# CONCRETE CARBON

## A GUIDELINE FOR SPECIFYING LOW CARBON READY MIXED CONCRETE IN ONTARIO

CONCRETE ONTARIO

NOVEMBER 2022

# ABOUT US

**Concrete Ontario (Ready Mixed Concrete Association of Ontario) was formed in 1959 to act in the best interest of Ontario's ready mixed concrete producers and the industry in general.**

**The Association is the voice and resource of the concrete and construction industries across Ontario and represents approximately 96% of all concrete production and manufacturing. With over 270 certified concrete plants and approximately 3,800 certified trucks across the province, concrete is readily available and is the most dependable construction material on the market.**

**We pride ourselves in bringing education, technologies, research and innovation to architects, designers, contractors, and concrete companies and continually promote concrete's sustainable advantages and benefits to society.**

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# ACKNOWLEDGEMENTS


**We greatly appreciate and acknowledge the contributions of the entire Concrete Ontario Technical Committee and the following industry professionals in the development of this guideline.**

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| Savio DeSouza | Bridge Check Canada Ltd. |
| Nicolas Ginouse | Lafarge Canada Inc. |
| Abdurahman Lotfy | Lafarge Canada Inc. |
| Mike Martin | St. Marys/CBM |
| Andrei Muresan | CRH Canada Group Inc. |
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| Ana Milena Rebellon | Lehigh Hanson Inc. |
| Tim Smith | Cement Association of Canada |
| Michael Stanzel | GCP Applied Technologies |

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# CONCRETE CARBON

# INTRODUCTION

Ontario's Concrete Industry is a committed partner in building a low carbon world. To this end, this document provides guidance on how to specify low carbon concrete for various concrete project types.

The "embodied carbon" emissions of concrete, which are generated by the production, transportation, manufacture, and end of life disposal/recycling have been well documented by numerous sustainability professionals throughout the province. These emissions can be minimized on projects through properly defined low carbon concrete specifications. Before we dive into that aspect, the fundamentals must be understood.

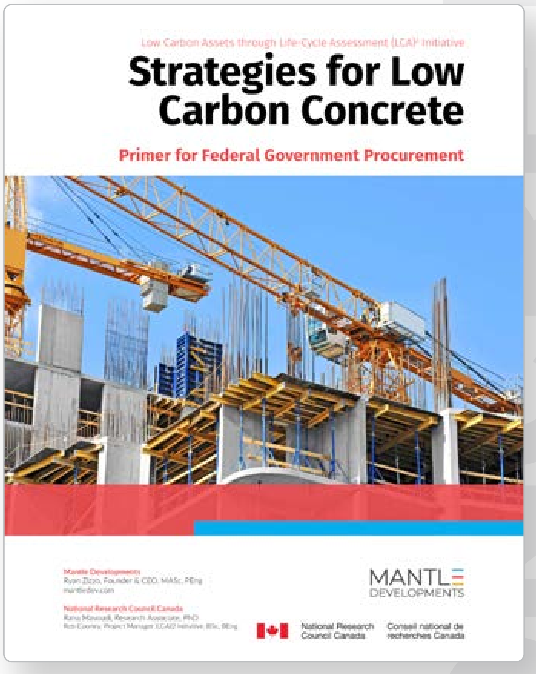
## Understanding the Fundamentals

To better understand the fundamentals of cement and concrete carbon emissions, an in-depth literature review may be conducted, and resources identified, as more and more information continues to be published.

A notable resource for Ontario which was derived from the Low Carbon Assets through Life-Cycle Assessment (LCA)[2] Initiative is the **Strategies for Low Carbon Concrete**, which was developed by Mantle Developments and the National Research Council of Canada (NRC). Concrete Ontario provided input into this document, and it puts a critical focus on the growing importance of embodied carbon, understanding concrete and carbon, the importance of using performance-based specifications, best practices for low embodied carbon concrete and even procurement strategies.

With buildings becoming more and more efficient through innovation and technology, the operational carbon has been significantly improved, and the construction industry and policy makers in Ontario are quickly shifting their focus to specifying low carbon concrete to meet their embodied carbon reduction goals.

Incorporating the information in the document Strategies for Low Carbon Concrete, it is the intention of this guideline to provide a resource for designers and specifiers in their pursuit of carbon reductions, and more importantly, to achieve low carbon concrete for Ontario projects.

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# ENVIRONMENTAL PRODUCT DECLARATIONS (EPDs)

## CRMCA Industry-Wide EPD for Canadian Ready Mixed Concrete

The ready mixed concrete industry's commitment to transparency of the carbon impact of specific mix designs was first introduced in 2017 with the release of the **Canadian Ready Mixed Concrete Association (CRMCA) Industry-Wide EPD for Canadian Ready Mixed Concrete**. This report was compiled by the Athena Sustainable Materials Institute and third-party verified by NSF. An Industry-Average EPD shows the environmental impacts for average concrete mixes produced in an average Canadian ready mixed plant within a specified geography. Although this information was a much-needed starting point for the industry, average Canadian information is simply not accurate enough for Ontario projects. Designers and specifiers in Ontario, who are in pursuit of quantifying the carbon impact for a specific mix design from a local Ontario ready mixed plant, require more local data or more specifically regional EPDs.


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Regional EPD information is vital to specifying accurate low carbon concrete and with the expiration of the previous CRMCA report on January 6, 2022, the industry began to pursue 7 regional reports representing all the provinces in the country. In July 2022, all 7 regionals reports were released, and their development further exemplifies the industry's transparency and dedication to reaching the net-zero carbon concrete goal by 2050.


**To access all 7 reports, please visit ASTM's website at:**

**https://www.astm.org/products-services/certification/environmental-product-declarations/epd-pcr.html**

## Concrete Ontario Member Industry-Wide EPD for Ready Mixed Concrete

The development of the **Concrete Ontario Member Industry-Wide EPD for Ready Mixed Concrete** report for Ontario further increases the reporting accuracy of the carbon impact mix designs have on projects in Ontario.


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This report was also created through Athena and third-party verified by ASTM International. A representative sample of Concrete Ontario member facilities was selected based on technical attributes, production scale, and geographic location. In total, 80 facilities operated by Concrete Ontario member companies completed LCI data collection questionnaires representing over 30% of all Concrete Ontario member facilities.

It features an up-to-date and accurate representation of mix designs used in the Ontario market.

In addition, it also addresses some significant limitations that were present in the CRMCA National report from 2017. Through a working group of ready mixed producer representatives, along with the guidance of Athena, the following improvements have been made in the recently released Ontario report:

**1.** Raw material EPDs are Ontario production facilities' averages (national average in prior version).

**2.** Addition of portland silica fume cement (Type GUbSF ~ Portland cement + silica fume up to 15%) for high-strength / high-performance concretes such as 50-70 MPa.

**3.** Mix designs fully representative of most common concrete applications and exposure classes in accordance with CSA A23.1 and the Ontario Building Code (OBC).

**4.** Specialty concrete mix designs for self-consolidating concrete (SCC) and shotcrete added to support growing demand for architectural applications.

**5.** Fifth slag replacement level (50%) added for mass concrete applications, such as multi-story office and residential construction.

**6.** Industry average baselines chosen based on 2021 Ontario average material proportions for each mix design, carefully set by a working group to represent most of the production in Ontario. Type GU cement used for all mix design baselines as the full switchover to Type GUL in Ontario continues.

**7.** Previously used CRMCA benchmarks of 6% slag and 4% fly ash have been completely phased out and replaced with the significantly more representative regional baselines.

**8.** Consideration given to the actual material proportioning of mix designs and the associated performance requirements of the various CSA A23.1 exposure classes to provide exceptional and important realism, connecting the EPD data to actual concrete in the field that meets CSA A23.1 and OBC.

Incorporating the noted improvements into the Concrete Ontario report significantly improves the quantification of the carbon impacts on a project, and gives designers and specifiers the tools, and the confidence in those tools, required to draft specifications for low carbon concrete in Ontario. The Ontario report is valid for 5 years, however an earlier update is possible if new materials and technologies become available which can significantly improve the EPDs of the mix designs.

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## INDUSTRY CARBON REDUCTION GOALS

**2017** CRMCA EPD Report

**2022** Ontario EPD Report

**2030** Carbon Reduction Goals

**2050** Net-zero Carbon Concrete


The 2017 CRMCA EPD report initiative started the conversation about concrete embodied carbon transparency in Canada and has since transitioned to the regional level. This transition and the usage of the 2022 Ontario EPD report has shown a significant reduction in embodied carbon of the baseline mixes and improvements will continually be made until the goal of net-zero carbon concrete is achieved. To summarize the drastic reductions that have already been achieved, the following table provides a comparison of the CRMCA EPD Benchmarks and the newly completed Ontario EPD Baselines.

| CRMCA EPD Report Benchmark | Ontario EPD Report Baseline | % Reduction |
|---|---|---|
| 25 Industry Average Benchmark with air<br>(6% SL, 4% FA)<br>(304.52 kg $CO_2$/m³) | Baseline 25 MPa concrete with air &<br>0.55 w/cm (F-2) GU 10 SL<br>(260.64 kg $CO_2$/m³) | 14.4 |
| 30 Industry Average Benchmark with air<br>(6% SL, 4% FA)<br>(349.68 kg $CO_2$/m³) | Baseline 30 MPa concrete with air &<br>0.50 w/cm (F-1) GU 15 SL<br>(292.72 kg $CO_2$/m³) | 16.3 |
| 35 Industry Average Benchmark with air<br>(6% SL, 4% FA)<br>(417.05 kg $CO_2$/m³) | Baseline 35 MPa concrete with air<br>GU 15 SL<br>(334.49 kg $CO_2$/m³) | 19.8 |
| 40 Industry Average Benchmark with air<br>(6% SL, 4% FA)<br>(458.98 kg $CO_2$/m³) | Baseline 40 MPa concrete with air<br>GU 15 SL<br>(361.65 kg $CO_2$/m³) | 21.2 |
| 45 Industry Average Benchmark without air<br>(6% SL, 4% FA)<br>(426.33 kg $CO_2$/m³) | Baseline 45 MPa concrete without air<br>GU 15 SL<br>(349.88 kg $CO_2$/m³) | 17.9 |

The significant baseline reductions since 2017 demonstrate the possibilities available to designers to pursue their carbon reduction goals as well as the commitment of the Ontario industry to carbon transparency and the net-zero roadmap. Further reductions will be pursued for 2030 until eventually the ultimate goal of net-zero carbon concrete by 2050 is achieved.


## Industry Average Self Declaration

In addition to having produced the seven regional reports, Athena also developed a basic industry average self declaration calculator (example provided) based on the data from each report. This calculator allows producers to enter their proprietary raw material information of a specific mix design, and then using industry-average material EPD information, the calculator generates a report which indicates Life Cycle Category Indicators. Although this self declaration is not classified as an official EPD, it is still an effective way to determine the impact mix designs have on a project based on industry average information. This calculator can also be used to evaluate special application impacts on a particular mix design such as accelerated strength. (example provided) Special applications will be examined in detail later on in this guide.

Although this industry average self declaration is not as accurate as a Type II or Type III EPD, there is no additional cost required to provide owners, designers, and architects more information about the impact mix designs have on their project. Allowing the usage of an industry average self declaration on a project gives specifiers a quick option for determining the embodied carbon of a concrete mix design based on already available industry average values and supports informed collaboration with their ready mixed concrete supplier to achieve their project carbon goals.

**Allowing the usage of an industry average self declaration on a project gives specifiers a quick option for determining the embodied carbon of a concrete mix design based on already available industry average values and supports informed collaboration with their ready mixed concrete supplier to achieve their project carbon goals.**

## Athena Industry Average Self Declaration calculator example:

Proprietary mix design information is entered into the calculator and the Life Cycle Category Indicators impact summary is calculated based on industry average EPDs.

**Note:** Mix proportions in a performance-based mix design are the intellectual property of the concrete producer and will not be shared with the construction team. Mix proportions are only shown in this example to demonstrate how the EPD impacts are calculated. The concrete producer will not disclose concrete proportions at any time but will provide the performance outputs of the calculator to allow the construction team to evaluate the proposed mixes.

## Standard Concrete versus Baseline Example:

**Concrete Ontario Mix #1**

| Ingredient | Amount | Units | Supplier | Action |
|---|---|---|---|---|
| Portland Limestone Cement | 300 | kg | Ontario GUL Cement | Edit Delete |
| Slag Cement | 50 | kg | Ontario Slag Cement | Edit Delete |
| Crushed Coarse Aggregate | 1,070 | kg | Ontario Crushed Coarse Aggregate | Edit Delete |
| Natural Fine Aggregate | 800 | kg | Ontario Natural Fine Aggregate | Edit Delete |
| Water Reducer | 150 | ml | Ontario Water Reducer Admixture | Edit Delete |
| Batch Water | 155 | L | Not Specified | Edit Delete |

Calculated: 10/4/2022 10:47:42 AM

**Impact Summary**

| Impact | Units | Per $m^3$ | A1 | A2 | A3 |
|---|---|---|---|---|---|
| Global Warming | kg CO2e | 281.91 | 88.49% | 8.07% | 3.44% |
| Ozone Depletion | kg CFC11e | 7.68E-06 | 97.61% | 0.01% | 2.38% |
| Acidification | kg SO2e | 1.36 | 73.31% | 19.73% | 6.96% |
| Eutrophication | kg Ne | 0.23 | 90.03% | 7.10% | 2.87% |
| SFP (smog) | kg 03e | 23.23 | 62.82% | 29.43% | 7.75% |
| Non-Renewable Energy | MJ, NCV | 1743.64 | 68.03% | 19.80% | 12.17% |

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The mix design can then be compared to the Ontario EPD report baselines through a graph and a printable report:

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In addition, if special applications will be required on the project, their impact can be quickly evaluated.

## Standard Concrete

**Concrete Ontario Mix #1**

| Ingredient | Amount | Units | Supplier | Action |
|---|---|---|---|---|
| Portland Limestone Cement | 300 | kg | Ontario GUL Cement | Edit Delete |
| Slag Cement | 50 | kg | Ontario Slag Cement | Edit Delete |
| Crushed Coarse Aggregate | 1,070 | kg | Ontario Crushed Coarse Aggregate | Edit Delete |
| Natural Fine Aggregate | 800 | kg | Ontario Natural Fine Aggregate | Edit Delete |
| Water Reducer | 150 | ml | Ontario Water Reducer Admixture | Edit Delete |
| Batch Water | 155 | L | Not Specified | Edit Delete |

Calculated: 10/4/2022 10:47:42 AM

**Impact Summary**

| Impact | Units | Per m³ | A1 | A2 | A3 |
|---|---|---|---|---|---|
| Global Warming | kg CO2e | 281.91 | 88.49% | 8.07% | 3.44% |
| Ozone Depletion | kg CFC11e | 7.68E-06 | 97.61% | 0.01% | 2.38% |
| Acidification | kg SO2e | 1.36 | 73.31% | 19.73% | 6.96% |
| Eutrophication | kg Ne | 0.23 | 90.03% | 7.10% | 2.87% |
| SFP (smog) | kg 03e | 23.23 | 62.82% | 29.43% | 7.75% |
| Non-Renewable Energy | MJ, NCV | 1743.64 | 68.03% | 19.80% | 12.17% |

Calculated: 10/4/2022 10:48:01 AM

## Accelerated Concrete

**Concrete Ontario Mix #2**

| Ingredient | Amount | Units | Supplier | Action |
|---|---|---|---|---|
| Portland Limestone Cement | 370 | kg | Ontario GUL Cement | Edit Delete |
| Crushed Coarse Aggregate | 1,070 | kg | Ontario Crushed Coarse Aggregate | Edit Delete |
| Natural Fine Aggregate | 800 | kg | Ontario Natural Fine Aggregate | Edit Delete |
| Water Reducer | 150 | ml | Ontario Water Reducer Admixture | Edit Delete |
| Batch Water | 155 | L | Not Specified | Edit Delete |

Calculated: 9/26/2022 9:30:36 AM

**Impact Summary**

| Impact | Units | Per m³ | A1 | A2 | A3 |
|---|---|---|---|---|---|
| Global Warming | kg CO2e | 330.48 | 90.14% | 6.92% | 2.93% |
| Ozone Depletion | kg CFC11e | 7.85E-06 | 97.66% | 0.01% | 2.33% |
| Acidification | kg SO2e | 1.47 | 75.11% | 18.43% | 6.46% |
| Eutrophication | kg Ne | 0.25 | 91.00% | 6.42% | 2.58% |
| SFP (smog) | kg 03e | 24.28 | 64.21% | 28.38% | 7.42% |
| Non-Renewable Energy | MJ, NCV | 1865.35 | 70.01% | 18.62% | 11.37% |

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Having the ability to provide Life Cycle Category Indicators quickly and effectively to a project is critical to allow the carbon budget to continuously be updated and analyzed. This concept will be demonstrated through an example and case study later.

## Type II EPDs

Type II EPDs are self-declarations made by ready mixed producers of their mix designs and are governed by ISO 14021. Type II EPDs are not third-party verified and factor in the actual raw material EPDs that the ready mixed producer would have at their specific plant location. This provides additional transparency over the industry average values and allows designers and specifiers to achieve a more accurate representation of the carbon impact on their project. Type II EPDs are more accurate than industry average values and must be considered by designers and specifiers.

## Type III Third-party Verified EPDs

Type III EPDs are governed by ISO 14025, are third-party verified and reflect the most accurate representation of a material's carbon impact from a manufacturer. More specifically, a Type III EPD provides information related to concrete from a specific mix design using plant specific carbon impact and material EPDs. As material sources for the plant change, the EPDs must be recalculated and resubmitted for third-party verification. Numerous Concrete Ontario members already have Type III EPDs, and their availability can be discussed at the project level.

**Athena disclaimer:**
This is an automated industry average self-declaration report based on Athena's concrete LCA software and database as used to generate Concrete Ontario's environmental product declarations (EPDs). This document is **NOT** a Type II or verified Type III EPD. Rather, the client has entered their company specific concrete mix design which is then compared to the appropriate regional benchmark mix based on the average Ontario plant operations profile. The declared results are only informational.

# WHAT IS LOW CARBON CONCRETE?

Concrete is a low carbon material compared to many other manufactured goods and is locally and responsibly sourced and used throughout the construction industry due to its structural performance, durability, versatility, and needed climate-change resiliency. Concrete technology has been advancing since its development, and as the industry continues to evolve and carbon reduction goals are better understood, the use of more advanced technologies and materials, combined with the transparency afforded by EPDs, will allow the designer to monitor, control, and optimize the embodied carbon content of their designs.

Low carbon concrete refers to concrete produced with a lower carbon footprint than traditional mix designs using baseline technology, while still meeting all relevant performance requirements. To employ low carbon concrete, specifiers, contractors, and ready mixed producers should work together to use available lower carbon impact materials and the design techniques outlined in this guideline.

# SPECIFYING LOW CARBON READY MIXED CONCRETE IN ONTARIO

Achieving low carbon specifications is highly dependent on using the latest concrete technology and local materials with the lowest possible carbon footprint. Since concrete production materials vary across the province, each individual ready mixed producer must use their expertise, experience, and available tools to determine and batch the optimal concrete mix design. Giving the ready mixed producers the flexibility to provide concrete that meets the specified performance criteria via the use of a CSA Performance-Based Specification approach will lead to an optimized design AND a more sustainable concrete solution.

**Giving the ready mixed producers the flexibility to provide concrete that meets the specified performance criteria via the use of a CSA Performance-Based Specification approach will lead to an optimized design AND a more sustainable concrete solution.**

As a starting point, the following aspects are vital to achieve an effective concrete specification:

1. **Qualification/Certification system for concrete production facilities (e.g. Concrete Ontario mandatory ECO Certification)**
2. **Designer defines performance requirements for the different concrete elements in the structure**
3. **Producer and contractor partner to ensure optimal concrete mixture is designed, delivered, and installed**
4. **Submittal and documentation of performance-based concrete mixes, delivery rates, traffic flows, washout areas, environmental and safety concerns, inspection and testing requirements, acceptance and rejection criteria, etc.**
5. **Quality assurance testing for acceptance of concrete**
6. **Clear responsibilities laid out for what to do in case of an abnormality**

Roles and responsibilities of each party involved in the project must also be understood to fully implement a concrete specification.

### OWNER OR DESIGNER

Clearly specifying:

- Project roles / responsibilities (ordering, scheduling, supply, verification, testing, inspection, etc.) & interactions (preconstruction, preplacement, and progress meetings)
- Concrete requirements, ensuring structurally-sound performance
- Submittal, certification, & qualification requirements for scope of work
- Acceptance criteria, dispute resolution & change management processes
- Conducting QA to ensure requirements are met
- Identify site requirements (health & safety, power & utilities, environmental, site access, traffic flows, storage capacities, etc.)

### CONTRACTORS

- Fully understand project scope and requirements
- Identify & select subcontractors and suppliers, with clear deliverables and scope of work at quote and award
- Determine initial construction schedule and methods
- Request feedback from subcontractors and suppliers regarding specification requirements and proposed scheduling
- Clarify concerns with the owner/designer
- Verify that all construction and specification issues have been addressed

## Successful Concrete Specification Implementation

### CONCRETE SUPPLIERS

- Identifying concrete mixtures required for the project
- Confirming exclusions and qualification to their scope of work
- Providing options for concrete performance enhancement
- Notifying the contractor of any confusing requirements
- Notifying the contractor of any prescriptive requirements that are causing non-value added restrictions in achieving strength, durability, and carbon performance-based criteria
- Perform pre-qualification testing and/or trials as necessary

### TESTING AGENCY

- Complying with CSA A23.2 test methods and relevant portions of project specifications
- Ensuring personnel and equipment meet requirements of CSA A283
- Assign CCIL-, ACI- or equivalent certified technicians for all field testing
- Use CCIL-certified laboratories for concrete testing
- Notifying the contractor of perceived issues, requirements for specimen storage, initial cylinder curing, etc.
- Informing the site representative and concrete supplier of plastic test results
- Distribution of test reports to all parties involved in a timely manner, especially the Concrete Supplier

## Performance-Based Specifications

It is the responsibility of the specifier to clearly outline the performance criteria that must be met by the contractor and ready mixed producer on any given project in Ontario.

These responsibilities are clearly defined in CSA A23.1 - Concrete materials and methods of ready mixed concrete construction Table 5 and must be followed if success is to be had in specifying low carbon concrete.

### PERFORMANCE

**Performance-based specifications offer the specifier the ultimate peace of mind that the ready mixed producer is responsible for the performance of the concrete as delivered.**

**They also give the ready mixed producer flexibility in optimizing mix designs.**

**This flexibility becomes critically important when a ready mixed producer needs to use multiple CSA-approved approaches in designing mixes to meet a variety of requirements including strength, durability, constructability, and carbon/sustainability.**

**Performance-based specifications are critical to specifying and achieving low carbon concrete.**

### PRESCRIPTIVE

**It is highly discouraged to specify any mix proportions, including material quantities (e.g., admixtures, aggregates, cementitious materials, and water), as the mix design becomes prescriptive, and the owner assumes full responsibility for the concrete performance.**

**Using prescriptive mix designs can not only negatively impact the performance of the concrete but can also very likely negatively impact the realization of carbon reduction goals on the project since the specifier will not be aware of the raw materials used by each individual concrete producer or plant.**

## 1 Required structural criteria, including strength at age (e.g., 35 MPa at 56 days)

### Strength at Age Design

If the project schedule is flexible, designing the concrete for the strength at a maximum allowable age gives the ready mixed producer the option to minimize the quantity of cement used (e.g., Type GU, GUL, GUbSF, etc.) and maximize the usage of supplementary cementitious materials (SCMs) such as slag. This in turn creates a more sustainable and overall lower carbon concrete.

For example, concrete is typically designed to achieve a strength target within 28 days, but if the structural element that is being constructed is not being put into service within that time frame, the design strength at age can be pushed until 56 days or even 91 days. For instance, under CSA A23.1 Table 2, C-1 class concrete is required to achieve 35 MPa within 56 days to ensure all other performance criteria can be met, including a chloride ion penetrability requirement of <1500 coulombs within 91 days.

Specifiers should make the determination of when elements will be put into service and whether the schedule allows for extending the age at which the strength must be achieved.

## 2 Required durability criteria, including class of exposure (e.g., Maximum 0.40 w/cm, Class C-1)

### Classes of Exposure

Classes of exposure, as defined in CSA A23.1 Tables 1 and 2, identify the environment that a concrete will be exposed to and must be used by Owners to clearly outline the performance requirements. For example, if a concrete will be used for an interior application (Class N) such as an interior wall, it is understood that this concrete will not be exposed to chlorides, freezing and thawing, sulphates, and so forth for the duration of its service life. On the other hand, if the application is an exterior sidewalk, Class C-2 would be applicable, and the concrete would be non-structurally reinforced (i.e., plain) and will likely be exposed to chlorides and freezing and thawing. Owners must understand the fundamental difference between the classes of exposure to ensure that the correct concrete will be used.

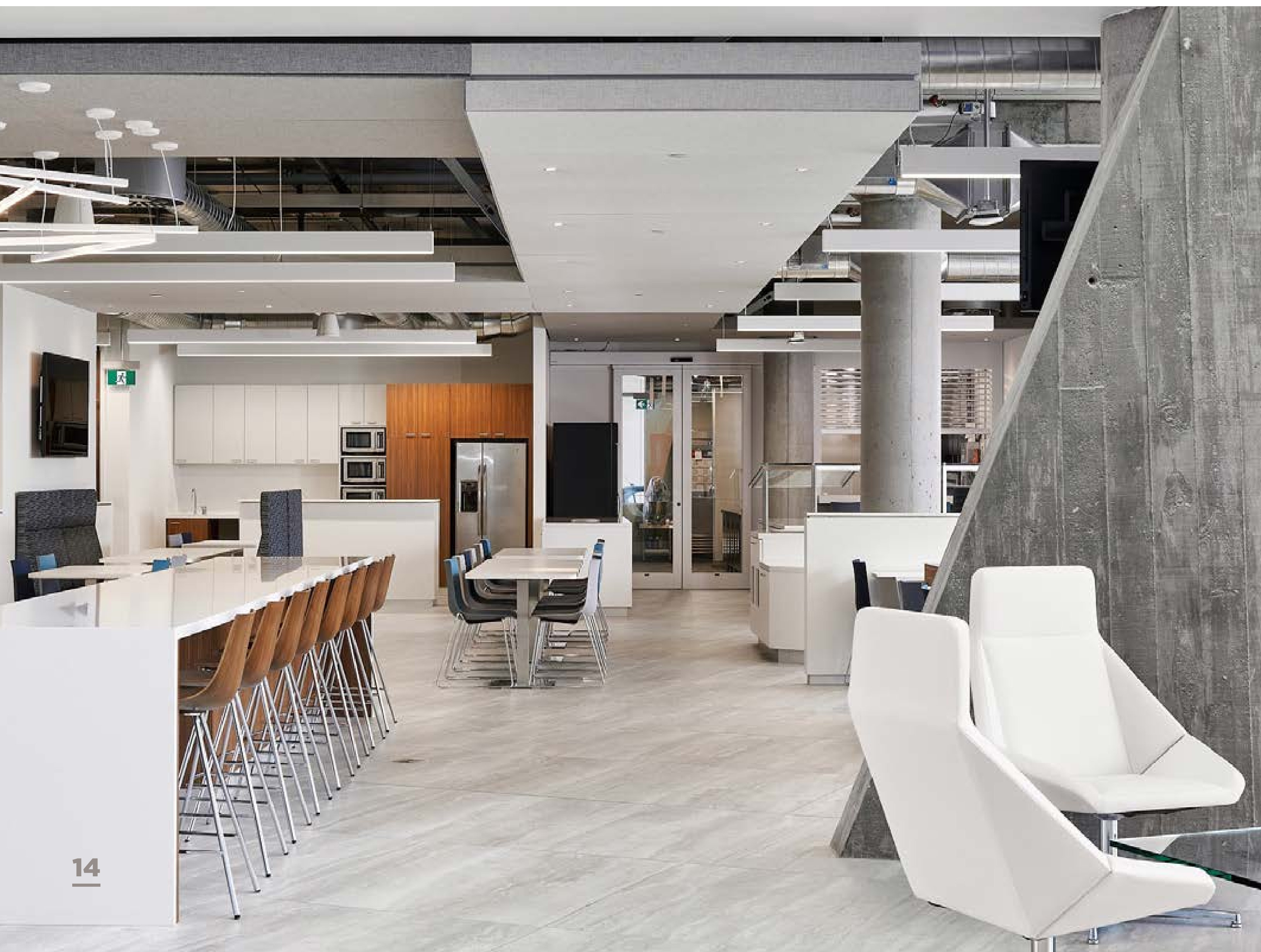
Since ready mixed producers must adhere to the classes of exposure requirements and the corresponding maximum water to cementitious ratios (w/cm), it is critical for the specifier to choose the most applicable classes of exposure for each element. Over-specifying will increase the embodied carbon content of the mix design and will limit the ability of the ready mixed producer to supply low carbon concrete.

For example, as shown in **Figure Class C-1 VS. Class F-1**, if a structurally reinforced mass concrete foundation will be exposed only to freezing and thawing and not to chlorides, then the correct classification would be an F-1 class of exposure, instead of the commonly assumed C-1 class of exposure. The structural requirement for the project might still be 35 MPa, but the maximum allowable w/cm would be 0.50 instead of 0.40, giving the ready mixed producer the ability to formulate a much less carbon intensive mix design.

## CLASS C-1 VS. CLASS F-1

2.1% GWP decrease

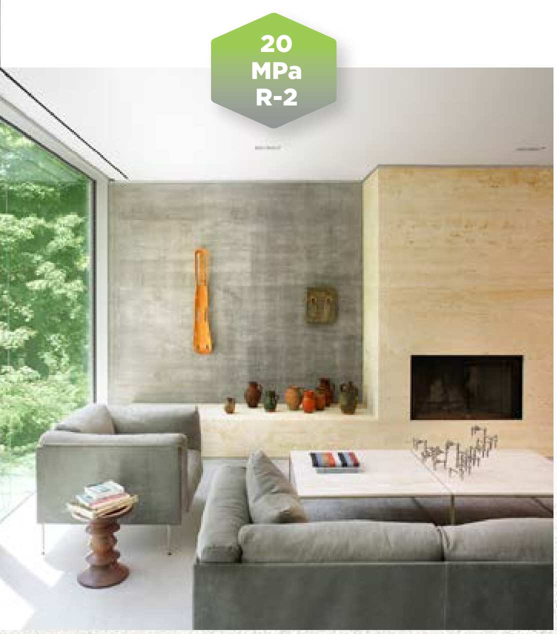
| Environmental impacts | 35 MPa concrete with air & 0.40 w/cm (C-1) GU 25 SL | 35 MPa concrete with air GU 25 SL |
|---|---|---|
| GWP kg $CO_2$ eq. | 313.07 | 306.42 |



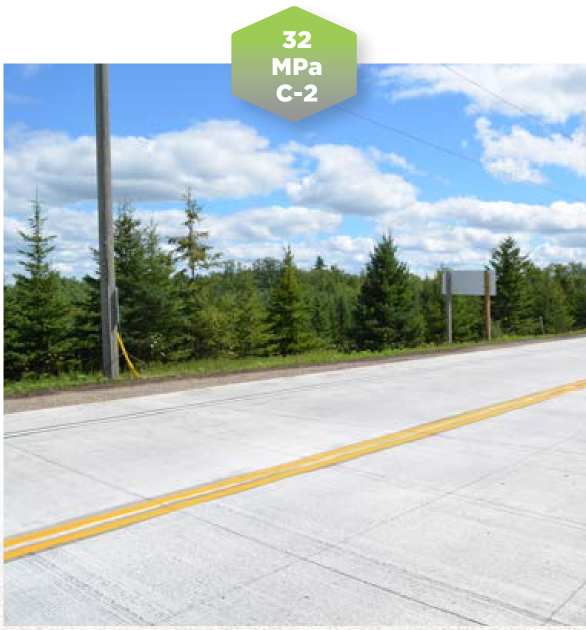
During the design phase, the specifier must give due consideration to the correct classes of exposure. The following are typical class of exposure examples from the Ontario Industry-average EPD report:

## GWP IMPACT OF INCREASING EXPOSURE CLASSES

| 20 MPa concrete with air & 0.70 w/cm GU | 25 MPa concrete with air & 0.55 w/cm (F-2) GU | 30 MPa concrete with air & 0.50 w/cm (F-1) GU | 32 MPa concrete with air & 0.45 w/cm (C-2) GU |
|---|---|---|---|
| 244.44 | 280.89 | 329.02 | 352.57 |
| House Walls | Exterior Walls and columns | Pool decks, patios, tennis courts, freshwater pools, and freshwater control structures | Garage floors, porches, steps, pavements, sidewalks, curbs and gutters |








It should be noted that if multiple classes of exposure are specified, the most stringent requirements must be followed.

## 3 Additional criteria for durability

Some concrete elements have specialized durability requirements beyond those defined by the typical exposure classes of CSA. These criteria can include exceptionally long service lives, more sophisticated testing such as direct abrasion resistance, salt scaling slabs, depth of chloride penetration, flexural strength, or resistance to other conditions such as abnormal temperatures or exposure to specific chemicals.

These requirements can necessitate the use of specialty materials or design considerations, and when it comes to integrating such criteria, it will serve the designer well to remain aware that anything driving a need for increased cement contents will increase the carbon impact of the concrete. Such design and testing can take considerable time and labour, and special requirements should be identified up front to ensure that the process can be completed and that mix designs are optimized for both performance and carbon intensity based on the results.

Use of a performance-based specification that fully allows the producer to leverage all available tools, techniques, and technology to develop appropriate mix designs is even more critical to projects of this nature.

## 4 Volume stability

### Low-shrinkage Concrete

Low-shrinkage concrete requires the use of special mixture proportions, materials, and/or shrinkage-reducing admixtures which result in drying shrinkage less than that of normal concrete. As per CSA A23.1, low-shrinkage concrete is defined as concrete where the shrinkage after 28 days of drying (at the concrete age of 35 days) is not greater than 0.040% if prisms with a cross-section of 75 × 75 are used.

To achieve these results, larger aggregate sizes, lower water to cementitious ratios, and potentially specialty admixtures are needed to reduce the shrinkage of the concrete. In turn, these performance enhancements and consequent mix design formulation changes may impact the carbon reduction goals of a project. Commonly low-shrinkage concrete is specified for wastewater treatment facilities and if it is required, Owners must factor in their impact on the overall project carbon.

## 5 Architectural requirements (e.g., Colour, surface finish, etc.)

### Architectural Concrete

Architectural concrete not only needs to meet the typical performance criteria of standard concrete but is also distinguished by having an aesthetic requirement. The aesthetic aspect may require a specialty type of concrete, placement method, or even unique forms to achieve the desired look. Commonly, self-consolidating concrete (SCC) and shotcrete are used for architectural concrete purposes, and both mix designs often require an increase in the cement content or even a special cement type like Type GUbSF. The benefits of using SCC, for example, must be put into perspective to fully understand the complexity and importance of this mix design. Several advantages include:

- SCC is designed to flow and consolidate on its own, which makes it particularly useful where placing conditions are difficult or complex geometries are required.

- SCC offers superior ease of placement and workability, which results in faster placement rates with less effort and can contribute to reductions in project timelines, equipment, labour, rework, and cost. Wear and tear on equipment is reduced, as are noise levels and vehicular emissions, and there is a reduced risk of worker strain and injury.

- SCC mixes have better consolidation and bond with reinforcement and other embedded elements. This provides greater flexibility for innovative structural and architectural designs, shapes, and finishes.

- SCC mixes typically have superior performance for both strength and durability. This can result in design with smaller members, better able to resist stresses and less overall material consumption.

Due to all these additional benefits over standard concrete, the carbon impact of SCC mix designs is increased, and must be factored into the carbon reduction goals. To give designers a better understanding of the impact of these specialty mixes, the recently released Ontario EPD report features Industry-Average mix designs for both SCC and shotcrete.

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## 6 Sustainability (e.g., Maximum Global Warming Potential limits in kg·$CO_2$ /$m^3$)

### Global Warming Potential (GWP) Limits

Specifying GWP limits for concrete mix applications is a new performance requirement which is slowly being phased in as specifiers and the industry continue to further understand the impact mix designs have on a project. The Ontario Industry-wide EPD report includes GWP baselines for specific mix designs that constitute a good starting point to be used by designers and specifiers to outline GWP targets for applications on a project. There are challenges associated with just specifying GWP limits for concrete applications and elements as an overall carbon reduction goal on a project, which will be addressed later in this guideline through a case study. The concept of a **Concrete Carbon Project Budget (CCPB)** will be showcased in the case study and will systematically look at standard and special application concretes' impact on the overall concrete carbon budget.

## 7 Pre-qualification or verification criteria (i.e., Compressive strength results)

The use of prequalification or verification criteria is common for non-standard concrete construction or where there are unique combinations of performance needs. Many designers already request submission of prequalification data to ensure that proposed concrete mix designs will perform as needed for strength development over time, durability, and/or architectural needs. When it comes to specifying lower carbon concrete, the same approach can be applied, where the designer may specify submission of performance data, and/or mock-up trials to verify that mixes meet the necessary requirements, and where the corresponding carbon impacts of those mixes can be evaluated.

## 8 Quality management requirements

A strong quality management system is key to ensuring a successful project, whether looking at the project deliverables or its sustainability. True quality management is not just a testing program – a holistic approach to systems and process management of the entire project must be adopted to realize any benefit. Investing in and supporting good quality control and assurance practices on a project is a must for the reduction of waste materials, time, and resources. A commitment by all parties involved to robust Quality Management means that the concrete will be properly specified, qualified, placed, tested, protected and cured, and put into service right the first time, minimizing the amount of waste and the associated carbon impacts.

**The concept of a Concrete Carbon Project Budget (CCPB) will be showcased in the case study and will systematically look at standard and special application concretes' impact on the overall concrete carbon budget.**

CONCRETE CARBON

Clearly outlining the submittal and performance requirements, carbon goals, prequalification requirements, acceptance and rejection criteria, corrective actions and change management plans, verification processes, and dispute resolution procedures ensure that the designer, contractor, testing agency, and ready mixed producer are aligned with the proper protocols to follow.

Communication channels must also be identified and open to ensure efficient notification, sharing, and processing of information. For example, sharing test reports immediately with the producer and contractor can help to efficiently identify potential issues or opportunities to allow for on-site optimization.

Likewise, improper scheduling, estimating, on-site labour and resource allocation, and last-minute change requests can result in confusion, project delays, excess waste and emissions, increased safety factors, potential safety hazards, and insufficient information to make optimal decisions. In particular, the importance of following all CSA testing standards in the field and laboratory cannot be overstated as proper, accurate, and timely testing and reporting is necessary to ensuring the reduction of overdesign, reduction of unwarranted waste, and the reduction of the associated carbon impacts of both. Preplacement and routine progress update meetings are essential to ensuring effective communication and that issues and opportunities are identified and addressed.

Particular attention should also be paid to change management. As materials and environmental conditions vary over time, minor adjustments to mix proportions may be required to maintain consistency. Likewise, if a mix design is overperforming, there may be opportunity for the producer to optimize their designs. As such, minor adjustments should be allowed, without time consuming and costly requalification, to maintain flexibility and to optimize performance and carbon.

When the designer, contractor, ready mixed producer, and testing agency are all following CSA standards and committed to best practices for quality assurance and control, a solid foundation for the true delivery of a lower carbon concrete project is in place.

**In particular, the importance of following all CSA testing standards in the field and laboratory cannot be overstated as proper, accurate, and timely testing and reporting is necessary to ensure the reduction of overdesign, unwarranted waste, and associated carbon impacts of both.**

## 9 Whether the concrete supplier shall meet certification requirements of concrete industry certification programs (i.e., Plant and truck certification according to the RMCAO)

**RMCAO Plant and Truck Certification**

Consistency in mix design batching and delivery can all be managed by adherence to an industry certification program such as the one provided by Concrete Ontario (RMCAO). The Concrete Ontario Plant and Truck Certification Program ensures that all the equipment, plants, and trucks meet the same industry standards which provides a level playing field for all certified producers and consistency of material delivery for owners. In addition, certified plants must also meet the strict air and noise requirements in accordance with the Ministry of the Environment, Conservation and Parks Environmental Compliance Approval (ECA) to achieve the minimum ECO Green certification. If producers wish to pursue an even stricter environmentally-conscious approach, the ECO Gold certification option is also available.

Having specifiers indicate a requirement of plant and truck certification is therefore critical in achieving low carbon concrete.

**The full current list of certified plants in Ontario can be accessed at:**

**https://www.rmcao.org/certifications/**

## 10 Any other properties that might be required to meet the owner's performance criteria

At times, other considerations may arise outside the scope of what has been discussed already within this document regarding additional properties that might be required for specialty applications, such as lightweight concrete, high density concrete, underwater placement, pervious concrete, use of innovative materials or technologies, and so forth. In such cases, the concepts discussed in previous sections may be applied, where the performance requirements should be clearly identified up front and discussed with all stakeholders in order to evaluate material, design, and placement options, the associated scheduling and carbon impacts, and the best path forward to a lower carbon solution.

## Concrete Raw Materials

Limiting the use of certain concrete raw materials and their quantities is considered prescriptive and goes against the fundamental approach of performance-based specifications. A far superior approach is to allow the use of already proven and standardized materials and give the ready mixed producer the option to determine what is required to meet the specified performance. As with many other industries, supply chain challenges have also been experienced by ready mixed producers in Ontario and communicating performance-based requirements and allowing the producers to optimize their materials will minimize any problems in achieving low carbon concrete.

**A far superior approach is to allow the use of already proven and standardized materials and give the ready mixed producer the option to determine what is required to meet the specified performance.**

## Cement Type

The most significant contributor to the carbon impact of concrete comes from the cement, and, as such, selecting the least carbon intensive cement available will lead to the least carbon intensive concrete. Specifying a cement type becomes prescriptive as availability from producer to producer varies across the province and therefore all available cements certified in accordance with CSA-A3001, Cementitious Materials for Use in Concrete, should be allowed. A notable mention is portland-limestone cement (PLC) which reduces the carbon impact of regular portland cement (PC) by up to 10% through a one-to-one replacement. The reduction in $CO_2$ emissions is realized by intergrinding up to 15% limestone with clinker to produce GUL cement instead of regular GU cement, which traditionally has incorporated up to 5% interground limestone.

Process and combustion emissions are thereby reduced by up to 10% for GUL cement while still producing concrete of equivalent performance to GU base mixes, including comparable strength and durability. There are several PLC cement types available for different applications, but the most commonly used in Ontario is Type GUL or General use portland-limestone cement. GUL cement will be replacing the traditional Type GU cement which is already being phased out in Ontario. PLC is fully approved in Ontario on all provincial and municipal projects and its use is highly encouraged by the ready mixed industry to specifiers to achieve a low carbon concrete.

The cement industry is constantly working in reducing their $CO_2$ emissions, thus GWPs are evolving as improvements are made by manufacturers at each individual plant. The Ontario industry average EPD uses the average of most of the cement producers in Ontario at a specific point in time.

For example by consulting the Ontario report and looking at the GWP values for GU versus GUL, the savings become evident, as highlighted in **Figure GU VS. GUL**.

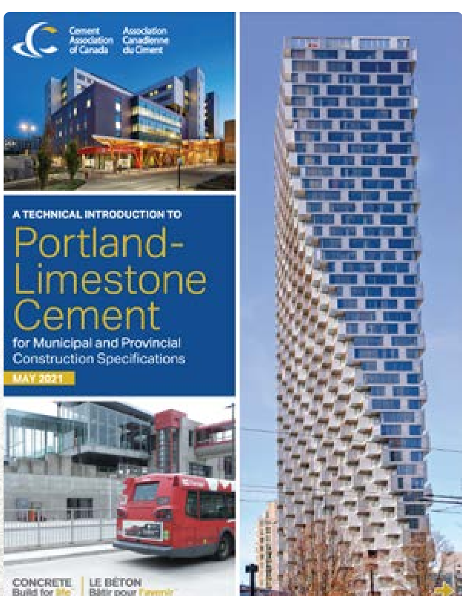
## GU VS. GUL

*6.5% GWP reduction

| Environmental impacts | 25 MPa concrete without air GU | 25 MPa concrete without air GUL |
|---|---|---|
| GWP kg $CO_2$ eq. | 273.67 | 255.89 |

*Cement makes up approximately 80 to 85% of the concrete $CO_2$ footprint so the resulting GHG savings in the concrete does not equal 10%. In addition, the soon to be developed 2022 cement LCI data will show the cement plants are closer to the 10% reduction in the $CO_2$ emission than the 2020 data this calculation is based on.

For further information about PLC, the Cement Association of Canada's PLC Compendium, **A Technical Introduction to Portland-Limestone Cement**, can be reviewed which features an in-depth look at PLC performance and a collection of projects where it has already been utilized successfully.

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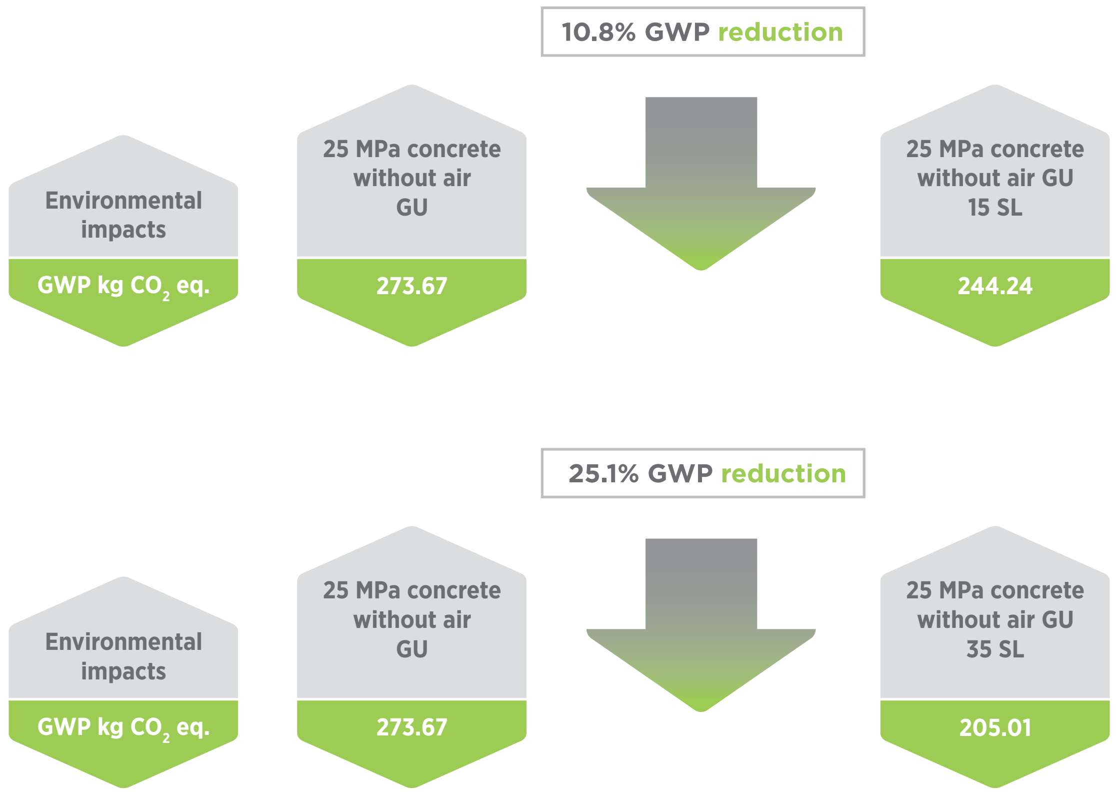
## Supplementary Cementitious Materials (SCMs)

Supplementary Cementitious Materials (SCMs) provide a multi-faceted impact on the long-term performance of concrete and achieving carbon reductions. In Ontario, slag (SL) is the most commonly used SCM and since it is a by-product from the steel industry, its inclusion has a beneficial impact on concrete's embodied carbon content. Additionally, when SL is used in concrete it provides the following benefits:

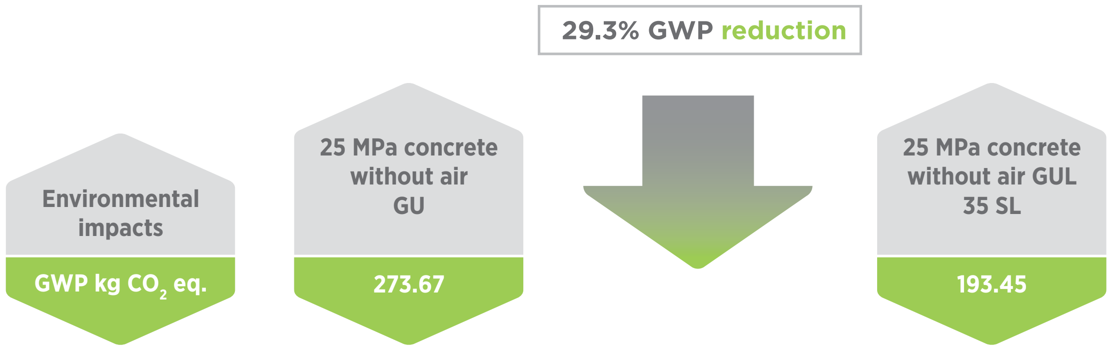
Although fly ash does have a similar impact, its use is very limited in Ontario due to the closure of coal powered energy generation stations in the province. Silica fume, as part of Type GUbSF cement, is also available and is primarily used for high strength and high-performance concrete. The Ontario report demonstrates that the more SL is used in concrete mix designs, the lower the GWP value of that concrete becomes in terms of kg $CO_2$ /m$^3$.

## INCREASING SLAG REPLACEMENT




This reduction is even more evident when SL is paired up with GUL compared to the GU mix designs, as shown in **Figure GU VS. GUL + SLAG**.

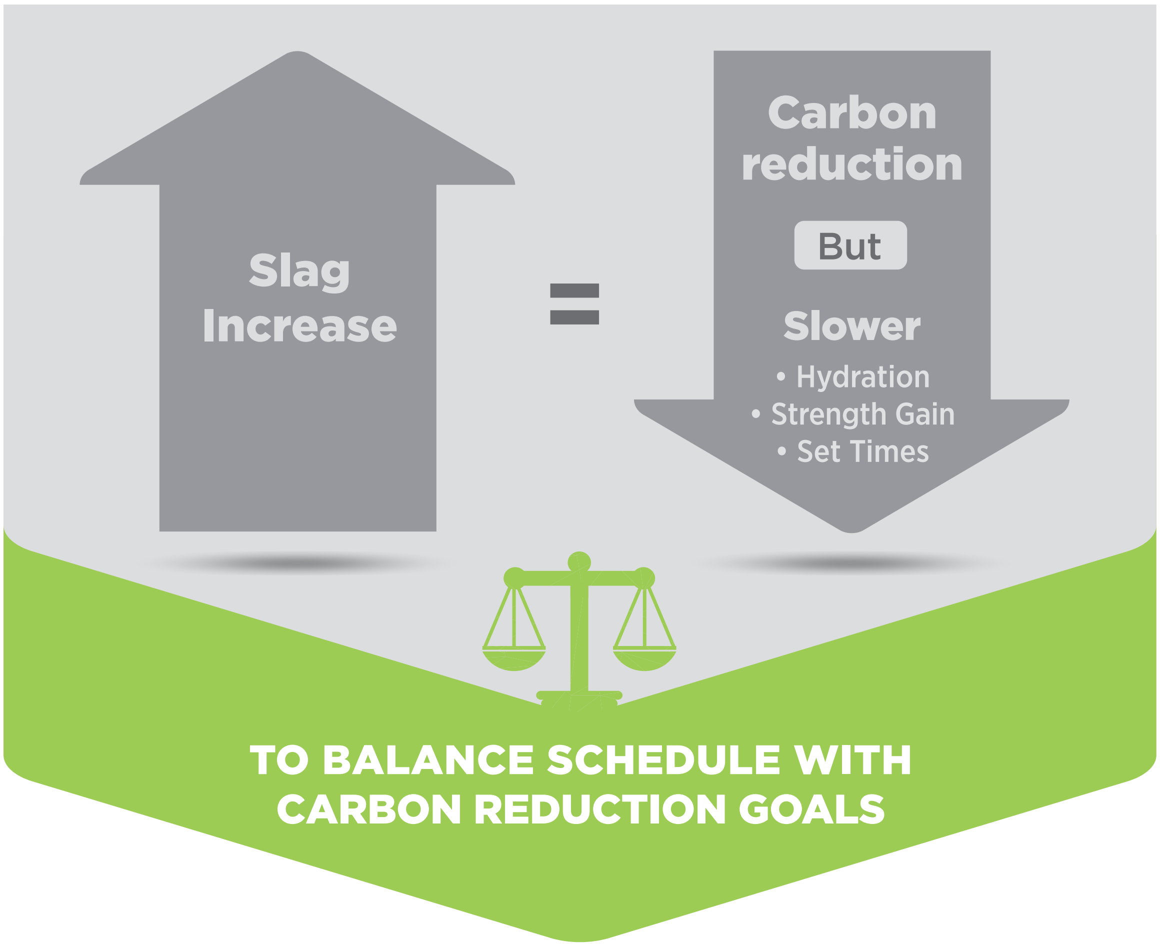
## GU VS. GUL + SLAG




Not only does slag improve the sustainability of the concrete, but it must also be used to achieve certain performance criteria such as the chloride ion penetrability requirements for certain classes of exposure.

There is a mandatory performance requirement for Class C-1 concrete of < 1500 coulombs within 91 days. To achieve this coulomb rating, the typical industry replacement level is a minimum of 25% SL and this is reflected in the Ontario EPD baseline for 35 MPa Class C-1 concrete.

An alternative approach to achieving the coulomb rating is to use Type GUbSF. It can be used without slag as the pre-blended silica fume is able to lower the overall permeability of the concrete.




- ✓ Review project schedule opportunities
- ✓ Prequalification testing of mixes
- ✓ Trials testing of mixes
- ✓ Additional curing needs
- ✓ Maturity testing during construction

## Additional Curing

The curing of concrete is the maintenance of a satisfactory moisture content and temperature for a period of time immediately following placing and finishing so that the desired properties may develop. Adequate curing of concrete cannot be overemphasized, and is a fundamental component of concrete construction. Proper-curing will increase durability, strength, watertightness, abrasion resistance, volume stability, and resistance to freezing and thawing and chlorides. It should go without saying that any carbon reduction strategy should also be committed to CSA and building code best practices that ensure good useful life of concrete construction.

**Proper curing will increase durability, strength, watertightness, abrasion resistance, volume stability, and resistance to freezing and thawing and chlorides. It should go without saying that any carbon reduction strategy should also be committed to CSA and building code best practices that ensure good useful life of concrete construction.**

The allowable curing regimes are defined in CSA A23.1 Table 19 and the Curing Type is dependent on the classes of exposure and the volume of supplementary cementitious materials (SCMs) used in the mix design. The greater the percentage of SCMs incorporated into the mix design, the longer the curing period must be to achieve the performance criteria outlined by the relevant classes of exposure. This relates back to the concept of most SCMs generally slowing down the overall rate of reaction where additional curing must be provided to achieve equivalent maturity and the desired performance criteria. In addition, more advanced curing methods such as wet curing may be required to maintain the necessary moisture within the concrete, particularly at lower w/cm ratios.

Looking at slag exclusively for Ontario, to determine what Curing Type must be used, the classification of mixes and their associated slag percentage is as follows:

1. Normal concrete (slag content < 40%)
2. HVSCM-2 (slag content ≥ 40 and < 50%)
3. HVSCM-1 (slag content ≥ 50%)

*HVSCM - High-volume supplementary cementitious materials.*

## CSA A23.1 – TABLE 19 – ALLOWABLE CURING REGIMES

| Curing Type | Name | Description |
|---|---|---|
| 1 | Basic curing | 3 d at ≥ 10°C or for the time necessary to attain 40% of the specified strength |
| 2 | Additional curing | 7 d total at ≥ 10°C and for the time necessary to attain 70% of the specified strength |
| 3 | Extended wet curing | A wet-curing period of 7 d at ≥ 10°C and for the time necessary to attain 70% of the specified strength. The curing types allowed are ponding, continuous sprinkling, absorptive mat, or fabric kept continuously wet |

For example as per CSA A23.1, Table 2, depending on the classes of exposure, normal concrete can be required to meet basic, additional, or extended wet curing. HVSCM-2 primarily is required to meet additional curing and HVSCM-1 is a combination of additional and extended wet curing.

## CURING (NORMAL CONCRETE)

| Environmental impacts | Baseline 35 MPa concrete without air GU 15 SL |
|---|---|
| GWP kg $CO_2$ eq. | 295.46 |

**Required curing: Basic curing**

3 d at ≥ 10°C or for the time necessary to attain 40% of the specified strength.

## CURING (HVSCM-2 CONCRETE)

| Environmental impacts | 35 MPa concrete with air & 0.40 w/cm (C-1) GU 42.5 SL |
|---|---|
| GWP kg $CO_2$ eq. | 262.87 |

**Required curing: Additional curing**

7 d total at ≥ 10°C and for the time necessary to attain 70% of the specified strength.

## CURING (HVSCM-1 CONCRETE)

| Environmental impacts | 35 MPa concrete with air & 0.40 w/cm (C-1) GU 50 SL |
|---|---|
| GWP kg $CO_2$ eq. | 241.35 |

**Required curing: Extended wet curing**

A wet-curing period of 7 d at ≥ 10°C and for the time necessary to attain 70% of the specified strength. The curing types allowed are ponding, continuous sprinkling, absorptive mat, or fabric kept continuously wet.

# CONCRETE CARBON

## LEED Requirements

LEED projects in Ontario continue to specify "Recycled content" requirements to promote sustainable design and low carbon concrete. Specification language such as "Concrete must replace a minimum 30% of Portland Cement by using post industrial recycled content (SCM in the cement)" is quite common and is considered prescriptive. Although this approach may have been beneficial in the past in achieving sustainable concrete, specifying minimum SCM values today can be quite detrimental to the overall project schedule and the flexibility with which ready mixed producers can operate. Furthermore, this is especially detrimental to achieving carbon reduction goals while considering special application requirements. The usage of performance-based specifications is highly encouraged and the shift from specifying prescriptive SCM values to instead defining performance GWP values is required. Since the project schedule and special applications will limit the ability to use SCMs as is showcased in the case study, using the prescriptive SCM specification approach is highly discouraged.

**The usage of performance-based specifications is highly encouraged and the shift from specifying prescriptive SCM values to instead defining performance GWP values is required.**

## Aggregates

By volume, aggregates are the largest component of concrete and are inherently a low carbon product. Most aggregates are naturally occurring materials which require minimal processing and, in Ontario, are usually locally sourced. The quality of aggregates used for concrete by ready mixed producers must be carefully considered as poor-quality materials can increase water demand or decrease strength and durability, resulting in a need to increase cement content which can have a detrimental impact on the GWP.

## Aggregate Size

Aggregate size can have a significant impact on the cement content of a concrete and should be factored in when specifying aggregate size for a specific application. As a basic guideline, larger aggregate sizes generally require lower cement contents for the same or similar strength class compared to smaller aggregate sizes and therefore the carbon impact is also reduced, with the caution that constructability always needs to be considered.

Larger aggregate sizes are typically used for mass concrete applications such as foundations and help tremendously in lowering the heat of hydration. They are also very useful when designing concrete to meet low shrinkage requirements. The placement method must be considered as the increase in aggregate size may lead to depositing and consolidation issues and this aspect should be discussed with the contractor.

When decreasing the aggregate size whether it is for placement or pumpability aspects, the cement content is increased to compensate for the increase in surface area that must be covered by the paste and therefore an increase in the GWP values is observed.

## Recycled Concrete Aggregate (RCA)

The usage of RCA in new concrete can have sustainable benefits as long as the composition of the RCA is consistent, and as specified in CSA A23.1, it does not impact the specified performance criteria of the concrete. Currently in the Ontario market the primary application that typically uses RCA are road bases. Designers and specifiers will need to consult each individual ready mixed producer to determine whether suitable RCA sources are available and what replacement level can be used in new concrete.

## Admixtures

Admixtures have become an essential component of modern concrete, and allow for unique and innovative building designs, improved job-site placement, long-term durability, unique and new concrete behaviour parameters, and overall optimized, sustainable mix designs. Although the dosage rates of admixtures are minimal and their own carbon contribution is insignificant to a concrete mix design, their overall impact on the cement reduction and ultimate carbon impact of the concrete itself can be quite substantial. Water-reducing admixtures and superplasticizers can play a critical role in reducing the amount of water used and in turn lowering the water to cementitious materials ratio without the addition of extra cement. It is highly recommended that specifications do not sole-source the usage of a particular admixture and that they allow all CSA and ASTM compliant admixtures to help reduce the carbon impact of the concrete. Even with admixtures, a performance-based specification approach is critical for true lower carbon achievement.

**It is highly recommended that specifications do not sole-source the usage of a particular admixture and that they allow all CSA and ASTM compliant admixtures to help reduce the carbon impact of the concrete. Even with admixtures, a performance-based specification approach is critical for true lower carbon achievement.**

## Early Strength Development Concrete

Building with ready mixed concrete offers designers and contractors flexibility in setting a realistic and attainable project schedule, as concrete can be placed at any time of the year. Furthermore, concrete mix designs can be optimized by the ready mixed concrete producer for scheduling needs as well as any required performance criteria and these changes can be made in real time as the project requirements and schedule changes.

However, sometimes the contractor can be required to place concrete during unfavourable cold-temperature conditions to meet the project schedule requirements. Since the strength development of in-situ concrete is highly dependent on temperature, and thus the time of year, it is critical that the designer and contractor understand the implications of placing concrete at different times of the year. If concrete placement is targeted for the spring and summer and a standard schedule is observed, the strength development timeline should be extended as long as possible to minimize the carbon impact as was previously discussed in the Performance-based Specifications section of this guide. On the other hand, if concrete will be required in the fall or winter, higher performance and accelerated mixes are often necessary, and the carbon reduction goals must be adjusted to accommodate the associated increase in GWP for those applications.

Compared to using conventional mixes in cold weather conditions, high early concrete reduces the length of time that temporary protection is required and offers savings from earlier reuse of forms and shores, shorter duration of temporary heating, earlier setting times for finishing flatwork, in addition to the earlier use of the structure. As with higher performance concretes, durability and strength parameters are often superior and the designer may be able to take advantage of the higher performance through smaller structural elements, reducing total concrete volume.

## Cold Weather Concreting

As per CSA A23.1, Cold Weather Concreting is defined as providing protection "when there is a probability of the air temperature falling below 5°C within 24h of placing (as forecast by the nearest official meteorological office)." When these conditions occur, the ready mixed supplier is typically asked to provide mix designs that accelerate the set time and/or the strength gain of the concrete while still meeting the required performance criteria without any delays.

Cold weather has a substantial impact on the set time of concrete as temperature affects the rate at which hydration of the cement occurs. More specifically, low temperatures retard hydration and consequently slow down the hardening of the concrete. To compensate for this retardation and to achieve a similar performance of the concrete as would be observed on a 20°C day, the ready mixed producer has the following options:

1. Increasing the amount of Type GU or GUL used.
2. Reducing the amount of SCMs (SL in Ontario) in the mix design, but not to the exclusion of durability performance specifications.
3. Incorporating set accelerating admixtures.

## Accelerated Set Times

Typically, a combination of 2 to 3 of the options noted will be used by the ready mixed producer to balance the low ambient temperatures with an increased rate of setting and strength development. In addition to these options, protection and curing are vital to achieving increased set times in cold weather and must be executed properly by the contractor. In terms of sustainability, both options 1 and 2 will have a negative impact on the embodied carbon content of the concrete as has already been revealed by examining the Ontario EPD report.

Reducing the slag percentage on mix designs has a similar impact as increasing the cement content shown above. Both increase the GWP and, overall, are necessary to achieve accelerated set times.

## Accelerated Strength Gain

Similar to accelerated set times, an increased rate of strength development of a mix design can be achieved by increasing the cement content and by decreasing the SCM content. Alternatively, changing the cement type from Type GU or GUL to high early-strength (HE) cement will also achieve the same result. Typically, Type HE cement is a premium product and would not be available at all ready mixed facilities and therefore its availability must be planned for if it is required on a project. In addition, Type HE cement typically has a higher $CO_2$ /MT impact than its GU or GUL counterparts from the same source.

Overall, the increase in strength and/or the increase in rate of strength gain of mix designs will negatively impact the carbon reduction goals and therefore it must be planned at the start of the project so that the concrete carbon project budget can be balanced with standard mixes.

## Carbon Mineralization Technology

Carbon mineralization or sequestration technology is currently available in the Ontario marketplace, and the technology injects a predetermined dosage of captured carbon dioxide into concrete during the mixing process where it ultimately mineralizes. In some cases, the process has been shown to improve the concrete's compressive strength, which allows for further mix optimization, leading to additional carbon footprint reductions and potentially even cost savings.

The specification of this technology is already being utilized by owners and architects to further reduce the carbon footprint of the concrete for Ontario projects. Since the usage of this technology is evolving and there are currently only a select few companies providing these services, it is important to fully understand how the carbon reductions will be achieved and what impact the technology will have on the EPD of the mix design. The specification of a singular company or product is highly discouraged, and a general technology approach should be taken when requirements are specified.


CONCRETE
CARBON

# CONCRETE CARBON PROJECT BUDGET (CCPB)

Setting GWP limits for specific concrete applications on a project allows the designer to clearly indicate performance requirements and ultimately control their carbon reduction goals. However, consider these challenges:

- The enforcement of these limits on a project, especially with cold weather concreting and project schedule impacts as were previously outlined, can become a significant constructability challenge.

- The consequences of not meeting these limits must also be clearly outlined, which is an aspect that the industry, including specifiers, have not been able to comprehensively define.

- Using application-specific GWP limits for carbon accounting on a project is unlikely to achieve effective carbon reduction goals.

- Specifying maximum GWP values for individual applications can create unanticipated problems on projects.

It is clear. A more flexible, mature, bigger picture approach is required.

A more sophisticated approach to carbon accounting on an Ontario project is to use the concept of a **"Concrete Carbon Project Budget (CCPB)"**. This concept pre-determines a carbon budget by using anticipated concrete application volumes and the Global Warming Potentials (GWPs) of the Ontario Industry-Average EPD Baselines. The sum of these values then creates the CO2e Baseline for the project and once all the concrete has been placed, the CO2e Project value can be determined. Finally, a Green House Gas (GHG) reduction value for the entire project can be calculated subtracting those two project-level calculations.

The formulas presented define the variables, and an example is provided as well to showcase the concept of CCPB accounting.

$$\text{GHG reduction} = \text{CO2e Baseline} - \text{C02e Project}$$

$$\text{\% GHG reduction} = \frac{(\text{GHG Reduction}) \cdot 100}{\text{C02e Baseline}}$$

**CO2e Baseline** represents the emissions calculated by the anticipated volumes of all the mixes used on the project multiplied by the Global Warming Potentials (GWPs) of the Ontario Industry-Average EPD Baselines as represented by:

$$\text{C02e Baseline} = \sum_{1}^{n} \text{Voln} \cdot \text{AveGWPn}$$

**CO2e Project** represents the emissions from the concrete placed on the project calculated by the volumes of all the mixes actually used on the project multiplied by their Global Warming Potential (GWPs) as represented by:

$$\text{C02e Project} = \sum_{1}^{n} \text{Voln} \cdot \text{GWPn}$$

**n** = the total number of concrete mixes used on the project

**Voln** = the volume of mix n concrete to be placed (anticipated or actual)

**GWPn** = the global warming potential of mix n

**AveGWPn** = Global Warming Potentials (GWPs) of the Ontario Industry-Average EPD Baselines for the strength class of mix n

CONCRETE CARBON

The following example will explain how to use a CCPB for carbon accounting and the process to determine the project-level % GHG Reduction at the conclusion of the project.

## 1 Calculate Anticipated CO2e Baseline

To define an initial CO2e Baseline, the designer must determine the anticipated volumes for each mix design. This will outline a starting point for the CCPB.

| Mix Design (n) | Anticipated Volume ($m^3$) (Voln) | Ontario Industry-Average EPD Baselines GWP (kg $CO_2/m^3$) (AveGWPn) | CO2e Baseline (tonnes $CO_2$) |
|---|---|---|---|
| 25 MPa non-air | 250 | 254.05 | 64 |
| 30 MPa non-air | 100 | 264.38 | 26 |
| 35 MPa non-air | 1500 | 295.46 | 443 |
| 30 MPa Class F-1 | 350 | 292.72 | 102 |
| 35 MPa Class C-1 | 75 | 313.07 | 23 |
| **Total** | **2275** | **Total CO2e Baseline** | **659** |

Using this example, the anticipated CO2e Baseline for this project would be 659 tonnes of $CO_2$. Since the volumes are anticipated, they will need to be continuously adjusted as the project progresses until the actual volumes of the project are achieved. This means that the CCPB will fluctuate to accurately represent the actual volumes required.

To reflect actual volumes at the project completion level, the following table will be used for this example.

## 2 Adjust & Calculate Final CO2e Baseline

| Mix Design (n) | Actual Volume ($m^3$) (Voln) | Ontario Industry-average EPD Baselines GWP (kg $CO_2/m^3$) (AveGWPn) | CO2e Baseline (tonnes $CO_2$) |
|---|---|---|---|
| 25 MPa non-air | 253 | 254.05 | 64 |
| 30 MPa non-air | 125 | 264.38 | 33 |
| 35 MPa non-air | 1600 | 295.46 | 473 |
| 30 MPa Class F-1 | 310 | 292.72 | 91 |
| 35 MPa Class C-1 | 75 | 313.07 | 23 |
| **Total** | **2363** | **Total CO2e Baseline** | **684** |

With the adjusted volumes at project completion, the final CO2e Baseline value becomes 684 tonnes of $CO_2$.

## 3 Calculate CO2e Project

• GWP reduction • GWP increase

| Mix Design (n) | Actual Volume (m³) (Voln) | Ontario Industry-average EPD GWP (kg $CO_2$/m³) (GWPn) | CO2e Project (tonnes $CO_2$) |
|---|---|---|---|
| 25 MPa non-air | 253 | 224.62 | 57 |
| 30 MPa non-air | 125 | 242.88 | 30 |
| 35 MPa non-air | 1600 | 210.18 | 336 |
| 30 MPa Class F-1 | 310 | 329.02 | 102 |
| 35 MPa Class C-1 | 75 | 284.38 | 21 |
| **Total** | **2363** | **Total CO2e Project** | **547** |

**Note:** Not all of the mixes used on the project were below their individual baseline values. This reflects instances where special applications, accelerated construction requirements, or cold weather placement were used.

In this example, using the actual volumes and the Ontario Industry-Average EPD information of the mixes that were actually placed, an overall CO2e Project emission of 547 tonnes of $CO_2$ is calculated for this hypothetical project. Industry-average information of mix designs is the standard starting point for any concrete carbon calculations. If more accurate information is needed, Type II or even Type III EPD information from ready mixed producers can also be used here for more accurate carbon reduction savings.

## 4 Calculate GHG Reduction

Having calculated the CO2e Baseline (684 tonnes $CO_2$) and CO2e Project (547 tonnes $CO_2$) values, the GHG Reduction in tonnes of $CO_2$ for this project is 684-547 = 137.

## 5 Calculate % GHG Reduction

Finally, using the values calculated previously, the % GHG Reduction for the overall project is (137*100)/684 = 20%.

Overall, this very simple project example would have achieved a 20% $CO_2$ reduction over the Ontario Industry-Average EPD Baselines. Factors such as an accelerated project schedule or specialty applications were not accounted for and will be covered in the case study.

## Special Application Carbon Impact

The importance of special applications, such as SCC, shotcrete, and accelerated mix designs, and their associated impact on carbon reduction goals have been clearly outlined in this guideline.

These specialty concretes are critical in achieving architectural concrete and in allowing the contractor to maintain a reasonable project schedule and therefore the usage of these mixes must be factored into the CCPB. To address this aspect, an increase in the GWP of Ontario Industry-Average Baseline EPDs is a necessary solution and this increase has already been well established by the Government Services Administration (GSA) in the United States and has been included in the standard (recently) set by the Treasury Board of Canada Secretariat for major federal projects. Both agencies represent significant infrastructure projects and the inclusion of an increased GWP value for special applications establishes a key addition to the process of the CCPB.

## Government Services Administration (GSA)

Increasing the GWP of baselines to accommodate special applications is a strategy which has already been implemented as part of the Biden-Harris Administration "Buy Clean" Task Force in the United States through the Government Services Administration (GSA). The GSA oversees $75 billion in annual contracts for the federal government and announced in March 2022 that it will set a new standard for contractors to use low embodied carbon concrete in all its major construction projects.

This announcement included a specification titled **"The Low Embodied Carbon Concrete Standards for all GSA Projects specification"** and it outlines a 35% increase of GWP from Standard to High Early Strength mixes and even a greater increase for Lightweight mixes. With the release of this specification, the missing component of how to deal with concrete special applications and their impact on carbon budget has been solved and it paved the way for the Treasury Board of Canada Secretariat to also incorporate this aspect as part of their upcoming specifications.

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## Treasury Board of Canada Secretariat

Led by the Centre for Greening Government of the Treasury Board of Canada Secretariat, the Government of Canada is looking to establish Canada as a global leader in government operations that are net-zero, resilient and green. Through this strategy the government will reduce the environmental impact of structural construction materials on all new federal projects by:

- Disclosing the amount of embodied carbon in the structural materials of major construction projects by 2022, based on material carbon intensity or a life-cycle analysis
- Reducing the embodied carbon of the structural materials of major construction projects by 30%, starting in 2025, using recycled and lower-carbon materials, material efficiency and performance-based design standards
- Conducting whole building (or asset) life-cycle assessments by 2025 at the latest for major buildings and infrastructure projects

**For the full details of the strategy, please visit:**
**https://www.canada.ca/en/treasury-board-secretariat/services/innovation/greening-government/strategy.html**

Similar to the GSA, the Treasury Board recently released their **Standard on Embodied Carbon in Construction**, which outlines the concept of the CCPB as shown in this guideline and it addresses the special application issue. The Treasury Board, in discussions with Concrete Ontario and the Cement Association of Canada, is standardizing the following: The baseline (AveGWP in the example) used for Special Application Requirements shall be 130% of the Regional (Ontario) Industry-Average Baseline EPDs for that strength class.

Treasury Board of
Canada Secretariat

**Standard on Embodied Carbon in Construction:**

**https://www.tbs-sct.canada.ca/pol/doc-eng.aspx?id=32742**

**The baseline (AveGWP in the example) used for Special Application Requirements shall be 130% of the Regional (Ontario) Industry-Average Baseline EPDs for that strength class.**

We believe this requirement should apply for the following special application mixes:

1. **High early strength**
2. **High-performance**

High-performance concrete is defined as per CSA A23.1:

High-performance concrete (HPC) — concrete that meets performance requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices.

3. **Cold-weather application**

As per CSA A23.1:

7.2.2 Cold weather concreting

Protection shall be provided when there is a probability of the air temperature falling below 5°C within 24 h of placing (as forecast by the nearest official meteorological office).

Using this information, an additional component can be used in the CCPB GWP targets, as shown in the following example.

## 2B Adjust & Calculate Anticipated CO2e Baseline for ANY Special Application Mixes

| Mix Design (n) | Ontario Industry-average EPD Baselines GWP (kg $CO_2/m^3$) (AveGWPn) | Ontario Industry-average EPD Baselines GWP (kg $CO_2/m^3$) (AveGWPn) Special Application |
|---|---|---|
| 25 MPa non-air | 254.05 | 254.05 x 1.3 = 330.27 |
| 30 MPa non-air | 264.38 | 264.38 x 1.3 = 343.69 |
| 35 MPa non-air | 295.46 | 295.46 x 1.3 = 384.10 |
| 30 MPa Class F-1 | 292.72 | 292.72 x 1.3 = 380.54 |
| 35 MPa Class C-1 | 313.07 | 313.07 x 1.3 = 406.99 |

Having the ability to accommodate special application mix requirements, which the contractor might need to execute the project effectively, is essential to creating a balanced project schedule and carbon reduction goals. This 30% increase in GWP baselines is a good starting point which can always be adjusted as the industry continues to gather more experience regarding low carbon concrete goals and objectives.

## Carbon Reduction Goals

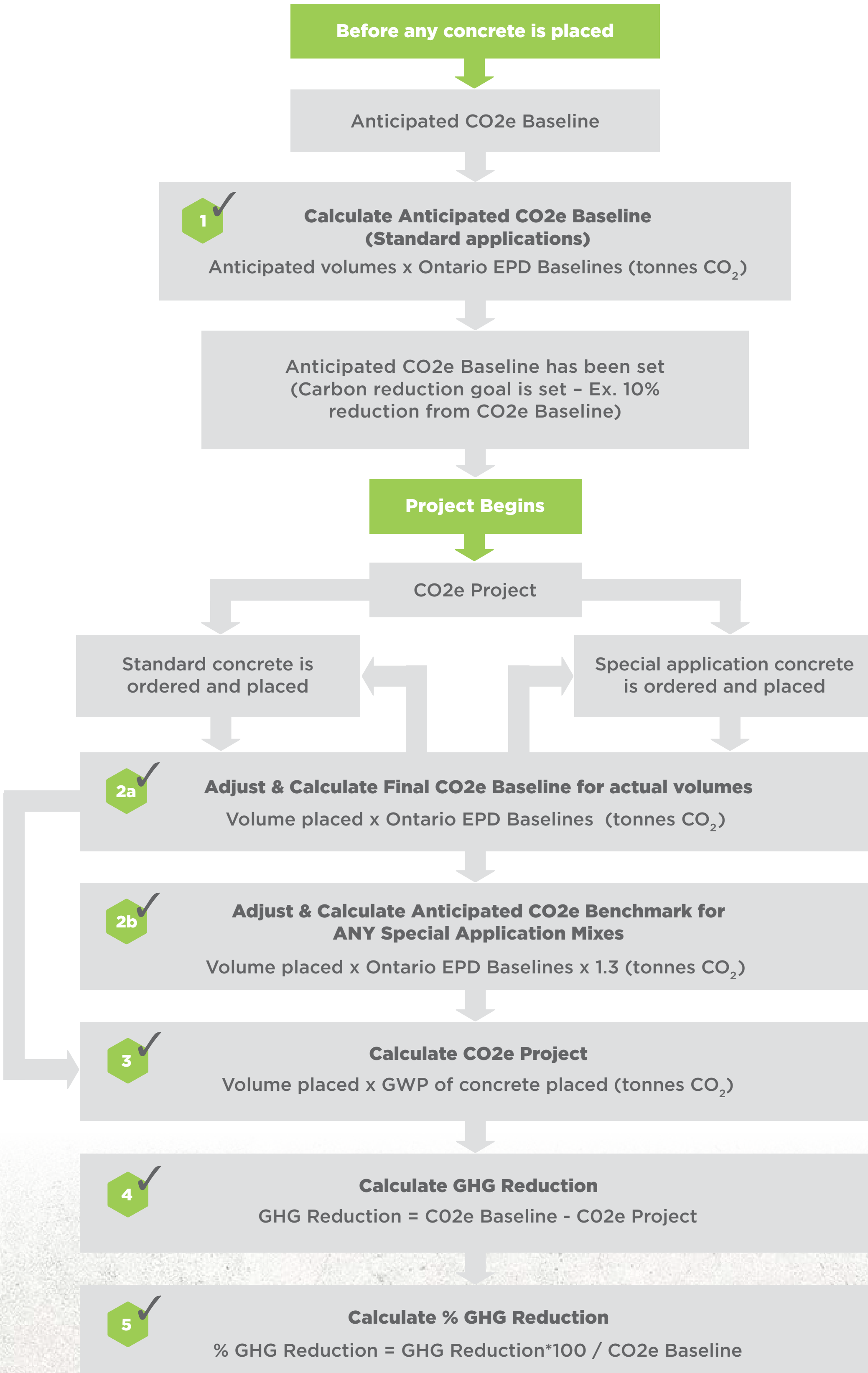
While each owner and specifier have the liberty to choose their own carbon reduction target based on the structure that is being built, setting a consistent target will allow the industry to gauge how achievable these targets are based on the Ontario report. As more and more projects are completed, the validity of the carbon reduction goals will be confirmed, and consistent targets can then be evaluated for future projects.

Over the past year, Concrete Ontario and the Cement Association of Canada have been in discussions with the Treasury Board of Canada Secretariat, and the following approach has been established as the starting point for concrete carbon reductions for all future Government of Canada projects:

**The total project GHG emissions from ready-mix concrete shall be at least 10% less than those calculated using the GWPs of the baseline mix in the Regional (Ontario) Industry Average Environmental Product Declaration (EPD) for the strength class of each mix and the volume of mix placed. (i.e., % GHG Reduction calculation of minimum 10%)**

This requirement is part of the already mentioned **Standard on Embodied Carbon in Construction** specification.

Using the example provided previously, a reduction of 20% was achieved for the hypothetical project and this means that the industry-proposed and Government-of-Canada-standardized carbon reduction goal of at least 10% would have been met. Defining a realistic and attainable carbon reduction goal from the start sets the expectation for the project to ensure that all stakeholders are aligned.


Before any concrete is placed
Anticipated CO2e Baseline
1
Calculate Anticipated CO2e Baseline (Standard applications)
Anticipated volumes x Ontario EPD Baselines (tonnes $CO_2$)
Anticipated CO2e Baseline has been set (Carbon reduction goal is set – Ex. 10% reduction from CO2e Baseline)
Project Begins
CO2e Project
Standard concrete is ordered and placed
Special application concrete is ordered and placed
2a
Adjust & Calculate Final CO2e Baseline for actual volumes
Volume placed x Ontario EPD Baselines (tonnes $CO_2$)
2b
Adjust & Calculate Anticipated CO2e Benchmark for ANY Special Application Mixes
Volume placed x Ontario EPD Baselines x 1.3 (tonnes $CO_2$)
3
Calculate CO2e Project
Volume placed x GWP of concrete placed (tonnes $CO_2$)
4
Calculate GHG Reduction
GHG Reduction = C02e Baseline - C02e Project
5
Calculate % GHG Reduction
% GHG Reduction = GHG Reduction*100 / CO2e Baseline

CASE STUDY

# THE MET CONDOMINIUMS

DEVELOPER: PLAZA/BERKLEY DEVELOPMENTS

# CONDO CASE STUDY

A condominium project has been chosen as an effective case study to demonstrate the importance of balancing carbon reduction goals with the project schedule. Condo projects continue to increase mix design requirements as the project evolves which may have negative impacts on the embodied carbon of the concrete. To fully see the repercussions of having accelerated mix designs due to cold weather and project schedule requirements, this case study will showcase a step-by-step process of how to determine a CCPB and the results associated with using special application mix designs.


The Met and projected future development in Downtown Vaughan, image courtesy of Plaza/Berkeley

## The Met Condominiums

**"The Met"** is a 35-storey condominium tower on Jane Street, north of Highway 7, in Vaughan and was developed by Plaza and Berkley Developments. It features 3 levels of underground parking and preliminary site preparation work started in December 2016. Since this project was completed between 2016 and 2019, it is very important to note that carbon reduction goals were not yet a primary focus of designers and specifiers, and, as such, the mix designs were not optimized to ensure that low carbon concrete was achieved. The case study's primary purpose is to showcase how a typical project schedule and special application mix designs, such as cold weather concreting can impact concrete carbon budgets. Using the information provided in this guideline and already available concrete carbon resources such as EPDs, designers and specifiers can formulate a plan to achieve their carbon reduction goals today.

The Met, Berkley, Quadrangle Architects, Plaza, Vaughan

## Concrete Needs on The Met

As part of the mix design submittal and review process, approximately 20 mix designs were submitted by the ready mixed producer to the contractor over the course of the project. However, once the project schedule and cold weather concreting requirements were fully implemented by the contractor, approximately 140 different mix design variations were used upon project completion. Mix design variations included a variety of performance enhancements such as:

1. **Accelerated set and strengths**
2. **Enhancement of slumps**
3. **Aggregate size adjustments**
4. **Fiber usage**
5. **Specialty admixtures (e.g., Corrosion inhibitors and retarders)**

This increase in specialized mix designs had a significant impact on the overall embodied carbon of the concrete, which will be discussed throughout the case study. It should be noted that the increase in the number of mix design numbers is typical for a project such as this, and it is attributable to the flexibility that concrete offers to accommodate the schedule, the structural requirements and the ease of placement under a variety of conditions.

The following summary of mix designs and associated applications represents the majority of the concrete placed for this project. Low strength fills were excluded from the calculations. The cement type for all concrete was either Type GU or Type GUbSF since Type GUL was not yet readily available.

| Mix Design | Applications |
|---|---|
| 15 MPa without air | N/A |
| 25 MPa without air | Interior slabs |
| 25 MPa Class C-4 | Slab on grade |
| 30 MPa without air | Footings, slabs, columns & walls (21st floor – roof) |
| 30 MPa Class F-1 | Balconies, terraces, mechanical PH roof |
| 35 MPa without air | Slabs & beams, columns & walls (14th floor – u/s 21st floor) |
| 35 MPa Class F-2 | Perimeter foundation walls, columns & walls (14th floor – u/s 21st floor) |
| 35 MPa Class C-1 | Parking slabs, balconies & terraces |
| 40 MPa without air | Columns & walls (7th floor – u/s 14th floor) |
| 45 MPa without air | Beams, pick-up slabs, columns & walls (2nd floor – u/s 7th floor) |
| 45 MPa Class F-2 | Columns & walls (2nd floor – u/s 7th floor) |
| 45 MPa Class C-1 | N/A |
| 50 MPa without air | Columns & walls |
| 50 MPa Class F-2 | Columns & walls |
| 60 MPa Class F-2 | N/A |

Knowing the concrete mix designs that are required for the project, the process of determining the CCPB can begin. The same procedure which was used in the “Example” will be followed for this case study.

## STEP 1: CALCULATE ANTICIPATED CO2e BASELINE

This represents a table of the anticipated mix designs and volumes for the project, and the tonnes of $CO_2$ using the baseline GWP numbers.

| Mix Design | Anticipated Volume ($m^3$) | Application | Ontario Industry-Average EPD Baseline Mix | Baseline GWP (kg $CO_2/m^3$) | CO2e Baseline (tonnes $CO_2$) |
|---|---|---|---|---|---|
| 15 MPa without air | 600 | Standard | **Baseline 20 MPa concrete without air GU 10 SL | 220.29 | 132.2 |
| 25 MPa without air | 7,000 | Standard | Baseline 25 MPa concrete without air GU 10 SL | 254.05 | 1,778.4 |
| 25 MPa Class C-4 | 900 | Standard | **Baseline 25 MPa concrete with air & 0.55 w/cm (F-2) GU 10 SL | 260.64 | 234.6 |
| 30 MPa without air | 2,500 | Standard | Baseline 30 MPa concrete without air GU 15 SL | 264.38 | 660.9 |
| 30 MPa Class F-1 | 3,500 | Standard | Baseline 30 MPa concrete with air & 0.50 w/cm (F-1) GU 15 SL | 292.72 | 1,024.5 |
| 35 MPa without air | 2,500 | Standard | Baseline 35 MPa concrete without air GU 15 SL | 295.46 | 738.7 |
| 35 MPa Class F-2 | 1,500 | Standard | Baseline 35 MPa concrete with air GU 15 SL | 334.49 | 501.7 |
| 35 MPa Class C-1 | 5,250 | Standard | Baseline 35 MPa concrete with air & 0.40 w/cm (C-1) GU 25 SL | 313.07 | 1,643.6 |
| 40 MPa without air | 1,000 | Standard | Baseline 40 MPa concrete without air GU 15 SL | 326.25 | 326.3 |
| 45 MPa without air | 3,000 | Standard | Baseline 45 MPa concrete without air GU 15 SL | 349.88 | 1,049.7 |
| 45 MPa Class F-2 | 20 | Standard | Baseline 45 MPa concrete with air GU 15 SL | 379.45 | 7.6 |
| 45 MPa Class C-1 | 1,700 | Standard | **45 MPa concrete with air GU 25 SL | 347.24 | 590.3 |
| 50 MPa without air | 70 | Standard | Baseline 50 MPa concrete without air GUbSF 20 SL | 335.76 | 23.5 |
| 50 MPa Class F-2 | 1,100 | Standard | Baseline 50 MPa concrete with air GUbSF 20 SL | 456.93 | 502.6 |
| 60 MPa Class F-2 | 150 | Standard | **50 MPa concrete with air GUbSF | 535.65 | 80.3 |
| **Total:** | **30,790** | | | **Total:** | **9,294.9** |

Photos: Edward Skira

Photo: DarksideDenizen

Due to the limited number of Ontario baselines available, the designer will have to determine which baselines to use if the required mix design is not available.

**For this case study, the following interpretations were made:

1. 15 MPa baseline is not available and thus the 20 MPa has been selected
2. Class C-4 concrete has the same performance criteria as Class F-2 and thus the Class F-2 baseline can be selected
3. 45 MPa Class C-1: Class C-1 mix designs require a minimum of 25% SL as previously outlined in this guideline, and thus the 45 MPa concrete with air GU 25 SL baseline was selected
4. 60 MPa baseline is not available and thus the most stringent 50 MPa concrete with air GUbSF version was selected

At this stage, the designer has estimated the volumes for each mix design and applied the Ontario Industry-Average EPD Baselines to determine the total CO2e Baseline (Volume x Baseline GWP). The mix designs are assumed to be standard applications, and the designs for special applications, such as accelerated set and strength, are unknown. The designs for special applications will be developed as the contractor communicates the concrete placement and project schedule requirements to the ready mixed producer, at which point the CO2e Baseline will need to be adjusted.

The Met, Berkley, Quadrangle Architects, Plaza, Vaughan

The Final CO2e Baseline requires the actual volumes of concrete placed and must factor in the special application component, which has a significant impact. Special applications such as architectural concrete, accelerated set and strength, and cold weather concreting will all impact the CCPB and must be accounted for to address constructability challenges that exist on numerous projects. For the Met, the following is a comprehensive breakdown of the numerous mix designs that were used.

## STEP 2: ADJUST & CALCULATE FINAL CO2e BASELINE

This table represents an update to the table in Step 1, updated as the project progresses, capturing additional mix designs and specialty applications, and actual volumes, to represent the final baseline for the project.

| Mix Design | Application | Total Volume ($m^3$) | Ontario Industry-Average EPD Baseline Mix | Baseline GWP (kg $CO_2/m^3$) | Updated Baseline GWP (kg $CO_2/m^3$) (30% increase) | C02e Baseline (tonnes $CO_2$) |
|---|---|---|---|---|---|---|
| 15 MPa without air | Standard | 626.0 | Baseline 20 MPa concrete without air GU 10 SL | 220.29 | N/A | 137.9 |
| 25 MPa without air | Standard | 2,596.2 | Baseline 25 MPa concrete without air GU 10 SL | 254.05 | N/A | 659.6 |
| 25 MPa Class C-4 | Standard | 548.0 | Baseline 25 MPa concrete with air & 0.55 w/cm (F-2) GU 10 SL | 260.64 | N/A | 142.8 |
| 30 MPa without air | Standard | 943.0 | Baseline 30 MPa concrete without air GU 15 SL | 264.38 | N/A | 249.3 |
| 30 MPa Class F-1 | Standard | 1,090.6 | Baseline 30 MPa concrete with air & 0.50 w/cm (F-1) GU 15 SL | 292.72 | N/A | 319.2 |
| 35 MPa without air | Standard | 2,031.0 | Baseline 35 MPa concrete without air GU 15 SL | 295.46 | N/A | 600.1 |
| 35 MPa Class F-2 | Standard | 1,184.8 | Baseline 35 MPa concrete with air GU 15 SL | 334.49 | N/A | 396.3 |
| 35 MPa Class C-1 | Standard | 2,245.8 | Baseline 35 MPa concrete with air & 0.40 w/cm (C-1) GU 25 SL | 313.07 | N/A | 703.1 |
| 40 MPa without air | Standard | 1,123.0 | Baseline 40 MPa concrete without air GU 15 SL | 326.25 | N/A | 366.4 |
| 45 MPa without air | Standard | 1,827.4 | Baseline 45 MPa concrete without air GU 15 SL | 349.88 | N/A | 639.4 |
| 45 MPa Class F-2 | Standard | 9.0 | Baseline 45 MPa concrete with air GU 15 SL | 379.45 | N/A | 3.4 |
| 45 MPa Class C-1 | Standard | 909.6 | 45 MPa concrete with air GU 25 SL | 347.24 | N/A | 315.9 |
| 50 MPa without air | Standard | 68.6 | Baseline 50 MPa concrete without air GUbSF 20 SL | 335.76 | N/A | 23.0 |
| 50 MPa Class F-2 | Standard | 411.0 | Baseline 50 MPa concrete with air GUbSF 20 SL | 456.93 | N/A | 187.8 |
| 60 MPa Class F-2 | Standard | 132.0 | 50 MPa concrete with air GUbSF | 535.65 | N/A | 70.7 |
| 25 MPa without air | Special | 408.4 | Baseline 25 MPa concrete without air GU 10 SL | 254.05 | 330.27 | 134.9 |
| 25 MPa Class C-4 | Special | 457.4 | Baseline 25 MPa concrete with air & 0.55 w/cm (F-2) GU 10 SL | 260.64 | 338.83 | 155.0 |
| 30 MPa without air | Special | 1,421.6 | Baseline 30 MPa concrete without air GU 15 SL | 264.38 | 343.69 | 488.6 |
| 30 MPa Class F-1 | Special | 809.8 | Baseline 30 MPa concrete with air & 0.50 w/cm (F-1) GU 15 SL | 292.72 | 380.53 | 308.2 |

Continued on Page 52

## STEP 2: ADJUST & CALCULATE FINAL CO2e BASELINE CONTINUED

| Mix Design | Application | Total Volume ($m^3$) | Ontario Industry-Average EPD Baseline Mix | Baseline GWP (kg $CO_2/m^3$) | Updated Baseline GWP (kg $CO_2/m^3$) (30% increase) | CO2e Baseline (tonnes $CO_2$) |
|---|---|---|---|---|---|---|
| 35 MPa without air | Special | 147.6 | Baseline 35 MPa concrete without air GU 15 SL | 295.46 | 384.10 | 56.7 |
| 35 MPa Class F-2 | Special | 362.0 | Baseline 35 MPa concrete with air GU 15 SL | 334.49 | 434.84 | 157.4 |
| 35 MPa Class C-1 | Special | 2,018.6 | Baseline 35 MPa concrete with air & 0.40 w/cm (C-1) GU 25 SL | 313.07 | 406.99 | 821.6 |
| 45 MPa without air | Special | 592.6 | Baseline 45 MPa concrete without air GU 15 SL | 349.88 | 454.85 | 269.5 |
| 45 MPa Class C-1 | Special | 736.0 | 45 MPa concrete with air GU 25 SL | 347.24 | 451.42 | 332.2 |
| 50 MPa Class F-2 | Special | 690.0 | Baseline 50 MPa concrete with air GUbSF 20 SL | 456.93 | 594.01 | 409.9 |
| 25 MPa without air (75% @ 24H) | Special | 36.0 | Baseline 25 MPa concrete without air GU 10 SL | 254.05 | 330.27 | 11.9 |
| 25 MPa without air (75% @ 48H) | Special | 4,064.8 | Baseline 25 MPa concrete without air GU 10 SL | 254.05 | 330.27 | 1,342.5 |
| 30 MPa without air (75% @ 48H) | Special | 13.0 | Baseline 30 MPa concrete without air GU 15 SL | 264.38 | 343.69 | 4.5 |
| 30 MPa Class F-1 (75% @ 24H) | Special | 69.6 | Baseline 30 MPa concrete with air & 0.50 w/cm (F-1) GU 15 SL | 292.72 | 380.53 | 26.5 |
| 30 MPa Class F-1 (75% @ 48H) | Special | 1,585.4 | Baseline 30 MPa concrete with air & 0.50 w/cm (F-1) GU 15 SL | 292.72 | 380.53 | 603.3 |
| 35 MPa without air (75% @ 48H) | Special | 333.0 | Baseline 35 MPa concrete without air GU 15 SL | 295.46 | 384.10 | 127.9 |
| 35 MPa Class C-1 (75% @ 48H) | Special | 1,048.2 | Baseline 35 MPa concrete with air & 0.40 w/cm (C-1) GU 25 SL | 313.07 | 406.99 | 426.6 |
| 45 MPa without air (75% @ 48H) | Special | 302.2 | Baseline 45 MPa concrete without air GU 15 SL | 349.88 | 454.85 | 137.5 |
| 45 MPa Class C-1 (75% @ 48H) | Special | 72.0 | 45 MPa concrete with air GU 25 SL | 347.24 | 451.42 | 32.5 |
| | **Total:** | **30,914.2** | | | **Total:** | **10,661.9** |

## STEP 2B: ADJUST & CALCULATE ANTICIPATED CO2e BASELINE FOR ANY SPECIAL APPLICATION MIXES

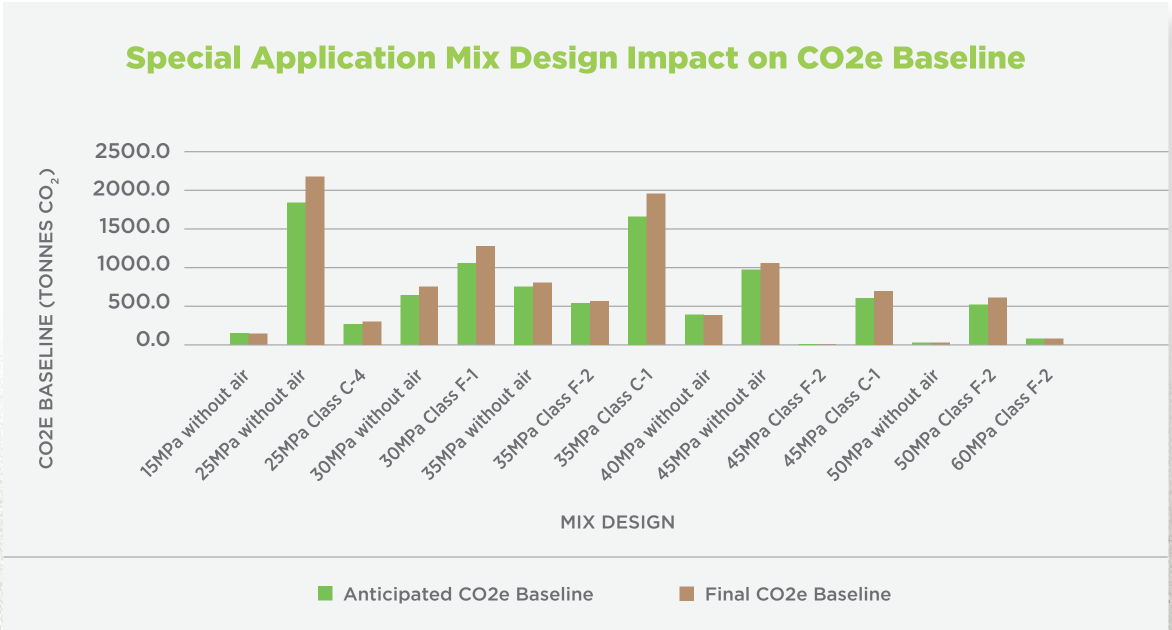
As portions of the project needed to meet accelerated strength requirements to stay within the project schedule, the CO2e Baseline consequently increased from 9,294.9 to 10,661.9 tonnes $CO_2$, a 14.7% increase. The Final CO2e Baseline calculation can only be completed once all the concrete has been placed but it also needs to be tracked as the project progresses to ensure that carbon reduction goals will be achieved.

If 20 m³ of 45 MPa Class C-1 (75% @ 48H) will be placed, the updated CO2e Baseline after the placement would be increased as follows:

$$20\ m^3 \times 451.42\ kg\ CO_2/m^3 = 9.0\ tonnes\ CO_2$$

This 9.0 tonnes $CO_2$ would be factored into the budget at that time during the project and, would represent 27.7% of the overall carbon budget of that mix at the end of the project. (Total CO2e Baseline of mix = 32.5 tonnes $CO_2$) The other application CO2e Baselines remain the same until a special application is required.

The transition from the Anticipated CO2e Baseline to the Final CO2e Baseline will need to be carefully managed by a sustainability expert to keep the project on track with the intended carbon reduction goals. As the project progresses, the carbon reduction goals should be evaluated to determine where optimization in terms of concrete mix designs can be achieved. A visualization of how the CO2e Baseline changed for the Met project is presented. Final concrete volume values were used in each case.



## STEP 3: CO2e PROJECT CALCULATION

This table represents the actual volumes and actual GWP values to compare against the final baseline from Step 2.

| Mix Design | Application | Total Volume ($m^3$) | Ontario Industry-Average EPD Mix | Ontario Industry-Average EPD GWP (kg $CO_2$) | CO2e Project (tonnes $CO_2$) |
|---|---|---|---|---|---|
| 15 MPa without air | Standard | 626.0 | 20 MPa concrete without air GU 15 SL | 211.99 | 132.7 |
| 25 MPa without air | Standard | 2,596.2 | 25 MPa concrete without air GU 15 SL | 244.24 | 634.1 |
| 25 MPa Class C-4 | Standard | 548.0 | 25 MPa concrete with air & 0.55 w/cm (F-2) GU 25 SL | 230.26 | 126.2 |
| 30 MPa without air | Standard | 943.0 | 30 MPa concrete without air GU 15 SL | 264.38 | 249.3 |
| 30 MPa Class F-1 | Standard | 1,090.6 | 30 MPa concrete with air & 0.50 w/cm (F-1) GU 15 SL | 292.72 | 319.2 |
| 35 MPa without air | Standard | 2,031.0 | 35 MPa concrete without air GU 30 SL | 258.92 | 525.9 |
| 35 MPa Class F-2 | Standard | 1,184.8 | 35 MPa concrete with air GU 25 SL | 306.42 | 363.0 |
| 35 MPa Class C-1 | Standard | 2,245.8 | 35 MPa concrete with air & 0.40 w/cm (C-1) GU 35 SL | 284.38 | 638.7 |
| 40 MPa without air | Standard | 1,123.0 | 40 MPa concrete without air GU 30 SL | 285.48 | 320.6 |
| 45 MPa without air | Standard | 1,827.4 | 45 MPa concrete without air GU 30 SL | 305.72 | 558.7 |
| 45 MPa Class F-2 | Standard | 9.0 | 45 MPa concrete with air GU 25 SL | 347.24 | 3.1 |
| 45 MPa Class C-1 | Standard | 909.6 | 45 MPa concrete with air GU 25 SL | 347.24 | 315.9 |
| 50 MPa without air | Standard | 68.6 | 50 MPa concrete without air GUbSF 25 SL | 321.41 | 22.0 |
| 50 MPa Class F-2 | Standard | 411.0 | 50 MPa concrete with air GUbSF 25 SL | 437.25 | 179.7 |
| 60 MPa Class F-2 | Standard | 132.0 | 50 MPa concrete with air GUbSF 25 SL | 437.25 | 57.7 |
| 25 MPa without air | Special | 408.4 | Baseline 25 MPa concrete without air GU 10 SL | 254.05 | 103.8 |
| 25 MPa Class C-4 | Special | 457.4 | Baseline 25 MPa concrete with air & 0.55 w/cm (F-2) GU 10 SL | 260.64 | 119.2 |
| 30 MPa without air | Special | 1,421.6 | Baseline 30MPa concrete without air GU 15 SL | 264.38 | 375.8 |
| 30 MPa Class F-1 | Special | 809.8 | 30 MPa concrete with air & 0.50 w/cm (F-1) GU 15 SL | 292.72 | 237.0 |
| 35 MPa without air | Special | 147.6 | 35 MPa concrete without air GU 15 SL | 295.46 | 43.6 |
| 35 MPa Class F-2 | Special | 362.0 | Baseline 35 MPa concrete with air GU 15 SL | 334.49 | 121.1 |
| 35 MPa Class C-1 | Special | 2,018.6 | 35 MPa concrete with air & 0.40 w/cm (C-1) GU 25 SL | 313.07 | 632.0 |
| 45 MPa without air | Special | 592.6 | Baseline 45 MPa concrete with air GU 15 SL | 379.45 | 224.9 |
| 45 MPa Class C-1 | Special | 736.0 | 45 MPa concrete with air GU 25 SL | 347.24 | 255.6 |
| 50 MPa Class F-2 | Special | 690.0 | 50 MPa concrete with air GUbSF 15 SL | 476.61 | 328.9 |
| 25 MPa without air (75% @ 24H) | Special | 36.0 | 40 MPa concrete without air GU 15 SL | 326.25 | 11.7 |
| 25 MPa without air (75% @ 48H) | Special | 4,064.8 | 35 MPa concrete without air GU 15 SL | 295.46 | 1,201.0 |
| 30 MPa without air (75% @ 48H) | Special | 13.0 | 45 MPa concrete without air GU 15 SL | 349.88 | 4.5 |
| 30 MPa Class F-1 (75% @ 24H) | Special | 69.6 | 45 MPa concrete with air GU 15 SL | 379.45 | 26.4 |
| 30 MPa Class F-1 (75% @ 48H) | Special | 1,585.4 | 40 MPa concrete with air GU 15 SL | 361.65 | 573.4 |
| 35 MPa without air (75% @ 48H) | Special | 333.0 | 60 MPa concrete without air GUbSF 15 SL | 376.81 | 125.5 |
| 35 MPa Class C-1 (75% @ 48H) | Special | 1,048.2 | 50 MPa concrete with air GUbSF 25 SL | 437.25 | 458.3 |
| 45 MPa without air (75% @ 48H) | Special | 302.2 | 70 MPa concrete without air GUbSF 15 SL | 386.50 | 116.8 |
| 45 MPa Class C-1 (75% @ 48H) | Special | 72.0 | 50 MPa concrete with air GUbSF 15 SL | 476.61 | 34.3 |
| | **Total:** | **30,914.2** | | **Total:** | **9,440.6** |

**Ontario Industry-Average EPD Mixes which were extrapolated to produce additional SL percentages and comparable accelerated mix designs which are not available. Selections were made based on the review of cement contents and compared to the Industry-Average submitted values.**

At the project close out stage, the CCPB can be analyzed to determine how the mix designs that were used impacted the overall carbon reduction goals. Using the available Ontario Industry-Average EPD mixes, the CO2e Project can be calculated for the Met which ended up being 9,440.6 tonnes of $CO_2$ as shown in the Step 3 table. The challenge with using available Industry-Average EPD mixes is that not all variations that were used in the field will be available to help the sustainability expert to determine an accurate representation of the CO2e Project. As such, guidance from the ready mixed producer in determining which Industry-Average mixes most closely correspond to the actual mix designs is necessary. A more effective method of GWP quantification is using Type II and Type III EPDs as they more accurately reflect the mix designs and can provide a more effective means of carbon accounting and reduction. A collaborative effort between the designer, contractor, and ready mixed producer is therefore required to achieve consistent and accurate carbon accounting.

**A more effective method of GWP quantification is using Type II and Type III EPDs as they more accurately reflect the mix designs and can provide a more effective means of carbon accounting and reduction.**

The Met, Berkley, Quadrangle Architects, Plaza, Vaughan

## STEP 4: CALCULATE GHG REDUCTION

Having calculated the Final CO2e Baseline (10,661.9 tonnes $CO_2$) and CO2e Project (9,440.6 tonnes $CO_2$) values, the GHG Reduction in tonnes of $CO_2$ for this project is

$$10{,}661.9 - 9{,}440.6 = 1{,}221.3$$

## STEP 5: CALCULATE % GHG REDUCTION

Finally, using the values calculated, the % GHG Reduction for the overall project is

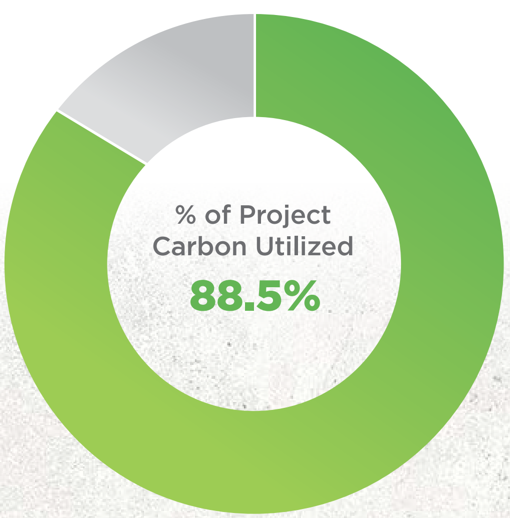
$$(1{,}221.3*100)/10{,}661.9 = 11.5\%$$

### Project Summary

Applying the concept of the CCPB and following the process throughout the case study, the Met project would have achieved a 11.5% reduction in $CO_2$. A full summary of the Final CO2e Baseline versus the CO2e Project results are shown here.

This reduction is quite significant, especially considering that the carbon reduction goals and project schedule were not optimized to achieve low carbon concrete. If this project was to be designed and specified today, with carbon reduction goals outlined from the start and enforced throughout the project, a much greater reduction in $CO_2$ would likely be achieved. In addition, the availability of Type GUL cement would lead to a much large carbon reduction.

## Concrete Carbon Project Summary (Type GU)




**Summary**

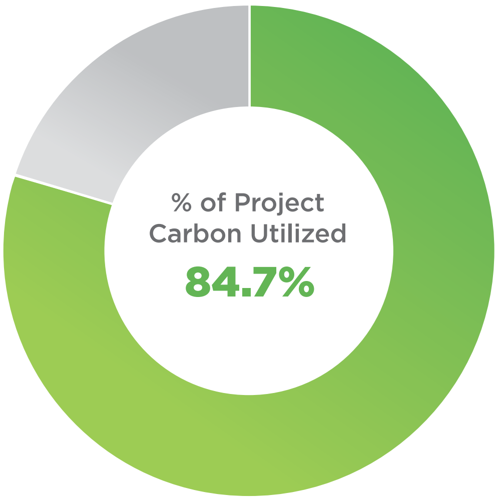
Total Concrete Carbon Project Budget
**10,661.9 tonnes $CO_2$**

Total Carbon Project Impact
**9,440.6 tonnes $CO_2$**

Total Carbon Savings
**1,221.3 tonnes $CO_2$**

% GHG Reduction
**11.5%**

## Concrete Carbon Project Summary (Type GUL)




### Summary

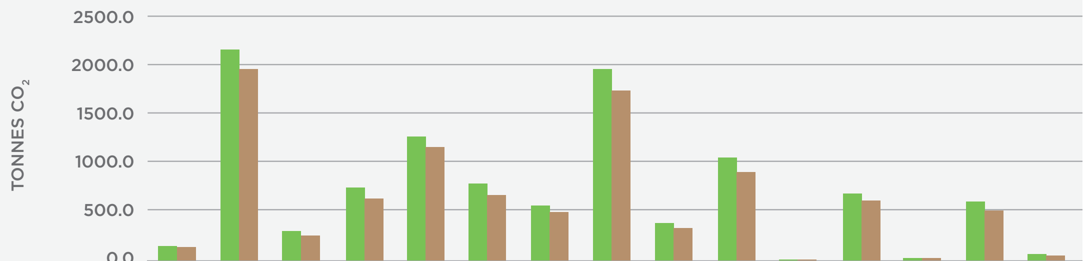
Total Concrete Carbon Project Budget
**10,661.9 tonnes $CO_2$**

Total Carbon Project Impact
**9,032.4 tonnes $CO_2$**

Total Carbon Savings
**1,629.5 tonnes $CO_2$**

% GHG Reduction
**15.3%**

### Final CO2e Baseline vs Project CO2e Results




| | 15 MPa without air | 25 MPa without air | 25 MPa Class C-4 | 30 MPa without air | 30 MPa Class F-1 | 35 MPa without air | 35 MPa Class F-2 | 35 MPa Class C-1 | 40 MPa without air | 45 MPa without air | 45 MPa Class F-2 | 45 MPa Class C-1 | 50 MPa without air | 50 MPa Class F-2 | 60 MPa Class F-2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Final CO2e Baseline | 137.9 | 2148.8 | 297.8 | 742.4 | 1257.2 | 784.7 | 553.7 | 1951.3 | 366.4 | 1046.4 | 3.4 | 680.6 | 23.0 | 597.7 | 70.7 |
| CO2e Project | 132.7 | 1950.6 | 245.4 | 629.7 | 1156.1 | 663.5 | 484.1 | 1729.0 | 320.6 | 900.3 | 3.1 | 605.7 | 22.0 | 508.6 | 57.7 |

MIX DESIGN

Final CO2e Baseline    CO2e Project

## Specifier Considerations

The concept of the CCPB clearly demonstrates the importance of not relying on application specific GWP values for carbon accounting as on numerous instances, as mix designs may need to be adjusted for a variety of valid reasons and will exceed the specified GWP values once special applications are considered. For the Met project, in numerous cases the standard mix design baselines were exceeded due to special application mix design requirements and the consequences of hard specifying any GWP value would have had to be addressed by the consultant, the contractor and ready mixed producer.

The 30 MPa Class F-1 mix designs (Balconies, terraces, mechanical PH roof) are a perfect example of how the standard GWP values were exceeded and a summary is provided. Special application GWP baselines are also indicated to highlight their importance.

## 30 MPa CLASS F-1 USAGE

| Mix Design | Application | Total Volume ($m^3$) | % of Total Mix Volume | Baseline GWP (kg $CO_2/m^3$ | Updated Baseline GWP (kg $CO_2/m^3$) (30% increase) | CO2e Baseline (tonnes $CO_2$) | Ontario Industry-Average EPD GWP (kg $CO_2/m^3$) | Standard Baseline versus Ontario Industry-Average EPD GWP | CO2e Project (tonnes $CO_2$) | Final Mix % GHG Reduction w/ Updated Baseline (30% increase) |
|---|---|---|---|---|---|---|---|---|---|---|
| 30MPa Class F-1 | Standard | 1,090.6 | 31% | 292.72 | N/A | 319.2 | 292.72 | 0.0% | 319.24 | 0.0% |
| 30MPa Class F-1 | Special | 809.8 | 23% | 292.72 | 380.53 | 308.2 | 292.72 | 0.0% | 237.04 | 23.1% |
| 30MPa Class F-1 (75% @ 24H) | Special | 69.6 | 2% | 292.72 | 380.53 | 26.5 | 379.45 | 29.6% | 26.41 | 0.3% |
| 30MPa Class F-1 (75% @ 48H) | Special | 1,585.4 | 45% | 292.72 | 380.53 | 603.3 | 361.65 | 23.5% | 573.36 | 5.0% |
| **Total:** | | **3,555.4** | | | | | | | | |

In summary, had the standard baseline GWP value been specified exclusively for this application for all 3,555.4 $m^3$ , 47% of the volume that was placed would have exceeded the **292.72 kg $CO_2$ /$m^3$** value and the carbon impact would have significantly been increased. The crucial schedule and cold weather accommodating 24-hour and 48-hour accelerated mix designs reflect a **29.6%** and **23.5%** increase over the standard baseline respectively.

In addition, enforcing the baseline GWP would have resulted in the project schedule being severely impacted. Typically, standard mixes achieve an industry guideline of 75% at 7 days, depending on SCM contents, and the Met mixes required 24-hour and 48-hour strength enhancements. This ultimately helped the contractor to meet their schedule deadlines.

Special application baselines did still offer a reduction of **0.3%** (24-hour) and **5.0%** (48-hour) respectively for the accelerated mix designs, compared to the updated baseline of **380.53** kg $CO_2$/$m^3$ The set accelerated mix design allowed for a **23.1%** reduction , compared to the updated baseline, due to an optimized mix design and the special baseline.

Currently, when specified GWP values are exceeded, there is no process for determining the consequences of not hitting the performance criteria and no possible way to enforce these requirements. Giving the ready mixed producer the flexibility to manage and adjust their designs by employing a CCPB not only will produce a better performing concrete, but it will also lead to a more sustainable low carbon product. The case study clearly showed that even when application specific GWP baselines were exceeded on numerous instances, the CCPB still showed an overall reduction of 11.5% on the project. The special application GWP increase of 30% is also critical here to allow the contractor to accelerate the performance of mix designs and to keep the project on schedule.

It is therefore imperative that specifiers understand the consequences of specifying application specific GWP values in a real-world project setting.

## Specifier Resources

Concrete Ontario offers complimentary support and specification reviews regarding low carbon concrete. In-person or virtual presentations can be scheduled on-demand.

**Please contact members of the Concrete Ontario team for more information:**

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CONCRETE CARBON

# CONCRETE CARBON

A GUIDELINE FOR SPECIFYING LOW CARBON READY MIXED CONCRETE IN ONTARIO

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NOVEMBER 2022