PNNL'S SELF-HEALING CEMENT

Dynamically Repairs Itself to Extend its Useful Lifespan

U.S. DEPARTMENT OF ENERGY

Pacific Northwest NATIONAL LABORATORY

Building the Future with PNNL's Self-Healing Cement

A "Molecular-Velcro" Cement Technology for Sustainable Development

Self-Healing Cement

A Concrete Solution

Repairs** throughout the **entire lifespan

*Exhibits **three times the lifespan** of traditional concrete*

70% more ductile

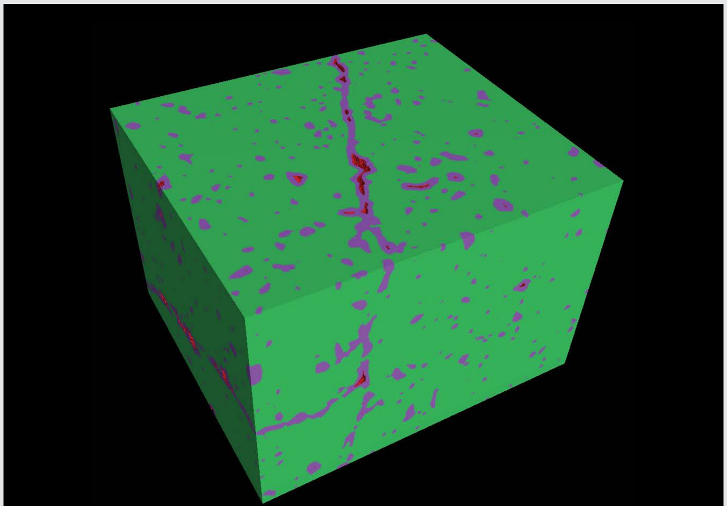
Prevents cracking** in concrete **by 90%

***Adheres to steel** and other structural or reinforcing members*

*Ideal for **high-pressure**, **high-temperature** environments*

Customizable** compositions for **various applications

*PNNL's Self-Healing Cement is the **FIRST** technology with the ability to self-repair cracks throughout the **ENTIRE LIFE SPAN** of the concrete structure.*



PNNL's patented Self-Healing Cement has special polymer material (shown in purple) distributed throughout the composite (shown in green); the polymer can dynamically fill and heal cracks and voids.

Material scientists and computational modeling experts at Pacific Northwest National Laboratory (PNNL) have developed Self-Healing Cement, the first technology with the ability to self-repair cracks throughout the entire life span of the concrete structure. The pollution-minimizing innovation—created by blending particular polymers into a cement composite—**prevents cracking in concrete by** as much as **90 percent**, is **100 percent stronger** than conventional concrete, and **extends the** commodity's **life span by up to three times**.

PNNL is also developing additional compositions utilizing biobased polymers that further improve healing performance and prevent cracking in the first place. The existing inventions, along with current and future developments, will lead to concrete with enhanced performance, extended life, and reduced environmental impacts.

Polymers Under Pressure

PNNL's patented technology combines select polymers—strong, flexible, and powerful ingredients—with cement to produce concrete that **heals itself within 24 hours of when cracks occur**. The result: prevention of costly downtime for repairs and replacement.

Researchers discovered that blending the polymers with cement enables the composite material to **reversibly and dynamically bond across fissures to heal damaged areas**. In addition, **the composite's elasticity increases by 70 percent** making Self-Healing Cement more resistant to fractures and able to withstand greater mechanical stress from natural disasters and extreme weather conditions, such as earthquake tremors or high winds. The polymers form dynamic bonds with the cement. When a crack forms, the polymers migrate to the crack and form a tight bond to fill the void reinforcing the material's structure. **This unique property differentiates PNNL's Self-Healing Cement from other technologies, which are only self-filling cements**.

Furthermore, PNNL's Self-Healing Cement can heal (and even adhere to steel structures) again, and again, and again—throughout the entire lifespan of the structure. By modifying the polymer mixture, it can be customized for various applications.

Industrial Applications

Cement is a key ingredient in concrete, which is the second most consumed material in the world, second only to water. Concrete has been a rock-solid solution for civil engineering structures for decades and now is vital to major industries like transportation, buildings, hydropower, nuclear energy, geothermal energy, and fossil fuels. But, even concrete's strength, longevity, and reliability will eventually crack. Literally. Fissure repairs to concrete structures are costing the U.S. industry $12 billion annually. Furthermore, our large appetite for conventional concrete is having a harmful effect on the environment.

Available for licensing, PNNL's Self-Healing Cement has the potential to radically affect U.S. industries where cement and concrete are used in high-temperature, high-pressure environments, such as geothermal energy plants and oil and gas well bores. Other industries that could benefit include nuclear energy, hydropower, transportation infrastructure, nuclear waste disposal, and long-term nuclear storage. This promising technology could also **mean $3.4 billion per year in future savings for infrastructure such as dams, roads and bridges, and skyscrapers**.

Environmental Impacts of Cement Manufacturing

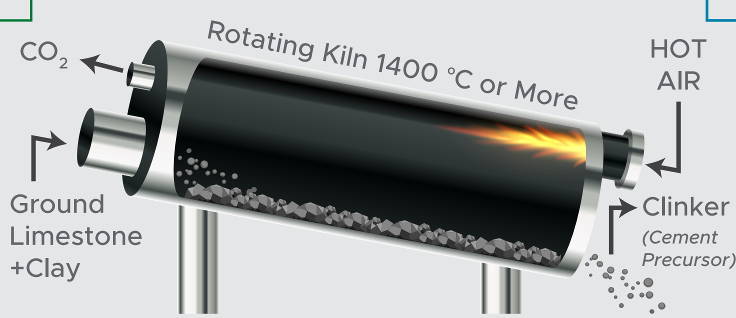
Cement manufacturing results in one pound of CO_2 for every pound of cement.

52x

About 10 billion tons of concrete are produced worldwide each year—enough material to fill 130 million train freight cars, which could circle the Earth 52 times.

Concrete is the second most consumed material in the world.

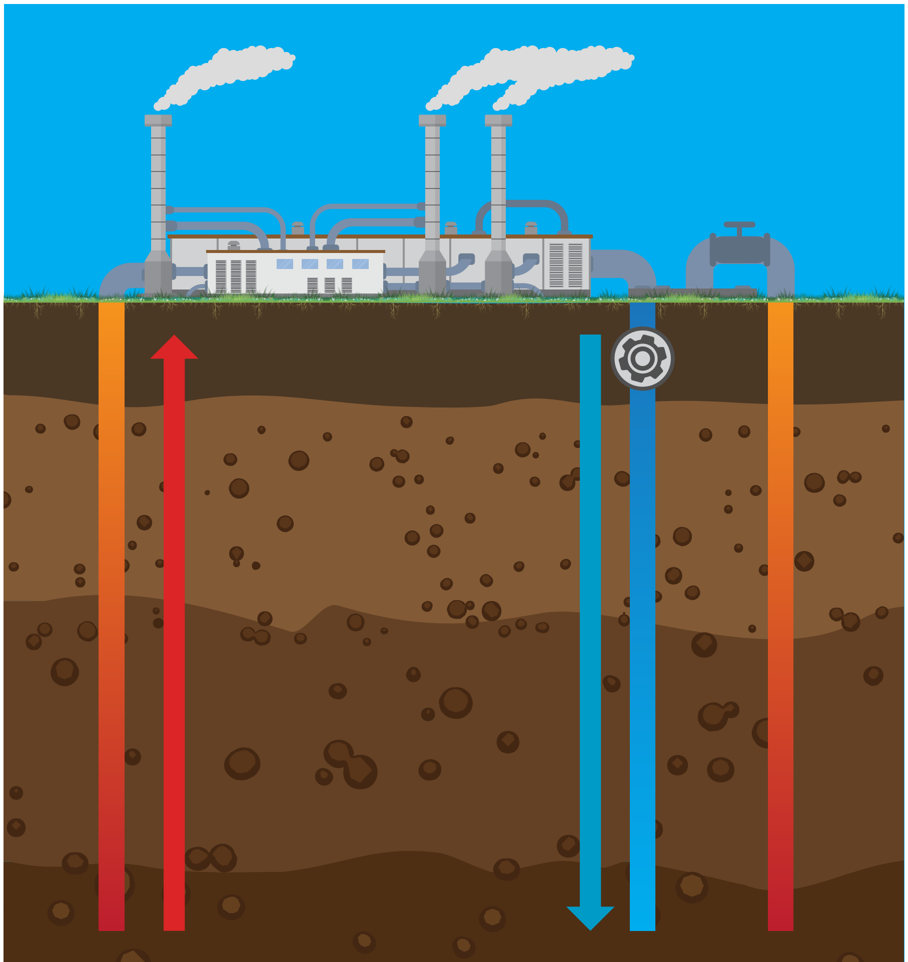
If the cement industry were a country, it would be the third largest emitter of carbon dioxide in the world.



The cement industry is the most energy-intensive of all manufacturing industries.

To manufacture cement, raw materials, mainly limestone and clay, are quarried, crushed, and fed into cylindrical kilns, which burn fuel to reach extraordinary temperatures, in order to create "clinker" that will then be ground up and made into the final product.

Geothermal and Fossil Fuel Production



The United States leads the world in the amount of geothermal energy generated, and more than 80 percent of the energy used is provided by fossil fuels. For these energy sources to remain safe, sustainable, and cost-competitive, we must invest in improving cement used in wellbores.

Cement around geothermal production wells undergoes at least two wellbore repairs throughout its 30-year lifespan. Each repair is generally greater than $1.5 million annually per wellbore—without taking into consideration the economic loss resulting from the production stoppage. Designed specifically for high-pressure, high-temperature environments, like those around geothermal and fossil fuel wells, PNNL's Self-Healing Cement can reduce or eliminate these costly repairs and can **extend the lifetime of wellbores by as much as 50 years**. Studies show that PNNL's Self-Healing Cement reduced the permeability of fractures in cement casings more than 80 percent and had far better resistance to thermal-shock-associated radial cracking than all other cement technologies. This pollution-preventing innovation—which reduces the carbon footprint because of fewer repairs and replacement—is ready to be licensed. In addition, PNNL is looking for more research funding to test Self-Healing Cement on a pilot scale at a manufacturing plant.

Hydropower

By 2025, more than a third of the dams in the United States will be more than half a century old. Experts estimate it will cost $70 billion to rehabilitate public and private dams in need of repair across the nation's waterways. Further, occasional dam failures result in severe economic and environmental damage. Improved cement compositions, like PNNL's Self-Healing Cement, could provide a more sustainable, environmentally friendly solution for repairing existing hydropower dams and for building new ones.

With more than 90,000 dams located around the nation, the United States is the second largest producer of hydropower, second only to China.

Nuclear Energy

For 60 years, 20 percent of the nation's electricity has come from nuclear energy, a clean, carbon-free solution.

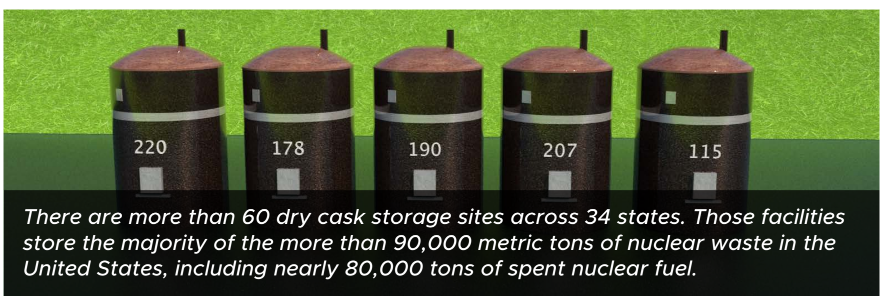
Cracks in concrete infrastructure at any of the 60 commercially operated nuclear plants around the United States could be catastrophic. PNNL's Self-Healing Cement could be engineered specifically for environments such as those at nuclear plants, particularly those including high-temperature and/or radioactive settings.

Transportation Infrastructure

The American Society of Civil Engineers estimates that the United States will need to spend $4.5 trillion to fix the nation's transportation infrastructure—including roads, dams, and bridges—by 2025. More than 47,000 bridges alone are in need of repair, replacement, or major renovation. Piled on top of these estimates are unaccounted for costs and time delays caused by traffic congestion due to road closures. Customized concrete that heals itself at ambient temperature—or prevents cracking altogether—would be a game-changer for the transportation industry.

The United States transportation system's highways, roads, and bridges are essential arteries of commerce and economic activity.

Nuclear Waste Disposal and Long-Term Storage

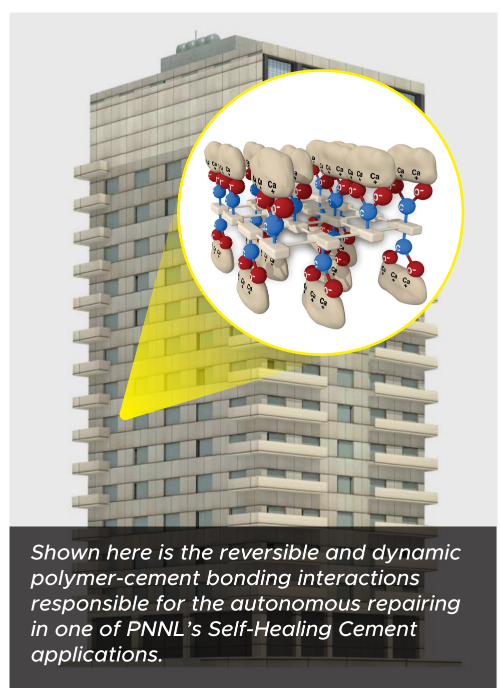


There are more than 60 dry cask storage sites across 34 states. Those facilities store the majority of the more than 90,000 metric tons of nuclear waste in the United States, including nearly 80,000 tons of spent nuclear fuel.

Nuclear waste cleanup and long-term storage sites would benefit from Self-Healing Cement by helping to prevent leaks and contamination into the ground and aquifers. The technology could serve as a safe and secure option for long-term low-activity and intermediate-activity waste storage.

Next-Generation Self-Healing Cement for Residential and Commercial Buildings

PNNL researchers have already begun to work on a next-generation of Self-Healing Concrete designed specifically for residential and commercial buildings. This cost-effective and environmentally friendly innovation will include self-healing and re-adhering polymer-modified cement materials that will significantly enhance the integrity of a building's infrastructure. The polymer-modified cement will be engineered to be readily mixed with typical fine and coarse aggregates to build new concrete structures. Early projections estimate that by using PNNL's Self-Healing Cement, the cost and frequency of concrete **infrastructure repairs would be reduced by 30 percent**. This advanced concrete technology is projected to reduce the cost of infrastructure repair and maintenance operations. That means that by 2020, the industry **could experience $3.4 billion in annual savings** associated with building repairs. Researchers also estimate the innovation will extend a building's lifespan by three times—up to **120 years**.



Shown here is the reversible and dynamic polymer-cement bonding interactions responsible for the autonomous repairing in one of PNNL's Self-Healing Cement applications.

INVEST IN THE FUTURE: BIOBASED ADDITIVES

PNNL researchers, in partnership with Washington State University, envision more new ways to minimize cement's carbon footprint by transforming waste carbon into products that are valuable to the cement industry. We will leverage our expertise in waste-carbon recycling to develop new cement compositions that include biobased additives as drop-in replacements or performance-enhanced chemicals, which help slow or reverse climate change while also improving cement performance. We are currently seeking research partners and federal sponsorship to turn our vision into reality.

Ready for Licensing

PNNL's Self-Healing Cement is available for licensing in all industrial markets. We're also looking for research partners and sponsors interested in concrete solutions to help significantly reduce carbon and energy footprints associated with cement manufacturing.

About PNNL

Located in Richland, Washington, PNNL researchers draw on signature capabilities in chemistry, Earth sciences, and data analytics to advance scientific discovery and create solutions to our nation's toughest challenges in energy resiliency and national security. Often, our federally funded research results in intellectual property that is available for licensing. You can view our Self-Healing Cement and other available technologies at **https://availabletechnologies.pnnl.gov**.

PNNL was founded in 1965 and is operated by Battelle for the U.S. Department of Energy's Office of Science.

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