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Evaluation of Sustainable Materials: NRRA and MnROAD Research

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National Concrete Consortium
Nashville, TN
Tuesday, April 5, 2022

NATIONAL CONCRETE CONSORTIUM

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Background: Climate Change

- Changes in global climate from human activities are occurring
  - Supported by historical observations and climate modeling
- Optimistic models predict substantial climate change over the next century
  - Rate of change depends on what we do
  - Long life of emitted heat-trapping, greenhouse gases and slow feedback functions of atmospheric systems drive climate change

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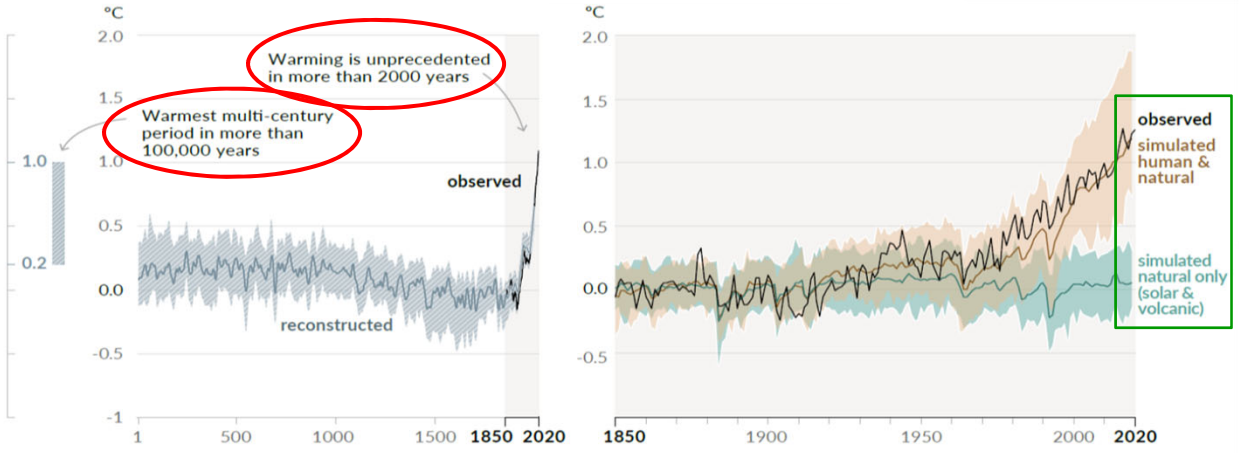
Changes in Global Surface Temperatures Relative to 1850-1900 (IPCC 2021)



IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis*

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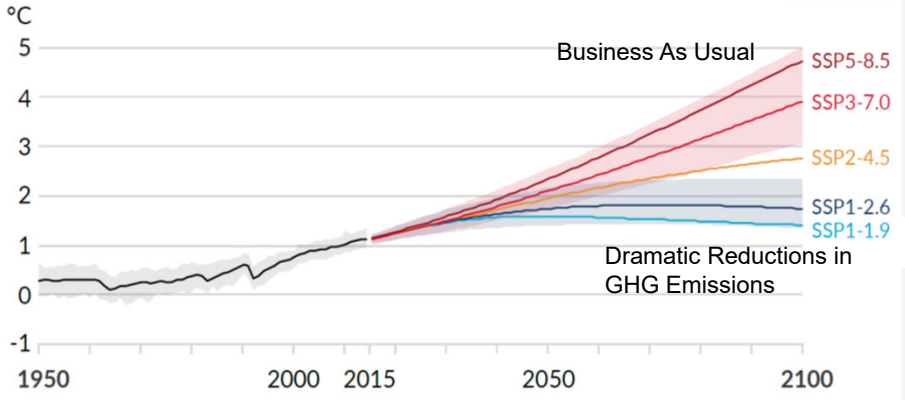
Global Surface Temperature Increases Compared to 1850-1900 Average



IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis*

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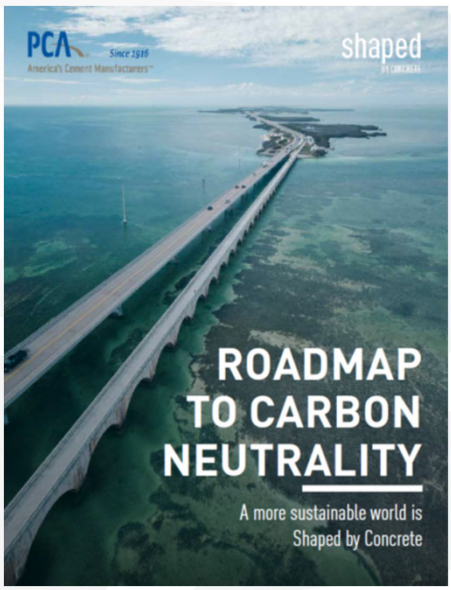
Challenges In Front of Us

- Change is difficult
  - Must ween ourselves from business as usual
- Traditional cement and concrete are carbon intensive
- Designs and materials are dictated by the past and "conservatism" in codes, specifications, and standards

DON'T BE SAD – INNOVATE!



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Hydraulic Cement and Concrete Mixtures

- Hydraulic cement concrete is humankind's most used material after water
  - Approximately 2.2 yd^3/person/year
  - Civilization is built on it – no exaggeration
  - 5% to 8% of global GHG emissions
- Massive economic, environmental, and social impacts
  - 90 million metric tons of cement manufactured in the U.S. in 2020 (4.1 billion MT worldwide)
  - In 2018, linked to 0.6% of US GHG emissions

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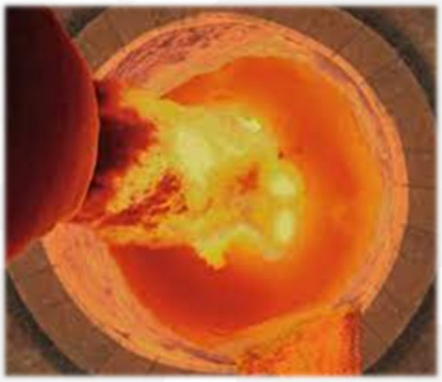
GHG Emissions Associated With Concrete at the Gate

- ~1.5% from acquiring and processing raw materials
- ~89% from cement manufacturing
  - ~37% from burning fuel
  - ~46% from calcination
- ~9.5% from making concrete



Net result: for every pound (kg, MT) of U.S. made ASTM C150 Type I cement, roughly 0.922 lbs (kg,MT) of GHG emissions are released

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Total GHG Emissions Embodied in Concrete

Cement

Gravel
Sand
Water

Typical concrete at the gate:
~0.26 tons CO_2 /yd^3 concrete
~0.23 tons CO_2 from portland cement

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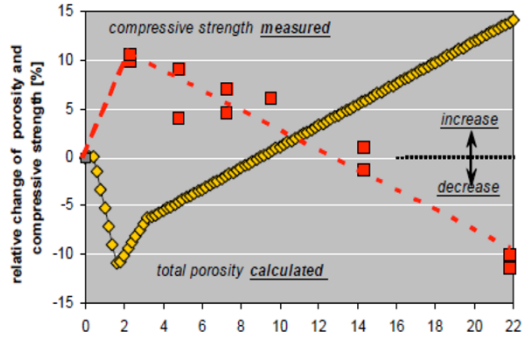
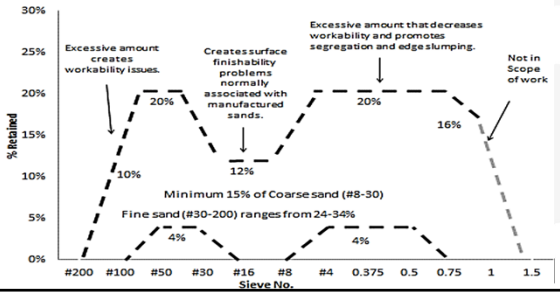
What Can Been Done?
Reduce Clinker in Concrete

- 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
- Use alternative SCMs and/or alternative cementitious materials





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Alternative SCMs

- Harvested coal ash
  - From landfills and ponds
  - Mix of fly ash and bottom ash
  - Requires processing
- Ground glass pozzolan (ASTM C1866)
- SCM produced by sequestering carbon dioxide
- ASTM is working on standards based on reactivity

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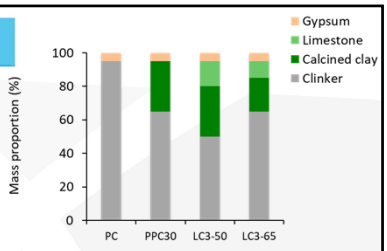
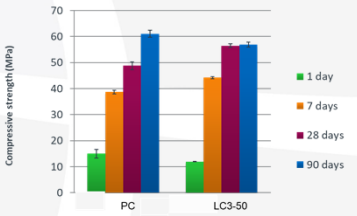
Alternative Cementitious Materials

- Non-traditional blended hydraulic cements
  - LC3 – portland cement, calcined clay, limestone
- Alkali-activated hydraulic cements
  - Alkali activator – liquid or powder
  - Precursor containing calcium and alumino-silica minerals
    - e.g., Class C fly ash, slag cement
- Geopolymers
  - Alkali-activated non-hydraulic reaction based on low calcium alumino-silica minerals
  - Dissolution and polymerization process



LC^3 is a family of cements, the figure refers to the **clinker** content



- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

K. Scrivener, 2020

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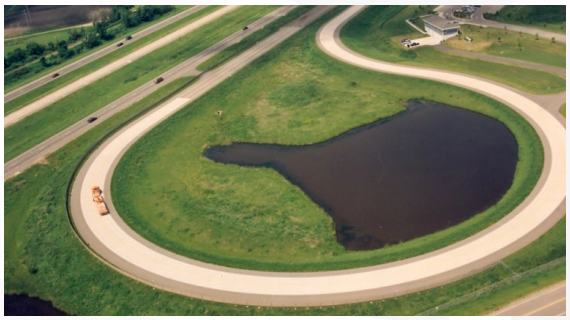
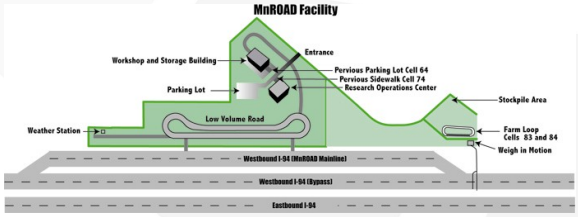
MnROAD

- 3.5 mile of I-94
- Partnership with NRRA
- 11 states
- 50 industries, associations, and academia





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NRRA Project Objectives

- Use of Carbon Dioxide for Sustainable and Resilient Concrete Pavements
- Use of Alternative Supplementary Cementitious Materials (SCMs) Towards Reducing Cement Content in Concrete Pavements
- Alternative Cementitious Materials (ACMs) – Geopolymer Concrete

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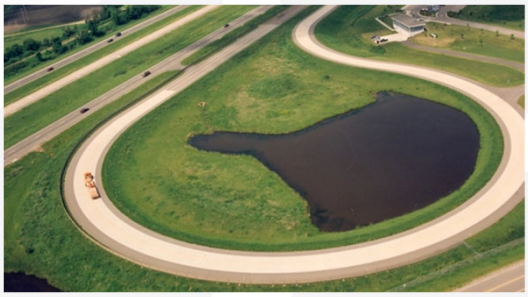
NRRA/MnROAD Reduced GHG Emissions Test Site

- A test site is under development at MnROAD to evaluate strategies to reduce GHG emission in concrete paving
- 16 test cells
  - 2 control cells
  - 1 optimized concrete
  - 6 alternative SCM cells
  - 5 alkali-activated cements
  - 3 carbon mineralization cells
- Construction scheduled for summer 2022



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Project Specific Mixtures

- General Requirements
  - Portland cement mixtures will use an ASTM C595 Type IL blended cement
  - Meet performance requirements based on AASHTO PP-84 Performance Engineered Concrete Pavement Mixtures
  - Batched and mixed at a central plant and paved using conventional paving equipment

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Project Specific Mixtures

- Control Mixtures – Standard MnDOT paving mixture
  - 570 pcy total cementitious with 30% Class F fly ash
  - Water-to-cementitious materials ratio of 0.40
- Two control mixtures needed to accommodate carbon mineralization study
  - One control mixture and the three carbon dioxide mineralization cells will use one set of constituent materials
  - Other control mixture and remaining cells will use another set of constituent materials

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Project Specific Mixtures

- Optimized Mixture – designed will conventional materials with reduced cementitious materials content
  - Work being done by Peter Taylor at ISU
- PLC Mixture (tentative plan)
  - Portland limestone cements are currently limited to 15% limestone
  - This cell will test the performance of cement using a higher replacement level (20-25%)
  - Will likely be blended with fly ash to create a ternary blend
  - The specific blend is yet to be determined

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Project Specific Mixtures

- Alternative SCMs
  - Numerous non-traditional SCMs (other than fly ash or slag cement) are available but most have limited performance history in pavements
  - These include natural pozzolans, ground glass pozzolan – ASTM C1866, harvested coal ash, and manufactured SCMs
  - These test cells with provide an opportunity to demonstrate performance
  - Several manufactured or processed SCMs also have the added benefit of sequestering CO_2 in their structure

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Project Specific Mixtures

- Alternative Cementitious Materials
  - These are cements that will serve as a complete replacement for portland cement in a concrete mixture – significant carbon reductions
    - LC3 cement composed of clinker, limestone, and calcined clay
    - ASTM C1157
    - Alkali-activated cements
    - Geopolymers

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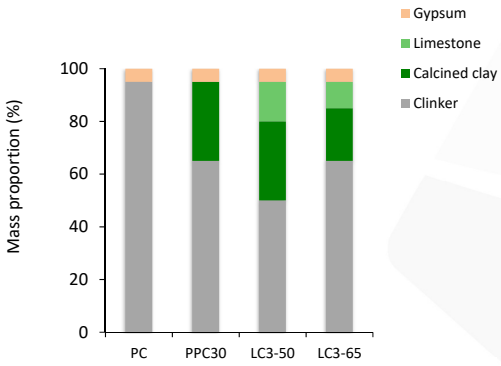
What is LC3?



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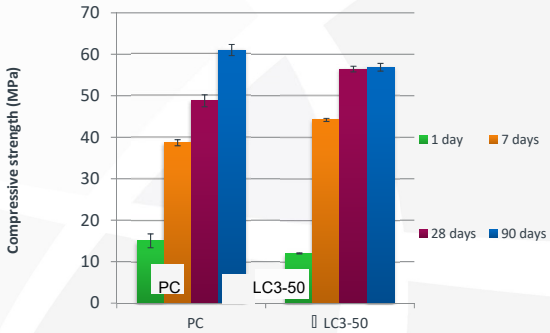

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K. Scrivener, 2020

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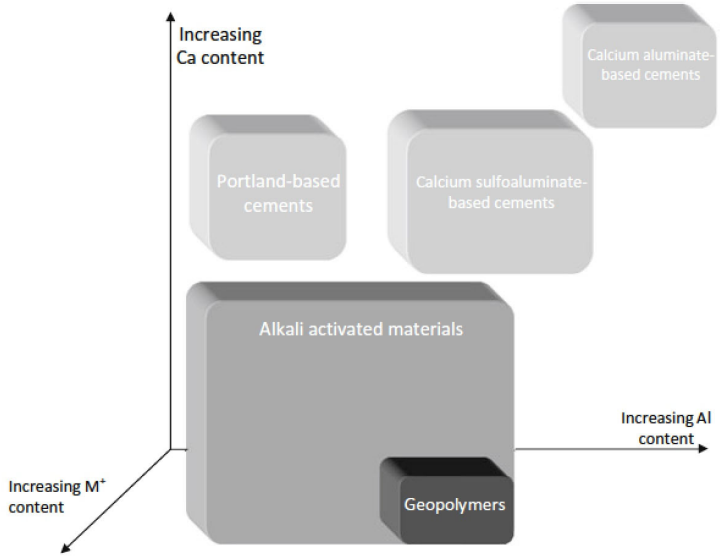

Fig. 1.2 Classification of AAMs, with comparisons to OPC and calcium sulfoaluminate binder chemistry. *Shading* indicates approximate alkali content; *darker shading* corresponds to higher concentrations of Na and/or K (Diagram courtesy of I. Beleña)

Provis, van Deventer, 2014

Project Specific Mixtures

- CarbonCure™ Mixture (tentative plan)
  - CarbonCure™ is a technology currently used in the ready-mix industry – not widely used for paving
  - The tentative plan is to test the following:
    - MnDOT paving mixture with CarbonCure™ added
    - CarbonCure™ designed/optimized mixture
    - CarbonCure™ designed/optimized mixture without the CO2 injection

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Current Status

- Construction is planned for Summer 2022
- Much needs to happen in the next 3-5 weeks
  - Finalize material selection
  - Finalize special provisions and construction requirements
  - Finalize testing plan
  - Get construction contractor under contract

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Current Status

- Material providers will have the next 4 months to gather their needed information
  - Develop mixture designs
  - Evaluate mixture performance
  - Provide environmental impact data (an EPD would be nice)
  - Logistics of getting material to MnROAD

Example: Specific Concrete EPD

Summary of Environmental Product Declaration

Central Concrete

Mix 340PG9Q1

San Jose Service Area

EF V2 Gen Use P4000 3" Line 50% SCM

Performance Metrics

28-day compressive strength	4,000 psi
Slump	4.0 in

Environmental Impacts

Impact name	Unit	Impact per m3	Impact per cyd
Total primary energy consumption	MJ	2,491	1,906
Concrete water use (batch)	m3	6.66E-2	5.10E-2
Concrete water use (wash)	m3	8.56E-3	6.55E-3
Global warming potential	kg CO2-eq	271	207
Ozone depletion	kg CFC-11-eq	5.40E-6	4.14E-6
Acidification	kg SO2-eq	2.26	1.73
Eutrophication	kg N-eq	1.31E-1	1.00E-1
Photochemical ozone creation	kg O3-eq	46.6	35.7

A sample EPD for a concrete mix design by Central Concrete Supply Co.

Credit: Central Concrete Supply

https://www.fhwa.dot.gov/pavement/sustainability/articles/environmental.cfm

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A Note on Environmental Impact

- Environmental Product Declarations (EPDs) likely do not exist for many materials
  - Would need to use ISO 21930 core PCR to develop EPD
- This will limit ability to assess environmental impact
  - Will gather data, draw boundaries, and do the best we can
- It is exciting that the FHWA is working on the LCA Commons to provide the necessary LCI data for EPD development

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Closing

- Important project to begin the transition to new materials in road construction
- Strong support from FHWA, DOTS, and industry
- After placement, performance will be monitored for three years under a separate contracts
  - Applied Pavement Technology
  - NCE
  - ISU

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Questions

- Contact
  - Tom Van Dam
    tvandam@ncenet.com
  - Larry Sutter
    sutter.engineering@gmail.com

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Assessing Sustainability

- Use unbiased, factually-based tools/resources to assess life cycle impacts
  - There is A LOT of greenwashing going on
- A life cycle assessment (LCA) meeting ISO standards is the best way to assess environmental impact
  - Request environmental product declarations (EPDs) based on approved product category rules (PCR)
  - Stay informed
  - Seek help as needed

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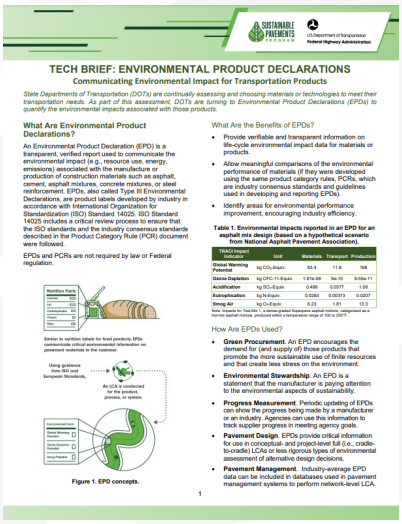
Environmental Product Declarations EPD?

- EPDs communicate potential environmental impacts of a product or process
- ISO has established processes that use life-cycle assessment (LCA) methods to develop Type III declarations = EPDs
- EPDs are preferred because they provide a high level of confidence as the information provided has followed a standardized and transparent scientific process



TECH BRIEF: ENVIRONMENTAL PRODUCT DECLARATIONS

Communicating Environmental Impact for Transportation Products

State Departments of Transportation (DOTs) are continually assessing and choosing materials or technologies to meet their transportation needs. As part of this assessment, DOTs are turning to Environmental Product Declarations (EPDs) to quantify the environmental impacts associated with those products.

What Are Environmental Product Declarations?

An Environmental Product Declaration (EPD) is a transparent, verified report used to communicate the environmental impact (e.g., resource use, energy, emissions) associated with the manufacture or production of construction materials such as asphalt, cement, asphalt mixtures, concrete mixtures, or steel reinforcement. EPDs, also called Type III Environmental Declarations, are product labels developed by industry in accordance with International Organization for Standardization (ISO) Standard 14025. ISO Standard 14025 includes a critical review process to ensure that the ISO standards and the industry consensus standards described in the Product Category Rule (PCR) document were followed.

EPDs and PCRs are not required by law or Federal regulation.

Figure 1. EPD concepts.

What Are the Benefits of EPDs?

- Provide verifiable and transparent information on life-cycle environmental impact data for materials or products.
- Allow meaningful comparisons of the environmental performance of materials (if they were developed using the same product category rules, PCRs, which are industry consensus standards and guidelines used in developing and reporting EPDs).
- Identify areas for environmental performance improvement, encouraging industry efficiency.

Table 1. Environmental impacts reported in an EPD for an asphalt mix design (based on a hypothetical scenario from National Asphalt Pavement Association).

TRACI Impact Indicator	Unit	Materials	Transport	Production
Global Warming Potential	kg CO_2-Equiv.	83.4	11.8	168
Ozone Depletion	kg CFC-11-Equiv.	1.81e-08	5e-10	9.58e-11
Acidification	kg SO_2-Equiv.	0.490	0.0577	1.99
Eutrophication	kg N-Equiv.	0.0265	0.00373	0.0207
Smog Air	kg O_3-Equiv.	8.23	1.81	15.3

Note: Impacts for Test Mix 1, a dense-graded Superpave asphalt mixture, categorized as a full-mix asphalt mixture, produced within a transportation range of 100 to 200 ft.

How Are EPDs Used?

- **Green Procurement**. An EPD encourages the demand for (and supply of) those products that promote the more sustainable use of finite resources and that create less stress on the environment.
- **Environmental Stewardship**. An EPD is a statement that the manufacturer is paying attention to the environmental aspects of sustainability.
- **Progress Measurement**. Periodic updating of EPDs can show the progress being made by a manufacturer or an industry. Agencies can use this information to track supplier progress in meeting agency goals.
- **Pavement Design**. EPDs provide critical information for use in conceptual- and project-level full (i.e., cradle-to-cradle) LCAs or less rigorous types of environmental assessment of alternative design decisions.
- **Pavement Management**. Industry-average EPD data can be included in databases used in pavement management systems to perform network-level LCA.

1

https://www.fhwa.dot.gov/pavement/sustainability/hif19087.pdf

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Development of EPDs

Adapted from N. Santero
by John Harvey

PCR: the framework

Product Category Rule (PCR)
"Set of specific rules, requirements, and guidelines for developing Type III environmental product declarations for one or more product categories" (ISO 14025)

LCA: the analysis

Life Cycle Assessment (LCA)
"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040)

EPD: the declaration

Environmental Product Declaration (EPD)
"Providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information" (ISO 14025) as defined in a PCR which is based on LCA