of integrating a source-separation plan into the pre-construction planning process. Because construction and demolition contractors are “playing a game of catch-up” daily, pre-construction waste management planning can avoid the possibility of waste forming into an unmanaged pile. Once this occurs, it becomes logistically difficult and less cost-effective to separate the waste, especially when the project budget is close to exhaustion. Ultimately, cost-effective jobsite sorting requires a commitment to a pre-construction waste management plan, which includes disposal areas and signage to enable convenient sorting.

[10] Ecowaste Industries Ltd. is developing a Materials Recovery Facility in Richmond, BC, and it will enable 70-80% diversion from mixed loads (Rischler 2020).

[11] In addition to wood contaminated by membranes, pressure-treating, and paint, Sea to Sky recommends sorting glue-laminated lumber (gluelam) and plywood in a pile of “dirty wood.” This is because most transfer stations do not accept plywood and gluelam as “clean wood.” Large volumes of plywood above four feet are donated.

Figure 12. Sea to Sky on-site sorting station. Photo by Sea to Sky Removal, 2018, via https://www.seatoskyremoval.ca/sea-to-sky-removal-blog/2018/9/28/sea-to-sky-removal-interviews-adisa-homes-ltd-on-sustainable-waste-managment.

The municipality of Palo Alto, California also offers lessons learned for the effective planning of jobsite waste management, focusing on full-house deconstructions. Through its Deconstruction & Construction Materials Management Ordinance, Palo Alto has managed stakeholder concerns about the logistical and cost barriers to deconstruction while achieving high diversion rates through source-separation. The ordinance, which applies to new building permit applications submitted after June 30th, 2020, mandates the deconstruction of all full-house removals within Palo Alto. In working towards Palo Alto's zero-waste goal of 95% diversion, the ordinance requires on-site waste sorting as a means of exceeding the mandated 80% diversion rate. A Palo Alto zero waste official notes that there was initial pushback to the ordinance at stakeholder meetings. This was due to the increased time, labor, and cost requirements for deconstruction compared to conventional demolition. The construction and demolition industry, however, is adapting to mandatory deconstruction, including the source-separation requirement. Based on weight tag information, the official notes that drywall loads, clean wood loads, and metal loads are increasingly being source-separated, enabling diversion rates of 97% for drywall, 99% for clean wood, and 95% for metal loads. Before the ordinance, demolition waste was typically sent to a processing facility as a mixed load, where 65 to 80% diversion rates were possible. The mandate to source-separate waste has been feasible in Palo Alto due to a number of factors, including:

- The requirement to conduct a salvage survey for marketable materials, including lumber, where salvage is mandatory. The survey is conducted by The ReUse People of America, a non-profit organization, which also operates a salvage warehouse in the area where salvaged items are stored and sold.
- A requirement to use disposal containers provided by GreenWaste, an approved waste management vendor, for source-separated materials (if the contractor chooses to use disposal bins, rather than self-hauling to facilities).
- Access to effective construction and demolition recycling facilities with high diversion rates in the San Francisco Bay area.
- Continuous communication between the City of Palo Alto and contractors throughout the project. This includes regular email contact during the permitting process and on-site inspections to reiterate requirements for source-separation.
- The use of an online waste management platform, GreenHalo, to track process documents and visualize salvage and recycling data throughout the deconstruction project.

The City of Palo Alto has not yet worked on deconstructions of post-1970 homes, so it is not known what kinds of diversion rates are achievable with source-separation in those cases.[12] The transferable lesson learned is that, with the proper site planning, equipment, and facilities in place, the residential construction and demolition industry can adapt to source-separation despite cost concerns.[13]

Market Feasibility: once salvaged and possibly refurbished, are there adequate recycling or reuse markets available to absorb the materials?

Most interviewees note a general lack of demand for reusable wood and recycled demolition wood waste in proportion to supply. Even in the city of Portland, where an established reuse market for old-growth lumber exists, supply currently outpaces demand, limiting a greater absorption of reusable wood material. For wood that is recycled rather than reused, biofuels

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[12] Another factor to consider is that the city of Palo Alto's population size (65,364 as of 2019) is significantly smaller than many municipalities in Metro Vancouver and allows for a manageable volume of deconstruction projects to regulate (US Census Bureau 2021).

[13] King County's Recycling Economics Worksheet provides a tool for calculating jobsite separation costs. It can be found at: https://kingcounty.gov/depts/dnrp/solid-waste/programs/green-building/construction-demolition/cost-effectiveness.aspx.

remain the primary end use, but new markets could spur further absorption and potentially better uses of the recyclable wood. Market-related issues affecting the feasibility of recycling and reusing building materials are not unique to post-1970 homes. They are familiar to stakeholders and influence the success of diversion from homes of all eras. However, the specific material composition of post-1970 homes will need to be considered when evaluating market-related issues. They include: cost and regulatory issues related to reusing and retailing lumber; and a lack of geographically feasible market opportunities for recycling demolition waste into new products beyond biomass.

Markets for used dimensional lumber from post-1970 homes are currently opportune if cost and regulatory issues are addressed. Used building materials, including but not limited to lumber and engineered wood products, allow contractors and consumers to potentially save money while mitigating the production of embodied carbon.[14] Outlets such as the Habitat for Humanity's ReStore locations in the region accept a range of building materials and other salvaged items for resale (Habitat for Humanity Greater Vancouver 2021). The global market for reclaimed lumber is expected to rise in value by 4.6% (to 16.90 billion USD) between 2019 and 2025 (Blois, Le Troy, and Morris 2019, 7). But salvaged wood products are not yet mainstream among architects, developers, and contractors. There is a potential for used lumber to become more popular with the up-to-fourfold increase in new lumber prices in North America in May 2021, as compared to June 2020 prices (Jang 2021). As prices fluctuate, higher-than-normal lumber prices are expected to maintain throughout 2022.[15]

In Metro Vancouver, the market for salvaged wood targets nonstructural applications, and it revolves around old-growth Douglas fir found most often in pre-1940 homes. The market value of this wood is based on its tight grain pattern and its rustic decorative appeal. Some Metro Vancouver stakeholders note the price fluctuations of lumber products as an opportunity to expand markets for used lumber, and to cultivate interest in salvaged lumber products that are not conventionally valued (e.g. modern spruce-pine-fir varieties from post-1970 homes). One stakeholder in King County, Washington does not yet observe a direct shift towards used lumber in the industry, but he does see increased interest among county stakeholders in a salvaged lumber warehouse for suppliers and retailers. A deconstruction stakeholder in Metro Vancouver

[14] The relationship between residential building materials from newer homes and embodied carbon deserves further analysis beyond this study. One tentative finding is that the embodied carbon savings gained from reusing fixtures and finishes is potentially higher than the savings gained from reusing framing lumber, as measured by British Thermal Units (BTUs). See The ReUse People of America (2021) for a case study of the potentially salvageable embodied carbon from a 2,200 square foot home.

[15] As of June 2021, the price of some lumber products has declined from the May 2021 peak, but they remain extremely high compared to 2020 prices. In Canada, a 2x4 spruce stud of 8' in length sold for up to $10-11 in the first week of June, compared to less than $3.25 in early 2020 (Jang 2021).

is optimistic about the recent price fluctuation. He notes that “there has never been an easier argument for deconstruction” because of the feasibility of processing used lumber for profitable resale prices in the current market environment. He suggests there is now an untapped opportunity to de-nail and recirculate clean dimensional lumber from post-1970 homes back into the market.

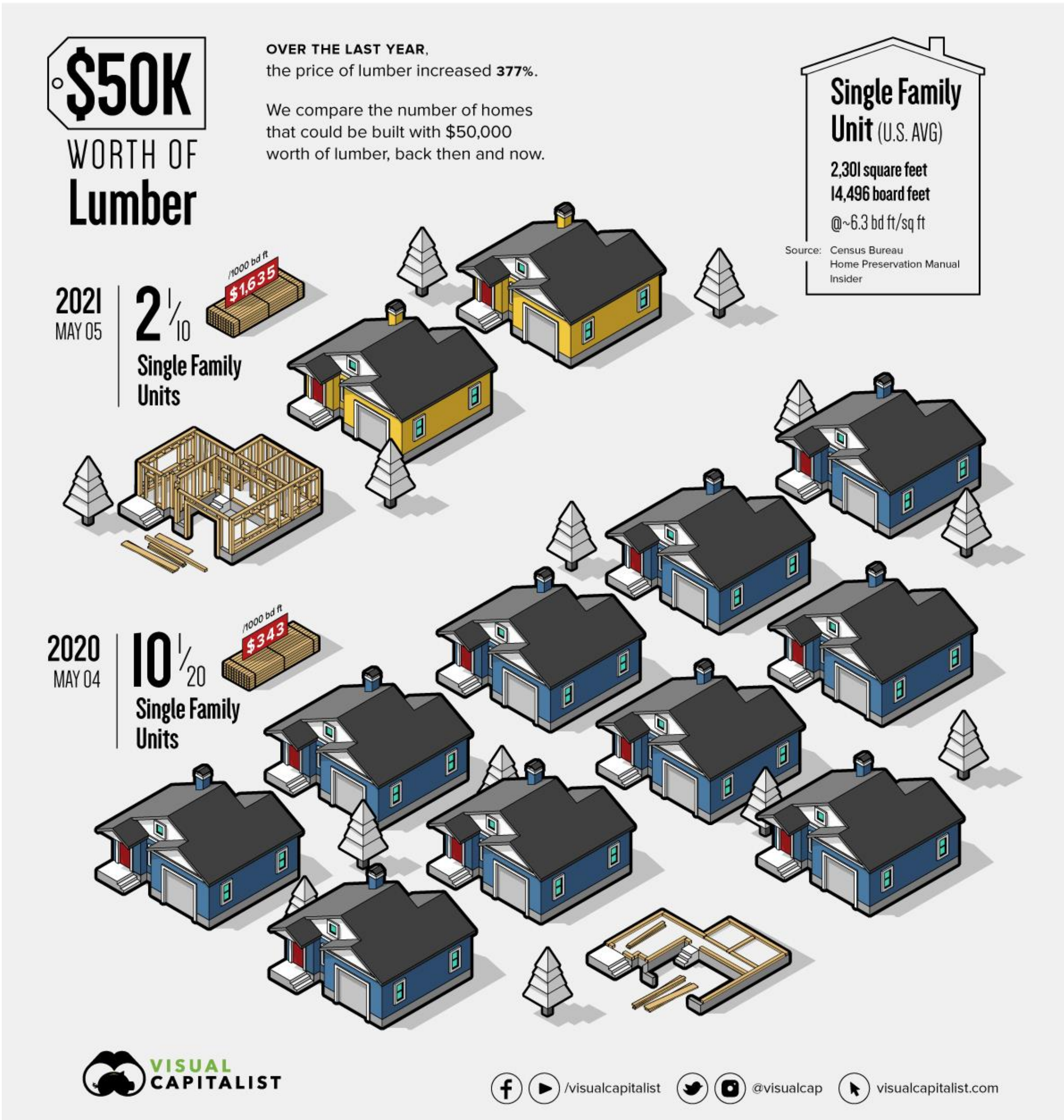

Figure 13: Visualizing the recent explosion in lumber prices. Infographic by Marcus Lu, via https://www.visualcapitalist.com/visualizing-explosion-lumber-prices-50k/.

A potential market barrier facing the resale of lumber from post-1970 homes, particularly for structural applications, remains perceptions around grading standards for used lumber. Section 1.2.2.3 of the BC Building Code allows for the reuse of used materials when they meet Code standards for new materials and when they satisfy the intended use (Province of British Columbia 2018). But the use of salvaged lumber in structure is not widespread, in large because of cost concerns. Typically, the process of regrading used lumber for structural purposes is cost-prohibitive due to the expense of hiring a structural engineer to certify the products (Schroeder 2017). The recent surge in lumber prices in North America, however, has created an incentive to pursue this market opportunity. One deconstruction stakeholder in Metro Vancouver observes that regrading is taking place in the region on deconstruction sites where new homes are being built. The regraded lumber from the old home is reused in the new construction project, which is a phenomenon he has never seen before the 2021 lumber price surge. The stakeholder will sell certified used lumber later this year. For post-1970 homes, the stakeholder further suggests that lumber from post-1970 homes could be advantageous for resale because it usually has a visible grade stamp, whereas older lumber does not, necessitating regrading.

There is also a need to further explore and promote the regulatory feasibility of reusing structural lumber. While the BC Building Code allows salvaged lumber to be used for structural purposes in principle, that does not mean it will be approved during the construction permitting process. One Metro Vancouver builder expresses that clients and building inspectors are often wary of used lumber products because of its perceived defects (especially nail holes), in addition to cost concerns related to the de-nailing of salvaged lumber. Moreover, an industry stakeholder in Metro Vancouver believes that there is currently not enough of a policy incentive for structural engineers to adopt the professional risk of regrading used structural lumber in instances when regrading is required.

Regulatory and liability issues around reusing lumber have been addressed to some extent by Oregon and Washington, which have waived regrading requirements in certain instances. In the state of Oregon, the 2017 Residential Specialty Code permits the use of salvaged dimensional lumber without a grade stamp. Salvaged dimensional lumber without a grade stamp or certificate is assumed to fall within the Douglas Fir-Larch No. 2 grade, as long as it is in good condition and free of decay (International Code Council 2017). This update will make it easier and more cost-effective for contractors to use salvaged material that is not grade stamped, although it does not relinquish the responsibility of builders to exercise discretion in situations where the species and grade is unclear (OHBA 2019) (see Appendix D for lumber grade stamp guidelines in BC). The 2018 Washington State Residential Code goes further by permitting the reuse of both No. 2 grade lumber and stud-grade lumber, which measures 2x6 or less, in lieu of a grade stamp or certificate (International Code Council 2018). Building code updates can address cost-related issues related to the regrading of used structural lumber and can potentially address liability concerns related to reusing lumber. But the more significant market-related issues for used post-1970 lumber, which typically have grade stamps already, are the costs of de-nailing for homeowners and the perceived lower quality of de-nailed lumber among homeowners and building inspectors.

Markets for recycled wood could expand beyond biofuels if entrepreneurial interest in remanufacturing is cultivated. For lumber that is unsuitable for reuse as an intact product, recycling into new products is the next most sustainable option. Stakeholders in the recycling industry noted that biofuels remain a basic, relatively stable market option for recycled wood. Many regional recycling and alternative fuel facilities maintain contracts with users of hog fuel, which typically involves the boiling of residual wood fiber to power manufacturing plants. In the Lower Mainland area, hog fuel is consumed primarily by pulp and paper mills (Management Decision Technology 2018). This end use is especially viable for post-1970 homes because it can absorb engineered wood products such as plywood and oriented-strand board which are difficult to recycle due to their adhesives. When blended with clean dimensional lumber, engineered wood can be used as a biofuel. Another potentially viable wood-to-energy product using construction and demolition wood waste is wood chips for cement kilns.[16] This end use can absorb wood waste not typically accepted by recyclers currently. Specifically, painted wood can be converted to wood chips and used to power cement kilns. Two cement manufacturing plants in Metro Vancouver have expressed interest in construction and demolition wood chips as an alternative fuel source, with an estimated combined demand of 160,000 tons of wood chips per year (Akhtari et al. 2021, 4).

[16] This was demonstrated by a six-month pilot project at the Vancouver Landfill to process incoming wood waste for cement manufacturers, and it was successfully completed in 2018. While a Material Recovery Facility was slated for development at the landfill, it has been put on hold because of a decline in construction and demolition wood waste at the landfill (City of Vancouver 2021).

Figure 14. Hog fuel. Photo by globalpro, 2018, via https://www.usedvictoria.com/classified-ad/Hog-fuelwood-grindings-for-riding-ring-or-paddocks-31447201

The global wood recycling sector is expected to grow by 4.53 billion USD between 2019 and 2023, in large part due to increasing demand for biofuels (Technavio 2019, as cited in Business Wire 2019). One recycling stakeholder in Metro Vancouver observes a recent uptick in interest in alternative fuel sources in the region. Demand for biofuels, however, is unpredictable on a regional scale. Reliance on the regional pulp and paper industry as an end user of wood waste means that plant shutdowns can reduce regional demand for biomass (Creasin-Heavilin 2018). Additionally, competition with natural gas as a power source has weakened the expansion of the biomass sector. A biofuels stakeholder in Metro Vancouver suggests that investment in new cogeneration projects has been hindered by competition with natural gas prices (Leblanc 2018). Given these market issues, five stakeholders suggest that new markets for construction and demolition wood waste should be pursued in order to maximize the diversion of wood from post-1970 homes.

Based on stakeholder insights, three challenges in securing new recycled wood markets for demolition and deconstruction wood waste include: (1) the identification of end products, (2) the attraction of entrepreneurial interest in using demolition waste wood as a feedstock for the products, and (3) the assurance of a consistent volume and quality of demolition waste wood for manufacturing the products. These market challenges apply to recycled wood from all homes, not just post-1970 homes. Portland and King County are tackling these challenges by pursuing engineered wood product manufacturers as potential processors of recycled wood. Products explored include finger-joined studs, manufactured trusses, particleboard, cross-laminated timber, and furniture. The finger-joining of recycled lumber, which stakeholders in King County, Washington are now pursuing, would combine short pieces of lumber into saleable building products, such as studs and cross-laminated boards. King County is awaiting results from a consultant's study into the technical feasibility of using 2x4 and 2x6 recycled clean lumber boards for engineered wood products, primarily finger-joined studs. The main concerns are whether quality controls for species, age, and hardness can be established for used wood as a feedstock for the studs.[17] Similar efforts to upcycle short pieces of used wood have been pursued, but not yet fully cultivated, in Portland. The main barrier in Portland is the lack of an engineered wood

[17] Technical research into the use of salvaged wood as feedstock for structural products appears promising, but is still preliminary. A recent study obtained promising performance results for cross-laminated timber made with different combinations of used lumber. But delamination was an issue. Also, the study analyzed recycled Douglas fir lumber only, so the results do not apply directly to other species that are commonly found in post-1970 homes (Arbelaez et al. 2020).

product company with the storage, expertise, and equipment devoted to recycling demolition waste wood. A Portland stakeholder also explored a relationship with a national furniture company as a potential user of recyclable wood for new products, but the wood suppliers in Portland were not able to find a sale price attractive to the furniture company.

In sum, securing new markets remains a multifaceted challenge for the construction and demolition recycling industry in North America and affects the recyclability of materials from homes of all eras. In Metro Vancouver, one wood recycling stakeholder reports there has not been an obvious option for the recycling of wood into building materials in at least fifteen years, when a chipboard manufacturing facility went out of business. Stakeholders suggest that addressing market-related issues should take priority when pursuing diversion opportunities for post-1970 wood.

Figure 15. Finger-joined studs. Photo by Lamco Forest Products Inc., 2021, via http://www.lamcofp.com/en/products/finger-jointed-studs-sps-3/#prettyPhoto.

Facilities Feasibility: is there an adequate supply of storage and processing facilities for the diverted materials, and are they accessible geographically?

Closely related to market issues affecting the diversion of post-1970 construction and demolition materials are facilities-related issues. Interviewees note that the processing capabilities and breadth of recycling options among regional facilities are fairly strong, with two major wood recyclers in the region. But issues of land cost, a lack of storage and retail hubs for salvaged lumber, and convenient recycling locations currently limit a greater diversion of wood materials for both recycling and reuse.

The cost of land in Metro Vancouver limits the expansion and growth of recycling and reuse facilities. The back-end processing of materials among regional recyclers requires space for facilities expansion as governments promote more recycling. Ecowaste in Richmond, BC, is pursuing the construction of a Materials Recovery Facility that will sort wood from mixed construction and demolition loads mechanically to be recycled into alternative fuels, with an expected diversion rate of up to 80% (Rischler 2020). While Ecowaste has the land to build the Material Recovery Facility, many facilities do not. An eight-acre site for a new facility can cost up to four million CAD per acre. Similar land-cost issues affect the creation of facilities for the storage and retail of salvaged wood and other building materials. Sales yards for reclaimed lumber, which typically market old-growth lumber, are available in Metro Vancouver, as well as Habitat for Humanity ReStore locations for the donation and sale salvaged lumber, engineered wood, fixtures, and finishes. Further expansion of reuse facilities for a greater variety and volume of salvaged materials will have to account for rising rents in and around the metropolitan area. One deconstruction stakeholder in the US cites the economic pressure of land costs as a major long-term problem for the deconstruction and reuse sector in expensive coastal cities in North America. Locating reuse warehouses outside of metropolitan areas can potentially control costs, but this would likely require shipment into storefronts within metropolitan areas, which could double handling costs. Lumber boards that have been unitized into one load could also be difficult to store if they are brought from a warehouse to a metro-area storefront for pick-up.

Market expansion is currently limited by the lack of processing and retail hubs for salvaged lumber. Metro Vancouver stakeholders report that there are few convenient locations for contractors to bring salvaged lumber for processing, storage, and retailing. While this is already the case for valuable old-growth lumber from older homes, it is perhaps a greater barrier for used lumber from post-1970 homes where fewer retailers and end users exist. With respect to retailing, one deconstruction stakeholder notes that non-profit organizations in Metro Vancouver are selective in the types of material accepted for donation. With respect to processing and storage, there is currently nowhere for contractors to bring used lumber to be de-nailed, and possibly remanufactured, into saleable products. A deconstruction stakeholder in Metro Vancouver suggests that a processing facility should be located in a different facility from the retail storefront, so that dust and noise from the processing facility is kept separate from the storefront. The stakeholder is currently pursuing a processing facility for contractors, as well as a research and development project to initiate an automated de-nailing process, which will be necessary to offset the labor costs of de-nailing used lumber. In addition, The Reuse People of America intends to establish a reuse storage and retail warehouse in Metro Vancouver, although plans have been delayed by the COVID-19 pandemic.

Recycling wood products is not always convenient. Three stakeholders suggest that recycling facilities' inconsistent acceptability criteria, combined with the distance among the different facilities, are obstacles to recycling wood that cannot be reused. For one Metro Vancouver builder, bringing materials to the correct recyclers sometimes requires "laps around the mainland." The time and expense of going to different facilities for different materials disincentivizes source-separated recycling over the comingling of construction and demolition waste into one bin. One deconstruction stakeholder has to coordinate trips to seven facilities throughout the region, which can be confusing for drivers. In addition, a waste management vendor notes that many jurisdictions refuse potentially recyclable materials. The vendor reports that plywood is the main wood product that is most often turned away because of recyclers' acceptance criteria, despite its potential use for hog fuel when mixed with clean wood. Moreover, the acceptance criteria for wood products at regional facilities change frequently, which further prohibits the recycling of wood other than clean dimensional lumber. These accessibility issues create a disincentive to recycle, especially for materials such as plywood which are potentially divertible in smaller loads but are not accepted as clean wood by regional transfer stations.

Gap Analysis

Material	Current situation in Metro Vancouver	Current situation in all jurisdictions
Engineered wood (Plywood, oriented-strand board, etc.)	Hard to recycle. Plywood reusable.	Hard to recycle. Plywood reusable.
Damaged clean wood	Recyclable, but end uses determined by regional markets.	Recyclable, but end uses determined by regional markets.
Polyvinylchloride (PVC) pipes	Hard to recycle. Reuse potential unclear.	Hard to recycle. Reuse potential unclear.
Painted wood	Hard to recycle. Possibly reusable.	Hard to recycle. Possibly reusable.
Pressure-treated wood	Hard to recycle. Possibly reusable.	Hard to recycle. Possibly reusable.
Membrane-coated wood	Hard to recycle and reuse.	Unclear.

Figure 16: Gap analysis of hard-to-recycle and hard-to-reuse materials.

The feasibility findings reveal six primary gaps regarding the recyclability and reusability of post-1970 residential materials. These materials are difficult to divert for recycling or reuse either (1) because of a lack of facilities in Metro Vancouver to absorb them, or (2) because the ability to recycle or reuse them is nearly impossible everywhere due to the problematic condition or composition of the product. The current situation for hard-to-recycle and hard-to-reuse materials is identified in Figure 16.

Recycling gaps exist in Metro Vancouver, and elsewhere, primarily due to a shortage of facilities to absorb recyclable materials:

- **Engineered wood:** Can be recycled for biomass when blended with clean wood at Ecowaste in Richmond, BC, but its acceptability at other locations is limited according to stakeholders.
- **Damaged clean wood**: Not technically hard to recycle in Metro Vancouver, but recycling options are limited because of the regional market's reliance on biofuels as an end use. Damaged wood is potentially recyclable as a feedstock for engineered building materials, such as particleboard (Tafisa 2021).
- **Polyvinylchloride pipes**: Difficult to recycle due to the specialized equipment required to process them, typically into plastic pellets for new pipes or other products (Blue Planet Recycling 2020). Three facilities in Metro Vancouver accept PVC for recycling, with two accepting it in large commercial loads only.
- **Painted wood:** Used successfully in a pilot project to power two cement kilns in Metro Vancouver, although the status of a permanent facility to source waste wood for the kilns is on hold currently (City of Vancouver 2021). Beyond Metro Vancouver, painted wood and other "dirty woods" have been acknowledged as usable in wood-to-energy facilities that deploy gasification to generate energy (Kotrba 2009; Sikarwar et al. 2016). The Kruger tissue mill in New Westminster, BC uses a gasification system for its wood-to-energy facilities (Nexterra 2019).
- **Pressure-treated wood**: Problematic for recycling in Metro Vancouver and elsewhere due to toxicity concerns. With advanced infrastructure, it can potentially be gasified for energy (Kotrba 2009; Sikarwar et al. 2016).
- **Membrane-coated wood**: Difficult, if not impossible, to salvage for either recycling or reuse because of the bonding of membrane products (such as acoustic seals and vapor barriers) on the wood. Further research required.

With respect to reuse gaps, it is feasible to reuse some items in Figure 16, but not often for their original use regardless of jurisdiction. Further research is required to confirm.

- **Engineered wood:** Plywood is reusable in Metro Vancouver and elsewhere through donation to reuse stores, or for recirculation into new building projects directly. Other engineered wood products, however, are less predictable for reuse due to their fragility in hot and wet conditions, and their vulnerability to damage in the process of deconstruction.
- **Damaged lumber**: Usually unfit for reuse everywhere.
- **Polyvinylchloride pipes:** Reusable for art projects, with one facility in Metro Vancouver accepting them for art. Their feasibility for reuse in residential drainage is unclear.
- **Painted wood and pressure-treated wood**: Can be reused if lead-free. Sanding or burning is not recommended, and professional advice is recommended for stripping paints (Bennett 2014).
- **Membrane-coated wood:** Considered by one stakeholder as difficult, if not impossible, to reuse. Further research required.

Summary

The feasibility findings and gap analysis suggest that the reuse and recycling of materials from post-1970 homes is feasible, but that specific diversion rates and types of deconstruction, recycling, and reuse suitable for these homes requires further exploration. The main difference between post-1970 and pre-1970 homes as candidates for deconstruction, recycling, and reuse relates to their different material compositions. Efforts to manage cost-related, market-related, and facilities-related issues should consider the unique challenges and potential opportunities offered by post-1970 homes' compositions. This can enable the transfer of deconstruction, recycling, and reuse best practices, such as on-site sorting systems and machine-assisted "hybrid" deconstruction, to this stock of homes. Accounting for post-1970 homes' distinct compositions will become necessary as the region pursues new market opportunities for reusable lumber and recyclable waste wood.

Summary of material feasibility: does the condition, appearance, and composition of the particular material or assembly warrant recycling or reuse?

Due to specific material barriers, homes built in the 1970s are likely the best candidates for deconstruction and wood salvage. These homes contain the most valuable wood products and are the least likely to be affected by adhesives, sprayfoam, and membranes. The main issue with this era is the potential presence of hazardous materials, such as asbestos and lead paint. The 1980s-and-after era is still potentially feasible for diversion, but less so due to membranes and large amounts of engineered wood in the frame. With homes built in the 1990s and after, the more likely appearance of adhesives and sprayfoam renders significant sections of the wall, floor, and roof assemblies potentially unsalvageable. This being said, post-1970 homes are candidates for a high-value initial salvage. The dimensional lumber in these homes is also more likely than pre-1970s homes to conform to modern actual dimensions, making them conducive to reuse.

Summary of cost feasibility: is it feasible to recover materials for recycling/reuse given the time, training, equipment, and personnel required?

Stakeholders generally anticipate that deconstructing a post-1970 home is less cost-effective than a pre-1970 home due to lower-value materials and potentially problematic assemblies. This requires further research to corroborate. Yet almost all of the interviewees agreed that it is still feasible from a cost perspective to recycle and, barring assembly concerns, salvage reusable material from post-1970 homes. Best practices exist to facilitate effective diversion rates while managing project costs, chief among them the planning of on-site sorting and machine-assisted "hybrid" deconstruction. Industry stakeholders emphasize the need for government support of these practices, including a continuous commitment to training deconstruction contractors, the promotion of planning and equipment to manage jobsite waste, and policies that level the economic playing field between demolition and deconstruction.

Summary of market feasibility: once salvaged and possibly refurbished, are there adequate recycling or reuse markets available to absorb the materials?

In Metro Vancouver, end markets for recycled wood products, which includes the engineered wood found in large volumes in post-1970 homes, are currently limited to biomass for wood-to-energy facilities. Reusable lumber and plywood can be donated to some used building materials stores in the region, notably Habitat for Humanity ReStores. Modular cabinetry and plywood are conducive to removal, storage, and reuse. Stakeholders suggest, however, that more options for recycling and reuse are needed to absorb further diversion.

With respect to reuse, one market opportunity is to salvage modern varieties of dimensional lumber, reprocess them, and reuse them for their original purpose. Modern spruce and pine lumber are often perceived as too costly to reprocess for reuse as a building material compared to more valuable old-growth Douglas fir, which makes up Metro Vancouver's wood reuse market. Concerns about the acceptance of modern dimensional lumber for structural reuse during the building permitting process was also raised by some stakeholders. Other stakeholders suggest that fluctuating prices in the North American lumber market are revealing an untapped opportunity to reuse modern lumber intact. The adherence of lumber found in post-1970 homes to modern actual dimensions, as well as their likelihood of containing a visible grade stamp, makes them potentially viable and cost-effective options for structural reuse. Plywood could also be salvaged and reused given its prominence in modern construction. With respect to recycling markets, most stakeholders believe that the sourcing of construction and demolition wood waste as a feedstock for building materials, such as finger-joined studs, particleboard, and furniture, would improve the feasibility of salvaging wood that is not reusable from post-1970 homes. Challenges involved in pursuing new recycling market opportunities include: identifying suitable end products, attracting entrepreneurial interest in using construction and demolition wood as a feedstock for the products, and maintaining a steady volume and quality of waste wood for the products.

Summary of facilities feasibility: is there an adequate supply of storage and processing facilities for the diverted materials, and are they accessible geographically?

Facilities for the recycling and reuse of construction and demolition materials are adequate, according to stakeholders, but could be expanded and improved. The main facilities gap found with respect to recycling from post-1970 homes is plywood that is unfit for reuse. Regardless of material type, stakeholders note that recycling is not always convenient for drivers who have to travel to multiple facilities to recycle building materials from a residential jobsite. This issue is compounded by nonuniform and changing acceptance criteria for building materials in the region. Facilities are available for the retailing of reusable of lumber, but one deconstruction stakeholder suggests that processing facilities to collect salvaged lumber from contractors are needed, as well as more opportunities for salvaged materials retailing. Opportunities currently being pursued in the region include: a Material Recovery Facility for improved wood recycling rates at Ecowaste in Richmond, BC; the exploration of automated de-nailing and a processing yard for contractors to deposit salvaged wood; and the intended future arrival of a reuse store operated by The ReUse People of America to store and sell a greater volume and variety of materials.

Opportunities for Future Exploration

The following list of opportunities targets the specific feasibility issues that affect post-1970 homes. But they are generally relevant for the further development of a regional construction and demolition wood waste policy that promotes diversion from *all* homes.

Opportunities to address materials-related issues include: a demonstration project of a deconstruction on a post-1970 home, and consultation with member municipalities with experience in post-1970 diversion.

Without diversion data and case studies of post-1970 demolitions and deconstructions, an estimate of the diversion potential of post-1970 homes is difficult to make. In order to better understand the costs and salvageability of materials for a post-1970 home, three stakeholders suggest pursuing a deconstruction demonstration project. The project could pursue three objectives:

1) A cost comparison between conventional demolition costs and the deconstruction costs for a post-1970 home.
2) The diversion rate attainable for the case house, with data about what was salvaged for donation/reuse, what was recycled, and what was landfilled.
3) The regional promotion of deconstruction as an environmentally beneficial and economically viable option for homes of all eras.

A home built in the 1970s is the best candidate for achieving the three objectives. These homes are advantageous due to the likelihood of obtaining valuable fir lumber, and at modern dimensions, without encountering significant assembly issues such as sprayfoam insulation, plastic-based membranes, and construction adhesives.

Stakeholder input and online research indicate that diversion will likely be lower for a home built in the 1980s and after. A deconstruction of a 1980s-and-after home would still be worth pursuing in order to obtain cost and diversion data. It would also offer a potential opportunity to document and promote the advantages of homes built in the 1980s and after for deconstruction, which include:

- The high economic and environmental value and low cost of the initial salvage of fixtures and finishes.
- The speed of removing plywood sheathing for intact reuse, as compared to shiplap sheathing.
- The modern actual dimensions of the lumber package for reuse.
- The workability of modern lumber types for re-milling.
- A reduced chance of discovering hazardous materials such as asbestos and lead paint.

Consultation with member municipalities such as the City of Richmond, which has a 70% diversion requirement for residential demolitions, could also generate insights into the diversion of wood from post-1970 homes. Deconstruction and reuse stakeholders in younger North American cities such as Pheonix, Arizona, can also provide useful insights into the salvage, storage, and sale of materials from post-1970 homes.

Opportunities to address cost-related issues include: the promotion of on-site sorting; the exploration of machine-assisted deconstruction; and the potential of expedited building permits as a tool to promote deconstruction.

On-site sorting allows for higher diversion rates than the comingling of demolition waste in disposal bins. But on-site sorting is usually perceived to be more costly and more complex. The convenience of sorting stations with clear signage, along with access to facilities with lower fees to recycle separated wood loads in Metro Vancouver, can help address concerns about the time and financial costs required to sort on site. The experience of Palo Alto indicates that the construction and demolition industry there is beginning to adapt to requirements for source-separation despite cost concerns. Source-separation planning and equipment could be further promoted through a deconstruction demonstration project on a post-1970 home.

Machine-assisted deconstruction offers another potential opportunity for further innovation in the deconstruction sector. The use of heavy machinery to disassemble a home into panels for reuse in other projects could result in cost savings compared to hand deconstruction, which may be less feasible for assemblies bonded with sprayfoam and membranes. A stakeholder who practices and promotes the technique notes its feasibility for homes built after 1950 because of the more uniform sizing of their frames. This could facilitate integration into new construction projects.

Some Metro Vancouver stakeholders note that incentives for pursuing deconstruction over conventional demolition would level the economic playing field in favor of sustainable house removal. One Metro Vancouver builder suggests that an expedited building permit for contractors who use deconstruction best practices to replace the previous house, instead of demolition, could become an effective incentive. Expedited permitting trades a (potentially) higher financial cost incurred by deconstruction services for a lower time cost in the permitting stage. An expedited permit would make it easier for contractors to justify the costs of deconstruction best practices to a client, such as onsite waste separation.

Opportunities to address market-related issues include: the promotion of pre-demolition salvage; the promotion of modern dimensional lumber reuse; and the exploration of new upcycling markets for nonreusable wood waste.

Most stakeholders consider the initial salvage of a home before a demolition or deconstruction commences as a relatively low-cost, but high-value opportunity to divert fixtures and finishes for recycling or reuse. “Salvage is a beautiful ethical direction to go,” as one Metro Vancouver builder states. Efforts to promote the reuse of materials from post-1970 homes would benefit from highlighting economic value and environmental benefits of the initial salvage stage. Lessons learned from the City of Palo Alto indicate that working directly with reuse store operators on the initial salvage can be beneficial for ensuring the marketability and proper handling of salvaged items.

Another market opportunity worth pursuing is the promotion of modern Spruce-Pine-Fir lumber as a candidate for reuse. Wood from post-1970 homes has not been historically valued by used lumber markets. Expected growth in the global used lumber market, coupled with the expected maintenance of high lumber prices into 2022, could encourage the reuse of modern lumber in non-structural applications such as stud walls, back framing, trim, fencing, decking, and garden beds. The existence of grade stamps on lumber from post-1970 homes could potentially enable its use in structural applications. Consultation with building inspectors and structural engineers in the region would help obtain more clarity on the feasibility of reusing modern dimensional lumber for structural applications. The Canadian Wood Council could be consulted on the suitability of modern spruce, pine, and fir lumber for circular design.

The recent market for virgin lumber provides an opportunity to re-examine the upcycling of demolition wood waste into building products. Recycling is suitable for shorter lumber boards and damaged wood materials that cannot be reused intact. While biomass markets are available, upcycling demolition wood into new products could expand diversion opportunities. Recycling could become more attractive to sustainability entrepreneurs in the region as an opportunity to compete with high virgin wood prices. In this regard, potential avenues to explore may include:

- **Consulting with existing manufacturers on upcycling challenges and best practices.** Major manufacturing facilities such as Tafisa, which is based in the Province of Quebec, use 100% recycled wood in their particleboard products while tapping into a national distribution network to sell them (Tafisa 2021). Further consultation with companies experienced in using recycled wood might illuminate specific challenges and best practices in the sourcing of residential demolition wood for new products.
- **Exploring innovative manufacturing models.** Promoting a large facility such as Tafisa's in Metro Vancouver could be exceedingly challenging given high land costs. Different manufacturing models suitable for constrained spaces, such as "micromanufacturing," might offer more feasible opportunities for upcycling. Microfactories between 1,500 and 2,500 square feet are being used to produce engineered wood products from recycled chopsticks in Vancouver (ChopValue 2021).
- **Promoting research focused on the upcycling of waste lumber and engineered wood products sourced from post-1970 homes.** Engineered wood products such as oriented-strand board and particleboard commonly use recycled lumber from a variety of sources. Using post-consumer demolition waste wood as a feedstock for new building products

remains a challenge, however, in part due to questions around the mechanical feasibility of demolition waste wood for manufacturing. With respect to structural materials, one study reports promising results for the recycling of clean residential lumber into cross-laminated timber. But this research uses fir lumber found in pre-1940s homes (Arbelaez et al. 2020). With respect to nonstructural materials, research into the recycling of used clean lumber and used engineered wood products for new particleboards reports mixed mechanical results, depending on the manufacturing processes used and the types of feedstock (see Iždinský et al. 2020 for a review). For instance, Laskowska and Mamiński (2018) demonstrate that, with proper shredding procedures, at least 20% of waste plywood can be used in the composition of particleboard with no negative mechanical effects. Their research uses post-industrial recycled plywood as a feedstock, however, and not demolition waste plywood. Promoting research that specifically focuses on waste woods from demolished or deconstructed post-1970 homes might illuminate more relevant manufacturing opportunities.

Opportunities to address facilities-related issues include: exploring the expansion of options for wood recycling and promoting the development of the region's reuse sector.

Stakeholders indicate a desire for more predictability, convenience, and uniformity in recycling locations for demolition wood waste in Metro Vancouver. This is particularly the case for products which are harder to recycle, such as plywood, which are accepted at some facilities during some periods but not widely accepted for recycling most of the time. Addressing this issue could involve, as one stakeholder suggests, a "one-stop shop" for the drop-off of separated recyclable materials to avoid multiple trips to different recycling facilities in the region. Promoting a wider range of wood products for acceptance among recyclers will require new developments within existing markets (such as the conversion of existing manufacturing plants to biofuels) and the pursuit of new markets focused on the upcycling of waste materials into new building products.

Gaps that stakeholders identify in the reuse sector will potentially be addressed by industry players. The opening of a processing yard for contractors to deposit salvaged wood, as well as the intended arrival of The ReUse People of America into the region, could become promising opportunities for further diversion. Reuse sector efforts could be promoted to raise awareness among homeowners and the construction and demolition industry about the reusability of lumber and engineered wood products.

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Appendices

Appendix A: Master list of interview questions.

1) Background of interviewee: Can you tell me about your ongoing work related to the recycling, salvage and reuse of materials from Post-1970 homes?

2) Policy and best practice: **As a practitioner in [x field; x city/region], what works and what doesn't when it comes to incentivizing and enforcing the diversion of residential wood products?**

- Have you seen or participated in successful examples of wood diversion from Post-1970 homes?
- On the regulatory side, to what extent have municipal or regional regulatory agencies helped drive the recycling and salvage of wood from Post-1970 housing?
- What conditions do you think would need to be in place to apply a demolition/deconstruction policy to Post-1970 houses?

3) Post-1970 homes recycling challenges [materials-related]: There are multiple, distinct challenges facing the recycling and reuse of wood from housing built after 1970. One issue involves the products themselves in these newer homes, such as the widespread use of composite wood and contaminants such as spray foam insulation. **Can you walk me through these materials-related challenges to recycling and reuse as they affect your work?**

- In your experience, are there specific materials from Post-1970 homes that have been reused and recycled successfully?
- Are there specific materials from Post-1970 homes that are currently so difficult to recycle or reuse that they are not worth trying to divert?
- Are there any hard-to-recycle materials from Post-1970 homes that have the potential to be recycled or reused successfully? And what are they?
- Can you tell me about the effects of bonding agents and contaminants, such as spray foam insulation, on the recyclability and re-usability of wood from Post-1970 homes?
- What do you think would need to be done in order to make the re-cycling and reuse of wood materials from Post-1970 homes feasible?

4) Post-1970 homes challenges [recycling market-related]: In Metro Vancouver, one of the barriers to widespread adoption of recycling in residential construction and demolition industry is simply the demand for recycled wood products. Sometimes there's a lack of demand for recycled wood for products like mulch and biomass, which affects ability of recycling facilities to accept wood. **To what extent does the demand for recycled wood affect your work?**

- What do you think would need to be done to ensure that recyclers can feasibly accept wood materials from Post-1970 homes?

5) Post-1970 home challenges [recycling versus reuse]: **Can you tell me about what will need to be done to encourage the salvage and reuse of wood materials, as opposed to just recycling?**

- Can you tell me about the opportunities and barriers to expanding markets for the reuse of wood products from Post-1970 homes?
- From your perspective, what role can municipal and regional governments play in helping to grow a de-construction and reuse industry incorporating recovered wood?

6) Wrapping up: Are there any other issues with diverting wood from Post-1970 housing that we haven’t talked about, but are important?

Appendix B: Tables of changes in Canadian housing technology from 1940s to 1990s. Adapted from Denhez (2000).

Table 1:
Outline of Changes in Mainstream Housing Production

Component	Mid-1940s	Mid-1960s
Excavation	Horse-drawn scrapers replaced by bulldozers. shaping and trenching disappeared.	Bulldozer yielded to backhoe. Hand shovel
Basements	Concrete blocks gave way to site-mixed poured concrete, with site-built board formwork. First transit-mixed and oiled-plywood forms used. Still some dirt floors.	Transit-mixed concrete and prefabricated plywood formwork. Blocks still served in rural areas and board formwork still used in Atlantic Canada. Concrete slabs.
Wall Framing	Typical builders used platform frame, but still some balloon frame used. West already used tilt-up and "stationary assembly line" processes.	Pre-cut studs, tilt-up, "stationary assembly line" with sequencing of piecework subs. Floors provided the "assembly table" areas for the walls, partitions and roofs.
Roofs	Still laid out and erected by skilled carpenters, with site-cut and fitted rafters.	Engineered, manufactured roof trusses took over typical house production.
Plumbing and bathrooms	Cast iron waste vent. Some galvanized steel. Site-fitted and installed. Bathtub and tile all installed separately.	Little change, but plastic drain waste vent piping speeded up on-site process.
Electricity	30-50 amps typical.	60-100 amps typical.
Heating	Gravity furnaces common.	Forced-air furnaces and electric baseboards. Ductwork sub-assemblies. Prefabricated chimneys became common.
Interiors	Wet-finished plaster walls and ceilings, cured, then brush painted. Hardwood and linoleum flooring.	Interiors were drywalled and roller-painted. Hardwood floors still typical, but carpeting gaining in popularity.
Windows	Still fabricated on site. Single-glazed, vertically hung, often with storms.	Manufactured windows, usually sealed double-glazed, horizontal sliders. Aluminum frames common.
Cabinetry, stairs, millwork	Still fabricated on site. Countertops were often lino or painted wood.	Manufactured cabinetry. Melamine for countertops.
Wall and roof sheathing	Used boarding (often stripped from the basement forms).	Plywood sheets widely used. Fibreboard used with brick or stucco.
Siding	Often clapboard applied, trimmed and painted on site using scaffolding. Brick and stucco dominant in some areas.	Pre-coated aluminum and hardboard competed strongly with wood. Brick and stucco often on first storey.
Insulation	Walls uninsulated or 5 cm (2 in.) of mineral wood or shavings. Vermiculite in attic.	Still minimal: 10 cm (4 in.) fibreglass batts in walls, 15 cm (6 in.) in ceilings. Cellulose introduced. Some insulating of basements.
Air/vapour barriers	Little awareness.	Kraft paper on batts. Some use of 2 mil polyethylene. Drywall and sheathings increased airtightness inadvertently.
Ventilation	Natural.	Some use of exhaust fans.
Scheduling, job control, costing	Rudimentary.	Generally effective costing and control among the larger builders.

Table 1 (Continued):
Outline of Changes in Mainstream Housing Production

Component	Mid-1980s	Mid-1990s
Excavation	No change.	Backhoe yielded largely to the excavator.
Basements	Generally no change, but steel forms increasingly used. Preserved wood foundations began to gain acceptance.	Little change, but more attention to drainage layer/membrane components. Granular fill and poly under slabs. Sub-slab venting and sealing for radon.
Wall Framing	Adaptations for thicker insulation and less bridging. Power nailers. Wood composite joists introduced. Some reversion to custom building because of large complex houses.	2 x 6 wall framing more common than 2 x 4. Engineered wood composites are widely used. Steel framing is taken seriously to the walls, partitions and roofs.
Roofs	High heel trusses to accommodate ventilation baffles.	Little change.
Plumbing and bathrooms	Easier, faster fittings and all-plastic plumbing. Plastic tub-shower units gain foothold.	Water-conserving fixtures. Plastic tub-shower and whirlpool baths are new standards.
Electricity	100 amps typical, 200 amps for electrically heated homes.	Energy-efficient lighting and appliances. Home automation and efficient fans and motors introduced.
Heating	Mid- and high-efficiency furnaces introduced. Oil largely supplanted by natural gas, where available. Airtight wood stoves and fireplace inserts. Chimneys and flues typically prefabricated.	Mid- and high-efficiency gas furnaces taking over. Requirements for spillage resistance. Central air conditioning increasingly common. Gas fireplaces popular. Combined heat/ DHW introduced.
Interiors	Carpeting and sheet vinyl placed directly over sheathing. Pre-finished plastic trim enhances speed.	Low-emission finishes introduced. Plastic or wood-plastic trim is new standard.
Windows	Improved thermal performance introduced: low-e coatings, gas fills, thermal breaks, less air leakage.	"Super windows" taking over.
Cabinetry, stairs, millwork	Little change. Pre-hung doors and prefabricated stairs often used.	Little change. Complete kitchen assemblies are standard.
Wall and roof sheathing	Waferboard sheets dominate.	Waferboard still dominates but insulating/ air barrier sheathings common.
Siding	Vinyl siding complete with other claddings. On-site painting essentially disappears.	Vinyl widespread. Fibre-cement composites begin to compete.
Insulation	Higher levels becoming common: R20 walls, R30 ceilings. Partially insulated basements typical.	Higher levels typical. Greater variety of high-performance insulations. Full-height basement insulation common.
Air/vapour barriers	Polyethylene increasingly sealed and continuous as air/vapour barrier, 2 mil replaced by 6 mil. Introduction of house wraps.	Variety of approaches to airtightness. Introduction of vapour barrier paints. House wraps common.
Ventilation	Heat recovery ventilators and central exhaust systems gaining in popularity.	Mandatory ventilation requirements. HRVs increasingly common.
Scheduling, job control, costing	Little change. Some use of computer-based costing and job control. Introduction of CAD.	Little change. CAD often used for both designing and selling.

Source: Scanada [1], updated 1996.

Appendix C: Bill of materials for a 1980 Vancouver Special. Adapted from Zhang et al. (2014, 432).

Table 2 Bill of materials

Material	Unit	Foundation	Walls	Floor	Columns/ beams	Roof	Building total
#15 organic felt	m^2	—	1048.3148	—	—	893.6413	1941.96
3 mil polyethylene	m^2	—	566.4526	—	—	138.5894	705.04
5/8" gypsum fiber gypsum board	m^2	—	624.1068	—	—	—	624.11
5/8" regular gypsum board	m^2	—	550.663	—	—	—	550.66
Aluminum	t	—	2.5467	—	—	—	2.55
Ballast (aggregate stone)	kg	—	—	—	—	7482.4599	7482.46
Batt, fiberglass	m^2 (25 mm)	—	651.1168	—	—	212.4047	863.52
Blown cellulose	m^2 (25 mm)	—	—	—	—	216.1932	216.19
Cold-rolled sheet	t	—	0.0076	—	—	—	0.01
Concrete 20 MPa (flyash av)	m^3	13.1801	—	4.0239	—	—	17.50
Concrete blocks	block	—	215.1757	-	—	—	215.18
EPDM membrane (black, 60 mil)	kg	—	136.211	-	—	—	136.21
Galvanized sheet	t	—	0.215	0.0462	—	0.1799	0.44
GluLam sections	m^3	—	—	—	0.3186	—	0.32
Hollow structural steel	t	—	—	—	0.0369	—	0.04
Joint compound	t	—	1.1724	—	—	—	1.17
Large-dimension softwood lumber, kiln-dried	m^3	—	—	6.5834	—	3.7052	10.29
Metric modular (modular) brick	m^2	—	39.3124	—	—	—	39.31
Mortar	m^3	—	5.1334	—	—	—	5.13
Nails	t	—	0.3047	0.0501	—	0.1036	0.46
Oriented strand board	m^2 (9 mm)	—	791.3842	307.1357	—	173.278	1271.80
Paper tape	t	—	0.0135	—	—	—	0.01
Rebar, rod, light sections	t	0.4838	1.1267	0.2695	—	—	1.88
Roofing asphalt	kg	—	—	—	—	5022.5329	5022.53
Screws, nuts & bolts	t	—	0.1824	—	0.0489	—	0.23
Small-dimension softwood lumber, green	m^3	—	8.5612	—	—	—	8.56
Small-dimension softwood lumber, kiln-dried	m^3	—	1.7107	—	0.7621	—	2.47
Softwood plywood	m^2 (9 mm)	—	52.2879	—	—	—	52.29
Standard glazing	m^2	—	92.009	—	—	—	92.01
Stucco over metal mesh	m^2	—	23.1452	—	—	—	234.15
Type III glass felt	m^2	—	—	—	—	1787.2826	1787.28
Water-based latex paint	L	—	342.8234	—	—	—	342.82
Wide flange sections	t	—	—	—	0.4996	—	0.5

Appendix D: Lumber grade stamps in British Columbia. Adapted from Canadian Wood Council (2021b).