CHAPTER 3: TECHNICAL REVIEW

3.1 INTRODUCTION

Globally, the building and construction sectors account for nearly 40% of global energy-related carbon dioxide emissions in constructing and operating buildings (including the impacts of upstream power generation).[1] Current building codes address operating energy, but do not typically address the impacts 'embodied' in building materials and products. However, more than half of all greenhouse gas (GHG) emissions are related to materials management (including material extraction and manufacturing) when aggregated across all industrial sectors.[2] As building operations become more efficient, these embodied impacts related to producing building materials become increasingly significant.

This technical review discusses the sources of embodied impacts in the major structural material categories selected in this study (concrete, masonry, steel, and wood), and discusses recommendations on how to incorporate embodied carbon in procurement policy, which includes technical support of EPD development and establishing performance targets.

A. QUANTIFYING PRODUCT EMISSIONS

In order to understand the magnitude of emissions produced by materials manufacturing, an accounting of emissions along the supply chain is required. Life cycle assessment (LCA) is a standardized environmental accounting method that can track these emissions, beginning with raw materials extracted from nature through manufacturing, use of materials, and end-of-life processes. LCA reports a range of potential environmental impacts of these emissions, including GHG emissions reported as a standard metric termed global warming potential (GWP), which is expressed in kilograms of carbon dioxide equivalent (kg CO_2e).

There is a strong global consensus on how to calculate GHG emissions and agreement that these emissions have the same global impact no matter where they are emitted. GHG emissions arising from material extraction and product manufacturing is commonly referred to as *embodied carbon*, which is the focus of this document and this study. Reducing the embodied carbon of products consumed in Washington State could have significant regional and global impacts.

Generally, the GHG emissions from product manufacturing can be attributed to four primary variables:

1. The source of energy used (both from electrical grid and fuels combusted during manufacturing)
2. Any chemical reactions that take place to create materials
3. The efficiency of the manufacturing facility, which affects the amount of energy used
4. The transportation method (e.g. barge or truck) and fuel source (e.g. diesel or electric)

Low embodied carbon in materials manufacturing is associated with:

- Low-carbon electrical grids

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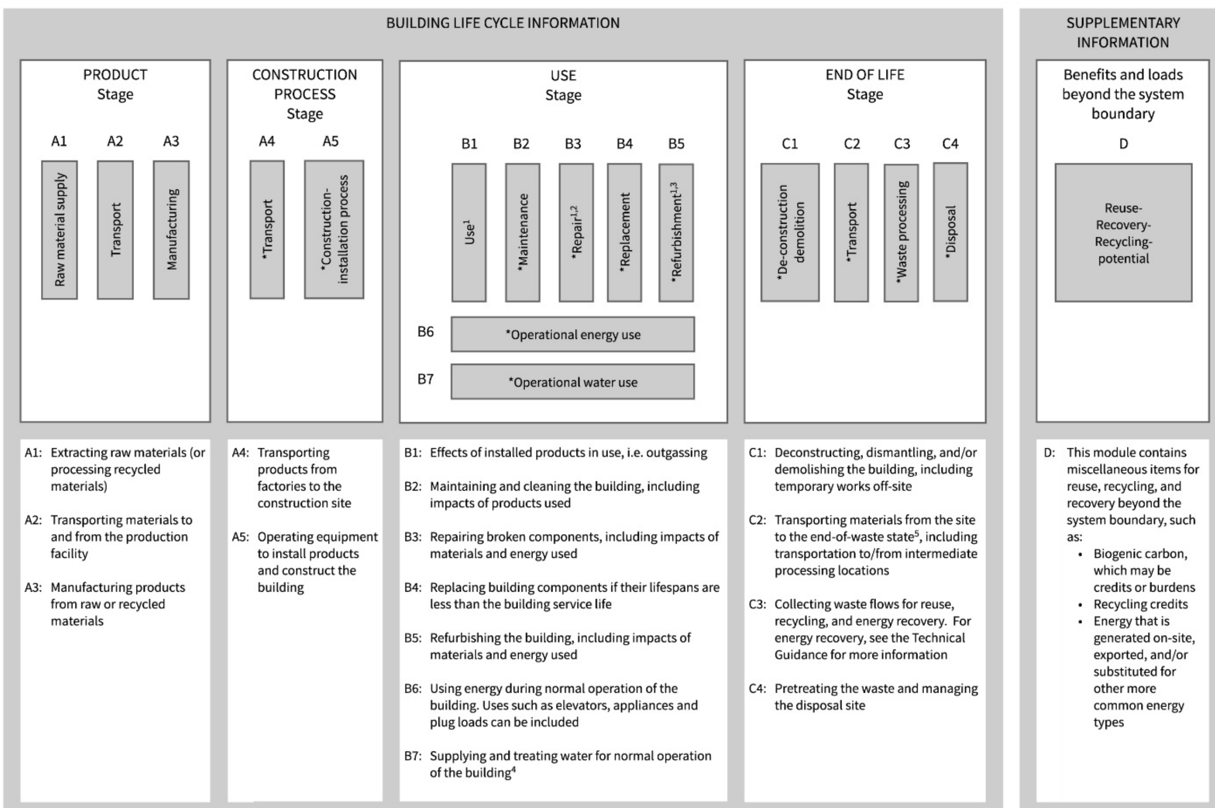
[1] UNEP and IEA, "Global Status Report 2017: Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector," 2017.
[2] OECD, "Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences" (Paris, 2019), https://doi.org/https://doi.org/10.1787/9789264307452-en.

- High investment in recycling infrastructure
- Stringent emissions control standards
- Newer, more process-efficient manufacturing processes

LCA standards divide the impacts that occur over the life cycle of a product according to the modules shown in Figure 3.1. Modules A1-A3 cover the product manufacturing stage from raw material extraction to manufacturing, and is often characterized as 'cradle-to-gate,' or from beginning-of-life to the factory gate. This cradle-to-gate scope comprises the 'embodied' in 'embodied carbon.'

In addition to estimating the emissions directly attributable to a product, LCA tracks impacts that are beyond the system boundary using module D. Examples of such impacts would include recycling at end-of-life for steel, or the carbon sequestered in wood products due to the biological process of growing trees. These impacts beyond the system boundary can be interpreted differently depending on the perspective and values of the interpreter, and care should be taken if stage D impacts are integrated into decision-making processes.



* Scenario descriptions required
[1] These modules are currently not well-supported by LCA databases and tools.
[2] Repair is defined as "returning an item to an acceptable condition by the renewal, replacement or mending of worn, damaged or degraded parts" [9].
[3] Refurbishment is defined as "modification and improvements to an existing building in order to bring it up to an acceptable condition" [9].
[4] Note that tracking operational water use is not common in whole building LCA tools and requires further development of the methodology.
[5] EN 15978 defines the end-of-waste state in Section 7.4.5.4.

Figure 3.1. LCA stages and modules per EN 15978, reproduced from *Life Cycle Assessment of Buildings: A Practice Guide.*[3]

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[3] Carbon Leadership Forum, "Life Cycle Assessment of Buildings: A Practice Guide," 2018, https://doi.org/http://hdl.handle.net/1773/41885.

ENVIRONMENTAL PRODUCT DECLARATIONS (EPDs)

EPDs are third-party verified LCA reports that follow a standardized accounting method (ISO 21930) outlined in a designated Product Category Rule (PCR), and are hosted by an EPD program operator. Program operators are organizations (independent companies, non-governmental organization, or trade organizations) that set up to oversee the third-party review of EPDs, as required by ISO EPD standards. There are multiple program operators in North America. A catalog of North America PCRs is being maintained by a group of North American EPD program operators and is available online.[4] While there are multiple EPD databases, no one single database includes all available North American EPDs.

Different materials and products report data at different levels of detail, which makes it difficult to compare EPDs because they have different underlying assumptions. Furthermore, as noted "EPDs do not indicate that any environmental or social performance benchmarks are met, and there may be impacts that they do not encompass. LCAs do not typically address the site-specific environmental impacts of raw material extraction, nor are they meant to assess human health toxicity. EPDs can complement but cannot replace tools and certifications that are designed to address these impacts and/or set performance thresholds."[5] The comparability of EPDs (or lack thereof) is important consider when comparing the environmental impacts of products. Factors that impact the comparability of embodied carbon reported in EPDs include:

1. Methodology: Do EPDs follow the same PCR? The PCR author and version can have a significant impact on the methods used to calculate LCA impacts.
2. Upstream data: Do EPDs use aligned upstream data for significant impacts such as electrical generation or transportation? If upstream data (life cycle inventory datasets) are not aligned, variation in results can be significant.
3. Performance: Do the compared materials have the same performance characteristics? Two products of the same material category may have significantly different performance characteristics (e.g. 3,000 psi concrete for a foundation vs 5,000 psi concrete for a high-rise floor slab), which would make it inappropriate to compare their EPDs.
4. Installation, use, and end-of-life: If all life cycle stages after manufacturing are not identical, comparing embodied carbon alone is not appropriate and LCA data should be considered in the context of a 'whole-building' LCA.

The comparability of EPDs for each of the different material categories is addressed in more detail in Section 3.2.

There are different types of EPDs, affecting how EPDs are assessed in this review:

1. Facility-specific EPD: results for a specific product produced at a unique facility.
2. Product-specific or manufacturer-specific EPD: Results are representative of the processes for a specific product or family of products made by a unique manufacturer. This may be a weighted average of different production facilities.

[4] Program Operator Consortium, "North American PCR Catalog (Google Sheet)," accessed December 14, 2018, https://docs.google.com/spreadsheets/u/1/d/1lS7ukMUG1cAWnMGHKiqIvgcgeHQOeICIIH5t95InZy8/pubhtml.
[5] ULe, "Environmental Product Declaration Steel Deck," 2015.

3. Industry-average EPD: Results are weighted to reflect production method and proportion of a region. Sometimes only a sample of companies who elected to participate in the creation of the EPD and thus may not be truly representative of the average in the industry.

Of note, the dominant standard for creation of EPDs is ISO 21930, which was significantly updated in 2017. While updates of the material PCRs are in different levels of development, no EPDs on the market currently comply with this new standard. Key aspects of the new version of the standard include: more clarity regarding the carbon emitted in burning bio-fuels, and the requirement to report of variability of the results (e.g. standard deviation).

DISCUSSION

Given that structural materials within the same material category commonly have the same construction, use, and end-of-life impacts, comparing cradle-to-gate EPDs can be appropriate for comparing within the same material category (e.g. steel 'A' vs steel 'B'). Given that the installation, use, and end-of-life impacts vary by material, comparing cradle-to-gate EPDs of different material category (e.g. steel vs wood, or even precast concrete vs ready-mix concrete) is not appropriate without conducting a more detailed LCA. The intent of this technical review is thus to evaluate options for differentiating products of the same material category, e.g. selecting the 'cleanest' structural steel available. The purpose of this study is not to compare different material categories, such as steel versus concrete, and thus cannot answer questions such as, "Is a steel or concrete structure a lower-emission option for a building?"

Note that EPD results for one product can be the LCA impact for stage A1 of another product. For example, modules A1-A3 of cement production is included in module A1 of concrete because cement is an ingredient of concrete. A 'facility-specific' EPD typically refers to the facility responsible for the last stage of manufacturing (module A3) of the product. However, for some materials, the largest impacts and largest variability of impacts occur 'upstream' and are reported in LCA stage A1. Thus, identifying the 'facility' type most appropriate to evaluate different materials and products requires careful consideration. For many material categories, the most significant contributor to embodied carbon will be not the facility that fabricates the material but rather the facility(ies) that produce(s) the upstream materials. These upstream impacts are typically reported in life cycle module A1.

B. STRUCTURAL MATERIALS

The Washington State House Bill ESSB 6095 directed this study to "analyze existing embodied carbon policy and propose methods to categorize structural materials and report structural material quantities and origins." The materials analyzed herein are those identified on page 51 of ESSB 6095, which include "any of the following that function as part of a structural system or structural assembly":

1. Concrete, including structural cast-in-place, shotcrete, and precast
2. Unit masonry
3. Metal of any type
4. Wood of any type including, but not limited to, wood composites and wood laminated products.

The project team interpreted this list and focused on the primary structural elements as categorized below according to the standard classification method OmniClass Table 22 Work Results:[6]

- 03 Concrete
- 04 Masonry
- 05 Steel
- 06 Wood

Note that for each of these structural materials, additional components such as concrete formwork, reinforcing ties, steel bolts and connecting plates would be required. This technical review focuses only on the primary structural materials of the elements noted above.

Examples of the impact sources and their approximate percentage contributions of common structural materials by life cycle module is shown in Table 3.1. Section 3.2 will describe impacts of in greater detail.

Table 3.1. Summary of LCA impacts per LCA module and relative impact for common structural materials.

Material category	Property	A1	A2	A3
Structural steel[7]	Approx. % of impact: Source of impacts:	>90% Steelmaking (includes material mining, etc.)	<5% Transportation to fabricator	<10% Fabrication (cutting, welding, shaping steel)
Concrete[8]	Approx. % of impact: Source of impacts:	>90% Production of cement, aggregate, water and admixtures (including material mining, etc.)	<5% Transportation to concrete plant	<10% Mix design (recipe) and concrete mixing
Cement[9]	Approx. % of impact: Source of impacts:	<10% Raw material mining	<5% Transportation to cement kiln	>90% Manufacturing cement
Clay masonry[10]	Approx. % of impact: Source of impacts:	<5% Mining of clay	small Transportation and storage	>95% Firing and factory operations
Glue laminated beam[11]	Approx. % of impact* Source of impacts:	<10% Wood milling (includes forestry harvest and lumber shaping)	<5% Transportation to a fabrication facility	>90% Fabrication (drying, cutting, gluing, pressing)

*not including emissions from bio-fuel combustion or within the broader forest context.

[6] OmniClass, “Table 22 - Work Products,” 2012, http://www.omniclass.org/.
[7] Ule, “Environmental Product Declaration Fabricateed Hot-Rolled Structural Sections,” 2016.
[8] NSF, “NRMCA Member Industry-Wide EPD for Ready Mixed Concrete,” 2016.
[9] Medgar L Marceau, Michael A Nisbet, and Martha G VanGeem, “Life Cycle Inventory of Portland Cement Manufacture,” 2006.
[10] Christophe Rafenberg and Eric Mayer, “Life Cycle Analysis of the Newspaper Le MONDE,” *International Journal of Life Cycle Assessment*, vol. 3, 1998, https://calculatelca.com/wp-content/themes/athenasmisoftware/images/LCA Reports/Brick_And_Mortar_Products.pdf.
[11] Ule, “Environmental Product Declaration North American Glued Laminated Timbers,” 2013.

3.2 EMBODIED CARBON OF STRUCTURAL MATERIAL CATEGORIES

This section evaluates the availability and quality of current EPDs and PCRs for the structural material categories of interest. The first subsection evaluates the current status of EPDs in the industry and Washington State as a whole, and the remaining subsections evaluate each material category in more detail with regards to their embodied carbon characteristics and PCR/EPD status.

CURRENT STATUS OF EPDs

Table 3.2 uses OmniClass to expand the classification of structural materials to distinguish between different structural products or application of materials, and references a representative industry EPD if available. These categories were identified from a broader list within OmniClass Table 22 to be the most representative of structural materials in common use in Washington State. Input from industry stakeholders could refine this list.

From this table, several interesting observations can be made:

A. Methodology for different materials and products are not aligned.
   1. A single PCR exists for wood and steel products, while concrete and concrete masonry products utilize four different PCRs.
   2. None of the four material categories use the same program operator for PCRs or EPDs.
   3. All product types are currently in their 'first generation' of use following the initial PCR. (Typically, PCRs are set to expire every five years, and EPDs are valid for five years from their issue date, even if the PCR is updated. In the near future there will be valid EPDs for the same material category that follow different PCR versions and thus may not be comparable.)

B. EPD development is at different stages and levels of refinement depending on the industry.
   1. The wood and concrete industry trade organizations led the development of industry-average EPDs early this decade.
   2. The concrete industry has published regionally-specific benchmarks to highlight regional variation within industry average data.
   3. The industry average data for wood products represents a national average of forest production.
   4. Both steel and concrete representative EPDs are based on a weighted average of companies that participated in the study and thus may not capture the range of all manufacturers.
   5. Concrete masonry and clay masonry both have less LCA/EPD information available.

Table 3.2. Summary of representative EPDs and PCRs for eligible structural materials in North America. X = no representative EPD was identified in this study.

Product type (numbered per Omniclass)	PCR	Representative EPD	Issued	Country
03 Concrete				
03-20 Concrete Reinforcing				
Reinforcement Bars	SCS 2015	CRSI Fabricated Rebar	2017	US
Fabric and Grid Reinforcing	none	none		
Stressed Tendon Reinforcing	none	none		
Fibrous/Composite Reinforcing	none	none		
03 31 Structural Concrete	CLF 2013*	NRMCA Ready Mix Concrete Regional Benchmarks	2016	US
03 41 Precast Structural Concrete	ASTM 2015	Structural Precast Concrete Industry Wide EPD	2014	US, CA
04 Masonry				
04 05 13 Masonry Mortaring	ASTM 2014	none		
04 05 16 Masonry Grouting	ASTM 2014	none		
04 21 Clay Unit Masonry	ASTM 2016	Under development		
04 22 Concrete Unit Masonry	ASTM 2015	CMU in Canada	2016	CA
05 Metals				
05 12 Structural Steel Framing				
Hot rolled steel section	SCS 2015	Fabricated Sections	2016	US
HSS section	SCS 2015	Fabricated Hollow Sections	2016	US
Steel plate	SCS 2015	Fabricated Steel Plate	2016	US
Open web steel joist	SCS 2015	Open Web Steel Joists	2015	NA
05 31 Steel Decking	SCS 2015	Steel Deck	2015	NA
05 41 Structural Metal Stud Framing	SCS 2015	Steel Studs and Track	2016	US, CA
05 42 Cold-Formed Metal Joists	SCS 2015	none (similar to metal stud)		
05 44 00 Cold-Formed Metal Trusses	SCS 2015	none (similar to metal stud)		
06 Wood, Plastics, and Composites				
06 11 Wood Framing	FP 2013*	North American Softwood	2013	US, CA
06 12 Structural Panels				
Structural Insulated Panel	FP 2013*	none		
Cross Laminated Timber	FP 2013*	none		
06 16 Sheathing				
Plywood	FP 2013*	North American Plywood	2013	US, CA
Oriented Strand Board	FP 2013*	North American OSB	2013	US, CA
06 17 Shop Fabricated Structural Wood				
Laminated Veneer Lumber	FP 2013*	North American LVL	2013	US, CA
Parallel Strand Lumber	FP 2013*	none		
Wood I-Joists	FP 2013*	North American Wood I Joists	2013	US, CA
Metal-Web Wood Joists	FP 2013*	none		
Shop Fabricated Wood Trusses	FP 2013*	none		
06 18 Glue Laminated Construction	FP 2013*	North American Glu-Lam	2013	US, CA

* PCR update compliant with ISO 21930:2017 expected in early 2019

Table 3.3 summarizes the number of companies for various products types in Washington State. Most notable is that very few local companies currently have product or facility specific EPDs. As will be noted in the material-specific assessments in later sections of the report, the environmental impact of local fabrication or assembly can often be quite small compared to the environmental impact of the upstream material manufacturing. Therefore, even though few local companies currently have facility-specific EPDs for their products, this part of the supply chain is not always a major environmental concern. Instead, it may be more important to focus on gathering accurate (or regionally-specific) data for the upstream parts of the supply chain.

To summarize Table 3.3:

- Only 10% of ready mixed concrete suppliers have facility- or mix-specific EPDs. These facilities are located in urban markets near Seattle.
- Almost 80% of the structural steel fabricators contributed to the industry average EPD yet none were identified as having facility-specific EPDs.
- 50% of the rebar fabricators contributed to the industry-average EPD, and 30% have developed facility-specific EPDs, highlighting the low-carbon rebar available locally.
- No facility-specific EPDs in Washington were located for structural wood or clay masonry.

The numbers in Table 3.3 likely underestimate the total number of companies in each category, since these results are based upon membership counts in industry trade organizations, and not all companies are members of these organizations. However, some trends are evident:

- Some industries (cement, steel mills, masonry kilns) have only a few businesses in Washington.
- Some industries (steel fabricators, ready mixed concrete, sawmills) have dozens of businesses in Washington.
- Some structural materials have no local manufacturing base (structural steel, pre-stressing tendons) in Washington State.

Table 3.3. Estimate of number of companies for product types and EPD count in Washington State.

Product type	Data source	Estimated total number of companies in WA and number of companies with manufacturer specific EPDs: Total	w/EPDs	Estimated number of WA companies that participated in the industry average 'representative' EPD
03 Concrete				
03-20 Concrete Reinforcing				
Rebar fabricators	CRSI[1]	18+	6	9
Rebar steel mills	Search[2]	1	1	N/A[7]
PT Tendon fabricators	Search[2]	4+	0	0
PT Tendon strands	Search[2]	0	N/A	N/A
03 31 Structural Concrete				
Ready mixed concrete suppliers	NRMCA/WACA[1]	50+	3	3
03 41 Precast structural concrete				
Precast	PCI/NPCA[1]	15+	N.I.	5
Upstream Materials (select)				
Cement	PCA[1]	2	0	1
Aggregate	WACA[1]	20+[6]	N.I.	N/A
04 Masonry				
Masonry subcontractors	MCAA[1]	13+	0	0
Clay unit masonry manufacturers	Search[2]	1	0	0
Concrete unit masonry manufactures	NWCMA[1]	6+	1	N/A
05 Metals				
Structural Steel Fabricators	AISC[3]	34	N.I.	27
05 12 Structural Steel Framing				
Hot rolled steel section	AISC[3]	0	N/A	N/A
HSS section	AISC[3]	0	N/A	N/A
Steel plate	AISC[3]	0	N/A	N/A
Open web steel joist	SJI[1]	0	N/A	N/A
05 31 Steel Decking	SDI[2]	0	N/A	N/A
05 41 Structural Metal Stud Framing	SFIA[3]	2+	N.I.	2
06 Wood, Plastics, and Composites				
Sawmills	DNR[4]	37	N.I.	N.I.
Engineered wood products	APA[5]	9	N.I.	N.I.

[1]Industry trade association member listings
[2]Web and professional network search followed by phone interviews
[3]Email correspondence with trade association
[4]Washington State Department of Natural Resources, "Washington Mill Survey 2016," 2017, https://www.dnr.wa.gov/publications/em_obe_2016_mill_survey_final.pdf?9s0o1
[5]APA – The Engineered Wood Association, "Manufacturer Directory," accessed December 24, 2018, https://www.apawood.org/manufacturer-directory?c=292
[6]The National Stone Sand and Gravel Association identifies 118 member locations in WA.
[7]There is not an industry average EPD for rebar from mill, only of fabricated rebar.
N.I. = Not identified during study period
N/A = Not applicable. Either no EPD's exist or no manufactures in that category

03 CONCRETE

This section presents an overview, key facts, LCA issues, status of PCR/EPDs, and innovations for concrete.

OVERVIEW

Structural concrete typically consists of both concrete and steel reinforcement. This section focuses on concrete only, as the embodied carbon impacts of steel reinforcement are better categorized with other metal products.

Concrete is a material created by mixing together cement (the binding agent), coarse aggregate (rocks). Fine aggregate (sand), water, and admixtures, which modify performance, constructability, finish and color. Supplementary cementitious materials (SCMs) can be made from waste products of other manufacturing processes to reduce the amount of cement required to achieve desired performance. A batch of concrete varies by its recipe or *mix design*. The amount of cement is a primary contributor to the structural performance of the concrete mix – more cement often correlates to higher strength and faster curing times. However, the embodied carbon of concrete is driven primarily by the amount of cement in the mix because cement production requires significant energy input and releases CO_2 as a part of the cement-making process. Table 3.4 describes the processes, sources of emissions, and strategies for reducing the emissions of concrete through the early stages of its life cycle.

Table 3.4. Concrete processes, sources of emissions, and strategies for reducing emissions by life cycle stage.

	A1: Manufacturing	A2: Transportation	A3: Fabrication
Description of processes	Production of material inputs (cement, aggregate, water, admixtures (typically chemicals) and SCMs. Structural precast concrete includes reinforcing steel.	Cement is sourced from around the world, while aggregate tends to be sourced regionally. In WA, aggregate is produced locally or barged down the Pacific Coast from British Columbia.	Concrete is mixed on site and in trucks. For precast concrete and fabrication, this module also includes fabricating rebar, building formwork, and curing concrete.
Sources of emissions	• Fossil fuel combustion for cement kiln • Chemical reaction of turning limestone into cement • Fossil fuels used in mining/processing • Fossil fuels used in chemical admixture production	• Combustion of fossil fuels	Facility operations, which include: • Electrical use • Combustion of fossil fuels
Strategies to reduce emissions	• Increase plant efficiency • Innovate processes • Change electricity source • Capture emissions • Integrate SCM materials into cement production • Use more recycled materials	• Prioritize rail and water transport • Switch to electric vehicles	• Reduce the amount of cement used • Use cement from efficient kilns • Increase energy efficiency of equipment and facility • Change electricity source

CONCRETE KEY FACTS

- Producing 1 kg of cement results in approximately 1 kg of CO_2e, half of which are from a chemical reaction when transforming limestone into cement.[12]
- Typical 4,000 psi concrete in the Pacific Northwest can have a carbon footprint varying between 366 and 582 kg CO_2e/m^3[3,13].
- Low-cement mixes tend to take longer to cure however full design strength is rarely needed as quickly as standard specifications require. Engineers can adjust these deadlines..
- High-strength aggregate can result in high-strength concrete with less cement.
- SCMs (fly ash or blast furnace slag) can increase concrete durability.
- Admixtures can help low-cement concretes meet placement and curing criteria.
- Facility-specific EPDs for more than 5,000 concrete mixes exist for approximately 17 companies in the US; three of these companies are in Washington.[14]

LCA ISSUES FOR CONCRETE

There is significant potential for reducing embodied carbon of concrete through optimization of concrete mixes. However, one of the most challenging aspects of concrete mix selection is connecting the actual performance needs of concrete to the mix design. Concrete mixes vary by strength (typically between 3,000 – 6,000 psi) and the strength is a critical aspect of the overall structural design. Additionally, the weather at the time of placement, the required finish quality, and construction schedule can impact which mixes will work and which will not. Setting limits to concrete embodied carbon without considering other performance criteria could result in significant construction challenges.

Ready-mixed concrete is an inherently local material because it cannot be transported far after mixing. This is because it begins to cure (harden) as soon as water is added to the cementitious materials. Additionally, aggregates (rocks and sand) are rarely transported long distances. Designing lower-carbon concrete can require more sophisticated concrete mix designs and additional materials which can require facilities to have additional equipment. Larger companies can more easily afford infrastructure for computer-controlled batching and on-staff engineering and testing teams. Smaller companies might have simple mixing facilities and commonly deliver a handful of standard mixes.

There are regionally-specific 'benchmarks' prepared by the National Ready Mixed Concrete Association (NRMCA). These benchmarks show significant regional variation. In this benchmark study, the Pacific Northwest Region includes Washington, Oregon, Idaho, and Montana. However, variation within this region is not known, and standard practice in Western Washington is not necessarily representative of the state as a whole.

As noted in Table 3.3, less than 10% of ready-mixed concrete producers in Washington State are equipped to deliver facility- or mix-specific EPDs at this time. All of these companies are in large urban

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[12] Portland Cement Association and ASTM International, "Portland Cements Environmental Product Declaration," 2016, https://www.astm.org/CERTIFICATION/DOCS/295.EPD_for_Portland_Cements_-_Industry_Wide_EPD.pdf.
[13] Athena Sustainable Materials Institute, "NRMCA Member National and Regional Life Cycle Assessment Benchmark (Industry Average) Report-Version 2.0 Prepared for: National Ready Mixed Concrete Association (NRMCA)," 2016, https://www.nrmca.org/sustainability/EPDProgram/Downloads/NRMCA_BenchmarkReportV2_20161006.pdf.
[14] NRMCA, "NRMCA | Sustainability," 2017, https://www.nrmca.org/sustainability/EPDProgram/Index.asp#VerifiedEPDs.

markets. Although setting embodied carbon performance targets for concrete might be possible in areas where the EPD market is established, data on production opportunities and manufacturer capabilities across the state are not currently available to assess the feasibility of performance targets.

PCR/EPD STATUS FOR CONCRETE AND CONCRETE PRODUCTS

Ready-mixed concrete

The concrete PCR is unique in that it provides detailed specifications for the upstream data to be used within EPDs. The second version of the concrete PCR (due in early 2019) will provide additional prescriptive requirements to enable greater comparability.

EPDs are fairly mature in the concrete industry and are supported by the NRMCA and industry tools. However, there are many concrete suppliers who have not produced EPDs, and thus educating and supporting concrete suppliers may be necessary to create EPDs across the state for both large and small companies. Creating a Washington-specific EPD calculator could enable suppliers to create EPDs with lower threshold of cost and effort.

Upstream materials

Given that the production of upstream materials is a significant contributor to the total footprint of concrete, improving the quality of the upstream data would improve the precision of concrete EPDs. Imported cement is sometimes used in this region (commonly from Asia). The second version of the concrete PCR is expected to address this issue, and not equate imported cement to default US production averages as it currently does. While the Portland Cement Association (PCA) has published an industry-average EPD for cement, facility-specific EPDs for cement would improve the precision of concrete EPDs.

The default EPD for aggregate has relatively high LCA impacts. Developing facility-specific EPDs for aggregates is likely to enable concrete suppliers to produce lower-carbon concrete EPDs.

Precast concrete

The National Precast Concrete Association (NPCA) has developed an industry-average EPD for precast concrete. This effort could be leveraged to facilitate precast plants to create manufacturer- or facility-specific EPDs. Note that EPDs of precast concrete report average results per pound of concrete, not for a specific application. Plants could obtain facility-specific EPDs that align with the industry-average EPD, or alternately establish a system to generate project specific EPDs that reflect the actual design delivered.

INNOVATIONS IN CONCRETE

The following are some strategies available now that can lead to lower-impact concrete. These all would require training of architects/engineers/contractors and suppliers to implement at scale.

- Eliminate the use of prescriptive concrete specifications, which put limits on items such as a minimum amount of cement or maximum water to cement ratio. Often these standard prescriptive specifications remain unchanged year after year in companies and government agencies. Instead, performance-based concrete specifications, which define performance attributes such as strength, durability, cure time, etc., should be used. See guidance from the American Concrete Institute (ACI).[15]

- Extend the curing time to longer than the historically specified 28 days for items such as slab-on-grade, foundations, and concrete shear walls if performance requirements permit. This could allow lower-cement concrete mixes to be used.

The following are carbon-related developments in concrete that have promise:

- The International Energy Agency (IEA) and the Cement Sustainability Initiative (CSI) have published a roadmap[16] which includes projections to achieve up to 24% CO_2 reductions by 2050. Key levers to carbon reduction include:
  - Improve energy efficiency
  - Switch to alternative fuels
  - Use innovative technologies, such as carbon capture
  - Develop alternative binders
- Innovative products that use CO_2 as a material resource include examples such as:
  - Utilizing CO_2 as an added ingredient to concrete reducing the amount of cement required (market-ready stage)[17]
  - 'Growing' aggregates via carbon capture mechanisms (prototype stage)[18]
  - Synthetic concrete aggregates using microbial calcium carbonate precipitation (research stage)[19]

[15] ACI, "329.1T-18: TechNote: Minimum Cementitious Materials Content in Specifications," 2018, https://www.concrete.org/store/.
[16] CSI & IEA, "Technolog Roadmap: Low-Carbon Transition in the Cement Industry," 2018, https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative/Resources/Technology-Roadmap-Low-Carbon-Transition-in-the-Cement-Industry.
[17] CarbonCure, "CarbonCure," accessed December 19, 2018, https://www.carboncure.com/.
[18] Blue Planet, "Blue Planet | Economically Sustainable Carbon Capture," accessed December 19, 2018, http://www.blueplanet-ltd.com/.
[19] Srubar Research Group, "Living Materials Laboratory | University of Colorado at Boulder," n.d., https://spot.colorado.edu/~wisr7047/.

04 MASONRY

This section presents an overview, key facts, LCA issues, status of PCR/EPDs, and innovations for masonry.

OVERVIEW

Structural masonry consists of multiple components: masonry units (either precast concrete blocks or fired clay bricks), mortar (a water/sand/cement paste used to bind the units together when stacking), grout (a water/sand/cement fluid enough to cast into openings running vertically through the blocks or bricks), and reinforcing steel to provide tension capacity. See Section 03 Concrete for information on concrete. The environmental impact of grout and mortar will also be similar to that of ready-mixed concrete, with the amount of cement influencing both the strength as well as embodied carbon of these products. Unique issues for grout and mortar are discussed in this section. The impacts of reinforcing steel are covered in Section 05 Metals.

Clay masonry units or bricks are unique building materials made of quarried clay that is mixed, formed, and fired. A higher heat of kiln firing tends to correlate with higher-strength bricks, increased fuel use, and thus higher emissions.[20] Table 3.5 describes the processes, sources of emissions, and strategies for reducing the emissions of clay masonry through the early stages of its life cycle.

Table 3.5. Clay masonry processes, sources of emissions, and strategies for reducing emissions.

	A1: Manufacturing	A2: Transportation	A3: Fabrication
Description of processes	Mining, crushing, screening and storage of raw materials (primarily clay and shale)	Often, the kiln is located close to the mine, minimizing quarry-to-kiln transportation impacts	Clay is mixed, formed into bricks, coated or glazed for finish, dried, fired, and cooled.
Sources of emissions	• Combustion of fossil fuel to power mining equipment	• Combustion of fossil fuels	• Facility operations • Combustion of fuels to heat kiln. Natural gas is a common fuel source.
Strategies to reduce emissions	• Increase equipment efficiencies	• Switch to electric vehicles • Reduce transport distances	• Increase kiln efficiency • Change fuel source • Formulate brick that needs less energy to make

Alternative materials and assemblies can provide structural load bearing capacity similar to masonry and concrete, such as: straw bale, rammed earth, hempcrete, rammed earth walls, and blocks.

[20] BIM, "9 TECHNICAL NOTES on Brick Construction Manufacturing of Brick," 2006, www.gobrick.com.

MASONRY KEY FACTS

The following clay masonry facts have been extracted from industry publications[21] and a published LCA for bricks:[22]

- Markets for masonry are usually local and regional due to its high material weight. Masonry plants are commonly located close to mines.
- Structural brick has a documented long lifespan that is not captured in typical cradle-to-gate LCAs. However, if comparing two different brick products, their lifespans should be comparable.
- The embodied carbon impact of brick products is influenced by the availability of local materials (such as regional clay sources), appropriate waste and recycled material inputs, and the availability of landfill gas or other alternative fuels. This in turn can influence opportunities for innovation by manufacturers.
- A high percentage of bricks are re-used at end of life.

LCA ISSUES FOR MASONRY

Concrete masonry units

The LCA issues for CMUs are the same as for precast concrete. See Section 03 Concrete**.**

Clay masonry/bricks

The published LCA for brick and mortar products evaluated Canadian brick manufacturing highlighted that the majority of the energy use occurs during the drying and kiln firing of brick, and that supply is very local. No further LCA studies on clay or brick in North America have been identified besides that study in 1998.

Grout/mortar

The embodied carbon impacts of grout and mortar depend on the mix design of these products. Masonry grout and mortar are typically mixed at the building construction site, combining sand, masonry cement, and water in set proportions to meet strength requirements. Most grout and mortar are mixed using proportioning methods. The amount of cement used and impact of the cement production will be the primary driver of LCA impacts.

PCR/EPD STATUS FOR CONCRETE MASONRY AND CLAY MASONRY

Concrete masonry units

An industry-wide EPD for CMU's exists for Canadian producers but not for US producers. Some manufacturer-specific EPDs for CMU exist, one CMU producer with EPDs for seven products has been identified in Washington State.

[21] BIM; BIA, "Sustainability and Brick: Technical Note 48," 2015, www.gobrick.com.
[22] George J Venta, "LIFE CYCLE ANALYSIS OF BRICK AND MORTAR PRODUCTS," 1998, https://calculatelca.com/wp-content/themes/athenasmisoftware/images/LCA Reports/Brick_And_Mortar_Products.pdf.

Clay masonry/bricks

The Brick Industry Association is developing an industry-wide EPD for clay masonry. No US manufacturer-specific brick EPDs were found during the course of this study.

Grout/mortar

An industry-average EPD for masonry cement exists. The amount of variation between manufacturers is not known. Custom grout mix designs are rare and thus the variation in impact of grout and mortar would require careful study and implementation. Incentivizing the use of low-carbon masonry cement would be possible if manufacturer-specific EPDs for masonry cement were available.

Alternative materials

There are few LCA studies and no known EPDs for alternative materials. These materials are often locally produced and do not have large trade organizations to support the development of industry-wide LCA data. Information on low-carbon material options has been published by Architecture 2030 in their Carbon Smart Materials Palette,[23] which includes a qualitative assessment of the benefits of alternate materials.

INNOVATIONS IN MASONRY

The following are strategies that can lead to lower-impact masonry:

- For concrete masonry units:
  - Similar to concrete, eliminate the use of prescriptive concrete specifications in favor of performance-based specifications (see Section 03 Concrete).
  - Use alternative cementitious materials and methods to create lower-carbon concrete mixes.
- Source clay masonry from a producer with a low-carbon energy source.
- Source masonry locally. Some architectural bricks are traded internationally for desired colors and finishes, which are highly dependent of the clay materials available at a mine.
- Utilize alternative low-impact materials with similar functions (however, different performance characteristics would need to be addressed), such as:
  - Unfired clay/soil units
  - Units made of carbon sequestering materials such as straw/hemp
- Use low-carbon masonry cements in making grout and mortar.

[23] Architecture 2030, "Carbon Smart Materials Palette – Actions for Reducing Embodied Carbon at Your Fingertips," 2018, https://materialspalette.org/.

05 STEEL

This section presents an overview, key facts, LCA issues, status of PCR/EPDs, and innovations for concrete.

OVERVIEW

Steel is the primary metal used in structural applications in Washington State. For this reason, this technical review addresses only the structural steel components defined in (both 03-20 Concrete Reinforcement and 05 Metals), and does not address other metals such as structural aluminum or steel cable structures. Aluminum is commonly used for window systems and rarely as a structural element in buildings. Steel cables are primarily used in specialty tension roof structures and long-span suspension bridges, both of which are not common in current practice.

Steel is produced using two primary manufacturing methods in North America: 1) from a majority of raw material inputs in a basic oxygen furnace (BOF), and 2) from a majority of recycled steel in an electric arc furnace (EAF). Other production methods such as direct reduced iron (DRI) are being used increasingly in the US and are more frequently in India, the Middle East, and the Commonwealth of Independent (CIS) States, Russia included. Steel shapes are typically purchased by fabricators either directly from a steel mill or from a 'service center,' which is a regional facility that stocks common shapes for fast delivery. The discussions in this section apply to steel sections, sheet products, and rebar.

Table 3.6 describes the processes, sources of emissions, and strategies for reducing the emissions of steel through the early stages of its life cycle.

Table 3.6. Steel processes, sources of emissions, and strategies for reducing emissions.

	A1: Steelmaking	A2: Transportation	A3: Fabrication/Manufacturing
Description of processes	Creation of steel and rolling into generic sections such as wide flange beam or sheet steel	Steel is typically transported by rail or truck domestically and via boat internationally.	Fabricators transform steel material from generic section (e.g. 30 feet of steel beam) to the configuration needed for a specific building. This is typically done near the building site.
Sources of emissions	**BOF** • Chemical reaction between coke (coal) and iron ore • Combustion of fossil fuels • Upstream material mining and processing **EAF** • Electricity • Fossil fuel as energy • Upstream material processing	Combustion of fossil fuels	Facility operations: • Electrical use • Combustion of fossil fuels Project-specific impacts for fabrication (that do not require a furnace), such as: • Cutting • Drilling • Forming • Welding
Strategies to reduce emissions	• New/retrofit plants to increase plant efficiency and implement process innovations. • Change electricity source • Capture emissions • Recover and re-use steel shapes	• Prioritize rail and water transport • Use electric vehicles • Source locally	• Reduce intensity of fabrication effort (reduce welding and cutting) • Increase energy efficiency of equipment and facility • Change electricity source • Recover and re-use steel shapes

STEEL KEY FACTS

The following facts were extracted from a variety of publicly-available EPDs for steel unless otherwise noted:

- The embodied carbon of North American steel products for life cycle modules A1-A3 ranges between 0.6 and 2.4 kg CO_2e/kg steel. Steel sections produced in Chinese BOF mills is estimated at 2.9 kg CO_2e/kg steel.[24]
- The majority (over 90%) of emissions due to steel products occur during the steelmaking process (life cycle module A1).
- A smaller portion (less than 10%) of the GWP impact is attributed to transportation and fabrication (modules A2 and A3)
- EPDs of four rebar fabricators in Washington and Oregon report embodied carbon values ranging between 0.50 and 0.58 kg CO_2e/kg steel.

The following facts are from *Steel in Figures 2018* [25] unless otherwise noted (these relate to the global steel market, not just structural sections):

- Approximately 80% of US steel demand is met by US suppliers.
- The US is the largest global importer of steel, importing 25.2 million metric tons, (Mt).
- 68% of the 81.6 Mt steel produced in the US is via EAF.
- 83% of the 1,162 Mt of steel produced in Asia is via BOF.

Additionally, from interviews conducted with industry representatives during the course of this study, the following pieces of information are also important to note:

- As EAF's are powered by electricity, the emissions depend on the electrical grid carbon intensity.
- Some shapes (e.g. plates, pipes and large wide flanges) are not readily available from US EAF mills and are commonly imported or produced in US BOF mills.
- US sheet steel used in metal decks and studs are currently produced in a mix of EAF and BOF mills.
- US rebar is typically produced in EAF mills.
- The project team did not locate any EPDs or LCA data for pre/post-tensioned tendons. Some tendons are drawn from steel bar produced in US EAFs, while others are imported from unknown mill types.

LCA ISSUES FOR STEEL

Recycling

As global demand for steel exceeds the amount of steel available for recycling, a significant amount of 'virgin' steel must be produced. However, in the US, nearly 100% of US structural steel is recycled at end-of-life. The use of recycled steel as a material input can be seen as avoiding the production of virgin

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[24] thinkstep, "China, Global Warming and Hot-Rolled Structural Steel Sections" (American Institute of Steel Construction, 2018), https://www.aisc.org/globalassets/aisc/publications/white-papers/global-warming-potential-of-chinese-and-domestic-hot-rolled-structural-steel.pdf.

[25] woldsteel, "World Steel in Figures 2018," 2018, https://www.worldsteel.org/en/dam/jcr:f9359dff-9546-4d6b-bed0-996201185b12/World+Steel+in+Figures+2018.pdf.

steel, referred to as an 'avoided burden' in LCA. However, not all LCAs report the impacts/benefits of steel recycling in the same manner. Some methods report this benefit as a negative (or reduced) impact or as credits for future recycling.

Allocation: Slag

During the purification process of steel production, impurities, known as slag, are removed from molten steel. Slag can have value; it can be ground and used as a cementitious material in concrete. Methods on how to allocate the impacts or benefits of slag vary. Some LCA studies treat this slag as a waste product (per the concrete PCR) while others (such as the aggregate PCR) treat it as a co-product. As a co-product, slag would take a share of the emissions of steel production, proportioning them by either mass or economic value, resulting in a reduced footprint for steel and an increased footprint for slag.

Grades of steel

LCA data for structural steel products do not commonly distinguish between different grades of steel. While steel is produced in different grades (denoting different strength and performance requirements), LCA results are not typically distinguished by grade. The differences in production relate to slight variations in chemical composition, and there is no known significant difference in energy requirements for these different grades. For mills that produce multiple grades of steel, plants do not typically track energy consumption separately by grade. Thus given current data using the same LCA results for different grades of steel appears to be appropriate.

PCR/EPD STATUS FOR STEEL

The steel PCR was published in 2015 by SGS Global Services.[26] It will not likely be updated to ISO 21930:2017 until 2020. This PCR covers the majority of steel products listed in Table 3.2. It excludes steel reinforcing bars with coatings, stainless steel reinforcing bars, and pre/post-tensioning strands.

Worldsteel collects LCI data for steel production globally. It also collects data from North American producers, and this data is used to estimate the production impacts (module A1) for North American industry average steel EPDs. Although not all steel manufacturers participated in the data collection to create this dataset, it is the highest quality LCA data currently available. The American Iron and Steel Institute (AISC) is in the process of updating the A1 steelmaking data, and new data should be available in 2019. Groups of fabricators have collaborated to produce average EPDs to integrate the average of upstream impacts (A1), transportation impacts (A2), and fabrication (A3) impacts. Four rebar producers in Washington have produced product-specific EPDs for their rebar production, including the mill-specific (A3) impacts. Notably, these EPDs report some of the lowest embodied carbon impacts reported for steel globally.

No EPDs currently exist for imported steel. Most whole building LCA tools use North American average data for steel production. Current LCA methods in practice do not effectively distinguish between the different production methods available for similar products. Unless steel EPDs are created using mill-specific data, or unless steel procurement is verified to match the local steel supply chain used in

[26] SCS Global Services, "North American Product Category Rule for Designated Steel Construction Products," 2015, https://www.scsglobalservices.com/files/standards/scs_pcr_steel-products_050515_final.pdf.

creating the EPD, using EPDs to distinguish between different fabricated steel products will not provide meaningful distinctions between products.

INNOVATIONS IN STEEL

The following are some strategies available now that can lead to lower-impact steel (these would require some deviation from the current practice of specifying and procuring steel):

- Procure steel from one of the mills included in the EPDs for steel products.
- Procure lower-impact steel with high-recycled content from regions with low-carbon electrical grids.
- Recover used steel and develop more robust and economical system for re-grading and re-warranting recovered structural steel.
- Encourage LCAs and EPDs for commonly used North American steel products that do not yet have them such as epoxy-coated rebar, pre/post-tensioning strands and stainless steel reinforcing bars.

The following are developing innovations in steel that have potential for lowering embodied carbon. These methods will require significant additional research and development investments:

- Process innovations for primary steel production as outlined in a steel industry fact sheet[27] include:
    - Redesigning the production process to integrate carbon capture and storage
    - Using hydrogen to replace carbon in chemical reactions during steelmaking
    - Using sustainably produced biomass as energy (or other low carbon energy sources)
    - Performing carbon capture and storage at the facility scale
- A Carbon Trust[28] report includes a list of actions that have the potential to reduce emissions per kg of steel by around 70 – 90% over the next 20 – 30 years.
- US industry and government bodies have invested in 'transformational technologies' such as Novel Flash Ironmaking.[29]

[27] worldsteel, "Fact Sheet: Climate Change Mitigation by Technology, Innovation and Best Practices," 2018, https://www.worldsteel.org/en/dam/jcr:0191b72f-987c-4057-a104-6c06af8fbc2b/fact_technology%2520transfer_2018.pdf.
[28] Carbon Trust, "International Carbon Flows Steel," 2011, https://www.carbontrust.com/media/38362/ctc791-international-carbon-flows-steel.pdf.
[29] DOE, "A Novel Flash Ironmaking Process | Department of Energy," 2016, https://www.energy.gov/eere/amo/downloads/novel-flash-ironmaking-process.

06 WOOD

This section presents an overview, key facts, LCA issues, status of PCR/EPDs, and innovations for wood.

OVERVIEW

Wood is used in building structures in many applications, such as dimensioned lumber (e.g. 2x4 stud wall), sheathing (e.g. plywood), shop-fabricated structural wood (e.g. wood I-Joists, etc.), and glued laminated (glulam) construction (beams, columns and cross-laminated timber (CLT)). Softwood lumber serves as both a finished product and a material input into fabricated elements known as *engineered wood products*. Table 3.7 presents the processes, sources of emissions, and strategies for reducing the emissions of wood products through the early stages of the life cycle.

Table 3.7. Wood processes, sources of emissions, and strategies for reducing emissions.

		A1: Manufacturing	A2: Transportation	A3: Fabrication
Description of processes	Softwood lumber	• Land preparation • Seedling preparation and planting activities • Thinning and harvest. Practices vary based on forest type and geography • Sawmilling activities	Via truck to mill	• Milling lumber to various sizes • Kiln-drying lumber (burning biomass and/or natural gas)
	Engineered wood	• Softwood lumber production (see above) • Adhesive manufacturing • Use of conveyor belts, fork lifts etc.	Raw materials (sawn lumber) is typically transported via truck from sawmills to manufacturing facility.	Wood members are shaped and fastened together using adhesives, heat and/or pressure.
Sources of emissions		• Fossil fuel as energy to power vehicles and other equipment • Biomass (wood chips etc.) as energy • Adhesive production • Production of fertilizers and other industry products, etc. • Waste disposal	Combustion of fossil fuels	• Burning wood chips • Burning fossil fuels • Electricity use.
Strategies to reduce emissions		• Increase plant efficiency • Better use of wood waste • Better wood recovery rates • Efficient/optimized resin use • Use of energy efficient drying and curing techniques.	• Prioritize rail and water transport • Streamline handling • Use electric vehicles	• Increase efficiency of equipment and facility • Capture emissions • Change electricity source • Efficient resource use
Pathway of biogenic carbon		• Carbon is converted to biomass via photosynthesis and stored in wood products • CO_2 is emitted (not reported in GWP) when biomass is combusted • Carbon remains in forest until wood residuals are burned, decomposed, or converted to soil carbon.	None	• Carbon remains in wood products, but is often emitted at end-of-life. • Carbon is emitted (but not reported in GWP) when biomass combusted.

WOOD KEY FACTS

Forest products and forests are part of a complex system that is difficult to model comprehensively using conventional LCA. Two open-access articles capture the complexities quite well addressing forest management and climate[30] and evaluating "tradeoffs in timber, carbon, and cash flow."[31] The following are some key facts about Washington structural wood and forests:

- Hardwood is not commonly used as a structural material.
- The most common species of structural woods grown in Washington State are Douglas Fir, Hemlock, and a Spruce-Pine-Fir (SPF) mix.
- Different woods have different performance characteristics and grow in different climates.
- Pacific Northwest structural lumber is typically higher in strength than the national average.
- Forestry practices vary significantly based on region, species, and forest type. In Washington State, there are two general regions separated by the Cascade Mountains: the Western forests, which tend to be wetter, and the Eastern forests, which are drier.
- The majority of wood that ends up in forest products produced in Washington is from private and state forests in Western Washington.
- Of Washington State's 43 million acres of land, approximately 22 million acres are forested.[32]

There are notable, publicly available LCA reports for wood products both as research[33] and as EPDs.[34] Some key facts from these publications include:

- At a national level, data shows an overall increase in the carbon stored in forests each year.[35]
- Current LCA practice treats all forest management practices as the same, using national data for forest management and harvest.
- Emissions from forestry practices account for less than 20% of typical wood product carbon footprint. Note that this does not model the carbon balance of the forest, just the emissions from harvesting wood.
- Wood production is often powered by a combination of burning wood waste (biomass) and fossil fuels with the majority of emissions related to drying lumber.
- Increasing the use of biomass as fuel can reduce product GHG emissions, since biomass emissions can be treated as carbon neutral. However, this policy only has grounds for as long as forest carbon remains neutral or is increasing in the region where the wood products are coming from.

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[30] Stephen Fain et al., "Managing Moist Forests of the Pacific Northwest United States for Climate Positive Outcomes," *Forests* 9, no. 10 (October 9, 2018): 618, https://doi.org/10.3390/f9100618.
[31] David Diaz et al., "Tradeoffs in Timber, Carbon, and Cash Flow under Alternative Management Systems for Douglas-Fir in the Pacific Northwest," *Forests* 9, no. 8 (July 25, 2018): 447, https://doi.org/10.3390/f9080447.
[32] Washington Forest Protection Association, "Washington Forests," 2006, http://www.wfpa.org/our-forest-today/washington-forests/.
[33] CORRIM, "LCA's on Wood Products," accessed December 18, 2018, https://corrim.org/lcas-on-wood-products/.
[34] AWC, "Environmental Product Declarations (EPDs) for Wood," accessed December 18, 2018, https://awc.org/sustainability/epd.
[35] EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015," 2017.

LCA ISSUES FOR WOOD

Standard wood product LCAs track the impacts of managing forests and harvesting timber, and allocate these forest management emissions to wood products. LCA is well-suited to track the industrial emissions of harvest and manufacturing, but it is not as well-suited to track the impacts and benefits to the forest itself. The assumptions made in conducting forest-level assessments can have a significant impact on the results.[36] Forestry systems are frequently evaluated in LCA assuming *carbon neutrality*, which assumes that the release of carbon dioxide due to burning biomass (e.g. wood chips) for energy production (biogenic CO_2) is balanced by the carbon dioxide that is sequestered by growing the same amount of biomass. This carbon neutrality is not necessarily true in a global context. LCA does not commonly capture the carbon impact of treating forests for forest fire mitigation or retaining additional trees for stream protection or habitat preservation.

Production of wood products also generates co-products or waste (wood chips etc.). Depending on the LCA methods chosen, the impacts of producing a wood product can be allocated (by mass or economic value) to these co-products. Mass allocation is less conservative, in a way, resulting in a lower estimated impact of wood products. For example, this method reduces the product emissions by around 10% for a glue laminated beam.[37]

Wood products store the carbon that was removed from the atmosphere and converted into tree mass during photosynthesis, a process known as *carbon sequestration*. LCA often reports this quantity of carbon as a net negative impact or a “carbon credit.” However, carbon removed from forest takes years to re-grow and at the end of life is often emitted in landfills or through combustion. The fact that the value of this credit varies depending on the temporal frame of reference is not commonly addressed.

Although the management of the forest has an impact on total carbon, there is no agreement on how to integrate these impacts into interpretation of LCA results. ISO does recognize that forest certification such as the Forest Stewardship Council (FSC) or Sustainable Forest Initiative (SFI) can be a measure of forest sustainability.

PCR/EPD STATUS FOR WOOD

The American Wood Council has published industry average EPDs for seven different structural wood products: softwood lumber, softwood plywood, oriented strand board, glued laminated timbers, laminated veneer lumber, wood I-joist and laminated strand lumber. This PCR conforms to ISO 21930:2017. The third version of the North American PCR for wood products is open for public comment as of the time of this publication and an update should be published in early 2019.

Current wood EPDs report industry average data for both the softwood lumber production and the manufacturing of engineered wood products. Mill surveys were collected in order to create these average datasets. Developing manufacturer-specific EPDs separately for mills (e.g. softwood lumber

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[36] Stephen Fain et al., “Managing Moist Forests of the Pacific Northwest United States for Climate Positive Outcomes,” *Forests* 9, no. 10 (October 2018): 618, https://doi.org/10.3390/f9100618.
[37] Tait Bowers et al., “Cradle-to-Gate Life-Cycle Impact Analysis of Glued-Laminated (Glulam) Timber: Environmental Impacts from Glulam Produced in the US Pacific Northwest and Southeast*,” *Forest Products Journal* 67, no. 5–6 (September 2017): 368–80, https://doi.org/10.13073/FPJ-D-17-00008.

production) and engineered wood products (e.g. glue laminated beam production) would enable differentiation between similar wood products.

As highlighted in the development of the wood PCR: "EPDs do not address different forest management activities that influence wildlife habitat, endangered species, and soil and water quality, these potential impacts may be addressed thorough other mechanisms such as regulatory frameworks and/or forest certification systems which, combined with EPD results will give a more complete picture of environmental and social performance of wood products."[38]

INNOVATIONS IN WOOD

The following are some strategies available now that can lead to lower-impact wood products:

- Purchase wood products from efficient manufacturers using low-carbon or carbon-neutral fuels.
- Purchase wood products from local suppliers, thus reducing the transportation impacts.
- Recognize specific forest practices (e.g. by jurisdiction based on forestry regulations, by certifications, or from DNR fire-thinned forests) as 'carbon smart' to differentiate between products.

The following are developing innovations in wood that have potential. These methods will require research and development investments to implement effectively:

- Move toward longer rotation forestry (50–75 years) in the moist forest region based on regionally specific analysis rather than the current business as usual of 38-44 years[39].
- Establish methods to differentiate forest management and product pathways that increase the total carbon in forests and in long-life wood products and represent these differences within wood product LCAs.

[38] ULe, "Part B: Structural and Architectural Wood Products EPD Requirements," 2018, www.ul.com/businesses/environment.
[39] David Diaz et al., "Tradeoffs in Timber, Carbon, and Cash Flow under Alternative Management Systems for Douglas-Fir in the Pacific Northwest," *Forests* 9, no. 8 (July 25, 2018): 447, https://doi.org/10.3390/f9080447.

3.3 TECHNICAL SUPPORT OF EPD PRODUCTION

EPDs provide the essential information needed to comply with any Buy Clean regulation, but EPDs are not yet commonplace in the building industry. Most product manufacturers will have to create EPDs if they want their products to be used on Buy Clean projects.

In order to create an EPD, a supplier will usually commission a consultant to perform LCA calculations. A consultant with expert knowledge can ensure that the calculations and supporting data comply with ISO 21930. However, the creation of an EPD can be simplified with the creation and use of an LCA or EPD calculator that standardizes the common inputs (e.g. quantity of material, energy source type and use etc.). LCA standards permit the use of self-declared EPDs. A Washington Buy Clean policy could recognize self-declared EPDs produced using approved EPD calculators and documentation, saving time and money for product manufacturers. Furthermore, if these calculators are configured to assume conservative estimates of production variation, suppliers could still be motivated to commission manufacturer- or facility-specific EPDs in order to cast their products in a "better" light. Section 3.4 recommends development of Washington State-specific LCA studies for benchmarking purposes. These studies would be useful to inform EPD tool development. As mentioned in **Chapter 2: Policy Review**, some governments (e.g. Oregon and France) have provided technical support to help facilitate broader adoption of EPDs in their jurisdiction.

The following are suggestions that the State could adopt to facilitate the creation of EPDs for Washington businesses, and could help the industry adopt better-aligned LCA data.

ACTIONS TO IMPROVE EPDs

In order to improve the quality, availability, usability, and comparability of EPDs in general, the following technical issues should be addressed:

1. **Quality: Align LCI databases**. Life cycle inventory (LCI) databases provide the background data (e.g. emissions for power generation or truck transport) to generate the data used in an EPD. The US LCI database is not adequately supported. Two initiatives are underway that need additional support: a developing Canadian initiative to create a LCI database (see **Appendix C.2**) and an effort create a North American LCI database (see **Appendix C.3**). Ideally these two initiatives would be integrated for efficiency and alignment.
2. **Availability: Incentivize EPD production.** Providing technical and financial support for Washington structural material suppliers will help local manufacturers produce more EPDs. LCA consultants have developed customized EPD tools for different industries that could be customized for Washington producers. Both Oregon and California have provided education, technical, and financial incentives to help producers develop EPDs.
3. **Usability: Collect and compare EPDs.** As there are multiple EPD program operators hosting EPDs in different places, it can be difficult for consumers to find EPDs. Additionally, EPDs are complex and non-uniform documents. A searchable EPD database and material quantity reporting tool could help facilitate use of EPDs in design and procurement.
4. **Comparability: Develop benchmarking methodology**. As summarized below, different materials have different opportunities and challenges for embodied carbon reduction. Given that the average impact of current practice is not yet known, the project team recommends

developing data-driven benchmarking methodology for each material category, allowing for the incorporation stakeholder input and continuous improvement over time.

The following are actions to improve the quality of EPDs specific to each structural material category.

Concrete/CMU

Given that over 90% of the impacts of concrete can be attributed to the upstream material production, developing a Washington-specific concrete EPD calculator would be beneficial. This simplified EPD calculator could be customized to address regional variability in the supply chain for upstream materials. Specifically, this calculator could:

- Utilize conservative default values for mix design inputs. This would allow concrete suppliers to easily generate self-declared or third-party-verified EPDs from standard mix design specifications, which are included with all structural concrete specifications.
- Allow manufacturers who wish to capitalize on their own manufacturing efficiencies to produce a plant-specific EPD.
- Recognize known variability in the cement supply chain, as specified in the upcoming version of the concrete PCR (version 2). This can be done one of two ways: 1) cements that are not captured in US or Canadian industry-wide EPDs should produce facility-specific EPDs, or 2) conservative default values could be applied to all cements that do not report facility-specific EPDs. Given that the two Washington cement producers have not published facility-specific EPDs, the impact of this policy option on local companies is unknown.

Masonry

For concrete masonry units, see “Concrete/CMU EPDs” above. For clay unit masonry, given that there is only one structural clay masonry producer in Washington, developing an EPD calculator would not justified however support for EPD creation could be beneficial. Masonry grout and mortar could be integrated into a concrete EPD calculator.

Steel

Given that over 90% of the impacts in steel products can be attributed to steel production, refining Washington steelmaking data for steel used in Washington would be the most logical point of focus. The remaining impacts due to fabrication could be assumed using conservative estimates. Specifically, Buy Clean policy could:

- Specify that the facility of interest for steel products is the steelmaking facility (not the fabrication facility). Impacts for steelmaking could be obtained by one of several methods:
    - Obtain an EPD from the steelmaking facility or steel mill from which the steel product was sourced (The one steel mill in WA State has produced a facility specific EPD).
    - Require that a steel fabricator-specific EPD includes supply chain-specific estimates of the steelmaking impacts (as is currently done by multiple rebar fabricators for their facility-specific EPDs).
    - Create an EPD based on supply chain of a service center. Service centers are the primary distributors of steel for small to medium projects. The variability in service center supply chains has not been evaluated.

  - Assume conservative (high) default estimates of steelmaking impacts in order to incentivize the creation of facility-specific steelmaking EPDs.
- Develop a simple EPD calculator to estimate the fabrication impacts of different product types. Ideally, this would draw upon data that has already been collected for industry trade organizations. The data could be used to establish a conservative estimate of the embodied carbon impacts of current practice (e.g. greater than 80% of current producers).
- Allow manufacturers wishing to recognize their own manufacturing efficiencies to commission a facility-specific EPD.

Wood

The carbon impacts of forest products arise in three distinct phases of the wood supply chain: forest management, harvesting, and wood product production. To better capture the embodied carbon impacts of wood products, Buy Clean policy could:

- Provide standardized calculation methods to compute sawmill-specific EPDs. This would enable engineered wood product manufacturers to create supply-chain specific EPDs of their products.
- Create an EPD calculator for Washington State engineered lumber products, which could then be used to develop facility-specific EPDs.
- Establish methods to recognize 'carbon smart' forestry products in EPDs.

State support for these initiatives would help advance technically accurate Buy Clean practices

3.4 ESTABLISHING EMBODIED CARBON PERFORMANCE TARGETS

In order to reduce embodied carbon in procurement decisions, meaningful performance targets should be set. These performance targets would ideally be established based on benchmarks, estimates of current practice, and would vary depending on the material category. Considerations for establishing performance targets are numbered 1-3 as follows:

1. **Commission material-specific benchmark studies.** Developing supply chain-specific studies that include the evaluation of variability for materials used in Washington State would provide useful data to help establish reasonable benchmark values. National average data would not necessarily reflect the supply chain of Washington suppliers. Additionally, currently available industry data presents averages without information on the statistical distribution of the data. As noted in item 3 below, industry benchmarks may not be the most appropriate performance target. Material-specific considerations for benchmarking studies are as follows:
    - **A concrete/CMU benchmarking study** that divides the state into 6-9 regions, similar to the NRMCA Benchmark LCA report,[40] would enable better understanding of the current state of practice. This data could also support the development of an EPD calculator.
    - **A clay masonry benchmarking study** would not be meaningful nor economical given the goals of this Buy Clean study since there is only one structural clay masonry producer in Washington State. However, a study into clay masonry benchmarking could be valuable for non-structural (architectural) applications but beyond the scope of this study.

[40] Athena Sustainable Materials Institute, "NRMCA Member National and Regional Life Cycle Assessment Benchmark (Industry Average) Report-Version 2.0 Prepared for: National Ready Mixed Concrete Association (NRMCA)."

   - **A steel benchmarking study** specific to Washington would add value. Many steel fabricators participated in the studies for the industry average/'representative' EPDs. The variation in embodied carbon would depend on different supply chain options for each of the different structural steel products.
   - **A wood products benchmarking study**: The North American wood industry has supported significant surveys of production methods across the state and region, but it currently reports data as a national average and does not report variability. A Washington-specific study could be used to create regionally-specific LCA reports that address the varying effects of forest management, harvest, and production processes in Washington State. It might be appropriate to divide forests into different zones and could help inform simplified methods to recognize forest management in EPDs.
2. **Normalize material impacts to compare to targets.** Setting fixed performance targets for generic material categories (e.g. "all steel shall be less than *X* $kgCO_2e$/kg steel") risks limiting design and construction teams from meeting needed performance requirements at specific applications. Using weighted averages over a full building would allow flexibility to address design and construction issues. Additionally, tracking material impacts per unit area of construction could provide useful data. See discussion in **Chapter 5** and **Appendix C**.
3. **Set achievable performance targets and establish a roadmap for improvement:** Setting a target at industry average could discourage disclosure and result in cost increases if a limited number of suppliers meet the target. Rather, setting a target that is achievable today (e.g. by 80% of market) would likely help incentivize disclosure. Developing a timeline to reduce targets could then be developed tied to data-driven opportunity roadmaps specific to each industry.

3.5 DISCUSSION

It is essential to emphasize that the assumptions for this Buy Clean study is founded on procurement decisions to compare between materials of the nearly same performance characteristics. It is not appropriate to compare different material EPDs without integrating into a full LCA. Examples of issues that are not addressed by this study and that should be addressed at the whole building scale are:

- Impacts on operating energy (thermal mass, insulation).
- Impacts on building lifespan (seismic performance, durability)
- Scenarios for material re-use (circular economy)

When designing an effective Buy Clean policy aiming to reduce the embodied carbon of building materials, the following key issues should be considered:

- Different structural materials have different supply chain structures, different technical issues, different embodied carbon opportunities and operate at different scales. No 'one size fits all' policy will be equitable for all materials.
- Efficiencies of scale show up in both cost and carbon impact. Small and developing enterprises may inherently be less energy efficient per unit of product resulting in higher embodied carbon.
- Some products/processes are electricity dependent. Others depend on on-site combustion of fossil fuels. Some processes emit CO_2 during chemical reactions that take place during manufacturing. Decarbonizing the electrical grid is not sufficient to drive towards zero carbon manufacturing in Washington State.