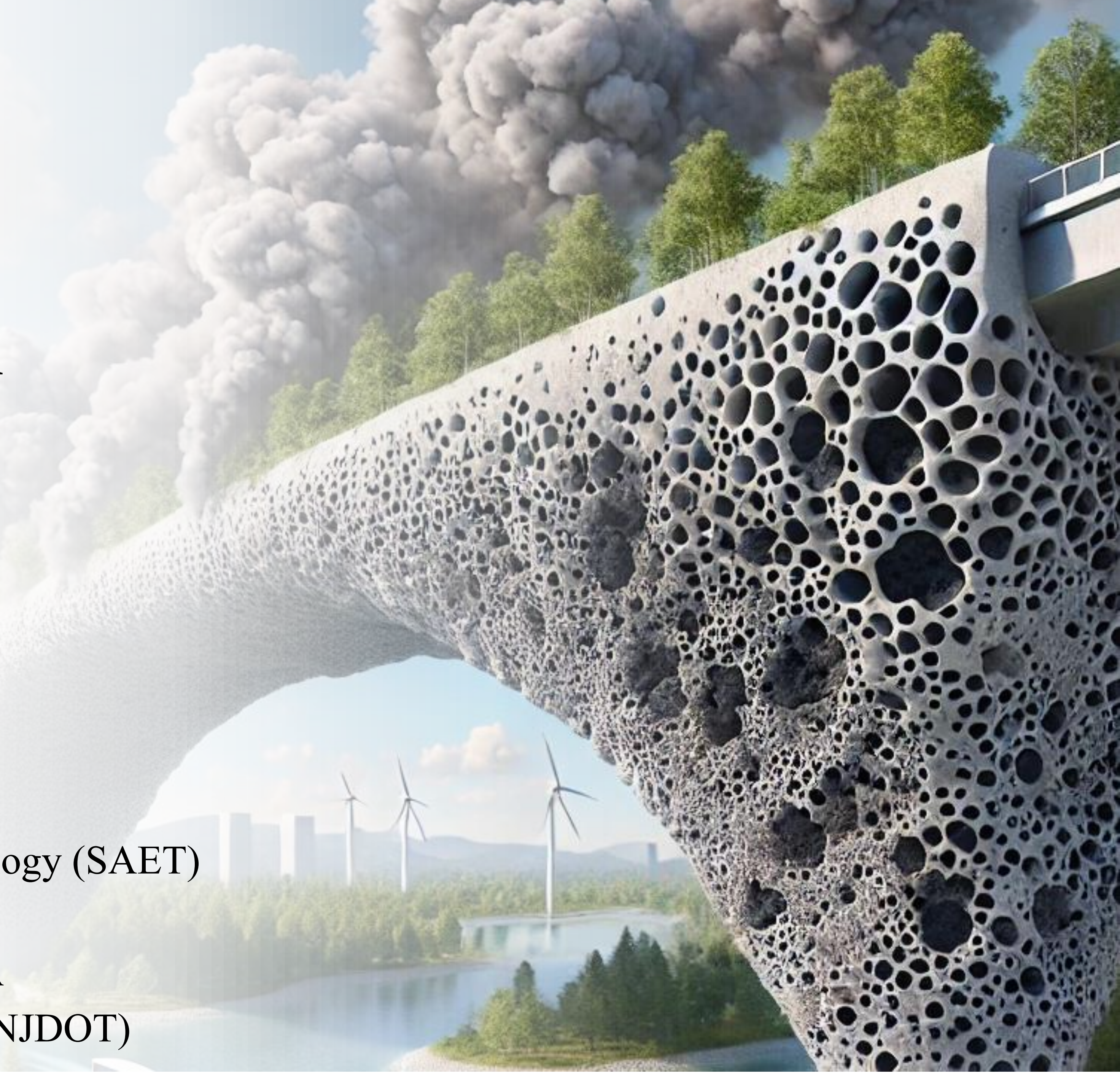
How Concrete is Becoming a Carbon Sponge



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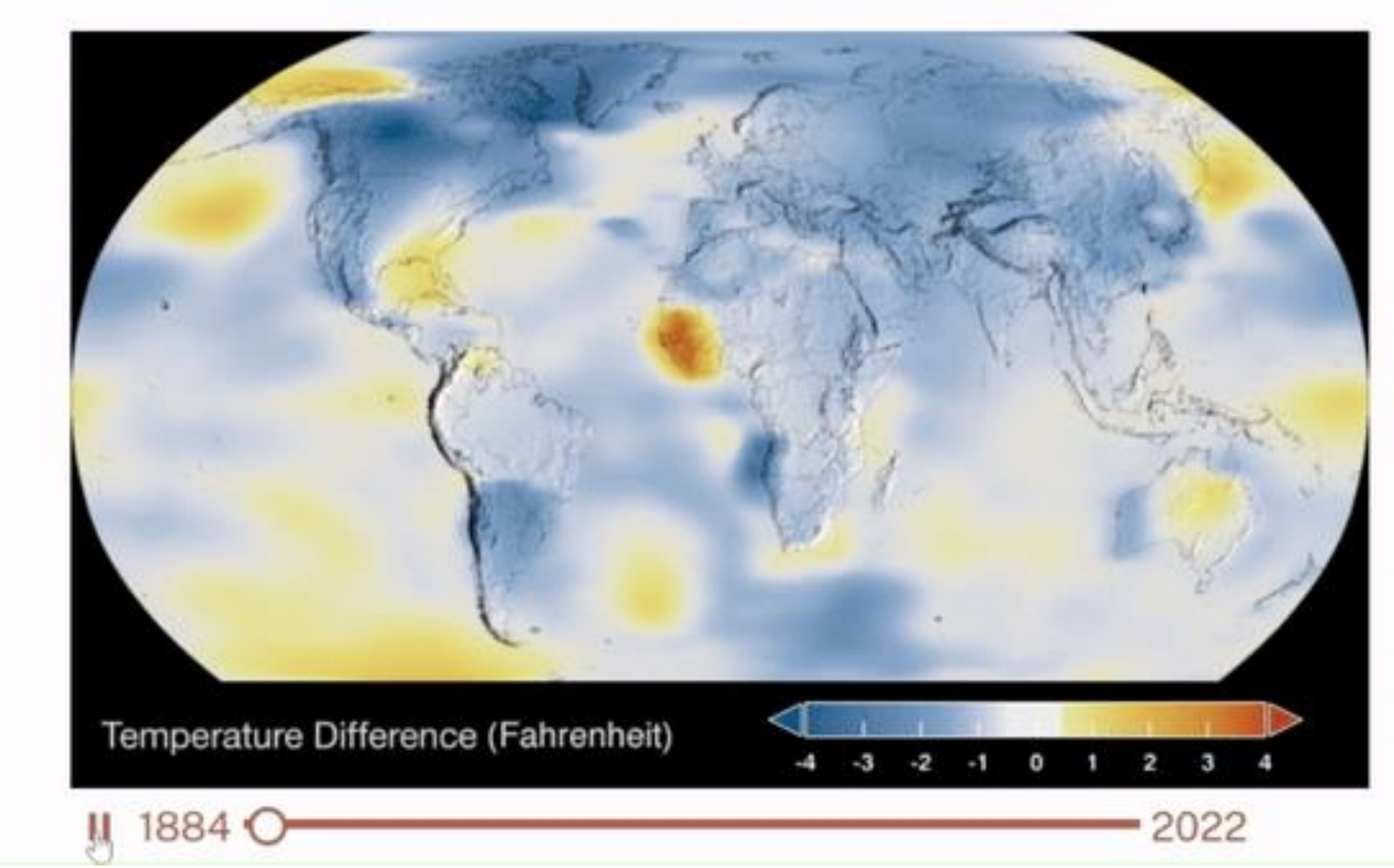
Climate Change



Climate Change: Global Impact

X 3

*The number of climate-related disasters has tripled in the last 30 years **

X 2.5

*Rate of global sea-level rise was 2.5 times faster than all of the 20th century between 2006 and 2016 *.*

45M

Drought in Africa: More than 45 million people are struggling to find enough food across 14 countries will in 2019 §.

$110B

Damages from the 2019-2020 Australian wildfires cost $110 billion cost ¥.

Oxfam International. "5 Natural Disasters That Beg for Climate Action." Oxfam International, 7 Apr. 2020, www.oxfam.org/en/5-natural-disasters-beg-climate-action.

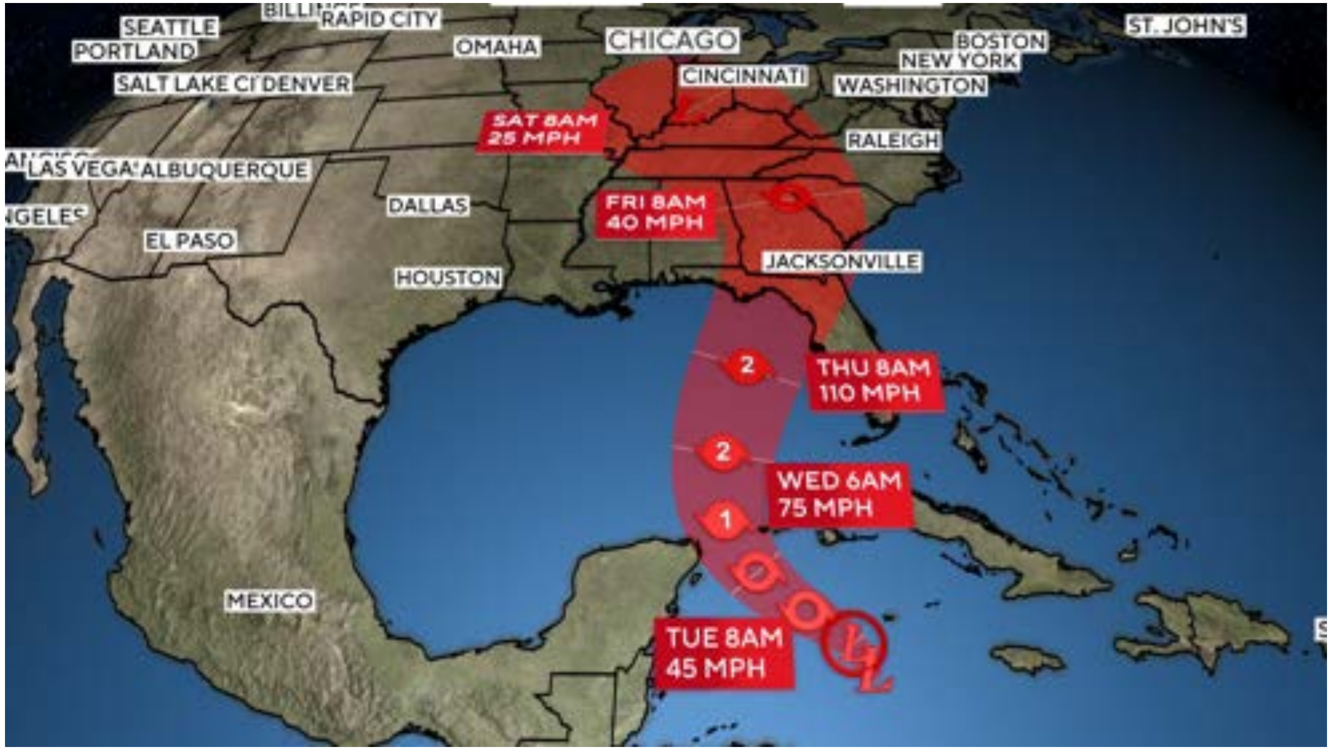
¥ Read, Paul, and Richard Denniss. "With costs approaching $100 billion, the fires are Australia's costliest natural disaster." *The Conversation* 17 (2020).

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

§ Anyadike, Obi. "Drought in Africa Leaves 45 Million in Need across 14 Countries." The New Humanitarian, 10 June 2019, www.thenewhumanitarian.org/analysis/2019/06/10/drought-africa-2019-45-million-in-need.

Climate Change: U.S. Impact

- Since 1980, 396 weather and climate disasters where overall damages exceeded $1B
- Total cost is approx. $2.78 trillion (~$63.2B per year)
- New annual record of 28 events in 2023



Source: NOAA National Centers for Environmental Information

Climate Change: U.S. Impact

- World produces 37.4 billion metric tons of CO2e each year worldwide in 2023.
- US emissions of GHGs in 2022 amounted to 6.343 billion metric tons.
- Transportation industry is responsible for the highest share (28%) of GHG in U.S.
- Global framework to reduce risks and the impacts of climate change by limiting global warming to well below 2° C and pursuing efforts to limit it to 1.5° C.
- U.S. is committed to reduce greenhouse emissions by 26%-28% below 2005 levels by 2025.

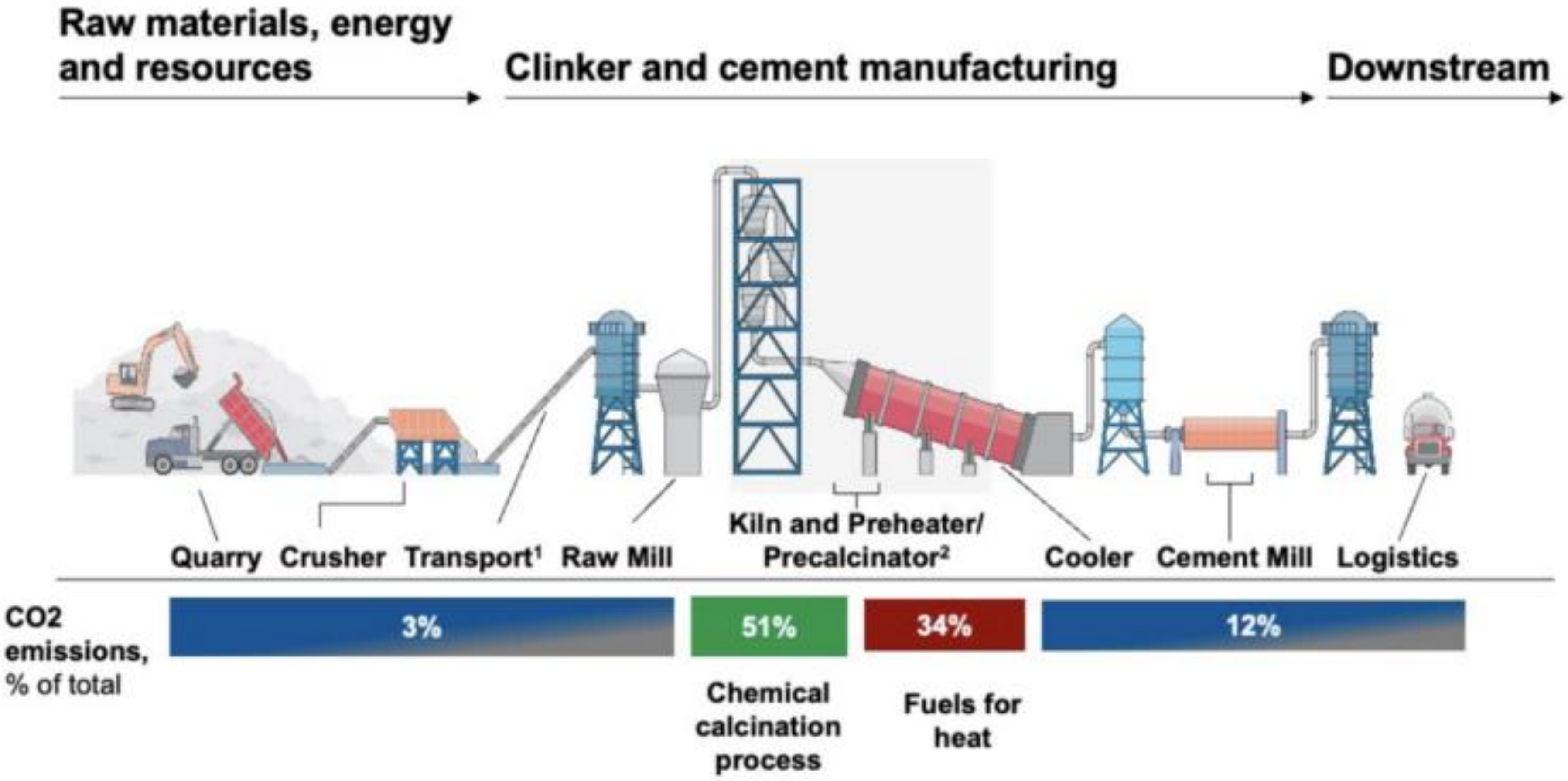
Source: EIA, EPA.gov

Concrete

- Concrete is the second most widely used material after water.
- Global annual production is 494 billion cubic feet.
- The concrete produced annually could pave a one-lane road halfway to Mars.
- Cement is, of course, a key ingredient of concrete.

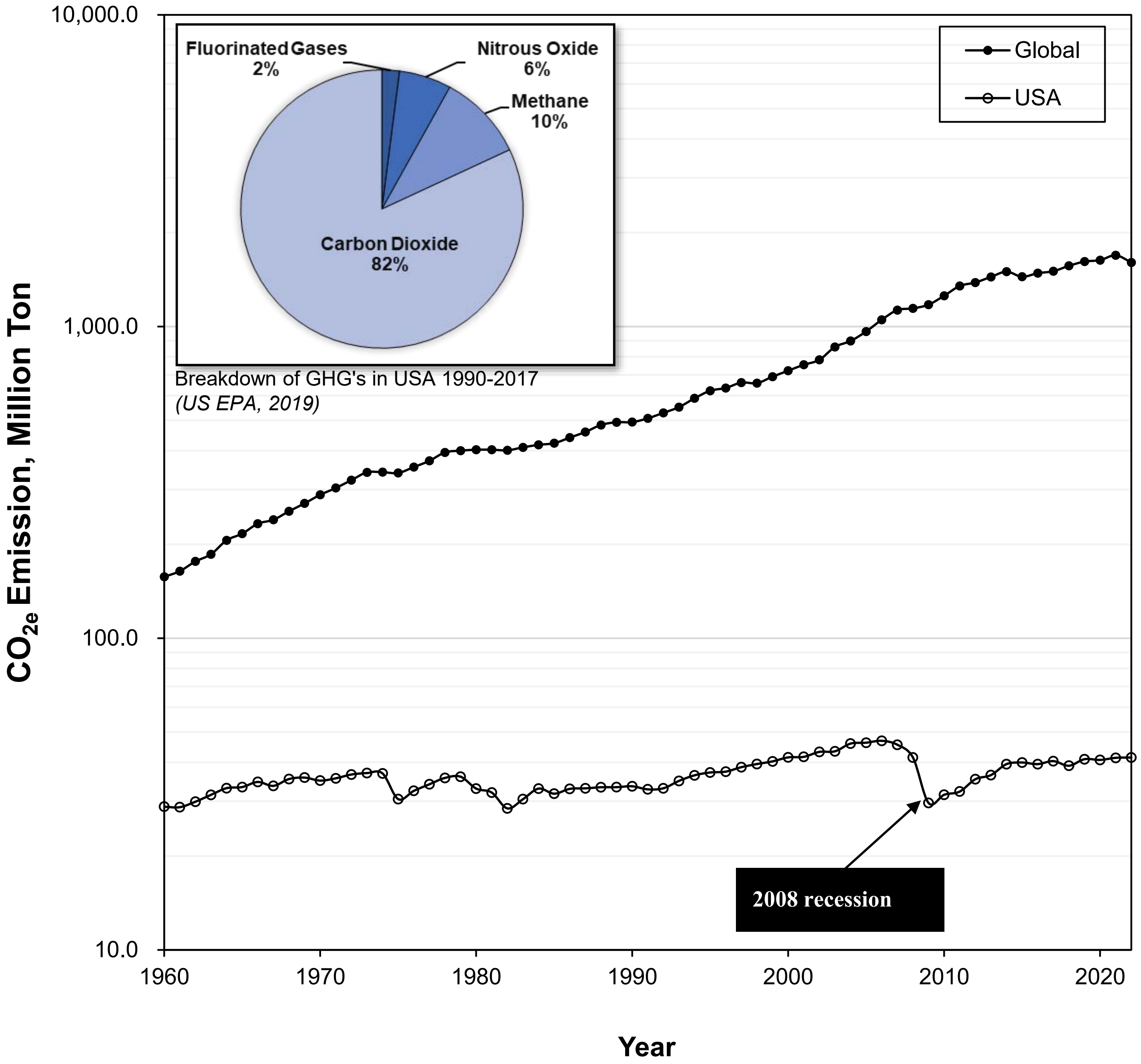
Greenhouse Gases: Cement

- Cement accounts for 8% of CO_2 emissions on the global level



Greenhouse Gases: Cement

- CO2e concentration has been steadily increasing since the 1960s.
- Major greenhouse gases: CO2, methane, and nitrous oxide
- CO2e traps heat in the atmosphere, leading to global warming.



Supplementary Cementitious Materials (SCMs)

Challenge

- Reduce CO_2 emissions at the same time as meeting global demand.
- Global cement production will grow up to 23%# by 2050.
- 10* gigatons of CO_2 would need to be sequestered annually for the next 30 years to meet climate goals.

Source: #*International Energy Agency projects;* * National Academy of Sciences

Biochar

- Biochar is a high carbon solid.
- Eco-friendly solution by converting waste materials.
- Produced through the pyrolysis of organic matter.
- Widely recognized for its ability to improve soil health.

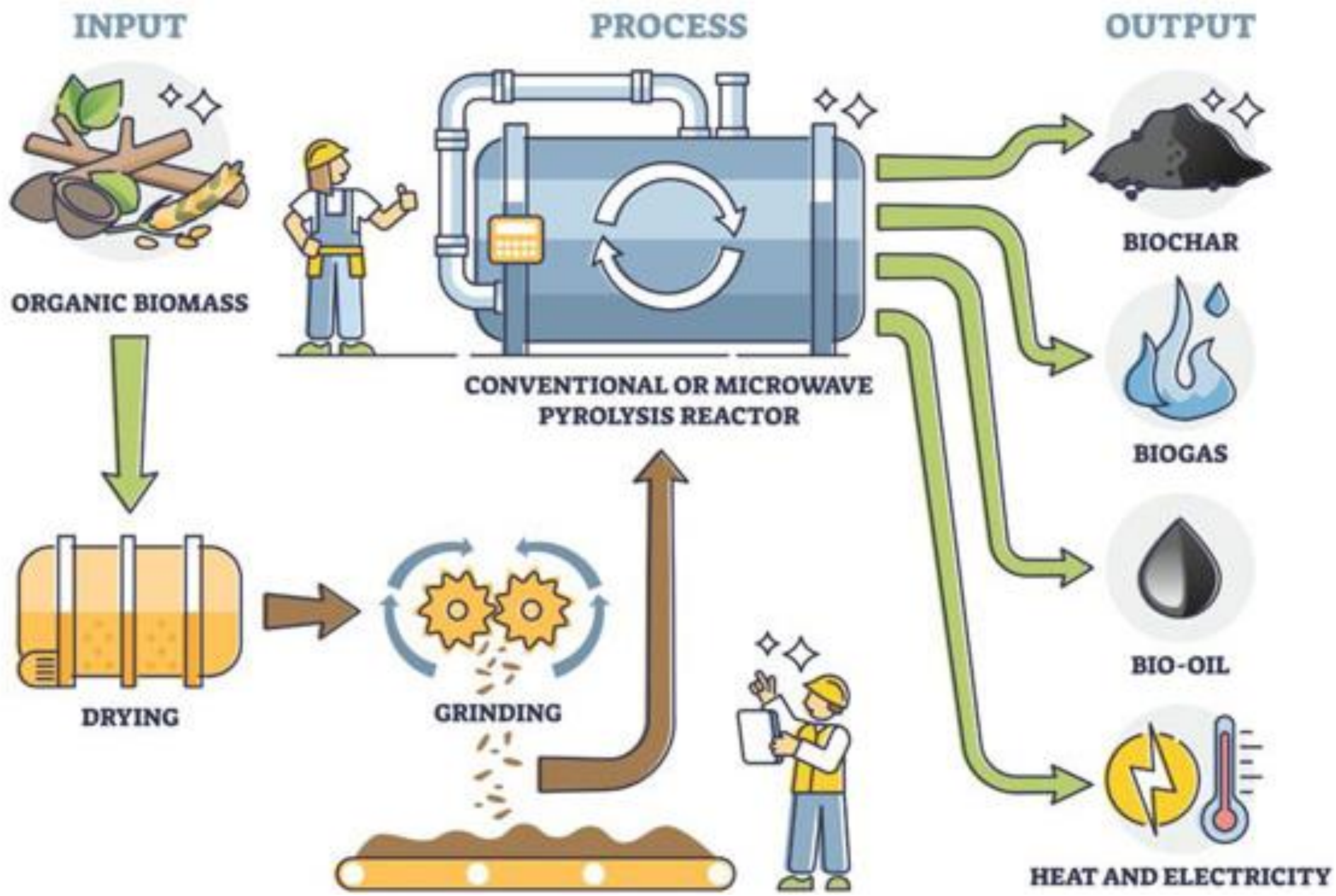
Biochar: Sources

Biochar: Sizes

Mean particle size (cm)	0.985	0.6	0.35	0.2	< 0.1

Biochar: Process

- Wood, crop residues, or manure are used as the feedstock.
- Dried and ground into smaller pieces.
- Heated without oxygen (pyrolysis) at 300° C to 700° C.
- Pyrolysis creates biochar, plus bio-oil and biogas, which can be used for energy.



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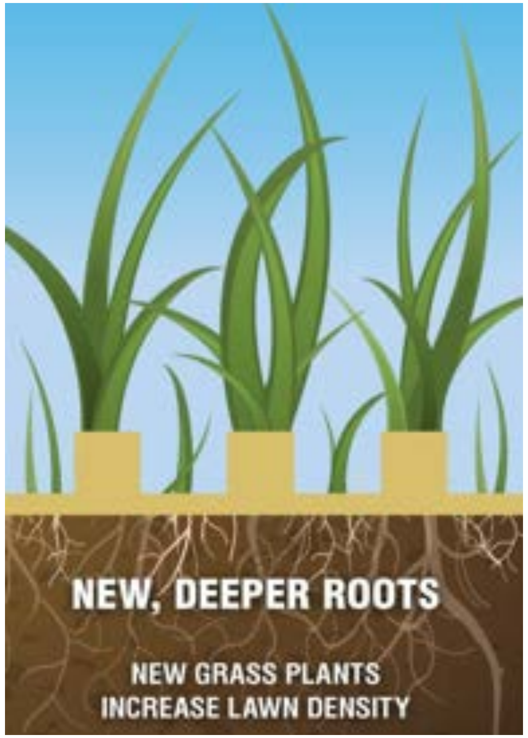
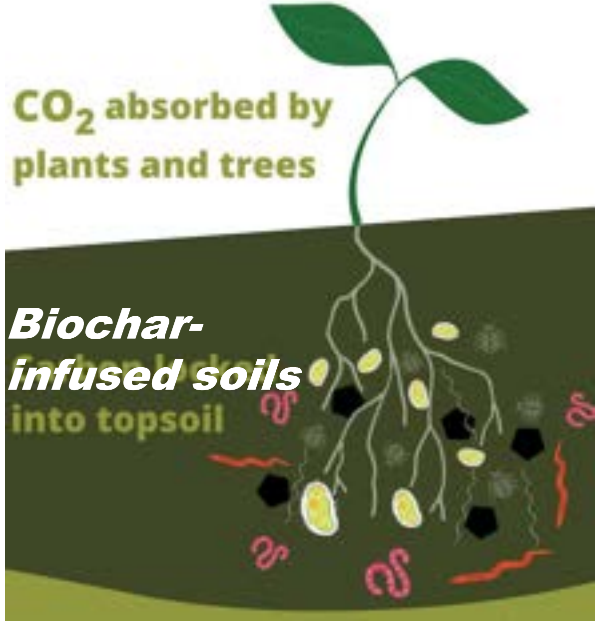
Biochar: Transportation Applications



Composting

Soil Stabilization



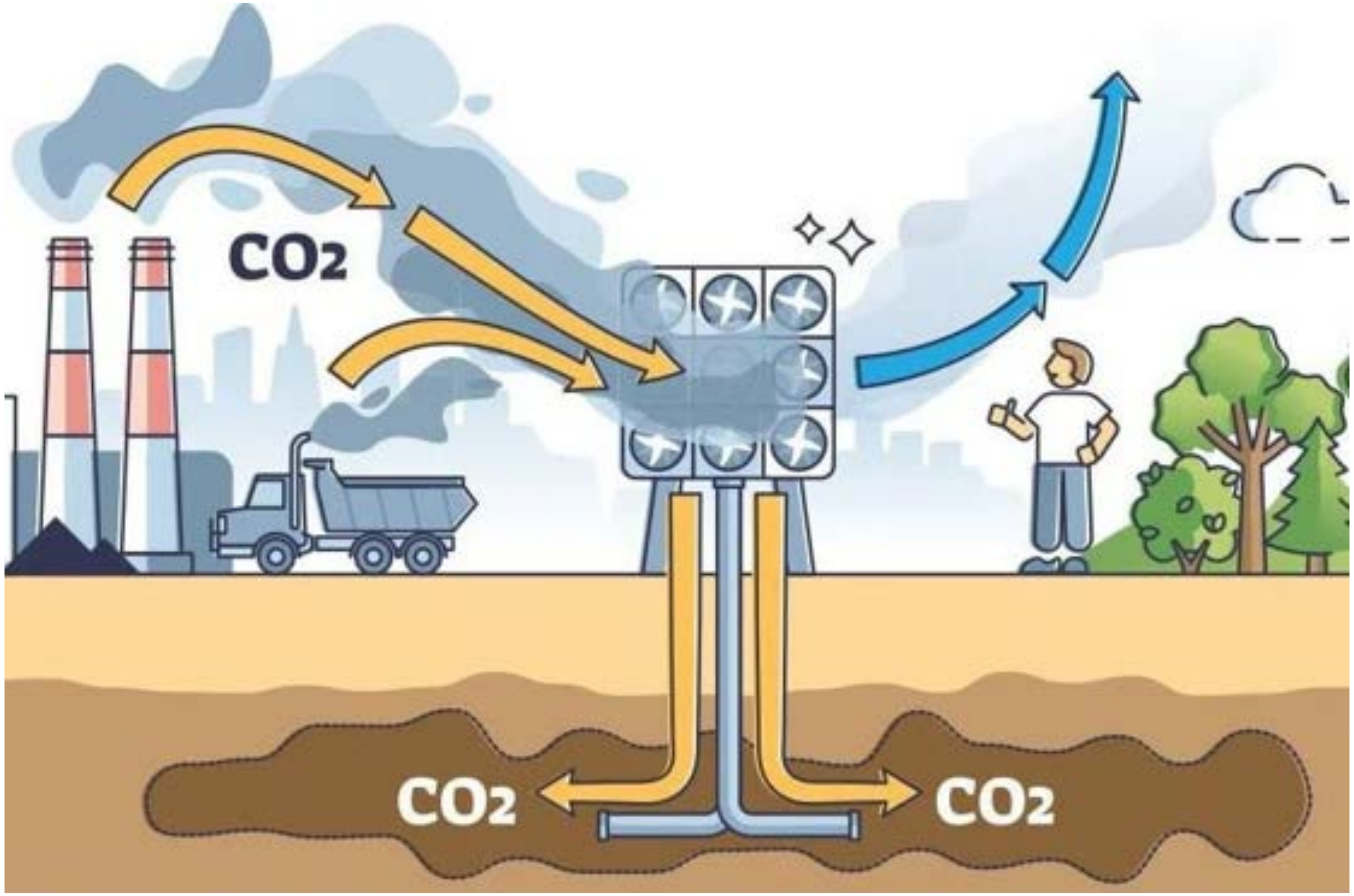
Carbon Sink

Water Treatment

Biogas

Biochar: Carbon Capture

- Biochar serves as a carbon sink by absorbing carbon from the atmosphere.
- The biochar was able to suck up to 23% of its weight in carbon dioxide from the air while still reaching a strength comparable to ordinary cement.



Objectives

- Utilize of Biochar as a partial replacement for aggregates in concrete production.
- Assess the practical feasibility of biochar-incorporated concrete in real-world construction scenarios.
- Reduce the environmental footprint of concrete while maintaining or even enhancing its performance characteristics.

Mix Design

- NJDOT Compressive Strength Specifications
- A standard Class B concrete mixture was selected

Table 903.03.06-3 Mix Design Requirements

	Class A	Class B	Class S	Class P	Class P-1	Class P-2
Class Design Strength[2] (28 days, psi)	4600	3700	2000	5500	6000	6500
Verification Strength[2] (28 days, psi)	5400	4500	–	6000	6500	7000
Maximum Water-Cement Ratio[3] (lb/lb)	0.443	0.488	0.577	0.400	0.400	0.400
Minimum Cement Content (lb/cy)	611	564	658	1	1	1

1. According to *PCI MNL-116.*
2. Record all concrete test results to the nearest 10 psi.
3. When a Type F or G water-reducing, high range admixture is used as specified in Table 903.03.06-1 and Table 903.03.06-2, reduce the maximum water-cement ratio by 0.043 for all classes of concrete except for Classes P, P-1, and P-2.

Base Mix (100% Portland Cement)

Component	Units	Weight	Specific Gravity
Cement	lbs./CY	660	3.15
Fly Ash	lbs./CY	0	2.50
Coarse Aggregate	lbs./CY	1719	3.01
Normal Fine Aggregate	lbs./CY	1390	2.636
Biochar	lbs./CY	0	1.16
Water	lbs./CY	320	1.00
W/C	N/A	0.48	

Concrete Properties?

(1) Workability

(2) Air Content

(3) Density

(4) Strength

Replacement (weight, or Volume)?

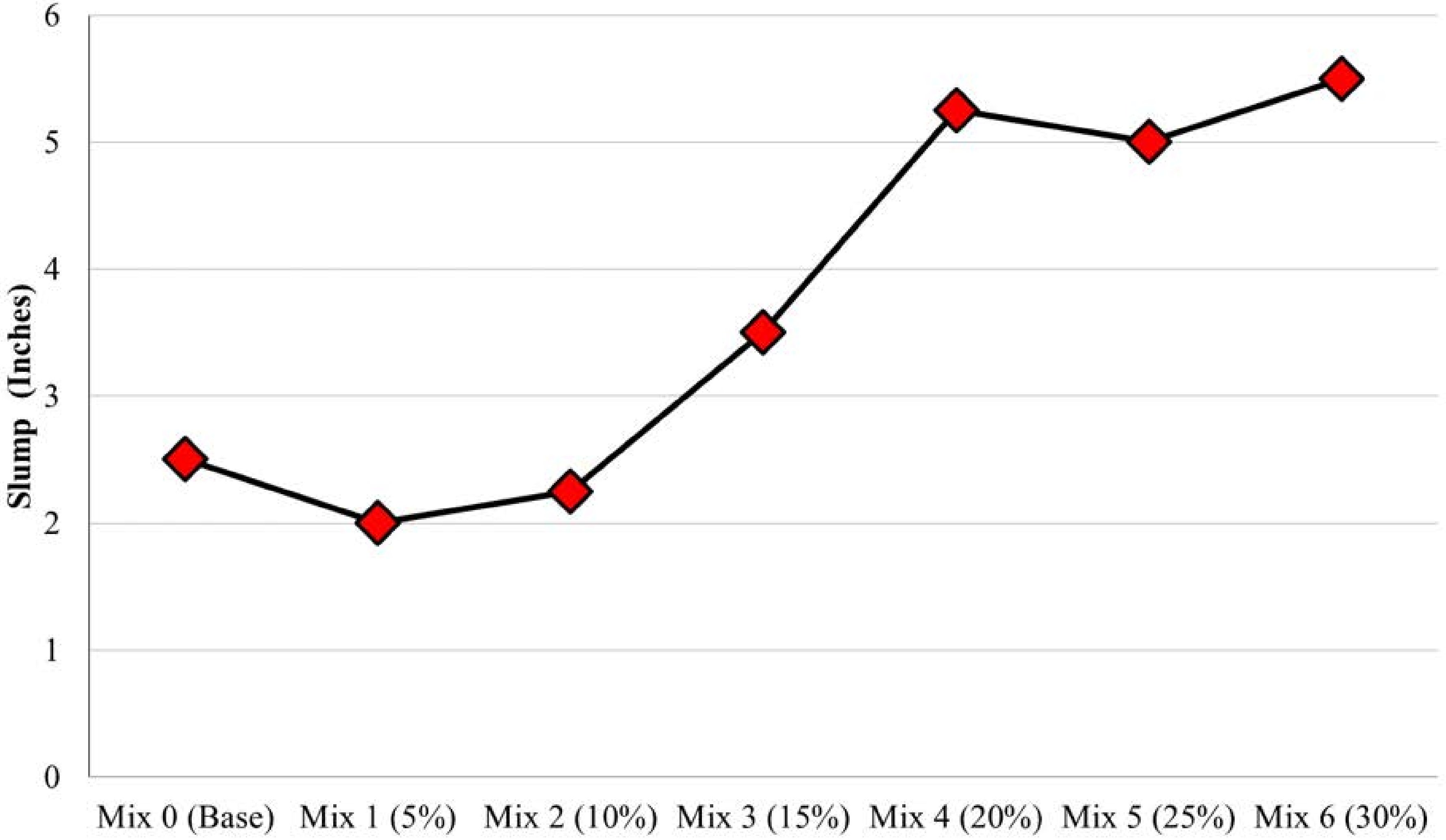
(1) Fine Aggregate

~~(2) Cement~~ (promising results not included in this presentation)

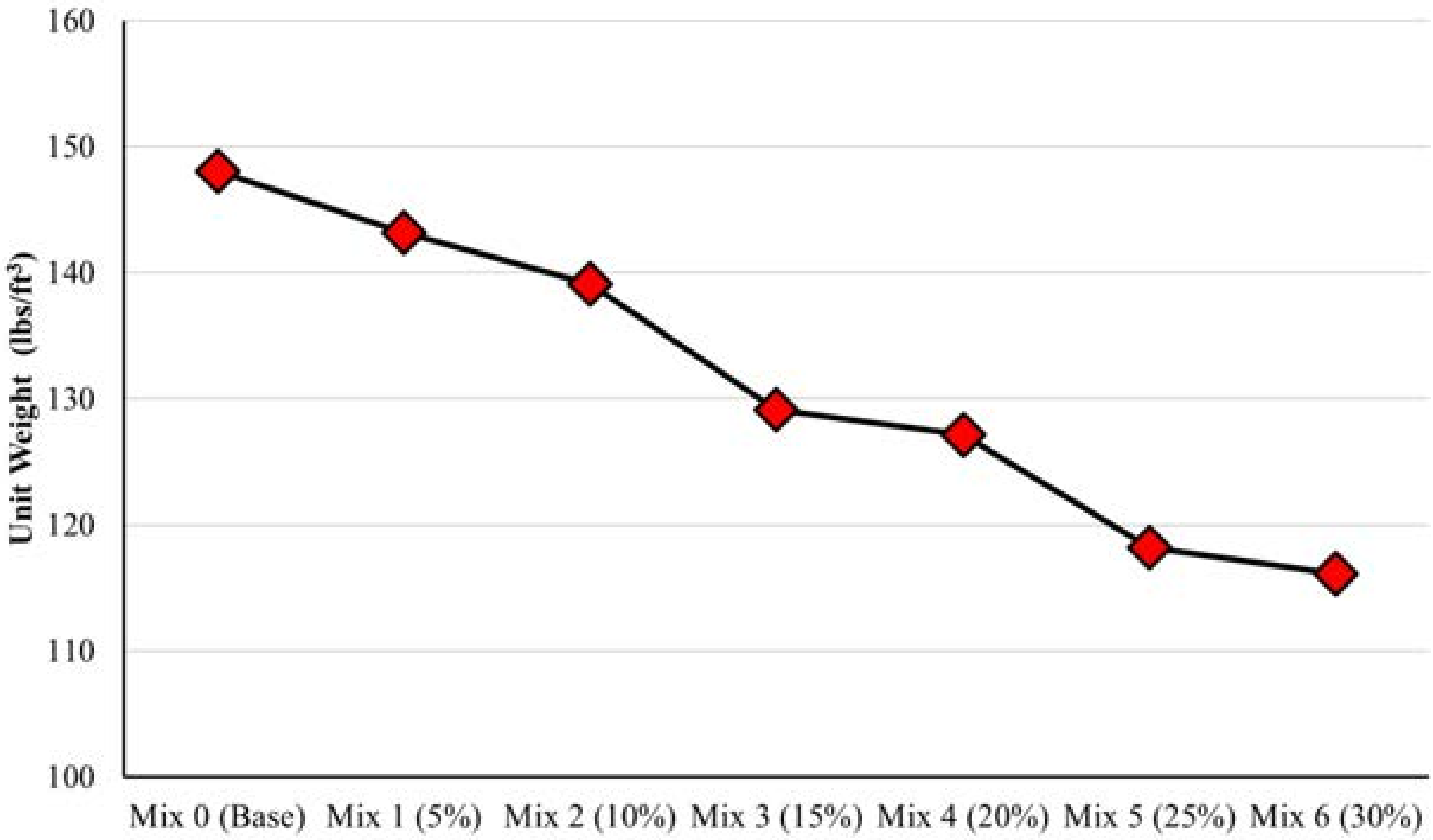
Fresh and Hardened Concrete Tests

Parameter	Test Method	Material State
Slump	ASTM C143/C143M	Fresh
Air Content	ASTM C231/C231M	
Density	ASTM C138	
Compressive Strength at 7, 21, 28, and 56 days	ASTM C109/C109M	Hardened

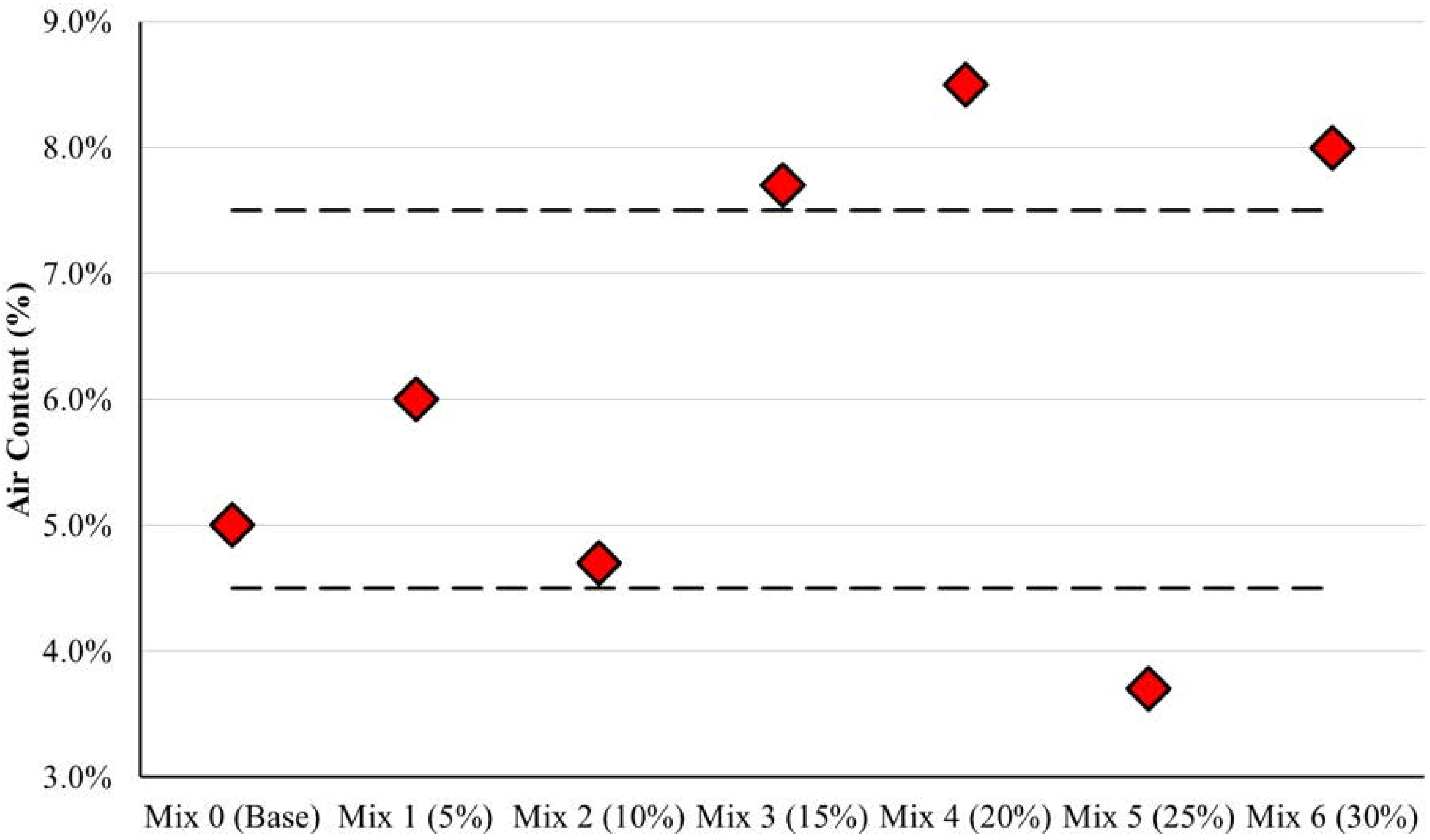
Test Results: Sump Test Results



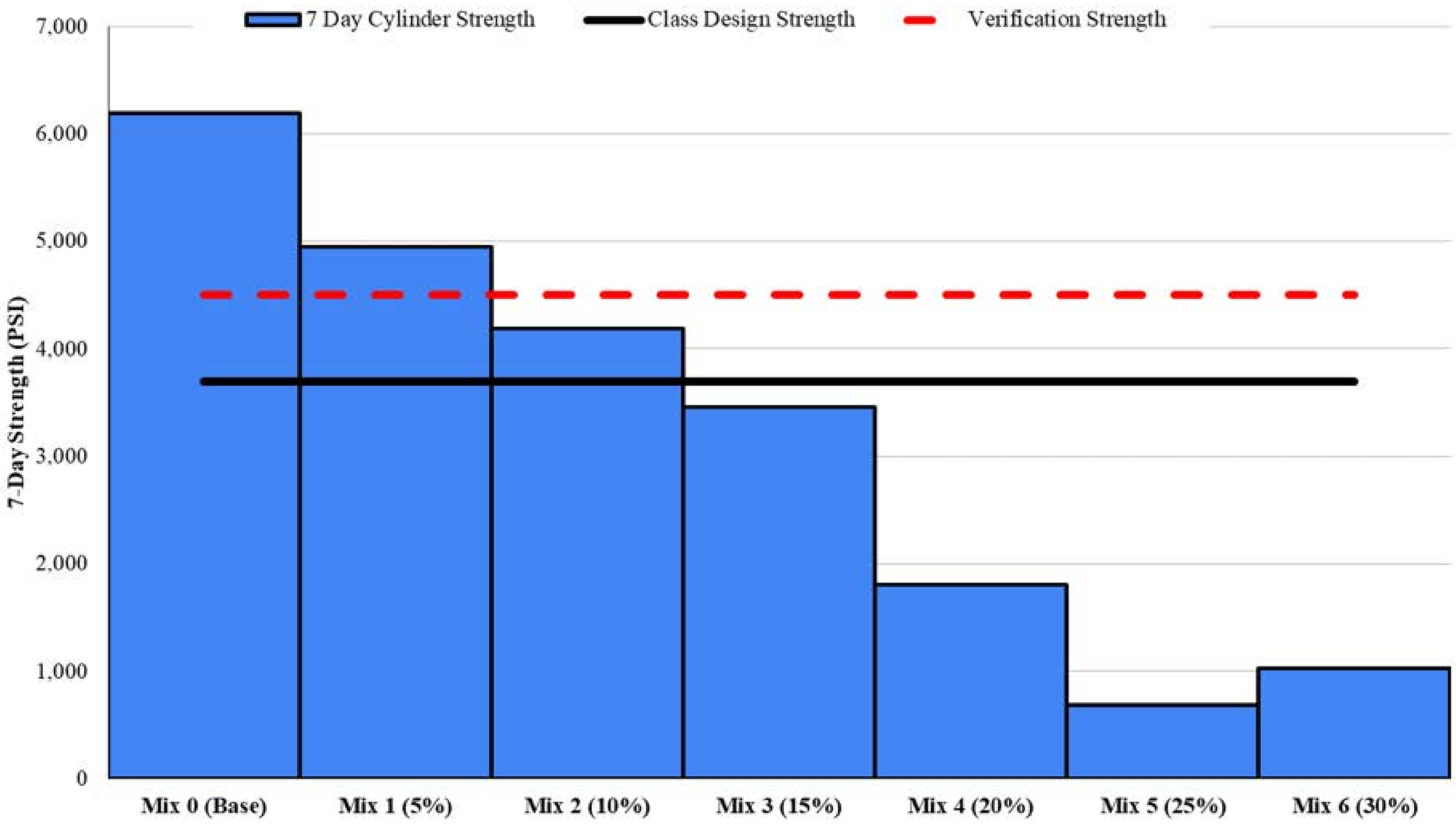
Test Results: Density



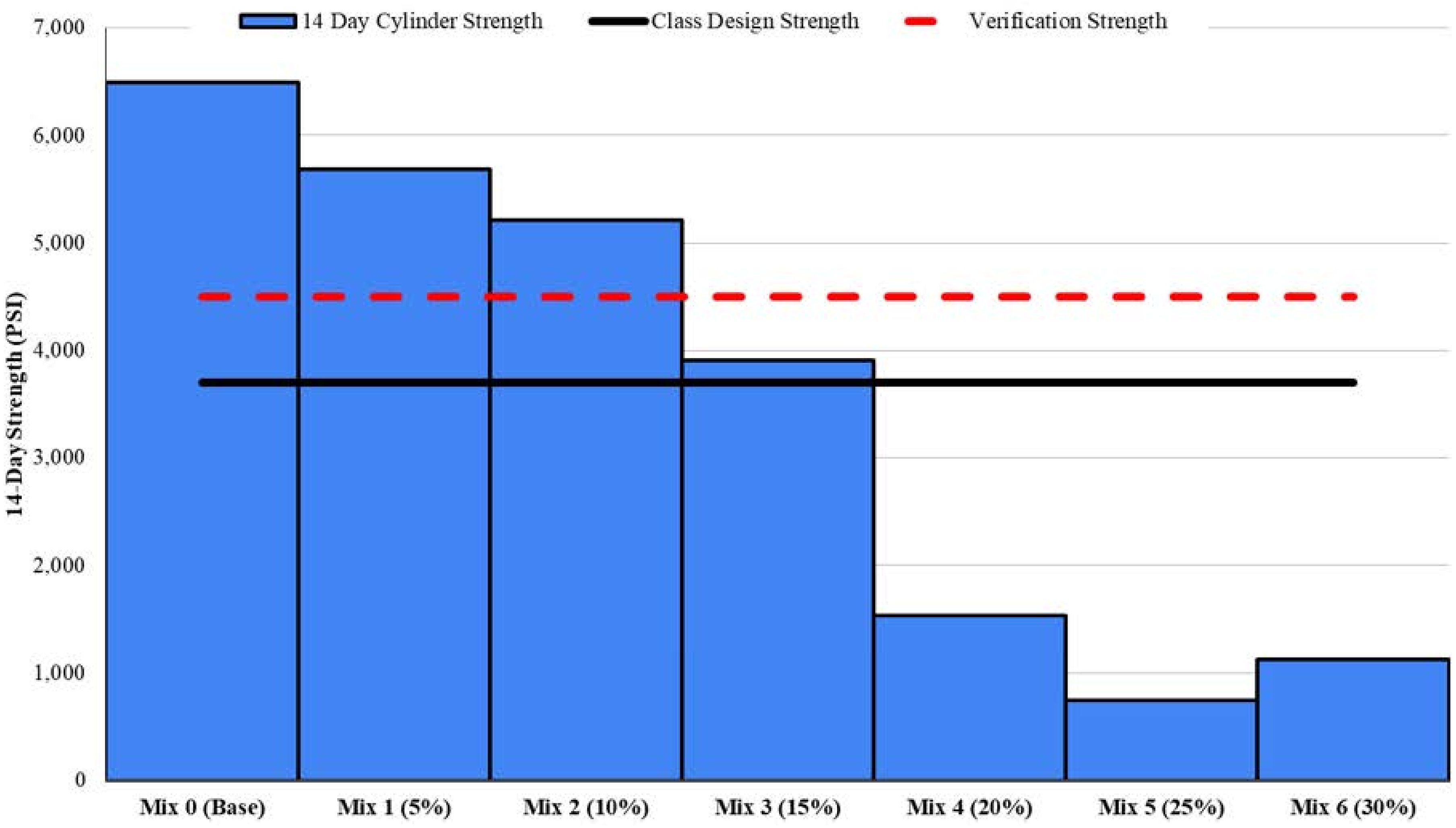
Test Results: Air Content Test Results



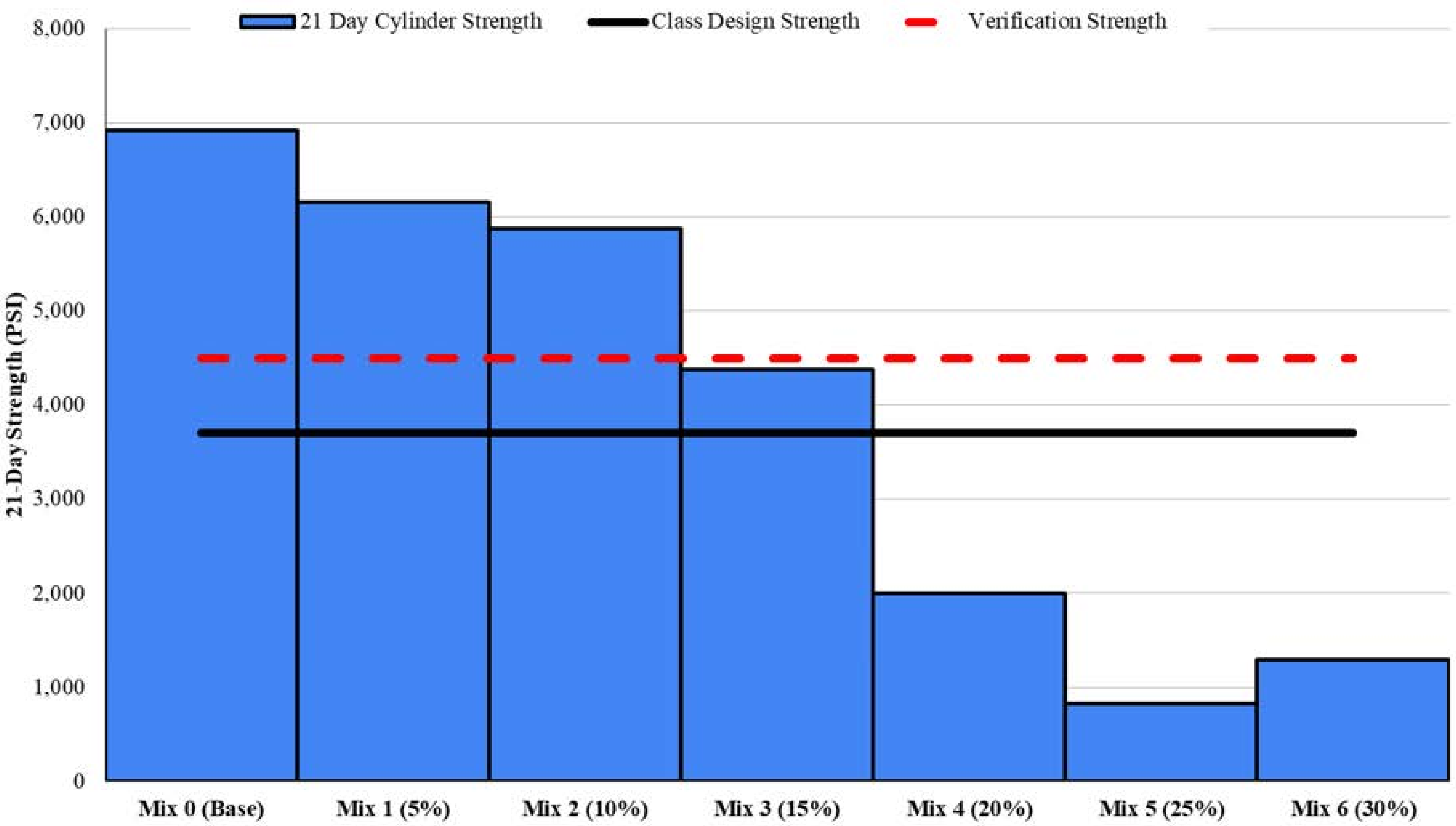
Test Results: 7-Day Compressive Strength



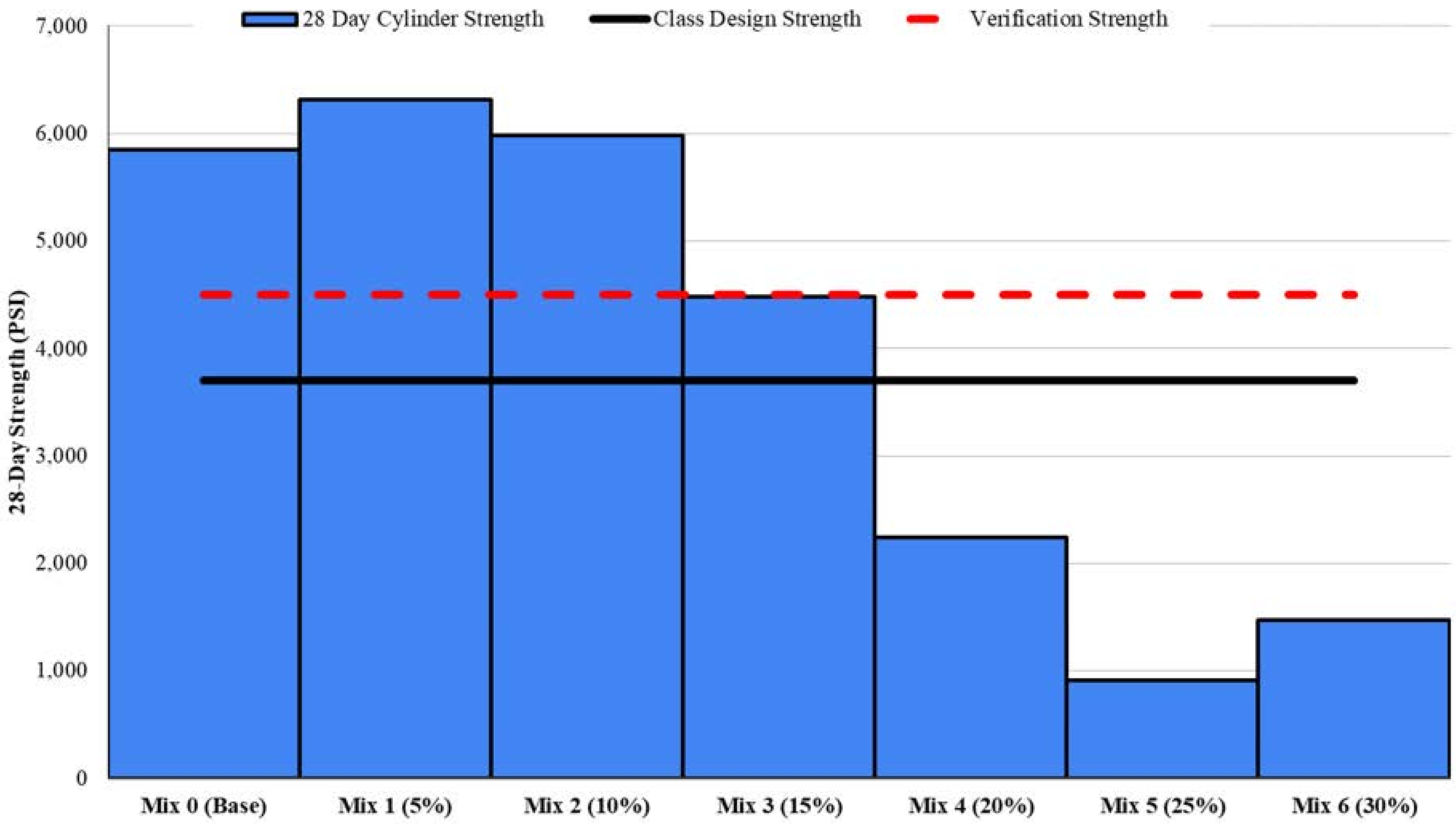
Test Results: 14-Day Compressive Strength



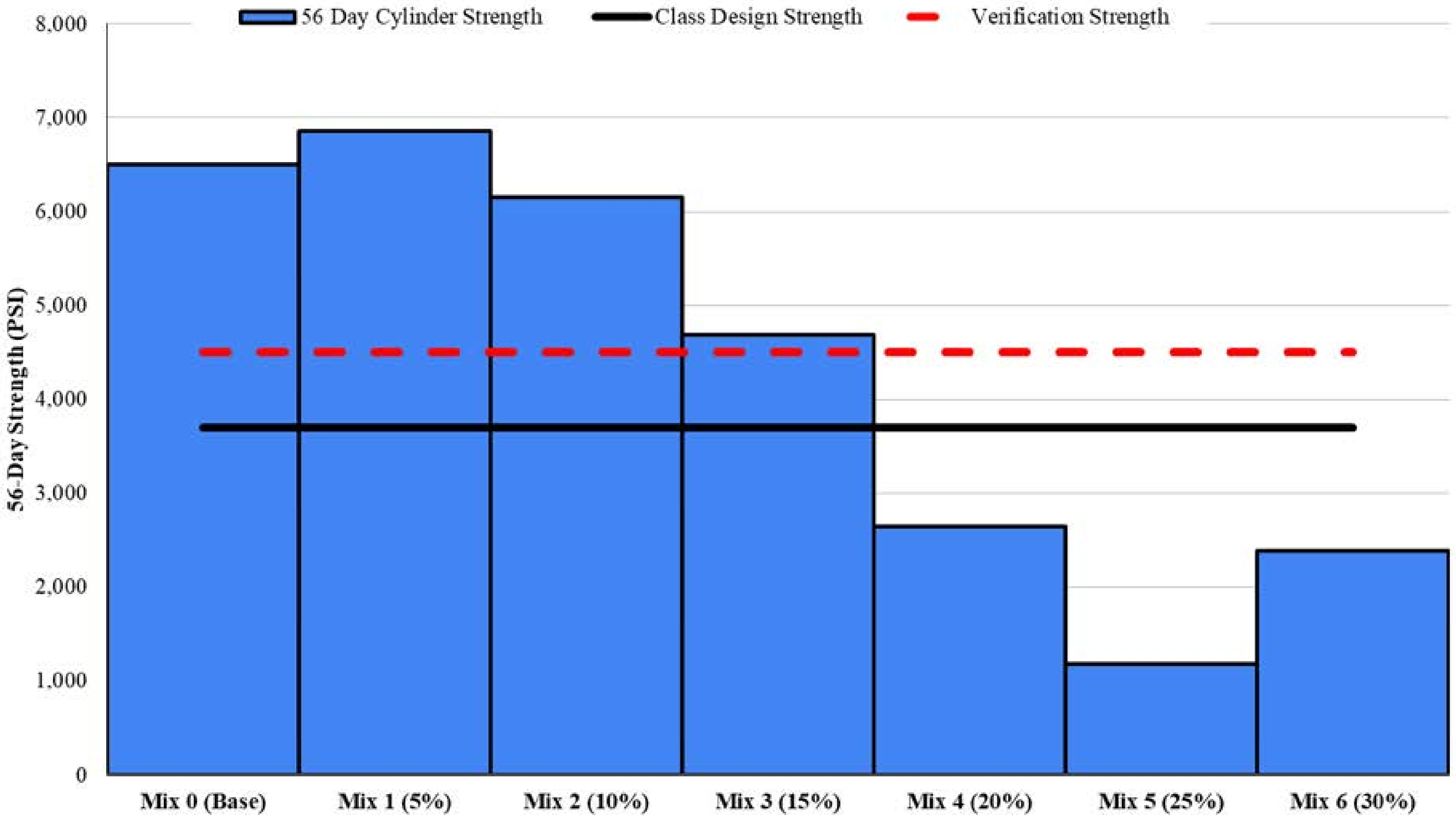
Test Results: 21-Day Compressive Strength



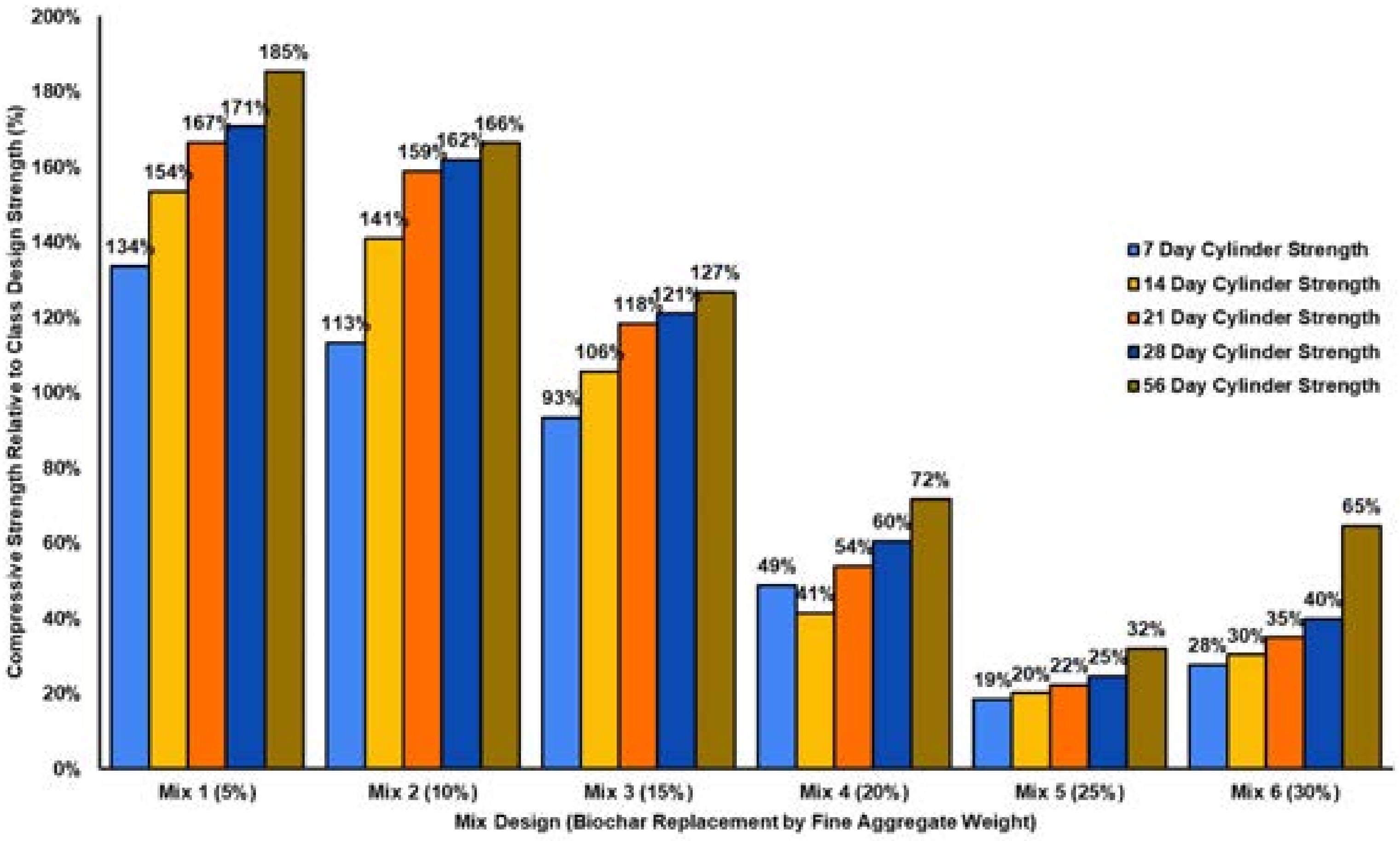
Test Results: 28-Day Compressive Strength



Test Results: 56-Day Compressive Strength



Test Results: Compressive Strength, comparison



Conclusion

- Biochar absorption varies due to material source differences, impacting uniformity.
- Biochar concentrations up to 15% as a fine aggregate replacement have met or exceeded strength requirements.
- High Biochar Content as Partial Replacement for Cement and Fine Aggregate has many lower strength applications (i.e. CLSM, non-structural concrete)
- High-quality biochar (90%) and less fly ash produce lighter, stronger carbon-based concrete.

Conclusion

- Internal curing of biochar assisted the cement hydration process by absorbing and releasing water.
- A water reducer is recommended to counteract biochar’s higher absorption rates.
- The higher biochar content and increased air content levels.

In the Works

(1) Cement Replacement (Fine Biochar)

(2) Both Fine Aggregate and Cement Replacement

(3) Environmental Life Cycle Assessment (LCA)

(4) Durability Assessment of (1) and (2)

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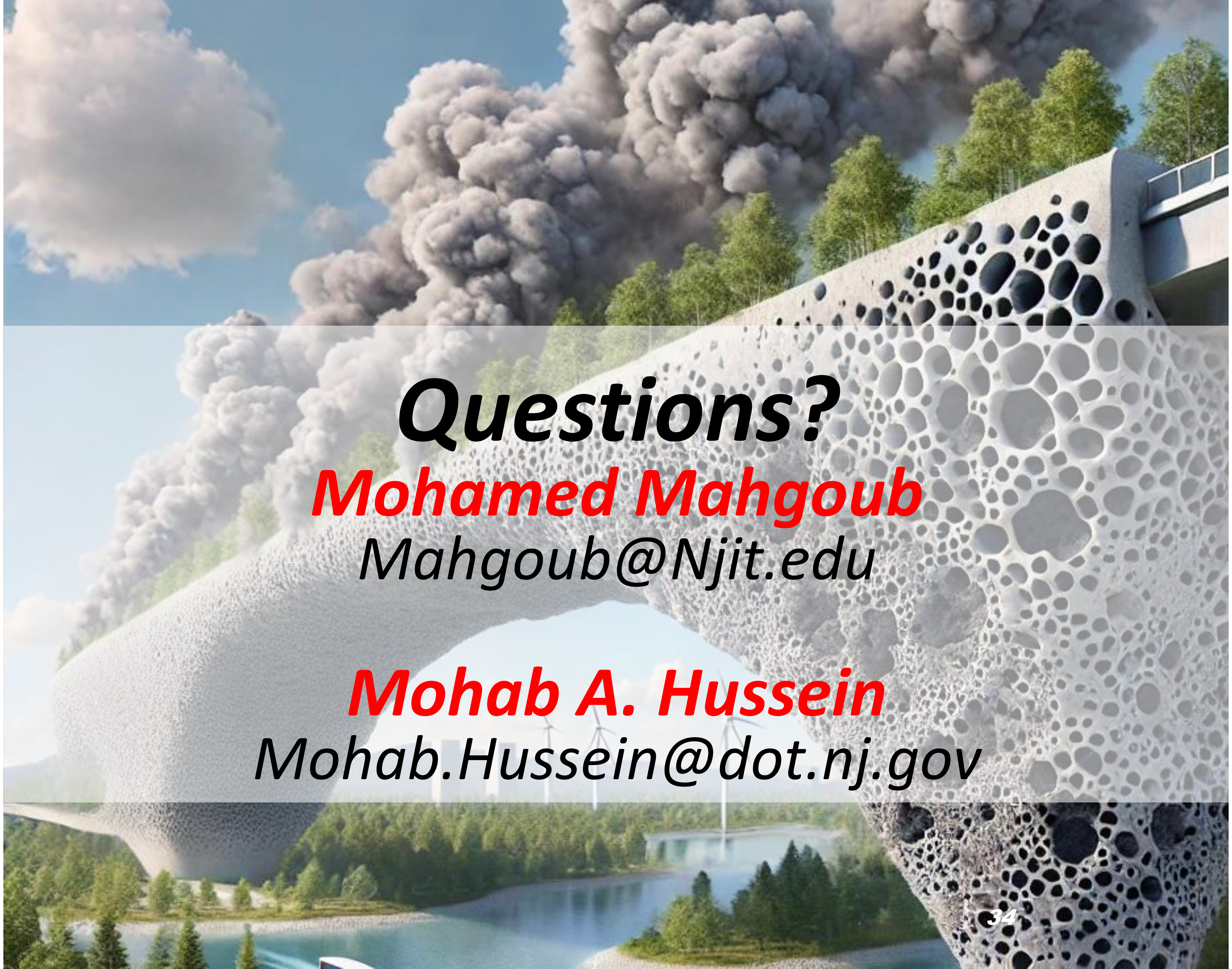

Questions?

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