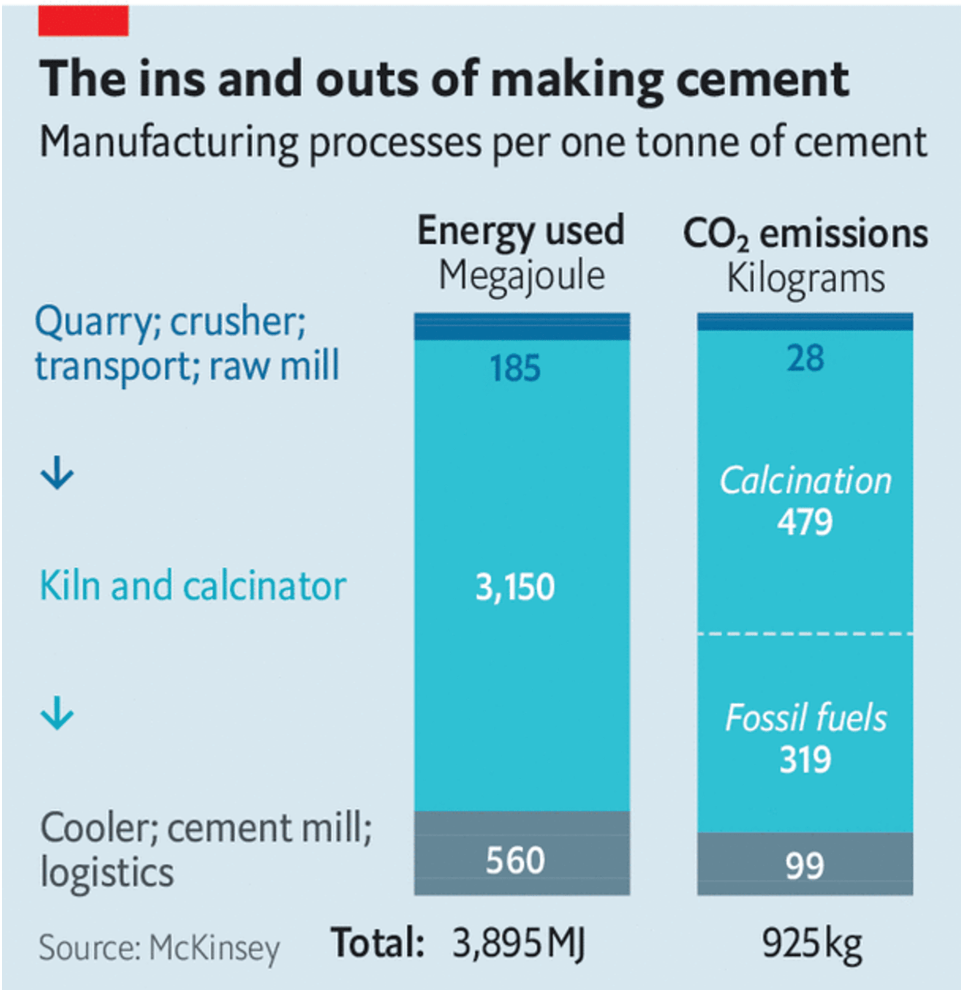
How cement may yet help slow global warming

THE ROMANS perfected concrete, and their legacy still stands in the form of the magnificent roof of the Pantheon, the world's largest unreinforced concrete dome. Since it was completed in around 125AD by the Emperor Hadrian, an awful lot more concrete has been poured—some 30bn tonnes every year, at the moment, to put up buildings, roads, bridges, dams and other structures. The grey stuff has become the most widely used construction material on the planet, and demand is growing.

This is bad news for global warming. The problem is that concrete's crucial ingredient, cement, which is mixed with sand, gravel and water to make the stuff, is responsible for a huge amount of greenhouse-gas emissions. Taking in its various stages of production, the 5bn tonnes of cement produced each year account for 8% of the world's anthropogenic CO_2 emissions. If the cement industry were a country it would be the third-largest emitter in the world, after China and America.

So far, concrete has few practical alternatives. The development of cross-laminated, “engineered”, timber—which, being produced from wood, can be a renewable resource—is gaining interest, even for some high-rise buildings. But compared with concrete, engineered timber remains, for now, a novelty. Concrete’s biggest users, especially China, which makes more than half of the world’s cement, are not about to stop using it. Hence cleaning up the industry might seem a hopeless task. But it isn’t, for technologies are being developed to make concrete greener. Green enough, perhaps, for it to go from adding CO_2 to the atmosphere, to subtracting it.



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The place to start is where emissions are greatest. Cement production begins with the quarrying of limestone, the main component of which is calcium carbonate ($CaCO_3$). This is mixed with clay and passed through a rotating kiln at more than 1,400°C in a process called calcination. The heat drives off the carbon and part of the oxygen, which combine to form CO_2. The remaining lumps, called clinker, are made of molecular complexes of calcium oxide and silica, known collectively as calcium silicates. The clinker is then cooled and milled into cement. More than half the emissions involved in cement-making are a consequence of calcination, and most of the rest result from burning coal and other fossil fuels to power the process (see chart). All told, nearly one tonne of CO_2 is released for every tonne of cement made.

Hot stuff

The inevitability of calcination's creation of CO_2 makes capturing the gas before it can enter the atmosphere, and storing it away, the most effective way to decarbonise the cement industry, according to a study by Paul Fennell of Imperial College, London, and his colleagues, published earlier this year in *Joule*. The captured CO_2 could be stored underground or used by other industries—for instance to make synthetic fuel. But it might also be injected back into concrete at the point when it is being mixed with water to cure it. Water promotes chemical reactions that cause cement to harden. CO_2 has a similar effect and, in the process, gets locked up as calcium carbonate.

In fact, reversing calcination in this way makes concrete stronger than if water alone is used. So, not only is some of the original emission thus dealt with, less cement is needed for a given job, lowering overall emissions still further. McKinsey, a consultancy, reckons reverse calcination could, at present, sequester up to 5% of cement's emissions. As the technology improves it expects that might rise to 30%.

Several companies are starting down this route. CarbonCure, a Canadian firm, has fitted equipment which injects CO_2 into ready-mixed concrete to more than 400 plants around the world. Its system has been used to construct buildings that include a new campus in Arlington, Virginia, for Amazon, an online retailer (and also a shareholder in CarbonCure), and for an assembly plant for electric vehicles, for General Motors, in Spring Hill, Tennessee.

At present the CO_2 used by CarbonCure has been captured by industrial-gas companies. But firms are developing equipment intended to collect the gas directly from cement kilns. And Calix, based in Sydney, Australia, is working on an electrically powered system which heats the limestone indirectly, from the outside of the kiln rather than inside. That enables pure CO_2 to be captured without having to clean up combustion gases from fuel burnt inside the kiln—so, if the electricity itself came from green sources, the resulting cement would be completely green.

A pilot plant using this technology has run successfully as part of a European Union research project on a site in Belgium operated by Heidelberg Cement, a German firm that is one of world's biggest cement-makers. A larger demonstration plant is due to open in 2023, in Hanover, to help scale up the technology.

Energising rubbish

Another approach—less green, but still better than using fossil fuels—is to substitute some of the coal burnt in kilns with municipal and industrial waste. Several firms are already doing this. Cemex, a Mexican building-materials giant, for example, makes a kiln fuel called Climafuel out of municipal waste that has been denuded of its recyclable substances. This is rich, in the form of plant material ("biomass"), in carbon that has recently been in the atmosphere, and is simply returning there, rather than having been dud up as fossil fuel. Up to 60% of the coal used by some of Cemex's British cement plants has been replaced with Climafuel.

Companies are also looking at ways to substitute some of the cement in concrete with other materials. Many add fly ash, a by-product of coal-fired power plants, or crushed slag from the blast furnaces used to make iron. But neither of these approaches is sustainable in the long run. As Peter Harrop, boss of IDTechEx, a firm of analysts in Cambridge, England, and the co-author of a new report on the future of concrete and cement, observes, coal-use is dwindling and steel production aspires to move to newer, cleaner technologies.

For Dr Harrop, an important part of the answer is to “tech-up” concrete in ways which mean that less of it will be needed to do particular jobs. This means adding things like synthetic and natural fibres—or even graphene, a substance stronger than steel that consists of single-layer sheets of carbon atoms. Only small amounts are needed to produce beneficial results.

Graphene and other reinforcement will lead to new, ultra-high-performance concretes, which Dr Harrop thinks will be particularly suitable for 3D printing. This builds up precise layers of material under robotic control, and greatly reduces waste. “Using much less cement is a very important part of the answer,” he adds, especially as cement production looks otherwise set to double over the next 20 years.

Additives can also make concrete last longer and reduce the need for maintenance. At the University of Michigan, Victor Li and his colleagues use synthetic and natural fibres, along with CO_2 injection, to produce a bendable concrete they call Engineered Cementitious Composite (ECC). The internal structure of this material was inspired by nacre, a flexible material, commonly called “mother of pearl”, that coats the insides of the shells of molluscs such as abalone and oysters.

Adding such flexibility to concrete lets bridges and roads cope better with heavy traffic, and makes tall buildings more earthquake resistant. ECC develops only tiny surface cracks when it ages. Dr Li says it is thus much better at keeping water out and preventing corrosion of reinforcing steel bars inside. Such corrosion can cause reinforced-concrete structures to crumble within a few years of their construction —sometimes resulting in their collapse.

To zero and beyond

Substitution of materials could go still further. Solidia, a firm in New Jersey, makes cement containing calcium silicates with a higher ratio of silica to calcium oxide than the standard "Portland" variety. This has two consequences. One is that Solidia's process requires less heat (and therefore less fossil fuel) than conventional calcination, and so releases less CO_2 in the first place. The other is that, when mixed into concrete, Solidia's silica-rich silicates can be cured more rapidly than regular cement by using captured CO_2 instead of water. Solidia is working on applications for its cement with one of its investors, LafargeHolcim, a Swiss building-supplies giant.

Taking all these developments into account, how green could concrete get? Dr Fennell says it would be reasonably easy to reduce the industry's CO_2 emissions to around 80% of present levels per tonne of concrete produced by better energy use and the modification of materials. But companies could really pull the stops out if they moved to kilns largely or entirely powered by biomass, such as wood. The carbon in this would, until recently, have been CO_2 in the air. If, after being turned back into that gas by being burned in the kiln it was stored away and not released, the consequence, as new trees grew to replace those consumed, would be a net flow of carbon out of the atmosphere.

This sort of system, called bioenergy with carbon capture and storage (BECCS), is one way climate modellers imagine providing the “negative emissions” needed for net-zero or net-negative emissions targets. BECCS-based electricity generation is often talked of, but BECCS might actually be better suited to cement making—because in a carbon-conscious world the CO_2-capturing equipment will already be there, dealing with results of calcination. And if that happened, one of the pariahs of global warming might thus redeem itself by helping alleviate the damage being done to the planet, and so leave behind a legacy as impressive in its way as that of the Romans.