CHANGING WHAT'S POSSIBLE

# Extremely Durable Cementitious Materials

## When Endurance Matters

April 10-11, 2017

Joseph King

# Schoharie Creek Bridge Collapse

**Design: Plate Girder Bridge**
**Collapsed: April 5, 1987**

**Opened: October 1955**
**Cause: Bridge Scour at the Foundations**

# ASCE 2017 Infrastructure Report Card: D+

## *Surface transportation needs >50% of investment:**

*Includes the critical highways, bridges, commuter rail, and transit systems*

| | Surface Transportation | Water & Wastewater | Electricity | Airports | Waterways & Marine Ports | All Sectors |
|---|---|---|---|---|---|---|
| **Investment Needs – 2016 through 2025** | **$2,042** | $150 | $934 | $157 | $37 | **$3,320** |
| **Investment Needs – 2016 through 2040** | $7,646 | $204 | $2,458 | $376 | $112 | **$10,796** |

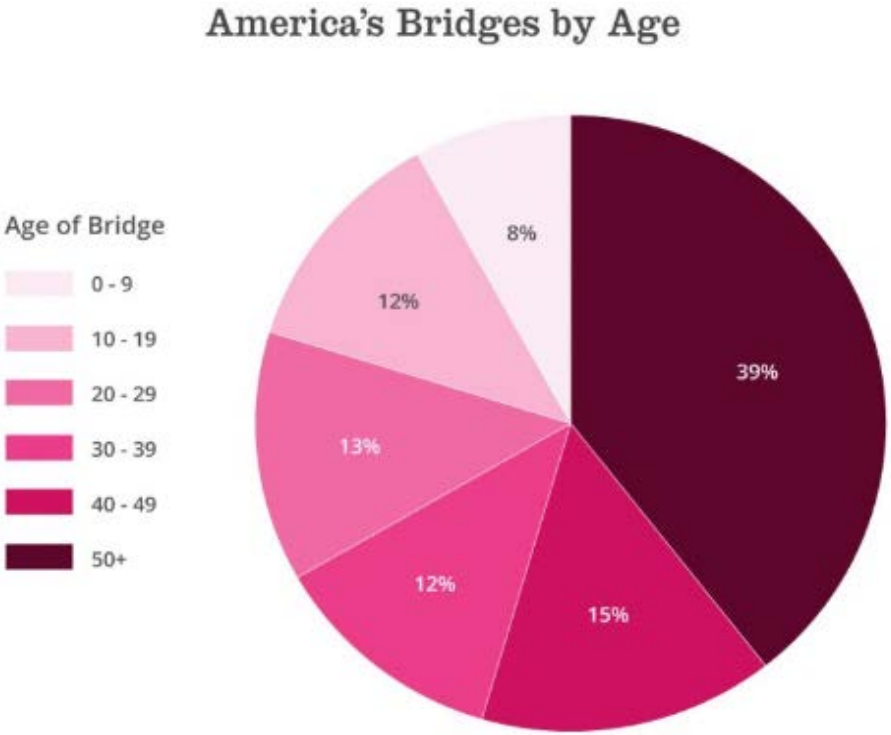
**2.9 Quads** **4.8 Quads**

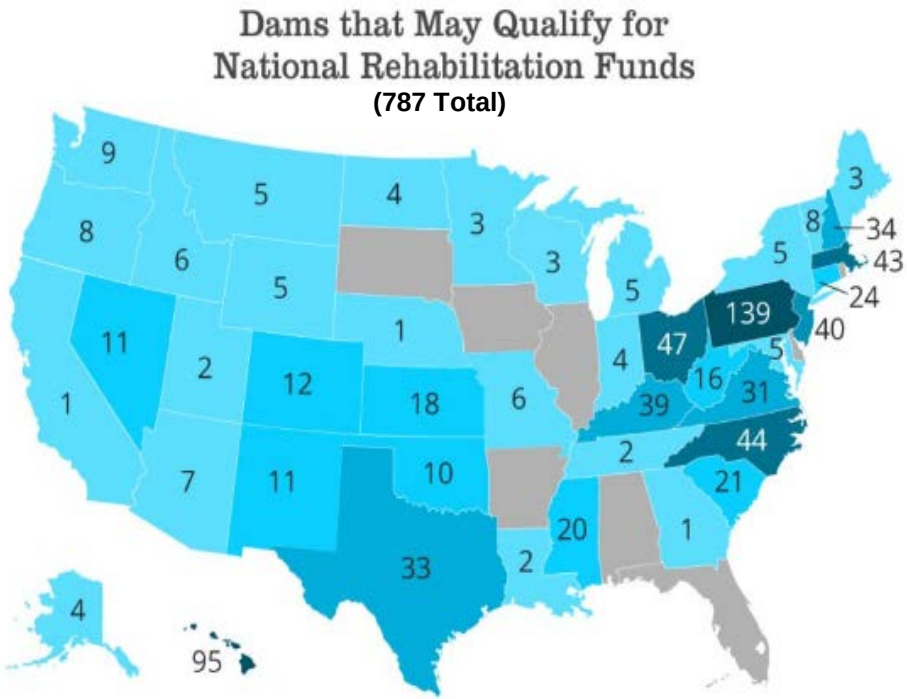
*** In Billions of dollars**



ASCE. 2017 Infrastructure Report Card. American Society of Civil Engineers. Available Online: https://www.infrastructurereportcard.org/
PCA. "2015 U.S. Cement Industry Annual Yearbook." Portland Cement Association (2015). Available online: http://www2.cement.org/econ/pdf/Yearbook_US_2015_2sided.pdf

# ASCE 2017 Infrastructure Report




The theoretical design life of a bridge has been 50 years; as of 2011, >39% of existing bridges had exceeded their 50-year theoretical design life.

***Newly*** constructed bridges are expected to last ~75$^{+}$ years.




ASCE. 2017 Infrastructure Report Card. American Society of Civil Engineers. Available Online: https://www.infrastructurereportcard.org/
DOT FHWA. Maintaining a State of Good Repair Using Cost Effective Investment Strategies. 2011. https://www.fhwa.dot.gov/bridge/preservation/guide/guide.pdf

# Nimitz Freeway Collapse


Collapsed: October 17, 1989 Cause: Magnitude 6.9 Earthquake

# Lake Oroville, California

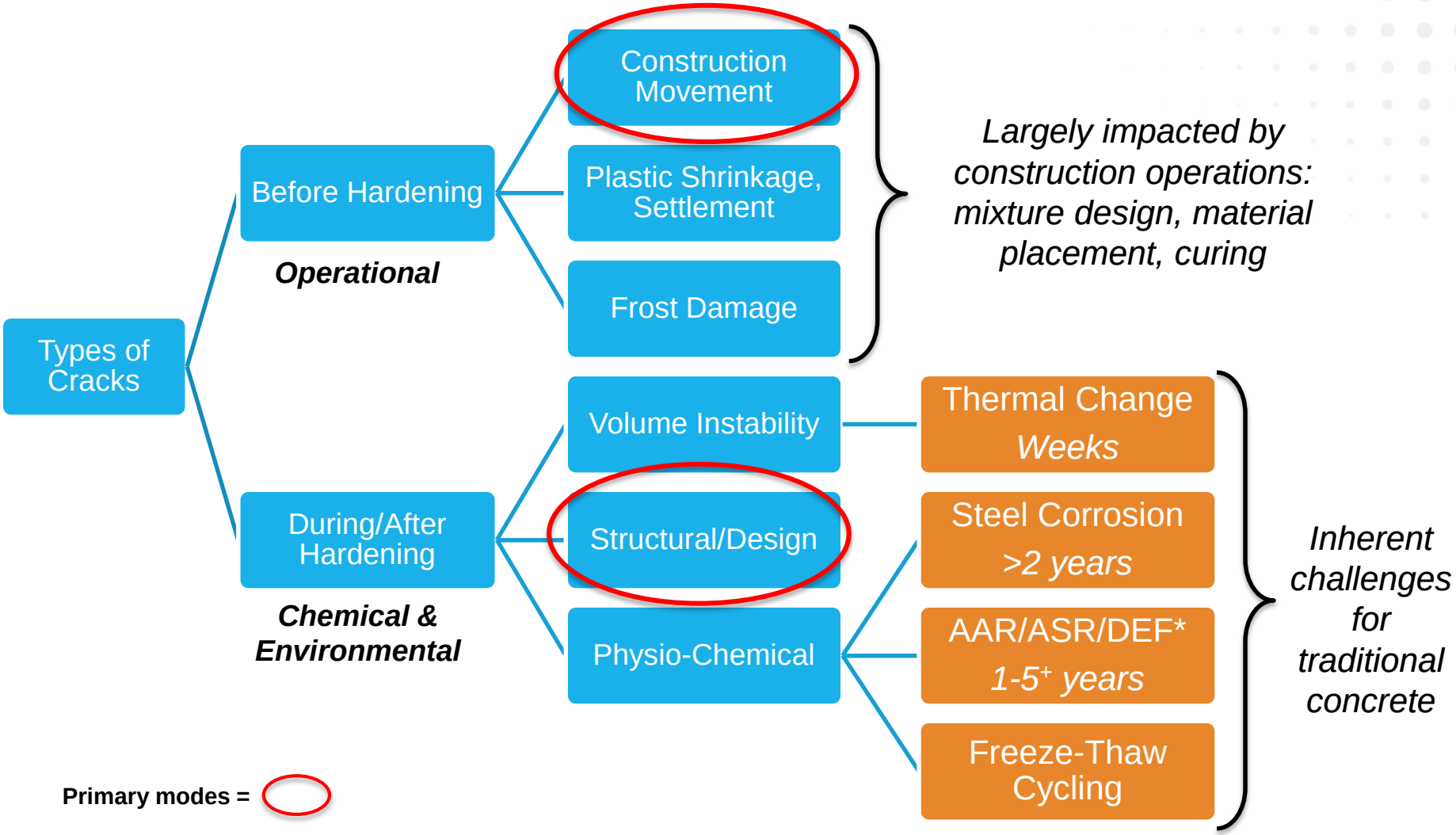
< 32% full out of 3,537,577 acre feet : August 19, 2014
Cause:  Third year of severe drought

After closing the spillway to investigate, a crator was discovered. High inflows to Lake Oroville forced dam operators to continue using the damaged spillway, causing additional damage.

# Oroville Dam's Main and Emergency Spillways

Opened: May 4,1968 Collapsed: February 2017 Cause: Rain

# Mechanisms of "Modern" Concrete Degradation




*AAR = Alkali-Aggregate Reaction; ASR = Alkali-Silica Reaction (most common); DEF = Delayed Ettringite Formation

Adapted from: Transportation Research Board (TRB). *Control of Cracking in Concrete: State of the Art.* 2006.


The main span of the FIU-Sweetwater UniversityCity Pedestrian Bridge was moved into position over the Tamiami Trail by four motorized lifts on March 10.

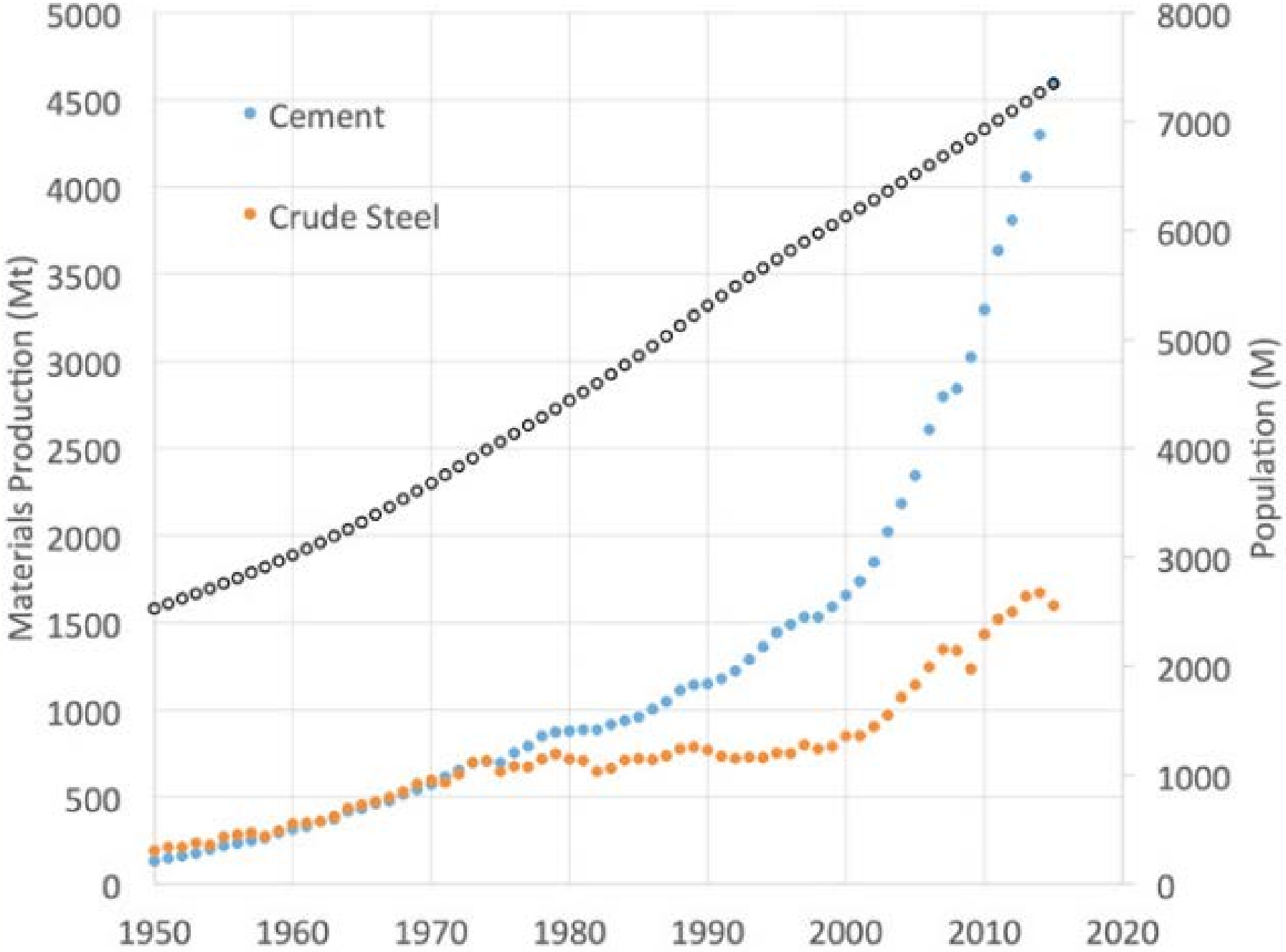
**Pedro Portal** - pportal@miamiherald.com

# Florida International University Bridge Debate

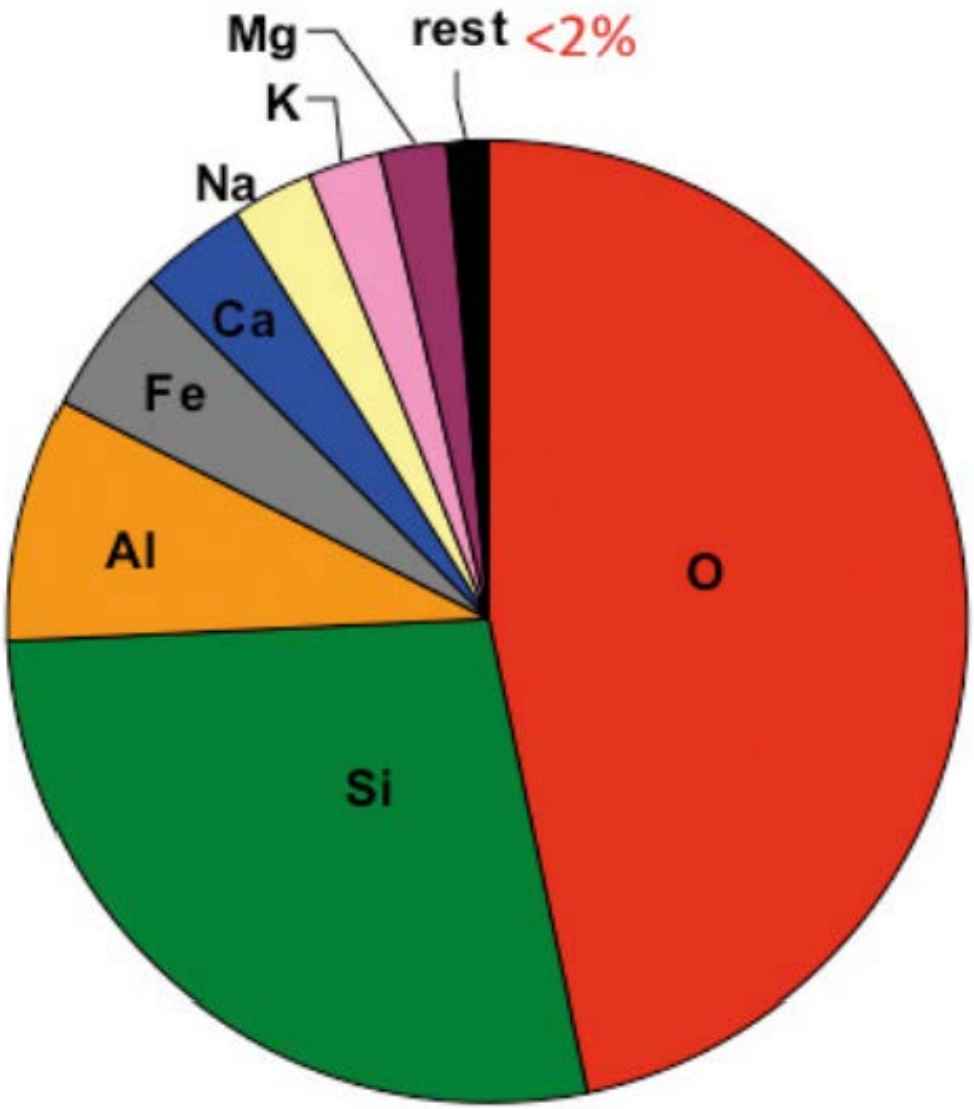
This photo provided by DroneBase shows the collapsed pedestrian bridge at Florida International University in the Miami area on Thursday, March 15, 2018. (DroneBase via AP)

# FIU: “Cable-stayed” or “Through-truss” Bridge?


**Photos:** Photos from the scene: Pedestrian bridge collapses in Miami


Cement
Crude Steel
Materials Production (Mt)
Population (M)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
8000
7000
6000
5000
4000
3000
2000
1000
0
1950
1960
1970
1980
1990
2000
2010
2020

# Earth Crust Elemental Abundance




*The most common chemical elements in the crust are:*

*oxygen (46.6%),*

*silicon (27.7%),*

*aluminum (8.1%),*

*iron (5.0%),*

*calcium (3.6%),*

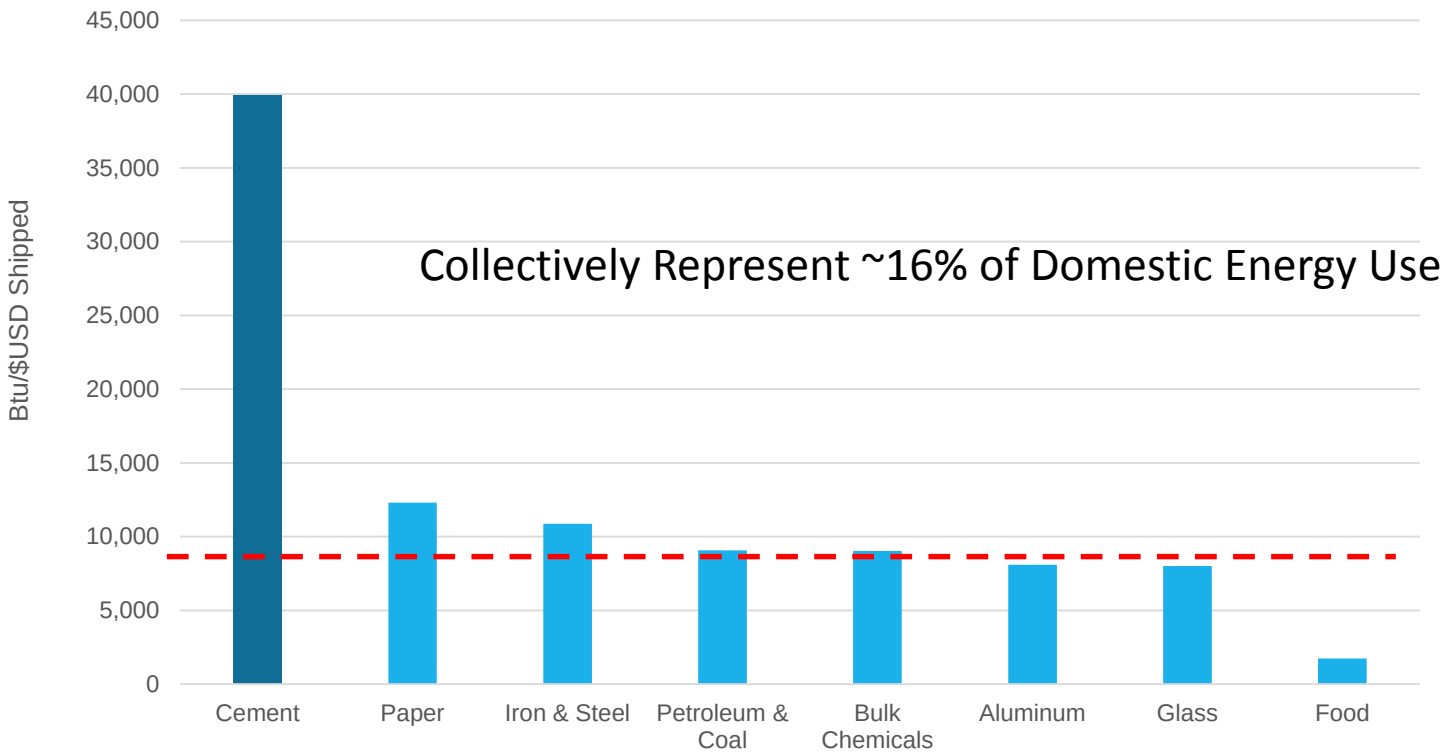
*potassium (2.8%),*

*sodium (2.6%), and*

*magnesium (2.1%).*

# "Cement is the Most Energy-Intensive Manufacturing Process"

- Btu/$USD Shipped for cement is more than 4x the average of other manufacturing industries (red dotted line; 8,452Btu/$)




Estimates are based on Energy Information Administration (EIA) selections for "energy-intensive" manufacturing, the Manufacturing Energy Consumption Survey (2010), and shipment data from the Annual Survey of Manufactures (ASM).

UN environment

Eco-efficient cements:
Potential economically viable solutions for a low-$CO_2$ cement-based materials industry

"We believe that ***Portland cement clinker based cements will dominate in the near future*** due to the economy of scale, level of process optimization, availability of raw materials and market confidence in these products."

**K. L. Scrivener, V. M. John, and E. M. Gartner Report on, " Eco-efficient cements . . . " United Nations Environmental Programme, Paris 2016**

# Reality . . . Constraint . . . Opportunity

". . . there is, as yet, no cost-effective alternative to Portland cement clinker in the current economic environment."

". . . the facility to cast cementitious materials on-site is key to their ubiquitous use in construction."

". . . there is still some chance for a breakthrough in the area of clinkers made ***using globally abundant ultramafic rocks*** instead of limestone as the main raw material."

**K. L. Scrivener, V. M. John, and E. M. Gartner**
**Report on, " Eco-efficient cements . . . "**
**United Nations Environmental Programme, Paris 2016**



**Mantle** composition = ultramafic rock called peridotite.

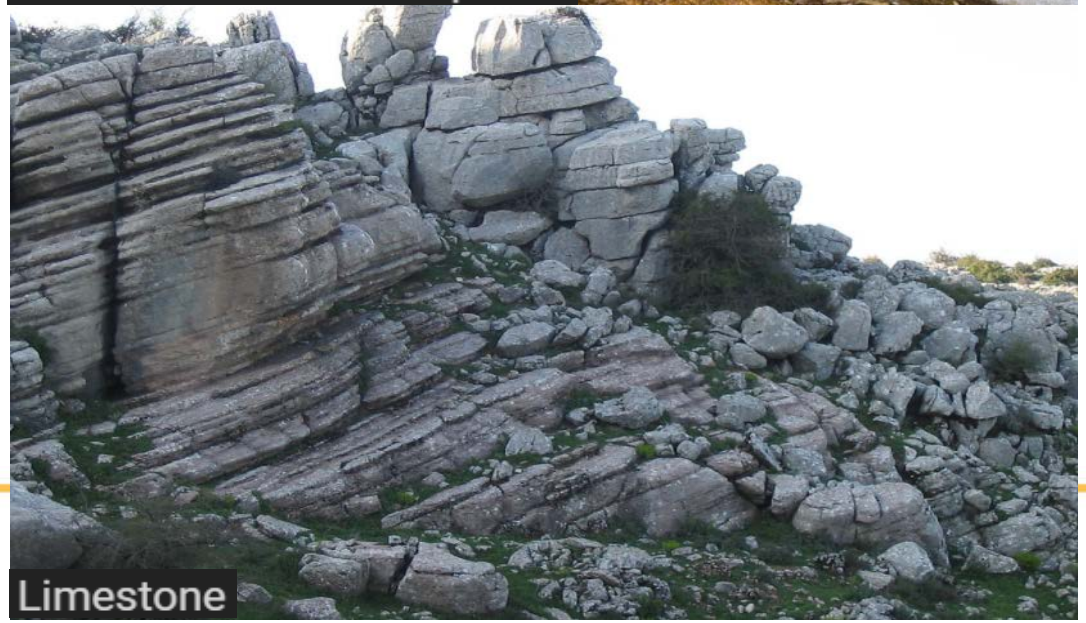
# Basalt Formations

# Minerology – Common Carbonates

Calcite

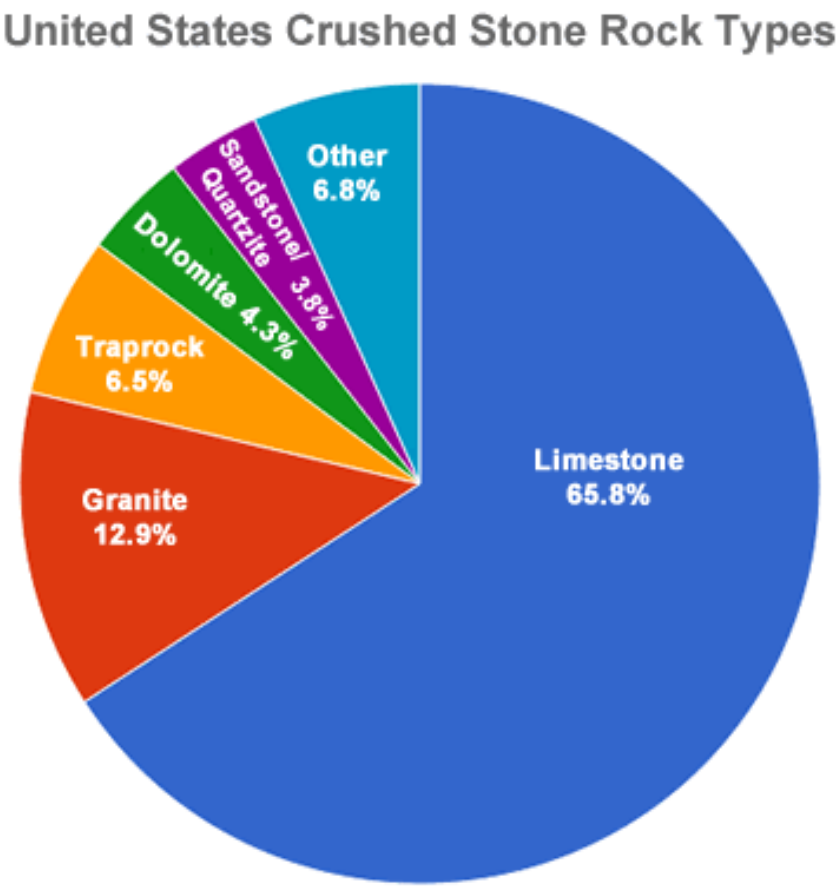
Calcium Carbonate deposits

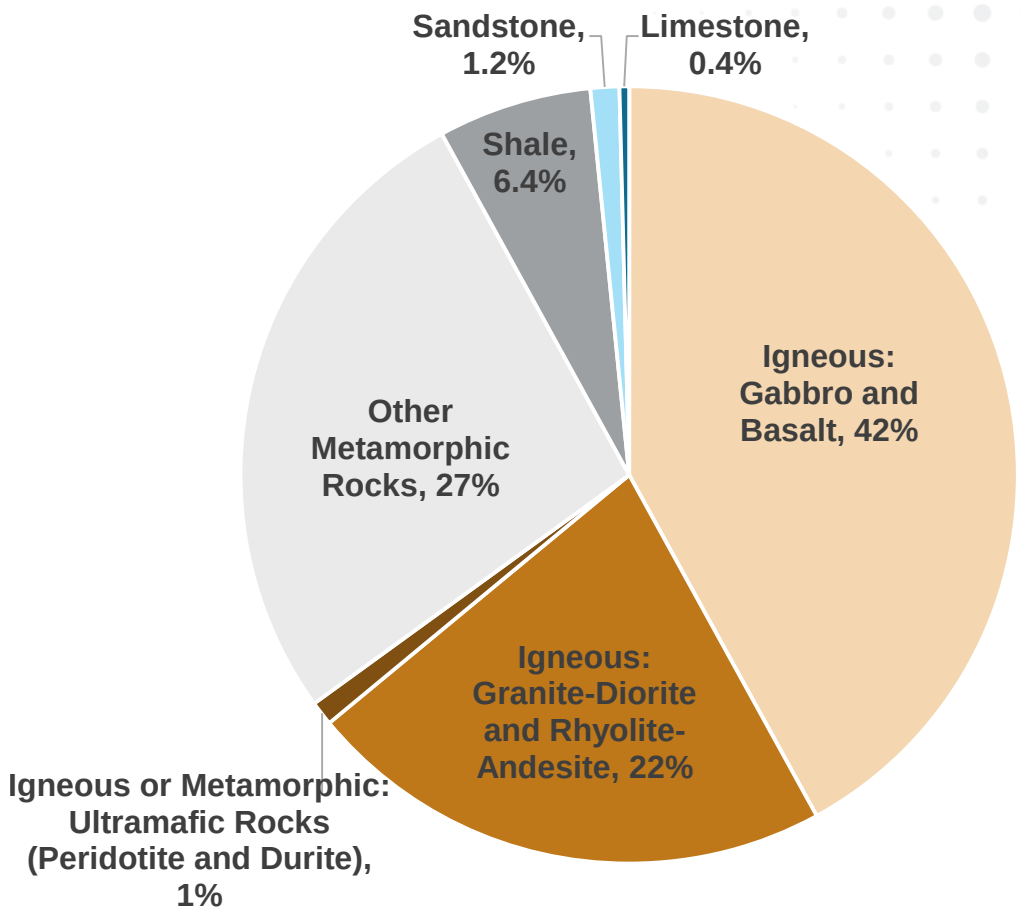
Limestone $CaCO_3$ (calcium carbonate)



Limestone

# What We Mine Versus Rock Distribution



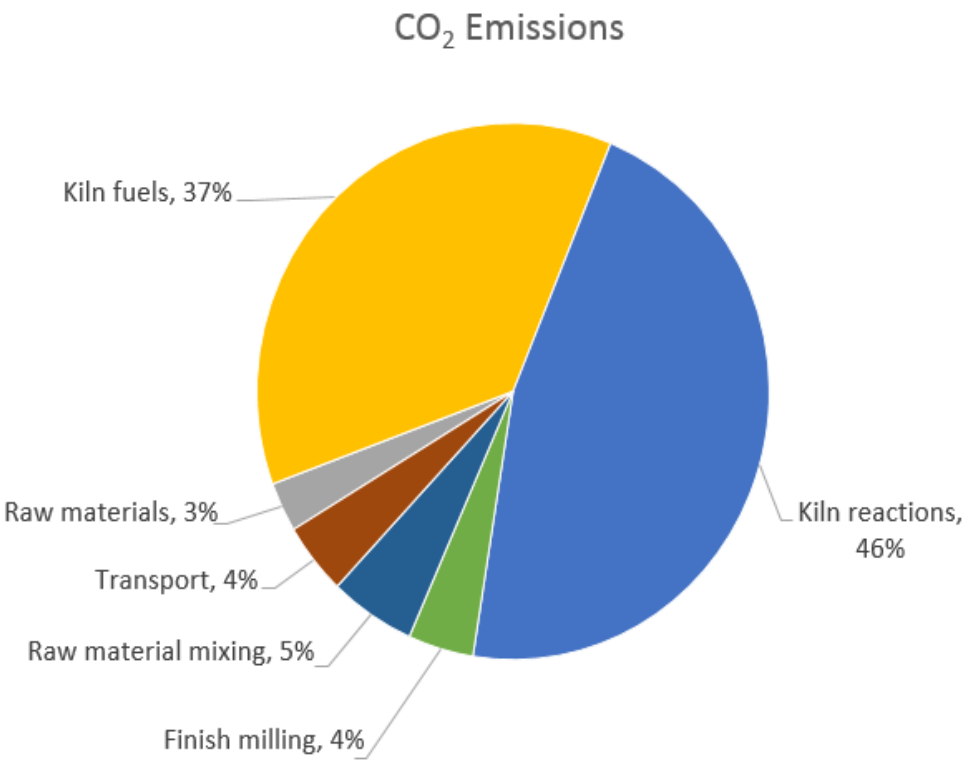



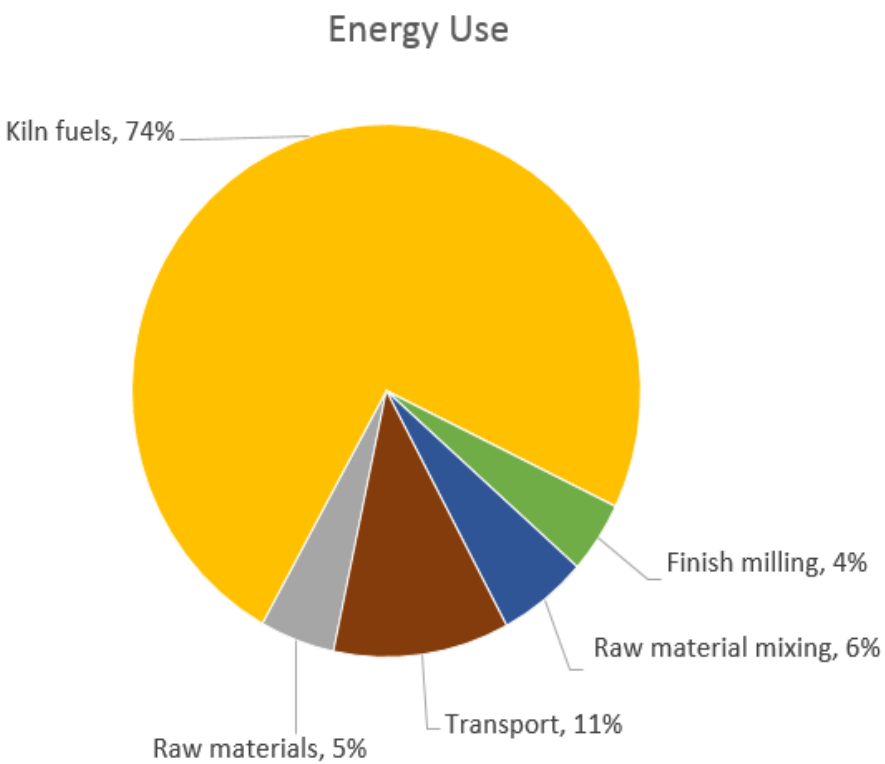

**Mafic** is an adjective describing a silicate mineral or igneous rock that is rich in magnesium and iron, and is a portmanteau of **ma**gnesium and **ferr**ic.

**Felsic** refers to igneous rocks that are relatively rich in elements that form feldspar and quartz, and is a portmanteau of **fel**dspar and **sil**ica.

# Kilns Drive Embodied Energy

**Temperatures of 800–1050°C enable the decomposition of calcium carbonate into calcium oxide (CaO) and $CO_2$ during the calcining step.**



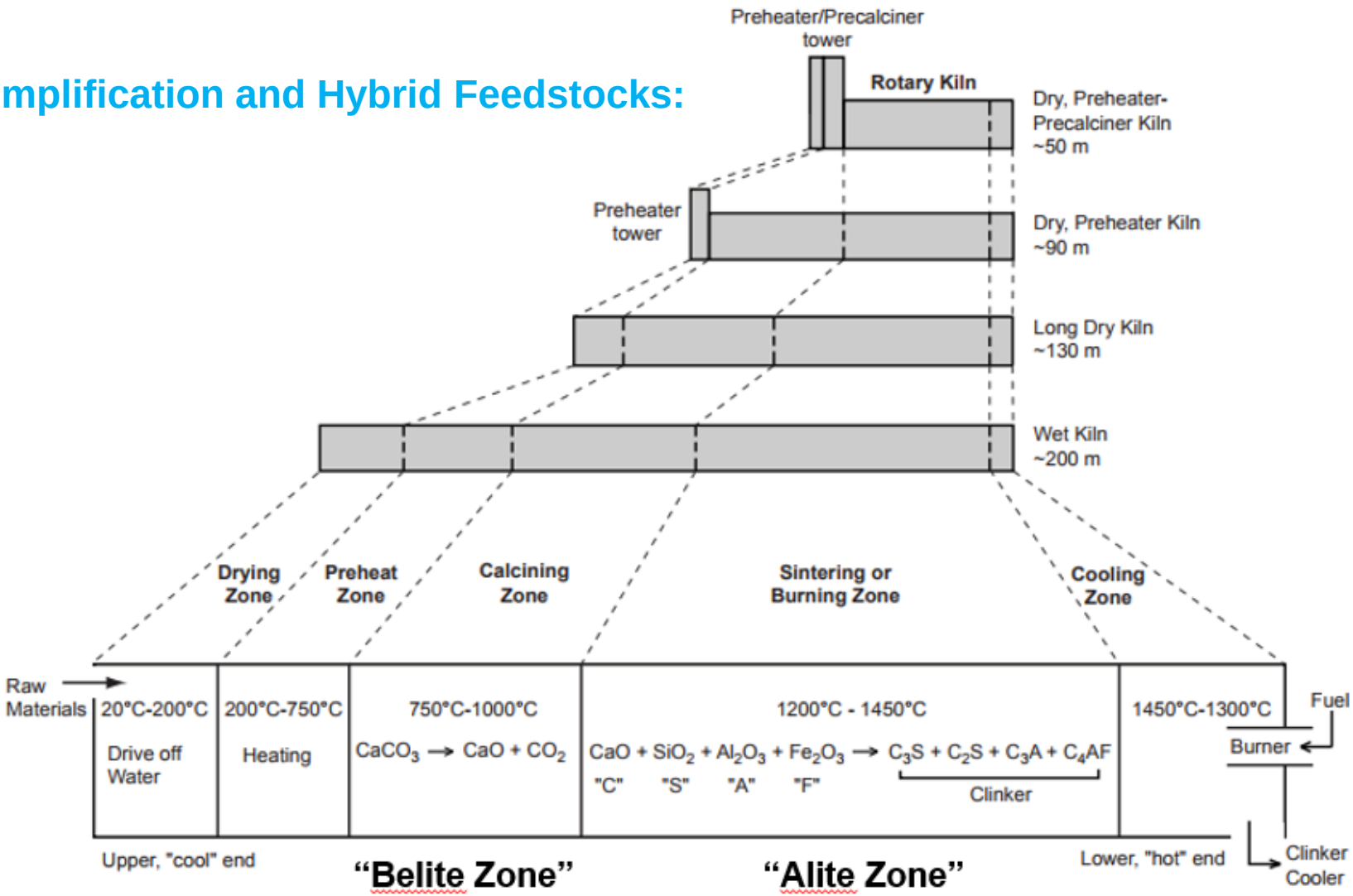




**. . . followed by a heating (sintering) step, ranging from 1400-1500°C partially (20–30%) melting the mixture of belite ($Ca_2SiO_4$) and CaO, resulting in the formation of alite ($Ca_3O{\cdot}SiO_4$) . . .**

Marland, Gregg, *et al*. "Global, regional, and national fossil fuel $CO_2$ emissions." *Trends: A Compendium of Data on Global Change* (2007): 37831-6335 and WBCSD, IEA. "Cement Technology Roadmap, 2009. Carbon Emission Reductions Up to 2050." *World Business Council for Sustainable Development and International Energy Agency* 2009.

# Process Challenge?

## Kiln Simplification and Hybrid Feedstocks:




Van Oss, Hendrik G. Background facts and issues concerning cement and cement data. 2005.

# Life-cycle Embodied Energy ∝ Durability

**Imagine … an Infrastructure, where the Materials used over the Next Decade:**


- ✓ **Double its Durability** **(2⁺x Greater Life)**
  - ➢ **Halve its Embodied Energy** **(9 Quads Saved*)**
  - ➢ **Cut Emissions by Half** **(≤ 50% Lower GHG's)**
- ✓ **Halve O&M Expenses** **(≤ 50⁺% Repair Frequency)**
- ✓ **Use Existing Facilities** **(No New Capital Outlay)**
- ✓ **Lower Concrete Costs** **(At or Below Today's)**

* Infrastructure estimate through 2040

“Creativity is just connecting things.”

**Steve Jobs**

**(1955-2011)**

“We fear things in proportion to our ignorance of them”

**Livy, Roman Historian**

**64 or 59 B.C. – A.D. 17**

| Time | Tuesday, April 10, 2018 Events |
|---|---|
| 8:30 – 9:00 AM | Registration, Breakfast on Your Own |
| 9:00 – 9:15 AM | **Welcome and Introduction to ARPA-E**<br>Chris Fall, Principal Deputy Director / Connor Prochaska, Senior Advisor & Chief-of-Staff, ARPA-E |
| 9:15 – 9:45 AM | **Workshop Overview, Structure and Desired Outcome**<br>Joseph King, Program Director, ARPA-E |
| 9:45 – 10:15 AM | Attendee Introduction: Table-by-Table |
| 10:15 – 10:45 AM | **Infrastructure Needs, Applications, and Pathways to Adoption**<br>Ben Graybeal, Team Leader - Bridge Engineering Research, Federal Highway Administration |
| 10:45 – 11:15 AM | **Ordinary Portland Cement (OPC) Overview**<br>Paul Tennis, Director Product Standards and Technology, Portland Cement Association |
| 11:15 – 11:45 AM | **Pozzolanic Materials and Aggregates Practice Overview**<br>Tom Adams, President, KMR Collaborative |
| 11:45 – 12:45 PM | Lunch / Networking |
| 12:45 – 1:15 PM | **Admixture Overview**<br>Jason Weiss, Chair & Professor, Oregon State University |
| 1:15 – 1:45 PM | **Increasing Material Sustainability Using Emerging Materials Technology and Design**<br>Jameson Shannon, US Army Corps of Engineers |
| 1:45 – 2:00 PM | **Breakout 1 Overview and Objectives**<br>Joseph King, Program Director, ARPA-E |
| 2:00 – 2:30 PM | Coffee Break / Networking / Transition to Breakout |
| 2:30 – 4:30 PM | Breakout Session 1 |
| 4:30 – 4:50 PM | Transition back to main room |
| 4:50 – 5:00 PM | Day 1 Wrap-Up |
| 5:15 – 7:00 PM | One-on-one meetings with Dr. King |

| Time | Wednesday, April 11, 2018 Events |
|---|---|
| 7:30 – 8:00 AM | Breakfast / Networking |
| 8:00 – 8:10 AM | Focus and Overview of Day 2 |
| 8:10 – 8:40 AM | Revealing the Role of Atomic Order-and-Disorder on Rate Controls on Silicate Dissolution in Aqueous Environments<br>Gaurav Sant, Associate Professor, UCLA |
| 8:40 – 9:10 AM | Rock and Glass Dissolution & Metamorphosis<br>Carol Jantzen & Cory Trivelpiece, Researchers, Savannah River National Laboratory |
| 9:10 – 9:40 AM | Durability of Ancient Roman Concretes and their Geologic Analogs<br>Marie Jackson, Research Associate Professor, University of Utah |
| 9:40 – 10:10 AM | Challenging Concrete Applications<br>Vinod Veedu, Director Strategic Initiatives, Oceanit |
| 10:10 – 10:20 AM | Breakout 2 Overview and Objectives<br>Joseph King, Program Director, ARPA-E |
| 10:20– 10:40 AM | Break/Networking |
| 10:40 – 12:15 PM | Breakout Session 2 |
| 12:15 – 12:20 PM | Transition back to main room |
| 12:20 – 12:30 PM | Day 2 Wrap-Up and Next Steps, Lunch on Your Own |
| 12:30 – 2:30 PM | One-on-one meetings with Dr. King |