LOW-CARBON CONCRETE INITIATIVE

We each have a winning card to play in the game of concrete decarbonization

This work was led by professional volunteers within the Boston/Northeast Hub of the Carbon Leadership Forum (CLF), a Knowledge Community within the Boston Society for Architecture (BSA), and consultants hired by BSA. This project was generously funded by the Jampart Charitable Trust.

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Table of Contents

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Foreword

The entire concrete industry is on the precipice of enormous change. Regulators are now joining the private sector in calling for manufacturers to reduce carbon emissions, and rapidly. Luckily, low-carbon concrete options have been around for decades, and new ones are emerging. Still, why hasn't more progress already been made?

If we are going to accomplish rapid transformation, we have to truly understand what has held us back until today.

To answer these questions and explore solutions, the Boston/Northeast Hub of the Carbon Leadership Forum (CLF) and the Boston Society for Architecture hosted a year-long stakeholder engagement process, funded by a grant from the Jampart Charitable Trust. The goal of this process was to identify obstacles and opportunities for adopting low-carbon ready-mix concrete in Massachusetts and throughout the Northeast U.S. We began by conducting interviews, administering a survey, and facilitating stakeholder-specific focus groups. This provided a baseline of insights, information, and challenges faced from each stakeholder's perspective. Four multi-disciplinary workshops subsequently built on this foundation, which allowed the participants to get a better understanding of each other's issues and finalize the content of this report. Throughout this process, we engaged over 100 participants from across the industry from five different stakeholder groups: owners, architects, engineers, contractors, and suppliers. The survey elicited feedback from 53 respondents; the five focus groups each had an average of 10-12 participants; and 30-40 attendees joined the workshops.

For most participants, this was the first time they joined stakeholders representing the complete concrete supply chain in one space. This report summarizes what we learned.

Introduction

WHAT BROUGHT US TOGETHER?

Critical momentum is building for decarbonizing concrete in Massachusetts. The number of stakeholders who volunteered their time to be a part of this engagement effort is a testament to how widely acknowledged and relevant this issue has become to the industry.

State and municipal agencies are implementing policies to achieve decarbonization goals. At the Commonwealth level, all agencies are required to submit decarbonization plans in service of Massachusetts goal to reduce greenhouse gas emissions by at least 85% by 2050. In addition, two proposed bills would establish maximum allowable global warming potential (GWP) thresholds for concrete used in projects funded by taxpayers (H.3035/ S.1981 and S.1982). In the Greater Boston area, Brookline, Cambridge, and Newton have all instituted local policies focused on low-carbon building materials, including concrete—either by mandating it directly or by requiring reporting of embodied carbon for larger buildings as the first step in a process towards reduction.

These legislative moves are part of a national trend making low-carbon concrete a key focus. Other states—New York, New Jersey, and California included—have taken steps to tackle the embodied carbon of concrete. Federally, the Buy Clean Initiative is also driving procurement policies, including concrete sourcing for all General Services Administration projects using at least ten cubic yards of concrete. Massachusetts is among 12 states to have committed to the Federal-State Buy Clean Partnership.

Meanwhile, there has been growing demand from the private sector. An increasing number of corporations and building owners with footprints in the Northeast, such as Microsoft, Accenture, Google, and Amazon, are announcing carbon commitments that include addressing the embodied carbon of their building projects. Other owner types are turning an eye toward embodied carbon as well, including higher education institutions, healthcare facilities, and real estate investment trusts.

If the industry is successful in decarbonizing concrete, we will have eliminated 8% of global greenhouse gas emissions. According to the International Energy Agency, emissions from cement alone must fall by an average of 4% annually through 2030 in order to limit global temperature rise to 1.5°C.

WHAT HAS KEPT US FROM SOLVING THIS?

Even with growing demand and projected regulatory support, progress on decarbonizing concrete has been slow. In our survey of regional architecture, engineering, and construction stakeholders, 54% said they see demand for low-carbon concrete on nine or fewer projects a year (see Appendix C on survey results).

Through this engagement, we asked: "What's likely to challenge mass adoption moving forward?" —first in stakeholder-specific focus groups, then in cross-disciplinary working sessions. Resoundingly, we heard that the technological and engineering solutions already exist to reduce the carbon impact of concrete—and possibly even to completely decarbonize (see sidebar). It quickly became clear that the central barrier lies not in a lack of technology but rather in our current design and construction process, which gets in the way of needed collaboration, communication, and mutual education across disciplines. Specifically, the group identified these top five challenges (more detail in Appendix D, Prioritized List of Barriers):

- Lack of early engagement with concrete suppliers
- Use of prescriptive specifications
- Lack of clear project goals
- Lack of education
- Lack of demand

But these barriers are surmountable, according to the workshop participants—especially if each stakeholder understands their most effective leverage point for championing low-carbon concrete. Most of the time, getting low-carbon concrete onto a project requires only one champion to take the right action at the right time.

Early in the process, the project facilitators created the following ecosystem map, which was refined throughout the engagement. The map highlights relationships of influence, and the stars indicate stakeholders who can initiate an action that gets low-carbon concrete onto a project. The stakeholder groups engaged in this process are the primary decision-makers: owners, architects, engineers, contractors, suppliers, and policymakers. However, as the diagram shows, many other stakeholders can positively or negatively influence low-carbon concrete adoption. They range from trade associations that help educate and support innovation for suppliers to private landowners that resist sand excavation. (Sand excavation does have real environmental costs, but lack of good quality sand causes a need for more cement and chemical additives.)

WHO DETERMINES SUCCESS?

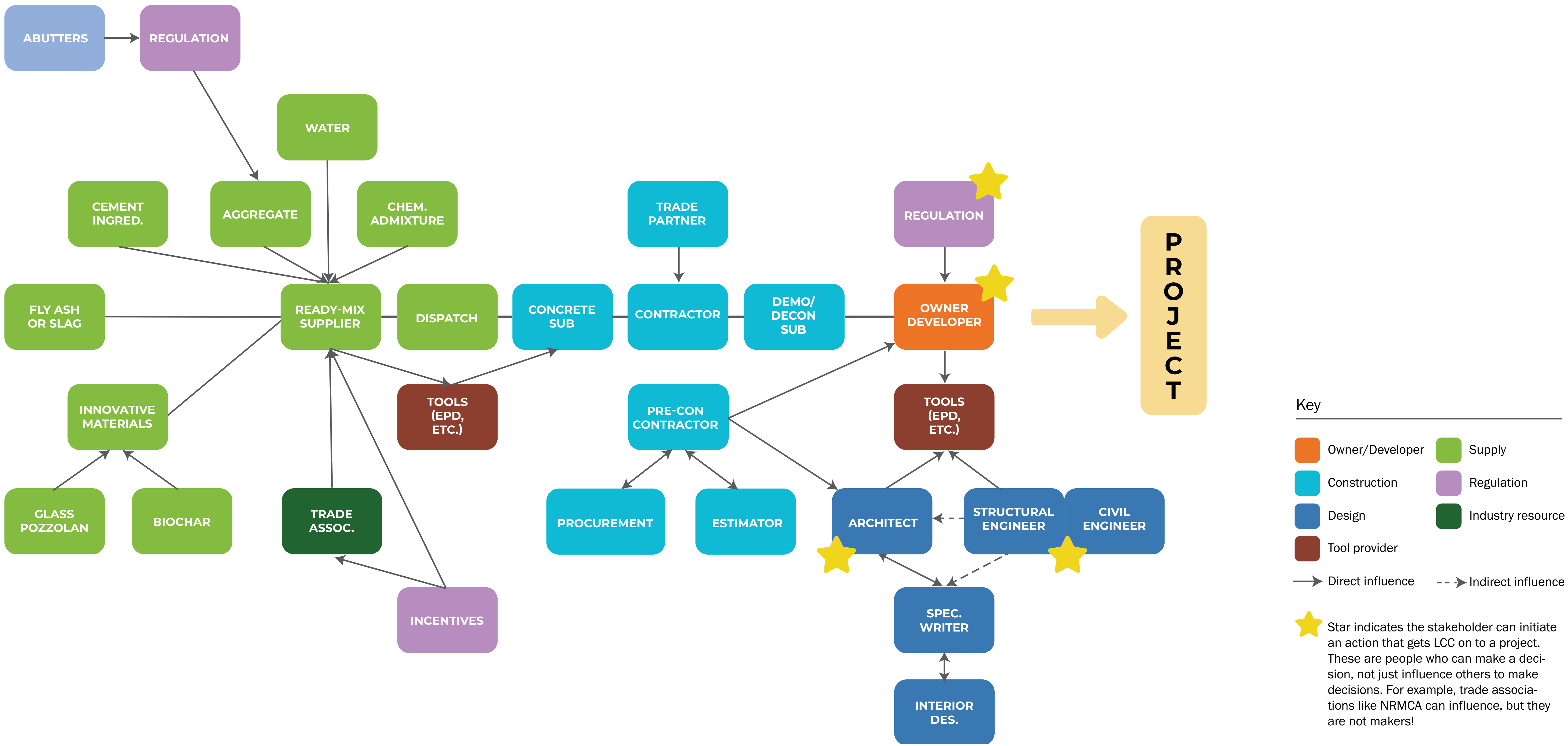
Even among the decision-making stakeholders, each has peak leverage at different points in a project's life cycle. Waiting until late in the project to initiate low-carbon concrete discussions increases cost and makes it less likely that it will be adopted. As a result, stakeholders with a lot of decision-making power early in the project are more effective champions of low-carbon concrete.

In summary:

- Regulation touches everyone! State and municipal requirements take longer but have far-reaching, automatic impacts.
- Absent regulation, owners have the next leverage point to initiate action. Owners can signal a commitment to low-carbon concrete as early as their request for proposal (RFP).
- Ready-mix suppliers have already been reducing the carbon in concrete mixes and can take the lead on their own. They can also influence their customers, concrete installers, and general contractors by proactively letting them know which mixes are available.
- The architect can use their close relationship with the owner to influence goal setting. They also can coordinate with the engineer earlier than usual to set expectations, especially around a performance specification for low-carbon concrete.
- If the construction team is onboard early, either because of the chosen construction delivery method or through providing preconstruction services, the contractor can influence an owner or architect who is not yet familiar with low-carbon options. The contractor will also ensure follow-through by proactively communicating expectations to trade partners.
- Engineers don't usually have a lot of early leverage unless they are engaged with the architect early, but they can engage with suppliers as soon as they are onboard to understand what is possible and coordinate specific mix designs through well-written performance specifications.

Through this engagement, we heard that low-carbon concrete can make it onto a project as a result of one or two stakeholders taking action rather than needing every stakeholder to be perfectly aligned. We simply need enough stakeholders to be champions and know the right actions to take.

ECOSYSTEM MAP OF STAKEHOLDERS



WHAT ARE THE TECHNOLOGICAL AND ENGINEERING SOLUTIONS FOR DECARBONIZING CONCRETE?

When most people refer to low-carbon concrete, they are referring to concrete with some portion of cement replacements or supplementary cementitious materials (SCMs). That's because the majority of the life-cycle emissions of concrete come from cement manufacturing (77%, according to Cao & Masanet, 2021), so reducing cement in the mix is the most obvious route for reducing the emissions of concrete. Each material has its benefits and drawbacks in terms of environmental and human health profiles, but the most popular SCMs include:

- **Fly ash**: a byproduct of coal combustion that is captured by emission-control systems at coal-fired power plants
- **Slag**: a waste byproduct of iron smelting
- **Silica fume**: particles produced during metal production
- **Ground glass**: post-consumer (and sometimes pre-consumer) materials processed into an amorphous silica powder
- **Limestone**: powdered particles of limestone

Aside from cement replacements, there is one other opportunity to reduce emissions in the raw material stage. Between 60% and 75% of concrete by volume is sand and gravel aggregate. Reducing the carbon footprint of that material by using local, responsibly sourced, or recycled aggregate can help. In addition, improving the quality of the aggregate has downstream impacts. Using high-quality sand can reduce the amount of cement and chemical admixtures needed. Alternatively, some proportion of biochar may be used as a sand replacement. Biochar is produced by burning organic waste at high temperatures without introducing oxygen. In doing so, carbon is sequestered from organic waste, material is diverted from municipal processing, and some persistent chemicals are destroyed, like certain Per- and Polyfluorinated Substances (PFAS). There are also newer products that sequester CO2 from industrial sources and turn it into aggregate.

Moving along in the life cycle, several opportunities relate to manufacturing processes and equipment. More efficient cement kilns, newer or more efficient concrete trucks, and all-electric construction equipment are all potential strategies.

Finally, at its end of life, concrete can be crushed and reused either as aggregate or fill, avoiding further emissions associated with procuring virgin materials. There are some limitations: chemicals, paint, oils, and unknown admixtures in the concrete could potentially contaminate soil if it is used as fill, and additional cementitious materials are often needed if it is used as recycled concrete aggregate. Crushing it also jumpstarts a recarbonization process, where CO2 from the air is absorbed into the concrete. An estimated 20% of the CO2 emitted from making cement is reabsorbed by the concrete—not enough to offset the initial climate impacts of portland cement production, but enough to make a dent. There are some products that speed up this process by directly injecting CO2 into the concrete mix.

For this project, and for the purposes of this report, all of these strategies might factor into why a given installation would be considered "low-carbon concrete." A claim of low-carbon concrete should be compared against a benchmark, such as the regional benchmarks from the National Ready Mixed Concrete Association (NRMCA). These benchmarks are based on environmental product declarations (EPDs), which follow a standard methodology for the calculation of GWP and can take all these life-cycle phases into account. However, in the absence of EPDs, some professionals put a cap on cement content (in lbs/cy) as a proxy for GWP limits.

Process strategies for using less cement and concrete can also be leveraged to achieve full decarbonization. These might include design approaches to reduce overall building size, footprint, or massing; optimizing the structural design to use less concrete; or optimizing compressive-strength requirements so that mixes with less cement can be used where less strength is needed. Between using less material and reducing the emissions from what remains, we can decarbonize this essential building material.

WHAT KEEPS US FROM PLAYING WELL WITH OTHERS?

As we dug further into how the process can short-circuit low-carbon concrete efforts despite the availability of decarbonization technologies, some common themes emerged.

We learned that each stakeholder group came to this work with its **own set of characteristics**: a unique set of skills, assets, and professional challenges. By virtue of their jobs, the ready-mix suppliers had a common set of experiences that were very different from those of the architects, for example.

We learned that the typical siloed and step-wise process of a building project sets up **challenges and traps** that prevent teams from successfully incorporating low-carbon concrete. These are often structural challenges that are outside any one person's control, and it takes smarts and skill to navigate them.

We learned that there are **shortcuts and proven solutions** to these collaboration and process problems. If you know them, you are more likely to move ahead and bring the rest of the team with you.

On the whole, this structure, and the added element of strategy, seemed reminiscent of what we experience when playing a board game. So to explain all the feedback we received during this engagement—and to illuminate the barriers teams face and must overcome—we've chosen a theme everyone can relate to.

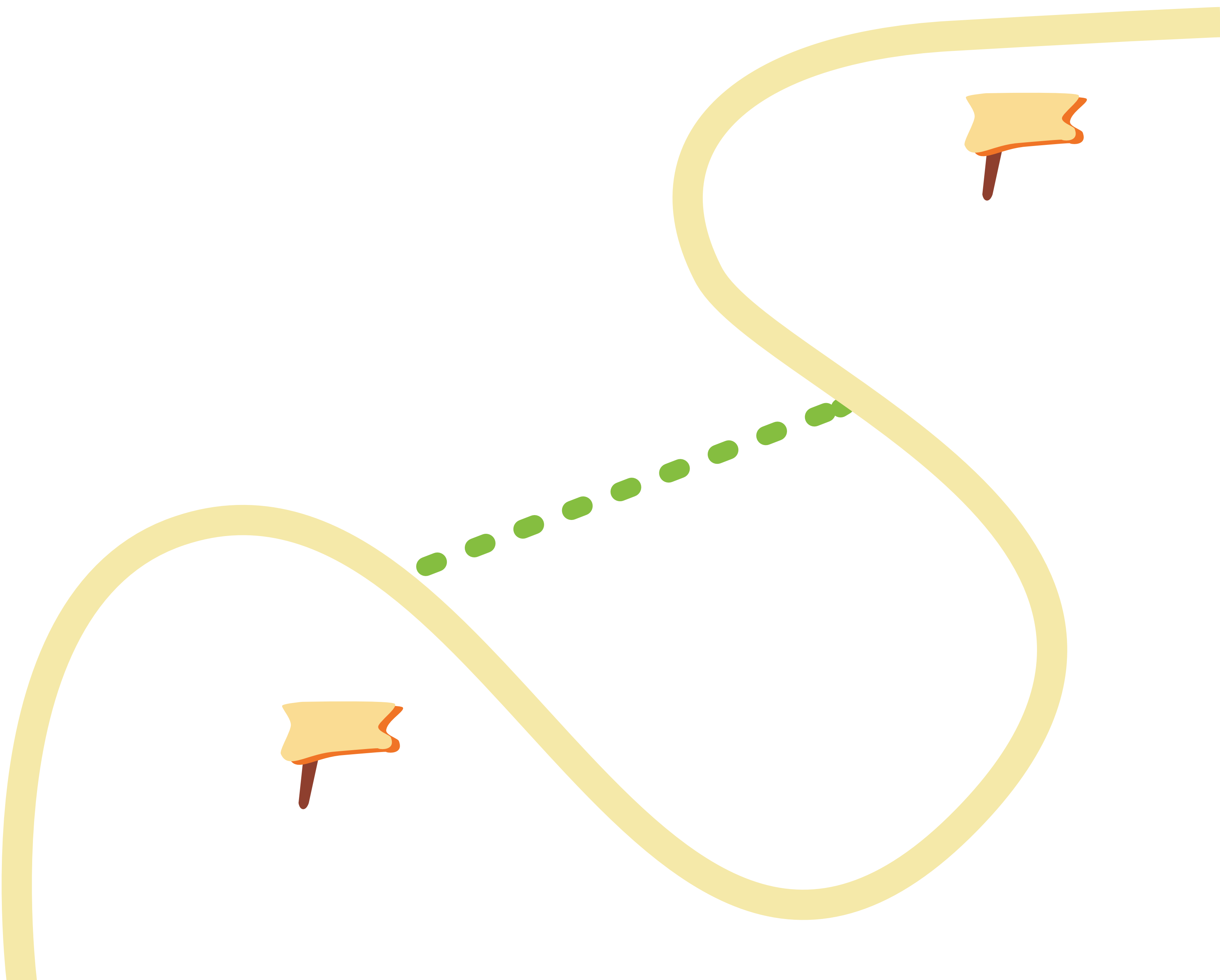
The themed section of this report is broken into two sections:

- **Who's Who in the Decarbonization Game**: Our engagement began with stakeholder-specific focus groups (contractors, architects, structural and civil engineers, ready-mix suppliers, and owners). Here we present how those stakeholders described their roles and their challenges—by giving them a character sheet. Although we present each stakeholder group as a single character for simplicity, the experience among stakeholder groups is not always uniform. Be advised that the content is not meant to represent the views of any one participant or company.

- **The Gameboard**: This section presents the major challenges identified in the cross-discipline engagement sessions and how stakeholders can overcome them. There are "shortcuts"—moonshot solutions that can fast-track adoption of low-carbon concrete. There are also "great play" descriptions or the ideal path toward low-carbon concrete that is totally within the project team's control. Finally—for the pragmatists—there are "get unstuck" sections, highlighting how each stakeholder can do their part to work around these challenges, even in less-than-ideal circumstances or acting as the sole champion.

As in any board game, the goal is to win. But in this cooperative game, we're aiming to solve the planet's very real climate crisis. That means using one of the most promising carbon reduction strategies that we have available to us in the Northeast: decarbonizing concrete.

The stakes are high, so get your game face on!



Who's Who in the Decarbonization Game?

All players must work together in order to win the game of Decarbonizing Concrete. Each player has a distinct role to play as well as unique challenges specific to their character.

Before beginning the game, review the traits represented on your character sheet:

- **Role:** The role that this character has to play in order to achieve low-carbon concrete.
- **Superpower:** The unique leverage point that this character brings to the challenge.
- **Kryptonite:** A barrier that is uniquely felt by this character. When presented with a setback, the player loses a turn.
- **Allies:** Each character is particularly compatible with a few other characters. Teaming up with these allies will make this character maximally effective.
- **Mastery:** The piece of knowledge or education needed for this character to effectively advocate for low-carbon concrete.

Let's introduce the players!

READY-MIX SUPPLIER

Role
As the ready-mix supplier, you store the ingredients needed to make low-embodied carbon concrete, maintain a roster of mix designs, and supply the mix materials to concrete subcontractors. You are responsible for understanding and reporting the carbon impact (GWP) of different mixes.

Superpower
Freedom to change the mixes offered. Ready-mix suppliers have already led a 40% reduction in GWP simply by incorporating more SCMs into the mixes they carry for cost and performance reasons. Working with material suppliers, they can go even further.

Kryptonite
Being asked to provide a low-carbon concrete mix at the last minute when SCMs are in short supply.

Allies
SCM and raw material suppliers who are willing to go the extra mile. Well-trained subcontractors, architects, and engineers comfortable with performance specifications. Public clients who can boost demand.

Mastery
Reach full power when you are able to generate EPDs for new mixes. Don't worry: there are incentives to help you get started.

GENERAL CONTRACTOR OR CONSTRUCTION MANAGER

Role
As the general contractor or construction manager, you can advise the owner and design team on setting low-carbon goals during preconstruction. You then select among various bids to find a concrete subcontractor that can meet the low-carbon concrete specification while managing cost and schedule impacts. You ensure low-carbon concrete actually makes it into a project.

Superpower
Proactive outreach with concrete subcontractors and ready-mix suppliers to support large-scale industry decarbonization. Coordinating the trades to facilitate the use of low-carbon mixes.

Kryptonite
Bid documents and RFPs that do not include low-carbon concrete. If the design is already baked, your hands are tied unless the low-carbon option is cost-competitive and readily available in the region.

Allies
Suppliers with lots of alternatives and those who do their own batch testing; subcontractors who are experienced and on board with working with new mixes; engineers who are comfortable with performance specs; owners who are willing to use newer technologies.

Mastery
You'll become an expert once you develop your network and tap the collective knowledge of your local suppliers and subcontractors.

CONCRETE SUBCONTRACTOR

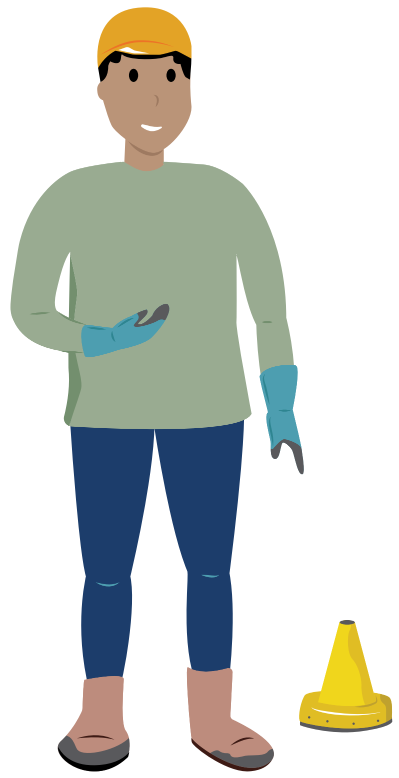
Role
As the concrete subcontractor or installer, you set up the formwork, receive material from the ready-mix supplier, and manage the pour on site.

Superpower
Knowledge of workability, cure times, and weather-related impacts. When schedule is a concern, you have crucial knowledge about how to avoid delays and how the work should be sequenced.

Kryptonite
The mix proposed is one you haven't used before. There is a learning curve to applying onsite to get the desired finish, and if something goes wrong, you are the first to be held accountable.

Allies
A general contractor who values your input and helps problem-solve if things go wrong; ready-mix suppliers that help you meet the demand you're seeing for low-carbon concrete; industry organizations that support continued education and testing of different mixes.

Mastery
Find peak potential when you've educated yourself on successful installations and worked with various low-concrete mixes.



ARCHITECT

Role
As the architect, you design the mass and form of a building, which ultimately influences how much concrete is needed. You also help assign the durability exposure class for each application of concrete, which limits the mix designs that may be used.

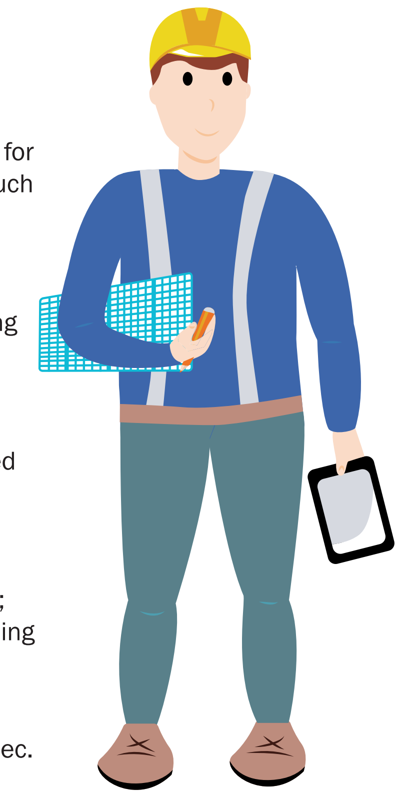
Superpower
Integrative process. As the owner's earliest partner and the liaison between the owner, engineer, and contractor, you can educate the team on low-carbon concrete and help the owner define embodied carbon goals. You also can engage engineers, contractors, and suppliers early in the project process.

Kryptonite
Owners who may not be educated and shut down pursuing low-carbon concrete because of perceived risk. Project partners that don't read the spec—or fight you tooth and nail. You may need to require that the contractor re-issue a bid request, or you may have to do a full redesign because of late-breaking opposition.

Allies
Curious and/or committed owners; structural and civil engineers who have standardized low-carbon concrete in their designs; contractors and suppliers who are willing to engage pre-bid.

Mastery
Reach starchitect level by learning how to use EPDs and do life cycle assessments with low-concrete mixes.

STRUCTURAL ENGINEER



Role
As the structural engineer, you write the concrete specification (not the overall project specification writer) and determine durability and strength requirements for each intended application of concrete. You protect safety while building in as much flexibility as possible to optimize for cost, schedule, and carbon impacts.

Superpower
Early engagement with suppliers and performance-based specifications. Assigning a durability exposure class that is not overly conservative and removing unnecessary prescriptive requirements allows for lower-carbon mix designs.

Kryptonite
Specifications that default to prescriptive requirements. Inertia and common practice mean prescriptive specifications are more the norm. Performance-based specifications may be more work for you until they become the default for the industry.

Allies
Concrete subcontractors that can advise on the workability of given mix designs; ready-mix suppliers that are working to address supply-chain issues; owners willing to share information about durability performance over time.

Mastery
You'll be the final authority when you've mastered the art of the performance spec.

CIVIL ENGINEER

Role
As the civil engineer, you choose where concrete is needed for the infrastructure on a project and translate a low-carbon concrete goal into a performance-based specification.

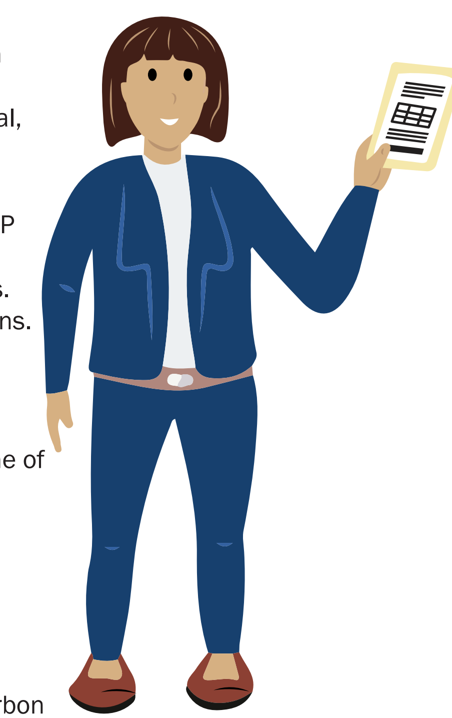
Superpower
Scale of impact and use of performance-based specifications. Carbon impacts will be lowest if there aren't arbitrary restrictions and there is instead flexibility to choose where to be aggressive on low-carbon mixes. Also, minimizing the amount of concrete altogether by only using concrete where concrete is needed.

Kryptonite
Restrictive requirements from municipalities and large scale purchasers that limit your ability to make lower-carbon choices. Poor soil conditions and drainage issues that require more concrete infrastructure to ameliorate.

Allies
Architects invested in rreducing overall concrete use; educated owners who are aware of potential cost and schedule impacts; ready-mix suppliers who are working to address supply-chain issues.

Mastery
Make your biggest impact by mastering the performance spec.

OWNER OR DEVELOPER



Role
As the owner, you identify low-embodied carbon goals as early as possible and remain committed to them throughout the project. Goals may be original to the project, translated from a carbon budget at the portfolio scale, linked to an ESG (environmental, social, and governance) target, or imposed by outside entities.

Superpower
Whole-building carbon budgets. Carbon budgets challenge a team to stay within a GWP limit. When the directive is to meet or beat a carbon cap rather than many different prescriptive requirements, the team can creatively pursue carbon-reduction strategies. Low-carbon concrete can arise as a low-cost strategy that immediately avoids emissions.

Kryptonite
Perceived risk of using materials that may have schedule or cost impacts compared to traditional mix designs. This can be overcome, in part, by engaging concrete subcontractors and ready-mix suppliers early since the lack of early engagement is one of the biggest cost drivers.

Allies
Architects and engineers who can help translate your overall carbon goals to a more specific goal for concrete; a general contractor and concrete subcontractor with experience that can ease concerns over not-yet-standard mix types.

Mastery
Become the ideal client by speaking with peers to develop a comfort level with low-carbon concrete and bust myths about cost and risks. Then make a commitment!

WHAT ARE PERFORMANCE-BASED SPECIFICATIONS?

Performance-based specifications describe the intended performance of concrete while avoiding unnecessary limitations on material ingredients or other restrictive provisions. The intent is to give the concrete producer and concrete subcontractor maximum flexibility to optimize for project goals like budget, schedule, or carbon impacts while still meeting the performance requirements for the given application.

A performance specification spells out performance expectations—such as strength, setting time, shrinkage, or durability—instead of listing ingredients or specific products. GWP can be added as an additional performance expectation. This can take two forms: 1) setting carbon footprint limits for individual classes of concrete or 2) setting a carbon budget for all of the concrete on a building. Participants in this process recommended providing both pathways but making the whole-project target easier to achieve than the class targets. This encourages the team to take a big-picture approach and decide where to be more aggressive with GWP reductions (within the performance requirements) while optimizing for other factors like cost and schedule.

What's most important is to avoid unnecessary prescriptions, as these can take low-carbon concrete mixes off the table without good reason. For example, many widely referenced specs have prescriptive water–cementitious materials ratio (w/cm) requirements, intending to ensure a certain level of durability with this stand-in metric for permeability.

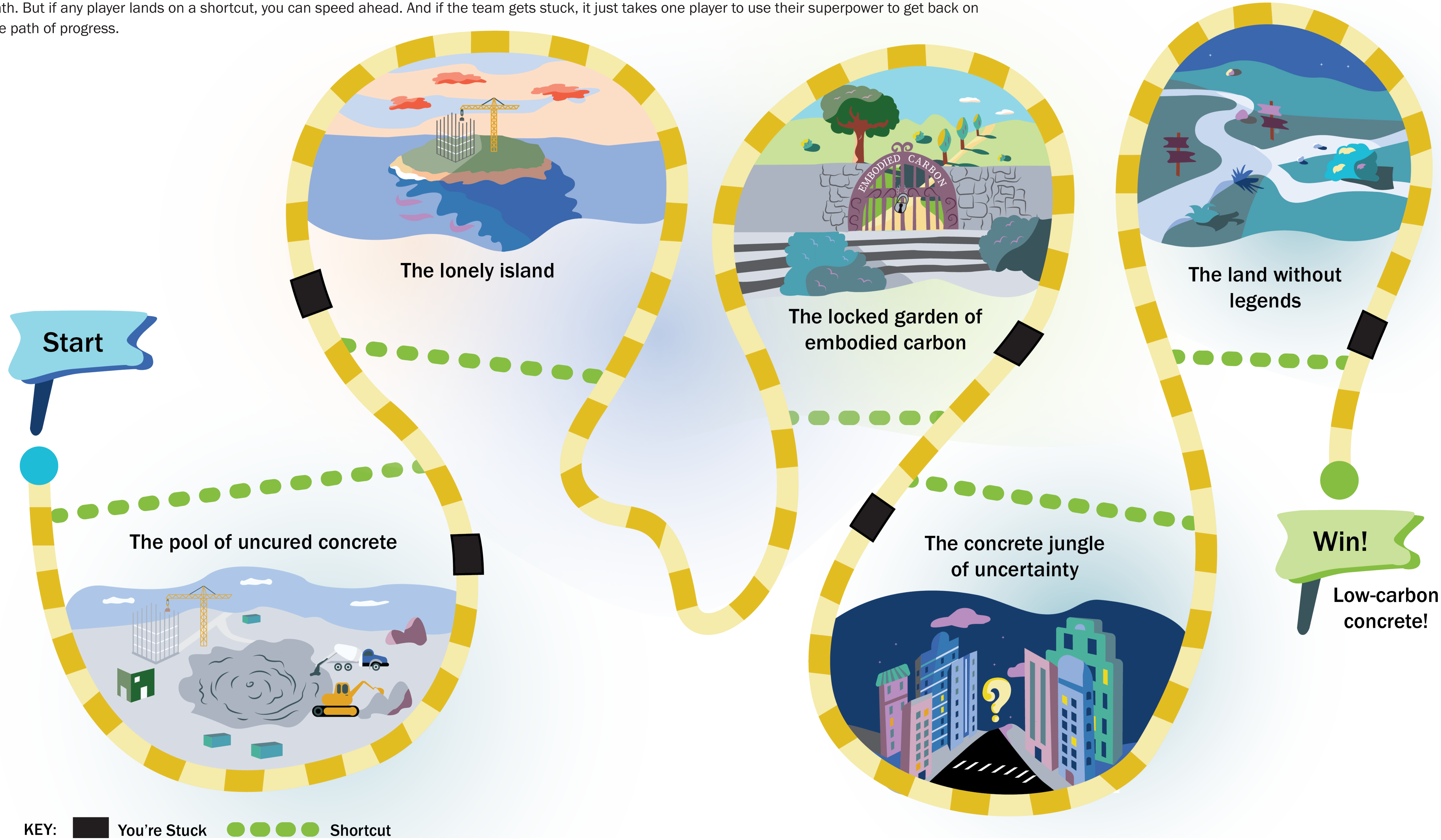
However, concrete mixtures containing fly ash, slag, silica fume, and other pozzolanic materials have lower permeability than a conventional mixture at the same specified water-to-cement ratio. These alternative mixes perform the same (or better) with less cement. But if the specification maintains that a certain amount of cement must be used, for example, then low-carbon concrete will likely not be selected.

There are many prescriptive requirements that can preclude low-carbon concrete options. The NRMCA guide The Top Ten Ways to Reduce Concrete's Carbon Footprint recommends avoiding:

- maximum or minimum cement content
- maximum or minimum SCM content
- quantity of admixtures
- requiring potable water
- limiting the aggregate gradation

The Game Board

In the Game of Decarbonizing Concrete, the goal is to get low-carbon concrete installed on a project. There are challenges that can make it a slow, winding path. But if any player lands on a shortcut, you can speed ahead. And if the team gets stuck, it just takes one player to use their superpower to get back on the path of progress.



The pool of uncured concrete: where you're stuck without industry demand

Challenge

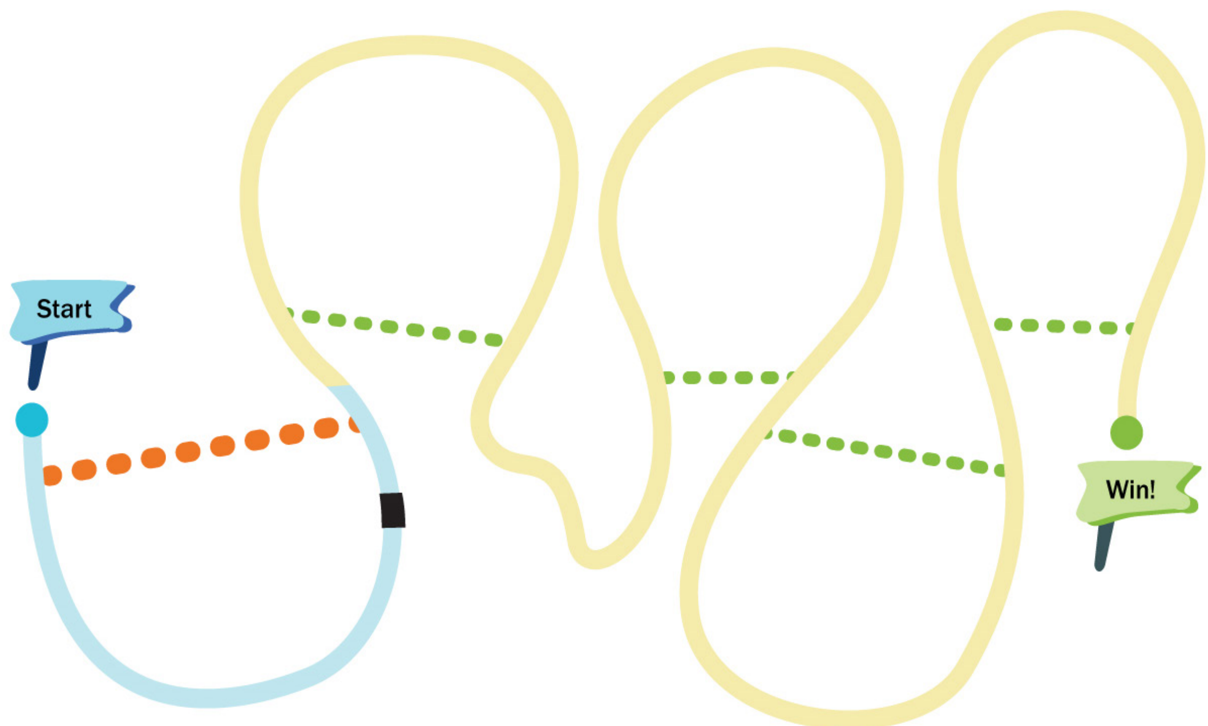
Without consistent, predictable demand for low-carbon concrete, ready-mix suppliers are hesitant to stockpile SCMs in dedicated silos. And because there are fewer producers of fly ash and slag than there used to be, especially domestically, there is often a fear that SCMs won't be available or will be too expensive to transport. If that fear can be overcome for the rare project, it may still be viewed as a one-off and not an indicator of increasing demand. It's a cycle that makes it feel like you're stuck in a swamp of quicksand.

Shortcut

The whole team can skip the slurry and leap ahead! Because with the swipe of a pen, policymakers have scaled up demand. If local governments or even state agencies, like the Department of Transportation, adopted more aggressive low-carbon-concrete standards, that would establish consistent demand, and everyone else would benefit.

Great play

It isn't a direct path, but you've rolled the dice and landed a great play. The owner or developer makes a public commitment to pursue low-carbon concrete and follows through, consistently including that expectation in RFQs/RFPs. Combined with other owners, this sends a clear market signal. The contractor ensures the signal is heard by proactively engaging with the ready-mix supplier to reinforce that there is demand coming down the pike and reaches out to concrete subcontractors, encouraging them to prepare to handle new mix types.



Getting unstuck

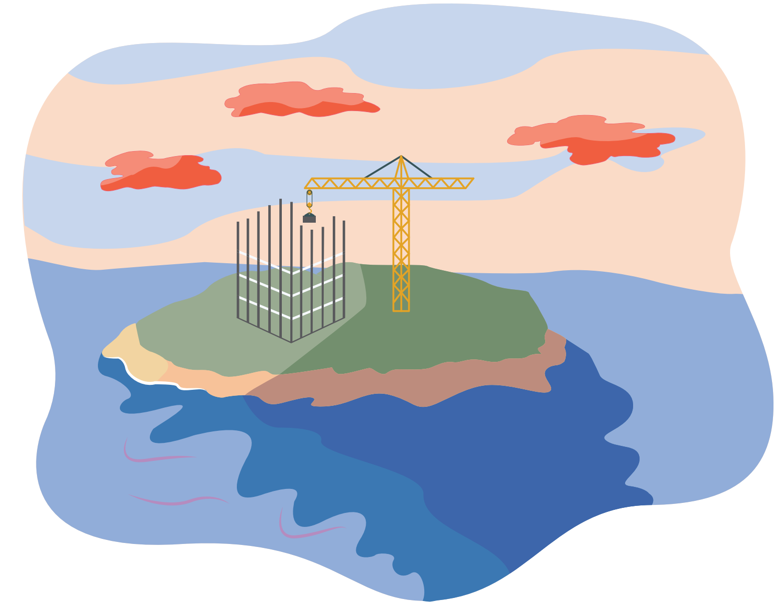
The owner has missed their opportunity to set a public low-carbon goal, and now you're stuck in the concrete slurry. Any of the following players can use their superpower to get the team unstuck and moving again toward a low-carbon solution.

The engineer uses their knowledge of performance specs and early supplier engagement to produce a low-carbon-concrete performance specification that can be met with readily available materials.

The contractor uses their proactive outreach with concrete subcontractors and ready-mix suppliers to keep tabs on what's available and reinforce that there is demand coming down the pike. They also reach out to concrete subcontractors to help them become comfortable with new mix types.

The ready-mix supplier can independently change the mixes they offer, motivated by their own commitment to decarbonize, despite a lack of clear market signal.

The lonely island: where you're isolated in the traditional design process



Challenge

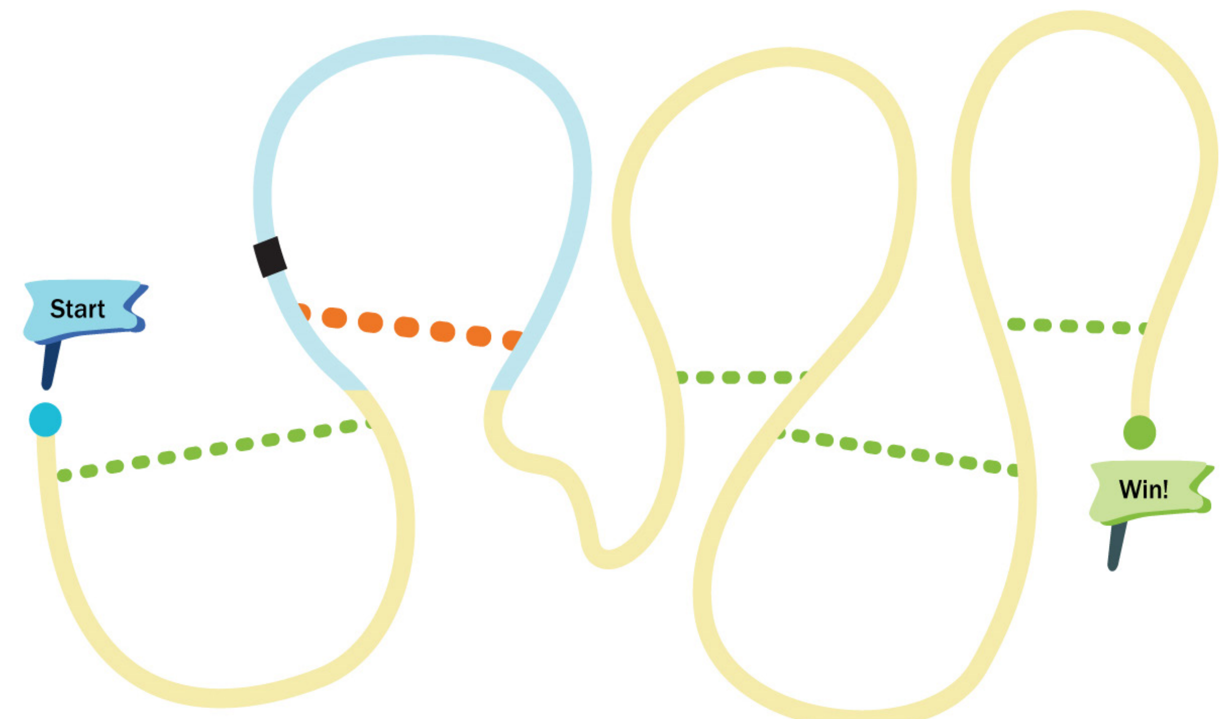
Players are used to interacting in a linear and siloed way in the traditional project delivery process. This inhibits the ability of players to problem-solve together. The architect does their conceptual work and only pulls in the engineer after the concept is fully baked, likely missing strategic ways to reduce the overall volume of concrete. The engineer develops a specification but has no opportunity to vet it with a concrete subcontractor or supplier because they aren't yet on the project. The concrete subcontractor joins the team once the design is fully developed, missing the opportunity to de-risk concerns about time delays, failures, finishability or workability, or cost increases. Everyone operates on their own lonely island, sending messages in a bottle.

Shortcut

You lucky castaway! By intentionally choosing a delivery model that allows for early engagement of key players, like design-build, CM-at-risk, or integrated project delivery, the owner has sent in a team of special ops. These models contractually allow the architect, owner, engineer, general contractor, and designated trade partners to formally work together rather than relying on informal relationships.

Great play

Sometimes design-bid-build is the only option, so you don't have a team of rescuers. However, you can still build a raft that will take you homebound. Each player can work within their role to get feedback from other key players despite not having their full engagement early in the process. The architect pulls in the engineer to minimize clear spans and cantilevers at concept design, lowering the volume of concrete needed. The architect, engineer, and general contractor all informally network with ready-mix suppliers and concrete subcontractors to vet ways to specify low-carbon concrete. As soon as the project is bid, the contractor quickly engages a concrete subcontractor, giving them as much lead time as possible. Design-assist agreements may be used as well.



Getting unstuck

Collaboration between different disciplines is never perfect. Along the way, assumptions were not verified with the correct stakeholder, and those decisions have now come back to bite you. You're sunburnt, hungry, and talking to a volleyball. The following players can get you out of this mess if they've been educated about low-carbon concrete and have mastery-level knowledge.

The architect failed to communicate the project's low-carbon goals to the rest of the team. The knowledgeable engineer has a ready-to-go, low-carbon specification that can be quickly swapped in.

Without ready-mix supplier involvement, a mix was specified that required SCMs that weren't readily available. The ready-mix supplier uses their research of SCMs and freedom to make their own low-carbon mixes to offer another low-carbon alternative.

The team did not know any concrete subcontractors from whom to get feedback about the workability of specified mixes. Once onboarded, the concrete subcontractor uses their knowledge to make site adjustments for pourability while maintaining lower emissions.

The locked garden of embodied carbon: where prescriptive specs guard the key

Challenge

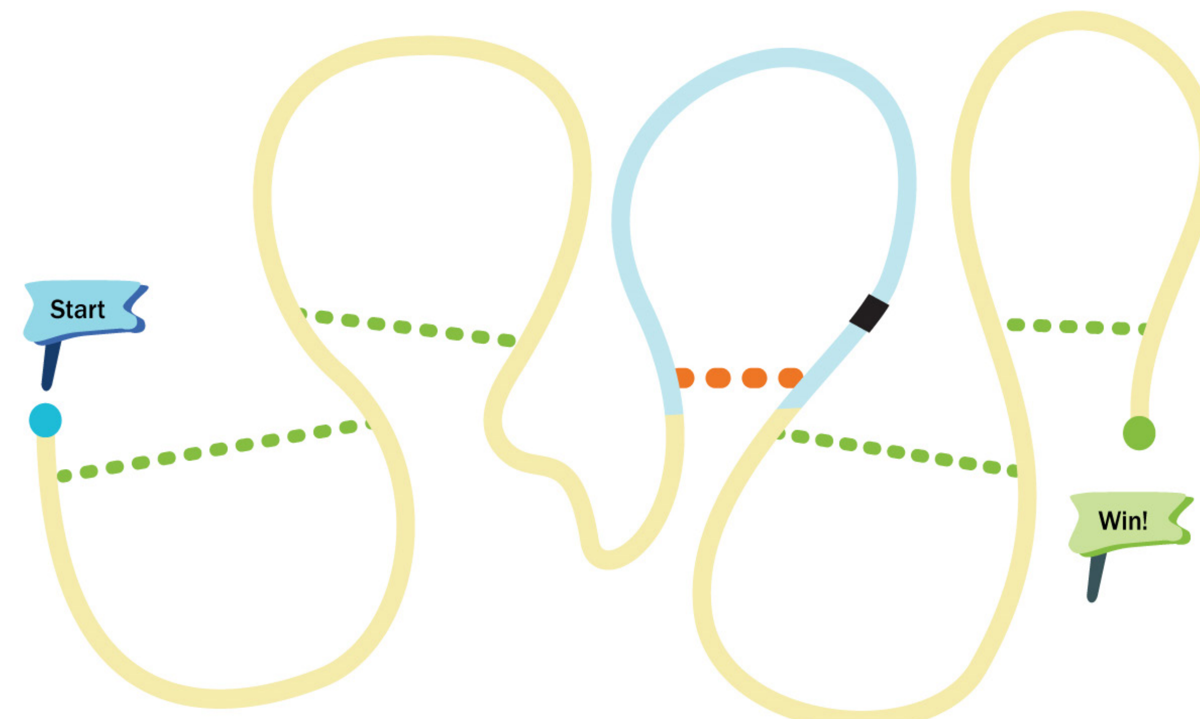
If the standard process is followed, prescriptive specifications are developed for the concrete scope. There are available mixes with SCMs that would meet the project's durability and strength requirements, but they don't meet the letter of the specification because they have a higher water–cement ratio. If prescriptive specs are used, the low-carbon-concrete mixes will be excluded. This also drives up the cost and may cause delays. The tantalizing fruit of a decarbonized future is far out of reach.

Shortcut

Step into paradise: you've found the hidden key to a true performance spec. If the general contractor, concrete subcontractor, and ready-mix supplier are brought on early, the on-the-ground knowledge lowers everyone's risk. Best practice is to set an overall reduction-from-the-baseline goal for the full concrete scope, even if you also have separate reduction goals by concrete class. This allows the team maximum flexibility to decide where they can be aggressive with GWP reductions within the constraints of concrete type and application.

Great play

The garden path may be rockier, but if you can't have a reduction from your baseline goal for the full concrete spec, it is still a great play to set GWP targets by application (footings, foundations, slabs, etc.). The team won't have as much flexibility on mix designs, which means costs may be slightly higher, but you will still achieve the desired carbon savings.



Getting unstuck

The engineer has missed their opportunity to issue a performance spec. Low-carbon outcomes now depend on the other stakeholders to take initiative within their role.

The contractor leverages their role as a preconstruction advisor to flag prescriptive requirements in the specification that might have unintended consequences.

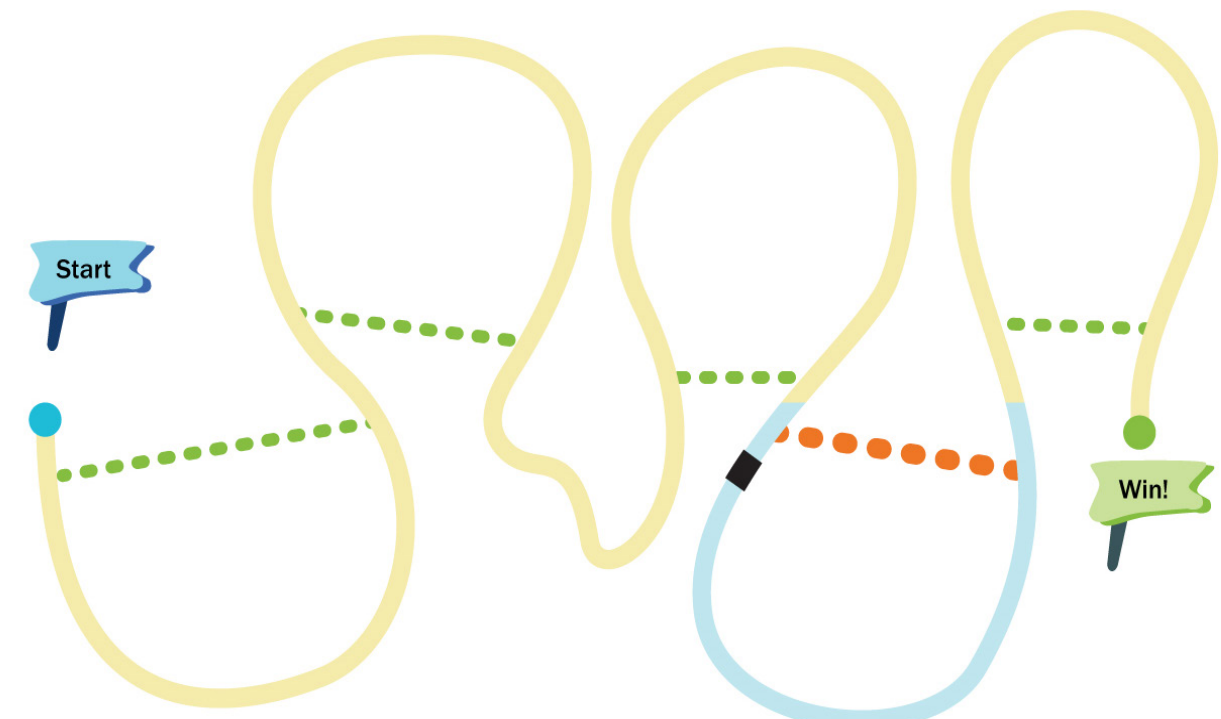
The concrete subcontractor submits substitution requests proposing low-carbon mix designs for workability reasons, citing their authority over the pour onsite.

The ready-mix supplier uses their knowledge of available mixes to educate the project team (working through the concrete subcontractor) on alternate mix designs that may save on cost and schedule.

The concrete jungle of uncertainty: where EPDs can't guide the way

Challenge

Data disconnect! Everyone is keen to find low-carbon concrete options, but there are too few published environmental product declarations (EPDs) for the mixes available. EPDs show the global warming potential of different concrete mixes and allow the team to compare options to find out which one has a lower carbon impact. As it stands, no one knows the carbon footprint of anything, and now you're lost in the concrete jungle of uncertainty.



Shortcut

Uncertainty would be quashed if every player proactively reached out to the ready-mix suppliers in their network and demonstrated a demand for EPDs. Concrete EPD kickstarter funds are now available in Massachusetts to support ready-mix producers who want to set up and generate EPDs for their plants. After EPD software and information are set up for an individual plant, instant EPD data can be generated for any concrete mix. Up to $3,000 is available per plant with at least five third-party verified EPDs, and an additional $1,000 is available for companies with only one or two plants. Once EPDs are generated, these mixes will be eligible for free product placement in tools like the Embodied Carbon in Construction Calculator.

Great play

The concrete jungle is dark, but you've been given a flashlight to light your way. Absent readily available EPDs, the project can still request GWP information, and the concrete subcontractor can respond with manual calculations based on SCM content. Theoretically, these mixes will have a lower carbon footprint.

Getting unstuck

Without auto-generated EPDs, any subtle change in the mix design may send the project team into the concrete jungle of uncertainty. Availability, cost, or site conditions might change the final mix designs, leading the team to question whether the original EPD is still valid. The following players, if they have the know-how, can lead the team out of the woods.

The concrete subcontractor uses their understanding of onsite processes to flag when mix designs change so substantially that it is worth asking for EPDs to be re-issued.

The ready-mix supplier consults their roster of mix designs and advises on whether a different mix design might serve as a comparable proxy.

The structural engineer uses their understanding of the specs to update embodied carbon estimates with as-built information.

The land without legends: where embodied carbon goals are unclear

Challenge

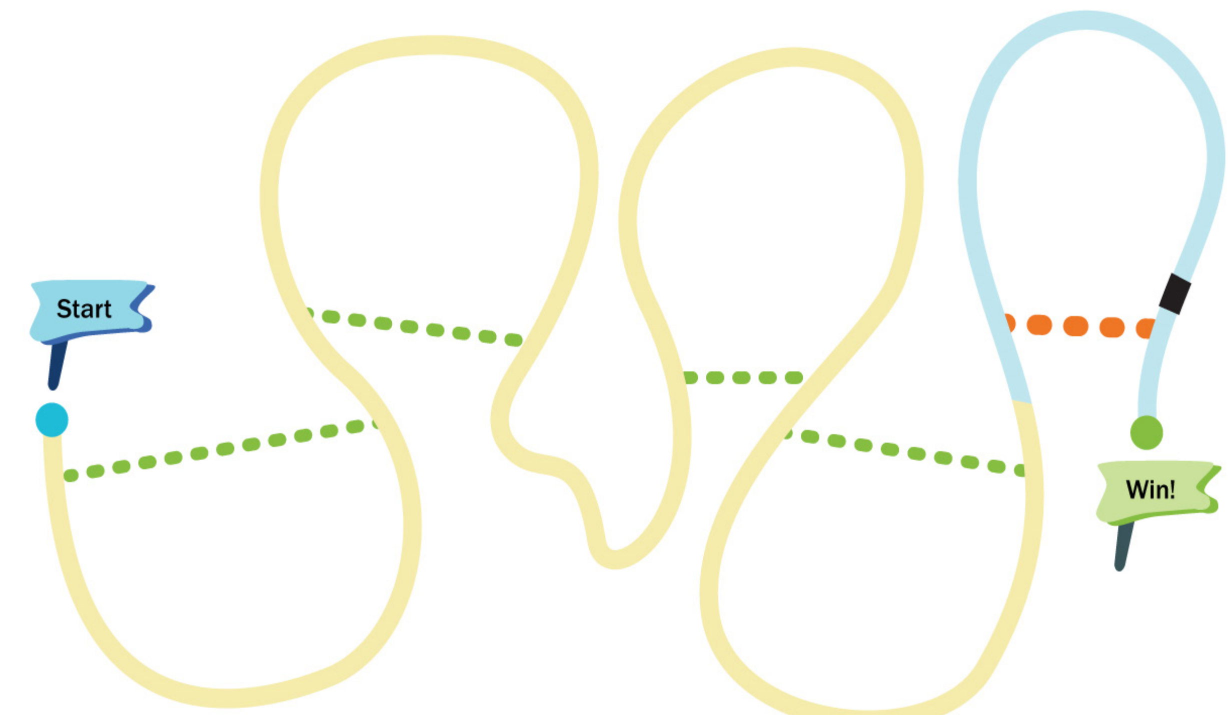
Building owners and project teams are often in favor of using low-carbon concrete, but they get hung up on defining an exact goal. A lot of information is needed to set a meaningful target. How much reduction is possible? Are the materials available from regional suppliers? What is feasible in terms of cost or schedule? There is currently no central case study database to share this kind of information. And the expertise needed to answer these questions for a particular project often isn't available until later in the process. So, many projects end up with vague goals or with unrealistic ones that weren't vetted. Without this guidance, you're fumbling your way through the dark without a map.

Shortcut

You've dodged this uncertainty altogether because an independent industry organization or municipality decided to publish vetted reduction targets by local market and to create a forum for sharing case studies and lessons learned. Having this information upfront helps project owners understand what is feasible and reasonable to expect in their market. This knowledge-sharing accelerates adoption and improves outcomes overall. Taking the bypass, you speed onward into the night.

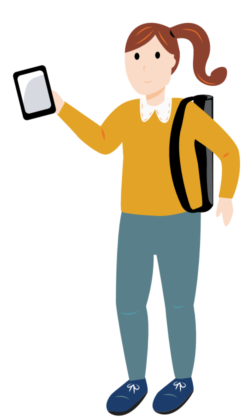
Great play

The path may not be mapped, but with a little legwork, an owner can still find their way toward creating an effective embodied carbon goal. The owner parses their organization's decarbonization commitments and expresses an embodied carbon goal in the building project's RFP or owner's requirements. This goal may be refined with input from a broad team and feedback about cost and schedule impacts.



Getting unstuck

If a clear goal is not set by the owner, other players may fill in the gaps. The following players are well positioned to do so because of their roles:



The architect uses their position as the owner's earliest partner to propose a reduction target based on benchmarking studies and life cycle assessment modeling.

If engaged while the design is being developed, the general contractor can propose that the engineer set a reduction goal as part of their preconstruction services.

If the project proceeds without a clear low-carbon concrete goal, the ready-mix supplier can supply a decent mix anyway, having already started the process of optimizing their mixes.

We Only Win If We Each Commit

Thanks for playing Decarbonizing Concrete. You may have been absorbed in the game, so let's reiterate the highlights. This initiative identified five primary barriers to low-carbon concrete adoption:

- Lack of early engagement with concrete suppliers
- Use of prescriptive specifications
- Lack of clear project goals
- Lack of education
- Lack of demand

But you will each quickly find that improving project processes to allow you to partner with others will get you much further.

These barriers are surmountable. There are practical policy solutions that could make a big difference and resources that would help speed adoption. But most importantly, we need each stakeholder to see promotion of low-carbon concrete as part of their job, even if no one else on the project team has advocated for it before. Whether each intervention point was seized or not, every stakeholder has a superpower in their back pocket. We just have to be willing to use it.

ACTION NEEDED FROM POLICYMAKERS, NONPROFITS, AND INDUSTRY ORGS

Some of the most effective solutions to these barriers will have to come from outside the project team. State and municipal agencies need to continue passing decarbonization policies. Requiring disclosure of embodied carbon is effective, but setting maximum thresholds for the GWP of concrete has more teeth and is relatively straightforward for concrete. Supporting policies might also be targeted toward encouraging building reuse, deconstruction instead of demolition, and design for deconstruction. Helping municipalities to draft these policies would be an excellent next phase for the work started through this engagement.

Stakeholders in our engagement process also specifically called for state buyers like the Massachusetts Department of Transportation to require lower-carbon mix designs than they currently do. Because these entities are such large purchasers of concrete, this would create predictable demand for low-carbon mix types, and ready-mix suppliers would have more confidence to invest in decarbonizing their mixes. This would increase supply for everyone else in the state. These large purchasers could also release their testing data, sharing lessons learned so that others don't have to repeat the same testing.

Another clear ask from this initiative was for regionally-specific resources. Owners requested that a trusted entity publish vetted reduction targets by local market and create a forum for sharing case studies and lessons learned. As we heard in this initiative, low-carbon goals are most effective when released as early in the process as possible (for example, in the RFP), but owners often don't know what is practical to request. Published reduction targets would help them know what others have asked for, what's feasible without significant added cost, and how to ask for low-carbon concrete in a way that gives project teams flexibility and encourages them to exceed expectations.

Similarly, project teams need access to a range of resources that are centralized and easy to find. This should include: simple explainers, project case studies, test batch data, performance-based specification examples, guidance on how to set baselines, and guidance for owners on how to review specifications. An organization like CLF is well-positioned to collect this kind of information, jumpstarting the education the industry needs. An entity in charge of these education resources could even start a low-carbon accreditation program, which would help distinguish stakeholders who have invested in learning about low-carbon concrete.

Finally, there are currently some kinks in the low-carbon concrete supply chain that require outside intervention to straighten out. Accessing high-quality sand is a problem in Massachusetts, and low-quality sand requires more cement and chemical admixtures. The state must balance this need with environmental protections and property rights governing sand excavation. Mapping high-quality sand deposits and identifying those locations where excavation would have the least environmental impact would help chart a way forward for suppliers. Separately, we know that concrete is rarely crushed and reused as aggregate or fill due to concerns about contamination. Providing some infrastructure for testing and cleaning would help improve the carbon footprint of this material.

ACTION NEEDED FROM PROJECT TEAMS

Within any given project, each stakeholder has a primary leverage point where they can advocate for low-carbon concrete. Many don't know the simple steps they need to take to get low-carbon concrete onto a project. This should be a primary focus of proactive education initiatives. Given that everyone is at a different point in this journey, it is equally important to understand how one stakeholder might be able to compensate for another if the first opportunity is missed.

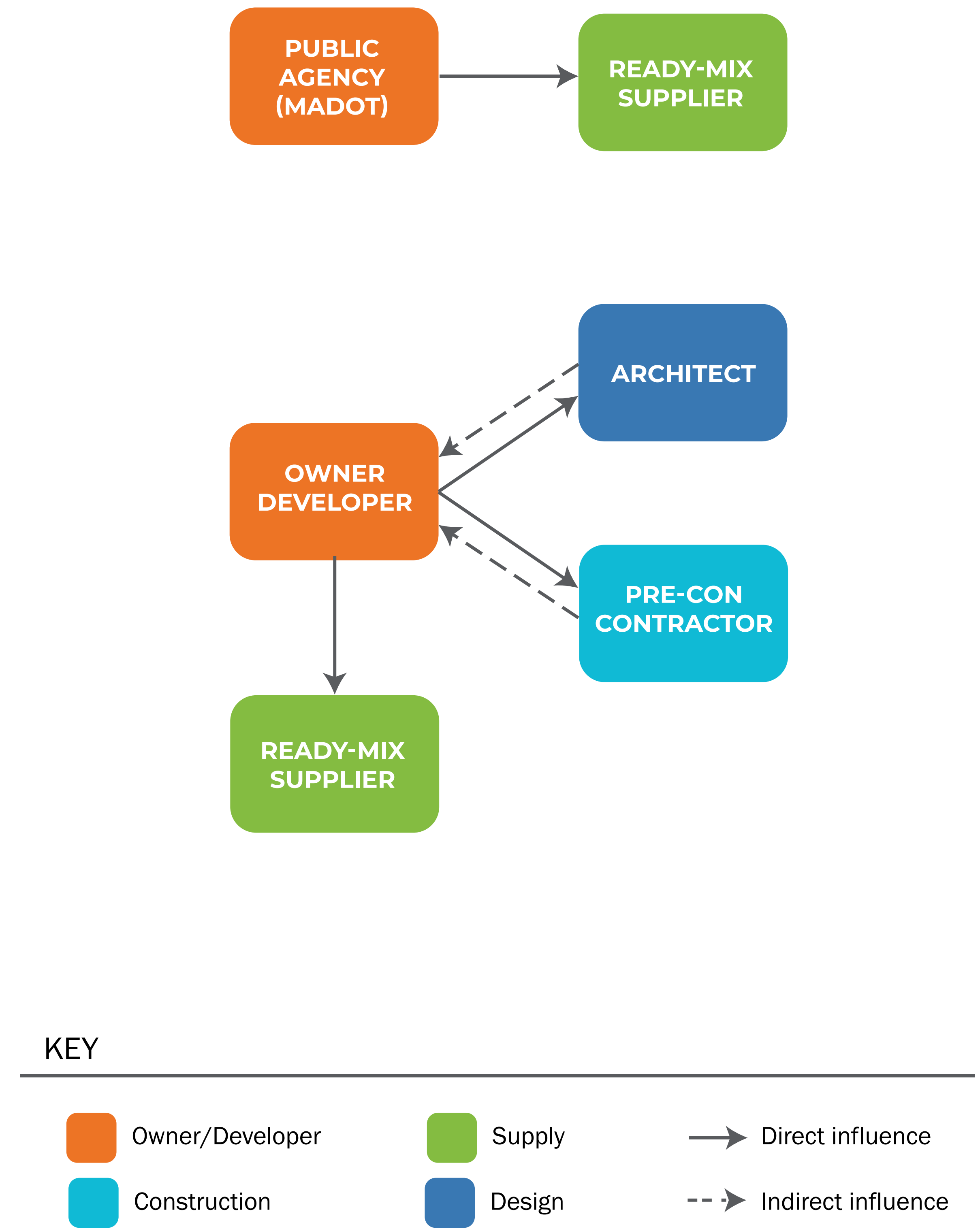
LEVERAGE POINTS FOR OWNERS

The owner's primary leverage point is to set an embodied carbon goal as early as the RFP. If they have internal commitments and clear project requirements, their project teams will follow through. Some owners who have many buildings in their pipeline may directly connect to suppliers to understand what the opportunities are and to give the suppliers a sense of demand.

However, architects and contractors (in the preconstruction phase, especially) can influence the owner to make a decision, even if a commitment was not in place in their RFQ or RFP.

Actionable steps for owners:

- Set an overall embodied carbon goal for the portfolio or project.
- Reach out to other owners to ask about their experiences with low-carbon concrete.
- Ask project teams to provide GWP implications along with cost data when comparing design options.



LEVERAGE POINTS FOR DESIGN PROFESSIONALS

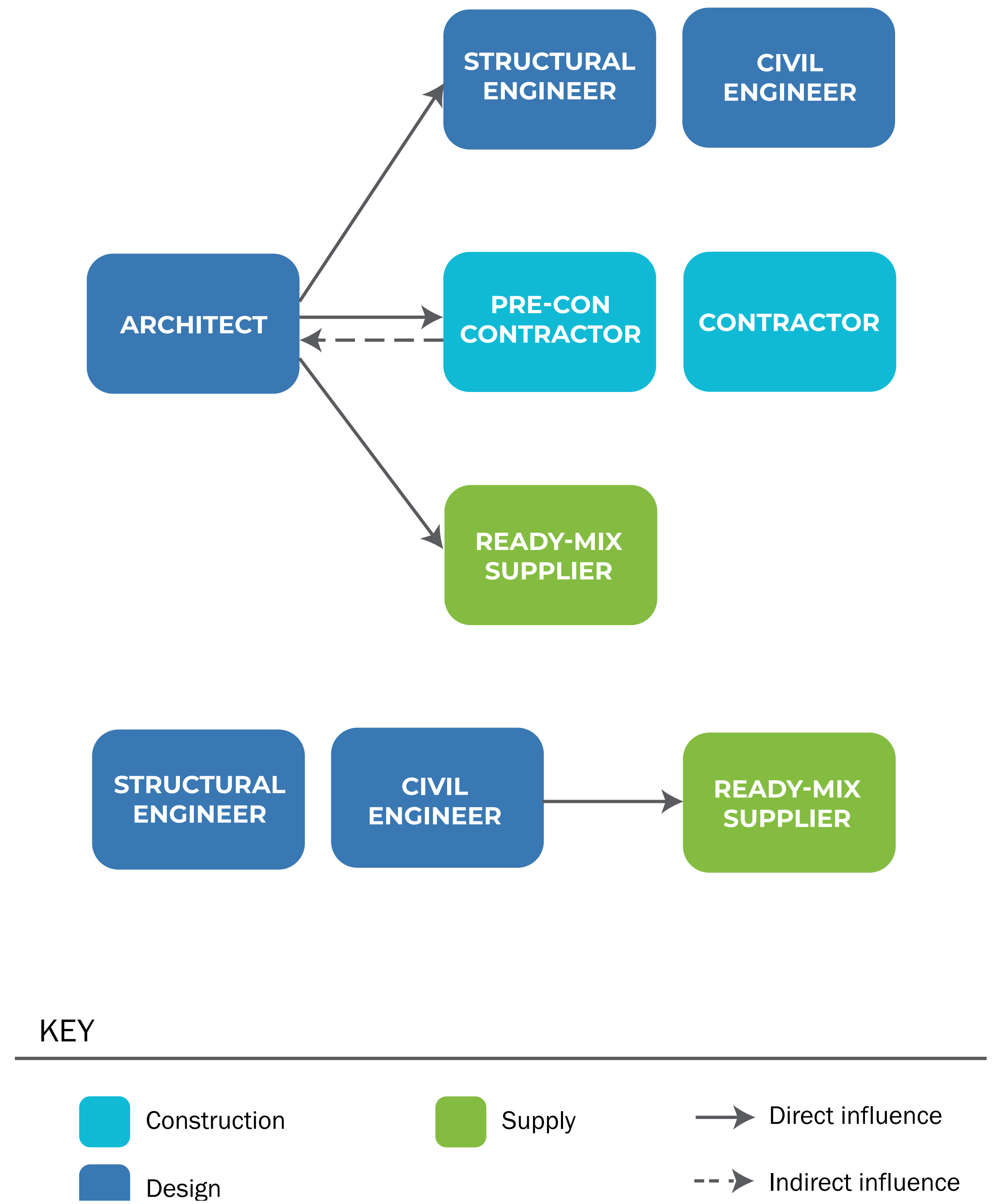
Once project goals are clear, the architect hires and manages the engineers, informing them of the expectations so they can write the specifications. The architect can also proactively notify all of their engineering partners of expectations in advance of any projects or reach out directly to suppliers early in a project, sometimes even before an engineer is on board.

The engineers must engage early with suppliers to understand what is possible, which SCMs are available, and to coordinate specific mix designs. Even with a perfect performance-based specification, there can be some back and forth to adjust the mix for workability and other factors.

If the architect is not yet familiar with low-carbon concrete, the engineer (or the construction professional as part of preconstruction services) may be able to help educate them.

Actionable steps for design professionals:

- Update internal standards and QA/QC processes to incorporate low-carbon concrete specifications.
- Engage structural engineers by asking them to present best practices for using low-carbon concrete to the firm.
- Proactively educate owners and developers on low-embodied carbon solutions.



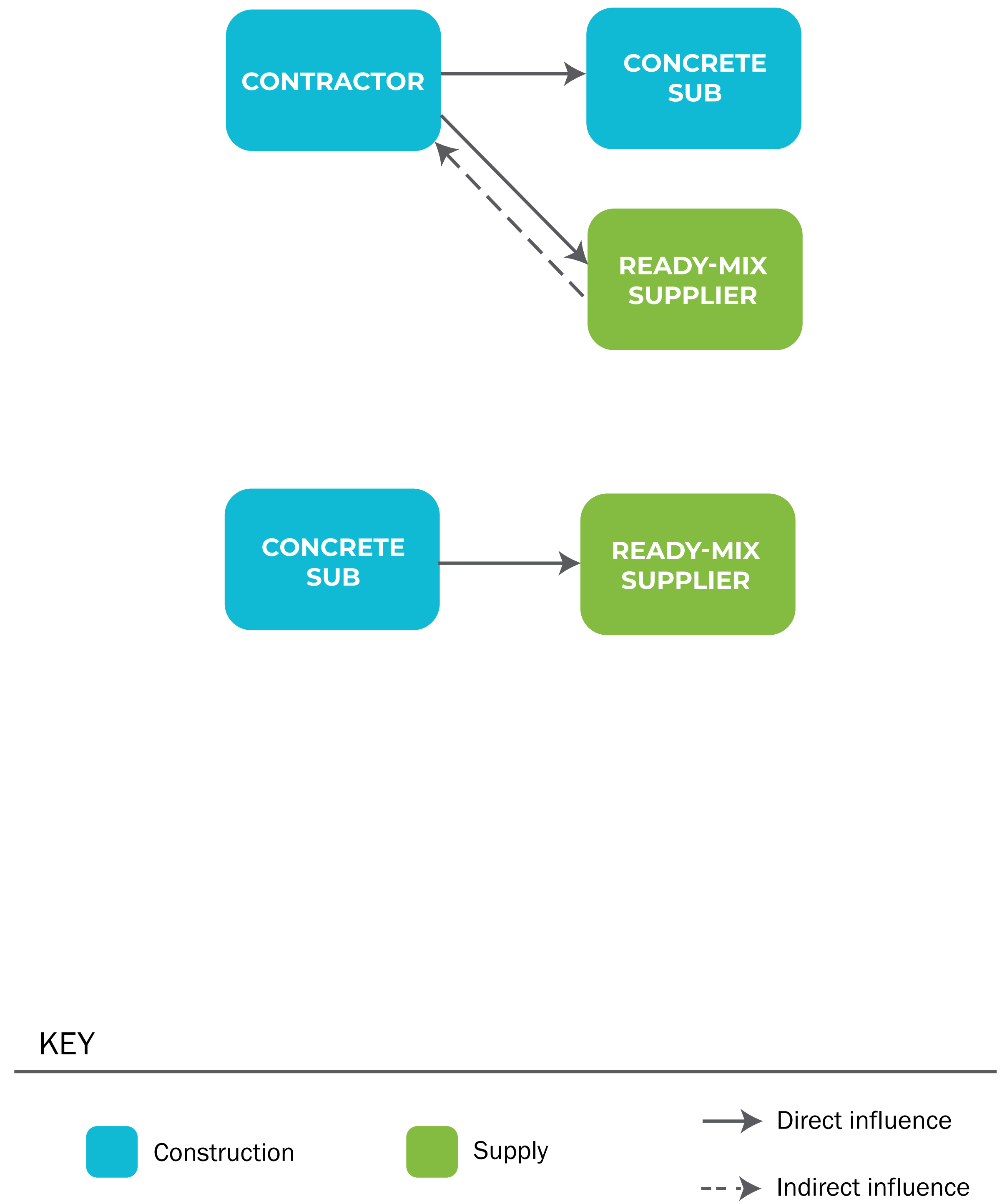
LEVERAGE POINTS FOR CONTRACTORS

The contractor hires the concrete subcontractor who performs the actual installation onsite. The contractor communicates expectations to subcontractors at the start of a project to ensure bidders are comfortable pouring low-carbon concrete. They can also proactively communicate expectations to all their existing partners, including suppliers, to understand what's available and signal demand.

Concrete installers can set expectations with ready-mix suppliers directly, as well.

Actionable steps for contractors:

- Make low-carbon concrete an agenda item in pre-bid meetings.
- Host a meet-and-greet with ready-mix suppliers to foster stronger relationships outside of individual projects.
- Explore investing in low-carbon concrete technologies to offset your Scope 3 emissions and satisfy ESG targets.



LEVERAGE POINTS FOR READY-MIX SUPPLIERS

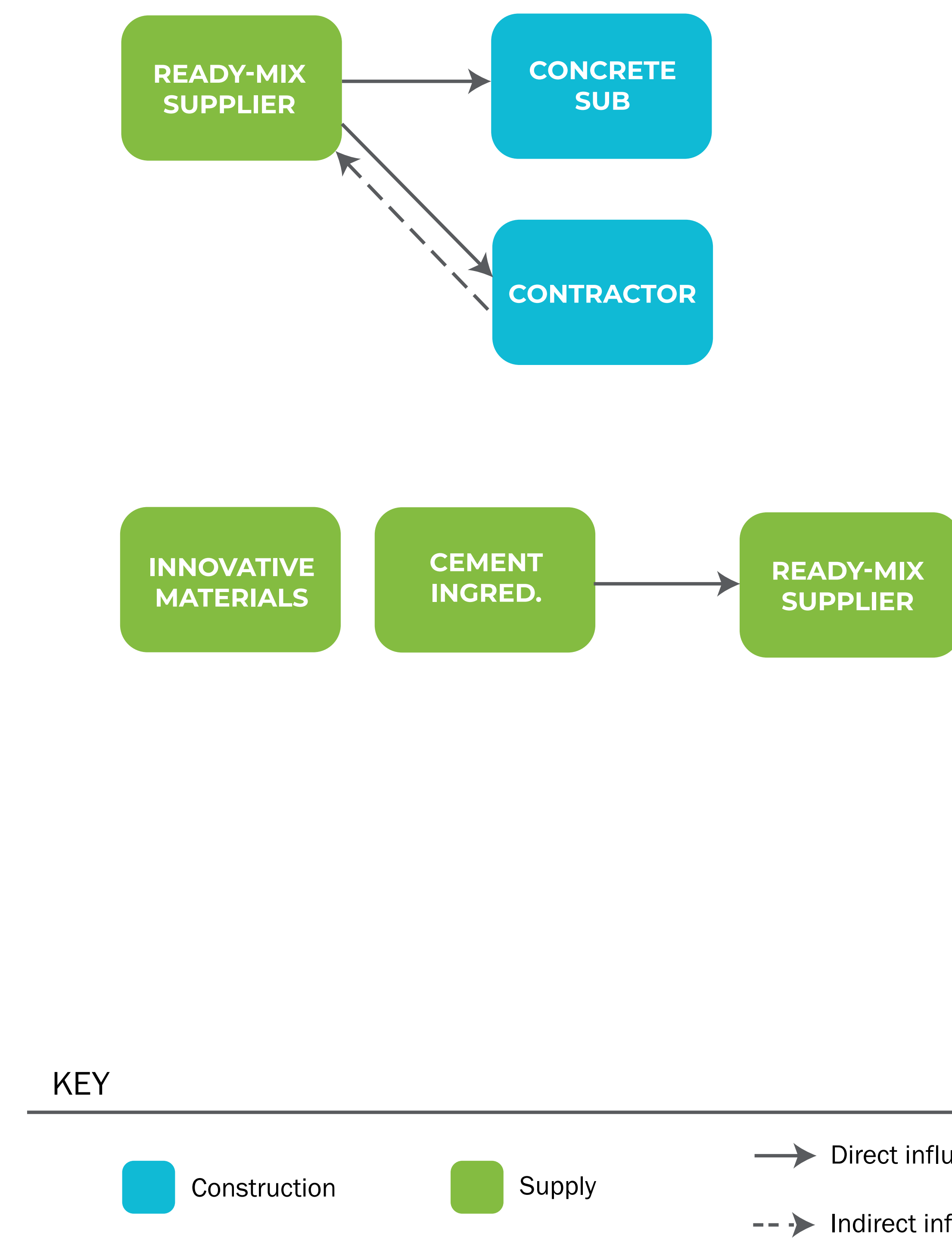
Ready-mix suppliers have already been reducing the carbon in concrete mixes and can make further reductions on their own. NRMCA and Massachusetts Concrete and Aggregate Producers Association (MaCAPA) support these efforts. Ready-mix suppliers can also influence their customers, concrete installers, and general contractors by proactively letting them know which SCMs and mixes are available.

Aggregate and SCM suppliers who provide ingredients to cement manufacturers can take action and proactively engage the ready-mix suppliers about what's available.

Actionable steps for ready-mix suppliers:

- Take this report as an indication of steady demand, and start storing SCMs so they are more readily available on demand.
- Broadcast that you have low-carbon concrete mixes available, and work those stats into your marketing and bid materials.
- Pursue getting EPDs for your mixes.

This initiative highlighted that early efforts, like proactive engagement with suppliers outside of projects and setting low-carbon goals in RFPs, pave the way for success. However, low-carbon concrete has made it onto projects because of champions that have come from anywhere within the delivery process. It is always better to assume that you need to be the advocate. Otherwise, you may unwittingly be the reason low-carbon concrete was dropped.



LET'S KEEP THE COLLABORATION GOING

Through this engagement effort, the participants highlighted that the project delivery process presents significant challenges to realizing low-carbon concrete and each stakeholder must take responsibility for what is in their control. For many of us, there was power in seeing stakeholders all along this single material supply chain in one room together. But we haven't yet found all the solutions or put them into practice. As we advocate for new legislative policies, change our firms' processes, and evaluate new technologies, we'll need to continue collaborating across disciplines.

Please consider participating in one or more of the following existing outlets to continue these conversations:

- The Carbon Leadership Forum Online Community
- BSA Knowledge Community and Carbon Leadership Forum Boston Hub
- Industry groups like NRMCA, MaCAPA, AIA, SEI, and AGC

The world is counting on us to get this right. Because low-carbon concrete is such an accessible, low-cost solution, it often only takes a champion or two with good timing. However, with such a short time frame to lower carbon emissions, we need everyone to use all the leverage they have to ensure mass adoption.

When a project chooses low-carbon concrete, we all win. Are you ready to make the game-winning move?

Appendices

A. PARTICIPANT LIST

Thank you to all the participants who attended a virtual or in-person workshop hosted by the Boston/Northeast Hub of the Carbon Leadership Forum (CLF) and the Boston Society for Architecture.

Name	Company
Abby Roberts	Turner
Alison Nash	Sasaki
Amelia Thrall	Ellenzweig
Andrew Bosco	Cranshaw Construction
Aprita Ganti	Stantec
Benjamin Coulehan	NEI General Contracting
Brad Mahoney	MP Boston
Brenda Stern	Thornton Tomasetti
Brett Lambert	Stantec
Brian Premont	Solomon Cordwell Buenz
Catherine L. Cai	MKA
Caitlyn Kelliher	Cranshaw Construction
Chris Gilmore	Turner Self Perform
Chris Hardy	Mass Design
Claire Nowasell	Heidelberg Materials
Coleman Horsley	Nitsch Engineering
Conor McGuire	Columbia Construction
Craig Dauphinais	MaCAPA
Dave Robb	Turner
Elsa Mullin	Skanska
Frank Dipitro	VHB
Frank Mruk	NRMCA
Gary Brock	HMFH Architects

Name	Company
GianCarlo Greco	SMMA
Greg Abbe	EOHLC
Guillaume Lemieux	CQ Cement
Harry Flamm	Stantec
Heather Henriksen	Harvard University
James Kitchin	MASS Design Group
Jennifer Hardy	Goody Clancy
Jennifer McClain	RSE
Jessica Morrissey	NEI General Contracting
Jim Burke	CBT architects
Jim Carreira	Boston Sand and Gravel
Jon Lannan	Northstar Project & Real Estate Services
Jon Richardson	Fennick McCredie Architecture
Kate Bubriski	Arrowstreet
Kate MacDougall	e2 engineers
Ken Donald	VHB
Kena David	Related Beal
Kent Gonzales	Northland
Kirsten Ritchie	Gensler
Lauren Wingo	Arup
Liz Galloway	Payette
Mark Liebert	Aggregate Industries
Matt Grosshandler	Bald Hill Builders

Name	Company
Matt Nelson	Cranshaw Construction
Melanie Silver	Payette
Michael Scancarello	Odeh Engineers
Mike Tilford	Sterling Concrete
Mick Albro	Tresca Brothers
Mike Collins	Commodore Builders
Mike Price	Odeh/WSP
Mike Scanarello	Fulcrum Land & Infrastructure
Neetu Siddarth	Boston Properties
Oliver Pires	Odeh/WSP
Pat Barb	S & F Concrete
Patrick Grasso	Urban Mining Industries
Patrick Kenny	Thornton Tomasetti
Rachelle Ain	Utile
Ralph Olds	Construction Service (CS)
Randa Ghattas	MIT
Rebecca Hatchadorian	Harvard
Rick Matthews	VHB
Rishi Nandi	Sasaki
Rowan Parris	Turner
Scott Engstrom	Elkus Manfredi
Scott Rabold	RSE Associates
Suni Dillard	HMFH Architects
Suzanne Robinson	LeMessurier

B. DESCRIPTION OF ENGAGEMENT PROCESS

The engagement kicked off with discipline-specific stakeholder focus groups, conducted virtually using a Miro board for live collaboration. Five focus groups were held: owners/developers, structural and civil engineers, architects, construction professionals, and ready-mix suppliers. The following questions were asked of each group:

- What are the challenges, barriers, and risks of using LCC?
- What would help reduce those risks?
- What are the cost drivers for LCC?
- What has changed (or needs to change) in your process and timing to make LCC the norm?
- How does the construction delivery method (CM-at-Risk, design, bid, build) factor in?

This input (along with an industry survey, see Appendix C) informed the sequence of questions that the facilitation team developed for the subsequent cross-discipline stakeholder workshops.

Workshop 1 (What) What are the barriers that make this difficult?
In this session, participants began by envisioning the future, answering the question, "What would it take to make low-carbon concrete the most cost-effective, most readily available option?" Given that future vision, they were then asked to rank a long list of barriers (sourced from the prior focus groups) by importance. Then they positioned the top-ranking barriers on a grid to determine which were most impactful if removed and least difficult to address. The results showed general consensus about top barriers but also interesting differences between stakeholder group perspectives. (See Appendix D on Prioritized List of Barriers).

The consensus was that the top barriers are all process-related and driven by relationships rather than a lack of available technology.

Workshop 2 (Who) Who are all the stakeholders and which have opportunities to drive change?
In this session, participants focused on stakeholders involved with low-carbon concrete and the relationships between them. After mapping which stakeholders are involved, the group discussed how each stakeholder has agency to lead solutions and how these stakeholders relate to each other. Many of these relationships are reflected in the Ecosystem Map introduced at the beginning of this report.

Finally, taking the top five barriers from the previous workshop, participants described the role that each stakeholder can play in addressing that barrier and how they might need to work together.

In this session, it became clear that multiple stakeholders can instigate the adoption of low-carbon concrete. And a knowledgeable stakeholder can often compensate for an opportunity missed by another stakeholder—or proactively educate them.

Workshop 3 (When) When do critical opportunities occur in the project process, and does the project type or construction delivery method make a difference?
Here, participants considered whether and how project type or delivery method impacts the barriers and opportunities related to low-carbon concrete. Breakout groups considered various project types, including public k-12, higher education, affordable housing, healthcare, corporate, and others. They also discussed the following project delivery models: design-bid-build, construction manager at risk, design-build, and integrated project delivery. (See Appendix E Project Delivery and Project Type).

The group concluded that the best opportunities to instigate low-carbon concrete adoption occur early, requiring early engagement of key players. This early engagement is harder to achieve in a public bid or design-bid-build process but can be accommodated through informal relationships or design assist contracts.

Workshop 4 (How) How will we achieve success, and what should we focus on first?
In the final session, participants unpacked what needs to happen in order to realize the success that was envisioned in the first session. The intent was to develop a roadmap of solutions needed to achieve our desired outcome. Future work would then focus on developing the solutions in detail for implementation. Breakouts were organized by the top five opportunities, which were the inverse of the top five barriers from Workshop 2. Participants discussed what needs to be done, what each stakeholder group needs to get to support success, what each stakeholder group can give, and also the resources needed to support those efforts.

In this session, we synthesized the many solutions that came up in previous workshops. These solutions are incorporated into the conclusion of the report and categorized as actions for project teams vs. actions for policy makers and organizations.

C. SURVEY RESULTS

Based in part on focus group conversations, survey questions were developed and circulated broadly to stakeholder groups (owners, architects, engineers, contractors, and suppliers). The survey was conducted using Survey Monkey, and everyone's responses were confidential but could be attributed to their role so differences in perspective could be identified. The survey questions focused on decarbonizing the ready-mix concrete supply chain in Massachusetts and New England. The results informed interdisciplinary workshop sessions that followed. Select comments are shown for each survey question but do not represent the full range of comments.

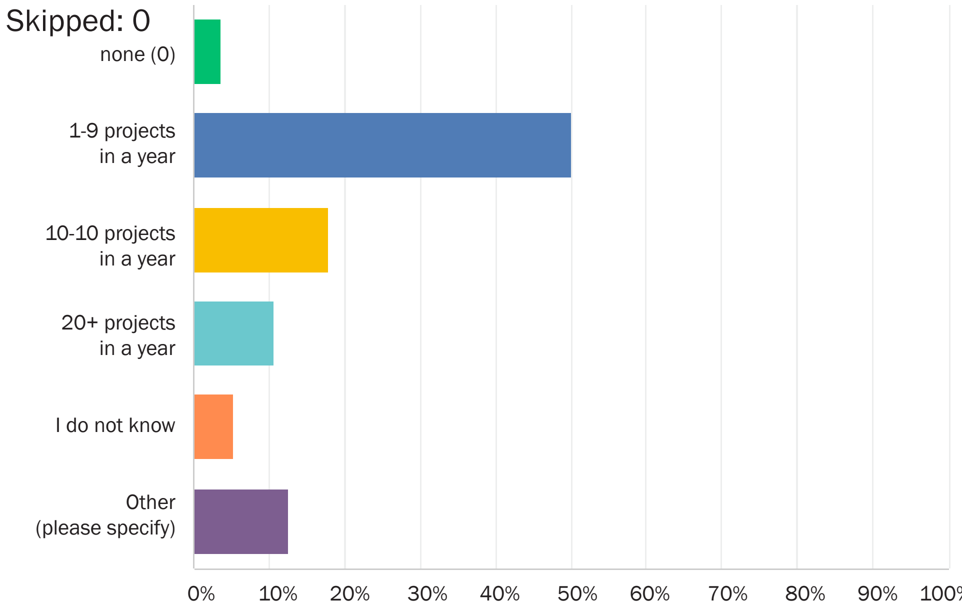
The takeaways from the survey were that fear of the unknown and perceived risk has been a significant barrier to adoption. Lack of early engagement with suppliers and the use of prescriptive specifications are two other causes of failure.

Numbers and demographics of the respondents:

- 86% worked on projects located in MA or New England
- Number of respondents in each stakeholder group
  - ◊ 7 owners
  - ◊ 18 architects/designers
  - ◊ 6 structural engineers
  - ◊ 0 civil engineers
  - ◊ 6 sustainability consultants
  - ◊ 3 general contractors
  - ◊ 0 concrete subcontractors
  - ◊ 3 ready-mix concrete suppliers
  - ◊ 3 municipal staff or policymakers
  - ◊ 8 "other"

How much demand do you see for low-carbon concrete in your company annually?

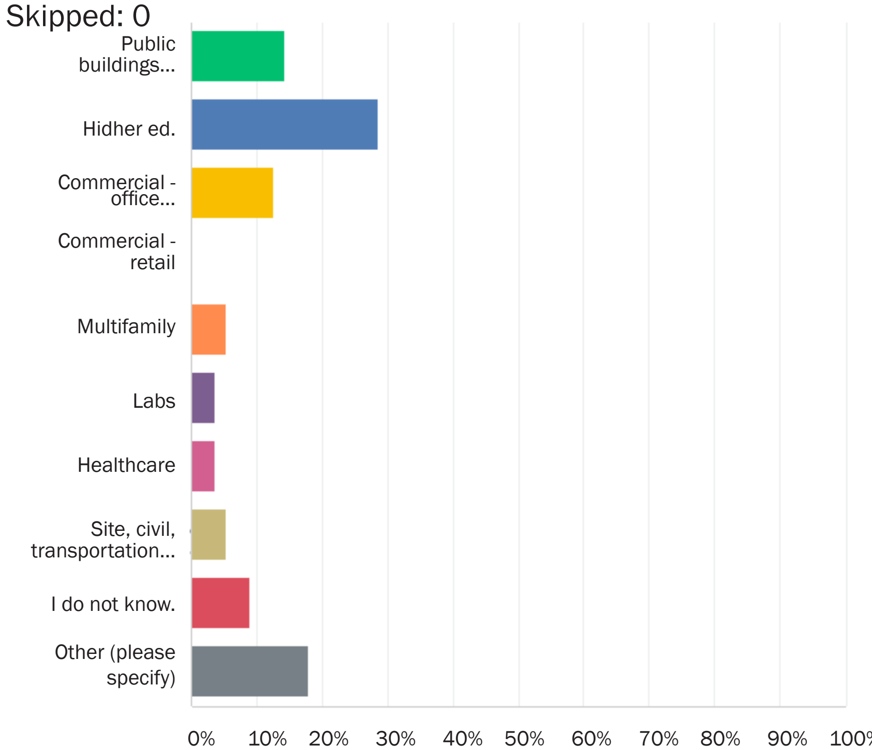
Answered: 53 Skipped: 0



Selective Comments: "I would say 20+ ask about it but the follow-through seems to be much less."

For which project type(s) is low-carbon concrete most requested or pursued?

Answered: 53 Skipped: 0



What are the top challenges you face to incorporate LCC into your projects?
Answered: 53 Skipped: 1

ANSWER CHOICES	RESPONSES	
Lack of demand (clients do not ask for it or do not want it)	30.77%	16
Timing: lack of earlier coordination between project team and ready-mix supplier and/or installer	48.08%	25
Prescriptive requirements from project team that are difficult to meet	19.23%	10
Lack of clarity in requirements or specifications	36.54%	19
Lack of supply (of lower carbon mixes)	36.54%	19
Longer lead times to obtain materials	9.62%	5
Silo / storage capacity	11.54%	6
Lack of testing (or other) equipment for specialized materials	15.38%	8
Research, trials, or testing	5.77%	3
Price fluctuations of raw materials	15.38%	8
Specific concerns about performance of new mixes after installation	30.77%	16
General uncertainty, fear, or perceived risk	57.69%	30
Real or perceived costs associated with low-carbon concrete (please explain in open text box below)	36.54%	19
Other (please explain below in open text box)	15.38%	8
TOTAL	*	192

*Percentage exceeds 100% because applicants were asked to check all options that apply.

Example "Other" comments: "Right now low-carbon concrete is focused on slag/fly ash which doesn't really affect climate change (you're not increasing supply with increased demand). The biggest challenge is bringing new low-carbon concrete options to the marketplace (i.e., GGP, calcinate clay, investment in cement production infrastructure)."

"My concern is that changing the CO2 content of concrete will reduce the ability of concrete to protect embedded steel from corrosion."

"Lack of industry (design + construction) enthusiasm to specify mixes outside of traditional SCMs, e.g., fly ash and slag."

What do you think are the top cost drivers for low-carbon concrete?
Answered: 52 Skipped: 1

ANSWER CHOICES	RESPONSES	
Fear of the unknown or un-tested	62.26%	33
Time (delays for testing, curing, etc)	35.85%	19
Time (delays related to the availability of new materials for new mixes)	18.87%	10
New mixes (cost of SCMs, other raw materials)	52.83%	28
Silo / storage capacity	20.75%	11
New equipment needed (for testing, etc.)	1.89%	1
Location of materials (transportation costs)	22.64%	12
Labor (additional)	11.32%	6
Requirements that limit choices (carbon reduction targets or specifications)	39.62%	21
Research, trials, testing	11.32%	6
Do not know	9.43%	5
TOTAL	*	152

*Percentage exceeds 100% because applicants were asked to check all options that apply.

Example "Other" comments: "We're seeing some of the concrete subs pricing GGP almost double what others are pricing it out as, just because of the fear of the unknown."

What do you think needs to change in the design/project delivery process to make low-carbon concrete standard (for example, earlier conversations between the project team and the ready-mix supplier and/or installer)?

Answered: 48 Skipped: 5

ANSWER CHOICES	RESPONSES	
Construction delivery methodology that allows for earlier collaboration with suppliers	64.00%	32
Performance-based specifications (specs that set a reduction target and let the supplier help determine the mix that will achieve the target)	80.0%	40
Prescriptive specifications that spell out exact mixes with SCMs	24.00%	12
Time for additional testing, mock-ups, or pilots	32.00%	16
TOTAL	*	100

*Percentage exceeds 100% because applicants were asked to check all options that apply.

Example "Other" comments: "Design teams typically working on design-bid-build projects do not often speak with ready-mix suppliers and installers. This would help to understand what can be done by suppliers more likely to supply to a project based on proximity."

"It is both construction delivery and designers using new materials. Performance specifications do not enable innovation in SCMs that don't rely on fossil fuels."

"Make sure # of GHG are specified, not a % of reduction. Also make sure concrete EPDs are specifics and made with cement-specific EPDs."

Design & Construction professionals: what design strategies or choices have you made to reduce embodied carbon in the concrete of your projects?

Answered: 43 Skipped: 10

ANSWER CHOICES	RESPONSES	
Targeting reductions by focusing on lower carbon concrete mix design (by substituting SCMs)	71.74%	33
Design strategies to reduce the overall quantity or volume of concrete used in the project	67.39%	31
Substituting materials other than concrete for parts of the building (such as mass timber)	58.70%	27
Designing for deconstruction (or future reuse of the concrete)	6.52%	3
TOTAL	*	94

*Percentage exceeds 100% because applicants were asked to check all options that apply.

Example "Other" comments: "Mass timber can also lead to more concrete in foundations, so there isn't always an easy substitution between structural materials."

"We do a substantial amount of adaptive reuse projects. Salvaging as much of the existing building as we can."

What do you think could reduce the risks of supplying or incorporating low-carbon concrete and support long-term success?

Answered:53 Skipped:0

ANSWER CHOICES	RESPONSES	
Pilots with SCMs	35.85	19
Incentives for suppliers to increase storage capacity (and/or testing equip.) for additional SCMs	60.38%	32
More testing of different mixes with published results	64.15%	34
Education and training (for building industry - design, engineering, construction)	66.04%	35
Education and training (for concrete suppliers)	62.26%	33
More regulations and policies (to drive demand)	54.72%	29
More data shared publicly (including case studies)	49.06%	26
More forums to discuss and/or problem-solve	37.74%	20
TOTAL	*	228

*Percentage exceeds 100% because applicants were asked to check all options that apply.

Selective Comments: "LEED is very successful at driving demand for operational energy reduction strategies. With LEED, this is often for just a few points out of many and yet even that is often enough to help drive demand. Something similar is needed that is achievable but truly focuses on embodied carbon goals to drive demand."

What are the risks of supplying or incorporating low-carbon concrete into your work?

Answered: 45 Skipped: 8

ANSWER CHOICES	RESPONSES	
Failure of installed materials	36.73%	18
Unanticipated costs	67.35%	33
Time delays	63.27%	31
TOTAL	*	82

*Percentage exceeds 100% because applicants were asked to check all options that apply.

Selective Comments: "No risk if it is planned, and if targets are known."

Circularity and reuse: what do you think could be done to support the reuse of concrete when the original building it was installed in is at the end of its life?

“Clear path on what testing is needed for being able to reuse concrete. New assembly/connection details to make things like concrete slabs more deconstructible.”

“We need an ecosystem of end-of-life companies that can take materials for reuse/upcycling. Need infrastructure for such systems (processing, storage)—and industrial symbiosis system.”

“1) Concrete repair products are incredibly common, cheap, and cost-effective. I have specified many concrete repairs, it is incredible what can actually be fixed! 2) Deconstructing elements by cutting them out of a building, capping the reinforcement, and then selling them as pre-cast units.”

“Retain footprint so that foundations can be retained.”

“Policies that require calculating the embodied carbon comparing reuse to new construction and setting benchmarks for new projects.”

Are there any other issues you want to raise that have not been touched on? Or questions you have that you would like answered by the end of this project?

“What do architects do vs. structural engineers vs. contractors to improve how we work towards low-carbon concrete? How do we address pushback from other players?”

“When can on-site batching of SCMs and ready-mix be advantageous - can this help expand the range of use of SCMs that may not be siloed at certain batch plants?”

“I [have not found] a resource that indicated 1) solar reflectance, 2) GWP, and 3) performance for specific mix ratios, together in one guidance doc.”

D. PRIORITIZED LIST OF BARRIERS

Sustainable Performance Institute developed a compilation of barriers that were pulled from conversations in the stakeholder focus groups. In a following engagement session, these barriers were ranked. Participants were asked to choose the top three barriers that were most important to address in order to make low-carbon concrete possible. The following table shows all the barriers. The ten barriers that most frequently made it to the top three are highlighted below.

Full List of Barriers from Stakeholder Sessions (with top ten ranking ones highlighted).

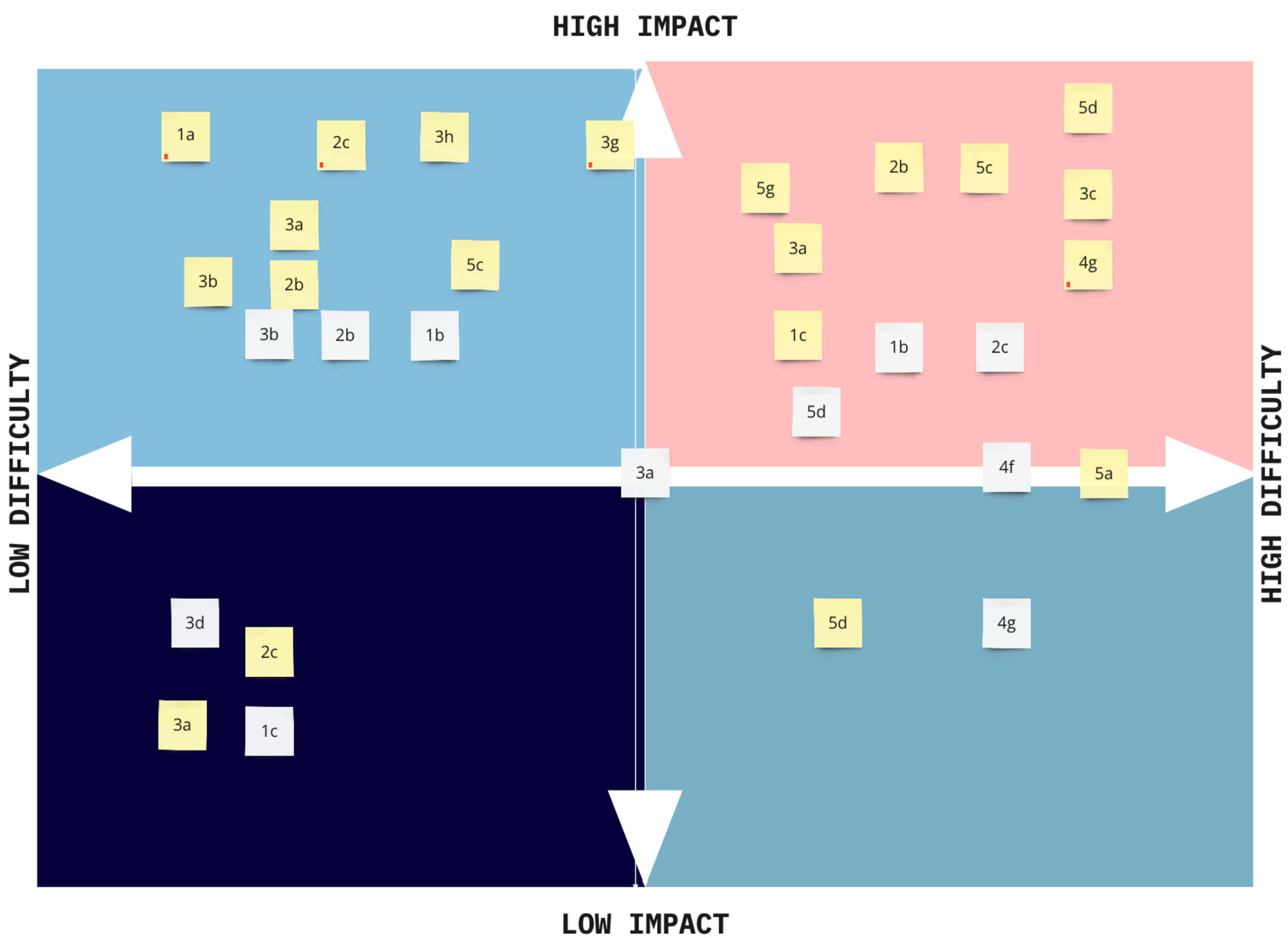
1	**Education: Different Learning Curves for Different Stakeholders**
1a	Education: for owners and architects about WHY it’s important and HOW to get it done
1b	Education: for GCs about why, how to get it done and how to support subs (or what to look for in new ones)
1c	Education: for subs about how to install (which info is needed for submittals etc.)
2	**Unknowns: Need research, pilots, and published data**
2a	Lack of local pilots and published case studies
2b	Lack of published test results for new mix types (including SCM impacts on curing time, workability, and ACI exposure class)
2c	EPD quality and availability: Plant-specific or mix-specific EPDs are lacking, so can’t quantify compliance accurately. Need cement-specific EPDs
2d	Sand: Lack of data re: a strategic approach to map and locate best quality sand supplies in accessible areas. Low-quality sand requires a water-cement ratio, chemical additives, etc. Communities don’t want excavation.
3	**PROCESS ISSUES**
3a	Lack of early engagement with suppliers during project (to give them time to source materials / SCMs without a rush)
3b	Lack of ability (for suppliers) to forecast demand before “last minute”
3c	Prescriptive specifications instead of performance-based limits choices and ties suppliers’ hands

3d	Lack of early dialog between structural engineer and supplier (engineer is gone by the time supplier is brought onto the project)
3e	Lack of good info sent to ready-mix suppliers (often get a PDF of spec in email asking for a price, often without drawings)
3f	"Add alternate" designation in the spec makes it easy to kill
3g	Lack of demand (clients don't always ask for it) and regulations/policies don't yet drive it enough
3h	Lack of clear goals: owner/team not stating reduction goals until later in project
3i	Lack of ability to make strategic design changes to reduce overall volume (architect sells client on design idea and can't change later)
3j	Inexperience: GC may need to establish relationships with new subs who have experience in larger projects
3k	If wrong mix shows up at jobsite, it may be unlikely to be turned away (schedule delay)
3l	Construction delivery method (to engage supply early)
3m	Proprietary design/limited options: Some structural systems like, girder slabs and shear walls, are proprietary and can only be performed by a few manufacturers
4	**PERCEIVED RISK**
4a	Time delay: longer cure times
4b	Time delay: increased labor hours for flat work, and separately, time till GC can set steel
4c	Time delay: increase set up time (i.e, moving, shoring/formwork)
4d	Failure: new mix causes catastrophic failure or just aesthetic cracking
4b	Failure: seasonal variability (weather) impact on new mixes
4e	Time delay: increased labor hours for flat work, and separately, time till GC can set steel
4f	Unknown finishability/workability of "new" mixes (combination of time and failure)
4g	Cost: increase in costs due to variety of reasons (see cost below)
4h	Health: unintended pubic health consequence of using fly ash, slag, chemicals
5	**COST INCREASES**
5a	Fear factor: too many unknowns can lead to upcharge due to uncertainty (rather than for specific reasons (below)
5b	Delay engaging suppliers: if suppliers aren't engaged early in project, the "rush" to source materials will drive up costs
5c	Prescriptive specs for concrete don't allow for flexibility and will drive up costs (especially if supplier is not engaged early)
5d	Cost of raw materials can be higher (less in demand, new to market, or limited/dwindling supply, so more expensive)
5e	Transportation costs: some sources of material may be far away so trucking/fuel costs are more
5f	Lack of storage silos and/or testing equipment for new mixes. (Each material needs its own silo. Uncertainty about what is in demand means not knowing what to store.)
5g	Schedule/time delay on site (for set-up time, finish time, cure time–as in Risks above)
5h	Additional labor needed for installation, finishing
6	**BARRIERS TO REUSE**
6a	Chemical admixtures and other contaminants make it challenging to recycle
6b	Lack of policy drivers (decon instead of demo, design for construction)

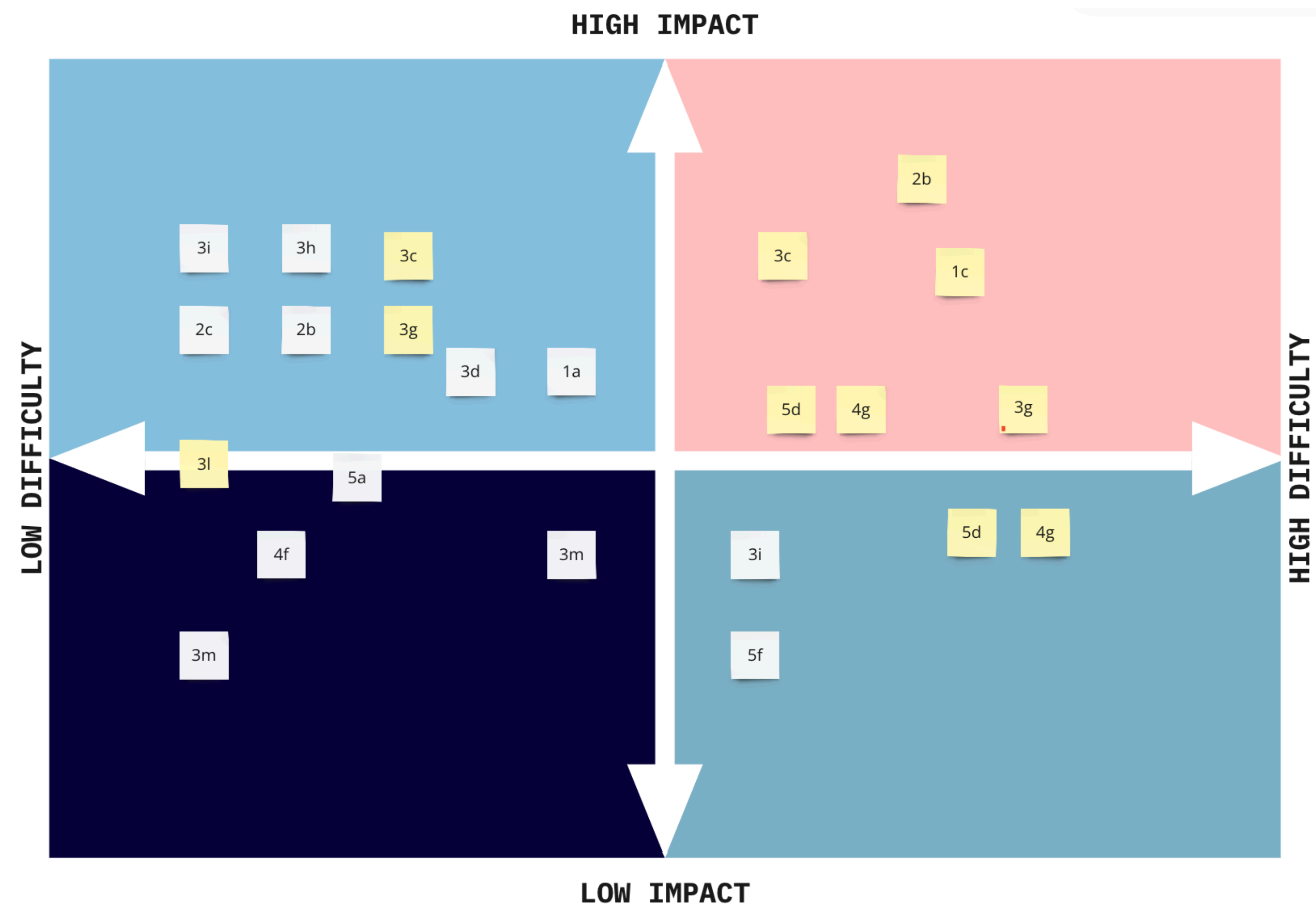
Most impactful and least difficult to address barriers (by stakeholder group)

Participants were then asked to place their top three barriers on a grid, positioning the barrier along the axis of “difficulty” and “impact.” The participants did this exercise in mixed groups, but the results were later analyzed by stakeholder affiliation. Below, you’ll find how the architects and the structural engineers placed their top three barriers in the graph. These two groups were selected because they had the most number of participants in the session and thus represent a decent sample size.

Architect:



Structural Engineer:



Prioritized List

Solving the high-impact, low-difficulty barriers will have the biggest decarbonization benefit for the least effort. Therefore, they should be prioritized first. Across stakeholder groups, there was generally good alignment that these were the highest priority (high-impact, low-difficulty) barriers.

1	Education: Different Learning Curves for Different Stakeholders

	Owners	Architects	Engineers	Contractors	Suppliers
Lack of early engagement	✓		✓		✓
Lack of clear project goals	✓	✓		✓	
Education	✓	✓		✓	
Use of prescriptive specs		✓	✓	✓	✓
Lack of demand		✓	✓		
Lack of good quality EPD data		✓			
Lack of published test data		✓			
Lack of ability to forecast demand		✓			

E. PROJECT DELIVERY AND PROJECT TYPE

In Workshop 3, the group focused on two questions:

1. When do critical opportunities occur in the project process?
2. Does the project type or construction delivery method make a difference at key points?

The following table represents the pros and cons of select project types using three common delivery models: design-bid-build, CM-at-risk, and design-build.

In general, the groups argued that design-build and CM-at-risk are preferred delivery models because they allow more stakeholders to be involved early, which helps to vet performance specs for low-carbon concrete and identify potential roadblocks or schedule constraints. However, getting the structural engineer engaged in the conversation around low-carbon concrete early in the process can help overcome limitations imposed by design-bid-build.

	Design-Bid-Build		CM-at-Risk		Design-Build	
	Pro	Con	Pro	Con	Pro	Con
Luxury multifamily	Repetitive structure is ideal for prototypes and innovation	Difficult to change mindsets	Portion of the project could "feature" low-carbon concrete			
Affordable housing	Early, targeted ask to the GC for studying feasibility of LCC	No access to subcontractors during design phase Low-carbon concrete as a change order is unlikely to succeed			Regulations and incentives drive performance outcomes	Uncommon: lowest first cost is prime driver
Private higher education	Early budgeting allows for setting informal goals	Lack of early conversation between subs and design team	Many subs onboard early provides ample opportunity for education	Need for university approvals sometimes puts too much emphasis on cost	If the subcontractor is known, could develop confidence in one innovation method	

F. EMERGING LOW-CARBON CONCRETE TECHNOLOGIES

This initiative mostly focused on low-carbon concrete technologies that reduce emissions by replacing some of the portland cement in the mix through increasing the proportion of SCMs. There are other emerging technologies that reduce the emissions from concrete—sometimes much more drastically than what is possible with SCMs alone. Using these alternative technologies may require entirely different processes, relationships, and incentives than those mapped through this initiative.

The participants in the engagement focused primarily on concrete with SCMs because that is currently the most prevalent low-carbon option available in the Northeast market and the most familiar solution—and yet the industry has still not adopted these mixes at scale. However, in this fast-changing field, it is worth keeping tabs on some other types of promising tech.

Carbon-absorbing tech

As concrete cures—and to some extent over the course of its entire life—some CO2 is absorbed back into the concrete in a process called carbonation. This absorption is not typically enough to offset the initial climate impacts of portland cement production. However, some companies are now injecting CO2 from industrial sources directly into the concrete mix to speed up the carbonation process. Solida and CarbiCrete currently apply the approach with their precast products. CarbonCure is the only supplier of this technology that can poured in place.

Carbon-sequestering aggregate

Recycled concrete has long been repurposed for aggregate, reducing the use of virgin material and saving on disposal costs. But now recycled concrete can be processed into two distinct aggregate products, permanently sequestering the embodied carbon. Blue Planet uses a chemical process that can strip cement from old aggregate, converting it to fine and coarse calcium carbonate (limestone) aggregate, while leaving a clean aggregate source behind. The same process can be applied to unpurified CO2 from industrial sources, like cement kilns, rather than using recycled aggregate.

Complete cement replacement

One company has claimed it has been able to replace cement entirely using alternative cementitious binders. The alternative binders in C-Crete avoid the CO2-intensive process of calcinating limestone and react together via a chemical process rather than needing energy-intensive kilns. The result is a carbon-negative or carbon-neutral concrete, according to the company, though it is still finalizing its EPD. The concept is not entirely out of the realm of possibility: the ancient Romans used lime, natural volcanic pozzolans, seawater, and locally available ingredients to make concrete without cement.

Many academic institutions and startups are exploring a wide variety of approaches to low-carbon concrete, all of which can't be covered here. Keeping track of further advancements is an additional wrinkle for practitioners but important for advancing the best solutions.

G. ACRONYMS

- EPD: Environmental Product Declaration
- ESG: Environmental Social Governance
- GWP: Global Warming Potential
- MaCAPA: Massachusetts Concrete and Aggregate Producers Association
- NRMCA: National Ready Mixed Concrete Association
- RFP: Request For Proposals (RFP)
- SCM: Supplementary Cementitious Materials (SCMs)