The Top 10 Ways to Reduce Concrete's Carbon Footprint

NRMCA

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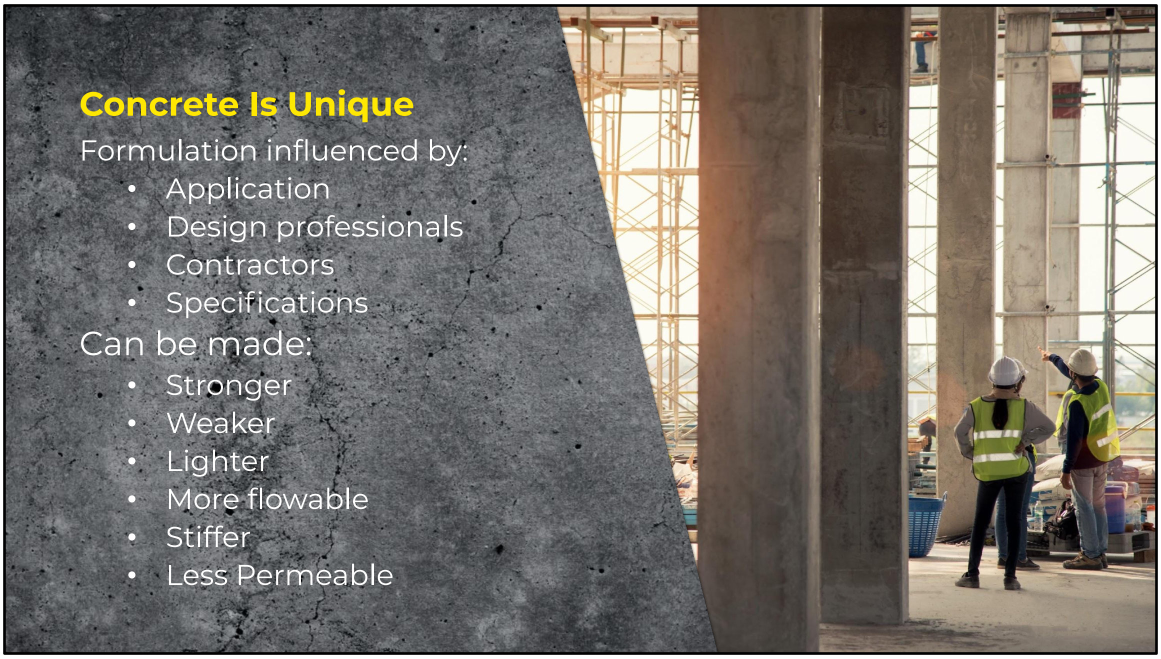
Learning Objectives:

- Explain the basics of embodied carbon of concrete.
- Evaluate the immediate steps that can be taken to reduce carbon footprint when specifying concrete.
- Prioritize design strategies to get the greatest reductions in carbon footprint using current technologies and design tools.
- Explore how innovative technologies will result in zero-carbon concrete in the future.

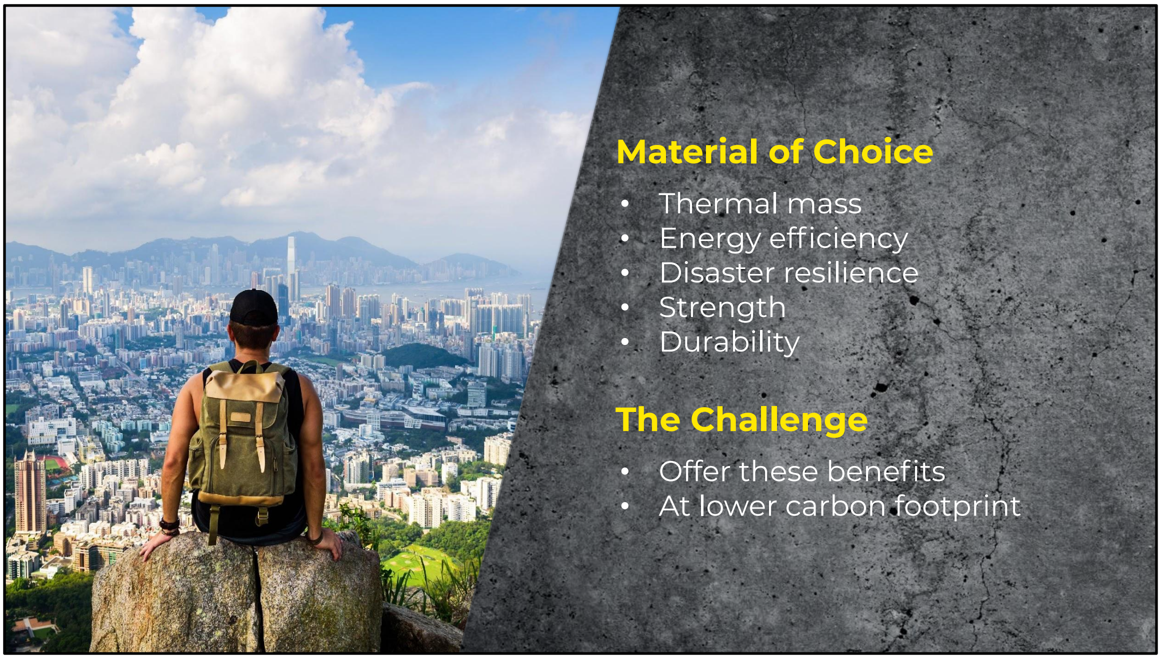


Concrete is unique for many reasons. Its formulation is highly influenced by its application. Design professionals and contractors have a greater influence on concrete formulation than they do with any other building product. Concrete can be made stronger or weaker, lighter, more flowable, stiffer, or less permeable depending on performance needs.

No other building material is as versatile. It can be exposed to the elements or exposed for architectural reasons. Concrete is economical, available nearly everywhere, and made from the most abundant materials on the planet, usually from local sources. Concrete does not rot, rust, or burn.

Concrete is used in nearly every structure where people live, work, learn, and play. It is used for the tallest buildings, the longest bridges, the largest buildings, the busiest airports, the most efficient rapid transit systems, roadways, theaters, stadiums, schools, apartment buildings, and houses. Drinking water is transported in concrete pipes and reservoirs, and waste is treated in wastewater treatment plants made of concrete. It is part of the infrastructure that connects us. It is the material that helped build modern society and will likely be part of improving modern society for some time.

According to UN Environment's Global Status Report 2017, the world is projected to add 3.4 trillion square feet of buildings by 2060. This is an area equal to 1.4 times the entire current global building stock. The UN report urges building designers and owners to design disaster-resilient buildings for the future, with zero energy consumption. At the same time, the UN report also urges the building industry to reduce the embodied impacts of the building materials it uses.



Because of its thermal mass, concrete has long been the material of choice for energy efficiency, and because of its strength and durability, it has been the material of choice for disaster resilience.

The challenge is to offer these concrete benefits with low carbon footprint. This presentation will discuss how design and construction teams can implement ten simple strategies to reduce concrete's carbon footprint today.

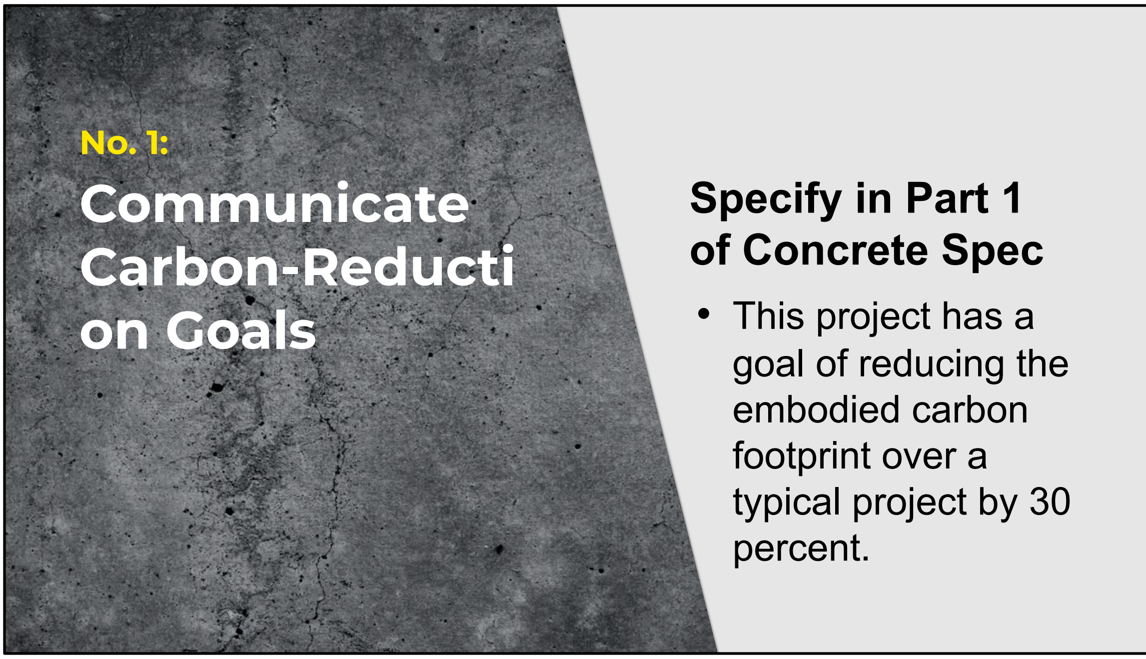
The recommendations are listed broadly in order of priority but not impact reduction. All are important and should be implemented. In addition, the strategies are meant to achieve a lower carbon footprint without impacting other traditional performance criteria for concrete. Let us start with the top 10 things you can do to lower concrete's carbon footprint. Then I will go through each one in detail.

1. Communicate carbon reduction goals
2. Ensure good quality control and assurance
3. Optimize concrete volume
4. Use alternate cements
5. Use supplementary cementitious materials
6. Use admixtures
7. Do not limit ingredients
8. Set targets for carbon footprint
9. Sequester carbon dioxide in concrete, and finally,
10. Encourage innovation

This is the most important step. One of the basic tenets of achieving a goal is to effectively communicate that goal to everyone on the team. For concrete, this is especially important because there are so many parameters and criteria for concrete mixtures. To make sure that reducing embodied carbon remains a top priority throughout the project, it must be included in drawings and specifications that are communicated to the owner, contractor, and product suppliers.

I have three basic recommendations:

The first is to collaborate. The only way you can set your carbon footprint goal is to understand the capabilities of contractors and producers who will work on the project. Invite them in for meetings with your design team. Understand what technologies and concrete ingredients are available locally. Just because a product (slag cement, for example) is not generally used in a market does not mean you should not specify a product or prohibit its use. Generally, the reason a product is not used is because there is no demand for it. You need to create the demand by permitting and encouraging its use.



Next, specify your goals or targets. State your goal at the beginning of the concrete specification. In Section 03300 of the specification, Part 1, make it clear what level of carbon reduction you are trying to accomplish for the project and for the concrete itself.

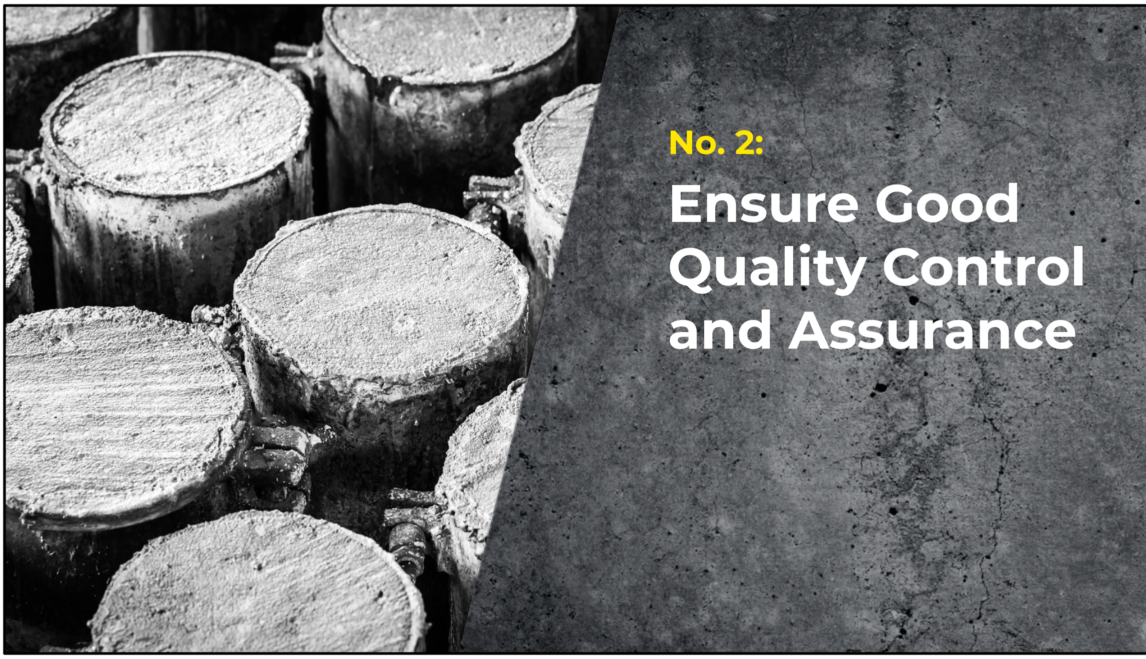
No. 1:

Communicate Carbon-Reduction Goals

Prebid Meetings

- Restate the carbon-reduction goals and encourage innovation.

Communicate again in pre-bid meetings. It is also important to communicate carbon reduction goals in other ways. Most projects have pre-bid meetings, which can be opportunities to communicate carbon reduction goals for all products to all potential bidders.



Concrete producers design concrete mixtures to meet the needs of the contractor in terms of workability (flowability, pumpability, finishability, etc.) based on their local aggregates and then use a sufficient quantity of cementitious materials to achieve the required compressive strength, which is higher than the specified compressive strength. This “overdesign” (the difference between the actual average compressive strength and the specified compressive strength) is based on well-established statistical methods described in the codes and standards for concrete.

There are well-established procedures for taking concrete samples, preparing test specimens, storing them on-site, transporting them to a laboratory, and finally testing them in a compression testing machine or other apparatus. Concrete rarely tests well when testing protocols are not followed. If test results constantly show lower strength, the only way to overcome this is to increase overdesign which generally raises cementitious material content.

Lower overdesign means lower cementitious materials content. For example, going from 1,200 psi to 600 psi overdesign would likely require 60 pounds less cementitious material, potentially an 8 percent decrease in embodied CO_2.

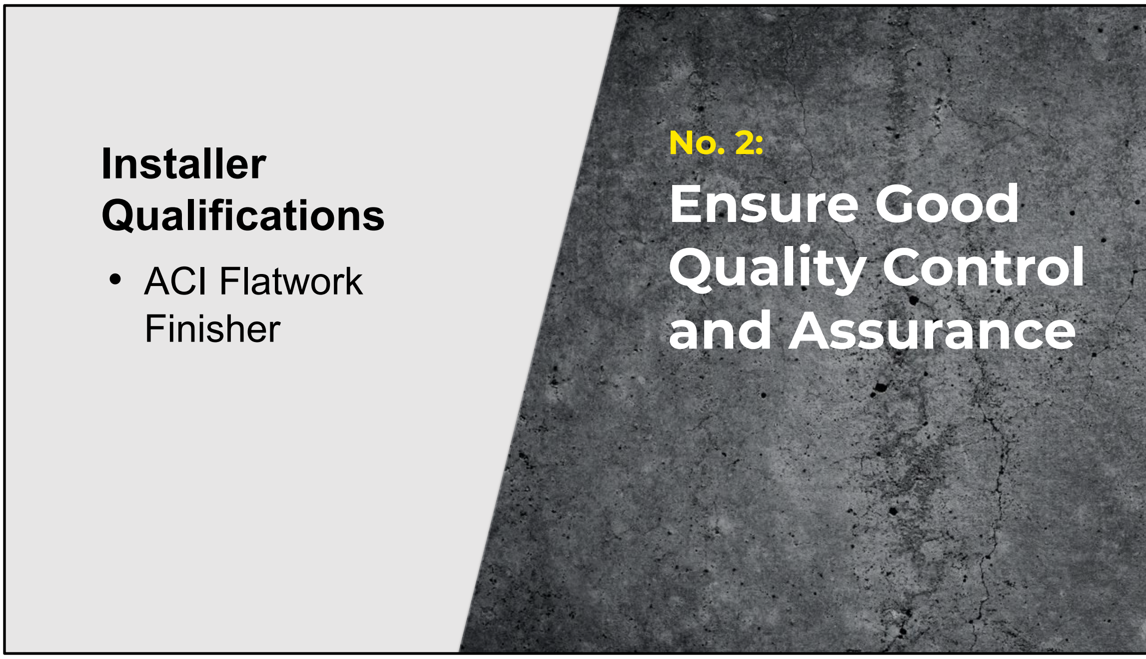
Manufacturer Qualifications

- Certified Concrete Production Facility
- Concrete Technologist Level 2

No. 2:

Ensure Good Quality Control and Assurance

One way to provide some assurance that a concrete producer has good quality control is to require certifications for its manufacturing facilities, mixer trucks, concrete technicians, and plant operators.



The same can be said of installers and independent testing laboratories and their personnel. In the quality-assurance section of the concrete specification, require that installers are ACI certified, and concrete producers have their plants and technicians certified.

Testing Agency Qualifications

- Meets ASTM C1077
- ACI Concrete Field Testing Technician Grade I
- ACI Concrete Laboratory Testing Technician Level I
- Results certified by a registered design professional

No. 2:

Ensure Good Quality Control and Assurance

These same principles apply to testing laboratories: Make sure they are qualified and their personnel certified.

This strategy is just about employing good design practices. If a structural element such as a column or beam is designed larger than required, excessive concrete is being used, which increases embodied carbon. Alternatively, for a high-rise building, reducing the size of the columns might be critical to keeping the rentable space to a maximum. This means using high-strength concrete, which generally means higher carbon footprint.

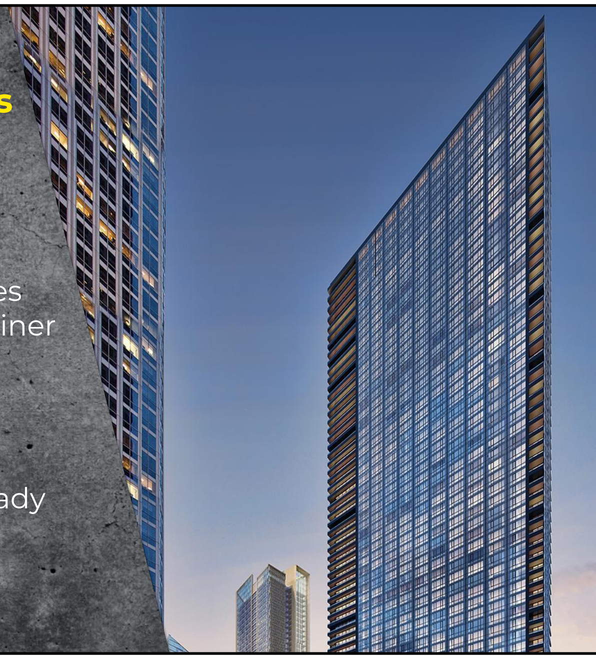
We suggest using life-cycle analysis software to quickly calculate the embodied carbon of concrete elements (structural or architectural).

Consider exposing concrete wherever possible. Finish materials have a considerable carbon footprint, and since exposed concrete can be attractive and is fire resistant without the need for additional protection, this is an excellent strategy for reducing the carbon footprint of the building. The other benefit of leaving concrete exposed is that concrete absorbs carbon over time through a process called carbonation. (More about this later.)

Case Study: 960 West Seventh Street, Los Angeles

- 64-story tower
- 780 residential units
- 807,000 square feet

- Developer: Brookfield Properties
- Design Architect: Marmol Radziner
- Executive Architect: Large Architecture
- Structural Engineer: MKA
- Contractor: Webcor
- Concrete Supplier: National Ready Mixed Concrete Company
- Photos: Brookfield Properties



Our first case study is 960 West Seventh Street, a multifamily high-rise development located in the heart of downtown Los Angeles. This 64-story tower has 780 residential units totaling 807,000 square feet.

The Challenges
Projects of this magnitude have challenges when it comes to balancing cost, long-term value, energy efficiency, occupant comfort, and sustainability. The design team, developer, contractor, and product suppliers need to have the same goals in mind when it comes to reducing environmental impact, including carbon footprint.

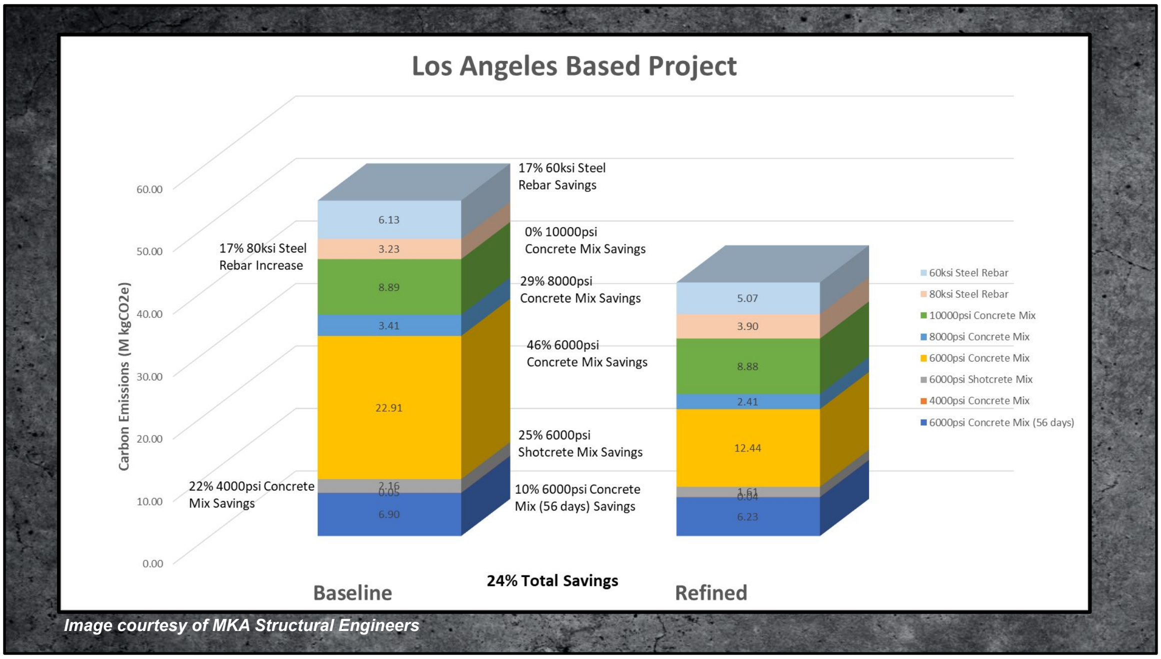
The first sustainable solution was to design and efficient structural system.

Structural engineers play a key role in selecting the structural system for most buildings, especially for a high-rise in a high seismic zone. In working with the design team to best meet project goals, the engineering firm proposed cast-in-place post-tensioned slabs, with a centralized buttressed concrete core that tapered with height. This system optimized floor to floor heights, eliminated transfers, and worked with residential and public spaces to optimize net/gross floor ratios while preserving unobstructed views at the building perimeter. The firm's optimization also included performance-based seismic design and 80 ksi rebar wherever it led to a material reduction.

The design team set targets for carbon footprint and used life-cycle assessment software to evaluate a benchmark building against the proposed building.

Engagement with the contractor and concrete supplier early on also helped "tighten up" the mix designs, where the single change of the aggregate being used, moving to imported and higher-quality aggregates, improved quality control, and variation in the mix performance allowed the same specified compressive strength reliability to be achieved with a lower quantity of cementitious materials.

The structural engineer worked with the contractor to determine where faster strength gain was really needed and adjusted testing age accordingly to accommodate higher volumes of SCMs.



The design team reduced 24 percent of the total project embodied carbon footprint at not additional cost—that is after accounting for the carbon from barging aggregate from the Pacific Northwest down to Los Angeles.

On the PT slab mixes alone, they reduced the carbon footprint of that mix by 47 percent.

No. 4:

Use Alternative Cements

ASTM C595		
Type	**Description**	**Notes**
Type IL (X)	Portland-Limestone Cement	Where X can be between 5 and 15% limestone
Type IS (X)	Portland-Slag Cement	Where X can be up to 70% slag cement
Type IP (X)	Portland-Pozzolan Cement	Where X can be up to 40% pozzolan (fly ash is the most common)
Type IT (X)(X)	Ternary Blended Cement	Where X can be up to 70% of pozzolan + limestone + slag, with pozzolan being no more than 40% and limestone no more than 15%

There are several alternates to portland cement, but the most common are called blended cements. These combine ordinary portland cement with other materials. The most common type of blended cement is portland limestone cement often called PLC for short, or technically ASTM C595 Type One-L cement. This blended cement combines up to 15 percent limestone interground with portland cement to make a cement with a carbon footprint that is up to 10 percent lower than ordinary portland cement with performance that is identical to—and in some cases better than—ordinary portland cement.

There are four types of blended cements under ASTM C595 ranging from Type One-L cement to Type One-S that combines slag and portland cement, Type One-P that combines a pozzolan like fly ash with portland cement, and Type One-T that combines two of these constituents with portland cement.

There is also another standard, ASTM C1157, for performance-based blended cements with no limits on cement composition, which allows considerably more flexibility.

Concrete Materials

- **Hydraulic Cement:** ASTM C150, ASTM C595, or ASTM C1157

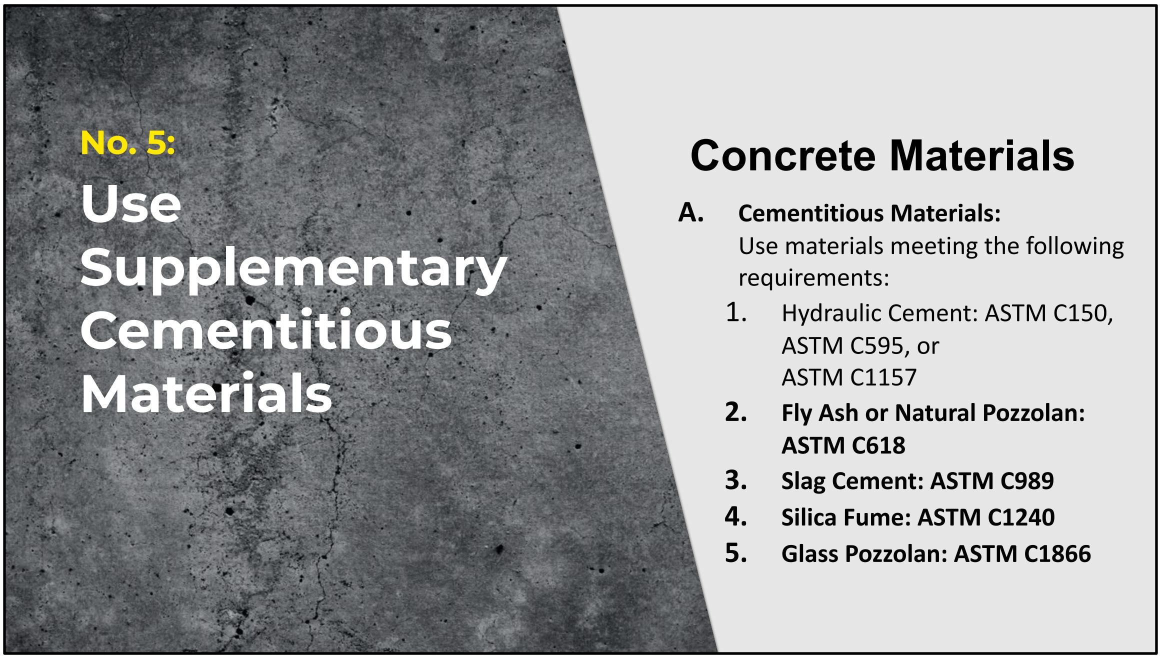
No. 4:

Use Alternative Cements

Both ASTM C595 and ASTM C1157 have been permitted in national standards such as ACI 318 and 301, ASTM C94 (ready-mixed concrete) for at least two decades. But most project specifications inadvertently prohibit their use by not listing them in the specification. The solution for this one is easy: Just list all three types of hydraulic cement in your specification.

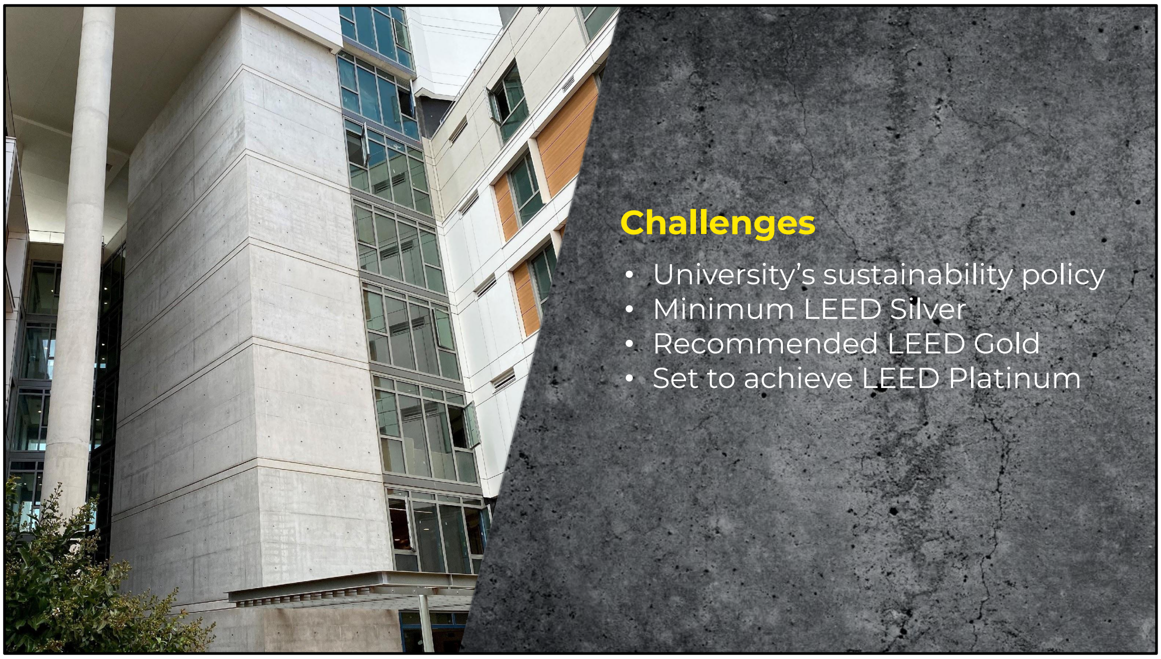
Nearly all concrete used today has some amount of supplementary cementitious material. The most common are fly ash, slag cement, and silica fume in that order. However, there are others, such as metakaolin, volcanic ash, rice husk ash, and ground glass, just to name a few. Some are waste by-products of other industrial processes, and others are naturally occurring materials that require little processing and therefore have small carbon footprints.

All enhance the performance of concrete when combined with portland cement, including increased strength, increased durability, and enhanced workability. There is a complex chemical process that occurs between the SCMs and the portland cement hydration by-products that contributes to these enhanced properties.



The solution for this one is also easy. Just list all the types of cements and SCMs permitted by codes and standards. There is no need to limit quantities in this part of the specification.

Our second case study is University of California San Diego's North Torrey Pines Living and Learning Neighborhood. The neighborhood will be 10 acres of academic, residential, commercial, and cultural buildings. The neighborhood will include an Arts and Humanities Building, a Craft Center with classrooms and specialized facilities, a Social Sciences Public Engagement Building, and four residential buildings that will house 2,000 students.



One of the biggest challenges faced for those constructing new buildings on the University of California San Diego campus is the university's sustainability policy. The University of California has a Sustainable Practices Policy. This policy requires that all new buildings are minimum LEED Silver; in most cases they are recommended to be LEED Gold, and North Torrey Pines Living and Learning Neighborhood is actually set to achieve LEED Platinum.

Cement Type	Global Warming Potential
Portland Limestone Cement Type IL (13)	871 kg CO_2eq
Portland Cement Type I/II/V	969 kg CO_2eq

Sustainable Solutions

- Life-cycle analyses (LCAs)
- Demonstrate sustainable design and outcomes
- Used Type IL blended portland-limestone cement
- Save 3,055 metric tonnes of CO_2

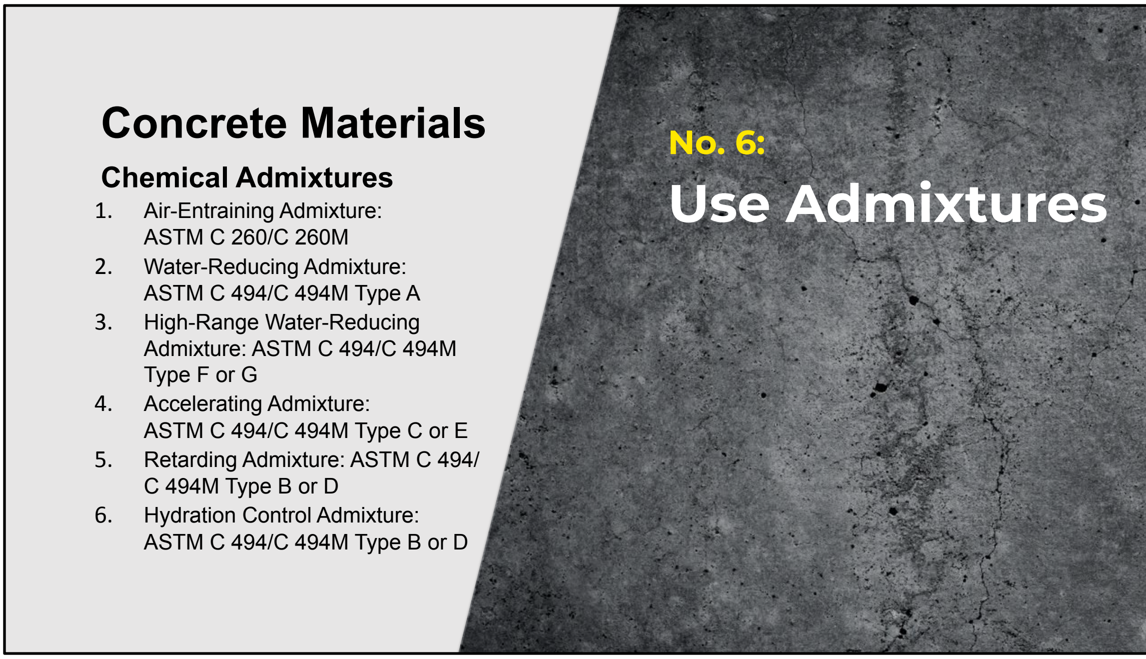
Here are some of the sustainable solutions:

- Life-cycle analyses (LCAs) were used by teams bidding on the project to demonstrate sustainable design and outcomes.
- Type IL blended portland-limestone cement with 13 percent limestone was used on the project.
- This project could use up to 31,170 metric tonnes of Type IL portland-limestone cement, which could save 3,055 metric tonnes of —the equivalent of 664 cars removed from the road for one year.

- The designers exposed concrete for aesthetic reasons but also took advantage of concrete's ability to absorb carbon dioxide.
- Through collaboration and open discussion, the project teams were able to determine the aesthetic, structural, and environmental benefits of the concrete.
- In addition to CO_2 reduction, the use of portland-limestone cement also enhanced the appearance of the exposed concrete.

Nearly every concrete made today uses some sort of admixture. Most affect the plastic properties to make concrete more workable, economical, shorten or lengthen set time, and so on. Without admixtures, concrete could not be pumped hundreds of feet in the air or transported hundreds of miles, and many architectural finishes could not be achieved. There are water-reducing admixtures that in effect reduce cement demand, accelerators that improve strength gain, and viscosity modifiers that permit concrete to flow into very tight spaces.

As an example of how effective admixtures can be, using a water reducing admixture that reduces water content in a mixture by 12 percent will result in a reduction of cement content by 70 pounds for equivalent slump and strength and in a carbon reduction of roughly 10 percent for 4,000 psi concrete. High-range water-reducing admixtures can reduce water content by as much as 40 percent, but the potential reduction in cementitious materials may not be feasible because of constructability needs.



Another simple solution: All admixtures that meet an ASTM standard should be permitted and listed in your concrete specification, and those that do not meet a standard should still be considered with proper submittals and technical backup.

All too often, there are seemingly random limits on material ingredients in project specifications that limit the concrete producer's ability to meet performance criteria, let alone reduce carbon footprint.

Having unnecessary limits on the water to cementitious materials ratio is one example. In most cases, requiring a maximum w/cm is unnecessary and drives up cement content. There are times when a maximum w/cm makes sense, mostly for cases of concrete exposed to freezing and thawing, but it is not necessary to call it out in the specification. Identifying the exposure class of the concrete per ACI 318 and ACI 301 will suffice. The requirements for w/cm for concrete exposed to freezing and thawing are outlined in the specification.

The same is true for air content. It is only required for concrete exposed to freezing and thawing. Air entraining decreases concrete strength. For instance, a 10 percent increase in cementitious materials content for 4,000 psi air-entrained concrete compared to non-air-entrained concrete of the same strength would roughly translate to a 9 percent increase in carbon footprint.

Do not list a maximum or minimum cement content, maximum or minimum SCM content, or quantity of admixtures.

Do not limit water used for making concrete to potable water. (There is an ASTM specification for water used to make concrete.)

No. 7:

Do Not Limit Ingredients

Class	Location	Nominal Max. Aggregate Size	Exposure Class	F'c, Psi @ Age
1	Mat Foundation	3”	F0, S1, W0, C0	6,000 at 90 days
	Basement Walls	1-1/2”	F0, S1, W0, C0	4,000 at 56 days
3	Shear Walls	3/4”	F0, S0, W0, C0	6,000 at 56 days
	Columns Level B2-L6	3/4”	F0, S0, W0, C0	6,000 at 28 days
5	Columns Level L7-L12	3/4”	F0, S0, W0, C0	4,000 at 28 days
	Slabs	3/4”	F0, S0, W0, C0	5,000 at 28 days
7	Exterior Pavements	3/4“	F3, S1, W0, C0	4,000 at 28 days

Our recommendation is to provide a table in your specification for concrete listing the important performance attributes for concrete. Each project will have different values depending on the project requirements. For this example, Class 7 concrete (exterior pavements) would have a w/cm and air content limit because of its exposure to freezing and thawing, which is spelled out in ACI 318 and ACI 301.

And finally, concrete that will not be stressed for significant time periods can be tested at later ages, which means higher volumes of SCMs can be used, resulting in a lower carbon footprint.

This strategy is for those who have some knowledge of life-cycle assessments, experience with environmental product declarations, and an understanding of global warming potential for the targets to be implemented effectively. First, resist the temptation to set carbon footprint limits for individual classes of concrete. In effect, this is the same as providing prescriptive limits on materials and leaves little room for the contractor and producers to innovate and meet the project performance requirements, including budget and schedule. The best approach is to use a whole building life-cycle assessment to set a carbon budget for all the concrete on the building. It is still necessary to have a general idea of what the carbon footprint of each mix will be to set a carbon budget for the building.

Concrete Materials

Supply concrete mixtures such that the total global warming potential (GWP) of all concrete on the project is less than or equal to 4,298,000 kg of CO_2 equivalents.

No. 8:

Set Targets for Carbon Footprint

Many concrete companies have published EPDs for concrete, and most would be willing to publish EPDs specifically for a project. NRMCA has published a Cradle-to-Gate Life-Cycle Assessment of Ready-Mixed Concrete report and an industrywide EPD for concrete. Armed with this information, you can conduct an LCA to determine the embodied impacts of concrete of a benchmark building using typical concrete mixes with typical amounts of SCMs, and a proposed building using concrete mixes with high volumes of fly ash and slag.

Once you have calculated the carbon footprint for the proposed building, list that target in your specification as shown here.

Case Study: Oracle Waterfront Campus, Austin, Texas

- 550,750-square-foot office building
- 147,000-square-foot ground-level parking and 646,800-square-foot parking garage

- Owner: Oracle
- Architect: STG Design
- Structural Engineer: Walter P Moore
- General Contractor: Ryan Companies
- Concrete Contactor: Keystone Concrete
- Concrete Producer: Centex Materials
- Photos: Casey Dunn

Our next case study is the Oracle Waterfront Campus in Austin, Text, a corporate office building with 550,750 square feet of floor space with a 147,000-square-foot attached ground-level parking garage and 646,800-square-foot detached parking garage.

The entire design and construction team was challenged to have the project blur the lines between public and private property and be welcoming to the pedestrian-friendly community that surrounds it while meeting the challenging sustainability criteria of LEED and Austin Energy Green Building (AEGB) standards.

The structural engineers worked closely with the design-build team to meet a demanding schedule, structural challenges, and environmental criteria for this concrete building. The design required oversized floor plates to accommodate open office spaces, expansive balconies and terraces, and large meeting spaces. They also made the designer's vision for a truly unique lobby space come to life with a floating stair and bridge that lead visitors to large meeting spaces.

Structural engineers conducted an LCA using software that considers the embodied impacts of all materials of the structure and enclosure for the project. Since this was such a concrete-intensive project, they focused on improving concrete mix designs to meet the LEED Whole Building LCA criteria for lowering environmental impacts. They created two computer models to compare the proposed building to a baseline building, fully maintaining the functional equivalence of the two buildings but varying the mix designs.

Impact Measure	Units	Estimated % Reduction from Baseline to Proposed
Acidification Potential	kg SO_2eq	-13%
Eutrophication Potential	kg Neq	-3%
Global Warming Potential	kg CO_2eq	-12%
Ozone Depletion Potential	CFC-11eq	-11%
Smog Formation Potential	kg O_3eq	-12%
Non-Renewable Energy	MJ	-6%

Sustainable Solutions

- Optimized mix designs
- High volume of SCMs
- Test age for drilled piers at 56 days
- Met LEED WBLCA requirement
- At least 10 percent reduction of GWP (12 percent in this case)
- At least 10 percent reduction in at least two other categories

The improved mixes were analyzed by the software to determine the embodied environmental impacts per cubic yard, and based on that analysis, the concrete mixes were implemented into the whole building LCA. They also varied the age for testing concrete to allow for higher volumes of fly ash. For example, since the foundations do not see the full design load until construction is complete, they specified testing concrete at 56 days for the drilled piers. As a result, the project met the rigorous LEED Whole Building LCA credit by showing at least a 10 percent reduction in global warming potential (12 percent in this case) along with at least a 10 percent reduction in at least two other environmental impact categories.

Carbonation is a naturally occurring process by which CO_2 penetrates the surface of hardened concrete and chemically reacts with cement hydration products to form carbonates. For in-service concrete, carbonation is a slow process with many dependent variables. The rate decreases over time. This is because carbonation decreases permeability and carbonation occurs from the surface inward, creating a tighter matrix at the surface that makes it more difficult for CO_2 to diffuse further into the concrete. While slow, the carbonation process does result in an uptake of some of the CO_2 emitted from cement manufacturing, a chemical process called calcination. Theoretically, given enough time and ideal conditions, all the CO_2 emitted from calcination could be sequestered via carbonation.

No. 9:

Sequester Carbon Dioxide

Concrete Materials

A. Normal-weight Aggregate: ASTM C33

B. Lightweight Aggregate: ASTM C330

C. Recycled concrete aggregate (crushed concrete) meeting the requirements of ASTM C33 or ASTM C330 may be used in structural concrete up to 10 percent of the total aggregate. Crushed concrete shall have been crushed and exposed to air at least one year before use in concrete (to maximize CO_2 sequestration).

Consider permitting the use of recycled aggregates made of demolished concrete on the project and possibly require that those recycled aggregates be exposed to air for one year before being used. In some cases, a certain percentage of aggregate used in concrete to be recycled (up to 10 percent) can be permitted, or it can simply be required that all aggregate base or fill be made of crushed concrete.

No. 9:

Sequester Carbon Dioxide

Concrete Materials

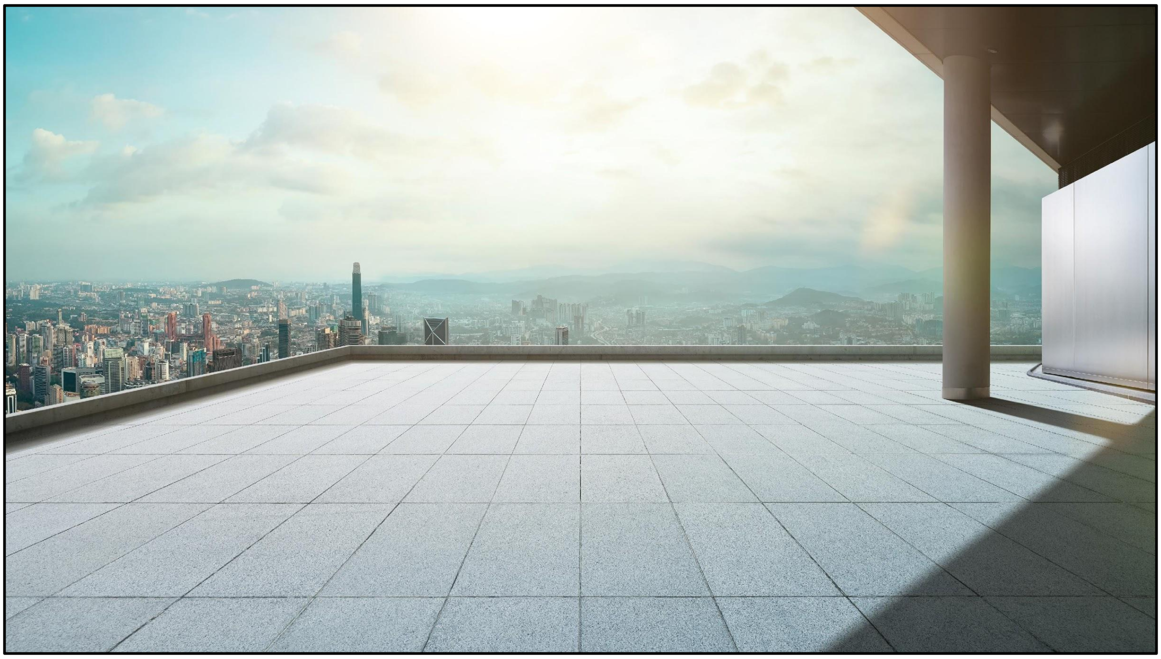
D. Artificial limestone aggregate meeting the requirements of ASTM C33 or ASTM C330 is permitted.

E. Carbon mineralization by injecting CO_2 into concrete during manufacturing or curing in CO_2 atmosphere shall be permitted.

The use of carbon mineralization processes such as injecting CO_2 into concrete or curing in CO_2 environments should be encouraged as well as the use of artificial limestone aggregates.

It is also worth considering the use of exposed concrete on the project, both on the interior and exterior. This has the added benefit of reducing the amount of finish material in addition to absorbing CO_2 throughout the lifetime of the building.

Of the 10 strategies, this is probably the most challenging. Throughout this presentation I have talked about the importance of not listing specific products or naming certain technologies. Instead, simply list the standards that one must meet. The problem with this approach is that it permits innovation but does not necessarily encourage it. And many innovations might not meet a standard.



The recommendation here goes back to Strategy 1. Communicating the carbon-reduction goals to contractors and producers during the design process is critical. Let them know that you are looking for innovative solutions. Design charrettes would be a great place to engage engineers, contractors, and concrete producers. Ask them to bring opportunities to the table. Most sophisticated producers are experimenting on new formulations all the time. Ask them to discuss some of their low-carbon concretes with you.

There is no silver bullet to making concrete with zero carbon footprint. It can be done, but not at the volume and cost demanded by today's building owners. For some concretes on a project, the carbon reduction might be 90 percent, others closer to 70 percent, and still others around 30 percent. All of these reductions lead to concrete with a significantly lower footprint than similar projects. If you choose to set carbon footprint targets, this will lead to the greatest reduction; but always refer to this Top 10 list when implementing ways to reduce concrete's carbon footprint.

Thank you for your time.
This concludes The American Institute of Architects Continuing Education Systems Course.

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Build with Strength, a coalition of the National Ready Mixed Concrete Association