INSTYTUT BADAWCZY DRÓG I MOSTÓW
ROAD AND BRIDGE RESEARCH INSTITUTE
1955 - 2025

Warsaw, 22 - 23 October 2025

II MIĘDZYNARODOWA KONFERENCJA
Nowoczesne nawierzchnie drogowe – recykling i dekarbonizacja

II INTERNATIONAL CONFERENCE
Modern road pavements - recycling and decarbonization

Advancing Electrically Conductive Concrete for Sustainable Infrastructure: From Thermal Activation to Energy Storage

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Environmental footprint of road salt

Snow plows in tandem formation deicing a multilane highway. Photo: Utah.gov

Every winter, hundreds of thousands of tons of road salt are used in to keep roads passable

Although effective, salt contributes to **soil degradation**, **water pollution**, and **infrastructure corrosion**, generating high maintenance costs

Icy road accident statistics in the US

1,836
Deaths Annually

136,309
Injuries Annually

536,731
Crashes Annually

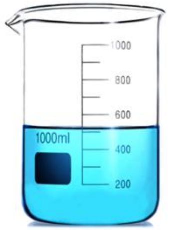
The USDOT Federal Highway Administration data lists an average of **1,836 deaths** and **136,309 injuries** per year due to snowy and icy roads [1].

[1] https://icyroadsafety.com/fatalitystats.shtml?

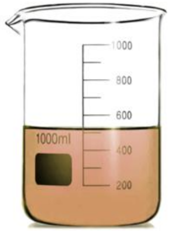
Electron-conducting carbon concrete (ec^3)

Cement

Aggregate



Water

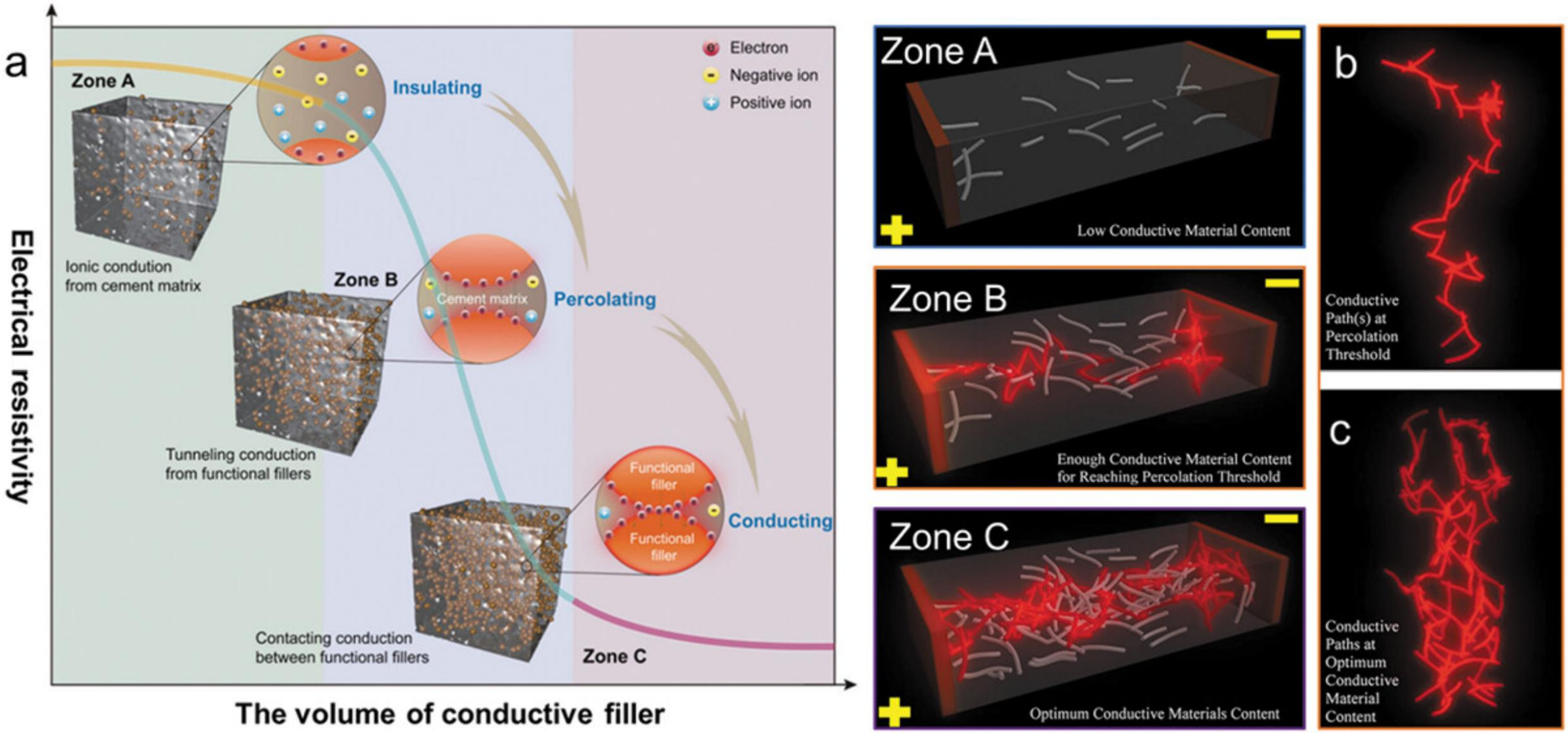


Superplasticizer

+

Nano carbon black

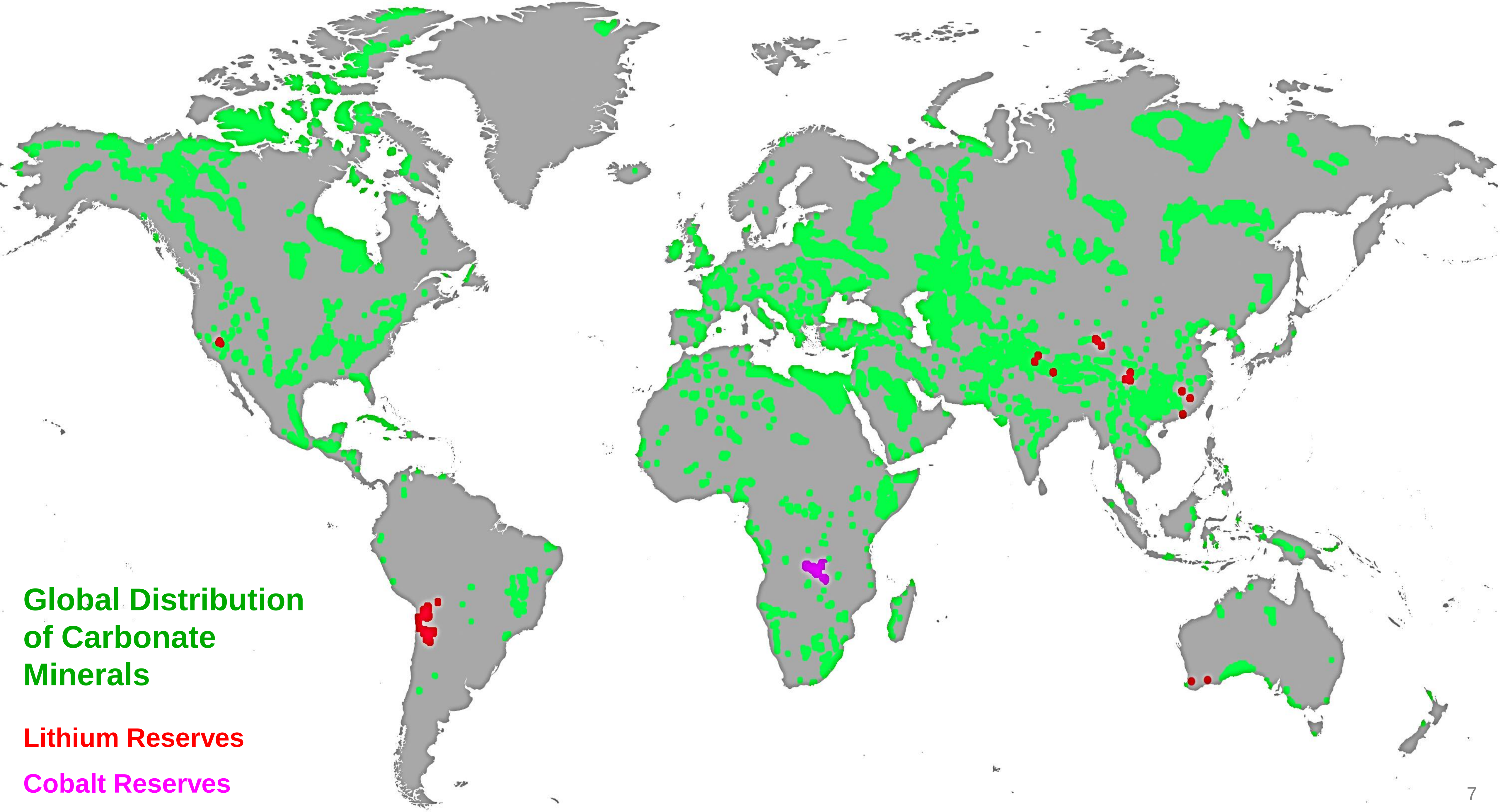
Electrical conductivity in concrete



Lu, D., Leng, Z., Lu, G., Wang, D., & Huo, Y. (2023). A critical review of carbon materials engineered electrically conductive cement concrete and its potential applications. International Journal of Smart and Nano Materials, 14(2), 189-215.

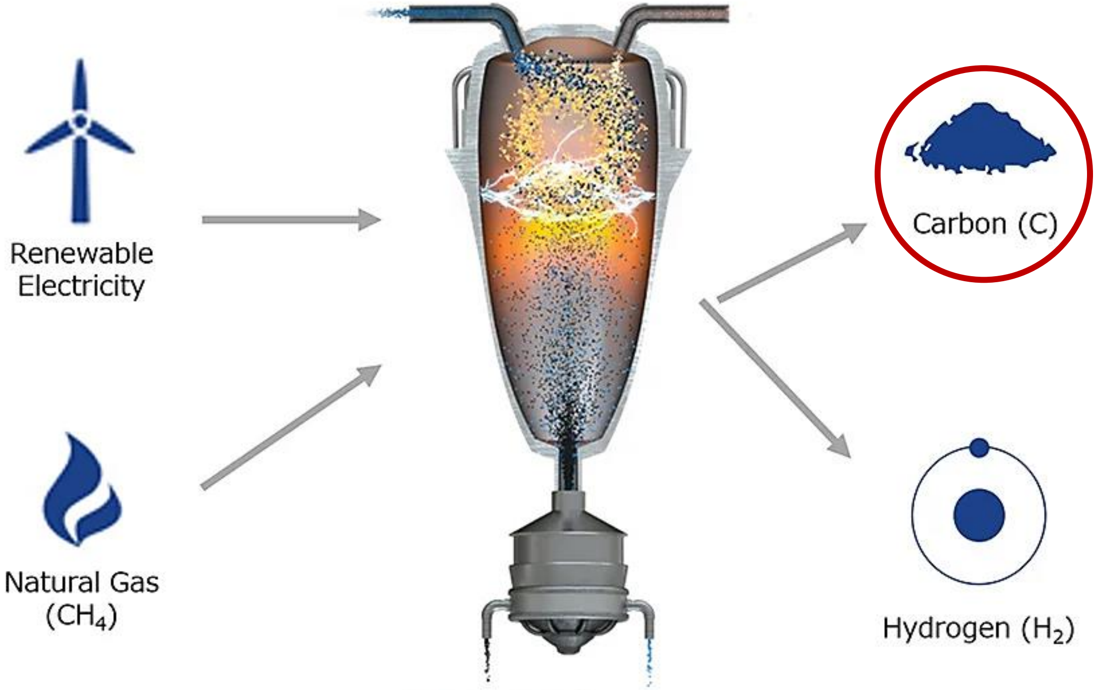
Electrical conductivity in concrete

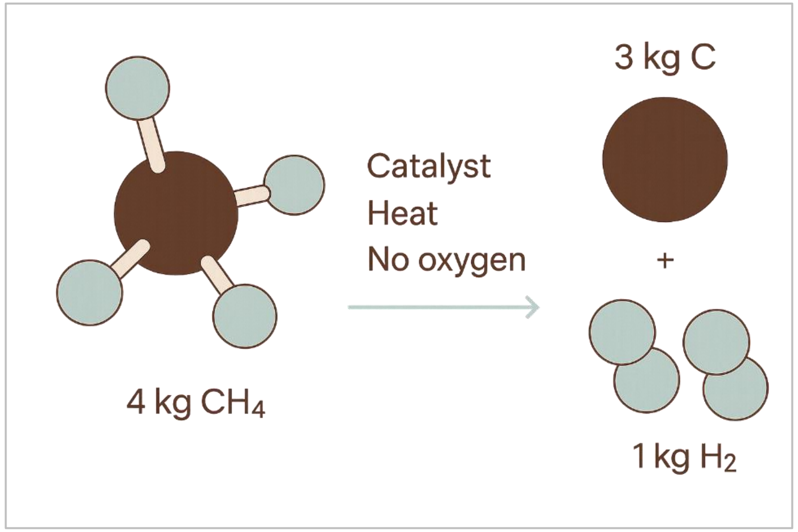
Filler Type	**Density (g/cm^3)**	**Specific Surface Area (m^2/g)**	**Electrical Conductivity (S/m)**	**Thermal Conductivity (W/m·K)**	**Texture**	**Porous**	**Hydrophobic**	**Cons**
Steel fibers	~7.8	*N/A* (<<1)	~6×10^6	~40–50	Short metallic fibers	No	No	**Corrode, low specific surface area**
Carbon fibers	1.6–2.1	*N/A* (≈0.3)	~10^4–10^5 (anisotropic)	10 (PAN CF) – 100+ (pitch CF)	Long graphitic fibers	No	Mostly (untreated)	**Expensive, low specific surface area**
Carbon nanofibers	0.06/2.1 (bulk/true)	13–1000	~10^4	~100	Filamentary "whiskers"	No	Yes	**Expensive, limited large-scale availability**
Carbon nanotubes	0.17/2.1 (bulk/true)	50–1315	~10^5	~3000 (along tube)	Nanotubes (1D fibers)	No	Yes	**Expensive, limited large-scale availability**
Graphite powder	2.1–2.3	<5	~10^3 (in-plane)	~5–10	Plate-like particles	No	Yes	**Low specific surface area**
Graphene nanoplatelets	~2.2	13–45	~10^4 (in-plane)	~500–5000 (in-plane)	Flat platelets	No	Yes	**Expensive, limited large-scale availability**
Nano carbon black	0.5–1.98	30–1307	~10^2–10^3	~0.1–0.5	Fine spherical particles	Yes	Yes	Comparatively inexpensive, highly available, and high specific surface area


Global Distribution of Carbonate Minerals
Lithium Reserves
Cobalt Reserves

Hydrogen production (methane pyrolysis)

“Turquoise hydrogen” (i.e., hydrogen produced without CO_2 emissions)





Research projects in Poland: Warsaw University of Technology, Silesian University of Technology, and the Institute of Physical Chemistry of the Polish Academy of Sciences

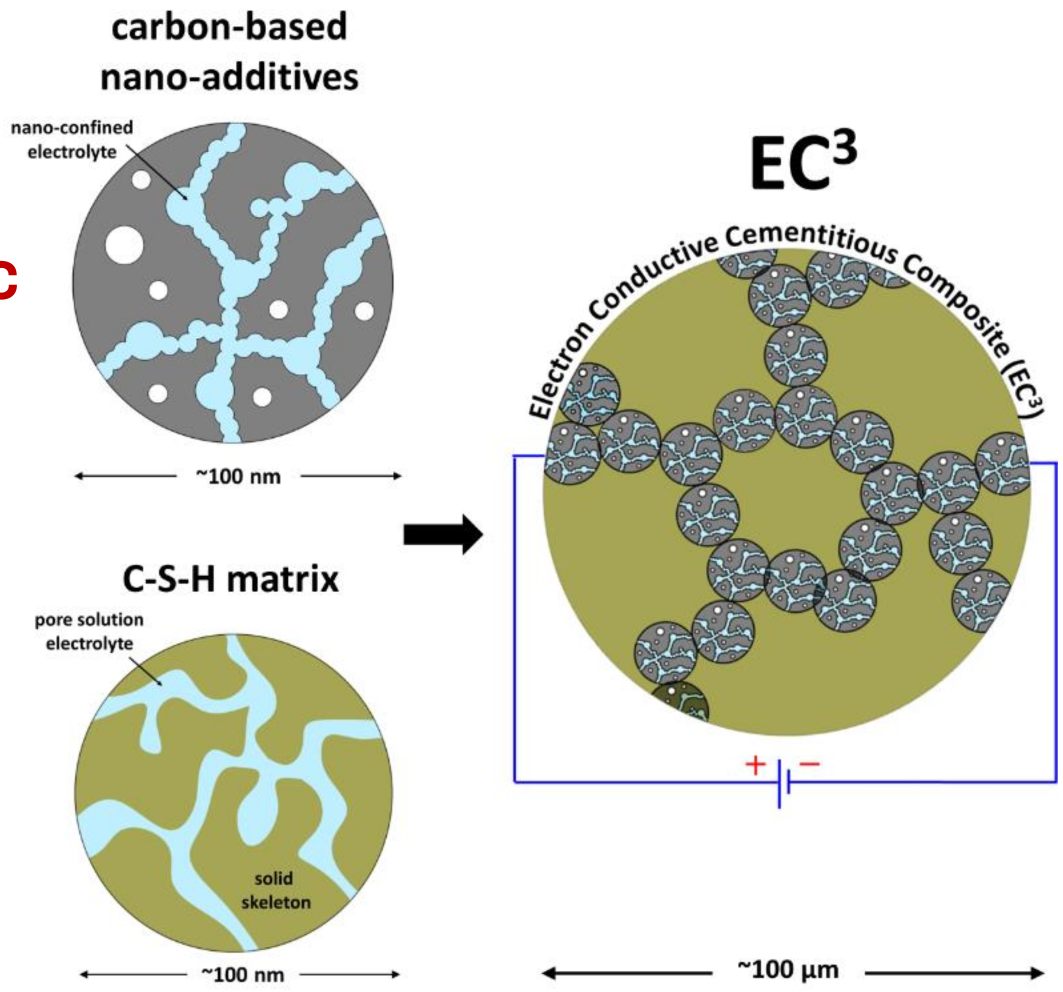
MONOLITH
(Proprietary Technology)

https://www.mhi.com/news/201130.html

Electron-conducting carbon network

Hydrophobic

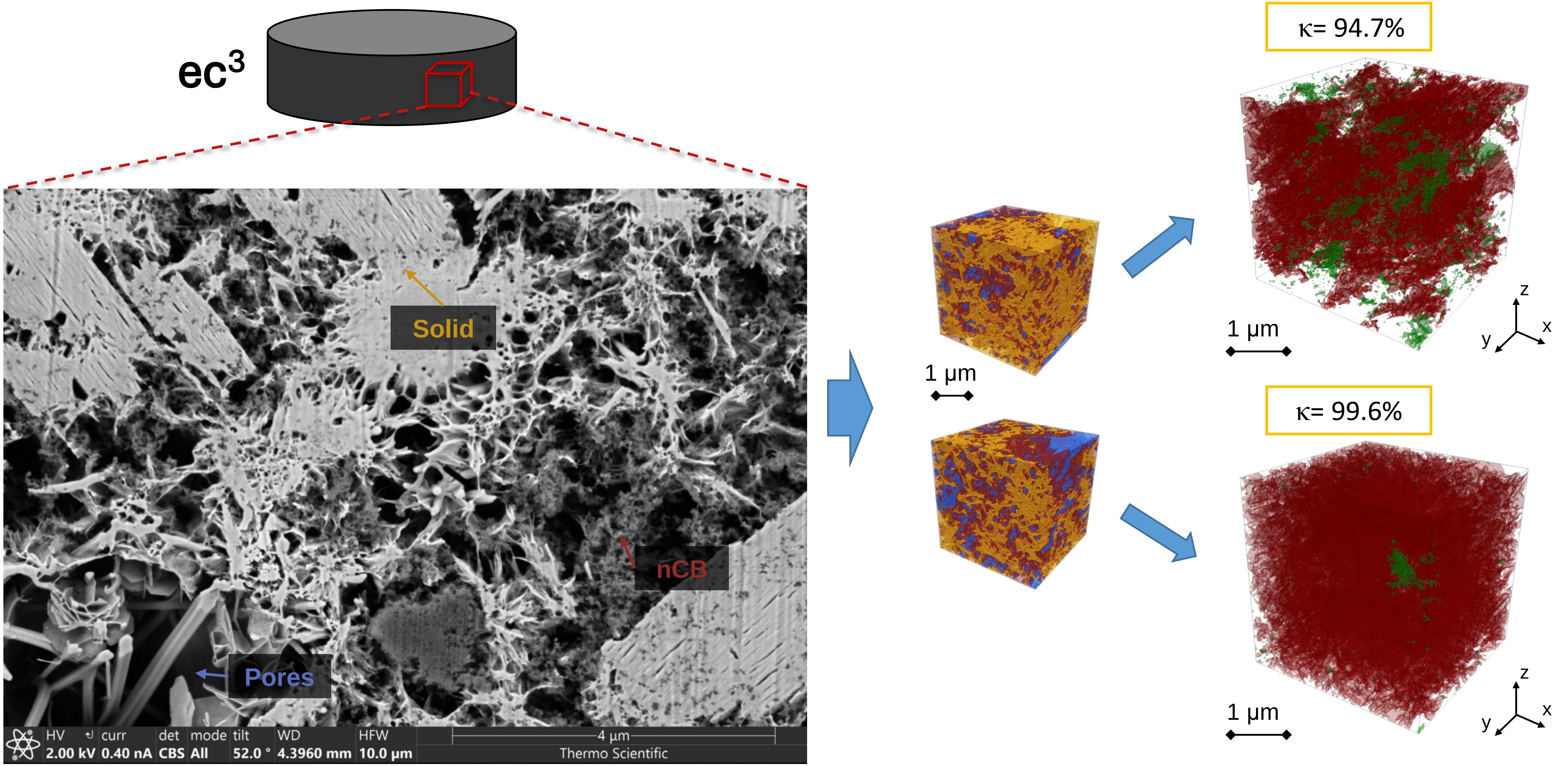
Hydrophilic



Percolation threshold >3-4%

Credit: *Konrad Krakowiak*

Electron-conducting carbon network



[1] Stefaniuk, D., Weaver, J. C., Ulm, F.-J., & Masic, A. (2025). High energy density carbon–cement supercapacitors for architectural energy storage. PNAS, in press.

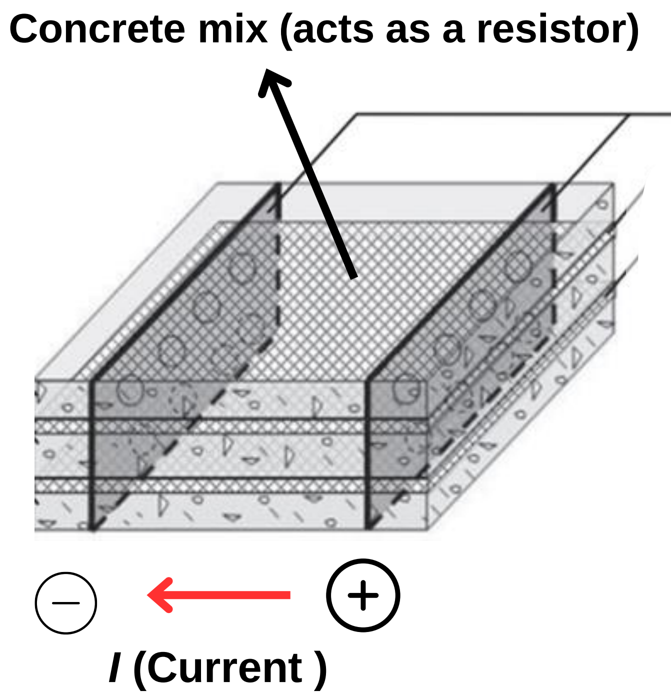
ec^3 technology potential

Heated Roads/Airport Runways

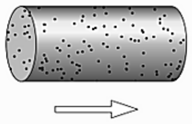
Renewable Energy Storage

Joule effect (resistive heating)

When a voltage is applied, electric current flows through the concrete, and its internal resistance converts electrical energy into heat through the Joule (resistive) heating effect—similar to how a heating element in an electric stove operates.



$$R = \frac{\rho L}{A}$$



https://isaacscienceblog.com/2016/07/09/joule-heating/

MIT EC^3 Hub

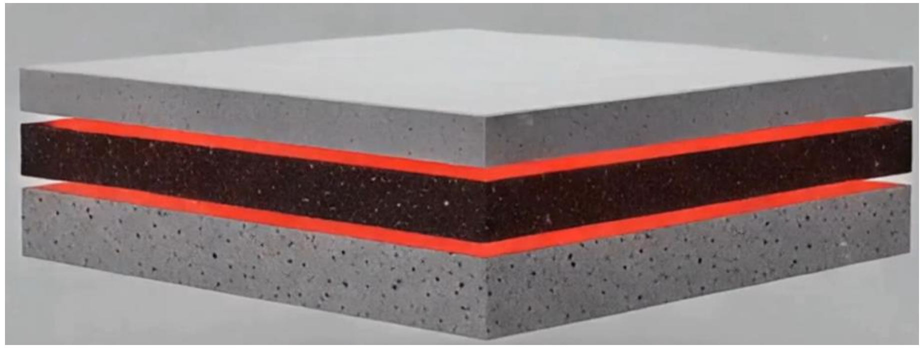
Self-heating application of ec^3

AIZAWA
Concrete basics for life.

December 2024

Built-in de-icing and temperature control system for:

- Roads and airport pavements
- Parking areas
- Underfloor heating systems



5-m long ec^3 pavement, Sapporo, Japan

Credit: Aizawa Corporation

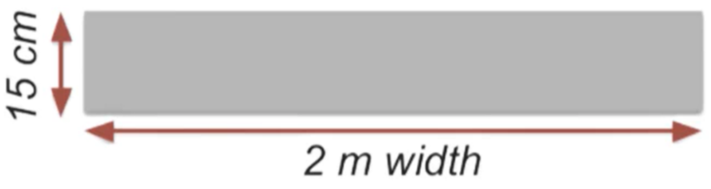
Self-heating application of ec^3

Credit: Aizawa Corporation, Japan

Self-heating application of ec^3

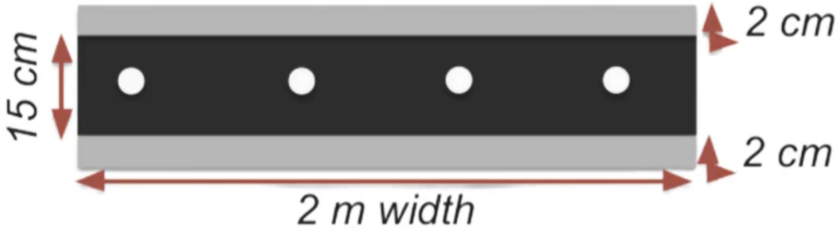
Case study of sidewalk in a cold climate region (Canada)

Conventional system



- **Maintenance:** Deicing salt 2.8 $kg/m^2/year$
- **Repair:** Replacement of the whole slab every 15 years due to freeze-thaw cycles
- **Mix design:** conventional concrete

Multifunctional system



= 4.5 tons of CO2 savings over the life cycle of a 100-m long sidewalk

Credit: Hessam AzariJafari, MIT Concrete Sustainability Hub

Sustainability of ec^3

Compatibility with low-carbon concrete products

Regular cement

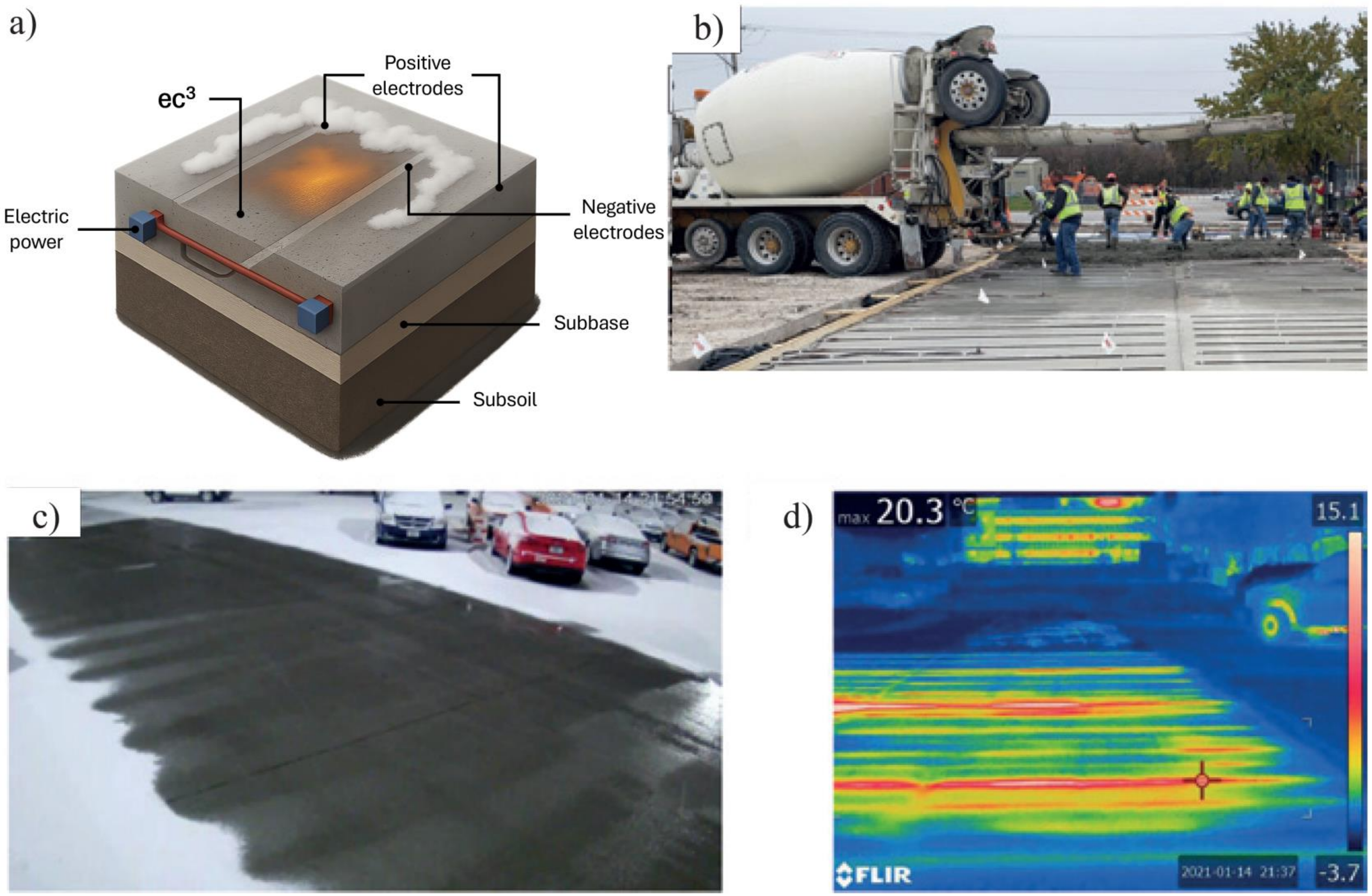
Low-CO_2 ("green") cement

Other deicing systems

Location	Institution	Project Description	Technology / Material	Objective
Nebraska	University of Nebraska–Lincoln	Demonstration project of the Roca Spur Bridge in Nebraska	Steel fibers, steel shavings, and carbon-based fillers	Bridge deck de-icing
Ames (USA)	Iowa State University	Full-scale ECON HPS system on road pavements	Conductive concrete with steel electrodes, PLC control	Effective de-icing, improved safety
Des Moines International Airport (USA)	Iowa State University	Test ECON HPS slabs in airport infrastructure	Concrete with temperature and current sensors	Evaluation of heating efficiency
Gyeonggi (South Korea)	Hankyong National University	Cement composites in cold climates	Carbon fibers, CNT, CNF, graphite	De-icing, accelerated concrete curing
Arlington, Texas (USA)	University of Texas at Arlington	TE-CO_2NCRETE project – thermoelectric concrete	Concrete with CNT and graphene	Thermal energy conversion, CO_2 capture from the environment

[1] Stefaniuk D., Krakowiak K. J., Świtała M., Bebłacz D., Przybylski P.Beton przewodzący prąd jako system samoodladzający / Electron-conductive concrete as a self-deicing system.W: Nauka w Budownictwie – Wybrane Problemy.Instytut Badawczy Dróg i Mostów, Warszawa, 2025.

Project in Iowa, USA



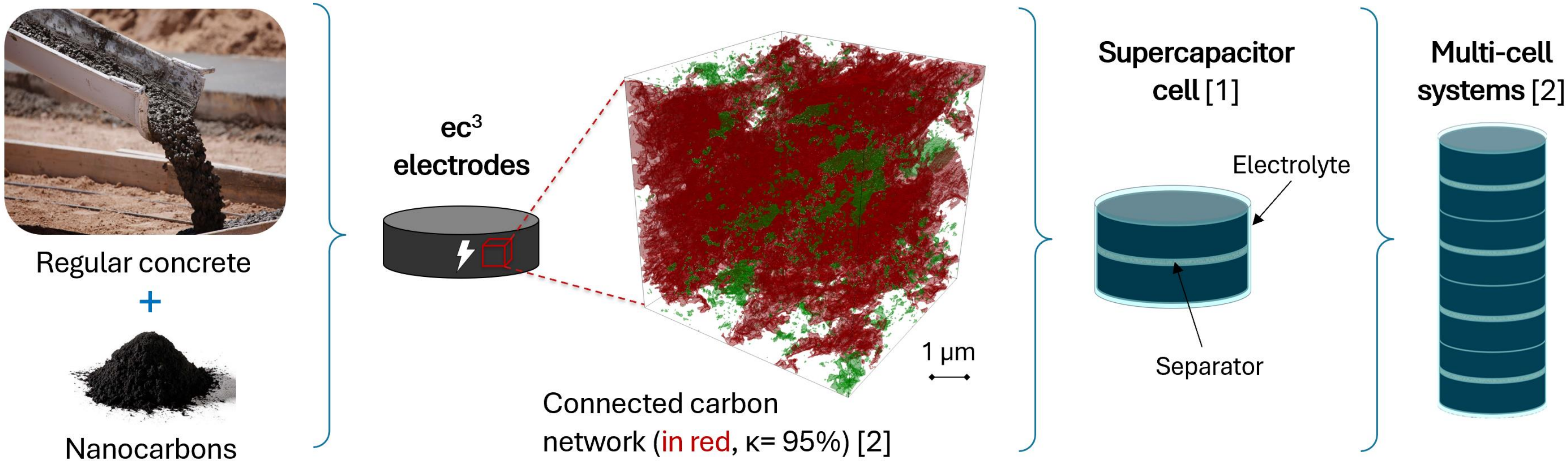
Malakooti A, Sadati S, Ceylan H, Kim S, Cetin KS, Taylor PC, Mina M, Cetin B, Theh WS. Self-Heating Electrically Conductive Concrete Demonstration Project. Institute for Transportation, Ames, IA; 2021.

ec^3 technology potential

Heated Roads/Airport Runways

Renewable Energy Storage

ec^3 structural supercapacitor



❖ **Potential applications:**

[1] Chanut, N., Stefaniuk, D., Weaver, J. C., Zhu, Y., Shao-Horn, Y., Masic, A., & Ulm, F. J. (2023). Carbon–cement supercapacitors as a scalable bulk energy storage solution. PNAS, 120(32), e2304318120.
[2] Stefaniuk, D., Weaver, J. C., Ulm, F.-J., & Masic, A. (2025). High energy density carbon–cement supercapacitors for architectural energy storage. PNAS, in press.

RESEARCH ARTICLE | ENGINEERING

PNAS

High energy density carbon–cement supercapacitors for architectural energy storage

Damian Stefaniuk, James C. Weaver, Franz-Josef Ulm, and Admir Masic

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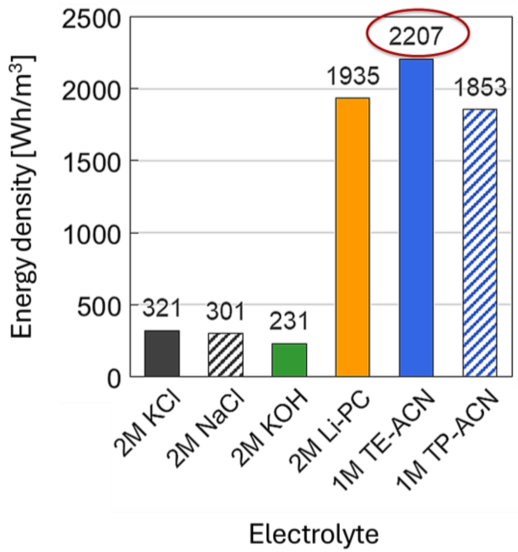
September 29, 2025 | 122 (40) e2511912122 | https://doi.org/10.1073/pnas.2511912122



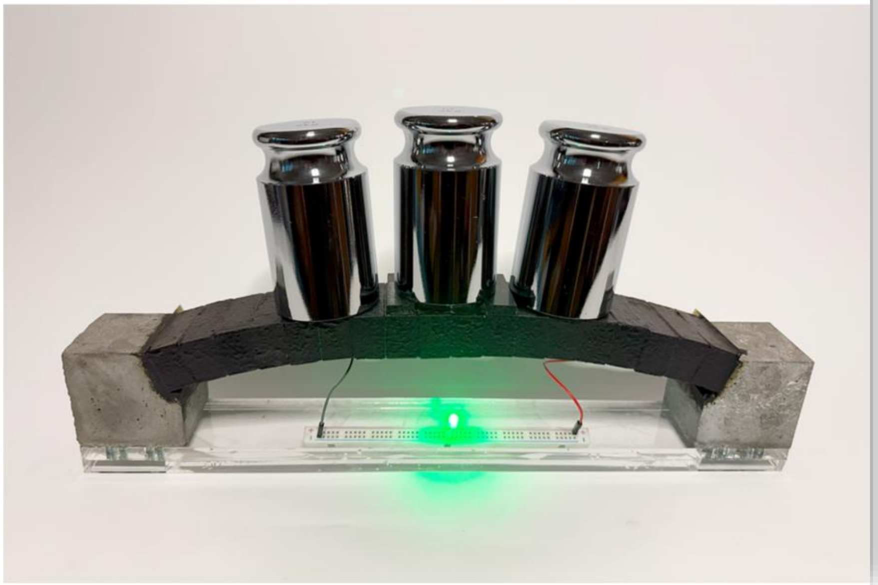
MIT News
ON CAMPUS AND AROUND THE WORLD
SUBSCR

Concrete “battery” developed at MIT now packs 10 times the power

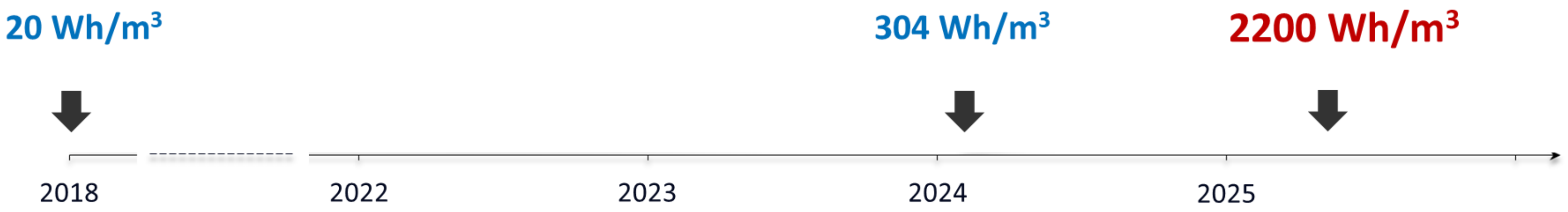
Improved carbon-cement supercapacitors could turn the concrete around us into massive energy storage systems.

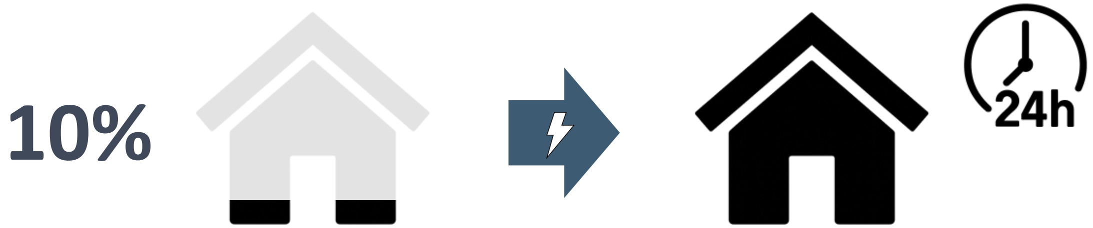
Andrew Paul Laurent | Concrete Sustainability Hub

October 1, 2025



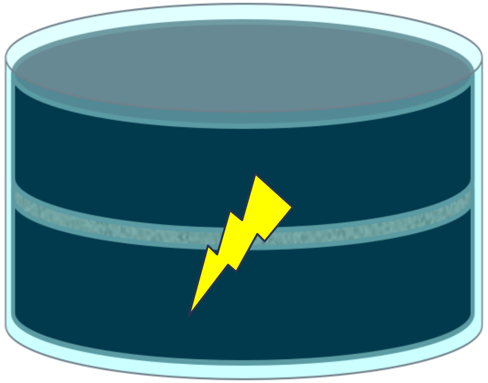
Energy storage capability



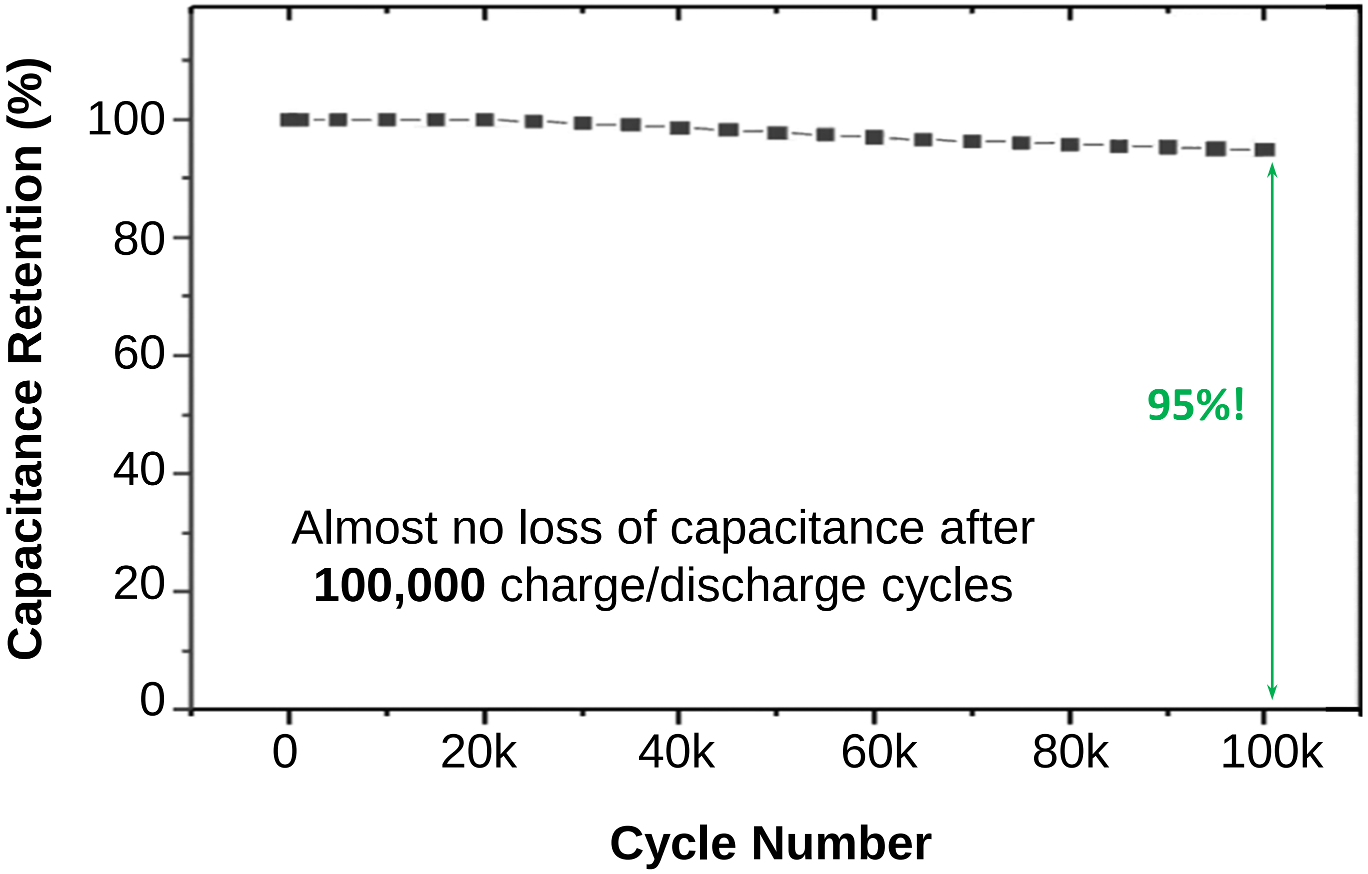


[1] Stefaniuk, D., Weaver, J. C., Ulm, F.-J., & Masic, A. (2025). High energy density carbon–cement supercapacitors for architectural energy storage. PNAS, in press.

Long-term durability of ec^3

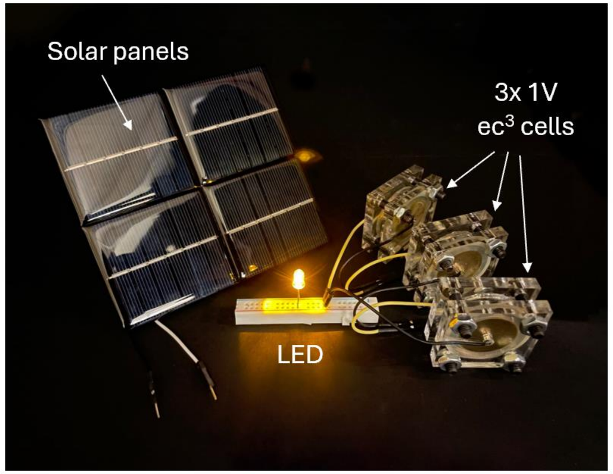


Galvanostatic charge-discharge tests:

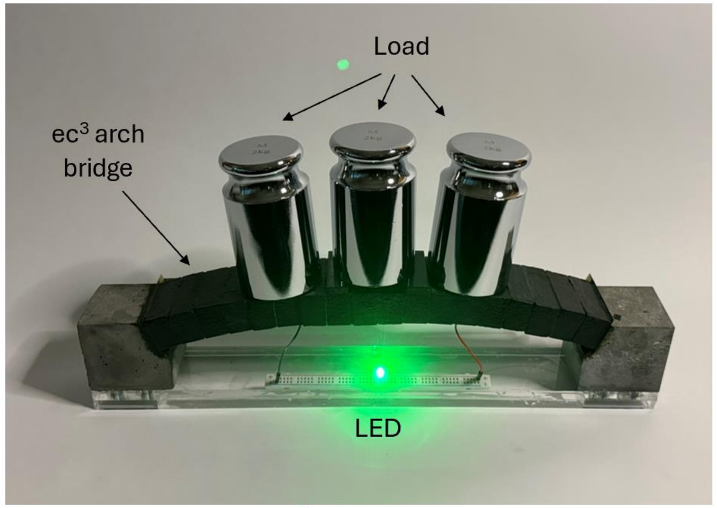


Prototype evolution

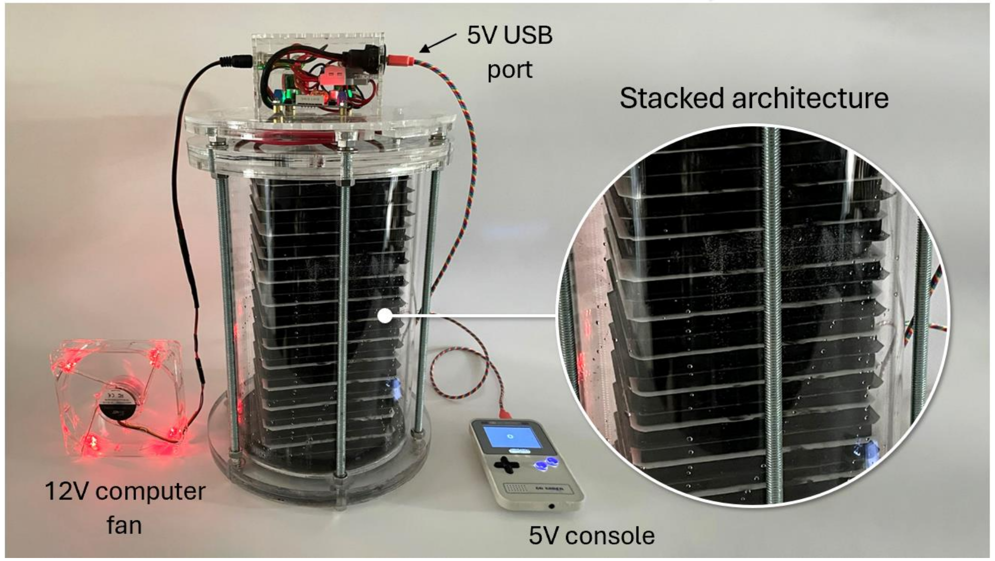
❖ 3V prototype (5 cm³) June 2023



❖ 9V prototype (5 cm³) [2] May 2024



❖ 12V column (0.003 m³) January 2024



Built-in energy storage for:

- Renewable-powered buildings
- Smart grids & microgrids
- Data centers
- Off-grid or backup power systems

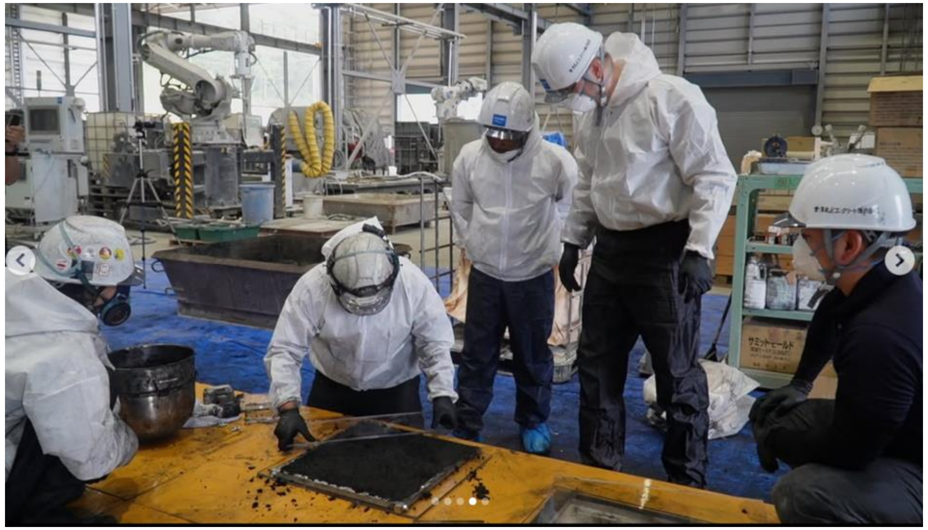
25V ec³ core

❖ 25V prestressed column (0.25 m³) September 2025

Credit: Walid Sebai

[2] Stefaniuk, D., Weaver, J. C., Ulm, F.-J., & Masic, A. (2025). High energy density carbon–cement supercapacitors for architectural energy storage. PNAS, in press.

Technology deployment in Japan

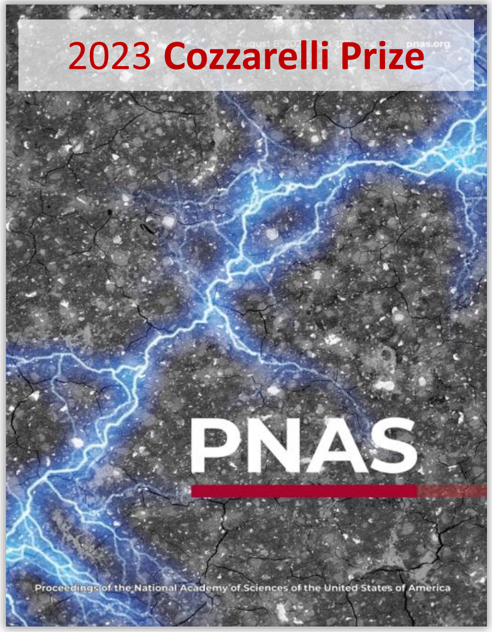


4 x 25V (1 m^3)

Photo by: *Admir Masic*
Credit: *Aizawa Corporation*

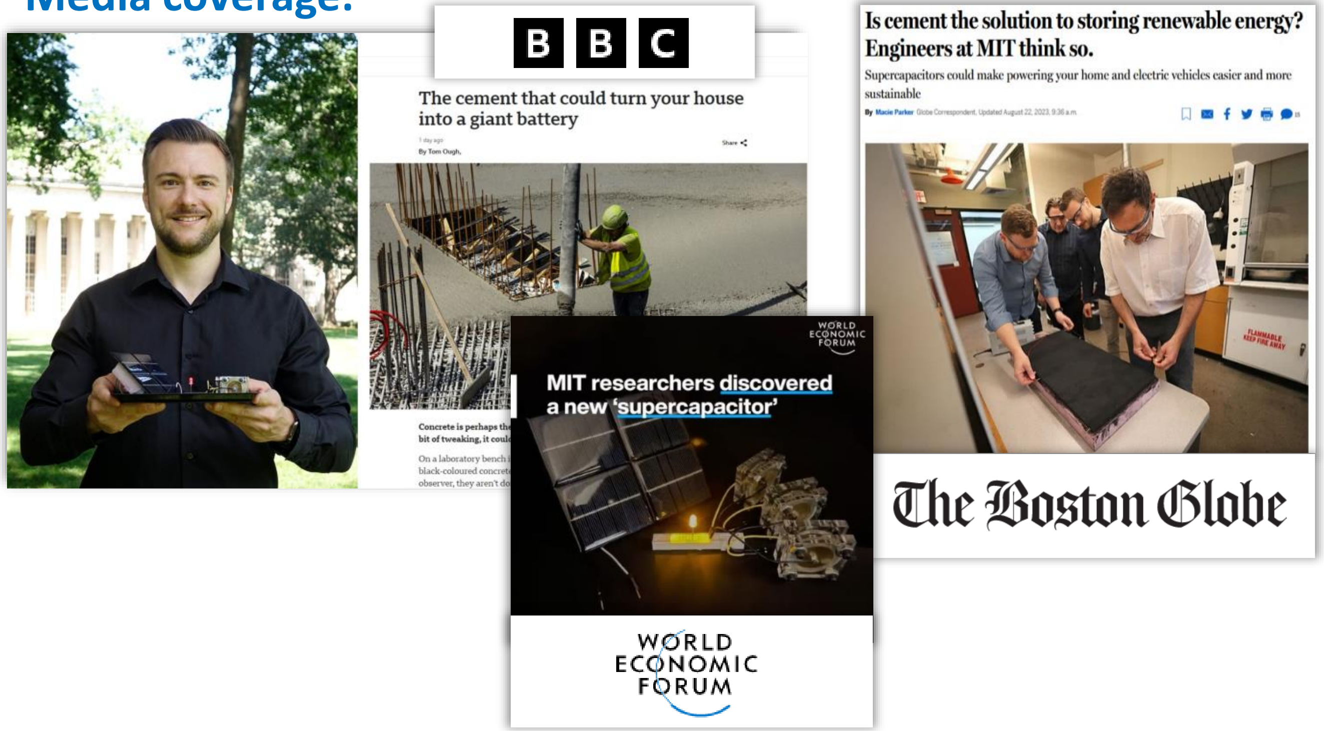
Global Recognition of ec^3

Journal paper:



WIPO Book:

Media coverage:



TV features:

Report (Dec 2024) :

Opportunities to solve US infrastructure challenges: **"Energy-storing materials (multifunctional concrete)"**

ARPA-I ADVANCED RESEARCH PROJECTS AGENCY • INFRASTRUCTURE

U.S. Department of Transportation

Implementation barriers in Poland and worldwide

Implementation barriers in Poland and worldwide

Despite their significant technological potential, the implementation of self-deicing systems made of electrically conductive concrete in Poland faces numerous challenges [1]:

- **Technological:** High cost of conductive additives, lack of national design standards and certification procedures, and uncertainty regarding durability under freeze–thaw cycles.
- **Organizational:** Lack of trained personnel and contractor experience, and the need to develop guidelines for operation and maintenance of such systems.
- **Economic:** High investment costs (CAPEX) and uncertainty of operational costs (OPEX); need for new financing models such as public–private partnerships.
- **Energy-related:** Integration with the power grid and renewable energy sources, ensuring stable energy supply, and minimizing transmission losses.

[1] Stefaniuk D., Krakowiak K. J., Świtała M., Bebłacz D., Przybylski P.Beton przewodzący prąd jako system samoodladzający / Electron-conductive concrete as a self-deicing system.W: Nauka w Budownictwie – Wybrane Problemy.Instytut Badawczy Dróg i Mostów, Warszawa, 2025.

Conclusions and future directions

The ec^3 technology demonstrates how innovative materials can address multiple challenges simultaneously — from self-deicing pavements to renewable energy storage.

Future efforts should focus on [1]:

- Developing national **design guidelines**,
- Conducting broader **life-cycle cost analyses (LCCA)**,
- **Advancing studies** on durability, efficiency, and scalability,
- Promoting **interdisciplinary collaboration** between academia, industry, and public administration.

[1] Stefaniuk D., Krakowiak K. J., Świtała M., Bebłacz D., Przybylski P.Beton przewodzący prąd jako system samoodladzający / Electron-conductive concrete as a self-deicing system.W: Nauka w Budownictwie – Wybrane Problemy.Instytut Badawczy Dróg i Mostów, Warszawa, 2025.

Collaboration between MIT, UH, and IBDiM

NAUKA W BUDOWNICTWIE – WYBRANE PROBLEMY

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DOI: 10.15199/33.2025.10.

Beton przewodzący prąd jako system samoodladzający

Electron-conductive concrete as a self-deicing system

Artykuł przeglądowy (Review paper)

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