Did You Hear Energy Intensity was Flirting with Carbon Intensity?

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ABSTRACT

Over the last several decades, energy-efficiency programs have standardized the use of efficient products to reduce operational carbon emissions. However, additional, innovative decarbonization efforts are required to help reduce catastrophic impacts of climate change. There is a path for energy-efficiency programs to strengthen their decarbonization impact by influencing the choice of construction materials to create less carbon-intensive buildings.

This paper examines how programs that influence building design and equipment choices can influence the construction materials being used—specifically insulation in residential projects—to become vehicles for decarbonization progress. The carbon emissions of insulation materials are examined using data from new homes in the Northeast to understand the impact of embodied carbon relative to operational carbon emissions. Emerging research has started to provide answers to the many questions surrounding the implementation of program designs that consider embodied carbon are being answered. This paper finds a broader program focus benefits efficiency programs with new savings opportunities and changes the cost-effectiveness equation when considering the cost of carbon.

Legislative changes will likely be required to expand efficiency program mandates. What is becoming clearer is that many practical barriers—methods of quantification, sources of emissions data, and software tools—are being addressed successfully. Traditional efficiency program activities and the established relationships these programs have in various market segments would support an expanded focus on material choices. The evolution of program design explored in this paper would increase program relevance and impact in a world where urgent decarbonization progress is needed.

Introduction

Alarming climate change trends and extreme climate events are fueling increased urgency for addressing anthropogenic climate change. This urgency is placing greater pressure on individuals, businesses, and governments to develop innovative ways to reduce their carbon footprints. Energy-efficiency programs have a long track record of reducing operational emissions (i.e., the emissions caused by building operation) by increasing the energy efficiency of equipment and systems in commercial and residential markets. However, the urgent need for greater progress in decarbonization across sectors necessitates novel perspectives on traditional efficiency activities that look beyond operational emissions.

In this paper, we begin looking beyond operational carbon emissions to lifecycle carbon impacts of buildings, and how efficiency programs affect this broader set of emissions. Programs that consider the full carbon impact of materials used to achieve operational savings become more effective decarbonization agents, in that they also address emissions from the manufacture, transportation, and retirement of materials. By examining efficiency programs with a new, more holistic focus on lifecycle carbon emissions, we envision a path forward where these programs have expanded relevance and make greater contributions to urgent climate interventions.

A New Perspective on Energy-Efficiency Program Activities

Efficiency programs have proven they are capable of transforming markets to make efficient products a standard choice, and many program administrators have established positions of influence in residential and commercial markets through their new construction and retrofit programs. A shift in program design that considers embodied carbon emissions could identify new savings opportunities and, with cost-effectiveness testing that properly values avoided carbon emissions, completely change the cost-effectiveness equation for many programs. Research from Builders for Climate Action demonstrated that building to higher efficiency levels can save somewhere between .08 and 6.5 tons of carbon dioxide equivalent (CO_2e) per year in operational emissions (depending on the grid fuel source), while adjusting the material selection in homes can save between 10 and 86 tons of CO_2e per year (Magwood et al 2021). This and other research has demonstrated the level of carbon savings available from addressing embodied carbon emissions and highlights opportunities for programs that consider these emissions.

The importance of materials becomes apparent when looking beyond a building's operational emissions to the *embodied carbon* of the materials being used in construction.[1] For efficiency programs to effectively address lifecycle carbon in participating projects, a program design must focus on how their activities contribute carbon emissions beyond building operation. Administrators can leverage their market position to influence decision-makers to consider lifecycle carbon impacts. Given the design and construction decisions programs typically affect, programs can have a greater influence on some building materials than others. The choice of insulation material is a key point in the construction or retrofit process that determines the full carbon emissions of a project. Here, we consider residential new construction (RNC) programs for their potential to influence insulation levels and insulation materials.[2] Residential retrofit markets, commercial new construction, and commercial retrofit markets are also likely entry points to influence broader material choices.

RNC programs, in their role as drivers of increased energy efficiency, can impact the choice of building materials, such as insulation. Closed cell spray foam (CCSF) insulation represents a flexible, effective path toward the high-performance building shell needed for a home to reach the efficiency levels required for program incentives. The amount of CCSF going into new homes has increased greatly over the last decade in several states as utility programs and energy codes push the housing market to greater levels of performance. CCSF also represents a family of materials with high levels of embodied carbon emissions (ECE).[3] Levels of ECE associated with common construction materials have traditionally flown under the radar in public consciousness, but they contribute 11% of all global carbon emissions (World Green Building Council 2019; Architecture 2030 2021). Operational carbon emissions (OCE) of buildings currently represent about 28% of global emissions. In new construction, the ratio of OCE to ECE moving forward will look quite different, with over half of the total emissions coming from ECE between now and 2050 (Architecture 2030, 2021).

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[1] According to the Carbon Leadership Forum, embodied carbon "refers to the greenhouse gas (GHG) emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials" (Carbon Leadership forum 2020).

[2] Research on embodied carbon emissions in the construction sector has identified materials that have the highest impact on lifecycle carbon emissions. In general, this is steel and concrete; in low-rise residential construction, this is typically insulation, exterior siding, and concrete (Magwood et al 2021).

[3] Note that some states have legislative mandates banning certain blowing agents from being used. Currently, there are ten states that have banned or plan to ban Hydrofluorocarbon (HFC) blowing agents. The blowing agents themselves are discussed in more detail in the analysis section.

Shifting Program and Regulatory Contexts

Energy-efficiency programs operate in ever-changing regulatory landscapes, including some where decarbonization is becoming a greater focus. Massachusetts provides an example: recently, the state passed an ambitious climate bill with a roadmap to achieving net-zero GHG emissions by 2050.[4] As part of this legislation, the state will require the Department of Public Utilities to make decarbonization a focus of its utility oversight. Mass Save®, the statewide energy-efficiency program administrator, is an industry leader in executing effective efficiency programs but will soon operate in an environment where decarbonization is a key focus. This shift elicits questions about how energy-efficiency programs can be more impactful in a regulatory environment focused on decarbonization. If a new construction program pushed for higher levels of home efficiency and used its connections with practitioners to push program participants to consider the ECE of project materials, the program could expand its role in decarbonization greatly.

This thought exercise raises questions about regulatory and practical feasibility, who is responsible for measurement and verification, etc. We do not offer answers to all these questions in this paper. Rather, we hope to start a conversation about efficiency programs and embodied carbon that is informed by the latest lifecycle carbon research and policy developments while being cognizant of the specific conditions and constraints under which efficiency programs operate.

Key Terms

A variety of definitions and terms are used to discuss GHG emissions in building lifecycle stages. This can lead to different interpretations among sectors, regions, and countries (World Green Building Council 2019). The term “carbon emissions” refers to all emissions of GHGs, and the global warming potential (GWP) of the GHGs are calculated as a unit of carbon dioxide equivalence (i.e., a kilogram of carbon dioxide equals 1 kgCO2e) over a specific period (typically 100 years). The GHG emissions associated with the carbon lifecycle of buildings are classified as either OCE or ECE. The operational carbon of a building consists of the energy consumed by the building—the direct fuels used and the fuel source of delivered electricity, commonly referred to as source energy (Sturgis, 2017). ECE accounts for GHG emissions from the building lifecycle, which includes the product stage, the construction process stage, the use stage, and the end-of-life stage. As defined by European Standard 15978, the product stage of the lifecycle accounts for the raw material extraction (A1), transportation (A2), and manufacturing of the building materials (A3) used to construct a building. The construction process stage accounts for transportation to the building site (A4) and construction and insulation processes (A5). The use stage accounts for use (B1), maintenance (B2), repair (B3), refurbishment (B4), replacement (B5), and operational energy use (B6). The end-of-life stage accounts for deconstruction or demolition (C1), transport (C2), waste processing (C3), and disposal (C4) (EN 15978).

This paper focuses on what is considered upfront carbon (i.e., A1-A3 and A5), which are emissions that occur before the building is occupied—specifically the upfront carbon associated with insulation materials. Note that some insulation materials, such as spray foams, use blowing agents that release GHG emissions during installation (B1). These emissions are considered a part of the GWP of the material (Nedzinski 2021). This paper does not consider the ECE associated with the transport to construction sites (A4) due to significant variations that may occur in this category. We also do not consider the ECE from the use stage (B2-B5) and end-of-life stage (C1-C4) in the buildings’ carbon lifecycle.

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[4] Senate Bill 9 – *An Act Creating a Next Generation Roadmap for Massachusetts Climate Policy*: https://malegislature.gov/bills/192/S9

Environmental Product Declarations (EPDs) are a voluntary and transparent process that documents the environmental performance of a product or material over its lifetime. EPDs include information on the GWP of a product or material and are commonly used by both practitioners and researchers to explore ECE impacts that result from building material usage (One Click LCA 2021). There are standards that guide the development of EPDs, such as the ISO 14025 Type III standard (ICC, 2021).

Research Methods

We conducted a literature review focused on ECE quantification and the impacts of building interventions and material choices on ECE and OCE levels. The literature review also covered policy developments around construction material procurement and influencing ECE outcomes in building construction. In addition, we looked at publicly available databases that included GWP data for embodied carbon, ultimately leveraging existing research and the Embodied Carbon in Construction calculator (EC3).[5] We also conducted a technical potential analysis to estimate the ECE associated with the insulation practices observed in RNC baseline studies conducted in several Northeast states between 2015 and 2019. This analysis covered the type of insulation, the carbon impact of those materials, volumetric data on insulation per project, and the volume of new construction occurring over the period covered in the evaluations. There is software available to estimate ECE impacts, but we did not assess any software as a part of this research. We conducted ten interviews with embodied carbon industry experts with backgrounds in building design, construction, and policy development. In these interviews, we asked about the state of research, current and potential policy interventions, the feasibility of measuring holistic carbon intensity baselines, the ability to quantify ECE, and potential incentive structures.

Examining the Technical Potential for Embodied Carbon in Efficiency Programs

Analysis Methods, Considerations, and Limitations

A series of RNC program evaluations conducted on single-family homes in the Northeast between 2015 and 2019 collected detailed data on insulation types and levels in new homes. The evaluations examined housing stock in Connecticut (NMR Group, Inc. 2017), Massachusetts (NMR Group, Inc. 2016 and NMR Group, Inc. 2020), and Rhode Island (NMR Group, Inc. 2018).[6] We selected these evaluations for the technical potential analysis because they provide publicly available data on the insulation materials observed in non-program (or baseline) homes and serve as baseline scenarios for calculating energy savings for energy-efficiency programs. These evaluations show trends of increased use of insulations with higher GWP than others, likely to achieve higher operational energy savings. These insulation data can bolster findings from recent studies that highlight the potential for carbon emissions reductions by lowering the GWP potential of materials used in the low-rise RNC market (Magwood et al 2021; Just 2021).

The purpose of this analysis was to understand the GWP impact of insulation materials used in typical baseline practices of the single-family RNC market in the Northeast. The data required to calculate the ECE of materials used in construction includes the type of material, the amount of material used, and the GWP of the material (obtained from an EPD). The data on material type and area are often collected

[5] EC3 is a free tool that interviewees commonly referenced as a source of information on the ECE of building materials and was commonly used as the data source for analysis in the literature reviewed. Additional public databases include the Inventory of Carbon and Energy (ICE) and Quartz.

[6] These baseline evaluations are referenced throughout the remainder of the paper. Note that all the information regarding home size, home efficiency, insulation material type, and average R-values use these evaluations as a source. The date of publication occurs one year after the on-site studies were conducted.

(to some degree[7]) to develop energy models. They can also be gleaned from project documentation submitted for projects that participate in energy-efficiency programs.

The baseline evaluations demonstrate how the saturation of insulation materials observed in newly constructed homes has changed over time. The evaluations included general statistics on the average home and key building shell details. In this analysis, we used these home characteristics to calculate building shell dimensions for a *baseline* home. We then calculated the GWP of the observed insulation materials with EPD data from the EC3 database. To corroborate our approach, the GWP data source (EC3) aligns with a case study conducted in Vermont that estimated the ECE for three RNC pilot projects (Building Transparency 2021; Just 2021). We multiplied the GWP of the material by the average area for each building shell component and the amount of insulation material needed to meet the baseline R-value, and then we multiplied it by the saturation of the insulation material. We then scaled these values to see the estimated impact of insulation materials in newly constructed homes using U.S. Census permit data. Example calculations demonstrate this process and allow for the analysis to be duplicated with comparable data from other jurisdictions.

There are inherent limitations to this analysis. These limitations include (1) the lack of data on specific insulation materials used in program participant homes from the example states and (2) the lack of consideration for the impacts of other materials used in the building assembly, such as cladding or structural materials like concrete, wood, and steel, all of which also have major implications on the overall ECE of the building.

Baseline Trends and Characteristics of RNC in the Northeast

The materials and equipment that make up newly constructed homes have evolved as energy codes have become more stringent, customer desire for lower energy burden has increased, and energy-efficiency programs look to achieve deeper energy savings. To inform the ECE analysis, Table 1, below, shows the saturation of insulation materials used for above-grade walls in baseline new construction projects from 2015 to 2019.[8] The trends over this period highlight a growing use of materials with higher embodied carbon, such as spray foams. These materials often have a higher R-value per inch of material than the traditional alternatives, allowing a designer or builder to maximize the thermal performance of the building shell within the confines of standard framing practices (such as 2x6, 16" or 24" on-center).

Table 1 – Saturation of observed insulation material for above grade walls in each baseline evaluation

Insulation type – Above Grade Walls	2015 MA RNC baseline	2016 CT RNC baseline	2017 RI RNC baseline	2019 MA RNC baseline
Fiberglass batts	88%	75%	71%	59%
Open-cell spray foam (OCSF)	4%	6%	7%	22%
CCSF – 2019[a]	--	--	--	8%
CCSF – HFC	3%	10%	2%	--
Rigid foam[b]	--	--	--	6%
Cellulose – dense pack	3%	4%	2%	4%

[7] Energy modeling software does not have an input for material type but does provide a notes field for the modeler to include notes. However, these evaluations included data collection on the type of insulation materials.
[8] Note that additional building components are included in the analysis results, but the component-level data is not presented here due to space constraints.

Mineral wool – batt	--	--	17%	2%
Extruded polystyrene insulation (XPS)	2%	2%	--	--
Polyisocyanurate	--	2%	1%	--
Mineral wool – blown	--	2%	--	--

[a]2019 Closed-cell spray foam assumes that 30% of the area uses an HFO blowing agent. HFO blowing agents have a significantly lower GWP than HFC blowing agents and are being phased out of some states through legislation.
[b] Some baseline evaluations did not distinguish between continuous insulation types and were just labeled as rigid foam board. We assumed an average of XPS, EPS, and Polyisocyanurate to determine the GWP.

To inform the ECE in the analysis below, we compiled material saturation data from the evaluations for all building shell components modeled (i.e., above grade walls, framed floor, foundation walls, and ceilings). We use the average R-value for each building component presented in the RNC baseline evaluations and used these average values and the saturation rates in the analysis.

The inputs used in the analysis are based on home characteristics from each of the baseline evaluations. The configuration of a building can be complicated to summarize as there are some components that may exist in one building and not in the other (e.g., a home may have all vaulted ceilings, all flat ceilings, or a combination). The example home used in this analysis reflects the prevalence of specific components among the sample of homes across the study samples (i.e., 2,700 square feet with 66% flat and 34% vaulted ceiling area, and prorated framed floor by 60% and conditioned foundation wall area by 26% based on the observed proportion of homes with these features). This approach allows the calculations to account for the insulation observed in all the building components without creating multiple variations of the prototype home.

GWP of Insulation Materials

The table below provides the GWP and R-value per inch for each of the insulation materials observed in the baseline evaluations. We used these values to determine the estimated ECE of insulation materials used in baseline new construction practices.

Table 2 – GWP and R-value per inch values for the insulation observed in the baseline evaluations

Insulation material	GWP (kgCO2e/m^2 at 1” RSI)	R-value per inch
Fiberglass batts	0.68	3.64
Fiberglass blown	1.30	2.68
Fiberglass dense pack	1.64	4.00
Cellulose – blown	-0.83	3.38
Cellulose – dense pack	-2.16	3.56
Mineral wool – batt	3.25	4.24
Mineral wool – Blown	5.18	2.95
CCSF – 2019	11.60	6.60
CCSF – HFC	14.86	6.60
CCSF – 2019, Roof	14.95	6.50
CCSF – HFC, Roof	19.33	6.50
OCSF	1.59	4.05
Polyisocyanurate	2.32	6.53
EPS (10-PSI, graphite)	1.78	4.70
Rigid Foam	14.72	5.41
XPS (15-PSI)	39.04	4.99

In Figure 1, we present an example of how we calculated the GWP of the insulation material and, ultimately, the ECE within the building. Readers can use this formula to calculate ECE for building shell components, applying the same process and substituting values based on the evaluation or use values from a jurisdiction of interest.

$$\begin{aligned}&Embodied\ carbon\ (kgco2e)\\&\qquad = GWP \times (R - value\ per\ inch \times RSI\ constant)\\&\qquad \times (average\ Rvalue \div Rvalue\ per\ inch)\\&\qquad \times (Component\ Area\ (sq.ft.) \times (1 - Framing\ Factor)\\&\qquad \div \text{meter}\ conversion\ factor) \times Saturation\ of\ insulation\ material\end{aligned}$$

Figure 1 – Equation to estimate embodied carbon of insulation materials.[9, 10, 11]

Estimated Embodied Carbon of Insulation Materials

Table 3 presents the overall estimated ECE of insulation materials used in baseline homes. The results are shown as average estimated per-home ECE of insulation materials by building component. These estimates reflect the observed saturation of different materials across evaluation samples. Comparing Massachusetts in 2015 and 2019 highlights the increased impact on ECE from insulation materials used. Between the 2015 and 2019 baseline studies, there was an increase of 88% in EC, but only a -0.3% to 27% increase in the average R-value, depending on assembly.[12] While spray foams exhibit a higher GWP than some alternative insulations, they do have air sealing properties that the alternative insulations may not, indicating that different air sealing strategies (or different overall design strategies) are likely required to effectively reduce OCE *and* ECE.

Table 3 – Estimated embodied carbon (kgCO2e) of insulation materials per home in baseline homes

Building shell component	2015 MA RNC baseline	2016 CT RNC baseline	2017 RI RNC baseline	2019 MA baseline
Walls	737	1,172	643	1,121
Floors	421	534	327	602
Flat Ceilings	575	885	843	736
Vaulted Ceilings	469	1,392	1,104	1,954
Foundation Walls	368	149	330	413
Total	**2,570**	**4,133**	**3,248**	**4,827**

[9] RSI to R-value conversion factor to account for the difference in units. An RSI value of one is equivalent to an R-value of 5.768.

[10] Framing factors account for the space taken by the frame and is not insulated. The framing factor that was most common was 16” on-center (framing factor of 0.23), except for the 2019 baseline, which was 24” on-center (framing factor of 0.20). Continuous insulation did not have a framing factor applied.

[11] The GWP of the material is presented per square meter of area, while the area of homes in the U.S. are typically represented in square feet. The conversion factor to get square feet to square meters is 10.764.

[12] Specifically, the change in R-values for the assemblies are as follows: above grade walls (3.8%), framed floors (-0.3%), flat ceiling (9.5%), vaulted ceiling (26.8%), and foundation walls (0%).

To estimate the statewide level of ECE in insulation materials, we multiplied the per-home estimates by the number of permitted new homes in each state for the given year of the evaluation (U.S. Census RNC permit data). Note that the lack of data on the insulation material-mix of the single-family program homes in each of these states is an inherent limitation to this estimate (i.e., the statewide estimate assumes all homes are similar to the baseline home). Having this information would allow for a more comprehensive estimate of statewide ECE. We hypothesize that with program data applied, the statewide estimates of ECE from insulation materials would increase, as program homes generally have a more efficient building shell.

Table 4 displays the statewide estimates for ECE. To develop this table, we multiplied the per-home ECE estimate based on each evaluation by the one- and two-unit permit counts for the year prior to the site visits being conducted. This approach assumes a one-year lag between permit and construction. To help the reader contextualize the statewide estimates, we include the emissions equivalence for home energy use and home electricity use, as well as the equivalence in sequestered carbon (EPA 2021). For example, the 2019 Massachusetts baseline results indicate that the CO2e associated with insulation materials is equivalent to the annual energy consumed in 4,548 homes, the annual electricity consumed in 6,860 homes, or the annual carbon sequestered in 46,268 acres of U.S. forests.

Table 4 – Estimated statewide embodied carbon emissions in one- and two-unit structures[13]

	2015 MA RNC baseline	2016 CT RNC baseline	2017 RI RNC baseline	2019 MA baseline
Permit year applied	MA, 2014	CT, 2015	RI, 2016	MA, 2018
Metric Tons of CO2e	19,712	10,390	3,246	37,764
Emissions equivalence**:**				
Average home's energy use	2,374	1,251	391	4,548
Average home's electricity use	3,580	1,887	590	6,860
Carbon Sequestered**:**				
Acres of U.S. Forest in one year	24,150	12,729	3,977	46,268

Why Programs Should Consider Embodied Carbon

Because efficiency programs already address OCE reductions and are designed around that specific purpose, some may argue that maintaining that focus and addressing ECE through other structures would be more effective. Efficiency programs already face challenges, including shrinking savings opportunities, accessing hard-to-reach populations, and determining specific measures and activities to support in an uncertain future. Many programs with more traditional resource acquisition designs must also meet cost-effectiveness testing criteria, such as the TRC test. Cost-effectiveness testing can constrain program designs and result in avoiding activities that carry risk of unrealized savings that might not balance out program costs, especially if the value of avoided carbon emissions is not included among the benefits.

Given what we know about the embodied carbon associated with materials choices, program influence over materials choices in participating projects in ways that are verifiable (i.e., the program can claim attribution under criteria set by regulators and independent evaluators) should change the cost-effectiveness for a program when the value of avoided carbon emissions is included. This could result in

[13] Emissions equivalence and carbon sequestered metrics are provided to help contextualize the estimates.

larger program budgets and expanded activities, including greater support for emerging technologies and other interventions that might not be pursued due to program funding constraints.

From a more practical standpoint, the application of ECE goals in programs would require many of the same activities that currently support efficient products and practices. Addressing ECE can fit into traditional resource acquisition frameworks, as it would focus on driving participating projects to consider materials with low GWP and claim impacts from that narrow interaction. A more market transformation-oriented approach to addressing ECE might include more education and awareness-building activities, perhaps leveraging existing program-sponsored or program-adjacent training efforts to share information about ECE considerations. One example is the code compliance and support trainings used in Massachusetts and Rhode Island to support compliance with energy code provisions.[14] A market transformation approach could also involve leveraging existing program relationships and workflows to disseminate information into the wider market and influence market actors beyond the direct reach of the program. Key examples here include HERS raters and the sustainability consultants that programs work with to facilitate the participation process and verify compliance with program requirements. Jurisdictions considering adopting a programmatic focus on ECE that takes a market transformation approach should consider that these types of programs are often supported with different regulatory structures and cost-effectiveness criteria. Market transformation efforts typically have a longer-term focus than resource acquisition. They are not expected to generate verifiable savings from day one. Regardless of approach, a shift in regulations guiding utility program savings targets to include ECE may spur beneficial changes—such as improvements to the cost-effectiveness testing to fully value environmental impacts, including lifecycle carbon emissions—that can position programs to take upside risks and pursue innovation.

Practical Considerations for Quantifying Embodied Carbon

Efforts to quantify and incentivize reductions in ECE must address who will collect the data and how regulators can accurately assess the true carbon impact of a project. EPDs have increased in availability for key products. While there are multiple types of EPDs with varied comprehensiveness and availability (Lewis et al. 2021), each provides a solid foundation upon which to base quantification efforts. The main variable is the volume of material going into a project. In many jurisdictions, these data are being collected as part of standard practice for energy code compliance, efficiency program participation, or building energy disclosure initiatives.

One of the key takeaways from those we interviewed who are addressing ECE is the potential to leverage existing building performance assessments to quantify ECE in projects. An example that came up often was the energy modeling software used to perform HERS ratings or similar energy ratings in homes.[15] This process includes calculating all the volumetric data needed to quantify the amount of a material, such as insulation or concrete in the home. Typical energy models will include the square footage of wall area, the stud depth or thickness of the wall assembly, and the R-value of the material in the cavity. Best practices for data entry include naming assembly entries with details about the type of material in the assembly (e.g., above grade wall, 5.5" open cell spray foam [OCSF]). With additional details on the type of product, or the inclusion of categories to select insulation-type within the software, an export of

[14] Massachusetts is currently assessing the implementation of a net-zero stretch code as part of its enhanced decarbonization efforts. Code compliance and support training efforts around this advanced code could represent entry points for discussion and awareness building on embodied carbon emissions.

[15] The HERS Index is an energy rating system developed by the Residential Energy Services Network (RESNET) and is aimed largely at the low-rise residential market.

this energy rating data into a tool that applies EPD data (from databases like EC3) for building products can streamline the ECE calculations.

As a result, embodied carbon advocates have identified software tools like Ekotrope® as key resources for tracking ECE in regulatory or incentive schemes aimed at the residential market. Similar workflows were implemented by Builders for Climate Action in their study comparing the OCE and ECE impacts of construction choices in new homes. That study team developed a carbon calculation tool that was able to process data exports directly from the HOT2000 energy modeling software. The data housed in the energy rating tool is pulled into the calculator, which has EPD data for building materials, and ECE totals are calculated from the combination of data points (Magwood et al 2021). Advocates in the U.S. propose a similar approach using software such as Ekotrope. The Northeast Home Energy Rating System Alliance (NEHERS) operates an embodied carbon working group that advocates for integrating an ECE focus into the HERS rating scheme. They note that HERS raters already collect over 65 data points that can contribute to both OCE and ECE quantification as part of standard rating practices (NEHERS, 2021).

For new construction markets, the factors discussed above point to the growing ranks of HERS raters and other sustainability consultants as candidates to assist with implementing ECE quantification for programmatic and regulatory purposes. NEHERS states that HERS raters are "uniquely poised to deliver the data needed to begin embodied carbon tracking in the United States" (NEHERS 2021). RNC efficiency programs already rely on these energy raters to provide the energy performance data needed to assess if homes meet program requirements. Available research and feedback from interviewees show that many practical barriers to quantifying ECE can be addressed through established industry relationships, synergies in data collection, and available EPD data compiled in secondary sources.

Regulatory and Funding Considerations for Embodied Carbon and Efficiency Programs

For the type of program design changes discussed in this paper to happen, the regulators overseeing efficiency programs will need to adjust the frameworks governing their goals and purpose. In Massachusetts, for example, the development of energy-efficiency plans have been directed by the Green Communities Act since 2008 to "provide for the acquisition of all available energy efficiency and demand reduction resources that are cost-effective or less expensive than supply." However, decarbonization policies are coming online that prioritize emissions reductions and increase the burden on key emitters to change their practices. The recent Massachusetts climate bill and similar efforts in other states may represent legislative openings to reconsider the goals and expand the purpose of efficiency programs.

Funding for efficiency programs typically comes from various charges to ratepayers. New approaches would be necessary to address program designs that move beyond the energy grid/ratepayer relationship. The Regional Greenhouse Gas Initiative (RGGI) in the Northeast and Mid-Atlantic regions provides an example.[16] The RGGI is a cap-and-trade framework. Regulated power generators are subject to emissions limits and are required to hold allowances, issued by the state regulator, equal to the total GHGs they emit. These allowances can be traded among states at regional auctions, and the proceeds from the auction of allowances have traditionally been used to fund some amount of the costs of energy-efficiency programs. Both The New York State Energy Research and Development Authority and Mass Save use proceeds from the RGGI to fund efficiency programs.[17] With an increased emphasis on decarbonization being placed on utilities in Massachusetts through new climate legislation and a mandate for the Department of Public Utilities to include decarbonization as a policy focus, there may be new

[16] RGGI states include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia. RGGI detail can be found here: www.rggi.org

[17] Mass Save uses the RGGI for about 10% of funding needs per year https://www.mass.gov/service-details/massachusetts-energy-budgets-investments

opportunities for regulated distribution companies to create more RGGI allowances by lowering their emissions, leading to increased auction proceeds. These additional proceeds could then fund expanded utility activities around controlling ECE.

Conclusion

The analysis revealed a potential strategy for program administrators to understand the ECE from insulation choice in their markets and highlights how increased home efficiency may lead to increased ECE if material choices are not considered. Limiting ECE through the activities of energy-efficiency programs represents a major evolution in the guiding principles of these programs. For this to be a dedicated effort, there will need to be new funding mechanisms, likely requiring high-level policy decisions and legislative changes. We encourage readers who wish to pursue ECE to focus on the expansive research and advocacy work that has reduced uncertainties surrounding program designs that address ECE in new and existing structures. Embodied carbon impacts can potentially outweigh operational energy-efficiency gains, and ECE reductions are immediate (unlike OCE reductions). Data on the emissions impacts of many building materials are publicly available as industry professionals already collect much of the data needed to quantify the ECE of specific structures. More tools are coming online to easily quantify the ECE of a building, and work is underway to tie these tools into common energy modeling and design software. Current energy-efficiency program structures and activities can be leveraged or repurposed to address ECE and influence the market to also consider the impacts of their material choices. Many of the practical considerations have answers, or information that could lead to answers. We hope that this progress will support productive conversations about new possibilities that will not be derailed by unknowns.

Additional research opportunities on this topic include potential savings from substituting commonly used materials with lower GWP or biogenic materials that sequester carbon for the life of the material; the baseline conditions for specific market segments (e.g., residential or commercial, retrofit or new construction); embodied and operational carbon savings assessments; health-benefits; economic impact of localized supply chains; and challenges and barriers to transform markets to materials that sequester carbon, including costs, impact on other material usage (for example using a double-stud wall vs. traditional wall), and industry awareness.

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