The High Greenhouse Gas Price Tag on Residential Building Materials: True Life Cycle Costs and the Opportunity to Reduce Them Through Design Decisions

Efficiency Vermont R&D Project: Greenhouse Gas Reduction

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Introduction

Construction material choices significantly affect the amount of embodied carbon—the full life cycle "cost" of carbon involved in building construction—as measured by the global warming potential (GWP) of the greenhouse gases (GHGs) associated with their manufacture and use.[1] How best to source and use the materials, and measure their effects, is still not well understood in the marketplace. Customers and contractors typically base decisions related to home insulation materials on cost-effectiveness, durability, regional availability of materials, and relevant building science, not on the materials' attendant GWP impacts.

In 2020, a research and development project quantified the GWP impacts of using low-GWP alternatives to common building insulation materials and applied the results of the analysis to actual projects slated for construction. The study analyzed projects in residential new construction, and the results were relevant to existing homes and commercial construction. Building on next steps identified in the 2020 research, new project work focused on insulation materials continued into 2021. This report summarizes the 2020–2021 effort.

By calendar year, project aims were:

- 2020
  - Quantify GWP in terms of CO_2e, or carbon dioxide equivalent, for insulation materials, and identify and characterize high-priority substitutions to reduce carbon impacts.
  - From an efficiency program point of view, determine the amount of an incentive, based on cost per ton of CO_2e, necessary to motivate changes to current insulation practices through a pilot program with three to five residential new construction projects.
  - Obtain qualitative feedback from building professionals on the logistics and ease of material substitutions.
  - Explore non-GWP co-benefits, such as potential health impacts on installers and residents.
- 2021
  - Publicly share information about this work, including information on the co-benefits of potential positive health impacts from these substituted materials.
  - Interview 2020 pilot program participants after project completion, gaining feedback on the logistics and ease of material substitutions, the cost impact, and whether they plan to repeat the substitutions in future projects.
  - Expand research to include new products and regulations.

[1] GWP is the measure of GHG in carbon dioxide equivalent (CO_2e).

Quantifying GHG Impacts

BACKGROUND

Discussion of reducing the GHG impacts of building construction tends to revolve around materials. One such publication has offered a carbon metric but notes that there is no broadly accepted mechanism for measuring building carbon emissions.[2] Analysis tools are available, but design professionals or contractors may be disinclined to use them because the tools are either subscription-based or relatively complex to navigate.[3]

> **Life Cycle Assessment**
>
> An evaluation of environmental impacts associated with all stages of a product's life, from extraction of materials to transport, manufacture, use, and eventual disposal.

To fill this gap, Efficiency Vermont compiled common questions about available information that can be applied to a deeper analysis of real-world factors for an "accepted mechanism" for measuring embodied carbon:

- For new or existing buildings, what metrics quantify embodied energy or carbon content of building materials?
- Is a whole building life cycle assessment needed?
- For a project whose builder, architect, or owner wants to achieve minimum GHG impact, and not have to track GWP closely, what is the best way to estimate or specify a goal?

LIFE CYCLE ASSESSMENTS

Life cycle assessments (LCAs) contain characterizations of lifetime stages and associated impacts (see Figure 1). This information is broken into four stages, each with one to several modules.

In LCAs, data for insulation materials are most consistently available for the product stage (modules A1–A3). This stage is also known as "cradle to gate"—referring to the product cycle from extraction of materials from the earth to the point at which the completed product is ready to leave the factory.

Other terms used in LCAs are *cradle to site* (modules A1–A5) and *cradle to grave* (modules A1–C4).

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[2] Edelson, Jim. "Efficiency and Carbon Reduction Goals Converge at the Built Environment." New Buildings Institute. 2019. https://newbuildings.org/efficiency-and-carbon-reduction-goals-converge-at-the-built-environment/.
[3] Examples include Athena Impact Estimator for Buildings, Embodied Carbon in Construction Calculator (EC3), One Click LCA, and Tally.

Module	A1-A3			A4-A5		B1-B7							C1-C4				D
Life cycle stages	Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundary stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction-installation proces	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse, recovery, and recycling potential
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Figure 1. Life cycle stages as defined in the European standard EN 15978[4]

ENVIRONMENTAL PRODUCT DECLARATIONS

Environmental Product Declarations (EPDs) detail the LCA and information relevant to a product's GWP, ozone depletion potential, water use, and other environmental impact categories. EPDs are valid for five years. The way they quantify environmental impact information is designed to allow relatively straightforward comparisons among products.

ISO 21930 is the North American standard for building construction-related EPDs, and EN 15804 is the European standard. Both generally adhere to ISO 14025, which establishes the rules (procedures, format) for developing an EPD.[5] EPDs are still relatively new, however, and can vary in presentation and content. Unfortunately, different reporting formats and functional units (the quantity-of-product evaluated) can make true product comparisons challenging.

PRODUCT CLASSES INVESTIGATED

Residential New Construction was the primary market for which Efficiency Vermont chose to investigate certain product classes. This study considered products common in the projects' building assemblies:

- Sub-slab
- Foundation / frost wall, interior
- Foundation / frost wall, exterior
- Above-grade wall, cavity
- Above-grade wall, continuous
- Joists
- Flat attic
- Sloped ceiling, cavity
- Sloped ceiling, continuous

[4] Trafik- og Byggestyrelsen (Danish Transport and Construction Agency). "Introduction to LCA of Buildings." 2016. https://www.trafikstyrelsen.dk/en/-/media/TBST-EN/Byggeri/Introduction-to-LCA-of-Buildings.pdf.
[5] "Environmental Product Declarations: Standards & Process" provides a concise summary. ArchEcology. 2017. http://www.archecology.com/2017/04/03/environmental-product-declarations-standards-process/.

The study then investigated the resulting insulation classes common to the above assemblies:

- Cellular glass, aggregate
- Cellulose: blown / loose fill and dense pack
- Expanded polystyrene (EPS): Types I, II, VIII, and IX
- Fiberglass: batt, blown / loose fill, blown / spray, and board
- HempCrete, block
- Mineral wool: batt, blown, and board
- Phenolic foam, board
- Polyisocyanurate, board
- Spray polyurethane foam (SPF): 2K-LP, closed cell, open cell, and roofing; with blowing agents hydrofluorocarbon (HFC), hydrofluoroolefin (HFO), and water
- Straw, panel
- Wood fiber, batt and board
- Extruded polystyrene (XPS): 15, 25, 40, 60, and 100 psi

Regulations that became effective on January 1, 2021, which are discussed below, spurred availability of new XPS products in 2021. These used HFO-HFC blends as blowing agents in place of HFCs. Thus two classes of XPS were evaluated; HFO-HFC was a 2021 addition to this work.

COMPILING THE DATABASE

Efficiency Vermont compiled a database of EPDs to assess GHG impacts, as a starting point in creating a carbon calculator tool. Although the Embodied Carbon in Construction Calculator [EC3] is already on the market as an open-source tool, this study found that it lacked a convenient method for comparing all the materials investigated here in equivalent terms.[6] Builders for Climate Action has a database / tool similar to the one Efficiency Vermont created, but it is not yet freely available to the public.[7]

For each insulation class, this research study analyzed the EPDs. Where possible, researchers sought three or more EPDs for a product class, for example, XPS foam board, and averaged their data. Compared with what researchers found in pre-2020 investigative work, there seemed to be a growing tendency for industries to use a generic EPD showing data that were averaged across manufacturers and factories; that is, individual manufacturers did not invest in their own EPDs. This makes it easier to compile a summary, but also means less ability to detect differences between specific products within a material class that may vary in manufacturing materials or process.

Efficiency Vermont researchers gave priority to valid EPDs for products manufactured in North America. They accepted European manufactured products wherever no North American

[6] Requires registration. See Building Transparency, "Embodied Carbon in Construction Calculator." https://www.buildingtransparency.org/en/.
[7] Called the BEAM (Building Emissions Accounting for Materials) Estimator, it is expected to become available in the first half of 2022. https://www.buildersforclimateaction.org/beam-calculator.html.

products existed and the source of the product was exclusively European. Two databases were the primary sources of the EPDs: EC3 and Sustainable Minds.[8] The Norwegian EPD Foundation[9] was a source for certain European EPDs.

To build and analyze this project's initial EPD database, the study team had to eliminate duplicate entries within source databases and examine EPDs that collectively covered more than one type of product. For example, the EC3 database had 187 EPDs for board insulation products, of which 130 were identical (the list contained each permutation of product name, manufacturing plant, and thickness; each permutation pointed to the same EPD). In some cases, an EPD covered several product types within a material class and listed multiplication factors to be applied for each variant.

ANALYSIS

The study team analyzed 80 EPDs—79 in 2020, plus a newly available product in 2021. It excluded some EPDs from the summary because they were expired or pertinent only for overseas markets; however, the study team compared those against current or North American EPDs. They excluded data from a small number of EPDs because they contained outlier data on the order of one magnitude.

A lack of data consistency complicated the analysis and comparison of functional units. Because the majority of EPDs used 1 m^2 of material at RSI-1—the thickness of material required to reach RSI-1,[10] which translates to R-5.678 in imperial units, all outputs in this work were standardized to 1 m^2 of RSI-1. Also, not all EPDs contained application data, which the study team looked up separately.

For insulation materials, LCA data are most consistently available for Modules A1–A3 (see Figure 1).

Module A4 is theoretically useful because it can differentiate locally sourced materials, and thus lower transportation impact, from those shipped from afar. However, A4 was not considered here because 1) it is usually not included in LCAs, and 2) determining factory-to-site impacts would require knowing from exactly which factory a given material is sourced. Obtaining that information would have required more time than was available for the project, and at least in part would have been dependent on successful supply chain tracing; many EPDs contain averaged values from manufacturing sites scattered across North America. Further, researchers would have had to calculate factory-to-construction-site data individually.

[8] Sustainable Minds Transparency Catalog. https://www.transparencycatalog.com/.
[9] The foundation hosts a search function and offers supportive information about drafting EPDs at https://www.epd-norge.no/?lang=en_GB (the English-language version of the site is not yet fully developed).
[10] *RSI* is a metric unit of thermal resistance, measured in m^2•K/W. R-value in the United States typically appears in the (unlabeled) units ft^2•°F•h/BTU.

Modules B1–B7 (use stage) are not, for most cases, valuable for differentiating materials. For example, the operational energy use (B6) of R-20 would be the same for Material X as for Material Y unless one material suffers performance degradation over time.

Beyond Modules A1–A3, the study team identified two other modules as significant:

- A5 (construction–installation process). This module is important to consider for materials manufactured on site, such as SPF, to allow fair comparison for products manufactured in a factory setting (where the impacts of their refrigerants would be accounted for in Module A3 [manufacturing]).
- B1 (use). This module is relevant as a differentiator for materials that off-gas refrigerants over time. Refrigerants encapsulated in foam products can have significant GHG impacts.

The study team credited stored carbon content in terms of CO_2e, based on the mass of elemental carbon in the product. In some EPDs, for example, European wood fiber products, this was integrated into the GWP by default. In others, the team needed to calculate it.

Efficiency Vermont summarized GWP (100-year value) and EPD-reported R-value per inch for certain materials (see Table 1). The team defined *GWP** as the GWP impact inclusive of A1–A3 plus A5, B1, and carbon storage. Table 5 (see Appendix) shows the complete GWP data with all materials analyzed, including notes. This table also informed another 2020-2021 Efficiency Vermont R&D project, Embodied Carbon in Vermont Residential Retrofits.[11]

[11] Efficiency Vermont. "Embodied Carbon in Vermont Residential Retrofits." 2021. Available at: https://www.efficiencyvermont.com/Media/Default/docs/white-papers/Embodied_Carbon_in_Residential_Retrofits.pdf.

Table 1. Summary of global warming potential and R-values for frequently used construction materials

Material	Form or variant	R-/"	GWP average, kg CO_2e [A1+A2+A3] per 1 m² RSI-1	*GWP** average, kg CO_2e [w/A5+B1] per 1 m² RSI-1	*GWP** includes
Cellular glass	Aggregate	1.49	3.93	3.93	A5
Cellulose	Blown / loose fill, 1.29 pcf	3.38	0.49	-0.83	A5, carbon
Cellulose	Dense pack, 3.55 pcf	3.56	1.27	-2.16	A5, carbon
EPS (expanded polystyrene)	Board, unfaced Type IX-25psi, graph.	4.70	3.47	3.49	A5
Fiberglass	Batt, unfaced, recycled content	3.64	0.67	0.68	A5
Fiberglass	Blown / loose fill	2.68	1.29	1.30	A5
Fiberglass	Blown / spray	4.00	1.61	1.64	A5
HempCrete	Block	2.14	-7.05	-5.67	A5, B1, carbon
Mineral wool	Batt, unfaced	4.24	3.11	3.25	A5 (1 EPD)
Mineral wool	Board, unfaced, "heavy" density	4.00	4.06	4.06	A5, B1
Phenolic foam	Board, glass tissue faced	7.21	1.54	1.54	Not given
Polyisocyanurate	Board, foil faced	6.53	2.32	2.32	Not given
Spray polyurethane foam	Spray, closed-cell HFC	6.60	3.31	14.86	A5, B1
Spray polyurethane foam	Spray, closed-cell HFO	6.60	3.47	4.00	A5, B1
Spray polyurethane foam	Spray, open cell	4.05	1.42	1.59	A5, B1
Straw	Panel	2.92	-10.95	-10.88	A5, B1, carbon
Wood fiber	Board, unfaced	3.47	-7.13	-7.13	Carbon
XPS (extruded polystyrene), HFC	Board, 25 psi	5.00	20.17	46.51	A5, B1
XPS (extruded polystyrene), HFO blend	Board, 25 psi	5.00	6.37	8.73	A5, B1

Carbon-containing insulation materials, for example, cellulose and wood fiber, have the lowest GWP, in some cases negative values indicating a net-positive impact. Generally, products without blowing agents and products that use water or pentane[12] as a blowing agent come next. Materials with the highest GWP are those with HFC blowing agents.

EXCEL TOOL

In order to operationalize this work, the study team used data that informed Table 1 to create a building impacts calculator in Excel. The inputs were building assembly, installed / added R-value, total area (with framing), framing factor (zero for continuous insulation), baseline material, and comparison material. Cost was an optional impact factor for users who had actual pricing data to compare.

The calculator used average *GWP** (A1–A3 and A5, B1, and carbon) for a given material to calculate GWP savings in absolute and percentage reduction terms.[13] The team equated savings to miles not driven by an average passenger vehicle to provide users with a frame of reference. Other frames of reference included number of 18-pound propane cylinders not burned, pounds

[12] Pentane is a relatively low-GWP hydrocarbon. It is used in EPS, phenolic foam, and polyisocyanurate insulation.
[13] B1 is the 75-year value linked to refrigerant loss. For example, one EPD for closed-cell HFC foam assumes that 24% of blowing agent is off-gassed over 75 years. Thus the *GWP** values for products including B1 are not purely up-front emissions, but Efficiency Vermont opted to include this value as a differentiator against products that do not off-gas higher-GWP chemicals.

of coal not burned, tons of waste recycled instead of being discarded in a landfill, and tree seedlings grown for ten years.[14] Figure 2 provides a snapshot of a sample calculation.

User Inputs [Ensure that each entry is correct -- or left blank if not needed]											GHG impacts [Do not modify calculations]				
	Base Case (Status Quo)			Alternative											
Building assembly [leave unused blank]	Insulation - Base Class	Insulation - Base Product	Installed (added) R-value	*Insulation - Alt. Class*	*Insulation - Alt. Product*	*Installed (added) R-value2*	Total area incl. framing [sq ft]	Continuous or Cavity application?	Framing factor [Cont = 0.00] [2x 16oc = 0.23] [2x 24oc = 0.20]	Include in summary?	GWP - *Base* [kg CO_2e]	GWP - *Alternative* [kg CO_2e]	Apples to Apples?	Incremental cost	GWP savings [kg CO_2e]
Foundation_UnderSlab	XPS	XPS - Board, 25psi HFC	15	CellularGlass	Cellular glass - Aggregate	15	1440	Continuous	0.00	Yes	16433	1388	Yes		15045
Foundation_Interior	XPS	XPS - Board, 25psi HFC	20	Polyiso	Polyiso - Board, foil faced	20	1216	Continuous	0.00	Yes	18502	923	Yes		17579
Foundation_UnderSlab	XPS	XPS - Board, 25psi HFO/HFC	15	CellularGlass	Cellular glass - Aggregate	15	1440	Continuous	0.00	No	3121	1388	Yes		1733
Foundation_Interior	XPS	XPS - Board, 25psi HFO/HFC	20	Polyiso	Polyiso - Board, foil faced	20	1216	Continuous	0.00	No	3514	923	Yes		2591
Totals	Baseline			Alternative						**Totals** [kg CO_2e]	34934	2311	Yes	$0	32624
										% reduction					93%
										m.t. CO_2e					32.6
										Equivalance to:					
										Miles not driven by average passenger vehicle					80,939
										Propane cyclinders (18#) not burned					1,334
										Pounds of coal not burned					35,951
										Tons of waste recycled instead of landfilled					11
										Tree seedlings grown for 10 years					538

Figure 2. GWP building calculator snapshot

This tool is currently available only to Efficiency Vermont staff. It informed a one-page summary for staff and customers (see Appendix) and was the basis for incentive offers to select residential construction projects in 2020–2021.

Case Studies

HIGH-PRIORITY SUBSTITUTIONS

Traditional insulation materials containing HFC blowing agents are by far the highest priority for replacement with low-GWP / lower-embodied-carbon materials. For example, and as Table 1 shows, the *GWP** of closed-cell spray polyurethane foam (with HFC blowing agent) per 1 m^2 of RSI-1 insulation is 14.86 kg CO_2e. For extruded polystyrene products widely available in 2020, it's 46.51 kg CO_2e. In contrast to these two high-GWP materials, closed-cell spray polyurethane foam using HFO blowing agent has a value of 4.00 kg CO_2e. For a mineral wool batt, it's 3.25 kg CO_2e. That value is partially a result of the energy-intensive process of melting glass, stone, or slag in manufacture. GWP is still lower for some products that use pentane as blowing agent: polyisocyanurate is 2.32 kg CO_2e, and phenolic foam is 1.54 CO_2e. Fiberglass materials fare well; the GWP value of unfaced batts is less than 1 kg CO_2e. And carbon-containing insulation materials such as cellulose and wood fiber can have a GWP of less than zero, because they receive credit for storing carbon in the product itself.

In Vermont, starting on January 1, 2021, XPS (boardstock and billet) and two-component spray foam (high pressure and low pressure) were prohibited from using certain HFCs and related blends (see Impacts of Regulations section). The market adapted; for example, Owens Corning released an "NGX" line of its Foamular XPS product and DuPont released a gray-colored "ST-

[14] Based on the EPA greenhouse gas equivalencies calculator, available at: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

100" line of its blue Styrofoam product.[15] The economics presented in the four case studies below use the HFC version of XPS as baseline. These economics change substantially when the newer HFO-HFC products are used as baseline. This paper covers that topic in more detail in the Discussion section.

CRITERIA

The team targeted repeat builders, architects, and building professionals who enrolled their services in Efficiency Vermont's residential programs. Although there were opportunities for one-off projects, the study team opted to use the available budget to share information and inspire action among those who were likely to continue using lower-GWP materials in future projects—and thus enable Efficiency Vermont to capture data on their willingness to specify those materials with and without program incentives.

PROJECT 1: SINGLE-FAMILY AFFORDABLE HOME IN BENNINGTON COUNTY

Overview

This was a planned single-story, slab-on-grade home of approximately 1,200 square feet. The builder constructs one to three homes per year. Standard construction details specify XPS under slab and for the frost wall. Above-grade walls are typically mineral wool batts and XPS continuous insulation outside the sheathing.

Incentive Offer

In 2020, Efficiency Vermont offered $1,250 to the builder for the following substitutions / deviations from the builder's plan:

- **Under slab:** R-15 minimum, replace XPS with suitable density EPS or a cellular glass aggregate product
- **Frost-protected foundation:** R-15 minimum, replace XPS with suitable density EPS
- **Above-grade wall:** continuous insulation, R-15 minimum, replace XPS with phenolic foam board or fiberboard

These substitutions would save an estimated 30 metric tons of CO_2e at an acquisition cost (to the utility) of GHGs reduced, at $41 per ton.

Status

The onset of the COVID-19 pandemic indefinitely postponed this planned build. The net cost, however, of the builder's planned substitutions was very low; quotes in early 2020 indicated that the foundation-related insulation substitutions using Type IX EPS would cost approximately

[15] As of July 2021, DuPont was selling its "ST-100" product in Canada and nine U.S. states with regulations similar to Vermont's. See https://www.beyondblue.dupont.com/compliance.html.

$600 less than XPS, whereas phenolic foam substitution for above-grade walls would add $700 (not including transportation cost).

PROJECT 2: QUADPLEX IN CHITTENDEN COUNTY

Overview

This building has a footprint of approximately 2,600 square feet and four housing units. The builder constructs several homes each year. Prior to discussing the project with Efficiency Vermont, the builder planned to continue his standard practice of XPS below grade, under the slab, and on the exterior foundation wall.

Incentive Offer

Efficiency Vermont offered $2,000 for the following substitutions / deviations from the builder's plan:

- **Under slab:** R-15 minimum, replace XPS with suitable density EPS or a cellular glass aggregate product
- **Foundation wall:** R-20 minimum, replace XPS with suitable density EPS (exterior) or polyisocyanurate (interior)

These substitutions save an estimated 52 metric tons of CO_2e at an acquisition cost of $38 per ton.

Status

The project was completed in early 2021. The builder reported that the price difference on replacing XPS with Type IX EPS (under slab) was less than $100. The builder also saved labor, as the EPS came in a thickness that required a single layer—previous practice was putting down two thinner layers of XPS. For the interior foundation wall, he chose Thermax (a sheet polyisocyanurate product). By shifting this insulation to the interior, he avoided having to follow local rules on covering exposed foam board. See Figure 3 for project photos. The builder's focus was on speed and price, and these substitutions worked well for the project. Carbon savings alone would not have been sufficient motivation.

Figure 3. EPS sub-slab insulation (left), polyisocyanurate interior foundation wall insulation (right).

PROJECT 3: SINGLE-FAMILY HOME IN CHITTENDEN COUNTY

Overview

This building is approximately 3,700 square feet and was under construction in August 2020 when an Efficiency Vermont energy consultant noticed the builder's plan for four inches of XPS on the exterior of its above-grade walls. The builder also planned XPS for all below-grade work. Efficiency Vermont offered incentives for replacing all XPS with lower-GWP materials, but the project's design team preferred to keep XPS below grade.

Incentive Offer

Efficiency Vermont offered $1,650 for the following substitution / deviation from the builder's plan:

- **Above-grade wall:** continuous insulation, R-24 minimum, replace XPS with phenolic foam board, fiberboard, or EPS

These substitutions save an estimated 52 metric tons of CO_2e at an acquisition cost of $32 per ton.

Status

The team (builder and architect) opted for phenolic foam board for the above-grade wall, exterior insulation. See Figure 4 for project photos. The project was completed in spring 2021. Post-completion, the builder reported that the project team appreciated the Kooltherm "K12" phenolic foam's R-8 per inch and the fact that it had, on an R-value basis, near price parity with XPS. The builder / architect team said that their biggest barrier to using phenolic foam in the future is supply, stating, "It needs to be on shelves." They noted that had they committed to a full truckload of the phenolic foam—enough for this home plus their next three projects—it would have come out at a lower cost than XPS.

The team did consider fiberboard, but it would have added several thousand dollars.

The builder was unwilling to substitute other materials for the below-grade applications, noting that XPS was used more commonly and was easier to get.

Figure 4. exterior insulation with strapping (left), phenolic foam detail at window opening (pre-flashing) (right).

PROJECT 4: AFFORDABLE SINGLE-FAMILY HOME IN CHITTENDEN COUNTY

Overview

This project was a 2021 addition to this research. It was an opportunity to reengage a 2020 participant—the same builder as in Project 2 above. A 1,500-square-foot single family home was planned, and the builder expressed interest in exploring a soon-to-be locally manufactured foundation insulation product previously available only from Europe.

Incentive Offer

Efficiency Vermont offered $1,600 for the following substitution / deviation from the builder's plan:

- **Under slab:** R-15 minimum, replace XPS with locally made cellular glass aggregate ("Glavel") or similar low-embodied carbon material
- **Foundation wall:** R-20 minimum, replace XPS with suitable density EPS (exterior) or polyisocyanurate (interior) (e.g., Thermax)

Using the same baseline material assumptions as in Projects 1 through 3, these substitutions would save an estimated 33 metric tons of CO_2e at an acquisition cost of $49 per ton.

Status

The team signed a purchase agreement for the Glavel product after receiving the incentive offer, but supply chain and other delays resulted in the product not becoming available until early 2022. They will complete the project in 2022.

Co-Benefits from Substituting Materials

GWP is not the only consideration for choosing insulation material. "The BuildingGreen Guide to Thermal Insulation" (fourth edition) summarizes insulation impacts by environmental attributes and health concerns, in addition to performance. The guide lists hazardous components, chemical by-products and residuals, fiber shedding, end-of-life issues, durability, and cost—all items that might not show up in an LCA.

Cellulose, for example, offers as advantages its high post-consumer-recycled content and regional manufacture that minimizes shipping costs. But it also frequently contains the flame retardant borate, which has possible health concerns.[16] Loose fibers and dust can also be respiratory irritants. For closed-cell spray polyurethane foam, details that don't stand out in an EPD relate to the material's proportion of recycled content, whether primary components are petroleum based, and whether the product is recyclable at the end of its lifetime. Further, methylene diphenyl diisocyanate, a toxic chemical, might be released during installation of closed-cell spray polyurethane foam, making it vital for installers to use proper protective equipment and for unprotected people to stay away from the building for 24 to 72 hours after installation. Off-gassing of dangerous chemicals after installation is usually not a concern, but has been reported. Table 2 groups common insulation materials according to GHG impact and contains notes on recycled content and toxic emissions.

Table 2. Recycled content and toxic emissions potential of insulation materials

Material	GHG impact[a]	Recycled content[b]	Toxic emissions[c]	Notes[d]
Wood fiber	Lowest / best			
Cellulose	Lowest / best			
Fiberglass	Low			Avoid formaldehyde binders
Polyisocyanurate	Low			Chlorinated flame retardant (otherwise fairly inert) Toxic manufacturing process
EPS (expanded polystyrene)	Low			Brominated flame retardant
Open-cell spray foam	Low			Off-gassing under investigation by EPA Chlorinated flame retardant Highly toxic when applied
Phenolic foam	Low		See note	Phenol formaldehyde content, but low emissions
Mineral wool	Medium		See note	Choose low-emitting products
Closed-cell spray foam, HFO	Medium			Off-gassing under investigation by EPA Chlorinated flame retardant Highly toxic when applied
Closed-cell spray foam, HFC	Highest / worst			Off-gassing under investigation by EPA Chlorinated flame retardant Highly toxic when applied
XPS (extruded polystyrene)	Highest / worst			Brominated flame retardant (otherwise fairly inert) Toxic manufacturing process

[a] Lowest: < 0 $kgCO_2e$ including carbon content, per 1 m^2 RSI-1. Low: < 5. Medium: 5-10. High > 10. Calculations are based on analysis within this report.

[b] From "BuildingGreen Guide to Insulation." Green indicates significant recycled content or renewable material. Red indicates little or no recycled content and fossil fuel-based materials in typical products.

[c] From BuildingGreen Guide to Insulation." Green indicates relatively low toxic emissions during use from typical products. Red indicates potential high toxic emissions from typical products or during manufacturing or application.

[d] From BuildingGreen, "Environmental Notes" in "Key Environmental and Performance Factors for Insulation Materials" table.

[16] Another BuildingGreen publication notes that "Health concerns with borates have been thought to be low but are not well known; in 2011 the European Union added boric acid to the 'Candidate List' of potentially toxic chemicals in its REACH program, with concern about reproductive toxicity." Sawyer, Chris. *Insulation Choices: What You Need to Know about Performance, Cost, Health and Environmental Considerations.* 2017. Page 39.

Discussion

The bulk of this research occurred in 2020. Work themes for 2021 were sharing the 2020 work more broadly, gaining feedback on the 2020-initiated material substitutions in pilot projects, and evaluating impacts of new regulations and products.

COMMUNICATION

The 2020 research was presented by Brian Just at the Better Buildings by Design conference in February 2021[17] and the BuildingEnergy Boston conference in May 2021.[18] Also, an article authored by Brian Just and titled "Choosing Low-Carbon Insulation" was published on Green Building Advisor in June 2021.[19] Multiple attendees and readers wanted to know more about the GHG impacts calculator and whether researchers would make it publicly available. Given the development cost and maintenance requirements, Efficiency Vermont does not have a plan in place to do so; nonetheless, the tool's value and relative simplicity gives researchers hope that something will appear in the market soon.

An updated version of the one-page guideline "Carbon drawdown in your next construction project: Choosing insulation materials with the lowest greenhouse gas impact" was published by Efficiency Vermont in 2021 and is included in the Appendix.

IMPACTS OF REGULATIONS

In late 2020, Vermont adopted a rule regarding the phase-down of the use of HFC refrigerants affecting anyone selling or installing products in Vermont that utilize refrigerants, foam insulation, or aerosol propellants. This includes commercial and residential refrigeration, HVAC, and many types of foam-based building materials. Prohibitions that went into effect on January 1, 2021, include XPS board stock and one-part and two-part spray foams.[20]

This effectively meant the phasing out of the ubiquitous XPS "blueboard" and "pinkboard" products heretofore common for many insulation applications. Two identified products entered the Vermont market shortly thereafter, the "NGX" (next generation extruded) line of Owens Corning's Foamular products and the "ST-100" line of DuPont's Styrofoam products.

In 2020, researchers found that an incentive of \$30 to \$40 per metric ton of averted CO_2e was a sufficient motivator for builders to participate in the small number of projects the study team

[17] "Tracking the Greenhouse Gas Impacts of Energy Efficiency Measures: New Tools and Lessons Learned for Designers and Contractors." https://www.efficiencyvermont.com/trade-partners/bbd/bbd-2021.
[18] "Tracking the Greenhouse Gas Impacts of Your Energy Efficiency Measures: New Tools & Lessons Learned for Designers & Contractors." https://nesea.org/conference/buildingenergy-boston-2021.
[19] This article is publicly available at: https://www.greenbuildingadvisor.com/article/choosing-low-carbon-insulation.
[20] Prohibited products or equipment manufactured prior to the applicable effective date are allowed to be sold and used in Vermont after the effective prohibition date. The Vermont Department of Environmental Conservation has jurisdiction over implementation and enforcement of this rule. For further detail, refer to https://dec.vermont.gov/sites/dec/files/aqc/laws-regs/documents/Vermont_HFC_Rule_Adopted_CLEAN.pdf.

worked with. The new regulation changes the accounting substantially. For example, Project 1 projected savings of 30 metric tons of CO_2e at an acquisition cost of $41 per ton, using a baseline of 25 psi XPS and its *GWP** value of 46.51 kg CO_2e per 1 m^2 of RSI-1. By contrast, the new formulation of the Owens Corning has a *GWP** of 8.83 kg CO_2e.[21] This drops the savings potential substantially, to about four metric tons of CO_2e at $304 per ton.

Although the *GWP** of this new class of XPS product is substantially lower than its predecessor, it is still on the high end for insulation products. However, these new products reduce cost-effectiveness of paying incentives for GHG savings measures via insulation material substitutions, given the significant difference in baseline—at least in states (currently about 10 states) that disallow the old XPS products. Researchers can make a similar statement regarding closed-cell spray foam, though HFO and HFC formulations have existed side by side in the market for a few years, meaning that using the HFC-blown products as a baseline was already questionable. Table 3 tabulates the differences in potential savings resulting from the new XPS product availability.

Table 3. GHG savings, pre- and post-HFC regulation changes

	GHG savings, metric tons of CO_2e (HFC XPS baseline)	GHG savings, metric tons of CO_2e (HFO-HFC XPS baseline)
Project 1	30.3	4.1
Project 2	52.4	7.1
Project 3	51.9	8.4
Project 4	32.6	4.3

The downsides of XPS and closed-cell spray foam materials, noted in Table 2, are unlikely to be improved by using a different blowing agent, according to the researchers.

OTHER PRODUCT UPDATES

Two developments have occurred in the availability of lower-embodied-carbon products previously available only in Europe. Glavel, Inc., a local manufacturer of foam glass aggregate will begin production of low embodied carbon building materials out of their Essex, Vermont facility in late February 2022. Used for residential and commercial sub-slab insulation, Glavel serves as both thermal insulation and drainage for subbases. "In addition to offering the environmental benefit of using regionally sourced recycled glass as feedstock, the embodied carbon of Glavel's foam glass will be significantly lower than current market alternatives, including EPS and XPS foam", said Alexandra Carroll, VP of Sales and Marketing at Glavel.

[21] Based on Owens Corning's *Foamular® NGX™ XPS Insulation* EPD (January 1, 2021). Another relevant EPD that came out later in the year, DuPont's *Styrofoam™ Brand ST-100 Products* (July 1, 2021) was not used because it did not break out product impact by material density.

In Madison, Maine, another North American manufacturing facility is setting out to create a product currently available at scale only from overseas. When TimberHP begins manufacturing its wood-fiber products, it will reduce reliance on European manufacturers such as Steico and Gutex. According to GoLab chief marketing officer Scott Dionne, the TimberHP factory will break ground in late 2021. He expects to be selling loose-fill wood-fiber insulation ("TimberFill") by the first quarter of 2023, wood-fiber batts ("TimberBatt") by the second quarter of 2023, and wood-fiber board ("TimberBoard") in the third quarter of 2023. Dionne notes that because wood in Europe costs three times as much as in the Northeast U.S., and European energy costs are twice those in Maine, the U.S.-manufactured loose-fill product will be priced on par with cellulose, batts will fall somewhere between fiberglass and mineral wool, and boards will be similar to foam and less than mineral wool. This is potentially transformative, because high prices and long lead times currently counter the attractive carbon impacts of wood-fiber products.

Phenolic foam, another relatively low-GWP alternative to XPS for above-grade walls, has supply chain limitations that result in high costs. When purchased by the truckload and compared on installed R-values, phenolic foam is cost competitive with XPS. But it is not stocked anywhere in Vermont, and its price is significantly higher when builders are required to order phenolic foam for a single project. In December 2021, Kingspan representative Jack Mitschele reported his 2022 focus on adding a regional stocking dealer with a broad geographic footprint to service Vermont with exterior wall- and interior foundation-suitable phenolic foam products. He also noted that dramatic increases in XPS pricing in 2021 has allowed phenolic to be more cost competitive.

OTHER OPPORTUNITIES

Insulation products are not the only opportunity for embodied carbon savings. Takeaways from a 2021 report published by RMI are included in Table 4.[22]

Table 4. Low-cost opportunities for reducing embodied carbon in buildings

Category	Reduction	Cost impact
Concrete	14–33%	None to low premium
Rebar	4–10%	None to low cost premium
Insulation	16%	No cost premium
Glazing	3%	10% cost premium
Finish materials	5%	None to low cost premium

Specific to the residential market, in consideration of new HFC regulations coming into place, concrete is the greatest current opportunity. The production of one component of concrete, Portland cement, dominates the GHG impact of making concrete. Replacing a portion of the

[22] Jungclaus, Matt, Rebecca Esau, Victor Olgyay, and Audrey Rempher. "Reducing Embodied Carbon in Buildings: Low-Cost, High-Value Opportunities." RMI. 2021. http://www.rmi.org/insight/reducing-embodied-carbon-in-buildings.

Portland cement with supplementary cementitious materials (SCMs) creates a significant embodied carbon savings opportunity. The most common SCM used is fly ash, a by-product of coal combustion commonly used by manufacturers to replace 15–50% of the cement portion of concrete mix.

High SCM content can increase concrete strength but also result in longer set times with potential to delay construction. Cold climates add complexity: Fly ash concrete is less resistant to scaling (loss of mortar on the concrete surface) and may have pouring temperature limitations. However, even in the Northeast climate, it is possible to formulate concrete mixtures containing SCMs that can work well for a given application.

To provide a sense of scale in comparison with insulation, consider a home with a 25' x 40' footprint with a 4"-thick slab and 6"-thick foundation walls that are 8' high. Converting to SI units and assuming a density of 2,400 kg per cubic meter, this building will contain approximately 58 metric tons of concrete. To support a simple calculation, assume 150 kg CO_2e per metric ton of concrete,[23] yielding 8,700 kg CO_2e attributable to the home's concrete. SCM use can realistically save on the order of a quarter of that, or two metric tons of CO_2e. Compare this with the impacts of insulation substitutions outlined in the projects detailed in Table 3 (approximately 30 to 50 metric tons of CO_2e savings before new HFC regulations, scaled down to four to eight metric tons post-regulation). Though still likely lower in potential impact in residential single-family construction compared with insulation material substitutions (especially in locations where new HFC regulations or restrictions exist), reducing embodied carbon in concrete becomes more compelling in terms of scale of its impact.

CONCLUSION

Insulation with the highest GHG impacts were XPS and closed-cell spray foams, including those blown with both HFC and newer HFO / HFC-HFO formulations. Those with the lowest impacts were wood and cellulose based. Research on environmental and health concerns revealed that low-GWP insulation materials generally correlated with lower toxicity and higher recycled content.

As reported in the Case Studies section, builders who participated in this project did not find lower-embodied-carbon products more difficult to handle or install. Barriers were lack of familiarity with material alternatives, lack of stocked products, and high price.

Builders that participated in this research are integrating low-embodied-carbon insulation products into future decision-making and reached out to Efficiency Vermont in 2021 for further guidance on specific applications. A continued barrier to substituting other materials for XPS

[23] "Carbon Footprint of Concrete," Green Ration Book. http://www.greenrationbook.org.uk/resources/footprints-concrete/.

(even the new, lower-impact versions) is perceived risk; one supplier stated that XPS is "tried and true" below grade. People trust it and know how to install it; it is considered a standard practice.

This R&D project succeeded in quantifying the embodied carbon impacts of replacing common insulation materials with substitute materials. Efficiency Vermont was able to inform customer-facing energy consultants about the highest GWP products and alternatives worth investigating as replacements.

Appendix

Figure 5 is a one-page summary supporting project teams in choosing insulation materials with the lowest greenhouse gas impact. Table 5 provides a summary of GWP and R-values by insulation material type.

Carbon drawdown in your next construction project

Choosing insulation materials with the lowest greenhouse gas impact

Embodied carbon refers to the greenhouse gas (GHG) emissions that went into the production of materials. A summary of common insulation materials appears in the table below. Materials that contain carbon and/or require less energy to produce have the lowest (best) GHG impact. At the other end, materials with high-GHG refrigerants tend to have the worst carbon footprint.[1]

Material	Example manufacturers / products	GHG Impact[2]	Notes
Wood fiber	Steico, Gutex	Lowest / Best	Boardstock, batts
Cellulose	Cleanfiber, GreenFiber	Lowest / Best	Densepack, loosefill
Fiberglass	CertainTeed Sustainable, Knauf EcoBatt	Low	Batts, boardstock, loosefill/densepack
Polyisocyanurate	DuPont Thermax	Low	Boardstock; Blowing agent: pentane
EPS* (expanded polystyrene)	Atlas, BASF Neopor	Low	Boardstock; Blowing agent: pentane
Open cell spray foam	Demilec APX, Lapolla Foam-Lok 450	Low	Site-blown; Blowing agent: water
Phenolic foam	Kingspan Kooltherm	Low	Boardstock; Blowing agent: pentane
Cellular glass	Glavel, Foamglas	Low	Aggregate, boardstock
Mineral wool	Rockwool, Owens Corning	Medium	Batts, boardstock
Closed cell spray foam, HFO	Demilec Heatlok HFO Pro, Lapolla ProSeal HFO	Medium	Site-blown; Blowing agent: HFOs
Next gen. XPS*, HFO/HFC	Owens Corning NGX series, DuPont XPS-ST-100 series	Medium / High	Boardstock; Blowing agent: HFO/HFC blend
Closed cell spray foam, HFC	Demilec Heatlok XT, Dow Froth-Pak	Highest / Worst	Site-blown; Blowing agent: HFCs
XPS*	Dow Styrofoam (blueboard), Owens Corning (pinkboard)	Highest / Worst	Boardstock; Blowing agent: HFCs

Partners have shared that many material substitutions are not only easy to implement, they can actually save money. Furthermore, many lower-GHG materials are less toxic to workers and/or building occupants.[3]

Example: A 2-story, 2,000 square foot home making insulation substitutions detailed below avoids approximately 55,000 kg CO_2e, roughly equal to not driving 136,000 miles or not burning 60,000 pounds of coal. Provided the installed R-value is the same and proper air sealing is done, there is no significant difference between the two homes' operational energy.

- XPS for sub-slab and foundation
- HFC-based spray foams in walls and cathedral ceiling

- EPS Type IX for sub-slab and polyisocyanurate (interior) foundation
- Densepack cellulose in walls and cathedral ceiling

[1] Our analysis is based on Cradle to Gate: extraction of resources from the earth until the point that a product leaves the factory. This corresponds to Life Cycle Assessment product stages A1, A2, and A3. We also include A5 for materials manufactured on-site (such as spray polyurethane foam that emits refrigerant at installation) and B1 (which is important to consider for insulations which off-gas refrigerants over time).
[2] Lowest: < 0 $kgCO_2e$ including carbon content, per 1 m_2 RSI-1. Low: 0-5. Medium: 5-10. High > 10.
[3] A useful summary of cost, health, and environmental considerations of insulation materials is available at: https://www.buildinggreen.com/sites/default/files/BG_Insulation_Recommendations.pdf
*Expanded polystyrene (EPS); Extruded polystyrene (XPS)

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Figure 5. One-page summary of GWP impacts, for staff and external use, available at https://www.efficiencyvermont.com/Media/Default/docs/printable-resources/GeneralInfoForHomes/EVT-Home-Insulation-GHG-OnePager.pdf

Table 5. Summary of GWP and R-values, by insulation material

Material	*Form or variant*	*Blowing agent*	*R-/"*	*GWP range, kg CO_2e [A1+A2+A3] (per 1 m^2 RSI-1)*	*GWP average, kg CO_2e [A1+A2+A3] (per 1 m^2 RSI-1)*	*GWP* average, kg CO_2e [w/A5+B1] (per 1 m^2 RSI-1)*	*GWP* includes*	*Basis / notes*
Cellular glass	Aggregate	NA	1.49	NA	3.93	3.93	A5	1 EPD
Cellulose	Blown/loose fill, 1.29 pcf	NA	3.38	NA	0.49	-0.83	A5, carbon	Used North American industry EPD; similar magnitude to 2 European EPDs
Cellulose	Dense pack, 3.55 pcf	NA	3.56	NA	1.27	-2.16	A5, carbon	Used North American industry EPD; similar magnitude to 2 European EPDs, scaled to dense-pack application
Expanded polystyrene (EPS)	Board, unfaced, Type I - 10psi	Pentane	3.60	NA	2.63	2.63	A5, B1	Used North American industry EPD
Expanded polystyrene (EPS)	Board, unfaced, Type I - 10psi, graphite	Pentane	4.70	1.73-1.74	1.74	1.78	A5	Average of 2 North American products
Expanded polystyrene (EPS)	Board, unfaced, Type II - 15psi, graphite	Pentane	4.70	2.78-2.80	2.79	2.80	A5	Average of 2 North American products
Expanded polystyrene (EPS)	Board, unfaced, Type IX - 25psi, graphite	Pentane	4.70	3.46-3.49	3.47	3.49	A5	Average of 2 North American products
Expanded polystyrene (EPS)	Board, unfaced, Type VIII - 13psi, graphite	Pentane	4.70	2.21-2.24	2.22	2.23	A5	Average of 2 North American products
Fiberglass	Batt, unfaced, recycled content	NA	3.64	0.46-0.94	0.67	0.68	A5	Average of 3 North American products, with recycled content
Fiberglass	Blown/loose fill	NA	2.68	NA	1.29	1.30	A5	1 EPD
Fiberglass	Blown/spray	NA	4.00	1.29-1.93	1.61	1.64	A5	Average of 2 North American products
Fiberglass	Board, unfaced	NA	4.23	5.56-9.12	7.34	7.37	A5	Average of 2 North American products
HempCrete	Block	NA	2.14	NA	-7.05	-5.67	A5, B1, carbon	1 EPD; embodied carbon incl. in A1-A3, accounts for carbonization of blocks, 240 days after production
Mineral wool	Batt, unfaced	NA	4.24	1.44-4.77	3.11	3.25	A5 (1 EPD)	2 EPDs; Owens Corning has formaldehyde-free variant but not included in summary
Mineral wool	Blown	NA	2.95	NA	5.16	5.18	A5	1 EPD
Mineral wool	Board, unfaced, Thermafiber "medium" density	NA	4.30	NA	9.71	9.71	A5	1 EPD
Mineral wool	Board, unfaced, Rockwool "heavy" density	NA	4.00	NA	4.06	4.06	A5, B1	1 EPD
Mineral wool	Board, unfaced, Rockwool "heaviest" density	NA	4.00	NA	5.63	5.63	A5, B1	1 EPD
Phenolic foam	Board, glass tissue faced	Pentane	7.21	NA	1.54	1.54	Not given	1 EPD (only commercially available), based on K5 version of product
Polyisocyanurate	Board, foil faced	Pentane	6.53	NA	2.32	2.32	Not given	Used North American industry EPD
Polyisocyanurate	Board, GRF facers (roof appl)	Pentane	5.76	2.19-2.80	2.47	2.63	A5 (for 2 EPDs)	Average of North American industry EPD and 2 manufacturers
Spray polyurethane foam (SPF)	Spray, 2K-LP HFC	HFC	6.15	NA	3.21	25.46	A5, B1	Used North American industry EPD; B1 approx. 2x impact of A5
Spray polyurethane foam (SPF)	Spray, closed-cell HFC	HFC	6.60	NA	3.31	14.86	A5, B1	Used North American industry EPD; B1 approx. 2x impact of A5
Spray polyurethane foam (SPF)	Spray, closed-cell HFO	HFO	6.60	NA	3.47	4.00	A5, B1	Used North American industry EPD; no B1 impacts
Spray polyurethane foam (SPF)	Spray, open cell	Water	4.05	NA	1.42	1.59	A5, B1	Used North American industry EPD; no B1 impacts
Spray polyurethane foam (SPF)	Spray, roofing HFC	HFC	6.50	NA	3.83	19.33	A5, B1	Used North American industry EPD; B1 approx. 2x impact of A5
Spray polyurethane foam (SPF)	Spray, roofing HFO	HFO	6.50	NA	4.05	4.74	A5, B1	Used North American industry EPD; no B1 impacts
Straw	Panel	NA	2.92	NA	-10.95	-10.88	A5, B1, carbon	1 EPD; embodied carbon included in A1-A3
Wood fiber	Batt, unfaced	NA	3.76	-2.11- -1.82	-1.96	-1.96	Carbon	Average of 2 EU products; EPDs include embodied carbon / not broken out separately
Wood fiber	Board, unfaced	NA	3.47	-8.57- -5.69	-7.13	-7.13	Carbon	Average of 2 EU products; EPDs include embodied carbon / not broken out separately
Extruded polystyrene (XPS-HFC)	Board, 15psi	HFC	4.99	NA	16.93	39.04	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC)	Board, 25psi	HFC	5.00	NA	20.17	46.51	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC)	Board, 40psi	HFC	5.00	NA	23.43	54.04	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC)	Board, 60psi	HFC	5.00	NA	28.65	66.06	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC)	Board, 100psi	HFC	5.00	NA	39.05	90.05	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC/HFO)	Board, 15psi	HFC/HFO	4.99	NA	5.35	7.41	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC/HFO)	Board, 25psi	HFC/HFO	5.00	NA	6.37	8.83	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC/HFO)	Board, 40psi	HFC/HFO	5.00	NA	7.40	10.26	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC/HFO)	Board, 60psi	HFC/HFO	5.00	NA	9.05	12.55	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous
Extruded polystyrene (XPS-HFC/HFO)	Board, 100psi	HFC/HFO	5.00	NA	12.34	17.10	A5, B1	1 EPD; A5 impact negligible, B1 impact enormous