When Endurance Matters
Virtual meetings are basically modern seances.

"Elizabeth are you here?"
"Make a sound if you can hear us."
"Is anyone else with you?"
"We can't see you. Can you hear us?"
Global Cement Production is Growing

- World GDP
- World Cement
- World Steel

GDP: World Bank
Materials: USGS

When Endurance Matters
“Cement is the Most Energy-Intensive Manufacturing Process”

- Btu/$USD Shipped for cement is more than 4x the average of the remaining industries (red dotted line; 8,452Btu/$)
The cement industry is one of the lowest CO$_2$-equivalent emitters on a mass basis.
Global Materials Production

- 0.5 Quadrillion BTU (Quad) of primary energy is consumed in the domestic production of cement; globally, this number is estimated to be ~11 Quad.
- Global cement production accounts for ~4-5% of all anthropogenic CO₂ emissions
The role of concrete in the life cycle greenhouse gas emissions reductions of the United States buildings and pavements. MIT Concrete Sustainability Hub; Jeremy Gregory et. al. August 20, 2020; Barcelo et al., 2014
## Alternative Cement Materials Comparison

<table>
<thead>
<tr>
<th></th>
<th>OPC</th>
<th>Mg Cements</th>
<th>Wollastonite (Rock/Mineral Wools)</th>
<th>Geopolymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength (MPa)</td>
<td>35 to &gt;70</td>
<td>50 to 70</td>
<td>~69&lt;sup&gt;8&lt;/sup&gt;</td>
<td>32 to ≥70</td>
</tr>
<tr>
<td><strong>Reserves (MT, Global)</strong></td>
<td>-</td>
<td>8.5 billion&lt;sup&gt;2,3,4&lt;/sup&gt; MgO precursors</td>
<td>&gt;100 million&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Extremely Large&lt;sup&gt;2,10&lt;/sup&gt; “Soil silicates” &amp; Aluminosilicates</td>
</tr>
<tr>
<td><strong>Reserves (MT, Domestic)</strong></td>
<td>-</td>
<td>35 million&lt;sup&gt;2,3&lt;/sup&gt;</td>
<td>“Large” deposits&lt;sup&gt;2&lt;/sup&gt;</td>
<td>NA&lt;sup&gt;11&lt;/sup&gt;</td>
</tr>
<tr>
<td>Annual Production (MT, Global)</td>
<td>4.1-4.3 billion&lt;sup&gt;1&lt;/sup&gt;</td>
<td>27.7 million&lt;sup&gt;2,3,5&lt;/sup&gt;</td>
<td>&gt;700,000&lt;sup&gt;2,5&lt;/sup&gt;</td>
<td>≥37 million&lt;sup&gt;2,10&lt;/sup&gt;</td>
</tr>
<tr>
<td>Annual Production (MT, Domestic)</td>
<td>105-125 million&lt;sup&gt;1&lt;/sup&gt;</td>
<td>N/A&lt;sup&gt;6&lt;/sup&gt;</td>
<td>N/A&lt;sup&gt;2,6&lt;/sup&gt; #3 globally&lt;sup&gt;2&lt;/sup&gt;</td>
<td>&gt;5.7 million&lt;sup&gt;2,10&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cost (USD/MT)</td>
<td>$100 to $110</td>
<td>$600&lt;sup&gt;7&lt;/sup&gt;</td>
<td>$230 to $490 (domestic)&lt;sup&gt;2&lt;/sup&gt; $80 to $105 (China)&lt;sup&gt;2,9&lt;/sup&gt;</td>
<td>$132&lt;sup&gt;2,4&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Limiting Reagents</strong></td>
<td>None</td>
<td>Soluble phosphates</td>
<td>Natural CaSiO&lt;sub&gt;3&lt;/sub&gt; resources</td>
<td>Alkali activators [NaOH ~57 MMT/yr] Chloralkali Process</td>
</tr>
<tr>
<td>GHG as Produced&lt;sup&gt;12&lt;/sup&gt;</td>
<td>0.972 MT CO&lt;sub&gt;2&lt;/sub&gt; Per MT cement</td>
<td>(↓) 40%</td>
<td>(↓) 70%</td>
<td>(↓) 80%</td>
</tr>
<tr>
<td>Embodied Energy&lt;sup&gt;12&lt;/sup&gt; (production)</td>
<td>0.5 Q primary energy (86 MMT)</td>
<td>-</td>
<td>-</td>
<td>(↓) 30%</td>
</tr>
<tr>
<td>Common Preparation/Use</td>
<td>ON-SITE</td>
<td>PRECAST (REPAIR)</td>
<td>PRECAST</td>
<td>PRECAST ON-SITE</td>
</tr>
</tbody>
</table>

<sup>1</sup>2017 data; <sup>2</sup>USGS 2017; <sup>3</sup>magnesite; <sup>4</sup>Russia, North Korea and China make up ~70% of global reserves; <sup>5</sup>excludes US production; <sup>6</sup>data withheld; <sup>7</sup>MgO; <sup>8</sup>Solidia data; <sup>9</sup>minimally refined; <sup>10</sup>kaolin clay; <sup>11</sup>country-specific data not available; <sup>12</sup>doesn’t include the limiting reagent contribution.
Alternative Binder/Reinforcement Compositions

Processing/Modeling Tools: Thermodynamics, Mechanisms and Kinetics

Novel Protective Coatings & SEED Project

Improved Ductility, Crack Mitigation and Monitoring
<table>
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<tr>
<th>DAY 1</th>
<th>OCTOBER 26, 2020</th>
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</table>
| 12:30 – 12:35 PM | Welcome Message  
*Hunter Faseler, ARPA-E Special Advisor* |
| 12:35 – 12:55 PM | Cement Program Overview & Perspective  
*Dr. Joseph King, ARPA-E Program Director* |
| 1:00 – 2:40 PM | **Alternative Binder/ Reinforcement Compositions**  
1 Rutgers University  
2 University of Virginia  
3 Neuvokas Corporation  
4 University of Kentucky  
*Richard Riman (1:00 – 1:25)*  
*Andres Clarens (1:25 – 1:50)*  
*Erik Kiilunen (1:50 – 2:15)*  
*Bob Jewell (2:15 – 2:40)* |
| 2:40 – 3:00 PM | BREAK |
| 3:00 – 4:40 PM | **Processing/Modeling Tools: Thermodynamics, Mechanisms and Kinetics**  
5 University of Utah  
6 Oregon State University  
7 UCLA  
8 Carnegie Mellon University  
*Marie Jackson (3:00 – 3:25)*  
*Jason Weiss (3:25 – 3:50)*  
*Gaurav Sant (3:50 – 4:15)*  
*Newell Washburn (4:15 – 4:40)* |
| 4:40 – 4:45 PM | Day 1 Closing Remarks  
*Dr. Joseph King, ARPA-E Program Director* |
# 2020 ARPA-E CEMENT Virtual Annual Meeting:
## Day Two

<table>
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<tr>
<th>Time</th>
<th>Session</th>
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| 12:30 – 12:40 PM | Day 2 Opening Remarks
*Dr. Joseph King, ARPA-E Program Director* |
| 12:40 – 2:20 PM | **Novel Protective Coatings & SEED Project**
9 C-Crete Technologies
Rouzbeh Shahsavari (12:40 – 1:05)
10 University of Colorado, Boulder
Wil Srubar (1:05 – 1:30)
11 University of Florida
Chris Ferraro (1:30 – 1:55)
12 Brimstone Energy
Cody Finke (1:55 – 2:20) |
| 2:20 – 2:40 PM | BREAK                                                                  |
| 2:40 – 4:20 PM | **Improve Ductility, Crack Mitigation and Monitoring**
13 University of Michigan
Victor Li (2:40 – 3:05)
14 UC San Diego
Yu Qiao (3:05 – 3:30)
15 Washington State University
Somayeh Nassiri (3:30 – 3:55)
16 Georgia Tech
Laurence Jacobs (3:55 – 4:20) |
| 4:20 – 4:40   | T2M Perspective: Present & Future
*Dr. Madhav Acharya, ARPA-E* |
| 4:40 – 4:55   | ARPA-E Reporting Guidelines & Requirements
Geoffrey Goode & Paul Gottlieb, ARPA-E |
| 4:55 – 5:00 PM | Closing Remarks
*Dr. Joseph King, ARPA-E* |