Low Embodied Carbon Concrete Workshop Series: A Deep Dive on Specifications

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RMI
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State DOT Low Carbon Concrete Workshops

Objective: Shape DOT action to address embodied emissions of concrete

1. **Build collective understanding of key barriers to adoption of low carbon concrete and identify solutions**

2. **Address specification barriers to low carbon concrete**

3. **Build confidence in emerging blended cements, such as LC3**

State DOT Low Carbon Concrete Workshops

Workshop 1: Case studies from Buy Clean / EPD program implementation

JUNE 2023

Workshop 2: DOT Application of Limestone Calcined Clay Cement (LC3)

AUGUST 2023

Workshop 3: A Deep Dive on Specifications *(Potential for multiple sessions)*

TODAY

DOT Specifications for Low Carbon Concrete

1 hour session, hosted by RMI & partner organizations

Objective

- **Align on pain points and next steps for US DOTs to adjust specifications to unlock lower carbon concrete mix design**

Meeting Outline

- **Introduction**
- **Technical presenter –** R. Douglas Hooton, University of Toronto, Performance-based specifications
- **Facilitated discussion** with 3 DOT staff on specifications for low carbon concrete
- **Live polling** to identify focus areas and align on next steps

US State DoT Concrete Spec Overview

How are they similar?

How are they different?

Satyam Maharaj
RMI

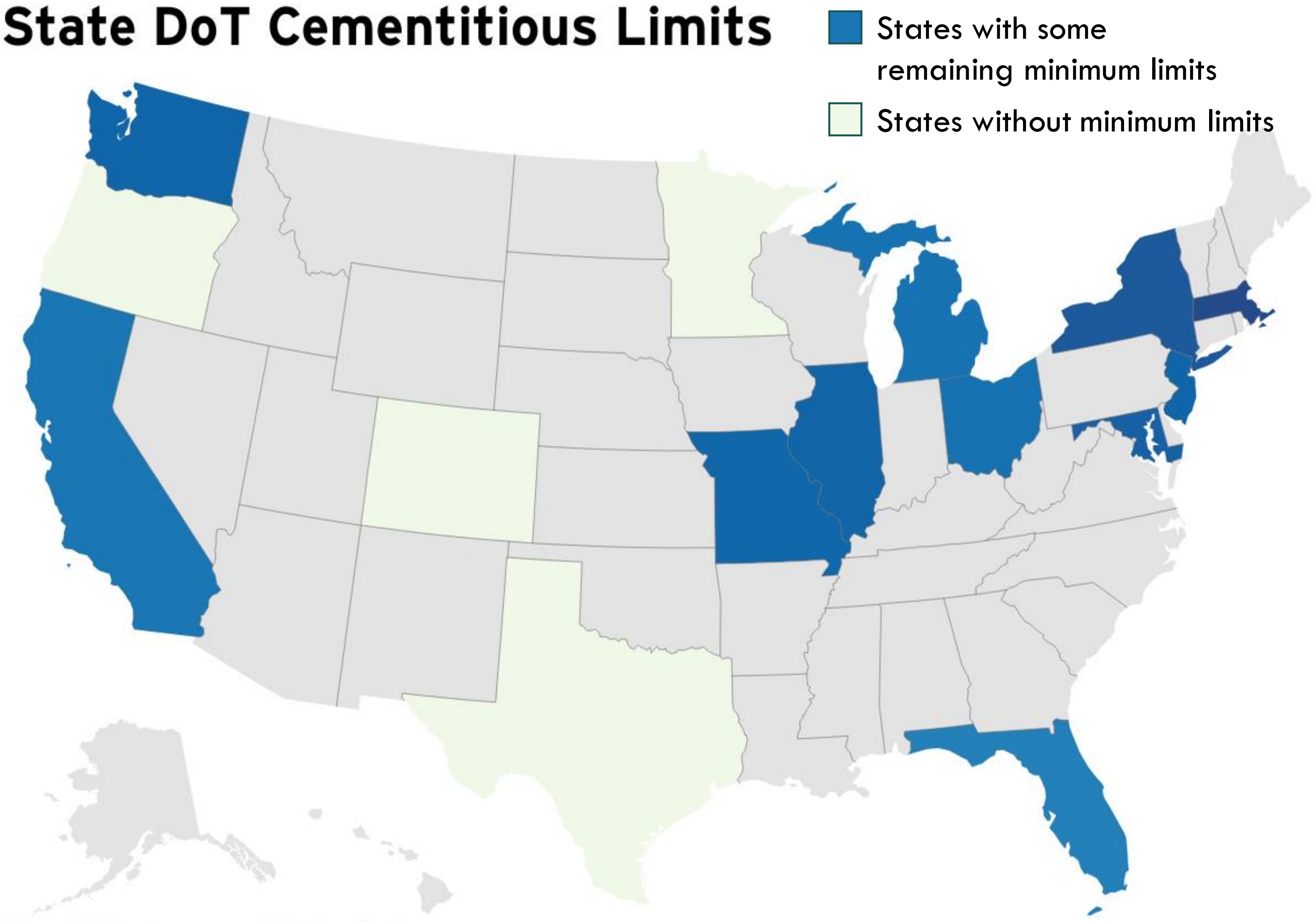
State DOT Specification Review

RMI reviewed concrete specifications in 15 states, with a focus on concrete pavement applications

We are looking for key takeaways on how these can be updated to enable low carbon concrete mixes

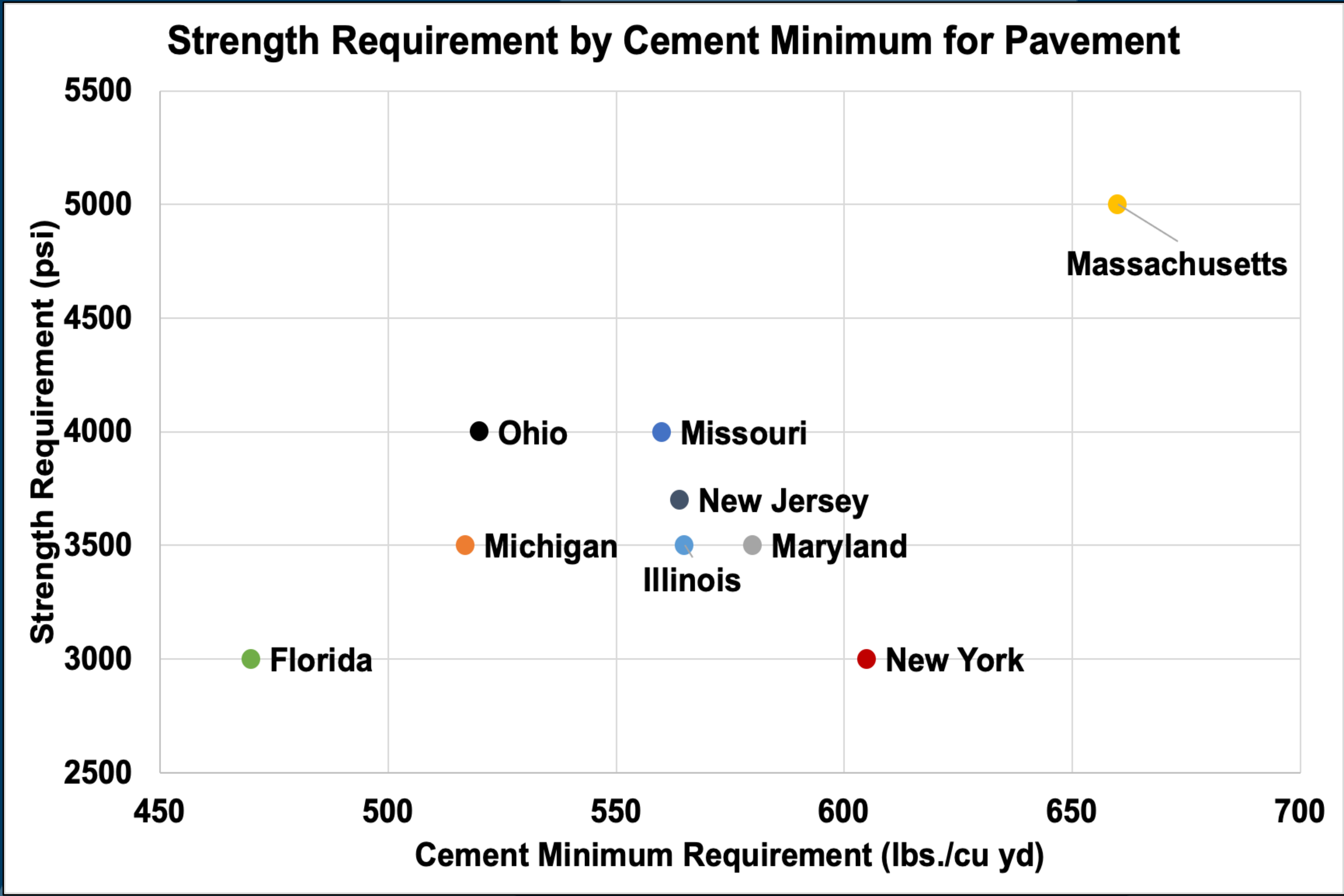
Most states continue to have prescriptive minimum cement limit specs

State DoT Cementitious Limits



Map: RMI • **Source:** RMI Analysis

Strength and Cement Requirements vary by State



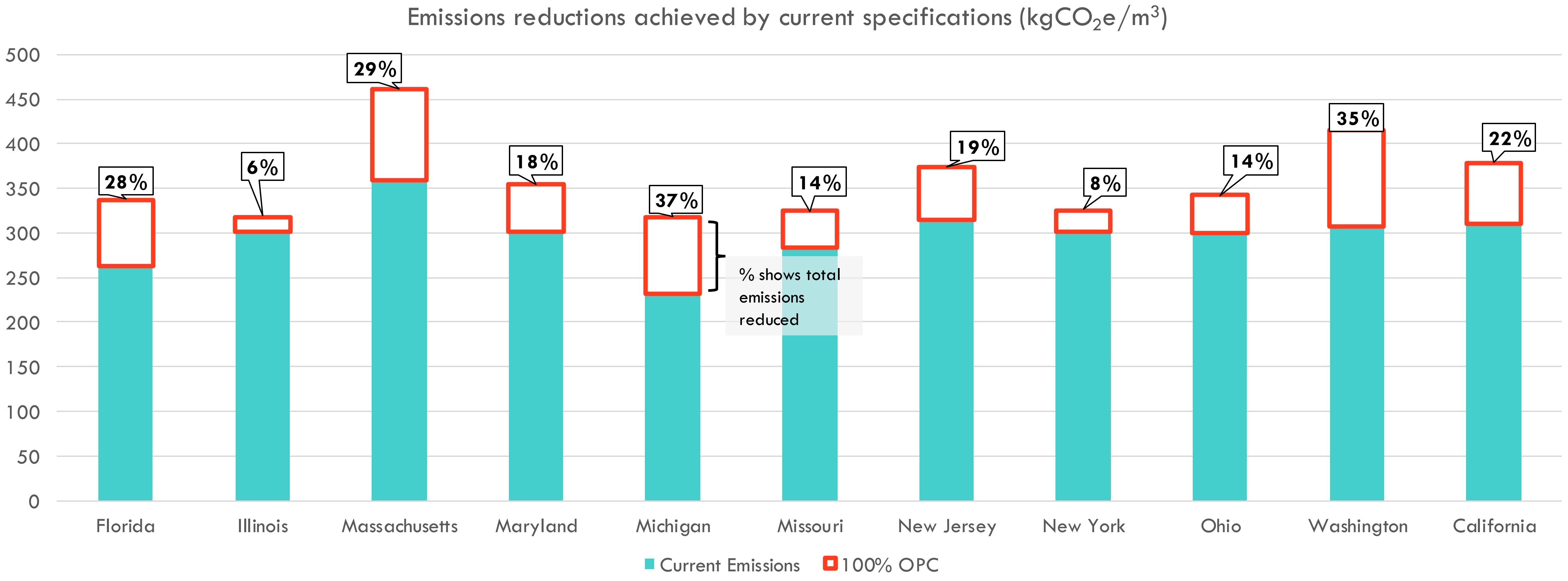
Analysis Overview

Gather State DoT specific specifications on minimum cement and strength requirements, and maximum allowable Fly Ash content

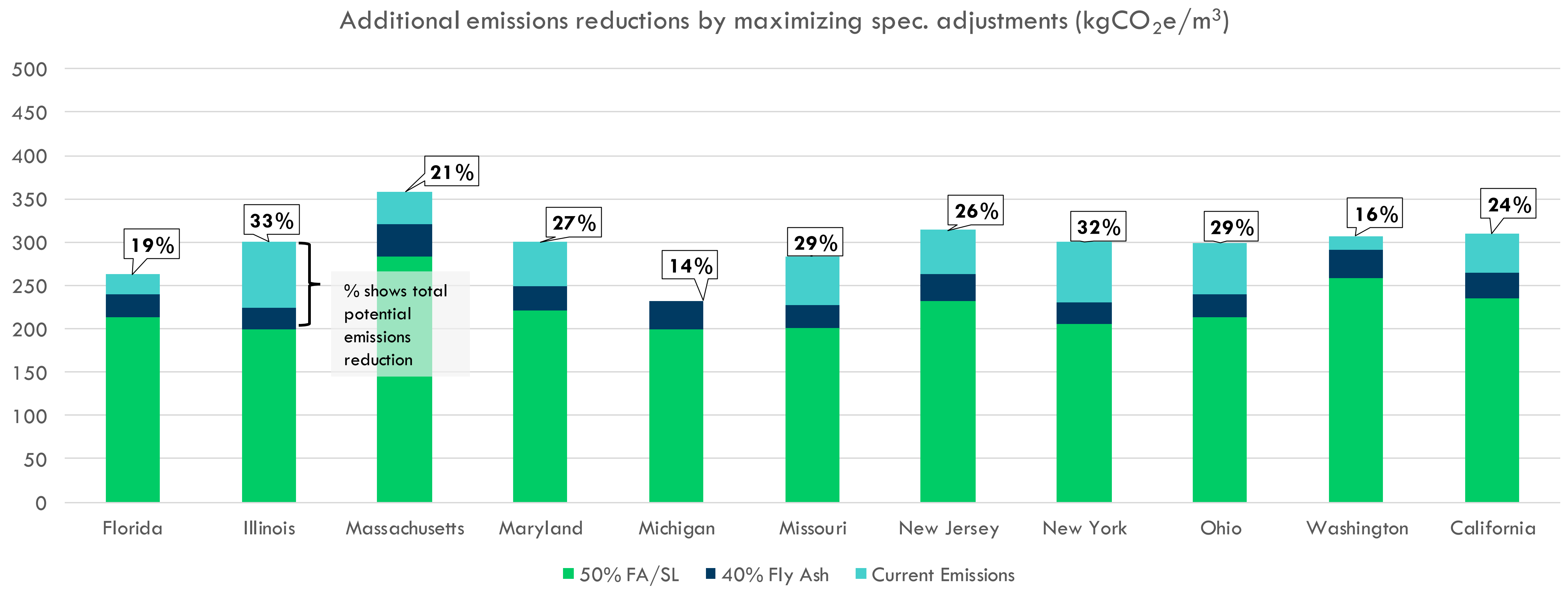
Use ACI design guidelines to develop typical mix design for 1m^3 of OPC concrete per state

Develop a GHG Emissions calculation based on NRMCA Emissions benchmark data

Current state DOT specifications have reduced pavement emissions by up to 37%



By specifying a 50% fly ash/slag blend, DoTs can reduce pavement emissions by up to 33%



Key Performance Specifications for Reducing Embodied Carbon

Carbon Intensity and Emissions Reduction

- Set limits on CO_2 emissions per unit of concrete produced
- Adjust minimum cement requirements to allow for utilization of maximum SCM limits

Optimize use of Supplementary Cementitious Materials (SCMs)

- Transition to using mixes with 40% Fly Ash content and 50% Fly Ash & Slag blend
- Prioritize use of emerging SCMs and blended cements such as LC3

Opportunities unlocked by performance-based specs

R. Douglas Hooton
University of Toronto

The Role of Performance Specifications in Enabling Low-Carbon Concrete

R. Douglas Hooton, Professor Emeritus, University of Toronto

Part I:
Laying out the vision for Performance Specifications & key current barriers

The Path Forward for Concrete

Less clinker in cement, less cement in concrete, less concrete in construction

- Replace clinker content in cement
  - Use blended cement (ASTM C595) or replace clinker with supplementary cementitious materials (SCMs) at concrete plant
- Use less cementitious materials
  - Optimized aggregate grading
  - Lower cementitious content
- Optimize designs & new mixtures

Use alternative SCMs and/or alternative cementitious materials

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But how do we specify these without being prescriptive and preventing adoption of new technologies?

Comparison – Concrete-Making Materials

Prescriptive Specification

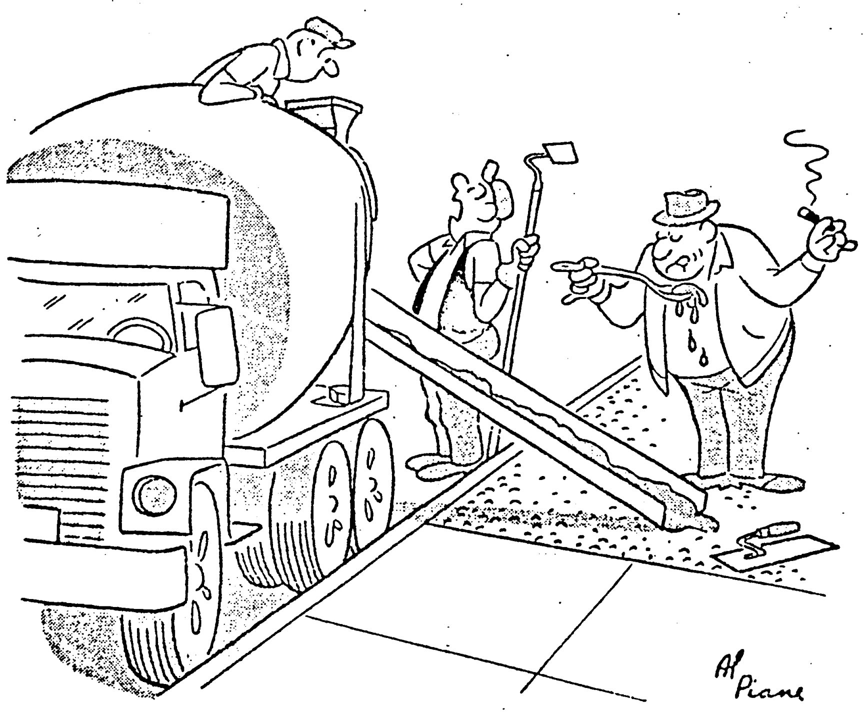
- *Generally* - Places the material into a defined category, based on chemical or physical properties
- Implies specific properties to the purchaser (*example: ASTM C618 Class F ash is low calcium, → mitigates ASR*)
- Sets specification limits that are rigid and can misrepresent a material.
- Implies all materials in the same category perform the same

Performance Specification

- Measures, reports, and in some cases limits properties but relates the material properties to performance outcomes
- Materials are categorized based on expected performance (example ASTM C1157 Type HS high sulfate resistance, MS moderate sulfate resistance)
- Lack of chemical & compositional limits allows multiple materials to be specified that meet the same performance

Barriers to Performance Specifications

- We need to learn how to use performance-based tests
  - ASTM C1157 – was adopted in 1992!
    - Only a small number of states have adopted; it is included in ACI Code 318 but rarely invoked
    - As a result, few producers
  - ***Users say they want performance, but for some reason still want to know what is in the cement***
  - Owners QA/QC is based on historic, legacy prescriptive approaches
  - New tests present additional challenges by measuring properties engineers and architects may not comprehend (example: calorimetry)



"He says it needs more sand!"

Moving to Performance Specifications

- Performance based specifications require performance-based tests
  - Currently rely mainly on prescriptive tests, some are nearly 100 years old
- Tests need to be practical, fast (relatively)
- Adoption is slow
  - Need correlation with field performance (takes time)
- Precision vs. Accuracy (reproducibility is most important)

Moving to Performance Specifications

- Performance-based specifications must rely more on reproducibility – demonstrating consistency is at the heart of performance-based specifications
    - The users can learn to live with not knowing what the material is if it can be demonstrated to perform consistently and if the performance can be substantiated by testing.
- Sampling and uniformity testing becomes more important

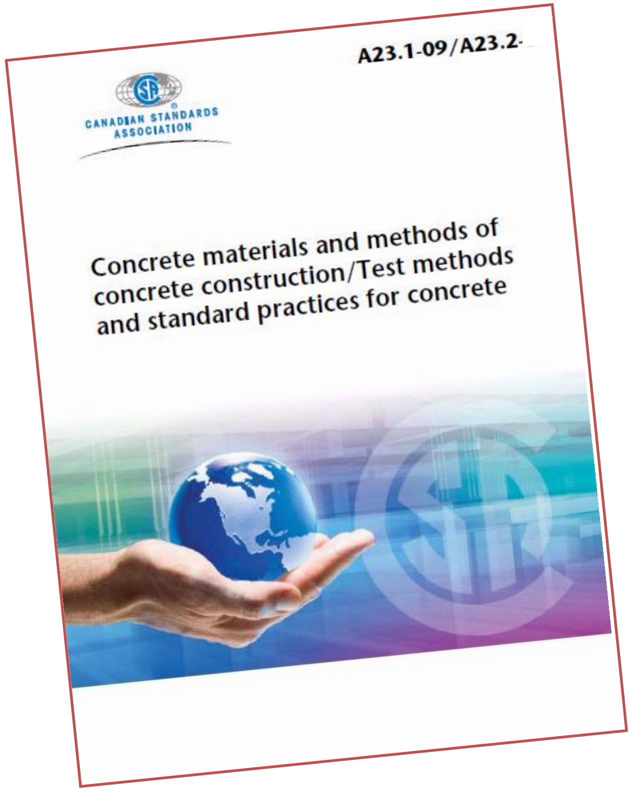
Part 2: Canadian Adoption of Performance Standards

R. Douglas Hooton

Professor Emeritus

University of Toronto

and Chair of CSA A23.1/A23.2



CSA A23.1

- Since 2009, the Canadian Standards Association (CSA) A23.1 Concrete Standard has required concrete to be specified either completely by prescription or by performance.
- Prior to that, there was also a hybrid "Common" method that was a mix of both prescription and performance—but this confused responsibilities.
- As a result, since CSA A23.1-09 was adopted in the National Building Code, almost all specifications in Canada have become performance-based, because prescription implies that owners/specifiers take on the responsibilities for performance of concrete that they have prescribed.
- In the later 2014, 2019 and new 2024 editions, changes have been made to improve details and to add new performance test methods & limits

Initially there was pushback from Designers & Specifiers

- Designers/specifiers were used to adding prescriptive limits on concrete materials and mix proportions in addition to performance.
- But this change to CSA A23.1 basically stated that if an owner/designer added prescriptive requirements, then it was deemed to be a prescriptive spec. and they would become responsible for performance.
- Then the lightbulb came on.
- They did not want to take on that responsibility, so the performance option became the norm.

What is a performance specification?

Canadian Standards Association (CSA): CSA A23.1

Performance requirements apply *"when the owner requires the concrete supplier to assume responsibility for the performance of the concrete as delivered and the contractor to assume responsibility for the concrete in place.*

*A performance concrete specification is a method of specifying a construction product in which **a final outcome is given in mandatory language,** in a manner that the performance requirements can be **measured by accepted industry standards and methods.***

***The processes, materials, or activities used by the contractors, manufacturers, and materials suppliers are then left to their discretion**".*

Key to Success with Performance Specifications

- **To achieve performance, the responsibilities of all parties need to be clearly defined in the contract documents (CSA A23.1 clearly defines these for the owner, contractor concrete supplier and testing company).**
- A performance-based specification also needs to provide a system for the owner/specifier, contractor and supplier/producer to assess and maintain quality of concrete.
- Good communication is needed to address any problems and deficiencies quickly in order to achieve the desired concrete performance.

CSA A23.1-14 Table 5 Defines Responsibilities

Performance Option

Prescriptive Option

Table 5
Alternative methods for specifying concrete
(See Clauses 4.1.2.1, 4.1.2.3, 4.4.1.2, 4.4.1.3, and 8.1.5 and Annex J.)

Alternative	The owner shall specify	The contractor shall	The supplier shall
(1) Performance: When the owner requires the concrete supplier to assume responsibility for performance of the concrete as delivered and the contractor to assume responsibility for the concrete in place.	(a) required structural criteria, including strength at age; (b) required durability criteria, including class of exposure; (c) additional criteria for durability, volume stability, architectural requirements, sustainability, and any additional owner performance, pre-qualification or verification criteria; (d) quality management requirements (see Annex J); (e) whether the concrete supplier shall meet certification requirements of concrete industry certification programs; and (f) any other properties that might be required to meet the owner's performance criteria.	(a) work with the supplier to establish the concrete mix properties to meet performance criteria for plastic and hardened concrete, considering the contractor's criteria for construction and placement and the owner's performance criteria; (b) submit documentation demonstrating the owner's pre-qualification performance requirements have been met; and (c) prepare and implement a quality control plan to ensure that the owner's performance criteria will be met and submit documentation demonstrating the owner's performance requirements have been met.	(a) certify that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard; (b) certify that the mix design satisfies the requirements of this Standard; (c) certify that production and delivery of concrete will meet the requirements of this Standard; (d) certify that the concrete complies with the performance criteria specified; (e) prepare and implement a quality control plan to ensure that the owner's and contractor's performance requirements will be met, if required; (f) provide documentation verifying that the concrete supplier meets industry certification requirements, if specified; and (g) submit documentation to the satisfaction of the owner, demonstrating that the proposed mix design will achieve the required strength, durability, and performance requirements.
(2) Prescription: When the owner assumes responsibility for the concrete.	(a) mix proportions, including the quantities of any or all materials (i.e., admixtures, aggregates, cementing materials, and water) by mass per m^3 of concrete; (b) the range of air content; (c) the slump range; (d) use of a concrete quality plan, if required; and (e) other requirements.	(a) plan the construction methods based on the owner's mix proportions and parameters; (b) obtain approval from the owner for any deviation from the specified mix design or parameters; and (c) identify to the owner any anticipated problems or deficiencies with the mix parameters related to construction.	(a) provide verification that the plant, equipment, and all materials to be used in the concrete comply with the requirements of this Standard; (b) demonstrate that the concrete complies with the prescriptive criteria as supplied by the owner; and (c) identify to the contractor any anticipated problems or deficiencies with the mix parameters related to construction.

CSA A23.1 Performance Option

- For durability, like ACI 318, CSA uses a table of exposure classifications to set the level of performance needed: Each exposure includes minimum requirements for concrete materials, performance properties and curing.
- The responsibilities of the owner, the supplier and the contractor are clearly defined in Table 5 with additional details provided in Annex J.
- Requirements for Qualifying concretes (for submittals) and for Acceptance Testing are now detailed in two Recommended Practices
  - A23.2-24C Qualification Testing
  - A23.2-25C Acceptance Testing

Performance Tests for Concrete

- Typically concrete is qualified and accepted based on fresh properties such as slump/ slump flow & air, and in many cases, 28-day strength is the only hardened property specified and measured.
- **But 28-day strength alone is not an adequate performance metric:**
  - Construction schedules are controlled by early-age strength development.
  - Concretes with high-SCM levels develop their ultimate properties at later ages (e.g. 56 or 91 days) Also, early strength of SCM-mixtures is underestimated by small mortar or concrete cube/cylinder tests stored at lab temperatures
  - CSA A23.1 sets strength limits for severe exposures at 56d and permeability index limits at 91 days
- Limits based on test methods that are indicators of other properties, including durability, also need to be specified.

Performance Tests for Durability

1. For all durability exposures:
   - A test that can measure or provide an index of the resistance to ingress of aggressive fluids (e.g. RCPT or Bulk Resistivity).
   – ASR tests to qualify the aggregates, or to determine required mitigation, if aggregates are potentially reactive

2. For specific exposures (as applicable):
   – Sulfate Resistance test for chemical resistance of cementitious materials.
   – Freeze/Thaw test
   – De-icer salt scaling test.

Summary

- Performance Specifications can result in better concrete construction and durability provided that all parties are on-board.
- **Performance specifications allow for innovation in the supply of concrete by providing flexibility in materials supply and concrete proportions.**
- This can be used to allow use of more environmentally friendly concrete materials and mix proportions.
- However, performance means more than acceptance of concrete at the end of the truck chute.
- To an owner it means in-place performance of the structure, so the concrete producer and contractor have to work as a team to meet the Owner's specifications.
- The risks & responsibilities are different than in Prescriptive specifications, so there is a learning curve.

Performance Engineered Mixtures (PEM)

Standard Practice for

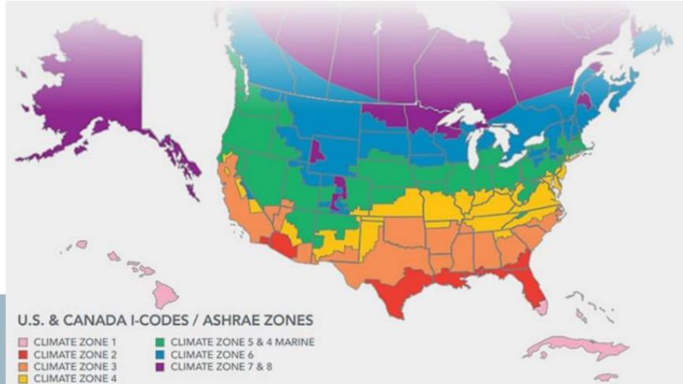
Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: R 101-22

- Provides Information on PEM initiative + Focus on key parameters & testing

DEFINING THE THINGS THAT MATTER

- Transport properties (everywhere)
- Aggregate stability (everywhere)
- Strength (everywhere)
- Cold weather resistance (cold locations)
  - De-icer resistance
- Shrinkage (dry locations)
- Workability (everywhere)



To meet the 2030 goals for Reduction in GWP, start with the Low-hanging Fruit:

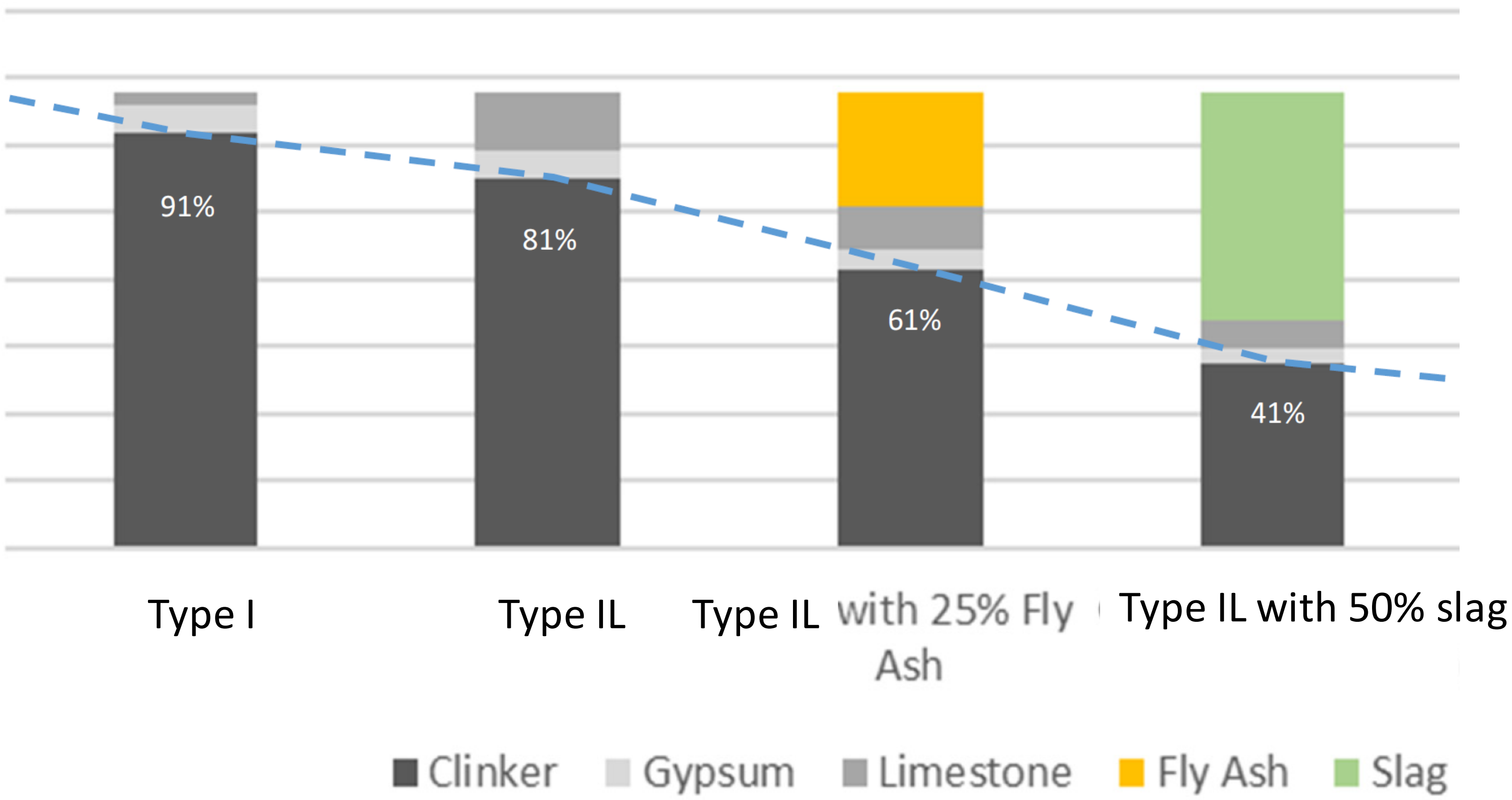
Use currently available levers to reduce Concrete's CO_2 emissions

Adopt Materials, Mixtures, and Methods meeting current standards and codes without compromising performance or durability:

1. **Use Portland-Limestone Cements (up to 15% interground limestone)**: →**10% CO_2** reduction over Portland cement while meeting the same performance targets.
2. **Increase levels of SCMs**: ---**CO_2 reduction is proportional to % replacement of cement (25-75%)**---- results in better durability in resisting chloride ingress, sulfate attack, ASR, and thermal cracking, but can impact set and early-strengths needed for some applications.
3. **Optimize total aggregate gradations and use of admixtures**: --- can **reduce cement paste fraction (and CO_2) by 5-15%,** while reducing both concrete shrinkage and permeability.

In North America, all of these levers are allowed by the ACI 318 building code, and by ASTM/AASHTO & CSA specifications, and all can be done simultaneously to obtain a cumulative reduction in GWP.

% Clinker in binders with PLC and SCMs



Cement Association of Canada 2021

Current Specs allow these materials and mixtures

- **ASTM C595-*Blended Cements* allows:**
  - Portland-limestone cements (Type IL) with up to 15% interground limestone that can be used together with SCMs. (Type IT)
  - Blended cements and separately added Supplementary Cementitious Materials (SCMs), including ground glass, natural pozzolans, harvested fly ash and ternary blends.
  - ASTM C94 allows Optimized Total Aggregate Gradations

Industry Status:

- Portland-limestone cement is now over 50% of the cement sold across USA and the majority of that produced in Canada
- Almost all concrete contains SCMs—although replacement levels are sometimes limited by prescriptive agency specs (and less SCM is typically used in winter construction)
- The paving industry makes used of optimized aggregate gradations, but there are supply chain issues and some government agency specs can make it difficult.

What can be done now to specify lower-carbon concrete?

- **Do not specify** prescriptive minimum cement content limits.
- **Do not** restrict the use of certain SCM types or replacement levels.

- Instead, **specify the performance requirements** needed for the application.
- E.g.
  - Is it setting time?
  - Is it early-age strength?
  - Is it de-icer scaling resistance?

Thanks for Listening

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Panel Discussion

David Dobson
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Ryan Rathbun
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Jacquelyn Wong
Caltrans

Joseph Harline
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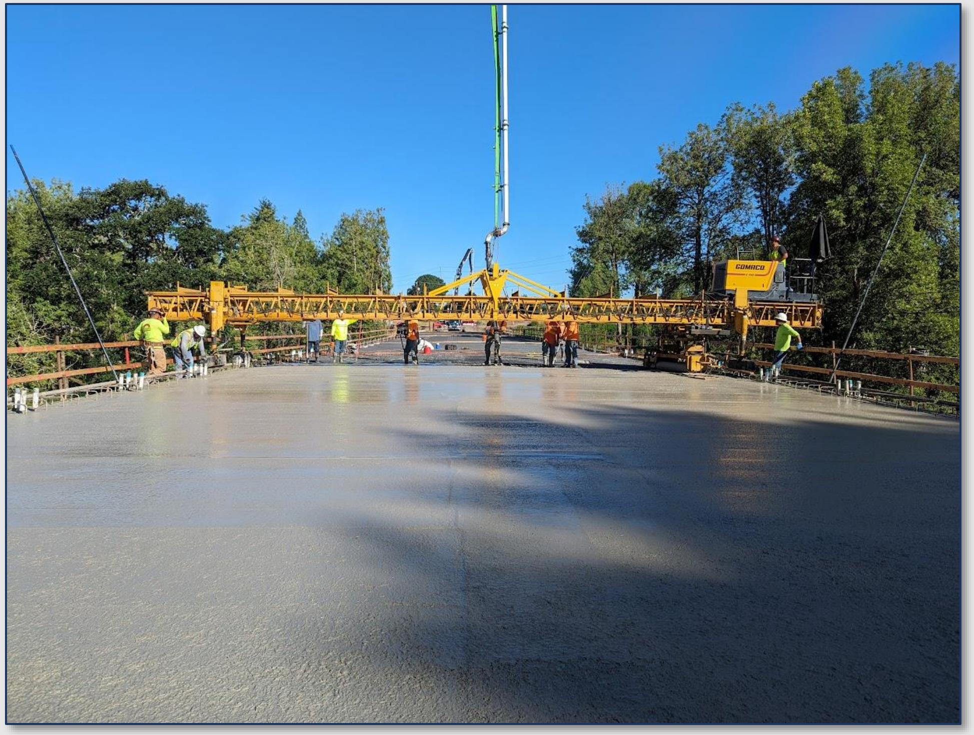
Current Low Carbon Related Efforts

- Oregon HB 4139 – EPD collection
- Encourage use of SCM's
  - Up to ACI limits
- Added natural pozzolans as a QPL material
- Increase concrete durability
  - High Performance Concrete (HPC), lower shrinkage and permeability
  - Internal Cure (IC)

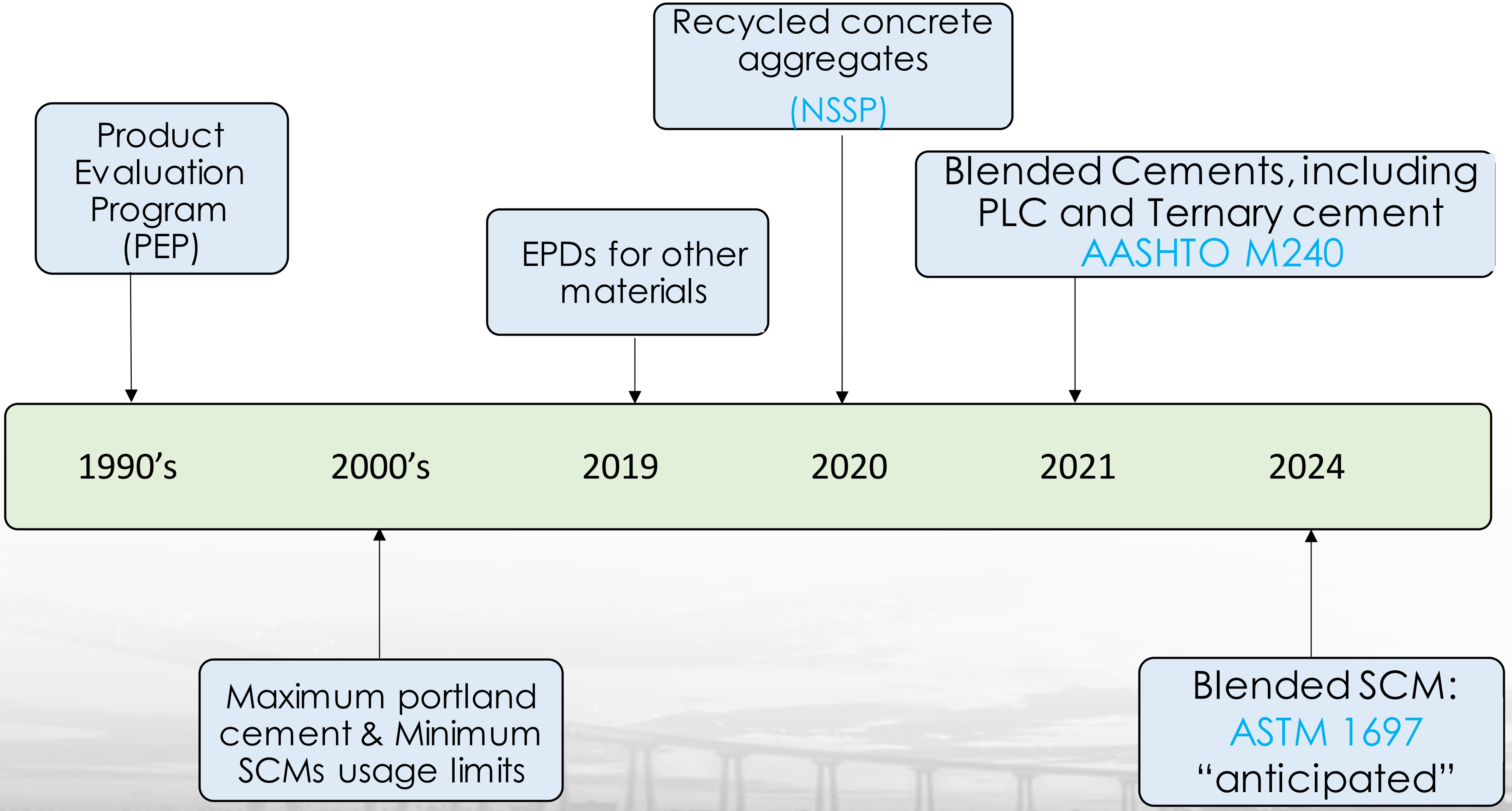


Oregon Department of Transportation

Recent NJDOT Efforts – Type IL Cement

- Beginning in 2018 NJDOT was approached by the Cement Industry regarding use of Type IL blended cement on Department Projects.
- A combination of factors including the adoption of Type IL in the C595 standard, the proven track record of Type IL in Europe and other areas, and the ability to substitute Type IL for Type I/II at a 1:1 ratio in concrete mixes made consideration of Type IL simple.
- Contractors and DOTs appeared to be satisfied with the product as it produces the same set times, similar early and late strengths, and the same amount of fly ash can be maintained without affecting admixtures.
- The combination of the above with added environmental benefits reducing carbon footprints by nearly 10% made Type IL seem promising.
- NJDOT revised the Standard Specifications to permit the use of PLC in 2021.
- Major cement producers began providing the NJ market with Type IL cement in 2021. The adoption has not been instantaneous, but we are seeing more and more of its use on Department projects three years in .

Active Sustainability Strategies



Ongoing Efforts Related to Lower Carbon Concrete Specification

Pavement and Materials Partnering Committee

- Sustainability and Performance-based concrete specifications
- Performance-based ASR
- EPD-for Concrete and Asphalt

Other Efforts

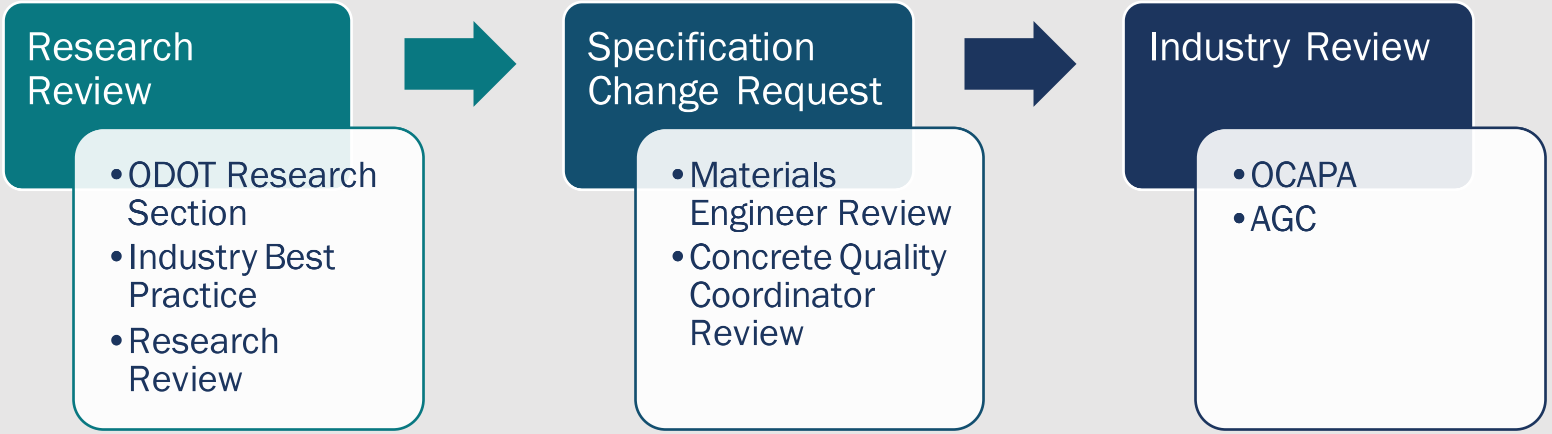
- "Green" CMU (based on EPDs)

Ongoing Academic Research

- In-Place Recycling for pavements
- Cold recycling for concrete pavement bases
- Multi-criteria decision-making
- Use of Alternative SCMs
- Recycled fibers

Specification Update Process

- Qualified Products List (QPL) for materials (cement, pozzolans/SCM's, admix, etc)
- Coordination with OCAPA (Oregon Concrete & Aggregate Producers Association)



Oregon Department of Transportation

Concrete Specification Overview – Section 02001

w/cm Ratio

Concrete Strength and Water/Cementitious Material (w/cm) Ratio		
Type of Concrete	**Strength f'_c (psi)**	**Maximum w/cm Ratio**
Structural	3300	0.50
	3300 (Seal)	0.45
	4000	0.48
	4000 (Drilled Shaft)	
	HPC4500	0.40
	HPC (IC) 4500	
	5000 +	
Paving	4000	0.44
PPCM's (with cast-in-place decks and no entrained air)	5000	0.48
	5500	0.44
	6000 +	0.42

No minimum cementitious content

High Performance Concrete

SCM Limits

Separate SCM	**Maximum**
Fly Ash + Other Pozzolans	30%
GGBFS	50%
Silica Fume	5%

Combined SCM	**Maximum**
Fly Ash + Other Pozzolans + GGBFS + Silica Fume	50%*
Fly Ash + Other Pozzolans + Silica Fume	30%*

Durability

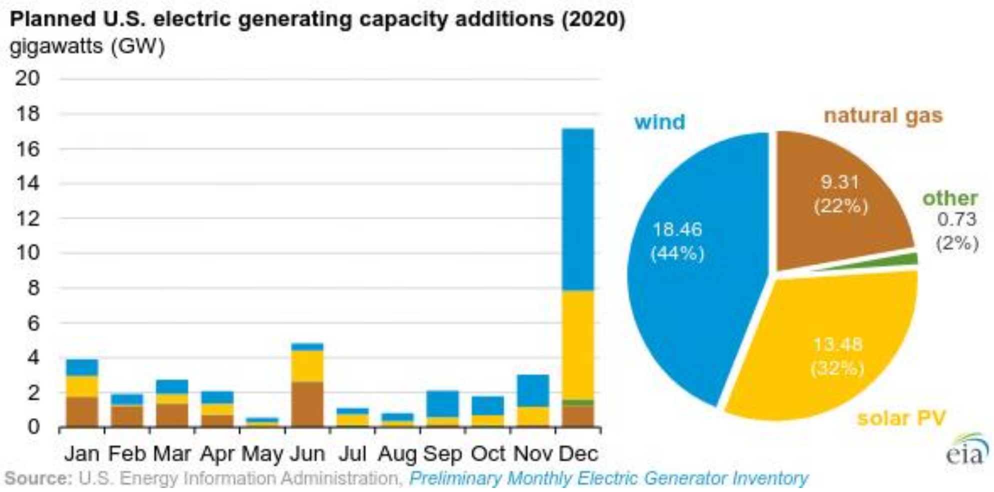
(e) **Durability** - For HPC designs, except designs for precast bridge rail elements, the following additional requirements apply:

Test	Test Method	Acceptance Value
Length Change	AASHTO T 160	-0.045%
Permeability	AASHTO T 277	1,000 Coulombs (max.) at 90 Days [1]

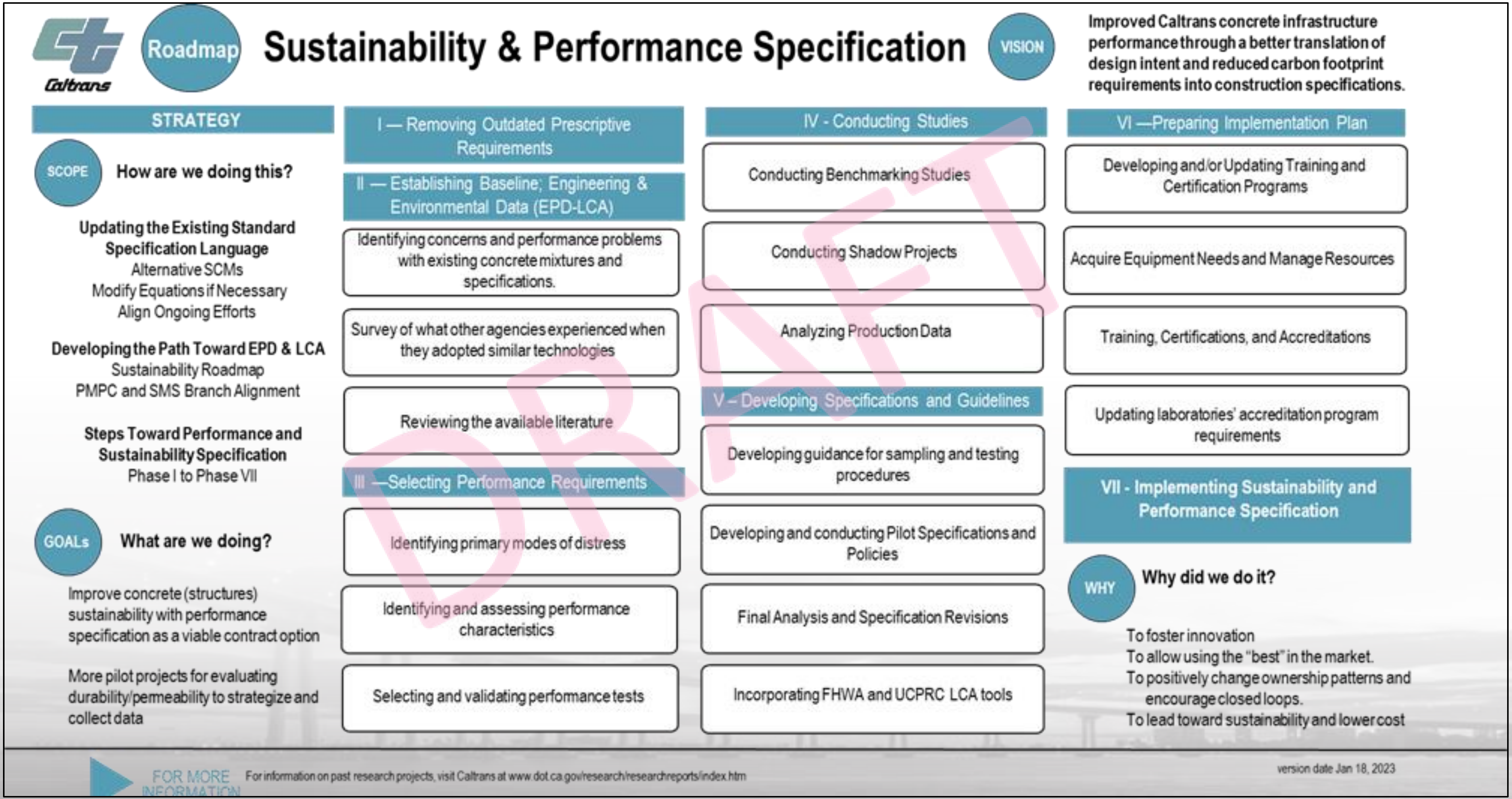
Oregon Department of Transportation

Recent NJDOT Efforts – Fly Ash Shortage

- Fly ash is a commonly used supplementary cementitious material (SCM) that is used to enhance concrete mixes. SCMs work to increase the pozzolanic or hydraulic activity of the mix, increase the strength of the mix, reduces the permeability, reduces the water requirement and the overall cost.
- Fly ash production has steadily decreased over the past 10 years primarily due to the closure of coal plants and the rise in natural gas. This shortage is further exacerbated at the regional level depending on the actual proximity to coal plants in operation.
- Trying to close the gap with alternatives:
    - Researching specification changes – One promising option is a reduction in the Loss on Ignition requirement (currently 3.0%)
    - Allow approval of sources of reclaimed ash stockpiles (fields, pits, and landfills). The material requires some processing before it meets specification.
    - Allow approval of foreign sources of fly ash that is coming from regions where coal power is still dominant.
    - Considering alternative sources of SCMS – meta-kaolin, recycled glass, recycled plastic (?).



Sustainability and Performance-Based Specifications



Toward Sustainability; EPD|LCA

	Tentative Steps and Schedule for EPD and LCA Implementation							
	EPD and LCA likely steps	2024	2025	2026	2027	2028	2029	2030
1	EPD collections for concrete and asphalt							
2	Develop methodology for concrete and asphalt GWP limits establishment							
3	eLCAP with non-proprietary data may become available (UCPRC)							
4	LCA with EPD data for shadow projects							
5	Guidance for interactive use of LCA and pavement design programs (CalME, concrete design programs) that consider materials/mix selection (developed through PMPC and research)							
6	LCA using EPDs to provide better average materials impacts for design may become available that quantify full impact of sustainability strategies to be used for shadow projects (Pavement Program)							
7	Likely ready for implementation of LCA with corresponding guidance for durability considerations for new materials and strategies							

Thank you!

For more information visit

rmi.org/buildings