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Concrete needs to lose its colossal carbon footprint

Concrete will be crucial for climate-resilient construction. But the cement industry must set out its plan for decarbonization.

Wet concrete has been poured into buildings, roads, bridges and more for centuries. Structures using concrete have survived wars and natural disasters, outlasting many of the civilizations that built them[1]. Alongside its strength and resilience, concrete is also a staple of building because it is relatively cheap and simple to make. Worldwide, 30 billion tonnes of concrete is used each year. On a per capita basis, that is 3 times as much as 40 years ago – and the demand for concrete is growing more steeply than that for steel or wood[2].

Versatile and long-lasting, concrete buildings and structures are in many ways ideal for climate-resilient construction. But concrete has a colossal carbon footprint – at least 8% of global emissions caused by humans come from the cement industry alone[3]. We must decarbonize its production.

Concrete is made by adding sand and gravel to cement, whisking the mixture with water and pouring it into moulds before it dries. Making the cement is the most carbon-intensive part: it involves using fossil fuels to heat a mixture of limestone and clay to more than 1,400 °C in a kiln. Also, when limestone (calcium carbonate) is heated with clays, roughly 600 kilograms of carbon dioxide is released for every tonne of cement produced (see go.nature.com/3exhg82).

There are alternatives to cement, but they're in the early stages of development, and cement itself remains highly profitable – two disincentives for companies to change.

Alternatives include the leftover compounds from iron and steel production, known as slag, and heaps of unused fly ash, a residual material from coal plants. Researchers are also experimenting with reducing the temperatures needed in the cement-making process – thereby decreasing the energy used.

In carbon-accounting terms, such replacements and procedural changes will reduce cement's environmental impact, and that of concrete, too. But they still involve carbon emissions. Coal is being phased out, so fly ash isn't a long-term solution. And alternatives have yet to be certified for use in building; for this to happen, long-term studies on their performance are needed.

Cement will be around for the foreseeable future, so cement production itself needs to be decarbonized, which could happen in a number of ways. For example, low-carbon fuels – such as hydrogen or biomass – could be substituted for fossil fuels in heating the limestone and clay. And scientists are examining whether electricity – instead of combustion – could be used for the heating.

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Carbon capture could be part of the cement industry's transition process[4]. In Sweden, for example, a company announced in July that it wants to capture 1.8 million tonnes of CO_2 from a cement plant and bury it in the North Sea. Another possibility is to pump the captured CO_2 into concrete itself, locking it up forever – which might also improve the properties of the resulting material. The injected CO_2 reacts with calcium ions in the cement, producing more calcium carbonate, and potentially making the concrete able to withstand larger loads.

Concrete options

Technological changes can be accelerated through regulation and legislation. A huge proportion of concrete is used in public building projects. In North America alone, public agencies buy as much as one-third of concrete manufactured annually. That means they have leverage in the low-carbon transition: they could work with researchers and manufacturers to reshape the concrete industry.

In New York and New Jersey, a bill is making its way through state legislatures that, if passed, will mandate that state agencies and departments prioritize cement that has a lower carbon footprint.

Other states are introducing legislation that requires construction proposals to declare the environmental impact of cement mixes. Some regions, such as Honolulu, Hawaii, have added a requirement that city construction projects must consider using concrete that stores CO_2.

In Europe, the European Union's Waste Framework Directive requires 70% of construction waste to be reused. Another idea, known as materials passports, could also help. When buildings are demolished, the waste concrete is smashed up and discarded, or sold for low-grade use such as backfilling in road construction. But a passport would ensure that concrete is recorded 'at birth' and then tracked throughout its life cycle – making it accessible for more kinds of reuse.

Finally, the cement industry needs to publish better emissions data so that progress can be tracked. In a study published last month, researchers from Columbia University in New York City report that some of China's cement-making companies have an ambition for emissions to peak in 2023 (see go.nature.com/39z1sdd). But only one of the ten companies surveyed is reporting emissions data. China is the world's largest cement producer (55% of global capacity), and cement accounts for 15% of the country's carbon emissions. Without data, it will be impossible to know whether national targets are being met.

Next month, a cement-industry campaign called Concrete Action for Climate will announce its road map for carbon neutrality by 2050. This is overdue, but the road map must also explain interim steps, how

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companies intend to achieve neutrality and how progress will be measured.

Parts of the ancient world were made with concrete, and the material was used to build much of the modern world, too. Researchers and governments must work with the cement industry to slash its carbon footprint, driving the climate-resilient construction the world now sorely needs.

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2. Monteiro, P., Miller, S. & Horvath, A. *Nature Mater.* **16**, 698–699 (2017).
3. Ellis, L. D., Badel, A. F., Chiang, M. L., Park, R. J.-Y. & Chiang, Y.-M. *Proc. Natl Acad. Sci. USA* **117**, 12584–12591 (2020).
4. Fennell, P. S., Davis, S. J. & Mohammed, A. *Joule* **5**, 1305–1311 (2021).

What a personal saga reveals about scientists' lives

Two scientists allowed *Nature* to follow their lives for three years. Their story speaks to the epic professional and personal struggles involved in establishing a career in research.

In 2018, a team of *Nature* reporters and editors began documenting, in real time, the lives and experiences of two scientists at the University of Sheffield, UK. Alison Twelvetrees, a neuroscientist, and molecular biologist Daniel Bose are on a path to establishing their own research laboratories. They are also a married couple, and their stories — the highs and lows, the triumphs and tribulations — are told in a Feature on page 608 (and can be heard in a four-part *Nature Podcast* series).

The intention, with Ali and Dan's agreement, was to present their lives in science over a year or more. Documenting such a process is not very common in science reporting, where the emphasis is more often on describing results. Our aim was to chronicle the journey involved in becoming a principal investigator (PI). But neither we at *Nature*, nor Ali and Dan, knew whether they would be able to build up their research groups, or that the story would run for more than three years. In addition to other crises that arose, the pandemic would shut down their experiments.

The United Kingdom's universities — like those of many countries — are powered by people such as Ali and Dan, who were employed as PIs on fixed-term contracts. In the United Kingdom, some 74,000 academic staff — out of a total of 223,000 — are on such contracts. In the smaller group of staff that do just research, 35,000 out of 50,000 are on fixed-term contracts, according to data from the UK Higher Education Statistics Agency. For the aspiring academic researcher, such a precarious existence is, sadly, a rite of passage.

> **"Our aim was to chronicle the journey involved in becoming a principal investigator."**

As if that wasn't hard enough, applying for a PI position — leading, eventually, to a professorship — is not like applying for a permanent job in many other professions. Researchers wanting to become PIs in universities are required to show evidence of a multiplicity of skills. They must be leaders and managers; entrepreneurs; mentors and teachers; accountants and administrators. And all the while, they must be doing world-leading research and building their publication list. Moreover, not all PI posts are permanent positions. In some cases, candidates must compete with their peers to secure income from external grants to pay their salary.

Cycle of precariousness

Ali and Dan's attempts to win funding provide some of the most revealing aspects of the narrative — for example, having to face questions from up to 20 interviewers for a fellowship worth more than £1 million (US$1.4 million). The researchers had a one-in-five chance of success. If they were successful, their funding would support new research talent in the form of PhDs and postdocs. But, as Ali and Dan's story indicates, these newer entrants would also be employed on temporary contracts — thus perpetuating the cycle of precariousness in future generations of researchers.

The employers of doctors, teachers, architects and engineers do not expect candidates to raise funding to pay their own salaries. Scientists working at universities should not be expected to do that either.

In the United Kingdom, a previous generation of research planners anticipated a situation in which researchers might one day find themselves struggling to pay the rent. A funding principle called the dual support system followed. Its architects established two sources of public funding: one funding pot to pay salaries for staff, and a second for grants and fellowships. It meant that researchers had access to a secure income stream to support their families while applying for grants. Today, that principle is under strain. Ali and Dan's story emphasizes why something closer to the original plan, which provides greater job security, is needed.

But Dan and Ali's story isn't just one of funding. It is also a chronicle of the process of science. Media reporting of science typically covers major findings or policy decisions. But, as researchers know only too well, such outcomes are the final steps in a much longer and more-complex process that typically doesn't make it into news stories: the joy of receiving a new microscope, or seeing a student's experiment succeed; the stress of explaining complex science to a lecture theatre packed with students; or the disappointment of getting a funding rejection. These don't always get covered, and that can create an unbalanced view of what science is.

We're grateful to Ali and Dan for allowing *Nature* a glimpse into their lives, to witness the day-to-day struggles, the anxieties, the crises and the victories, large and small. None of us expected this project to last three years. In publishing Ali and Dan's experiences, we hope to redress some of the imbalance, and to provide a key missing piece of the picture of what it means to be an academic scientist today.