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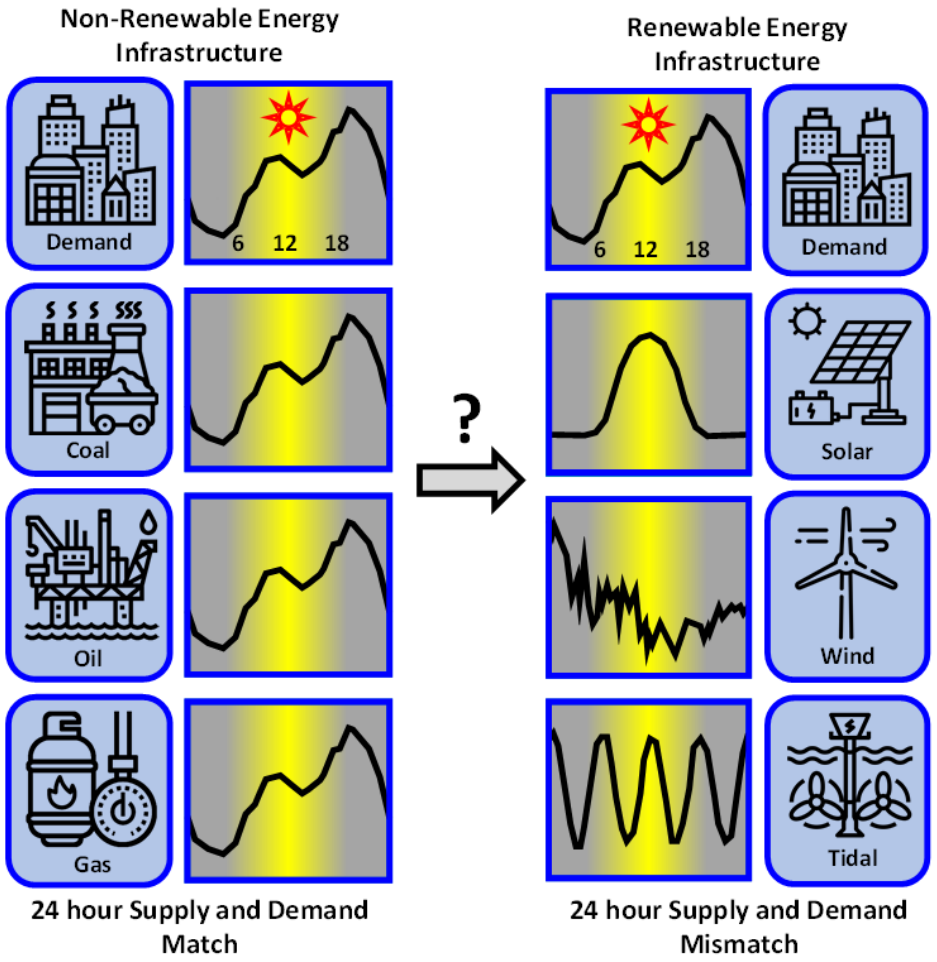
Concrete Innovations Session 30 Webinar
June 18th, 2025

Concrete as a Carbon Sink: Cement Carbonation Tracking and the Rise of Multifunctional Concrete

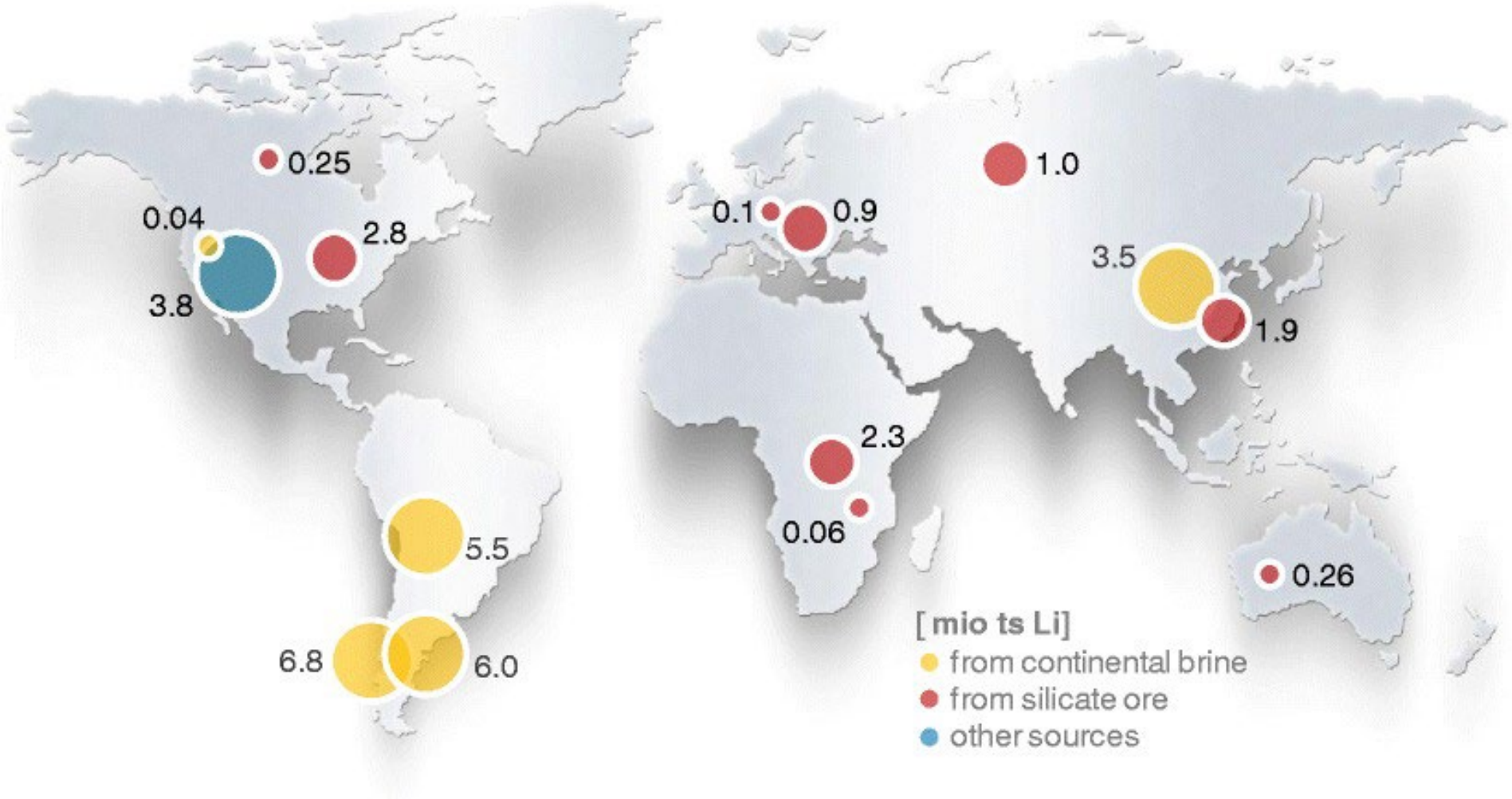
Massachusetts Institute of Technology | Civil and Environmental Engineering | Masic Lab @ MIT | CSHub MIT Concrete Sustainability Hub | MIT ec^3 hub

Challenge #1: Energy storage challenge



The pace of the transition from fossil fuel-based economy to a renewable energy economy will strongly depend on the availability of bulk energy storage solutions

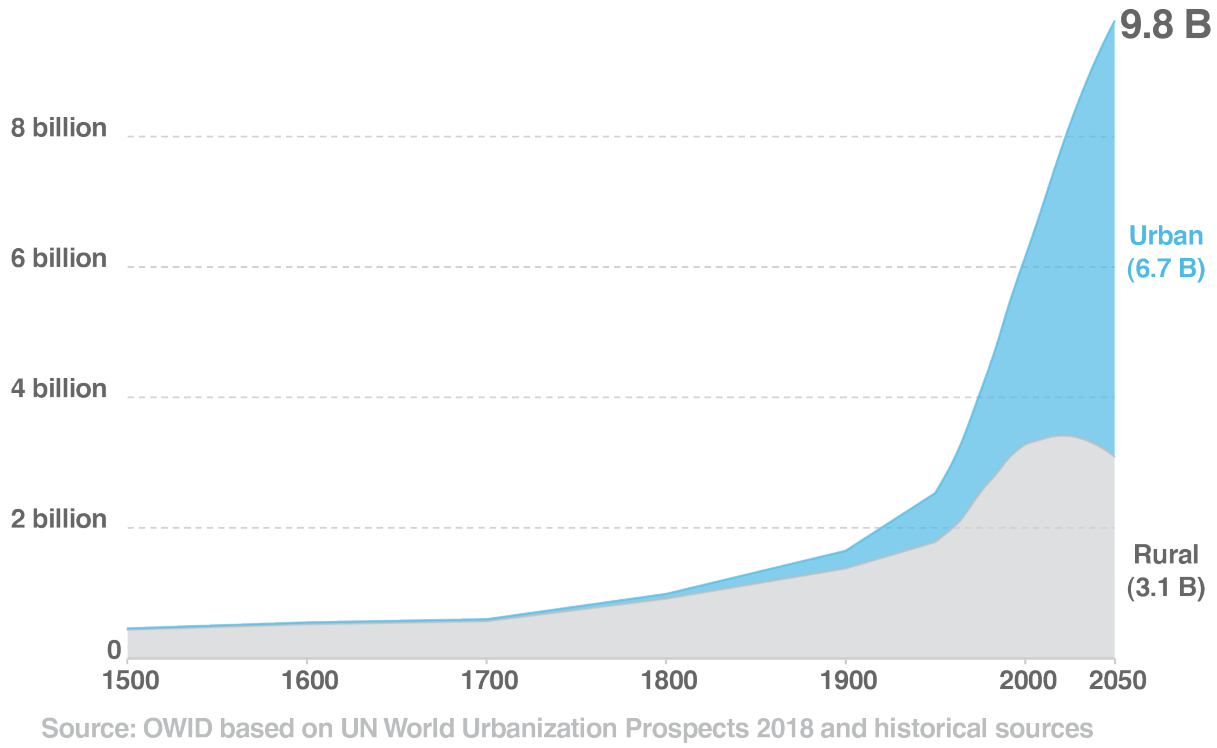
The problem: minerals for batteries are scarce



NEED SCALABLE ENERGY STORAGE SOLUTION, EVERYWHERE AVAILABLE, WHICH EVERYONE CAN USE...

Challenge #2: The use of concrete is increasing exponentially

- **6.7 billion** people are projected to live in **urban areas** by 2050

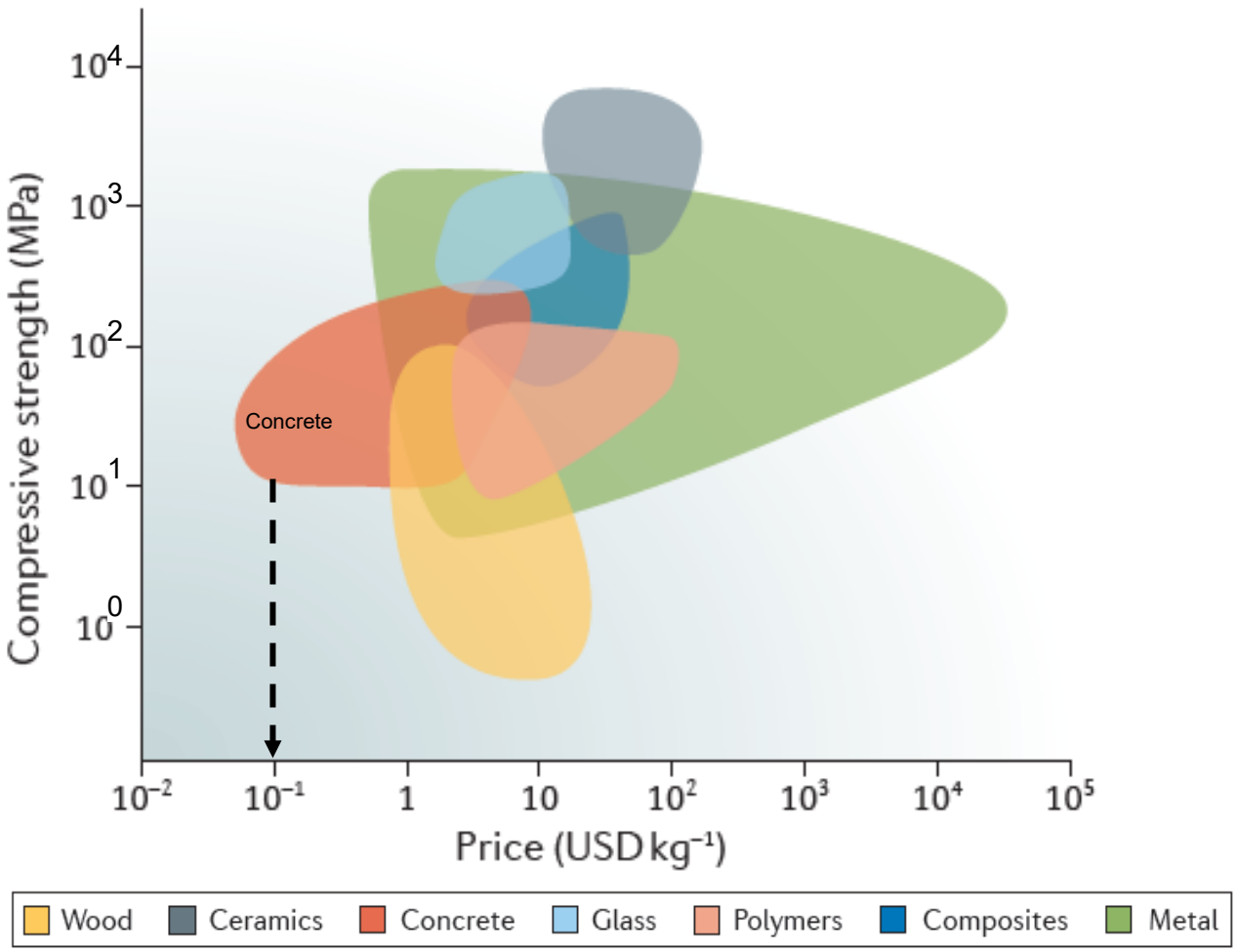


Source: OWID based on UN World Urbanization Prospects 2018 and historical sources

- Need to build **~13,000 buildings everyday** to support the exploding urban population

Boston, Tokyo, Seoul, Rio, Mumbai, LA

UN World Urbanization Prospects (2018)
IEA Technology Roadmap (2018)
Bertollini, Here's What Building the Future Looks Like for a 10-Billion-Person Planet, *Redshift* (2018)



Bechthold, M. & Weaver, J. C. Materials science and architecture. Nat. Rev. Mater. 2, 17082 (2017).

Concrete is a STRONG, DURABLE, VERSITILE, INEXENSIVE construction material

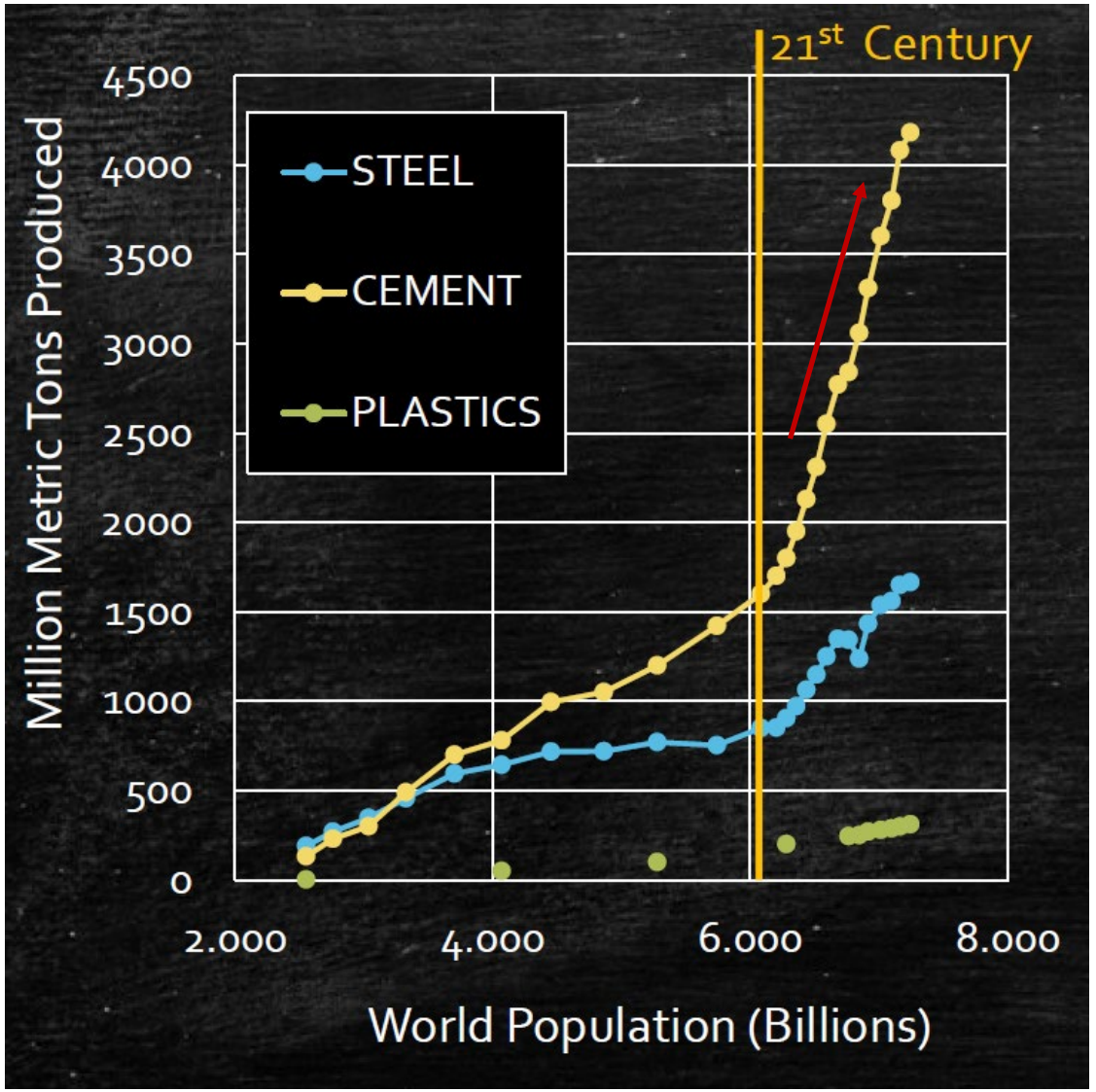
The future of concrete?

1. Concrete = material most produced on planet Earth (commodity). Scalable, availability.
2. Concrete has an environmental problem: around 8% global CO_2 emissions.
3. If Carbon Tax: $150-$200

No Concrete Future… unless

Transform & Disrupt

MATERIAL PRODUCTION/CONSUMPTION

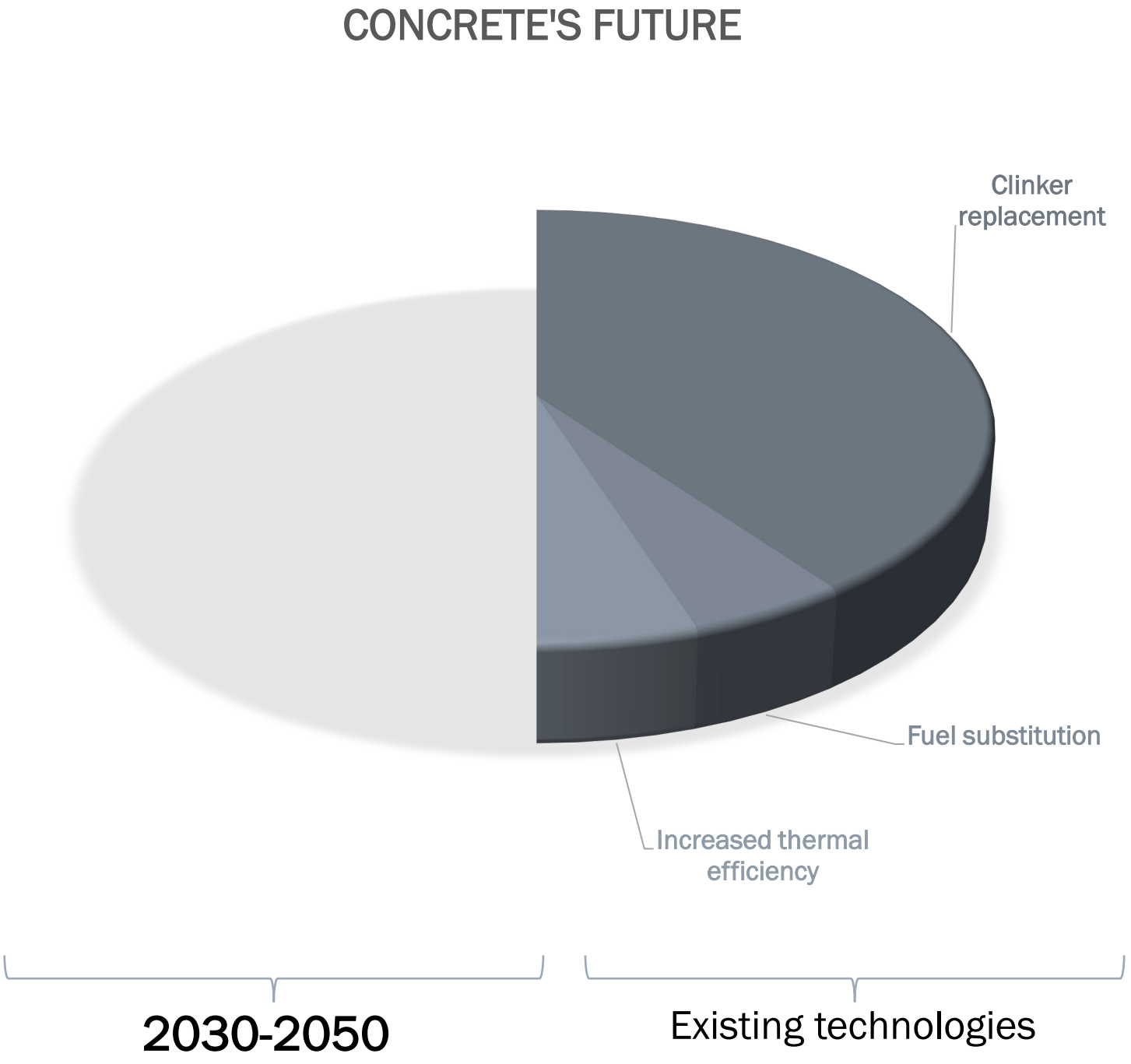


0.89 ton CO_2/ton Cement

3.0 ton CO_2/ton Steel

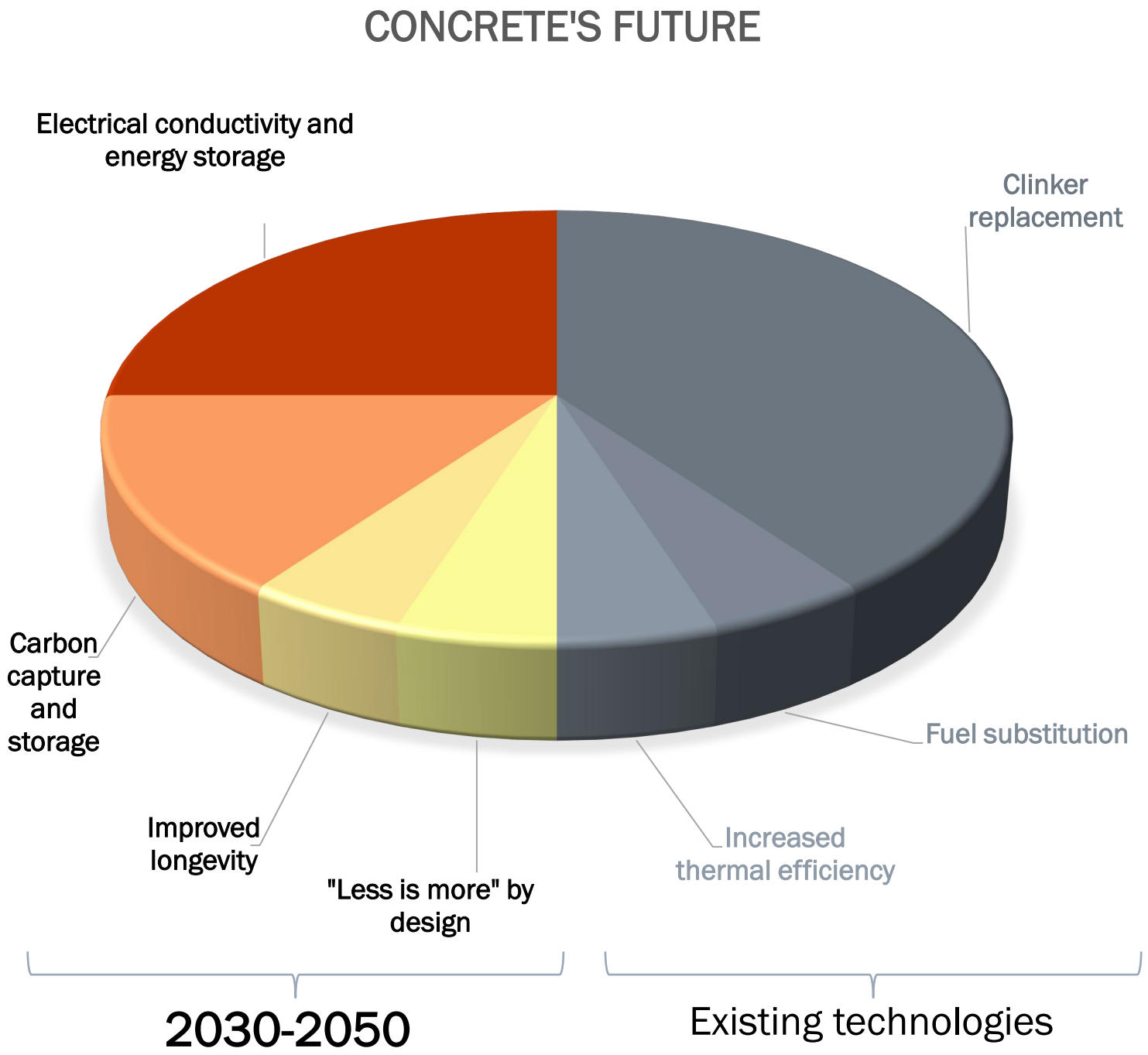
Carbon footprint of cement?

Portland Cement Association released in October 2021 the industries' 2050 carbon neutrality roadmap



CONCRETE'S FUTURE:

Multifunctionality!



Multifunctional concrete

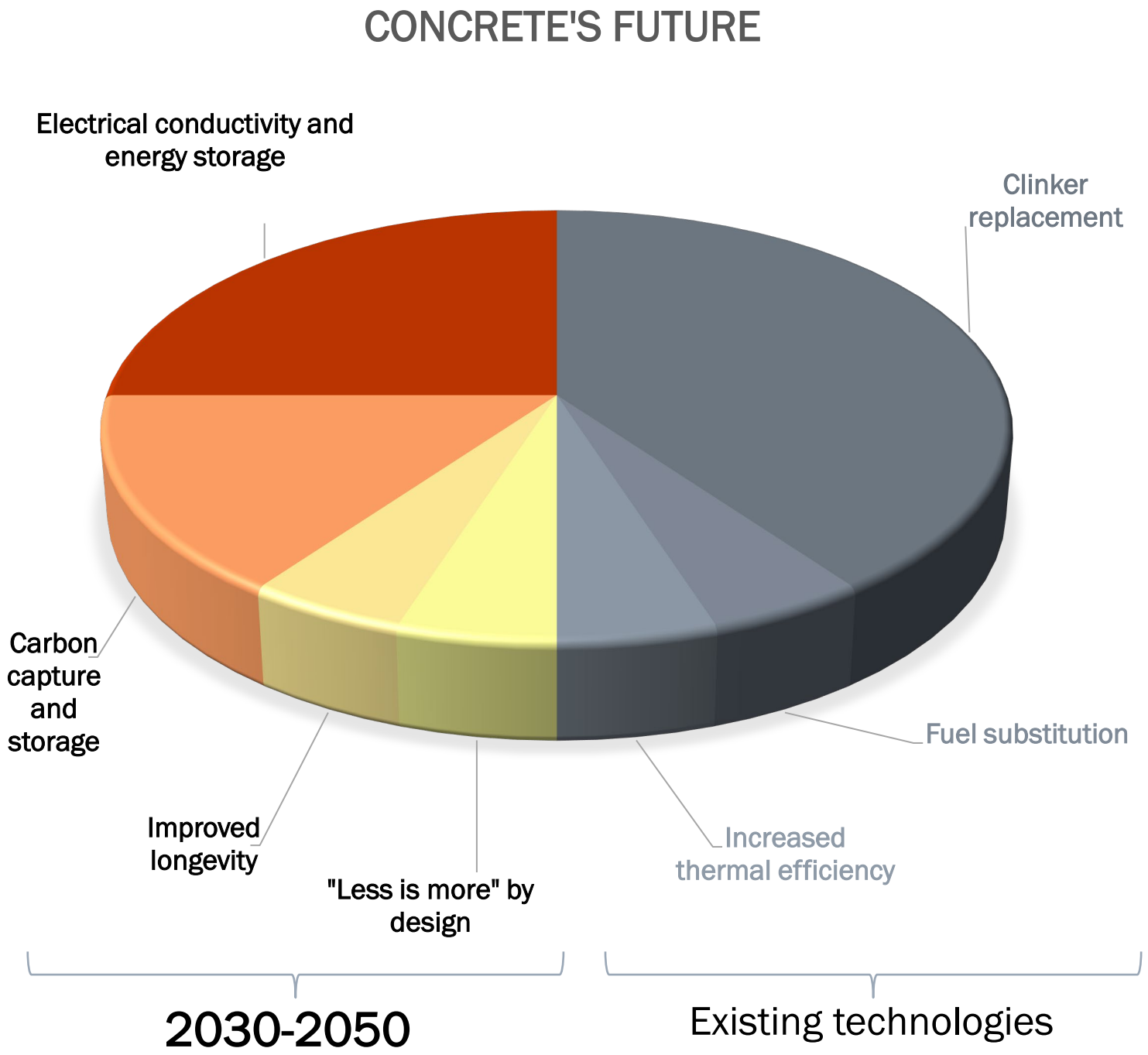
CLIMATE CHANGE

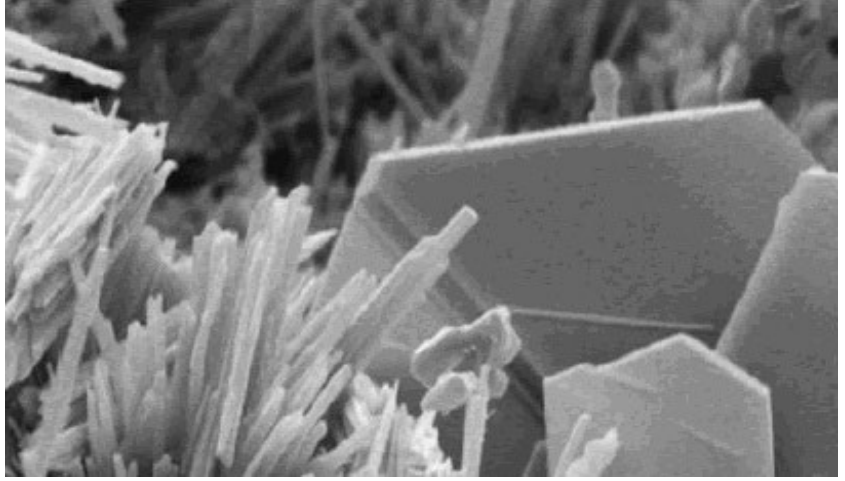
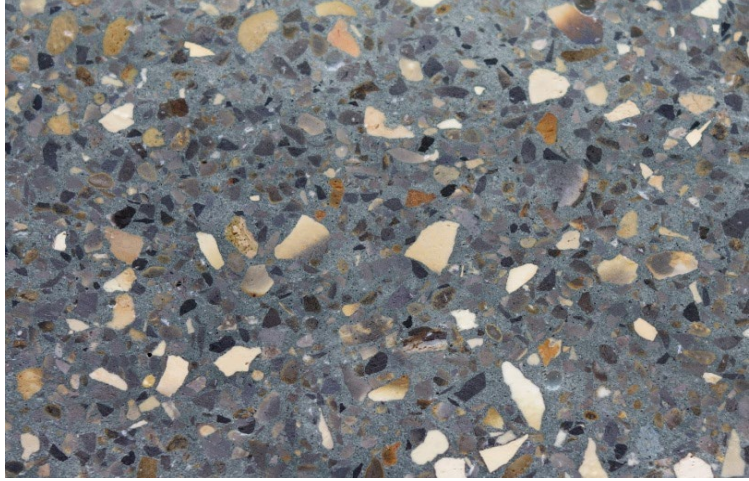
ENERGY TRANSFORMATION

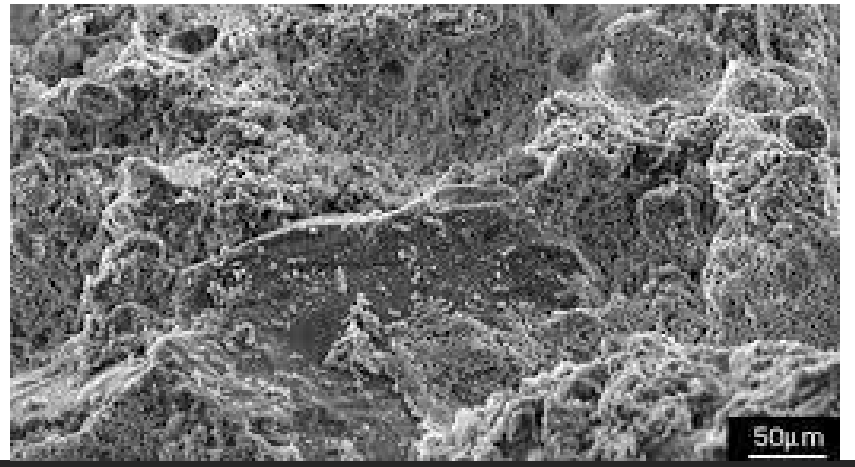
RESILIENCE

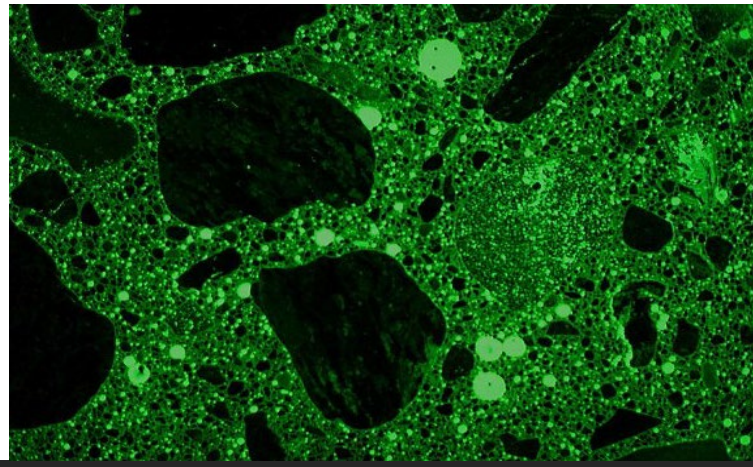
SUSTAINABILITY

SOCIAL JUSTICE



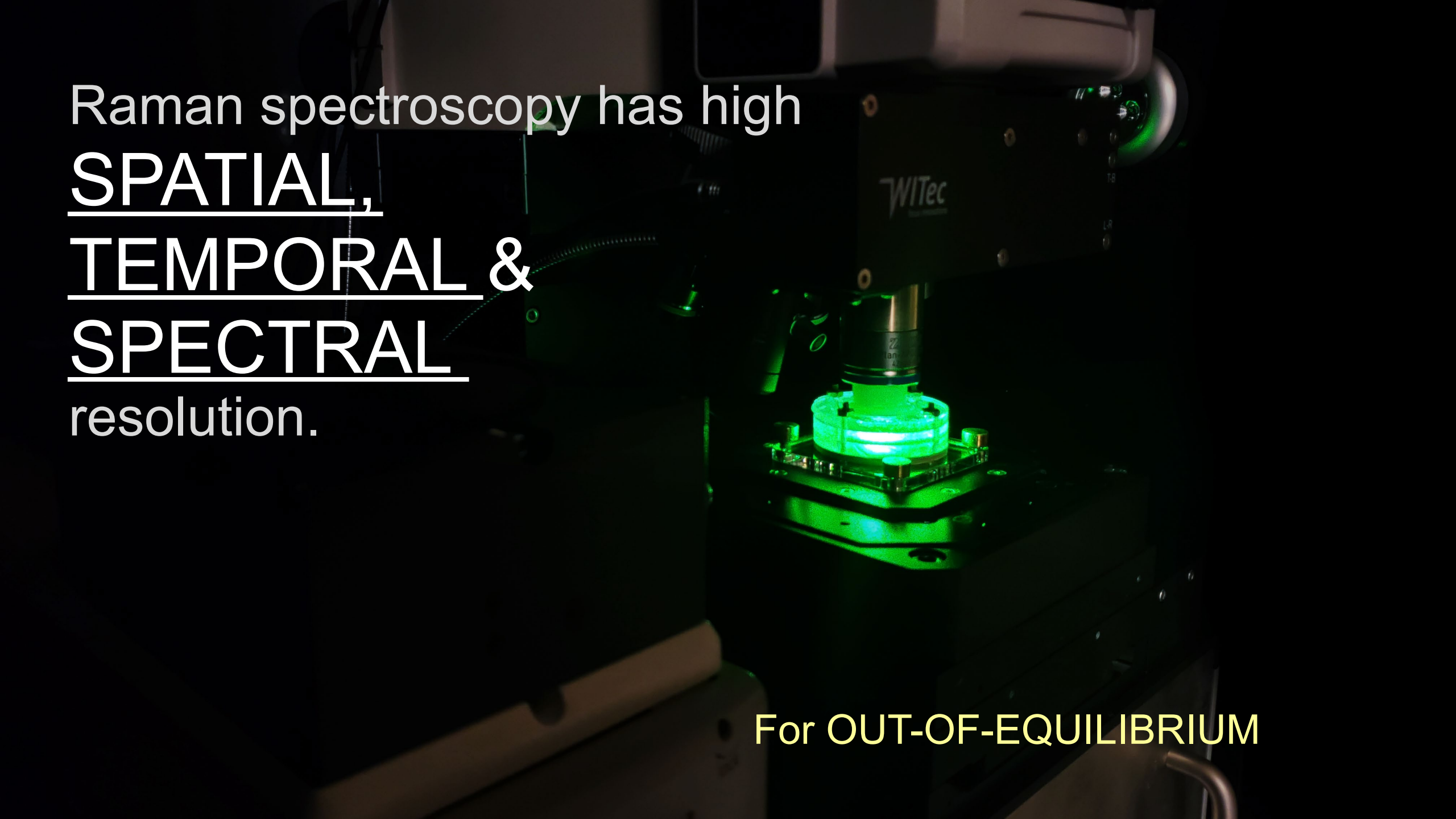




Capitalizing on cement chemistry

Concrete is a remarkably rich deposit of interesting and contemporary research questions, all contained in its ambiguities: granular or continuous?, liquid or solid?, crystalline or glassy?, smooth or rough?, “porous”, brittle or ductile?, material or process?

Henri Van Damme, CCR (2018)



Raman spectroscopy has high

SPATIAL,

TEMPORAL &

SPECTRAL

resolution.

For OUT-OF-EQUILIBRIUM

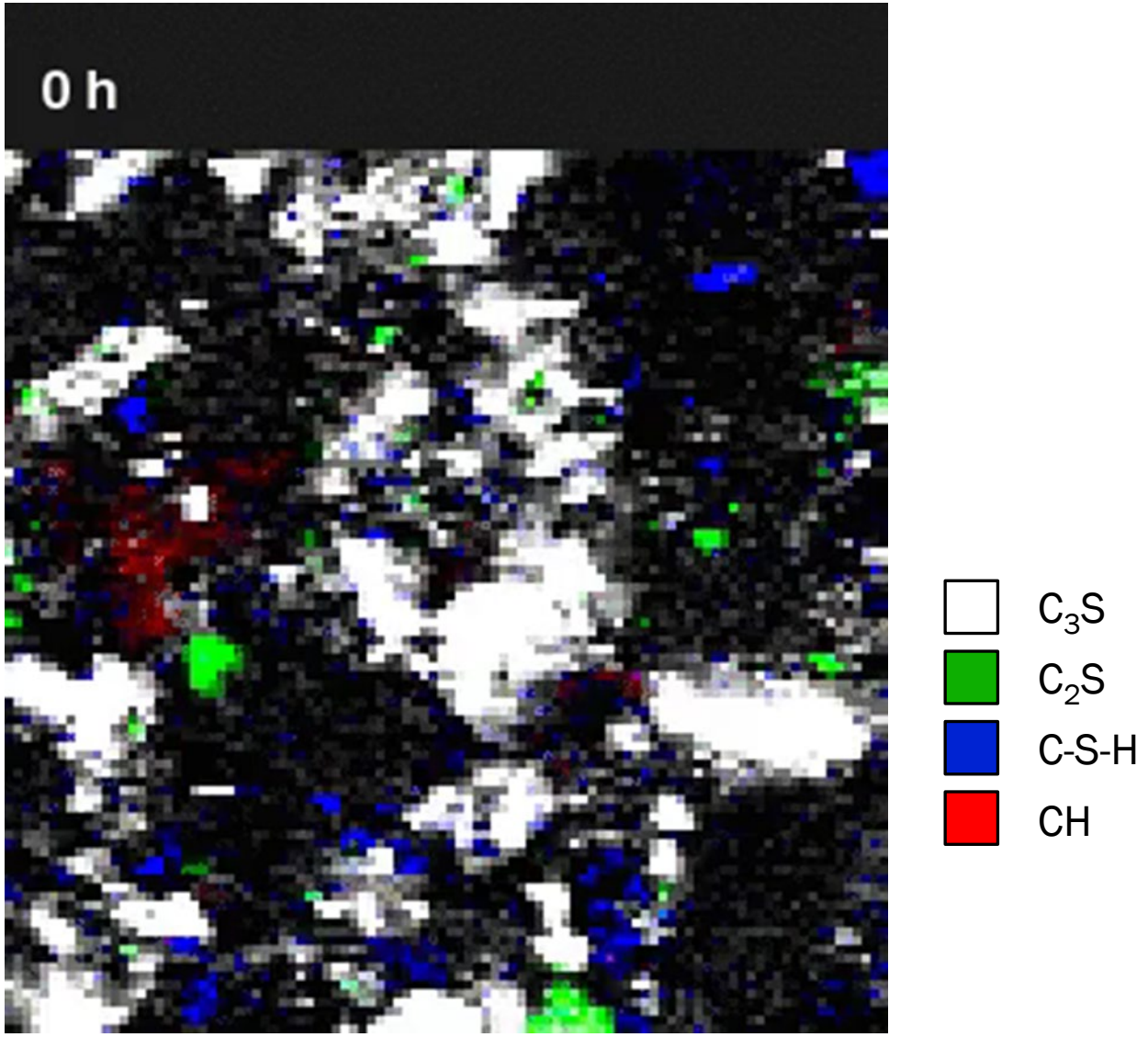
Raman spectroscopy + Cement chemistry

Underwater Raman enabled monitoring in **real-world conditions** with **higher temporal resolution**

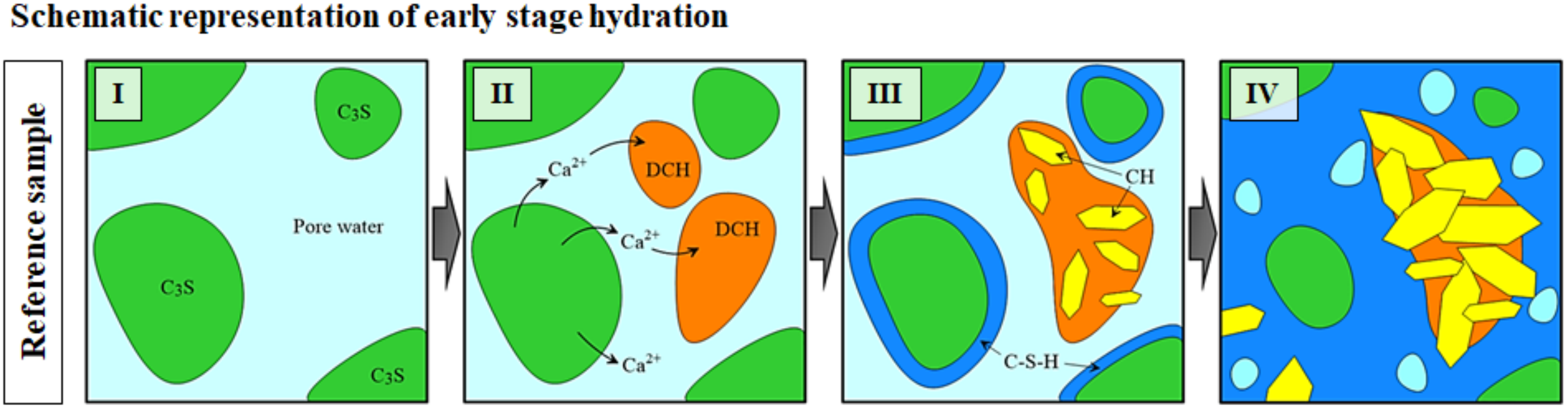
+ Underwater Raman

***Operando* real-world condition**

OPC w/c=0.4



Loh et al., Langmuir (2021)



Loh et al., Langmuir (2021)

Early stages of cement hydration

Discovery of OUT-OF-EQUILIBRIUM/transient phases

Multifunctional concrete

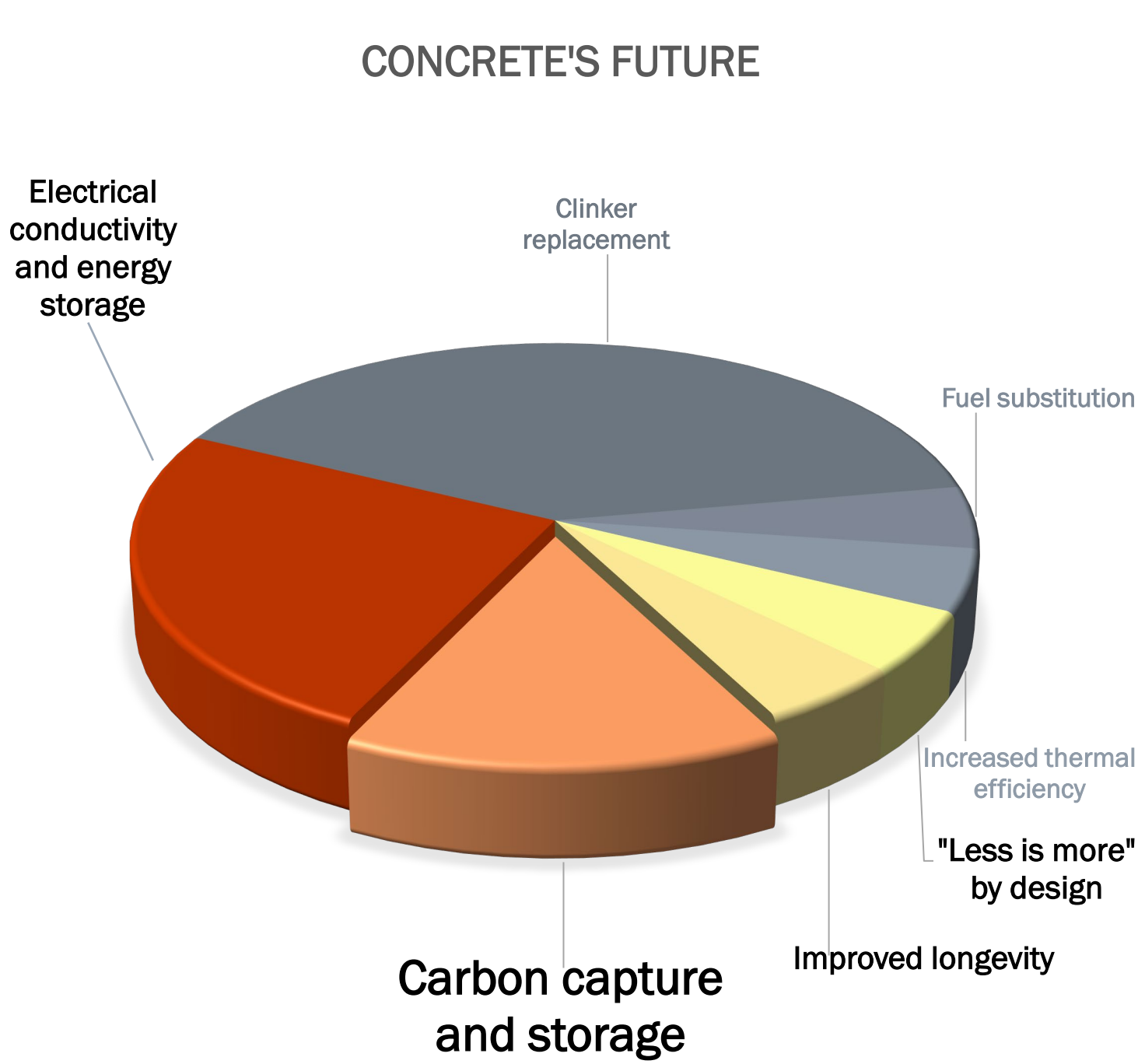
CLIMATE CHANGE

ENERGY TRANSFORMATION

RESILIENCE

SUSTAINABILITY

SOCIAL JUSTICE

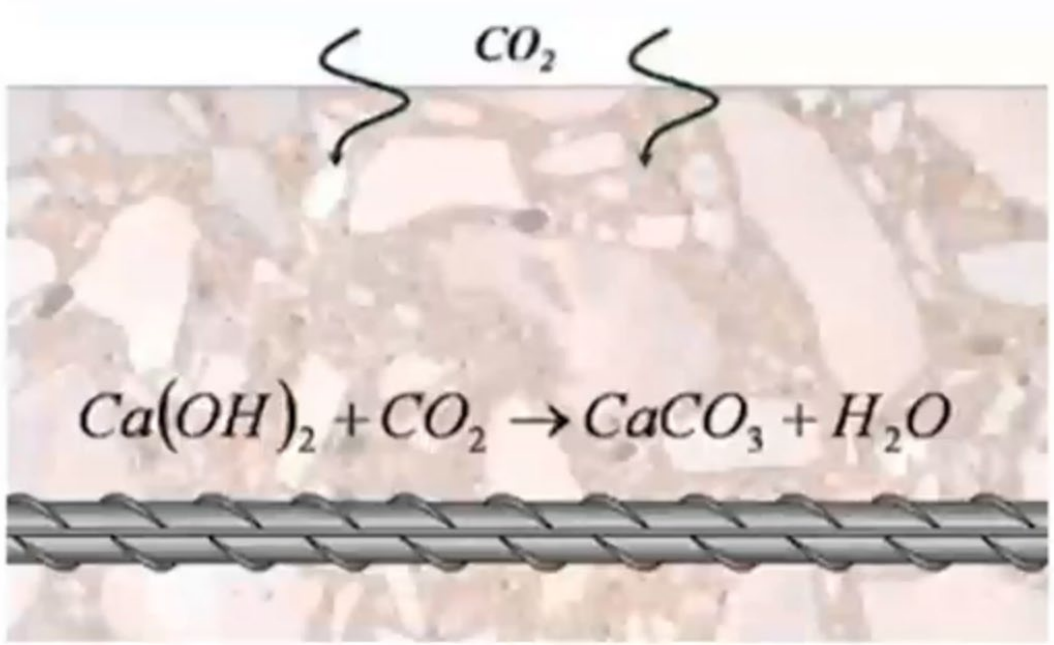


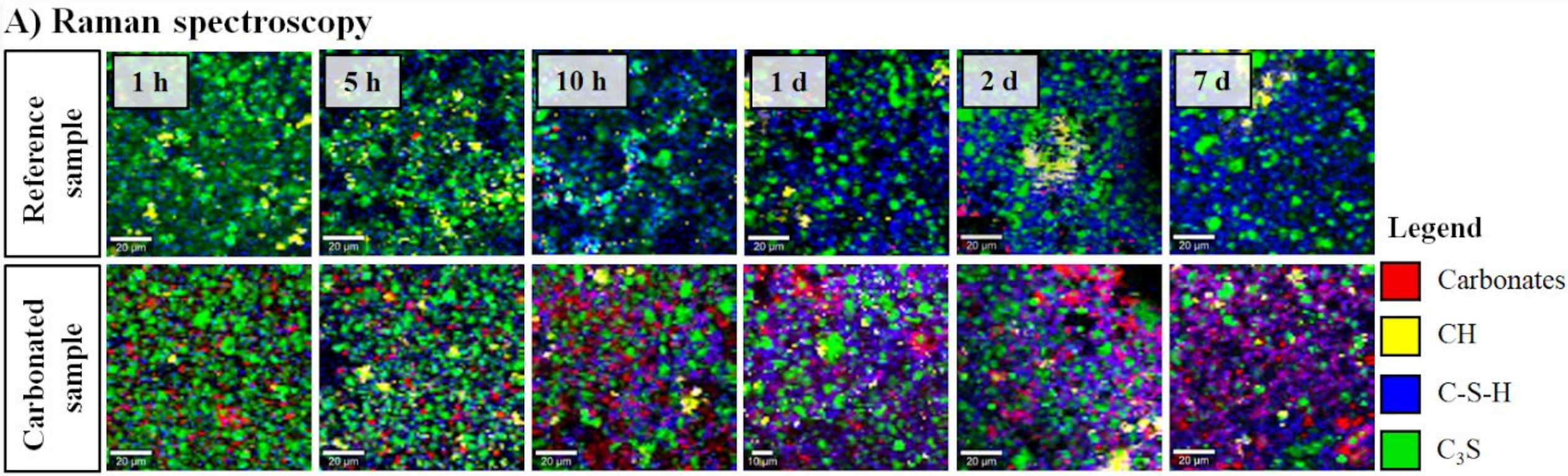
CO_2 uptake in concrete over time: problem or opportunity?

Late-stage carbonation leads to pH drop associated with reinforcement corrosion and concrete **spalling**.

But:
CARBONATION = CARBON SINK!

How to reconcile the two phenomena





Stefaniuk et al., PNAS Nexus, 2023

Fresh concrete carbon capture and storage: cementing CO_2 into C-S-H

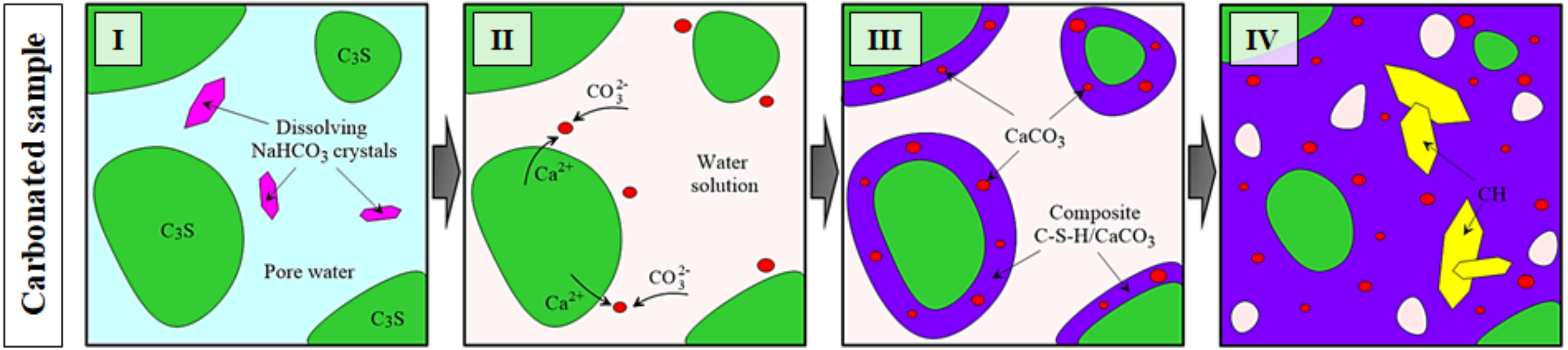
Carbon capture

Permanent carbon storage

Early strength development due to seeding

MULTI-FUNCTIONAL!

Schematic representation of early-stage carbonation



Stefaniuk et al., PNAS Nexus, 2023

Cementing CO_2 in concrete

Up to 15% of total CO_2 emissions can be permanently stored in cement

Multifunctional concrete

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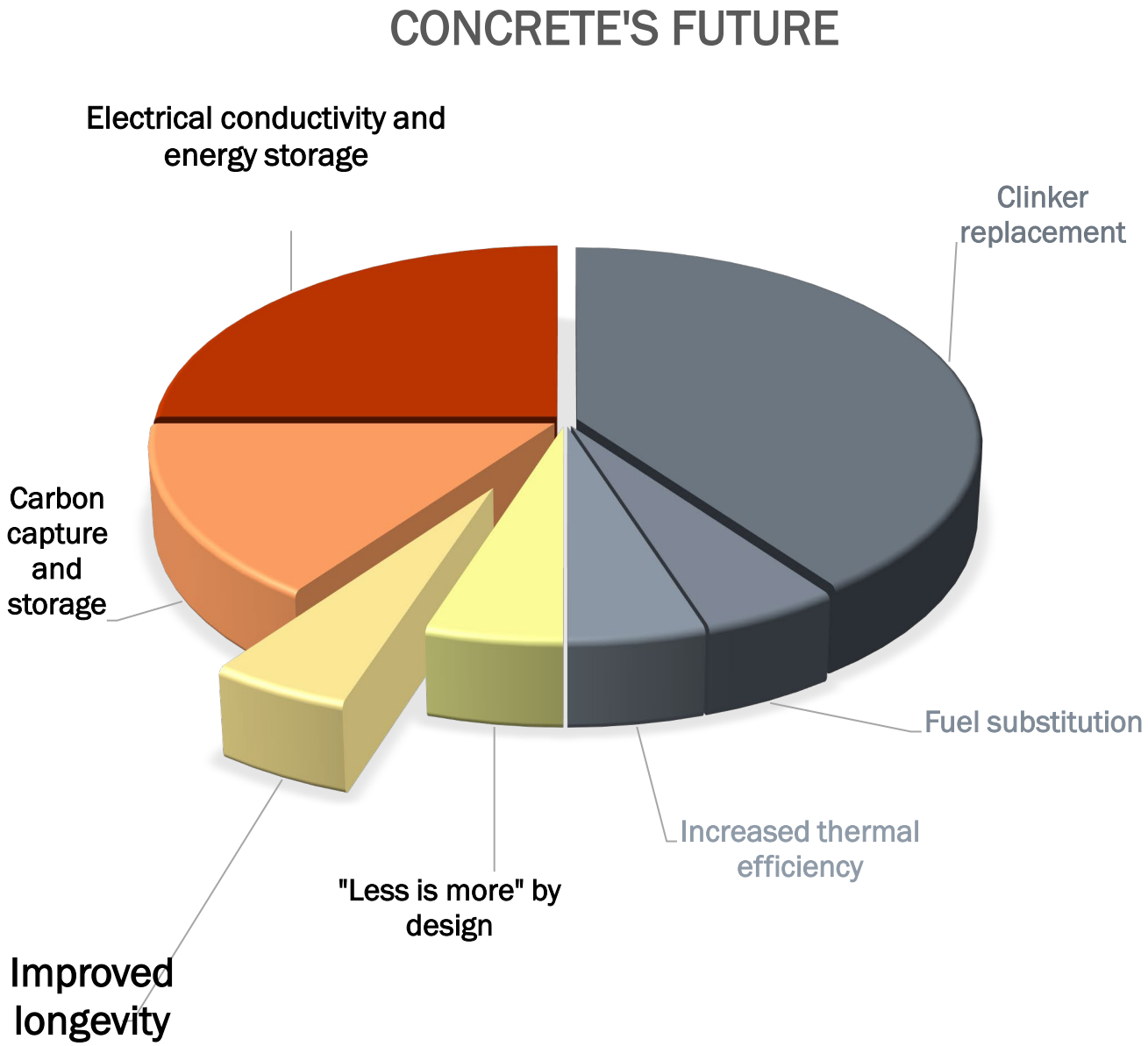

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America's Infrastructure Scores a

C-

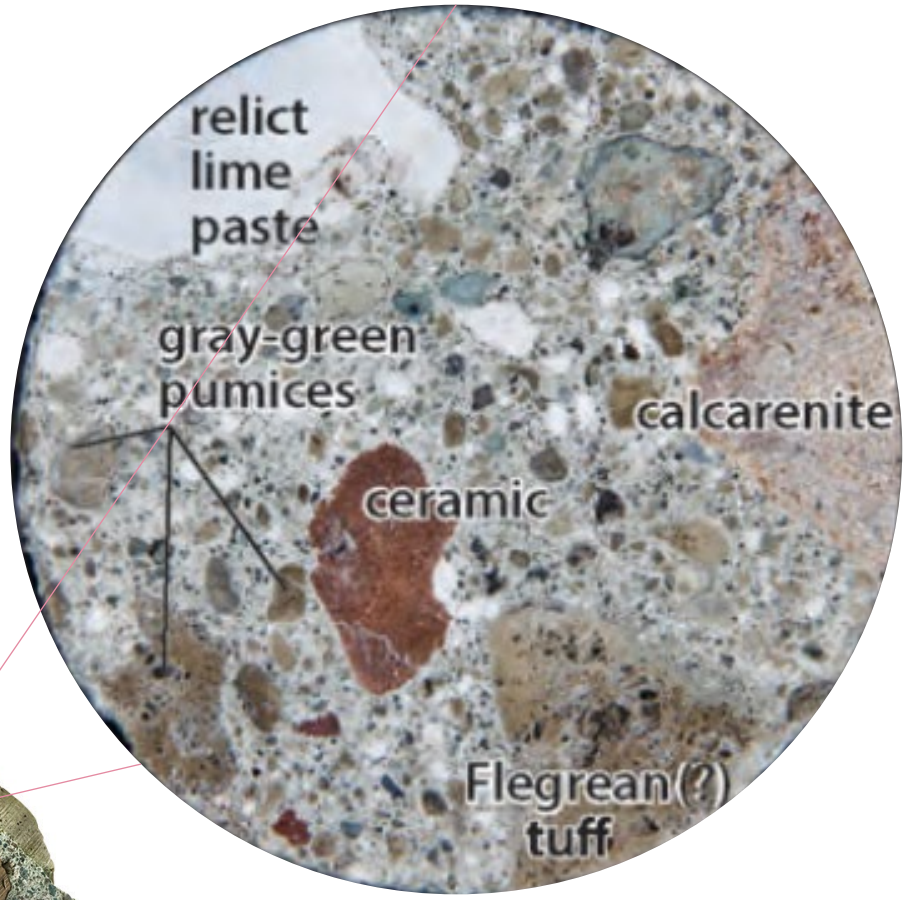
Self-healing functionality highly desirable!

Pantheon, Rome (Italy)

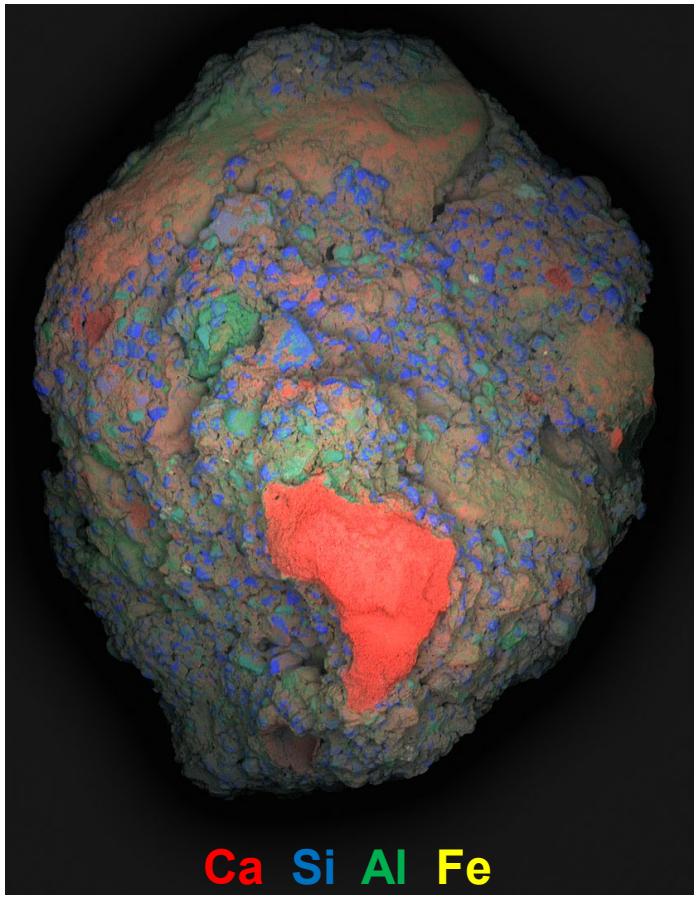
What are the origins of extreme long-term durability of ancient Roman concrete?

Roman concrete mix

Hydraulic cement mortar
Calcium-aluminum-silicate-hydrate (C-A-S-H)

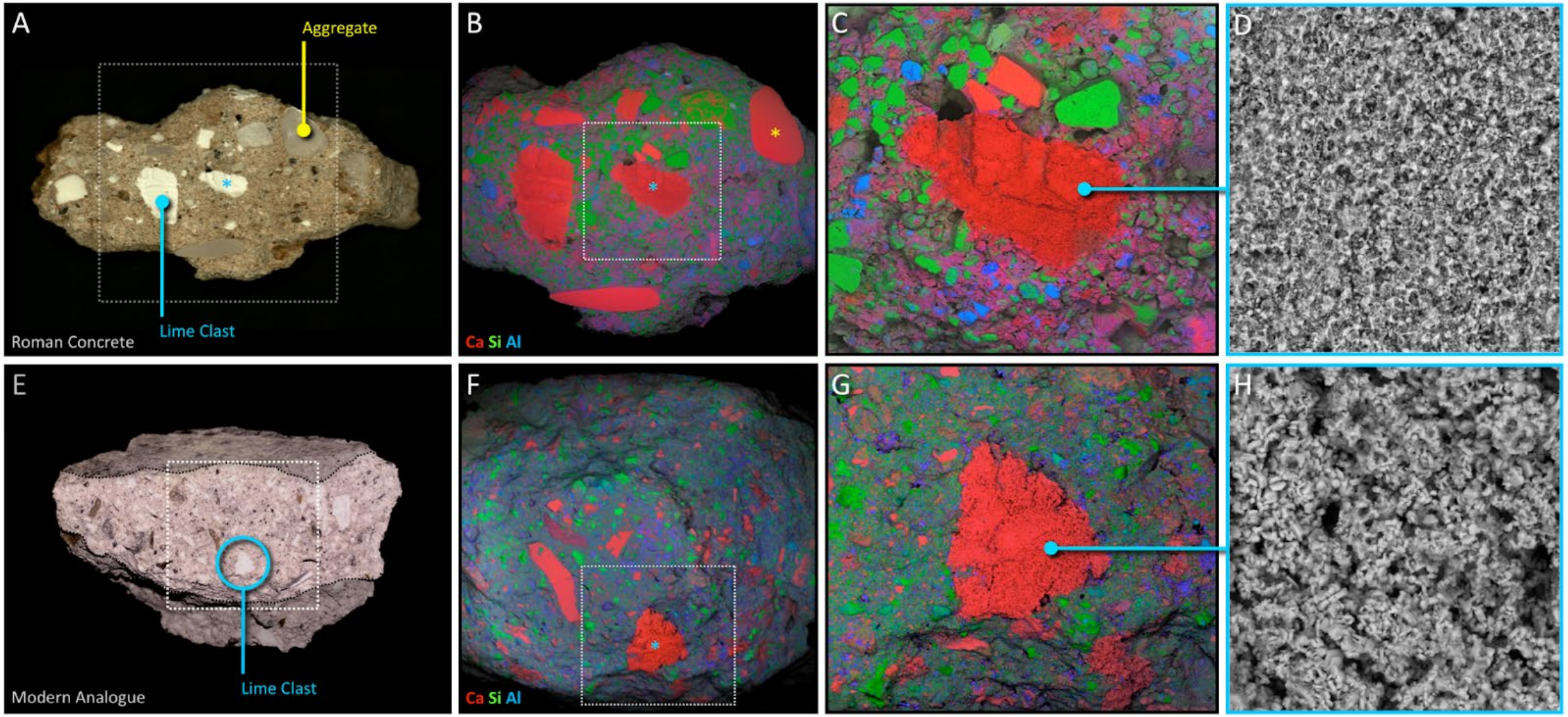


Jackson et al. (2016)



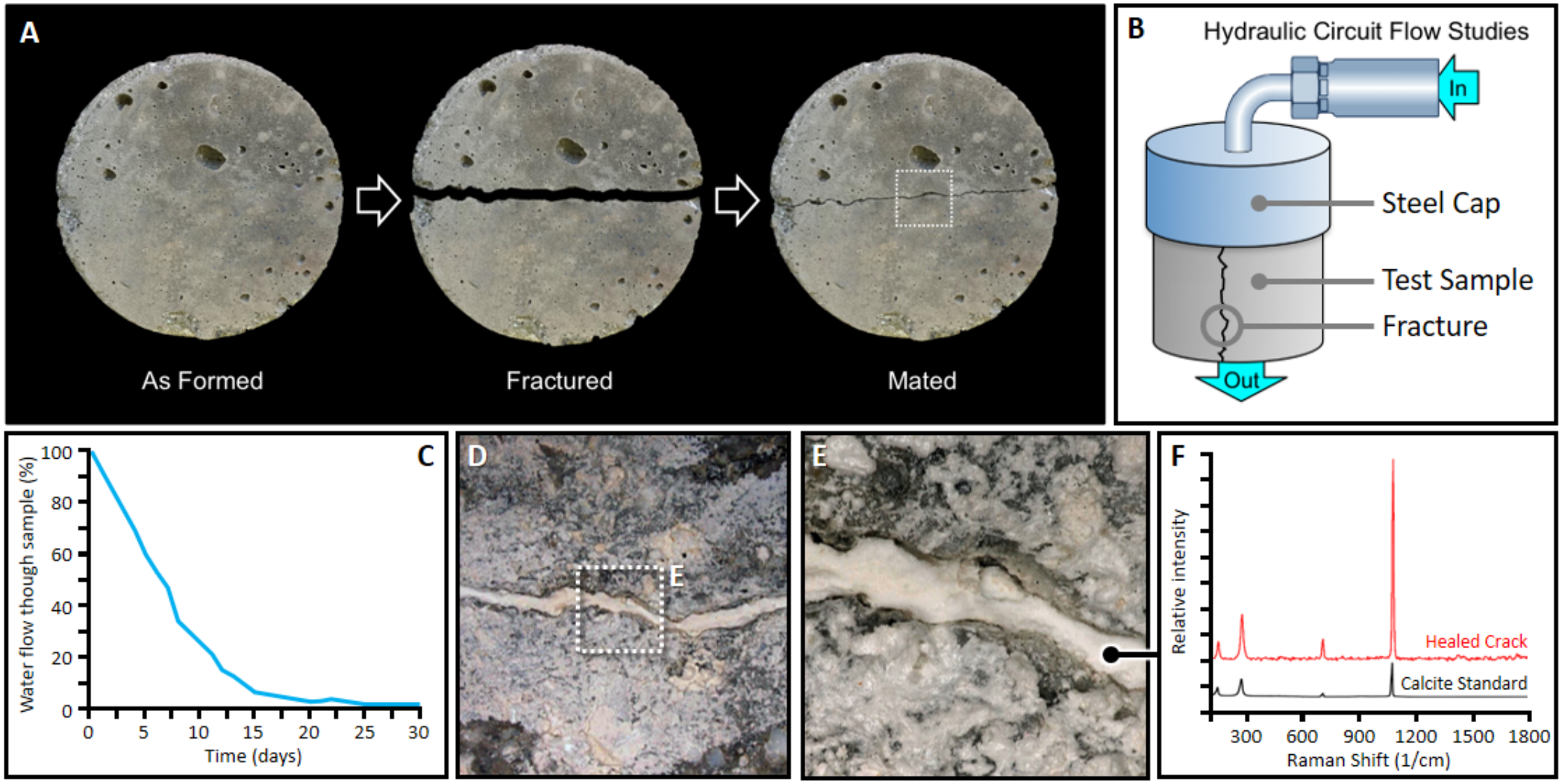
How relict lime clasts are formed in ancient samples and can they be the missing link in "self-healing" picture?

Roman concrete: Long-lasting, self-healing ancient materials



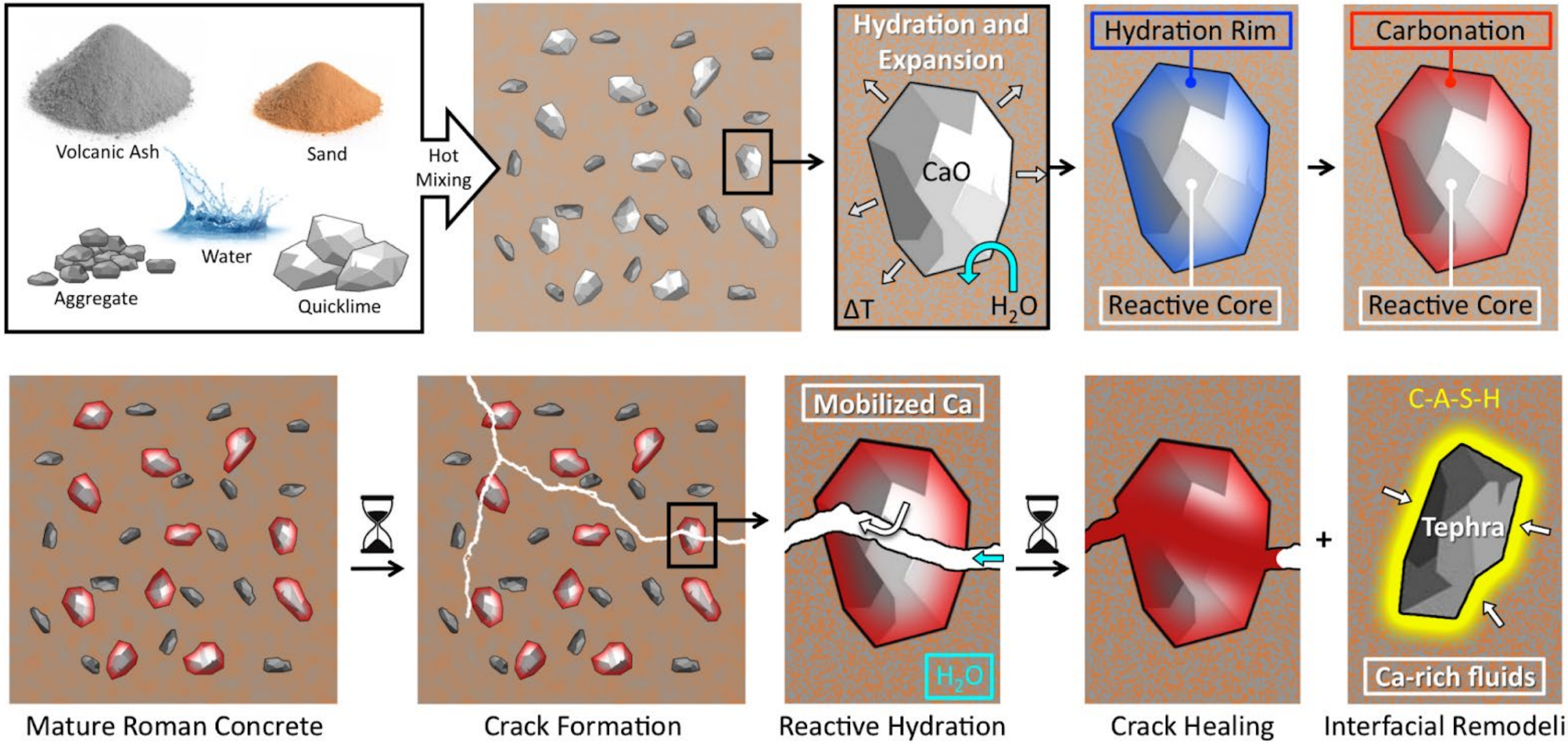
Seymour et al., Science Advances, 2023

Design of self-healing modern concrete incorporating hot-mixing strategy



Seymour et al., Science Advances, 2023

Self-healing mechanism



Seymour et al., Science Advances, 2023

Media coverage

Science Advances

Hot mixing: Mechanistic insights into the durability of ancient Roman concrete

Overview of attention for article published in Science Advances, January 2023

The MIT News article: **Riddle solved: Why was Roman concrete so durable** is the most-viewed article ever to appear on MIT News.

CNN

6 historical mysteries that scientists finally cracked in 2023: The ingredient behind Roman concrete's legendary strength

The Guardian

'Self-healing' Roman concrete could aid modern construction, study suggests

Research finds secret of durability of buildings such as the Pantheon could be in the techniques used at the time

'The Pantheon would not exist without the concrete as it was in the Roman time,' said Prof Admir Masic, lead author of the study. Photograph: Andreas Solaro/AFP/Getty Images

CNN

Mystery of why Roman buildings have survived so long has been unraveled, scientists say

REUTERS®

Scientists chip away at how ancient Roman concrete stood test of time

By Will Dunham

January 9, 2023 10:43 AM EST · Updated 8 months ago

The Economist

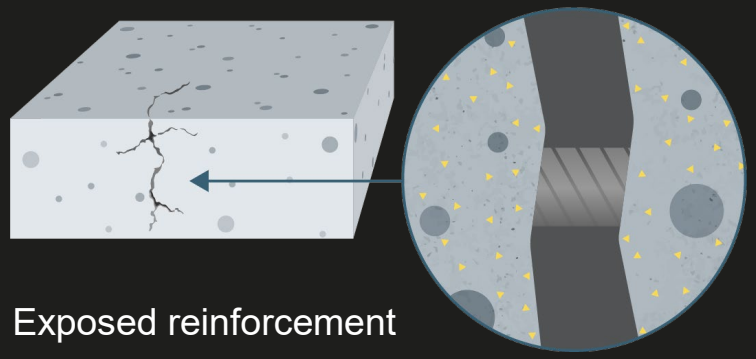
Roman civil engineering has lessons for the modern world

The concrete used was self-healing and anachronistically green

DMAT

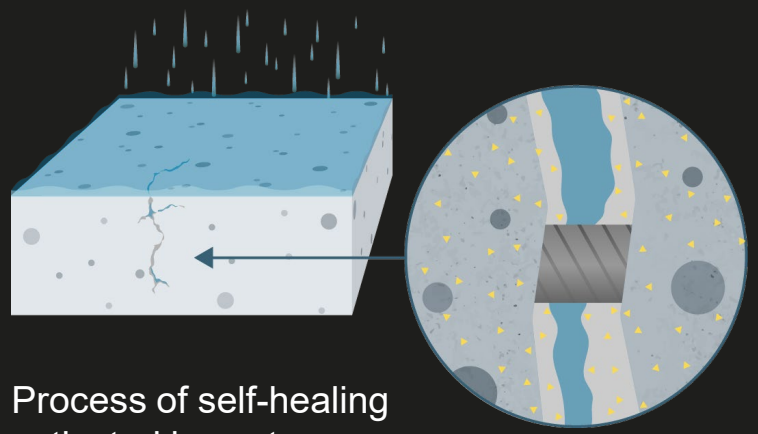
PERFORMANCE MATTERS

MICROFRACTURE



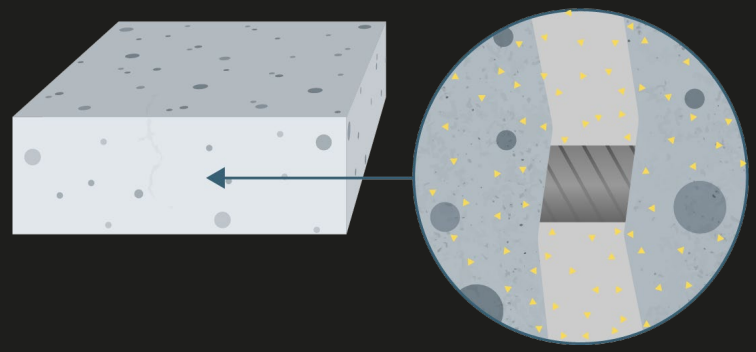
Exposed reinforcement

WATER INFILTRATION



Process of self-healing activated by water

SEALED CRACK



Fractures up to 0,6 mm

Technology made of inexpensive and readly available material precursors

Roman-inspired self-healing concrete (50% lifespan extension at 50% cost reduction compared to other self-healing solutions)

Current research in Pompeii

SCIENCE

The New York Times

Reinventing Concrete, the Ancient Roman Way

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By learning the secrets of 2,000-year-old cement, researchers are trying to devise greener, more durable modern options.

By Amos Zeeberg

Published Oct. 19, 2024 Updated Oct. 21, 2024

Multifunctional concrete

CLIMATE CHANGE

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RESILIENCE

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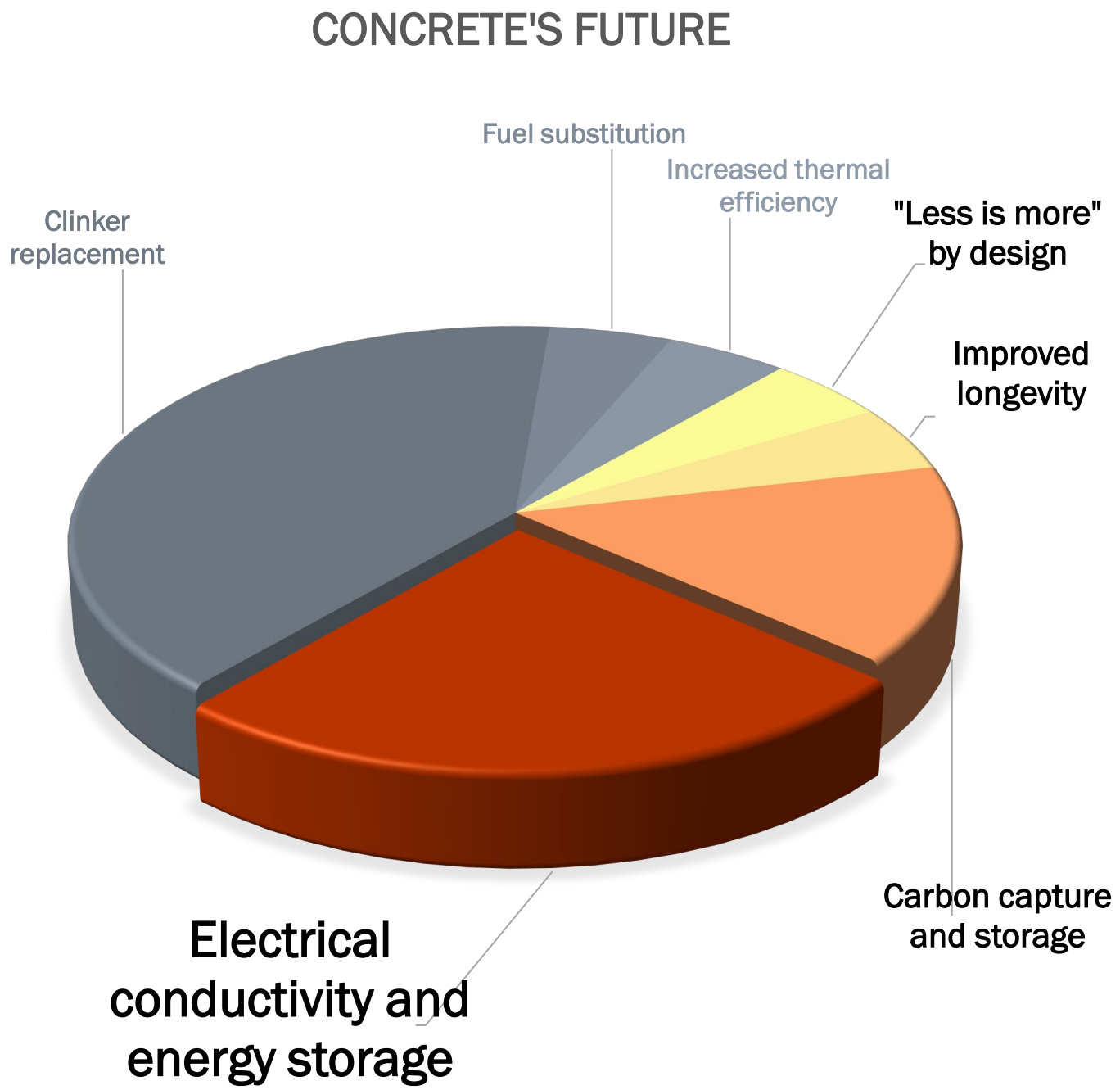
SOCIAL JUSTICE

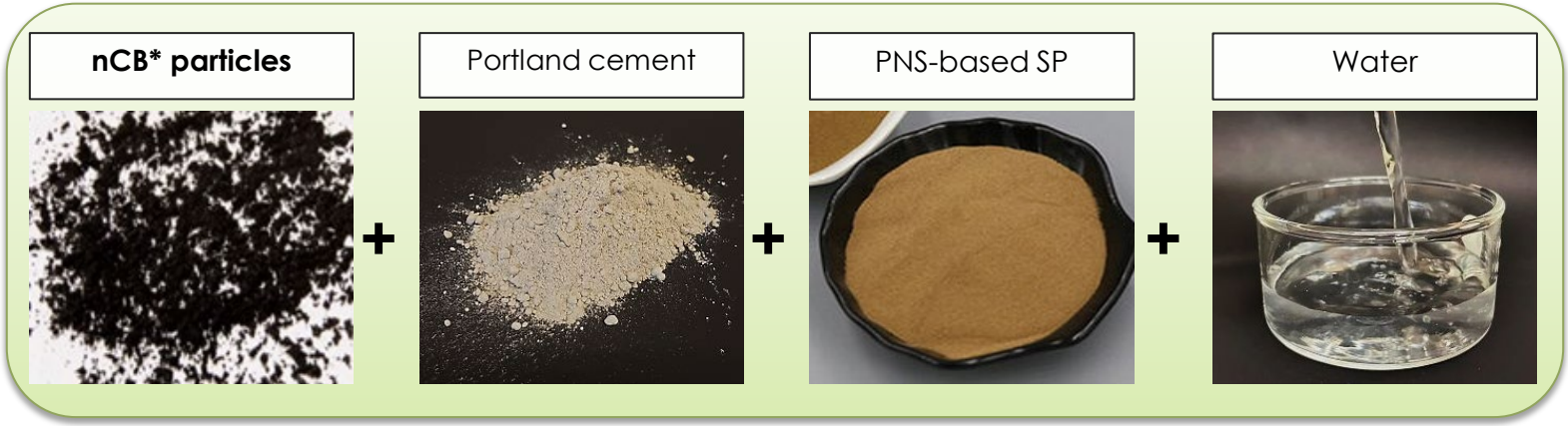


How do we make Electron-Conducting Concrete

TAKE:

1. A Hydrophobic CONDUCTOR: NanoCarbon Black
2. A Hydrophilic INSULATOR: Concrete = Cement + Water + Sand + Stones

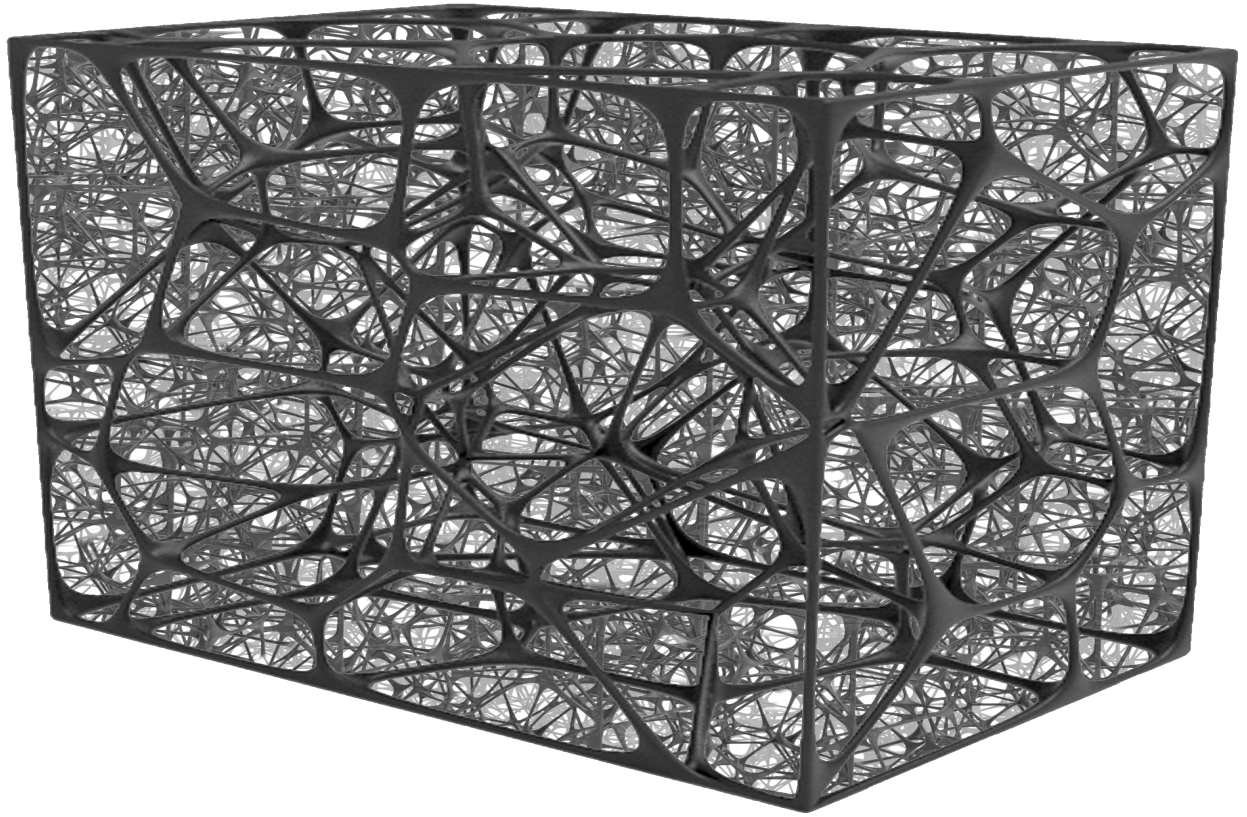
MIX – WHAT HAPPENS?



*nCB – nano Carbon Black

Carbon-Black

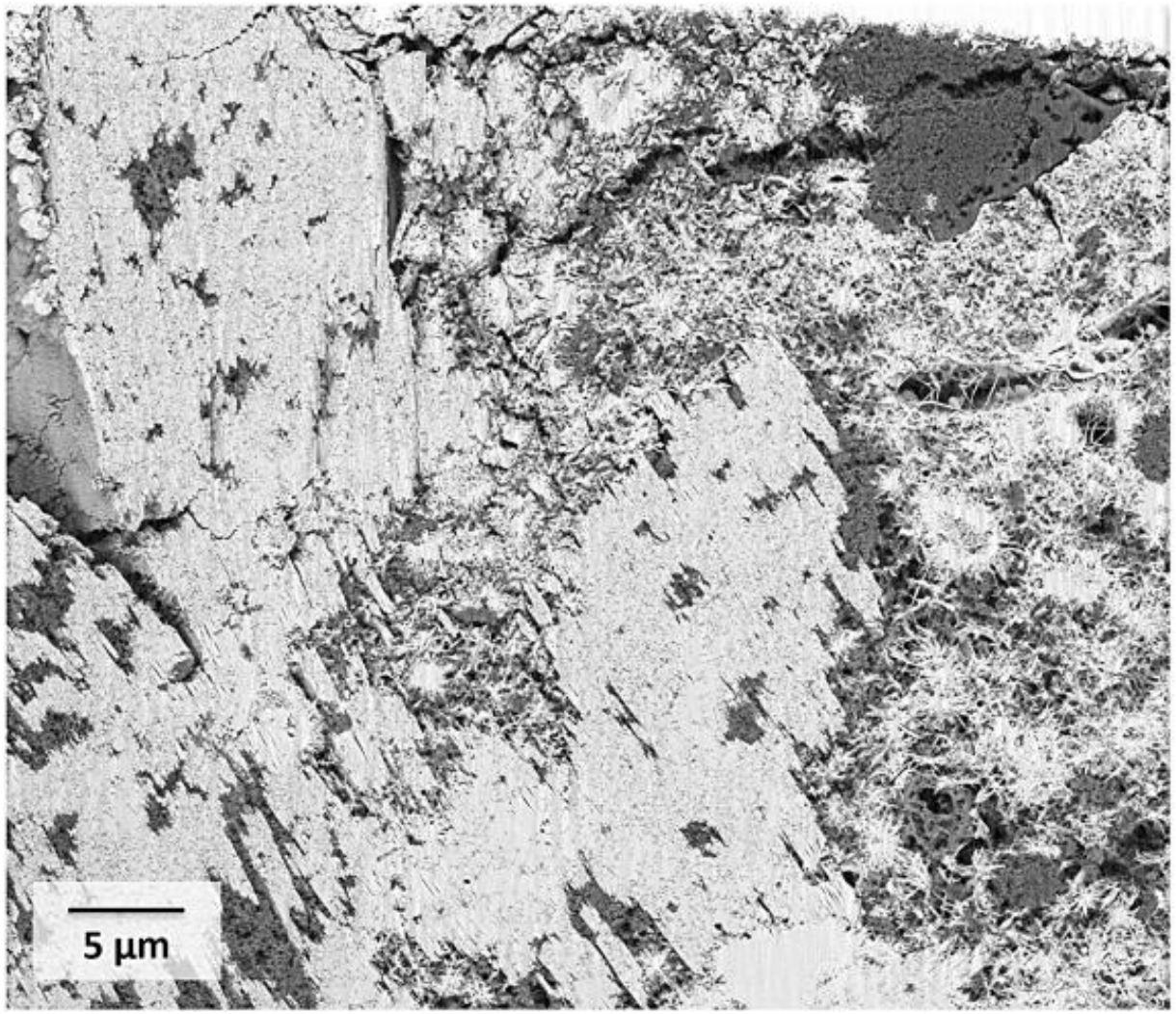
Cement Composite



Percolation of a Volumetric Wire through a load-bearing cement skeleton

A Physical Chemistry Driven Process = Highly Repetitive

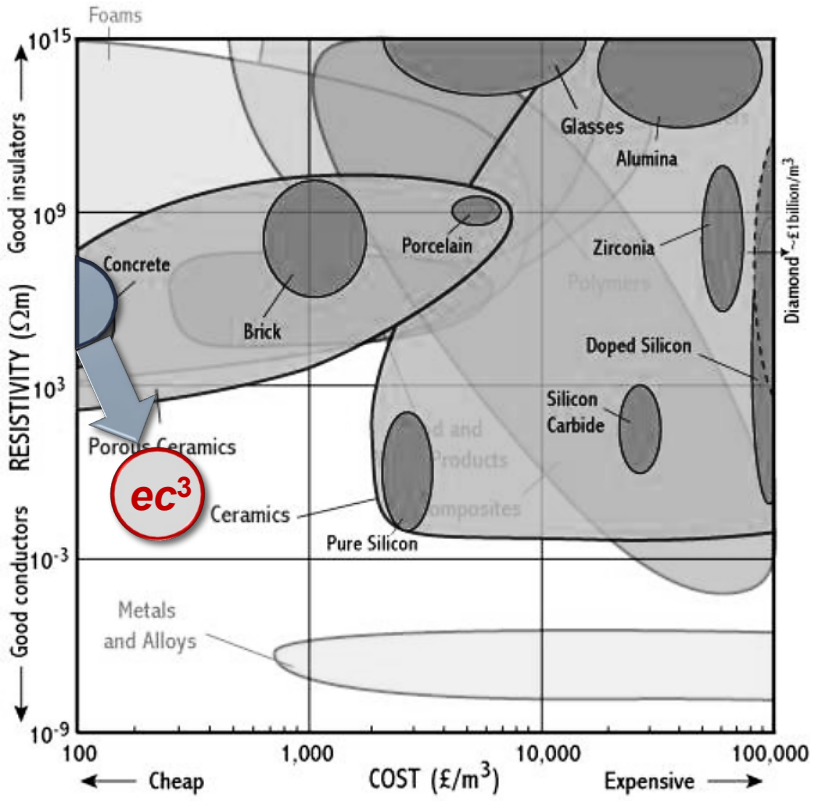
Linking nano and microstructure: FIB-SEM

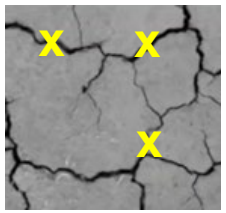


nCB=40-50nm
resolution=15nm

ec^3 = ELECTRON CONDUCTING CARBON-CEMENT BASED MATERIALS

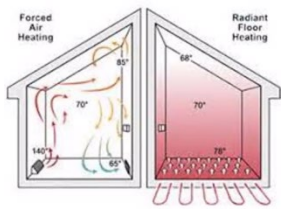
Resistivity vs. cost



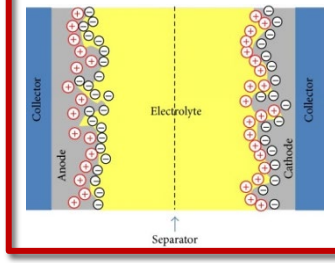


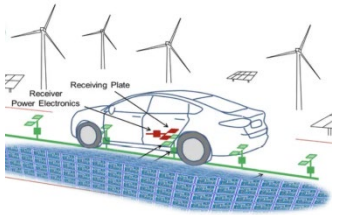
Freeze-thaw resistance
(Hydrophobicity)
Longevity of structures

ec^3 (electron conducting carbon concrete)

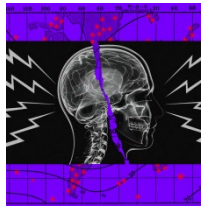


Self-heating
(Joule effect)
De-icing bridges, sidewalks, airport runways, etc.
Radiant floor heating





Energy storage
(Structural supercapacitor)
Renewable energy buffer
Autonomous housing
Smart charging roads



HPEM* shielding
(Faraday cage effect)
Military structures
Data storage
Human health

*High Power Electromagnetic impulses

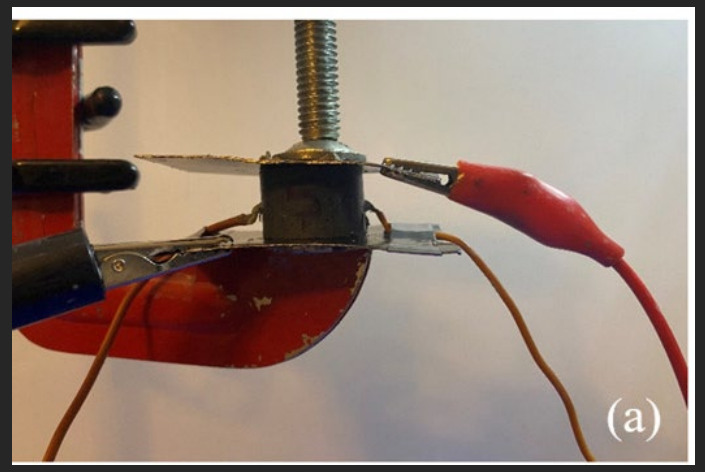
http://www-materials.eng.cam.ac.uk

ec^3 for Self-heating

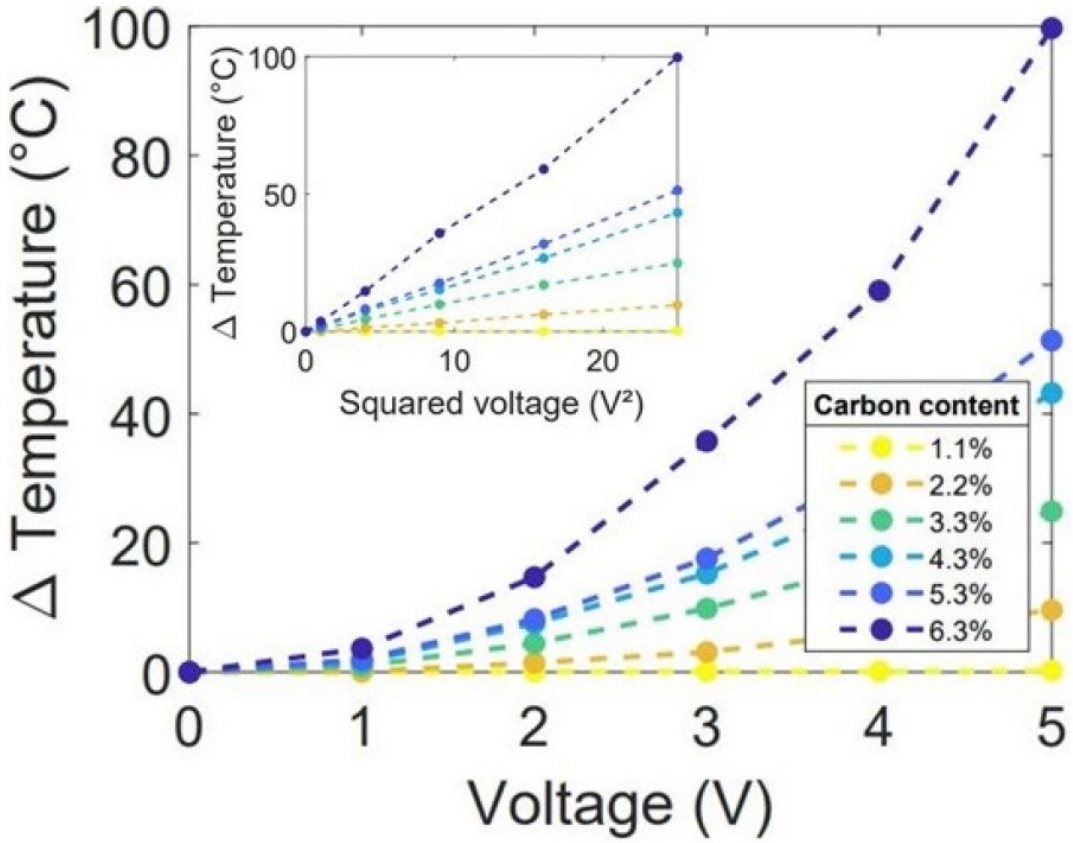
ec^3 = ELECTRON CONDUCTING CARBON-CEMENT BASED MATERIALS

Self-Heating

So-called Joule Effect (~ Stove Plate)



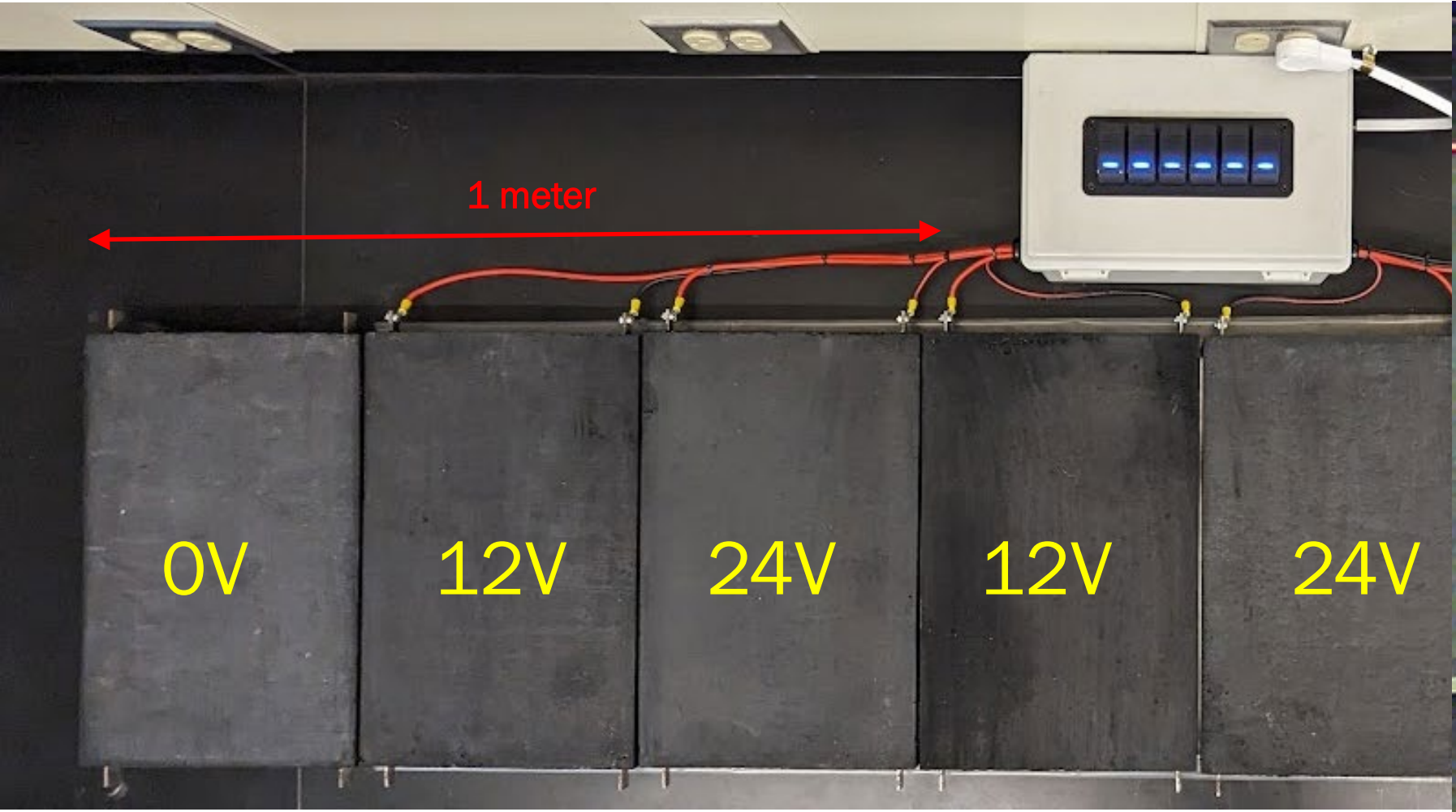
Temperature Increase ~ Voltage x Voltage

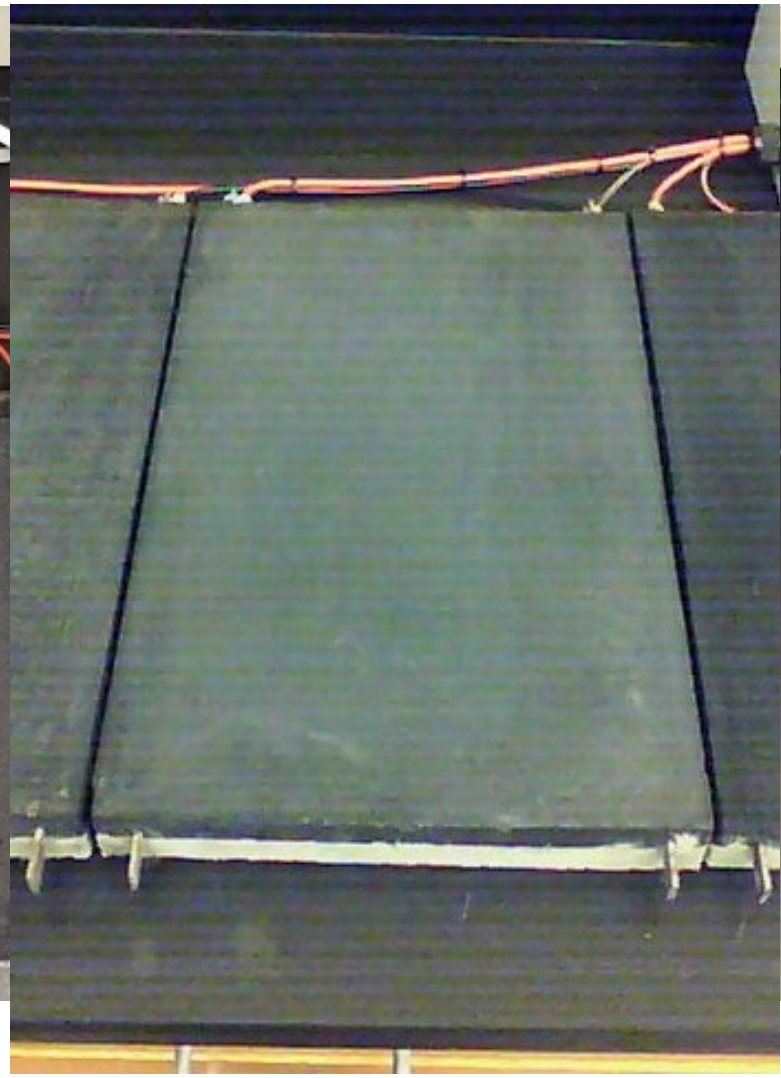


Self-Heating

So-called Joule Effect (~ Stove Plate)

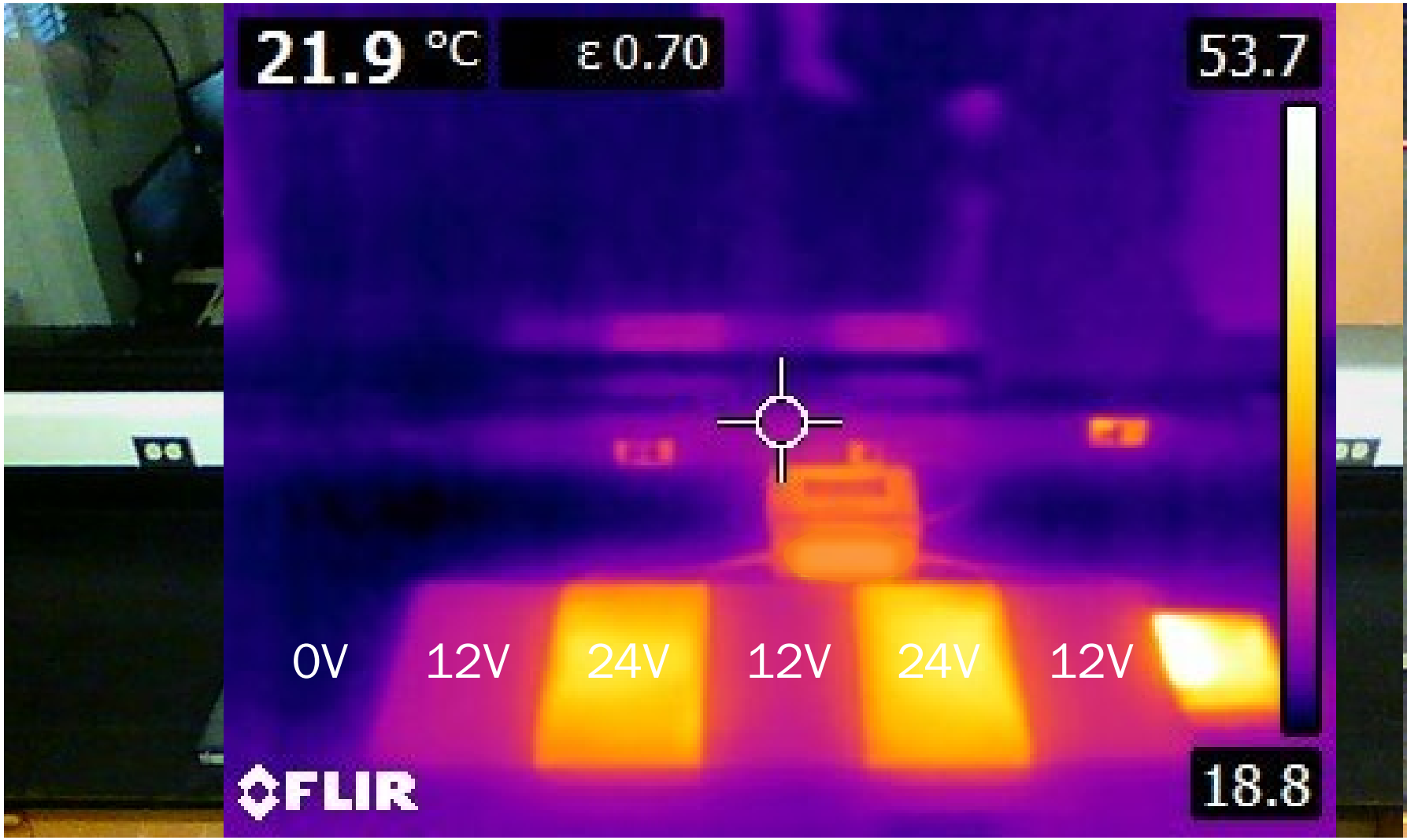
MIT ec^3 hub

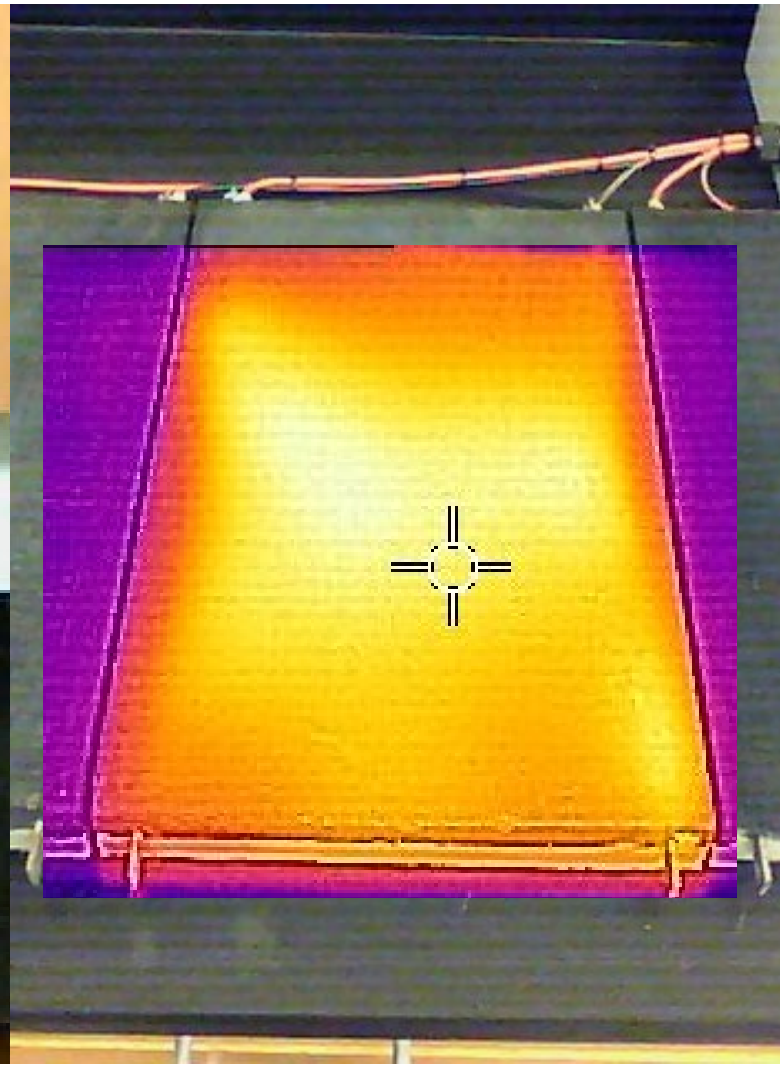




Self-Heating

MIT ec³ hub



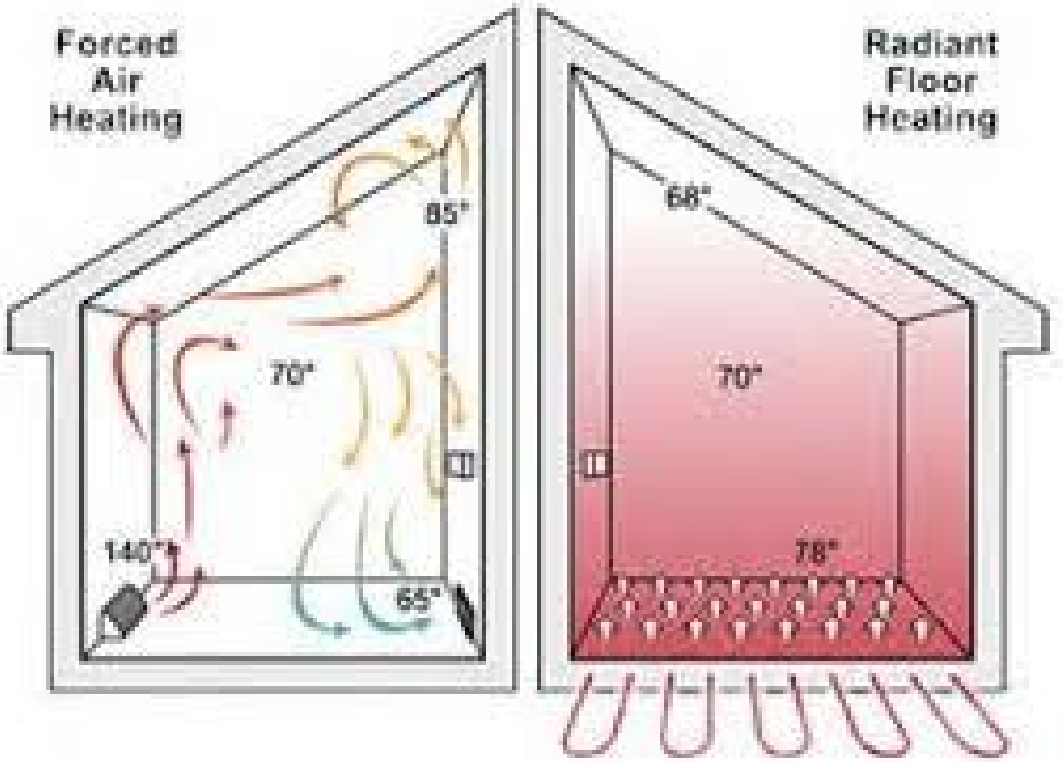


De-icing by Self-Heating Concrete

CY. Tuan, J. Cold Reg. Eng., 2008, 22(1): 1-15

Radiant Floor Heating

Replace “wired” radiant floor heating by e-conducting cement-based materials

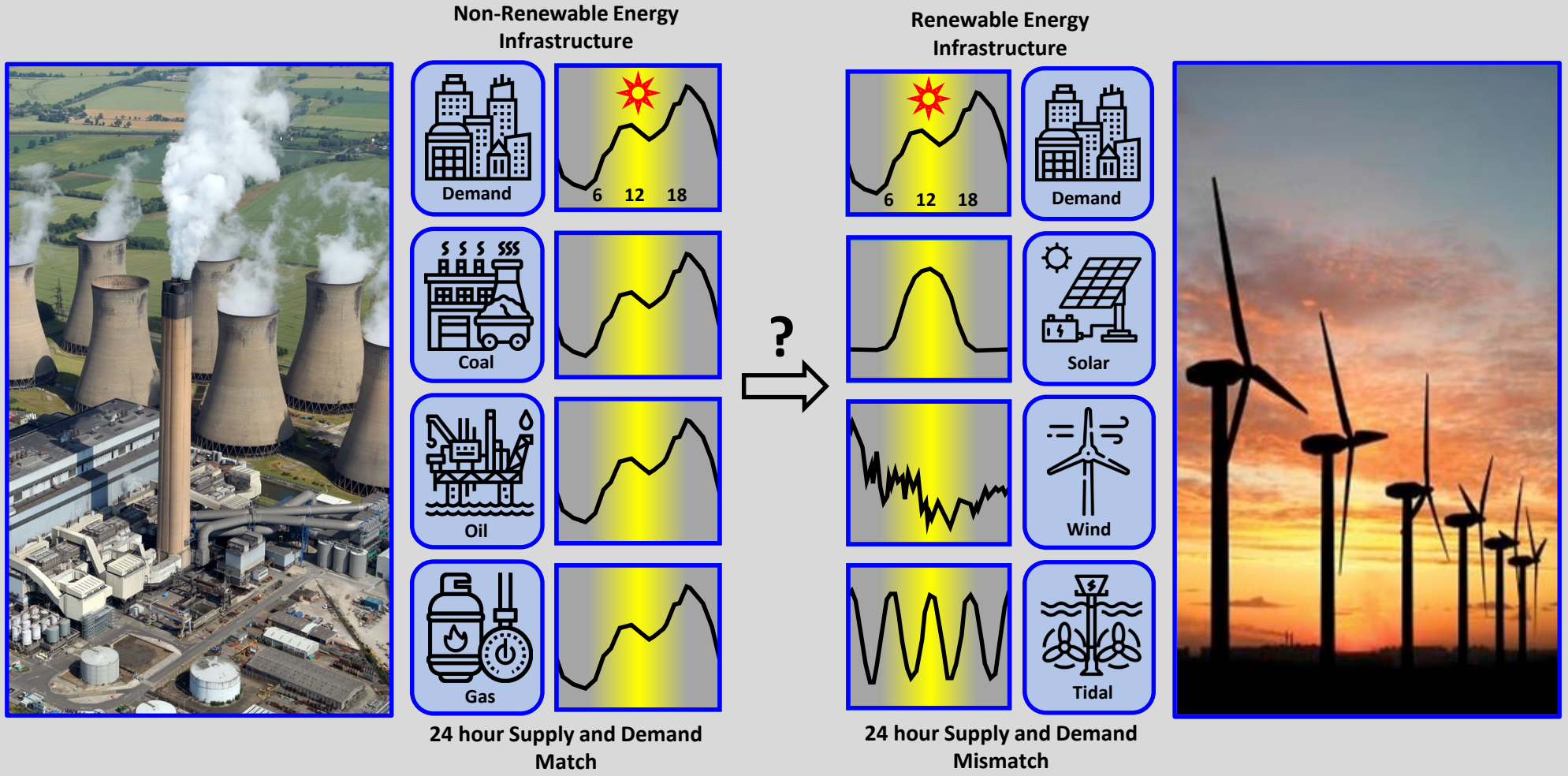


Sapporo Odori Park, Japan


実証実験
特殊コンクリートで
ロードヒーティング
札幌 大通公園

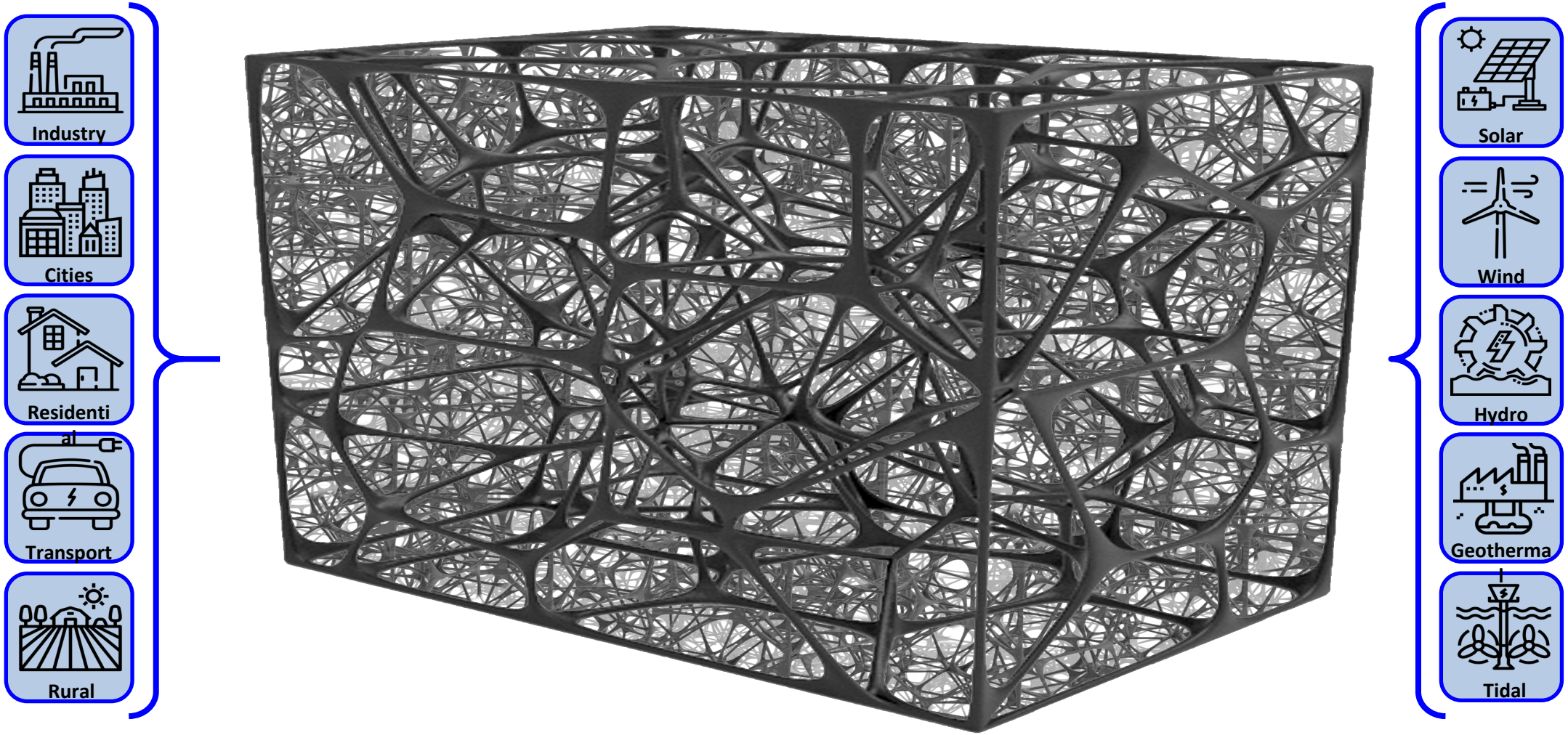
ec^3 for Energy Storage

ec^3 = ELECTRON CONDUCTING CARBON-CEMENT BASED MATERIALS



Why now? – Shift to green energy requires massive storage solutions & structures

Current Battery Technology NOT scalable | Need for NEW Bulk Storage Solutions – HERE IS ONE



A future with Concrete “Batteries”

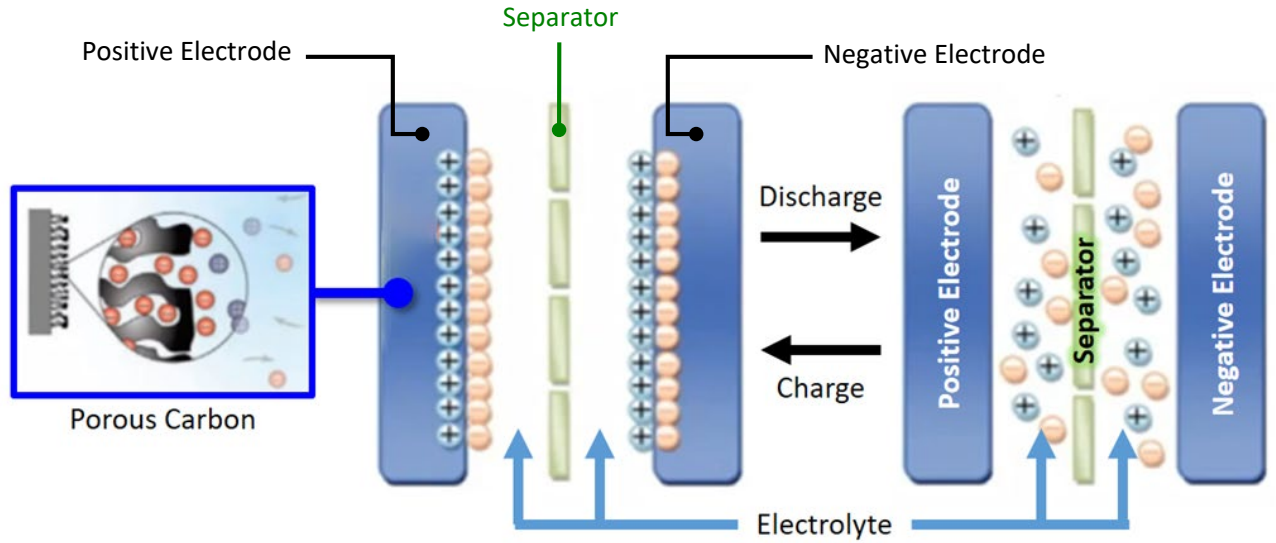
Electron-Conducting Carbon Cement-Based SUPERCAPACITORS

Cement + Carbon + Porosity = Supercapacitor

Battery = Change electrical energy into chemical energy

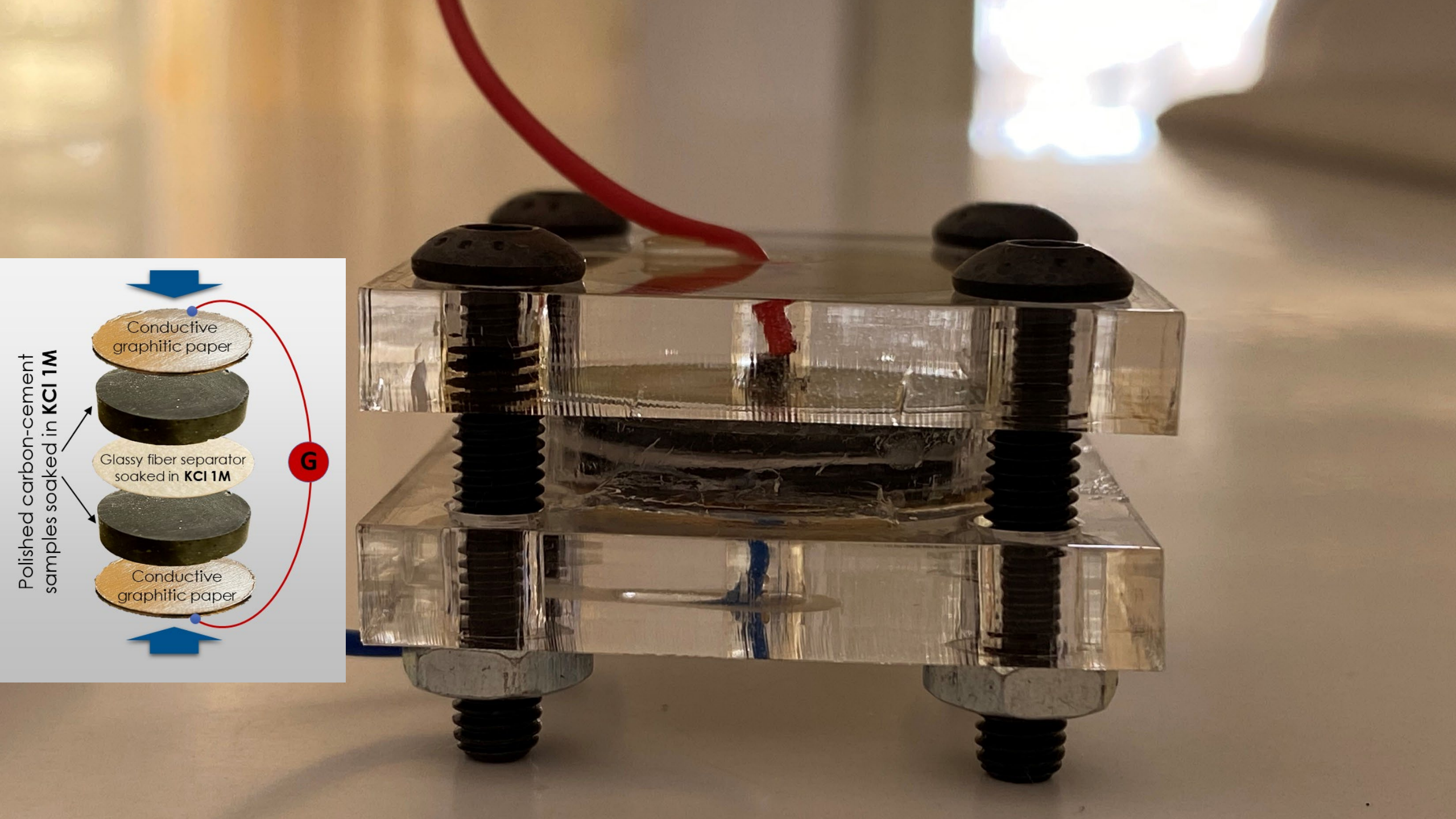
Supercapacitor = Electrical Charge stored in a shell around the carbon (no chemical reaction)

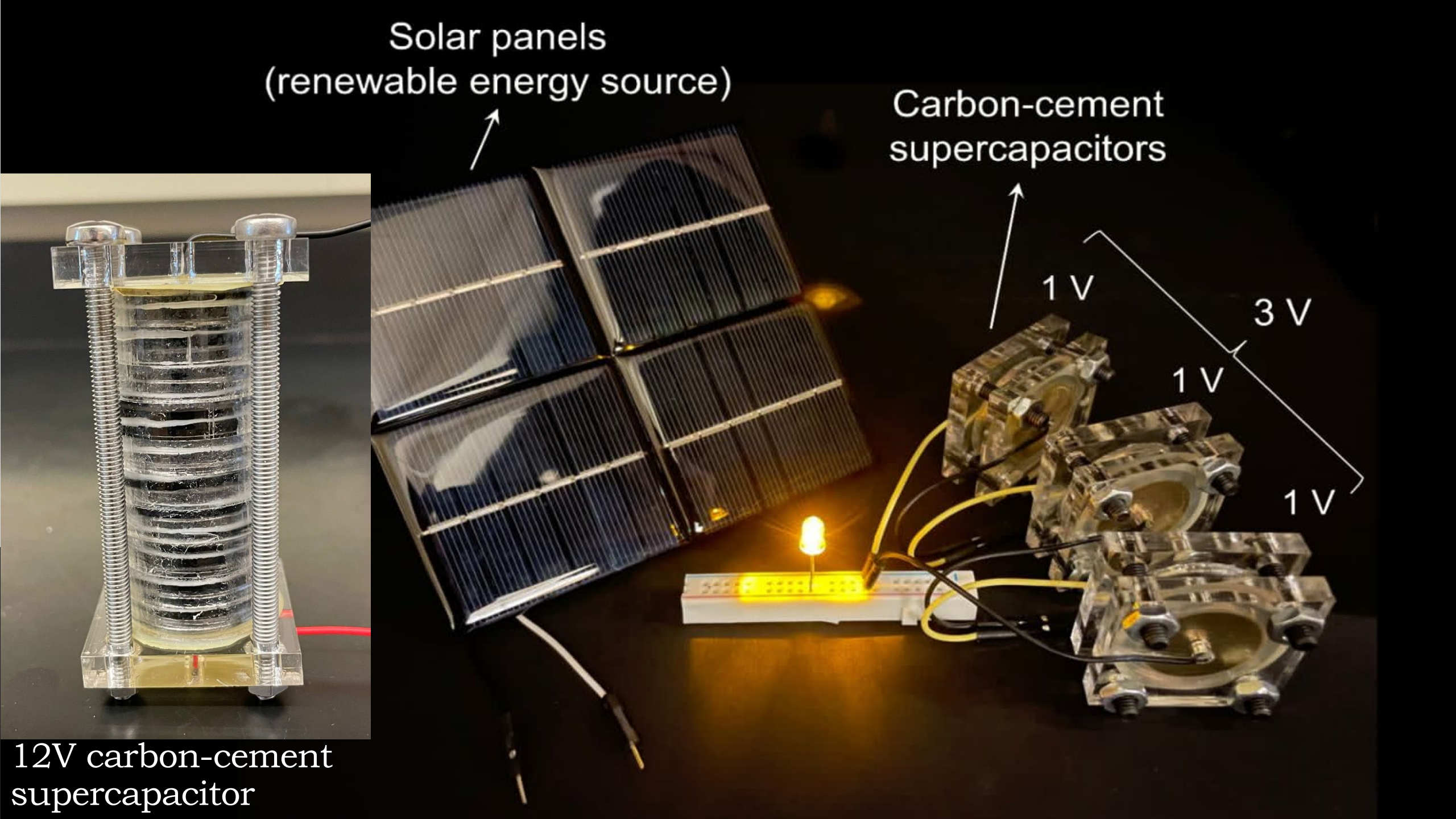
HOW DOES A SUPERCAPACITOR WORK?



CONCRETE AS “structural” SUPERCAPACITOR:

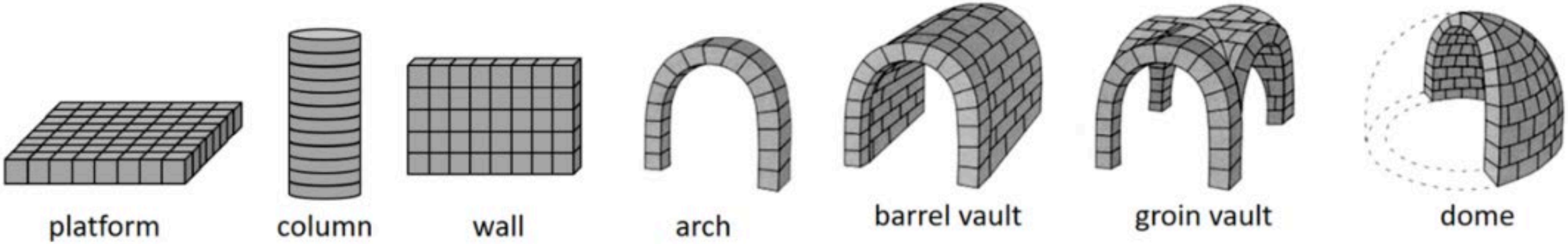
- Porosity of cement paste (for Electrolyte)
- Carbon-Cement Composite for Energy Storage

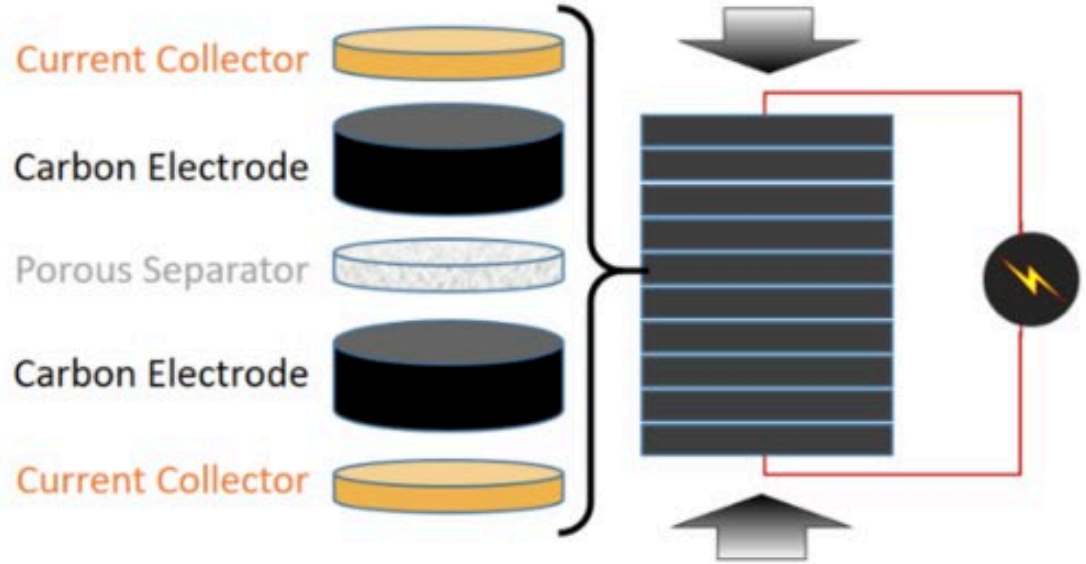

Polished carbon-cement samples soaked in **KCl 1M**
Conductive graphitic paper
Glassy fiber separator soaked in **KCl 1M**
Conductive graphitic paper
G



12V carbon-cement supercapacitor

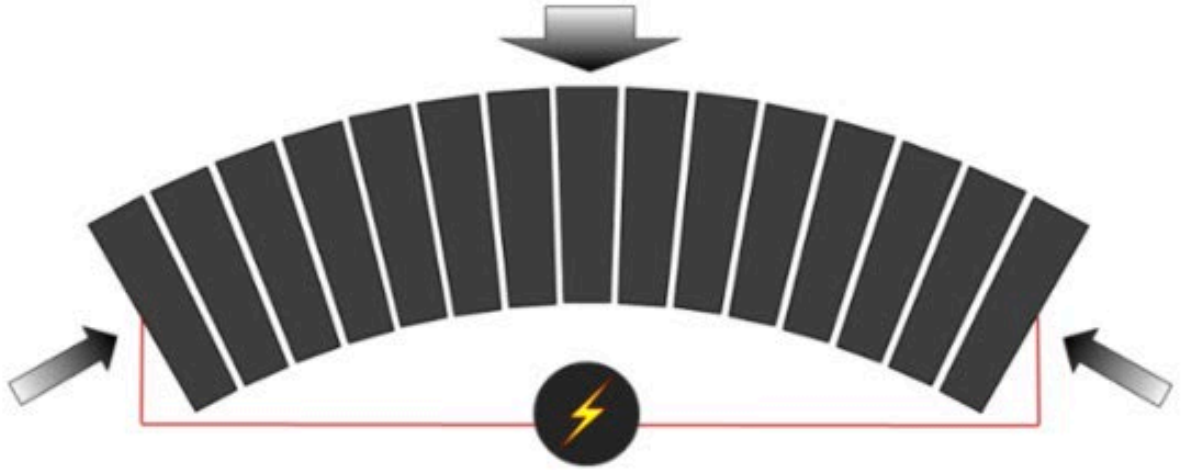
Architectural geometries and modular ec^3 units





Unit cell schematic

Column loading regime



Arch loading regime

RESEARCH ARTICLE | ENGINEERING |

Carbon–cement supercapacitors as a scalable bulk energy storage solution

Nicolas Chanut, Damian Stefaniuk, James C. Weaver, Yunguang Zhu, Yang Shao-Horn, Admir Masic, and Franz-Josef Ulm -3 Authors Info & Affiliations

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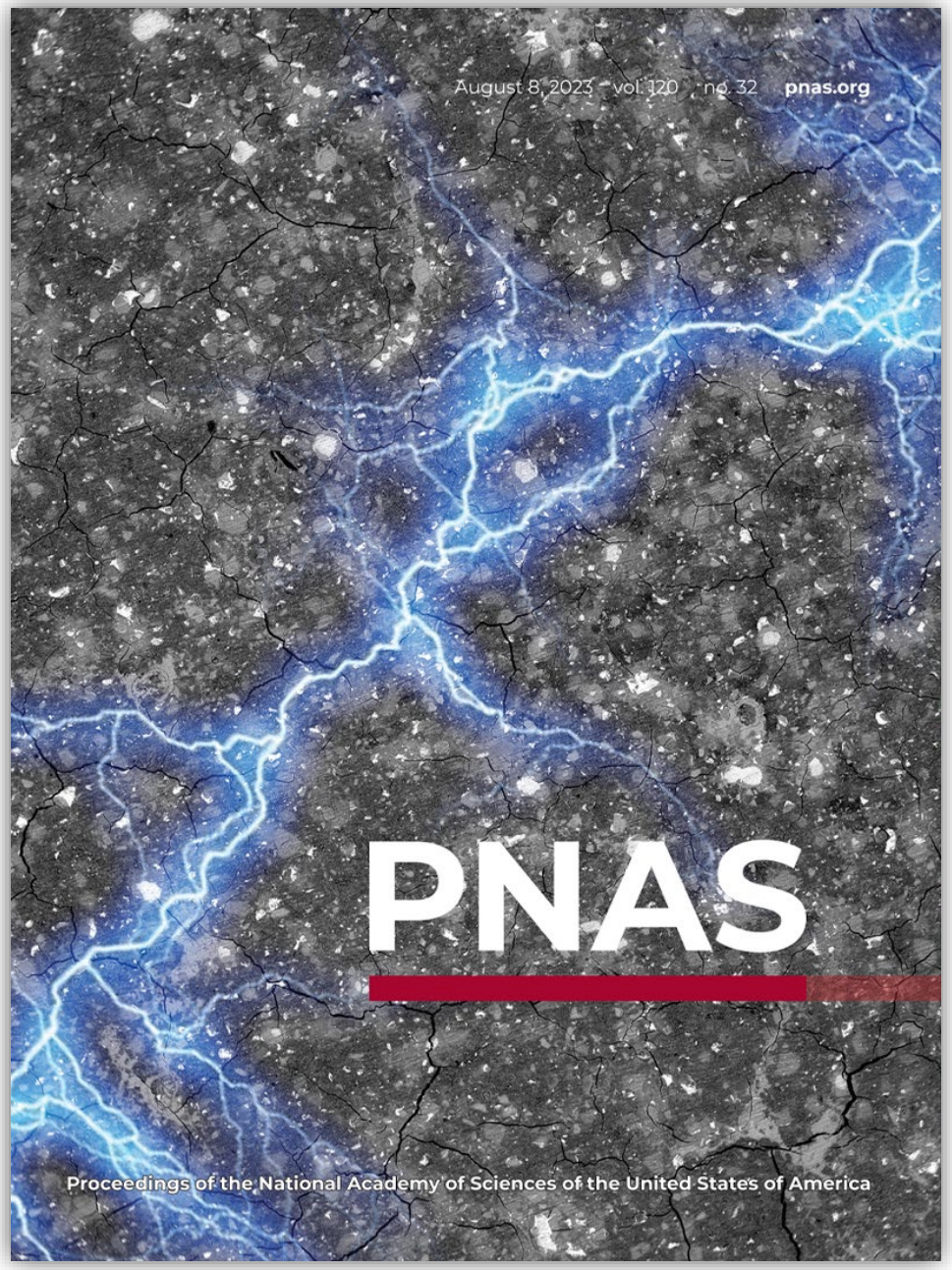
July 31, 2023 | 120 (32) e2304318120 | https://doi.org/10.1073/pnas.2304318120

NATIONAL ACADEMY OF SCIENCES

Cozzarelli Prize 2023, Finalist.
Class III: Engineering and Applied Sciences

MIT ec^3 hub

Electron-**C**onducting **C**arbon-**C**ement-Based Materials Hub



PNAS cover by **James C. Weaver**

Increasing global interest

The Boston Globe

Is cement the solution to storing renewable energy? Engineers at MIT think so.

Supercapacitors could make powering your home and electric vehicles easier and more sustainable

By Macie Parker Globe Correspondent, Updated August 22, 2023, 9:36 a.m.

At the Massachusetts Institute of Technology, from left to right, Professor Admir Masic, visiting scholar James Weaver, postdoc Damian Stefaniuk, and Professor Franz-Josef Ulm surround a supercapacitor, which can store renewable energy using cement, water, and carbon. SUZANNE KREITER/GLOBE STAFF

MIT researchers say they have developed an energy storage system that could allow homes to store their own power without external batteries and highways to charge electric vehicles as they traveled on the road — no charging stations needed.

And the best part, the researchers say, is their system, called a supercapacitor, could be built from three of the world's most abundant materials: cement, water, and carbon.

The researchers, who work at MIT's Concrete Sustainability Hub, recently reported their breakthrough in the Proceedings of the National Academy of Sciences, a peer-reviewed scientific journal. They detailed how a tiny prototype — around 1 centimeter wide and 1 millimeter thick — powered an LED light at least 10,000 times.

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These scientists are using widely available materials to create an alternative to batteries

Learn more about sustainable battery chains: https://ow.ly/phaE50PAite

Massachusetts Institute of Technology

FAST COMPANY

07-31-2023 | IMPACT

MIT engineers developed a new type of concrete that can store energy

By tweaking the way cement is made, concrete could double as energy storage—turning roads into EV chargers and storing home energy in foundations.

BBC

Home News Sport Business Innovation Culture Arts Travel Earth Video Live

The cement that could turn your house into a giant battery

11 June 2024

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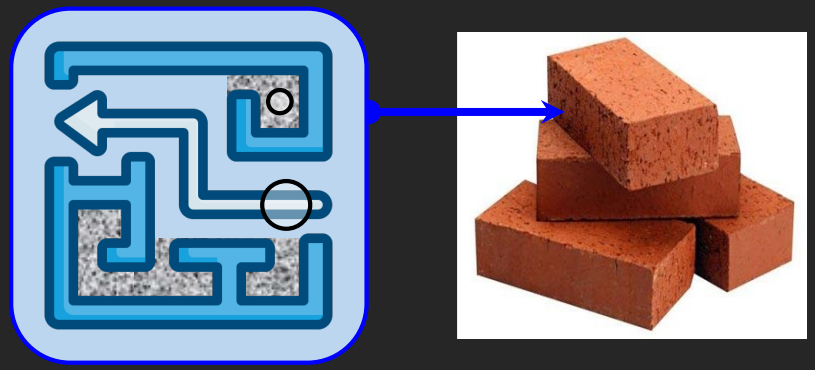
Tom Ough

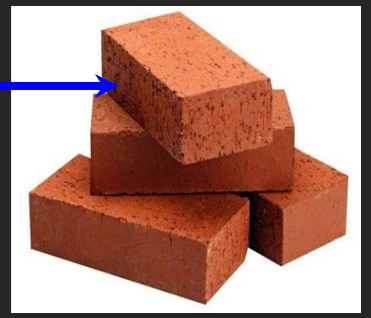
Needed: Engineering Now – System Design

How will multifunctional concrete structures look like



Needed: Engineering Now – System Design

How will multifunctional concrete structures look like



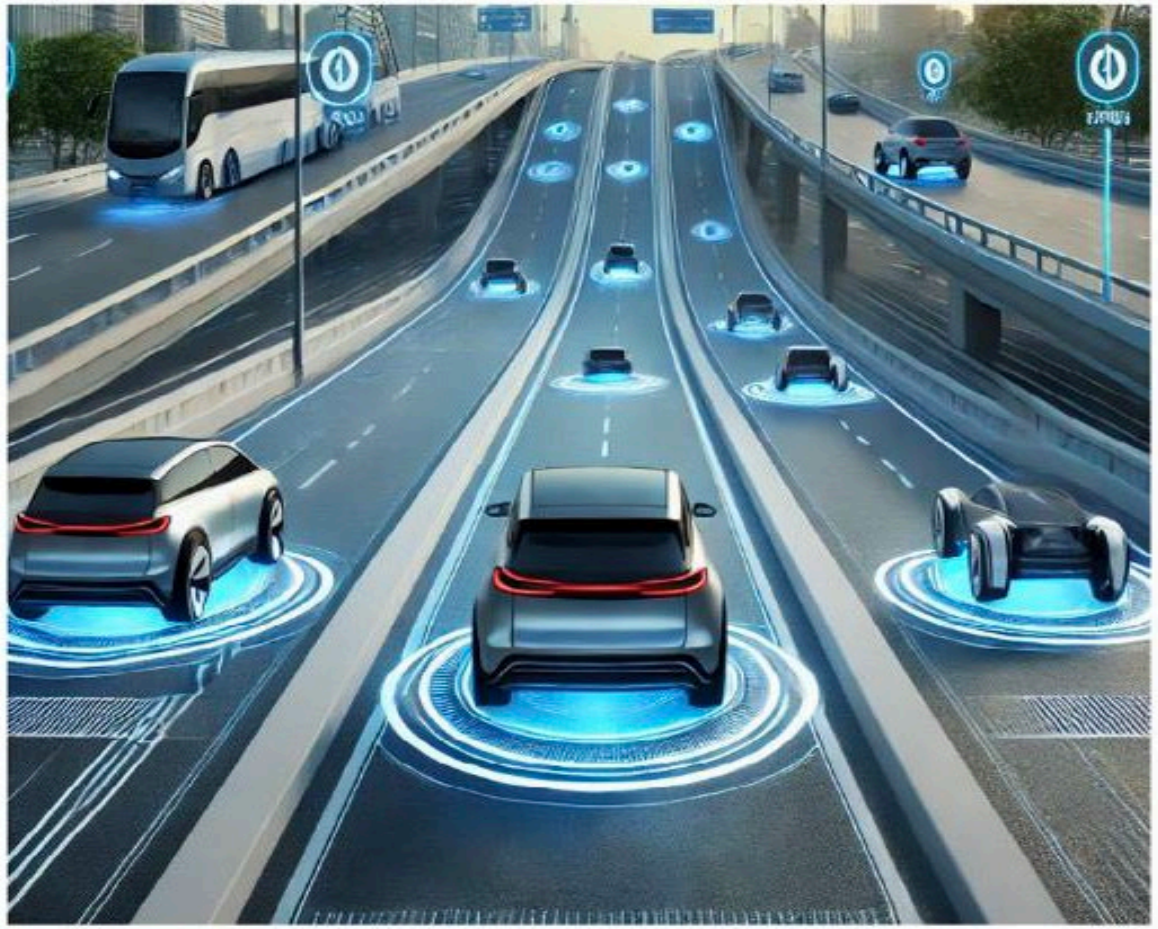
Massachusetts Institute of Technology | Civil and Environmental Engineering | Masic Lab @ MIT

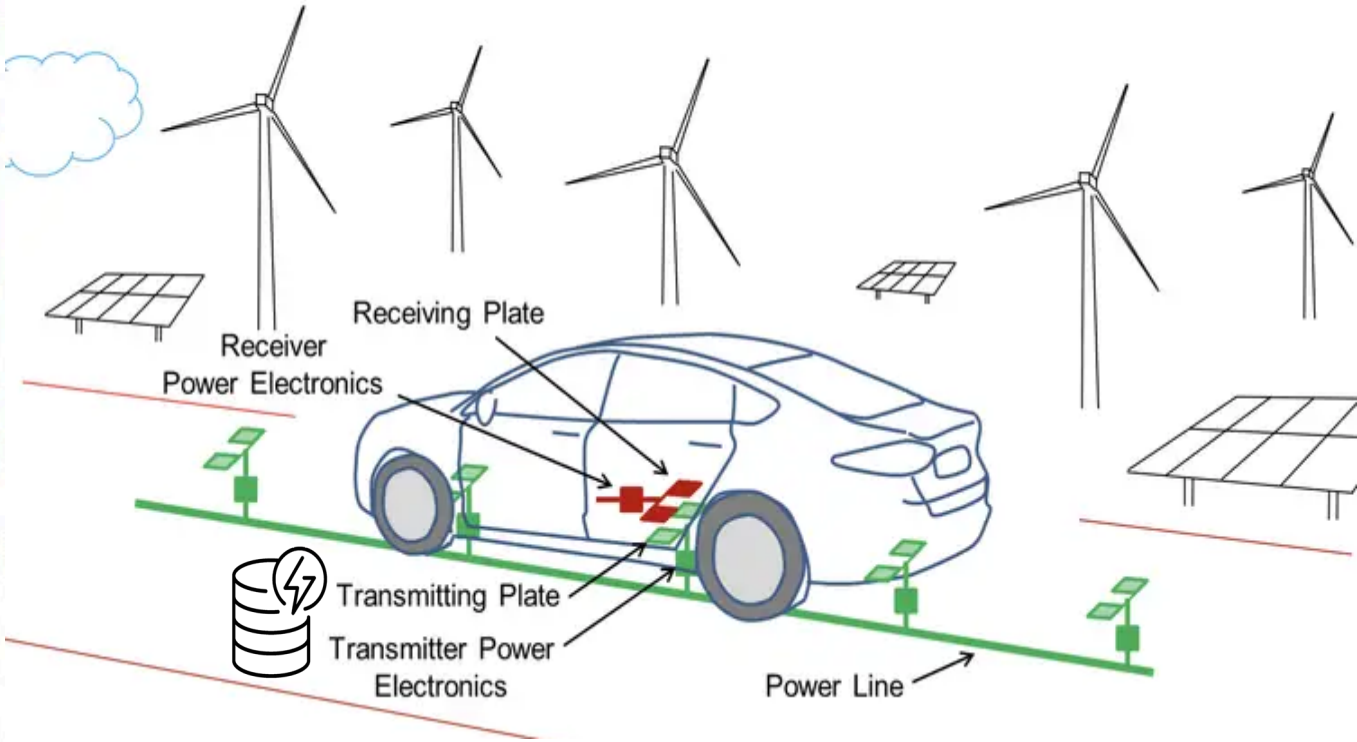
Decentralized electrical energy supply

Home foundations and walls as ‘batteries’

For reference:

Daily residential energy consumption: ~10 kWh ~ 33 m^3 ec^3-concrete





Application: Self-charging roads

Road as a renewable energy storage

Wireless charging of EV-cars by means of Electromagnetic Induction

Ancient Rome experienced architectural revolution through discovery and use of concrete

We may be on the verge of a new breakthrough that could completely revolutionize our perception of concrete, architecture, and the overall built environment:

MULTIFUNCTIONAL CONCRETE

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MIT ec³ hub

CSHub MIT CONCRETE SUSTAINABILITY HUB

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