Embodied Carbon Values in Common Insulation Materials

KPMB LAB

KPMB Architects + KPMB LAB
May 2021

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Like many architects, we have begun to pay much closer attention to the embodied carbon associated with the materials we are specifying. All other things being equal, selecting a material with a lower global warming potential (GWP) is preferable. However, at this early stage, not many of us have a strong intuitive sense of how meaningful various GWP values might be. For instance, is 223 $kgCO_2e/m^2$ of insulation good or bad?

To present GWP values in a relatable way, we performed a study to compare the embodied carbon values for 11 commonly used types of insulation. The insulation products considered include two brands of standard XPS, two brands of next-generation XPS, Polyiso, spray foam, EPS, Rockwool, Neopor GPS, fibreglass batts, and blown cellulose.[1]

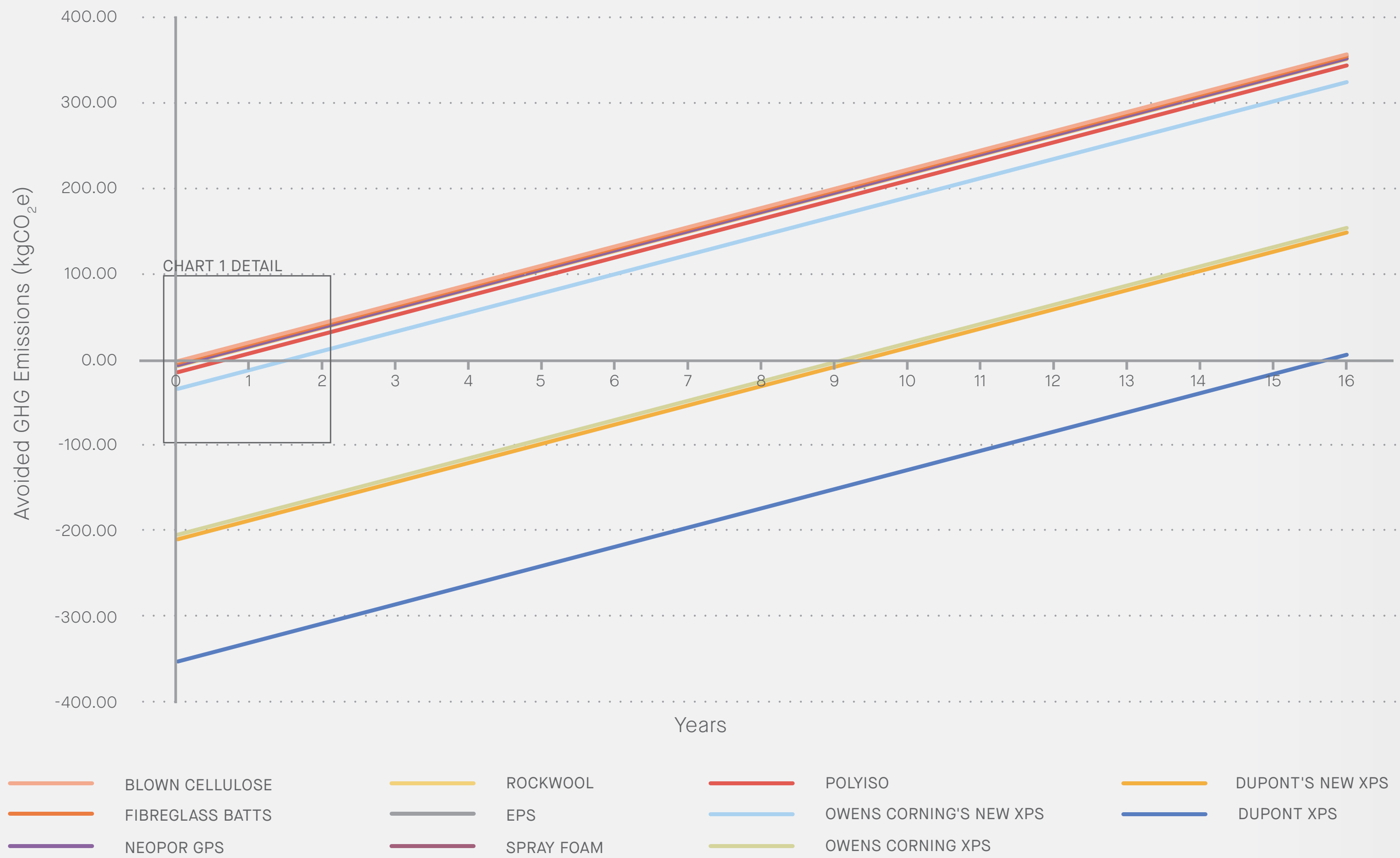
Insulation is somewhat unique among building materials in that one of the primary reasons it is incorporated in buildings—to reduced energy flow through the building envelope—directly impacts the building's operational emissions.

In our study, we contrive a familiar scenario: a homeowner with an uninsulated bearing masonry house wishes to add insulation to reduce their energy costs and increase comfort in the home. Specifically, they would like to increase the effective R-value of their home from its current performance of $R4_{IMP}$ to a value more in line with the current building code, $R24_{IMP}$.

We calculate the embodied carbon associated with the amount of each type of insulation required to achieve that level of thermal resistance. We then calculate the quantity of emissions that is avoided each year the house is operated with the higher level of insulation (due to the reduction in heating energy needed to maintain the internal temperature of the house.)

The conclusion of our study is a payback analysis that expresses the relationship between the emissions associated with the production of each insulation and the emissions avoided each year due to the presence of the insulation.

Chart 1 – Carbon Payback Analysis Natural Gas Heating Scenario (0-16 Years)



Said another way, we identify how long it takes for the operational savings (reduced operational emissions) to exceed the investment (embodied carbon) in the insulation.

We assumed the house was heated with natural gas for our baseline scenario.[2] We also contemplated an alternative scenario where the house was upgraded to a heat pump.[3] The relative performance of each insulation does not change in the heat pump scenario. However, the operational emissions resulting from the heat pump are much lower than with gas heating. As such, the notional payback periods are significantly longer in the heat pump scenario (though the total carbon emissions in any period of time would be lower.) The findings of this analysis are illustrated in the three graphs above. Several conclusions bear mentioning:

1. The operational emissions associated with natural gas heating are approximately 12 times greater than for electric heat pump heating. This translates into much shorter payback periods for the insulation materials considered.
2. XPS is an outlier in this selection of materials, with a GWP 15 to 20 times greater than the other materials. In the electric heat pump scenario, it is not reasonable to expect the operational carbon savings to ever outweigh the embodied carbon of the material itself.
3. Owens Corning's next-gen XPS has a much lower GWP than either brand of traditional XPS considered. However, it is still twice as high as the other non-XPS products considered in the study.

Chart 1 Detail – Carbon Payback Analysis Natural Gas Heating Scenario (0-2 Years)

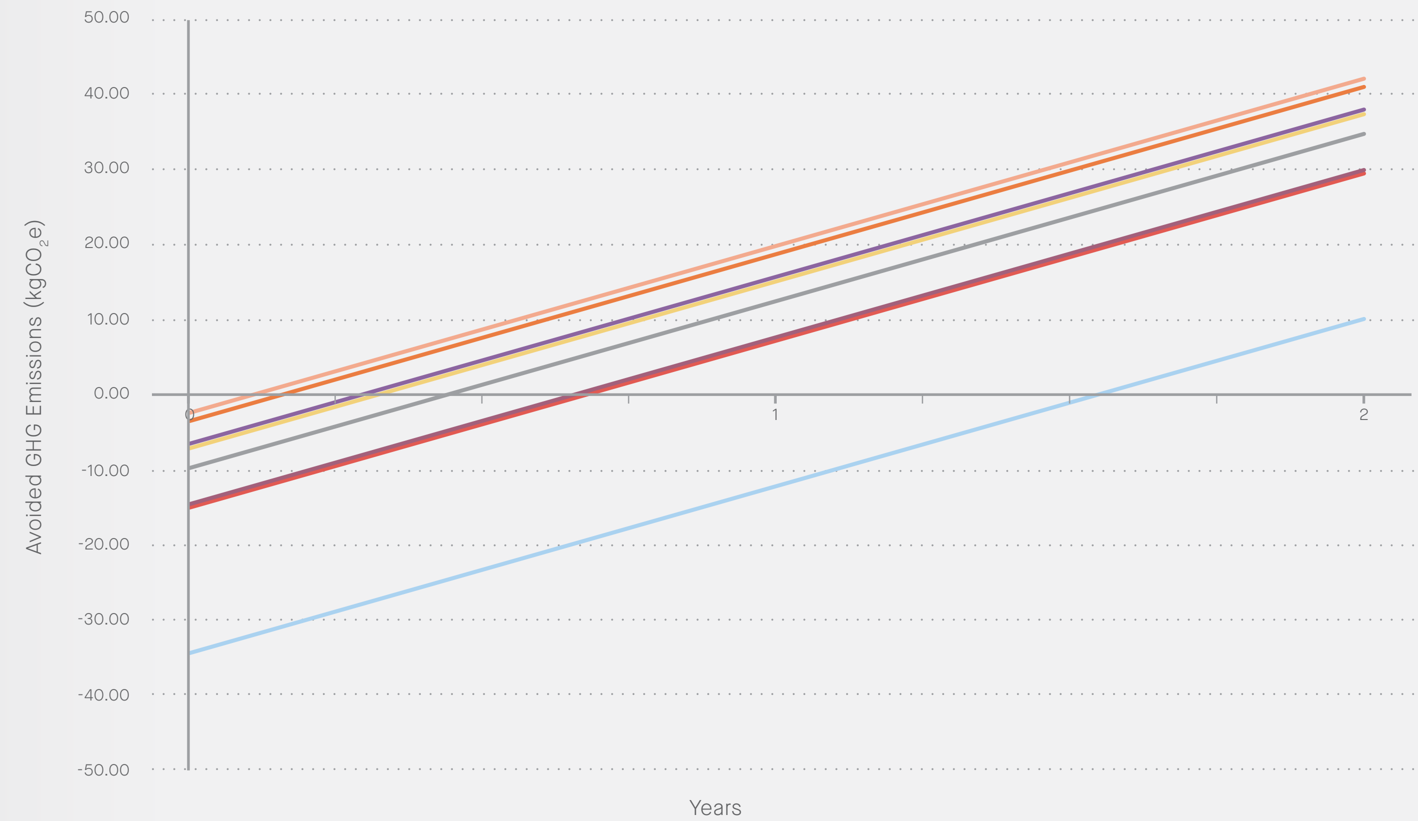


Chart 2 – Carbon Payback Analysis Heat Pump Scenario (0-16 Years)

The world is already 1°C warmer[4] than it was in preindustrial times and our current infrastructure will take us past 1.5°C by mid-century. The next ten years are pivotal. In order to avoid 2°C of warming – widely understood as the tipping point into ecological catastrophe – we must reduce greenhouse gas emissions to zero.[5]

4. Blown cellulose insulation has the lowest GWP value of the group, as might be expected given the relatively low amount of processing involved in producing the material. That said, it needs to be contained in a wall cavity or similar container, and therefore might not be applicable in as many situations as the other board and batt products considered.
5. Polyiso, EPS, Rockwool, and GPS are all board or semi-rigid batt products, and all have GWPs that are significantly lower than XPS. In situations where blown cellulose insulation is not a suitable choice, these products—Rockwool and GPS in particular—offer considerable flexibility in terms of suitable installations, along with quite good embodied carbon values.

It is our hope that this analysis provides a somewhat more intuitive sense of scale for the embodied carbon quantities of these materials. The study also underscores the significant differences in operational emissions resulting from gas versus electric heat pump systems.

The Effect of Varying Levels of Insulation on Total Carbon

After examining the relationship between embodied carbon and operational carbon savings over time for a given quantity of insulation (R20IMP), we thought it would be interesting to also look at the effect of varying levels of insulation.

In this second analysis, we work with the same 11 insulation materials we looked at in the first analysis. We set a 30-year service life for the materials, and we make a few assumptions about the building the insulation is being applied to. Specifically, the building is in Toronto, Ontario; its interior will be maintained at 20°C (giving 93 kKh per year); and it is being heated with natural gas (0.183 kgCO_2e/kWh).

We then look at the two component aspects of total carbon: the operational value and the embodied value.

For this analysis, we define "operational carbon" as the amount of emissions produced by the heating plant to maintain the interior temperature of 20°C for 30 years, at each specified level of insulation.

We start the analysis at $R1_{IMP}$ and look at each integer value up to $R40_{IMP}$. (Note that the type of insulation is irrelevant to this part of the analysis, as the heat flow through the hypothetical envelope is a function of the R-value, regardless of the insulation used to achieve the given level of resistance.)

Chart 3 – Total Operational Carbon Over 30 Years per R-value, Natural Gas Heating Scenario

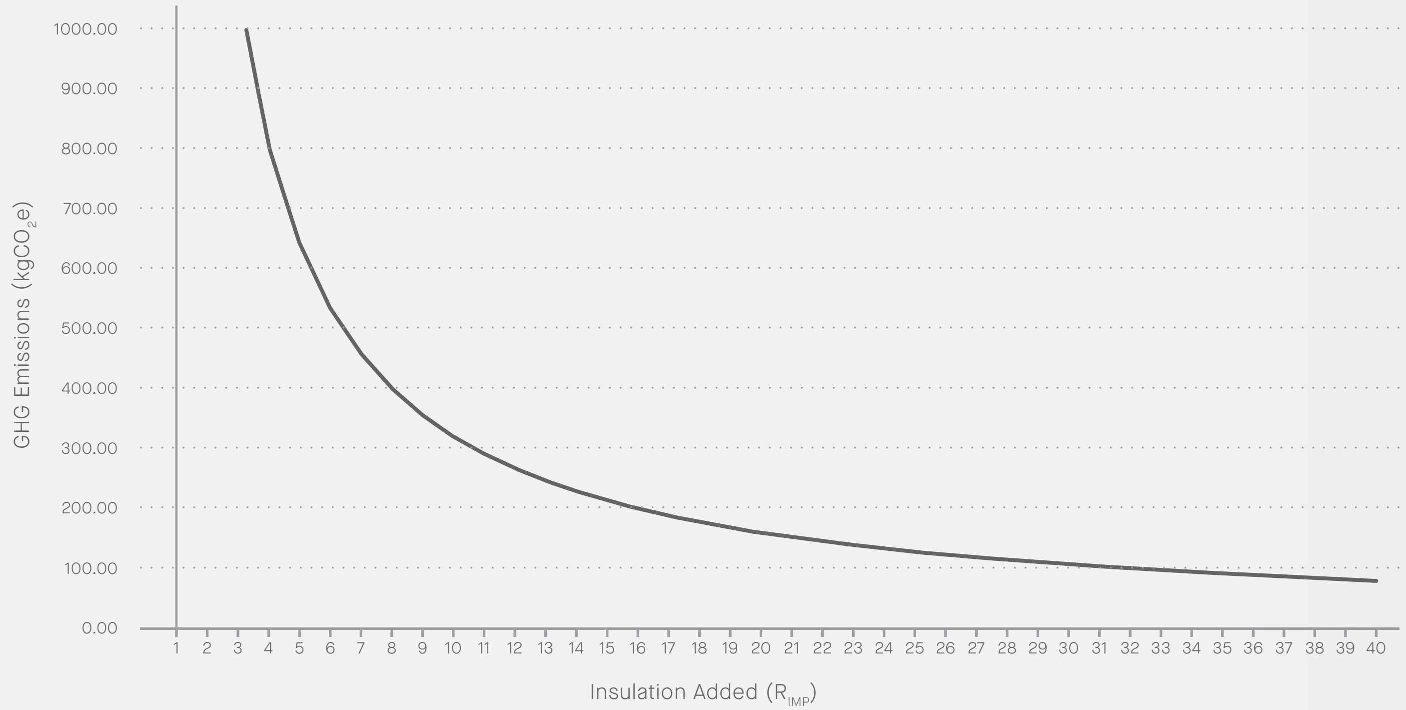
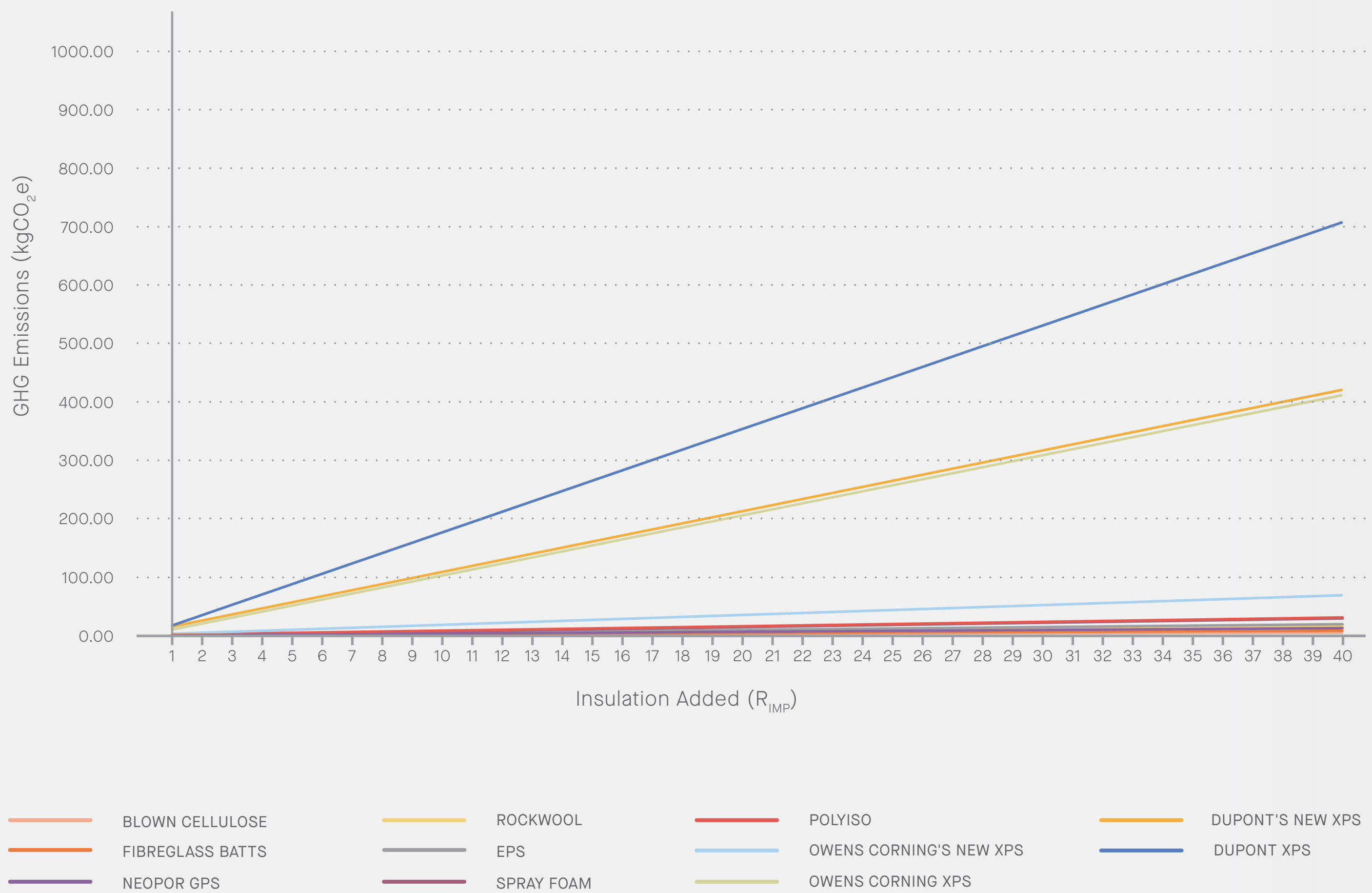


Chart 4 – Embodied Carbon per R-value



Buildings are associated with approximately a third of all greenhouse gas emissions, so architects have a special responsibility to help minimize the amount of warming to come, and to help our societies become resilient and adaptable in the face of the warming we have already caused.

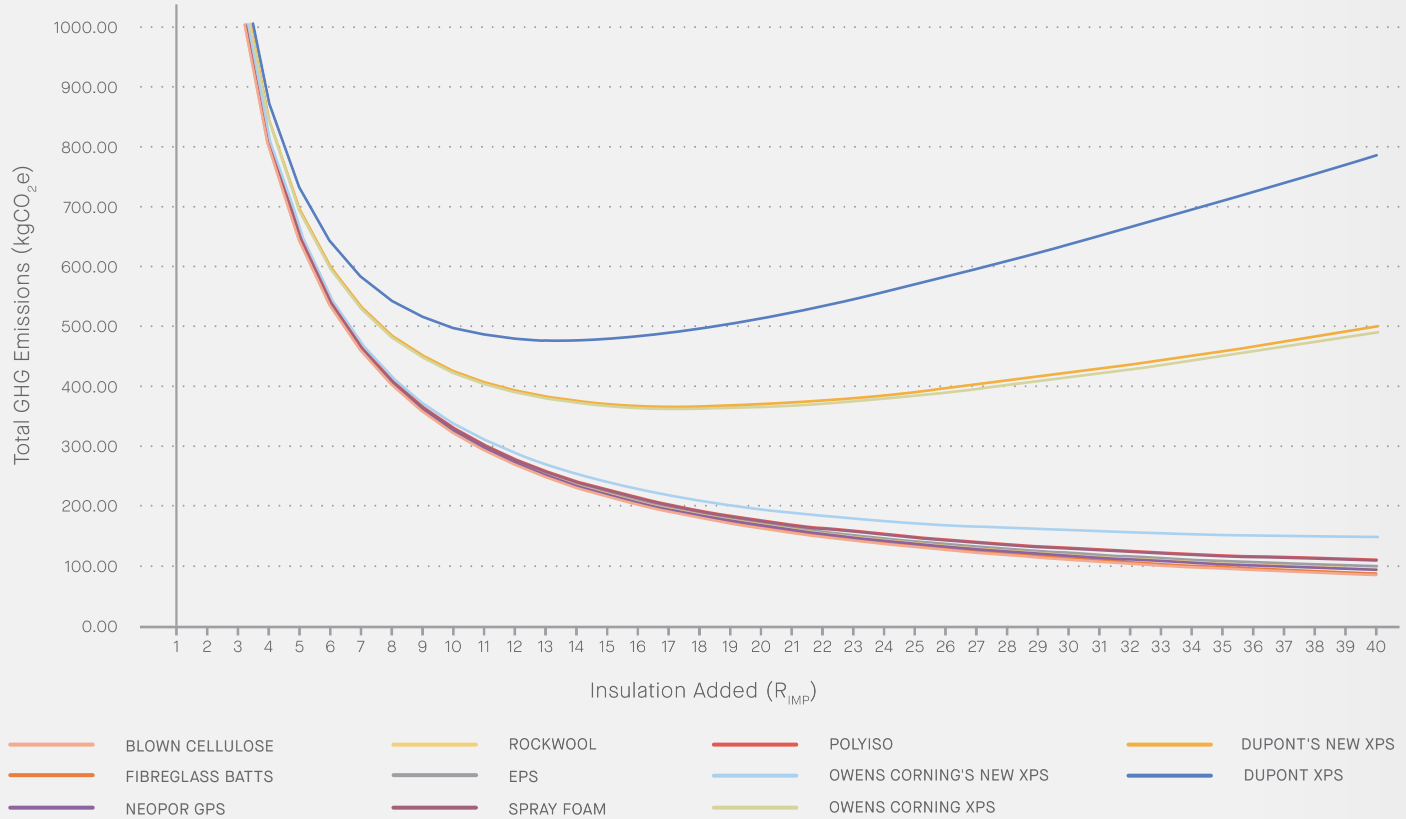
Chart 3 shows the operational carbon values for $R1_{IMP}$ to $R40_{IMP}$. From the shape of the curve, we see that adding insulation provides diminishing returns as the R-values increase. The carbon value drops by 50% from $R1_{IMP}$ to $R2_{IMP}$, as doubling the resistance halves the heat flow through the assembly. By contrast, the energy savings (and carbon reduction) from $R39_{IMP}$ to $R40_{IMP}$ is only 2.5%.

The second piece of the puzzle is the embodied carbon value. Chart 4 shows the 11 materials and the embodied carbon values for $1m^2$ of each, for thicknesses delivering $R1_{IMP}$ up to $R40_{IMP}$.

The relationship between thickness of insulation and R-value is linear—e.g. $R20_{IMP}$ of EPS is 20 times thicker than $R1_{IMP}$ of EPS—and the chart reflects this. The steepness of each line is a reflection of the GWP of each material, where a higher GWP gives a steeper line.

What we're calling "total carbon" is simply the addition of these two charts. By adding the embodied values to the operational carbon values, we get Chart 5.

Chart 5 – Total Carbon Over 30 Years per R-value, Natural Gas Heating Scenario

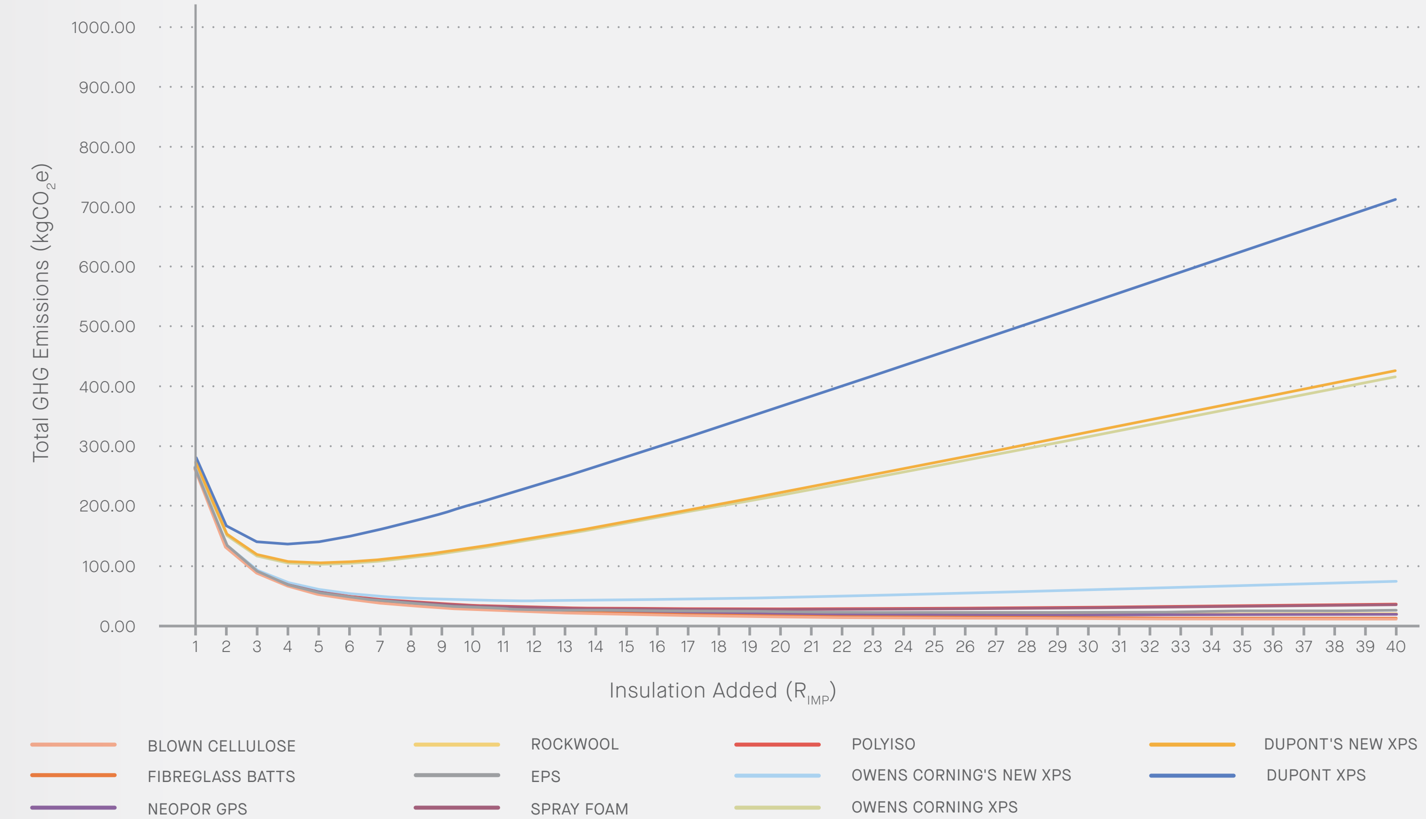


This produces an interesting effect—an optimization function. At lower levels of insulation, the operational savings of small amounts of additional insulation tend to drive the curve. As the levels of insulation get higher, the marginal savings accrued by each additional R-value diminish, but the embodied carbon value increases linearly. The result is that at some point for each material, the amount of embodied carbon being added outweighs the operational savings that results, producing an inflection point on the chart, where the curve flattens and begins to bend upwards. As the operational savings are consistent for all of the materials, the specific inflection point for each material is determined by that material's GWP value. Higher GWP values result in inflection points at a lower R-values.

Observations:

1. The total value of emissions indicated on the y-axis is the truly important piece of information in this analysis. Choosing an insulation material that will result in the lowest total carbon output while meeting the requirements of the application is the appropriate objective.
2. The 30-year service life considered is an arbitrary value. If a shorter service life were considered, the total carbon values would be lower, and the inflection points would happen at lower R-values (as the total operational emissions considered would be lower, given more weight to the embodied emissions). The converse is true for considerations of service life periods longer than 30 years.
3. Three of the four XPS materials considered produce inflection points

Chart 6 – Total Carbon Over 30 Years per R-value, Electric Heat Pump Heating Scenario



(or total carbon minimums) at insulation levels below current OBC (SB-12) code requirements for walls above grade in new home construction. It would be desirable to select a material with a lower total carbon value at the code-required level of insulation.

4. All of the non-XPS materials show values for total carbon that are still declining at $R40_{IMP}$ levels of insulation. These materials do have inflection points, however they occur at higher R-values that are not typical in construction. (For instance, the inflection point for Polyiso is ~$R65_{IMP}$. The inflection point for blown cellulose would be closer to ~$R160_{IMP}$.)
5. This analysis considered natural gas as the fuel source for heating. If we consider an electric heat pump connected to the Ontario grid as the fuel source (see Chart 6) the effect of operational carbon on the shape of the graph reduces dramatically, and the curves more closely resemble those describing the embodied carbon values for each material (i.e. Chart 5). At KPMB LAB, we strongly endorse the electrification of buildings as a critical strategy for mitigating climate change. The heat pump heating scenario is the desired condition for all buildings and should inform material selection. In all heating system scenarios, our analysis emphasizes the importance of selecting the material with the lowest GWP that meets the requirements of the specific application.

Table 1 – Insulation EPDs and GWP values

INSULATION	PRODUCT	EPD DATE OF ISSUE	GWP $kgCO_2e/m^2$
Dupont XPS	Dupont Styrofoam™ Brand XPS Products	01-Jan-21	100.06
Dupont's new XPS	North American Grey Reduced GWP Styrofoam™ Brand XPS Products	01-Jan-21	59.49
Owens Corning XPS	Owens Corning Foamular® XPS Insulation	01-Jan-19	58.07
Owens Corning's new XPS	Owens Corning Foamular® NGX XPS Insulation	01-Jan-21	9.77
Polyiso	PIMA Polyisocyanurate Wall Insulation Boards	04-Nov-20	4.29
spray foam	SPFA Closed Cell Spray Polyurethane Foam Insulation (HFO)	29-Oct-18	4.16
EPS	EPS-IA Expanded Polystyrene Insulation	8-Oct-17	2.78
Rockwool	Rockwool™ Stone Wool Insulation	17-Jul-19	2.06
Neopor GPS	BASF Neopor® Plus Graphite Polystyrene Insulation	14-Feb-20	1.87
Fibreglass batts	CertainTeed Sustainable Insulation® Unfaced Batts	01-Jan-19	1.04
blown cellulose	CIMA/CIMAC Conventional Loose-Fill Cellulose Insulation	23-Dec-19	0.70

Endnotes

1. See Table 1 for list of relevant EPDs and GWP values. GWP values stated are for 1 m^2 of $R_{SI}1$ insulation material, including LCA phases A to C.

2. We assume a natural gas condensing boiler operating at 90% efficiency, giving a GHGi of 0.183 $kgCO_2e/kWh$ (GHGi does not include values for extraction and delivery of gas, only site combustion.)

3. We assume the house is located in Ontario where the electricity grid intensity is 0.050 $kgCO_2e/kWh$ and is using an electric heat pump operating at a COP of 3.0.

4. “Global Land-Ocean Temperature Index.” Climate.nasa.gov. NASA’s Goddard Institute for Space Studies (GISS). https://climate.nasa.gov/vital-signs/global-temperature/. Accessed 12 April 2020.

5. Griffith, Saul. “How do we decarbonize?” Medium.com. 23 May 2019. https://medium.com/otherlab-news/how-do-we-decarbonize-7fc2fa84e887. Accessed XX April 2020.

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