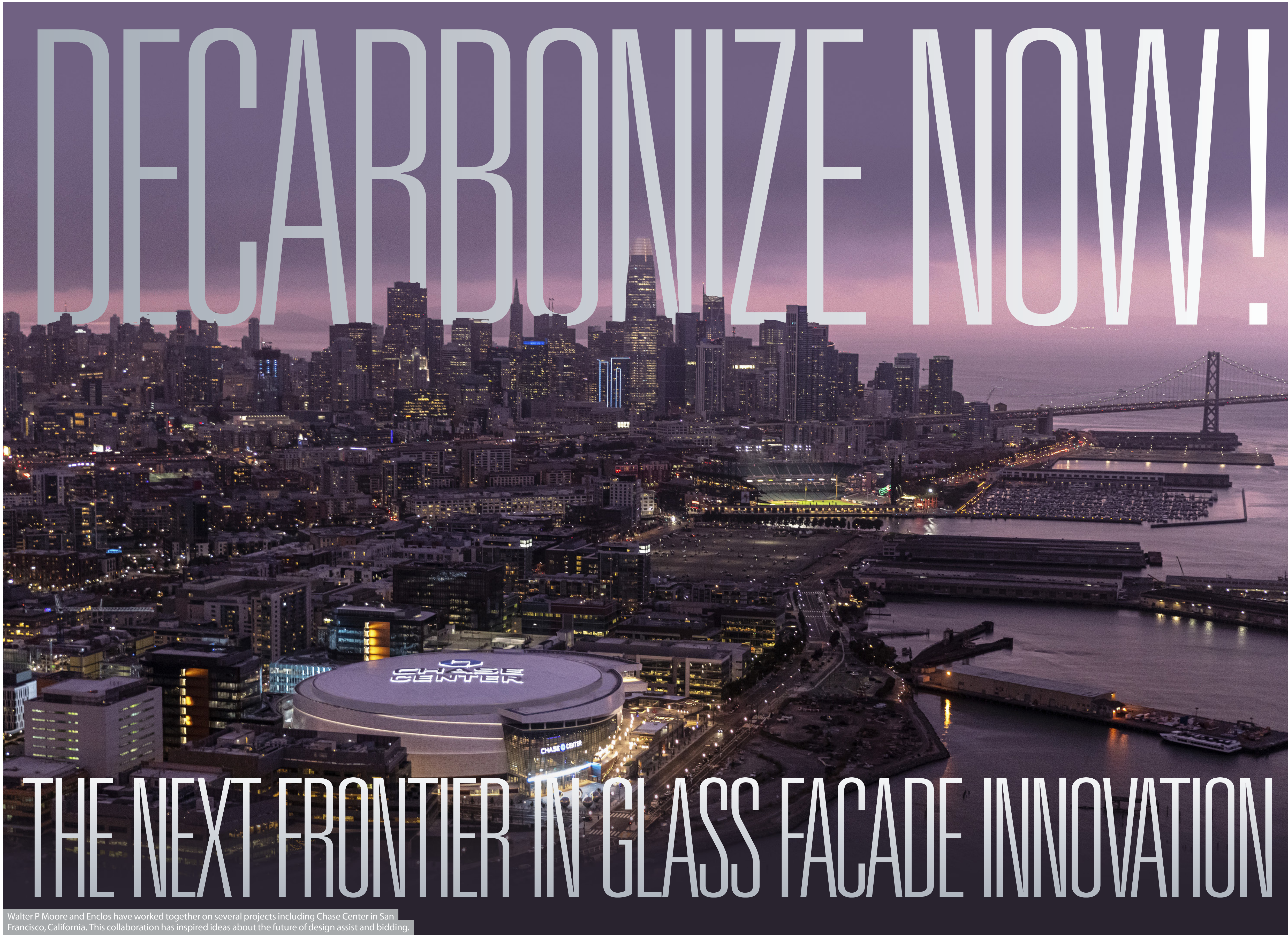
DECARBONIZE NOW!

THE NEXT FRONTIER IN GLASS FACADE INNOVATION



Walter P Moore and Enclos have worked together on several projects including Chase Center in San Francisco, California. This collaboration has inspired ideas about the future of design assist and bidding.

Laura Karnath, AIA, NCARB, Senior Associate and Senior Enclosure Technical Designer, Walter P Moore and Sophie Pennetier, Associate Director, Special Projects, Enclos

Addressing the costs of carbon through the life cycle of buildings, from manufacturing, transportation, use, and less tangible social costs

In search of natural daylight, views, and enhanced performance, architectural glass has a long history of driving innovation in construction. Today the greatest challenge facing the building industry is the climate crisis. It is well known among building industry professionals that buildings are responsible for approximately 40 percent of global carbon emissions. There are two types of building-related carbon emissions we must consider: operational carbon and embodied carbon.

Operational carbon emissions correspond to the building's energy use throughout its entire life and represent 28 percent of global carbon emissions, according to the Carbon Leadership Forum. Embodied carbon emissions, representing approximately 11 percent of global carbon emissions, are the emissions associated with building materials and construction: from the extraction and processing of raw materials to manufacturing, transportation, and installation on site (see Fig. 1). These emissions occur up front, before a building is even occupied. Tackling embodied carbon emissions is crucial to meeting the near-term climate goals set forth in the Paris Agreement.

The building industry as a whole and the architectural glazing industry in particular have been markedly successful at reducing operational carbon emissions through improvements in insulated glass units and low-e coatings. There is still much progress to be made, however, on reducing and eventually eliminating embodied carbon emissions associated with the production of facade materials, including glass, aluminum, gaskets, and sealants. We believe supply chain decarbonization is the next frontier of innovation in architectural glass.

Drivers of Embodied Carbon

To understand embodied carbon, we need to understand supply chains and manufacturing processes. Designers should ask themselves: "How and where are the materials I am specifying made?"

The power sources used in manufacturing, including both power purchased from the local grid and on-site fuel combustion, have a substantial impact on embodied carbon of building products. Norsk Hydro and the NSG Group are two manufacturers who are leading the charge in decarbonizing materials used in glazed facades. The NSG Group recently announced they conducted a successful trial of hydrogen power in one of their float lines, which if implemented at scale could dramatically reduce the carbon emissions of glass production. Norsk Hydro currently offers low carbon aluminum with a global warming potential (GWP) of only 4kgCO2eq per kg of aluminum, which they claim is approximately one quarter of the industry average emissions. They achieve carbon reductions through the use of renewable energy at their Norwegian smelters and recycling of post-consumer aluminum, using much less energy than the production of primary aluminum. They aspire to deliver commercial quantities of near-zero carbon aluminum in 2022, with a GWP below 1kgCO2eq per kg of aluminum, and to achieve net-zero aluminum by 2030. Sourcing materials from low-carbon manufacturers seems ideal, but is not yet available at scale and might not match the client's budgets and schedules. Design and construction teams will have to explore other options for carbon reduction while these technologies are scaling up.

Beyond manufacturing, the emissions from transportation, especially in the U.S. market, cannot be ignored. Research by Isabelle Hens in collaboration with Sophie Pennetier and Simon Schleicher, to be published at the next Facade Tectonics 2022 World Congress, shows GWP variations in the range of +/- 5 to 15 percent for the few supply chain options considered. It is important to note that this was a specific benchmark study, and not necessarily representative of systems outside of the context of the study, but it gives us a window into transportation impacts.

Curtain wall supply chains are complex, and design decisions can have unexpected impacts on embodied carbon due to this complexity. Unknown to most designers, choice of location for aluminum extrusion is driven primarily by finish, then length and profile width (die diameter). The location of assembly is driven by a number of factors, such as: economics, labor rates, trucking distances, and more. The same factors apply to the glass supply chain. Glass may be produced in one location, coated in another, fabricated into an IGU in a third, and the IGU installed in a curtain wall unit in a fourth, with each step requiring potentially hundreds of miles of transit between locations (see Figs. 2 & 3). All these steps happen before the glass is even transported to the construction site for installation.

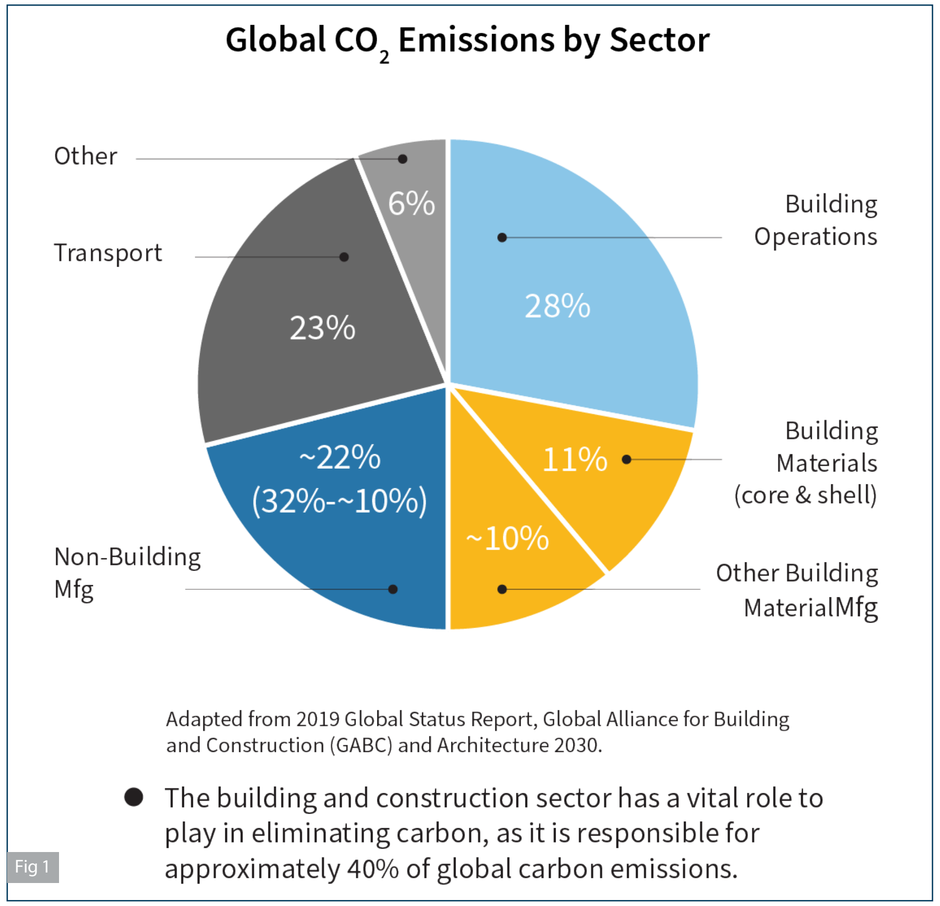


Fig 1

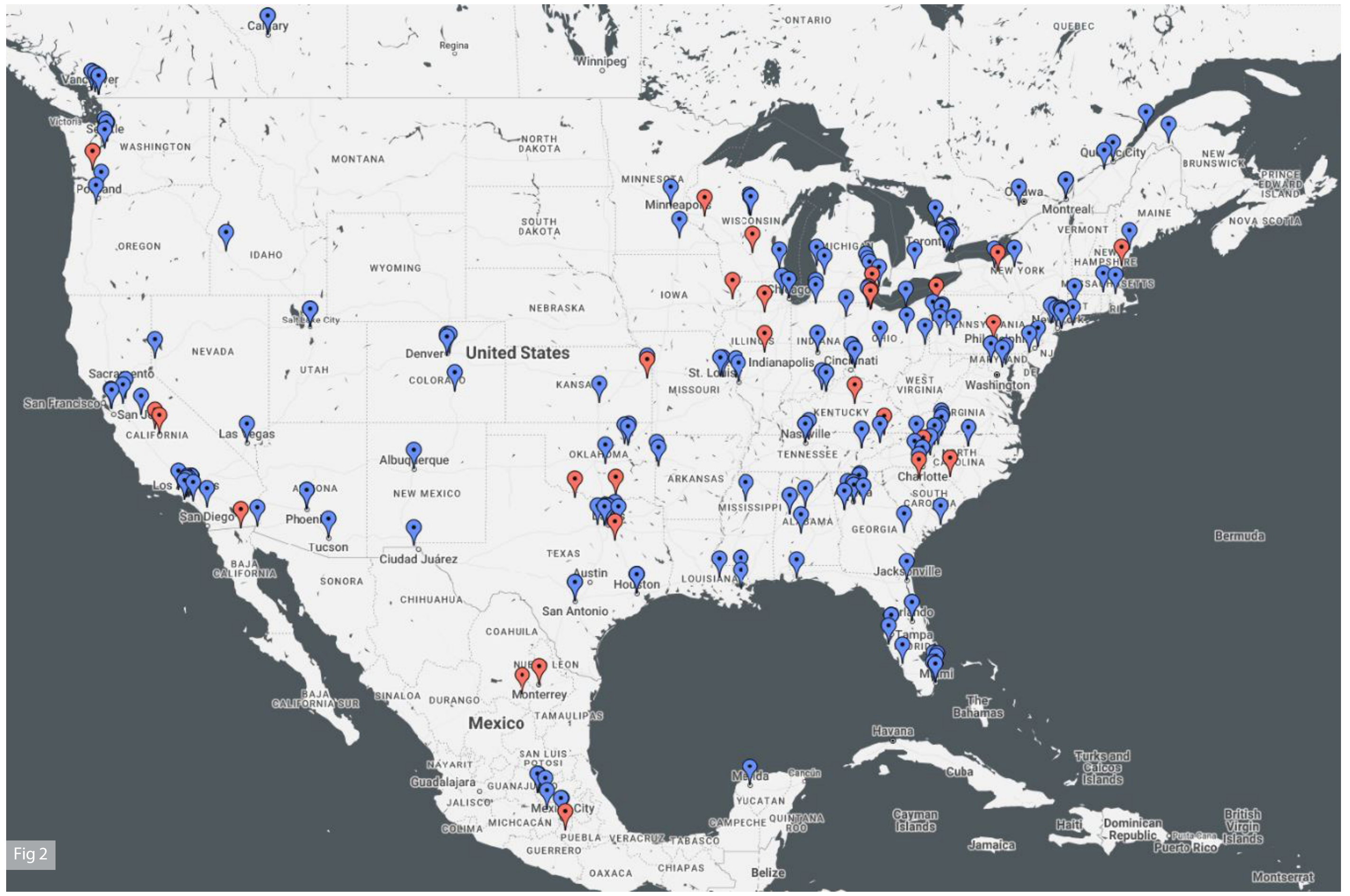


Fig 2

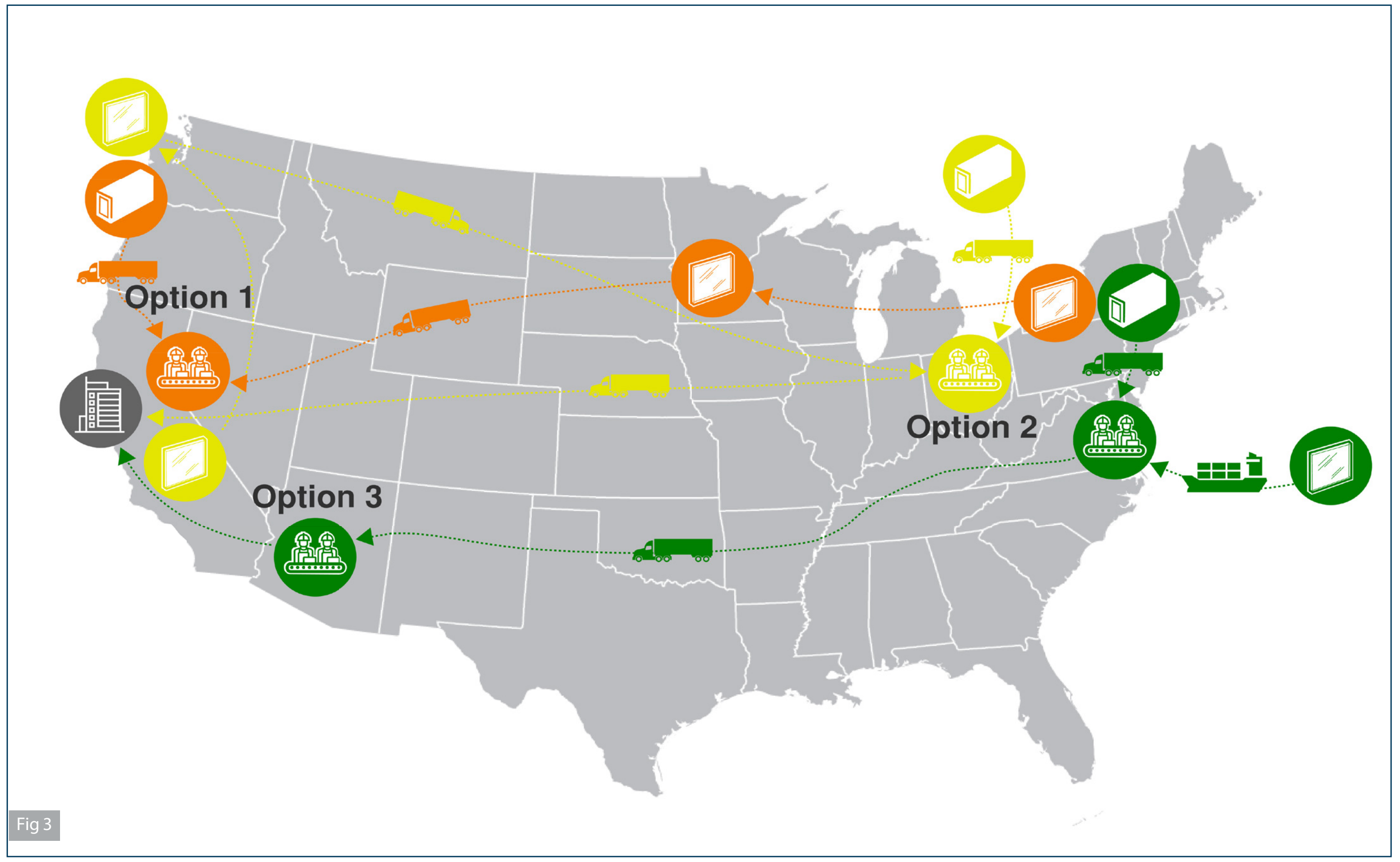


Fig 3

This fragmentation of curtain wall production has increased as shops have become more specialized, and owners' budgets have become increasingly aggressive in the context of a global market. Transportation between facilities may require trucking, which is highly carbon-intensive transportation. The North American market is most affected by this challenge, where distances are greater than in places like Europe, and where road transportation has limited alternatives.

It is important to note that transportation method matters as much as transportation distance. Walter P Moore's 2020 stewardship report, Embodied Carbon, A Clearer View of Carbon Emissions, deconstructed the impacts of different transportation methods. Its findings showed each mile of truck transport to emit nearly four times as much carbon as barge transport, when transporting the same amount of material the same distance. Thus, manufacturers in regions with better access to transportation by waterways and rail are likely to have lower transportation emissions. Where rail and water transportation are not available, transportation decarbonization is possible through electrification of trucking. California is pushing for decarbonization of trucking, and will require increasing percentages of truck sales in the state to be zero emissions vehicles starting in 2024.

Transportation impacts are even greater towards the later stages of manufacturing when trucks are "shipping a lot of air" after elements have been assembled. Many manufacturers have optimized trucking by shipping some parts "KD" (Knocked Down), to be installed on site. This approach is common for large sunshades, but yields greater installation times. It is also at odds with some virtues of unitized facades and can be a significant upcost in high-market cities.

Carbon Informed Design Assist

Due to the complexity of material procurement and manufacturing, combined with factors that influence a design, the only way to fully understand the available opportunities to reduce embodied carbon is through transparency and collaboration. Design Assist is a highly collaborative process in which the owner engages the construction team to assist the architect during the design phase. The goal of a traditional Design Assist process is to reduce cost, accelerate the schedule, and improve the curtain wall design by providing early constructability feedback and advice on material cost and availability.

We propose taking this collaborative approach to the next level by leveraging the expertise of the contractor and curtain wall fabricator to optimize the curtain wall for embodied carbon reduction through a Carbon-Informed Design Assist process. This process enables every stakeholder to understand the environmental impacts of design and procurement decisions early enough to have a real impact.

As a Design Assist partner, a contractor can provide insight into the complexity of supply chains and drivers of carbon emissions that designers may not have access to, and through a Carbon Informed Design Assist process can suggest simple changes which could dramatically reduce embodied carbon emissions associated with the facade. For example, they can notify the design team and client when a design decision triggers carbon-intensive supply chains. Currently, the bigger aluminum extrusion presses used for curtain wall mullions, shading fins, and other aluminum features larger than 16 in. (typically) are located outside the U.S., while 12 in. presses are still rare across the U.S. While the die diameter threshold is ever evolving, a continued dialog between parties should identify when a design change yields a supply chain change. The same logic applies to maximum lengths and weights for finishing lines for painting and anodizing tanks. Typically, smaller parts are available from a wider range of suppliers and there are likely to be more local options.

Architectural glass may be produced in one location, coated in another, fabricated into IGU in a third location, and installed in a fourth location. There may be hundreds of miles between each location.

Architectural glass may be key to supply chain decarbonization.

These factors can all be considered through an optioneering process, which designers are especially well-positioned to take on. By the time a bid is out, it is typically too late for the manufacturers to make any substantial change to reduce environmental impacts. Designers are accustomed to using computational tools to iterate through multiple options throughout the design process, taking a diverse array of factors into account. Traditionally, this process has been used to define and rationalize complex geometry for constructability and to enable more efficient design coordination. We propose re-deploying the computational tools, skill sets, and workflows design firms have at their fingertips in service of developing low-carbon design solutions. The best results can only be achieved if the right information is available when design and procurement decisions are being made. Vital to this process are transparency, collaboration, and shared commitment to a common goal of delivering the lowest carbon projects possible. Key information from the contractor, when provided at the right time, can be integrated back into the computational design and optimization process.

Holistic Bidding

Holistic bidding is a departure from the typical combination of Budget + Schedule + Specifications. It is a transparent evaluation process, adding criteria beyond industry standards but not necessarily connected to a points system like LEED (which is typically not considered during the bidding process). In the table in Fig. 4 (adapted from a matrix designed to evaluate embodied carbon in concrete mix designs) several wall systems are evaluated based on cost and carbon in the context of an example project. It is important for all stakeholders involved to understand the importance of considering each system cost in a specific project context, as factors like local labor rates, project schedules, and others can be variable. Within the U.S. the same curtain wall system may have different unit costs from place to place. (Note: the costs included in this example are for illustration only and do not reflect a real project.)

XXXX

Wall Type	Area [sf]	Design Team Estimate/Target/Cap					Supplier BASE Bid					Supplier Low Carbon ALTERNATE				
		GWP [kgCO2/m2]	Total GWP [kgCO2]	u_cost [$/sf]	Projected Cost	Lead Time [weeks]	GWP [kgCO2/m2]	Total GWP [kgCO2]	u_cost [$/sf]	Cost	Lead Time [weeks]	GWP [kgCO2/m2]	Total GWP [kgCO2]	u_cost [$/sf]	Cost	Lead Time [weeks]
EWS-1	4,000	180	720,000	175	$700,000	12	155	620,000	190	$760,000	12	130	520,000	200	$800,000	16
EWS-2	2,000	160	320,000	200	$400,000	16	180	360,000	210	$420,000	16	190	380,000	185	$370,000	16
EWS-3	7,000	100	700,000	300	$2,100,000	18	80	560,000	260	$1,820,000	18	80	560,000	310	$2,170,000	20
EWS-4	8,000	130	1,040,000	250	$2,000,000	20	150	1,200,000	110	$880,000	20	110	880,000	270	$2,160,000	12
TOTAL COST			**2,780,000**		**$ 5,200,000**			**2,740,000**		**$ 3,880,000**			**2,340,000**		**$ 5,500,000**	
GWP REDUCTION								**-1%**		**-25%**			**-16%**		**8%**	

Fig 4

$$f(x) = \sum \left[(GWP_{A,N})^a + (GWP_{A,N} - GWP_{IND,N})^b + (GWP_{A,N} - GWP_{A,N-3})^c + (D)^d + (E)^e \right]$$

$f(x)$: Carbon evaluation parameter value, unitless

a, b, c, d, e: factors at the discretion of the bidding team

$GWP_{A,N}$: GWP of supplier A, at year N, reflects the supplier's system current GWP
$GWP_{A,N-3}$: GWP of supplier A, at year N-3, reflects the supplier's system GWP 3* years ago
$GWP_{IND,N}$: GWP of industry, at year N, reflects the supplier's industry system current GWP
$(GWP_{A,N} - GWP_{IND,N})^b$: current carbon competitiveness of the supplier vs. the industry
$(GWP_{A,N} - GWP_{A,N-3})^b$: current carbon improvement of the supplier over the past 3* years
D : represents the positive impact of investments over the past 3 years towards decarbonization (covers equipment capital, research and development, etc.)
E : other factors to be defined, such as project-specific carbon innovation

* 3 years for illustrative purposes only, at the discretion of the bidding team

Fig 5

With increased demand for faster turnaround times during the post-lockdown economic recovery, contractors and manufacturers will also need further improvement of the bidding process in order to free up resources to evaluate low-carbon supply chain options. For instance, in the U.S. market, still too few projects leverage BIM as the central bidding platform. The ideal solution is to incorporate into the bidding platform the necessary framework to quantify the project more completely, query the model to extract relevant data, and produce accurate estimates of embodied carbon. This means using live schedules and 3D information with embedded attributes, in lieu of PDFs and stripped-down models shared via under-featured cloud platforms. The AEC industry in the U.S. could tie LOD standards to specific project stages for better bidding. Often, BIM data used during bid is broken, outdated, and/or inconsistent. Further, the offline RFI process is often insufficient at addressing issues for manufacturers to timely and accurately explore and price complex projects. In other words, in order to provide meaningful feedback to designers, not just on price but also on carbon, contractors need better data.

Building upon the table proposed in Fig. 4, Holistic Bidding could potentially include a rating of each system, such as proposed in the formula in Fig. 5, with factors and data points (or absence thereof) at the discretion of the owner and designer.

Why and How to Incentivize Holistic Bidding?

To incentivize Carbon-Informed Design Assist and Holistic Bidding, the industry needs a framework to understand how to factor carbon into the decision-making process. Because there is not yet a robust policy framework governing the entire North American market, we need to look at other options. There are several mechanisms available to us, through both voluntary measures and policy. Here we will divide them into two broad categories: carbon pricing and carbon limits.

On the pricing side, one possible mechanism is to apply a "social cost of carbon" (SCC). The social cost of greenhouse gasses is a tool developed by the U.S. government, combining climate science and economics to estimate the cost in dollars of the long-term damage done by today's greenhouse gas emissions. These estimates include the costs associated with climate change-driven events such as wildfires, floods, and storms, and their impacts on communities. Converting the negative effects of carbon emissions into dollars makes it easier to incorporate carbon emissions into the decision-making process. Unfortunately, there is not a single agreed-upon number for the social cost of carbon. This is due to uncertainty in estimating future impacts, and different discount rates used in various models (see Fig. 6).

Currently, the widely accepted calculation for the social cost of carbon in the U.S. uses a 3 percent discount rate, placing the social cost of 2022 carbon emissions at $53 per ton. However, an alternative model designed to capture the damages associated with extreme outcomes

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

Fig 6

Type	GWP [kgCO2eq/m2]	Social Cost of Carbon Emissions in 2022 [USD/m2]		
		3% Average	2.5% Average	3% 95th Percentile
		$53	$79	$159
Curtain Wall System A	111	$5.90	$8.78	$17.69
Curtain Wall System B	136	$7.21	$10.72	$21.60
Curtain Wall System C	166	$8.80	$13.08	$26.36
Curtain Wall System D	180	$9.54	$14.18	$28.58
Curtain Wall System E	188	$9.96	$14.81	$29.85
Curtain Wall System F	204	$10.81	$16.08	$32.40

Fig 7

Specific building materials and products may be subject to carbon caps, which can lead to carbon reduction and a mechanism to incorporate carbon reduction into Holistic Bidding.

places it as high as $159, and these valuess will increase every year. The table in Fig. 7 shows GWP values per square meter of several different curtain wall systems, along with their associated social cost of carbon. We observe that the current recognized SCC value does not add substantially to the unit cost of a typical curtain wall system, depending on the model used, however, it does provide a framework for factoring carbon emissions directly into pricing. In the absence of a policy governing this, owners, designers, and contractors can decide what model they want to use for pricing carbon.

Many companies now use an internal carbon pricing scheme to inform their decision-making around emissions reduction. Some companies in the AEC industry are making voluntary commitments to purchase offsets for estimated carbon impacts of each project. To do this, design and construction teams would use life-cycle assessment to estimate the embodied carbon emissions associated with a given project, and then purchase high quality carbon offsets. Simply buying offsets without reducing emissions is not enough to reach climate goals, however. The purpose of committing to purchasing offsets is twofold: to mitigate the effects of unavoidable emissions, and to create a financial incentive to innovate and to optimize projects for embodied carbon reductions. The architectural firm Miller Hull, for example, has committed to offset embodied carbon emissions of the projects they design, and more AEC firms may follow their lead.

Carbon caps for specific building materials and products are another avenue for carbon reduction, and a promising mechanism to incorporate carbon reduction into Holistic Bidding. Many designers are already estimating the GWP of systems and materials they are specifying. Benchmarking to industry average GWP values or design estimates and prioritizing bids that meet or exceed the benchmarks can provide another incentive for supply chain transparency and decarbonization. Bids showing carbon reductions over the baseline would be prioritized, and those that do not would require revision before consideration.

Although not yet widespread across all North American jurisdictions, regulation will also increase transparency and drive innovation in embodied carbon reduction. One example of this is the Buy Clean California Act (BCCA), which governs procurement on state projects. BCCA caps embodied carbon for specific building materials, including flat glass, and requires contractors to submit facility-specific Environmental Product Declarations (EPDs) documenting the product's environmental impact. The current GWP limit on flat glass is 1.43 metric tons of CO_2eq per ton of flat glass. BCCA contains a mechanism to reevaluate and potentially lower the GWP cap every three years to drive greater reductions in the future, compelling manufacturers to continually reduce their emissions below the threshold.

Buy Clean policies are being adopted by an increasing number of public entities such as the City of Los Angeles, are in development in other U.S. states and cities, and can even be translated to private sector building owners. Tellingly, the White House recently announced that the federal government is developing a Buy Clean program.

Taking the Next Steps

Momentum to decarbonize the building industry is building rapidly, which leaves AEC professionals and built environment stakeholders asking: where do we go from here?

Everyone involved in the design and construction process has a shared responsibility in reducing environmental impacts. Knowing that none of us can solve the problem of decarbonization alone, change requires development of creative ideas in a culture of mutual contribution and benefit.

What can designers do? Learn more about manufacturing and the weight of their decisions. Measure and optioneer creative ideas with input from manufacturers. Consider crossing the entrepreneur wall and joining the industry.

What can contractors and manufacturers do? Elevate carbon as a factor in their supply chain evaluation and decisions, especially when they are highly dynamic. Further measure and document the environmental impact of their production via EPDs. Propose more low-carbon alternatives to standard designs, processes, or products.

What can owners do? Track their emissions and educate themselves about the impact of their choices. If starting small is the only option, start small. Forward-thinking owners with the ability to work at a larger scale can set ambitious goals for reduction of emissions, both operational and embodied and hold designers and builders accountable for reaching them.

What can policymakers do? Policy often lags behind innovation in design and technology, but policy can drive widespread adoption beyond the small circle of forward-thinking early adopters. A wide array of policies can incentivize building industry decarbonization, from grid decarbonization to emissions caps to zoning regulations. The City Policy Framework for Dramatically Reducing Embodied Carbon provides policy templates, allowing cities to choose which frameworks are likely to be most effective for them. Leadership is also needed at the national level, including emissions caps similar to the Buy Clean California Act and mandatory disclosure of environmental impacts via EPDs.

The Future of Decarbonization and Environmental Stewardship

Building on the advances in operational efficiency of the past decades and the accelerating developments in embodied carbon calculation and reduction of the present, the future of decarbonization is promising, but not without its challenges. While policies remain the most effective way to enforce best practices, they typically lag behind market innovation. The widespread and immediate switch to triple glazing as a standard practice after the passing of Local Law 97 in New York demonstrates that in many cases, the primary problem is not one of technology: it is the lack of incentives to adopt better technology. To face the carbon crisis head-on, we need to find the junction of innovations in technology, policy, procurement, financing, and design.


Transparency is a critical step to decarbonization, and all stakeholders in a project must be aware of the impact of their decisions may have on the environment.

Clients, customers, and designers can no longer afford to ignore the impact of their consumption. Transparency is critical to decarbonization, and all stakeholders need to know the impact of their decisions. Manufacturers must propose new products and develop low-carbon technologies to stay ahead of regulations. Whole life considerations will also be key, to ensure that lower carbon products have the same (or better) durability as their carbon-heavy equivalencies. Beyond carbon, design for circularity and material health for both building users and communities where building products are manufactured should remain amongst the top considerations.

Decarbonization is the foremost challenge facing the building industry, and one for which we do not have perfect or easy solutions. The costs of carbon through the life cycle of buildings, from manufacturing, transportation, use, and less tangible social costs, are of paramount concern and must be addressed. Innovations and re-evaluating the status quo have led to improvements, but there is still a long way to go. By reaching a shared understanding of definitions and calculations, best practices in all steps of manufacturing and construction, and looking beyond that narrow focus to see the social costs of the carbon emissions for which we are responsible, the industry can change. Regulation and policy may be required to compel some of this change, and we are positioned to defend its importance and make it possible. By working together, all stakeholders can take meaningful steps toward reaching our goals of carbon reduction, shrinking the impact our industry has on our planet while still maintaining the integrity of our vision and design.

Laura Karnath
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Senior Enclosure Technical Designer
Laura is a registered architect with a background in computational design and experience working with globally distributed project teams delivering highly complex projects. As a senior enclosure technical designer at Walter P Moore's Los Angeles office, she brings her expertise and passion to the problem of decarbonizing the built environment through high performance, low carbon facades. She is a member of Walter P Moore's Sustainable Design Community of Practice and a contributing author to the report Embodied Carbon: A Clearer View of Carbon Emissions. Laura is a co-founder of the Los Angeles hub of the Carbon Leadership Forum where she works to connect professionals across the AEC industry to share best practices and innovative approaches aimed at radically reducing embodied carbon in building materials and construction. Prior to joining Walter P Moore, she worked as a consultant at Gehry Technologies, where she gained experience in the organizational models and technical challenges involved in the delivery of large international projects. She holds an M.Arch from SCI-Arc and a B.S. in Architecture from SUNY Buffalo.

Sophie Pennetier
Associate Director
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Sophie holds 15 years of experience in the design of complex structures and facades. She joined Enclos in 2018, where she has steered various projects' specialty facades scope sales and design assist efforts, engaged in prototyping, kit of parts curtainwall systems, structural glass, and various R&D topics such as ultra-thin glass, facades acoustical analysis and sustainability. Prior to joining Enclos in Los Angeles, Sophie worked as a Structural Engineer with Arup in New York, SHoP Construction, and RFR in Paris. In 2010 through the industry-academia partnership IAPP ARC between RFR, Evolute and the Vienna University of Technology, she developed cold bent glass numerical analysis tools for freeform facades. Sophie authored several research papers on structural glass and has been involved in the development of US structural glass codes with ASTM, the Journal of Architectural Engineering as an Associate Editor, and the Facades Tectonics Institute where she has served as a Paper Reviewer, 2020 Congress Organizing Committee, Special Advisory Council and currently sits on its Board of Directors.

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