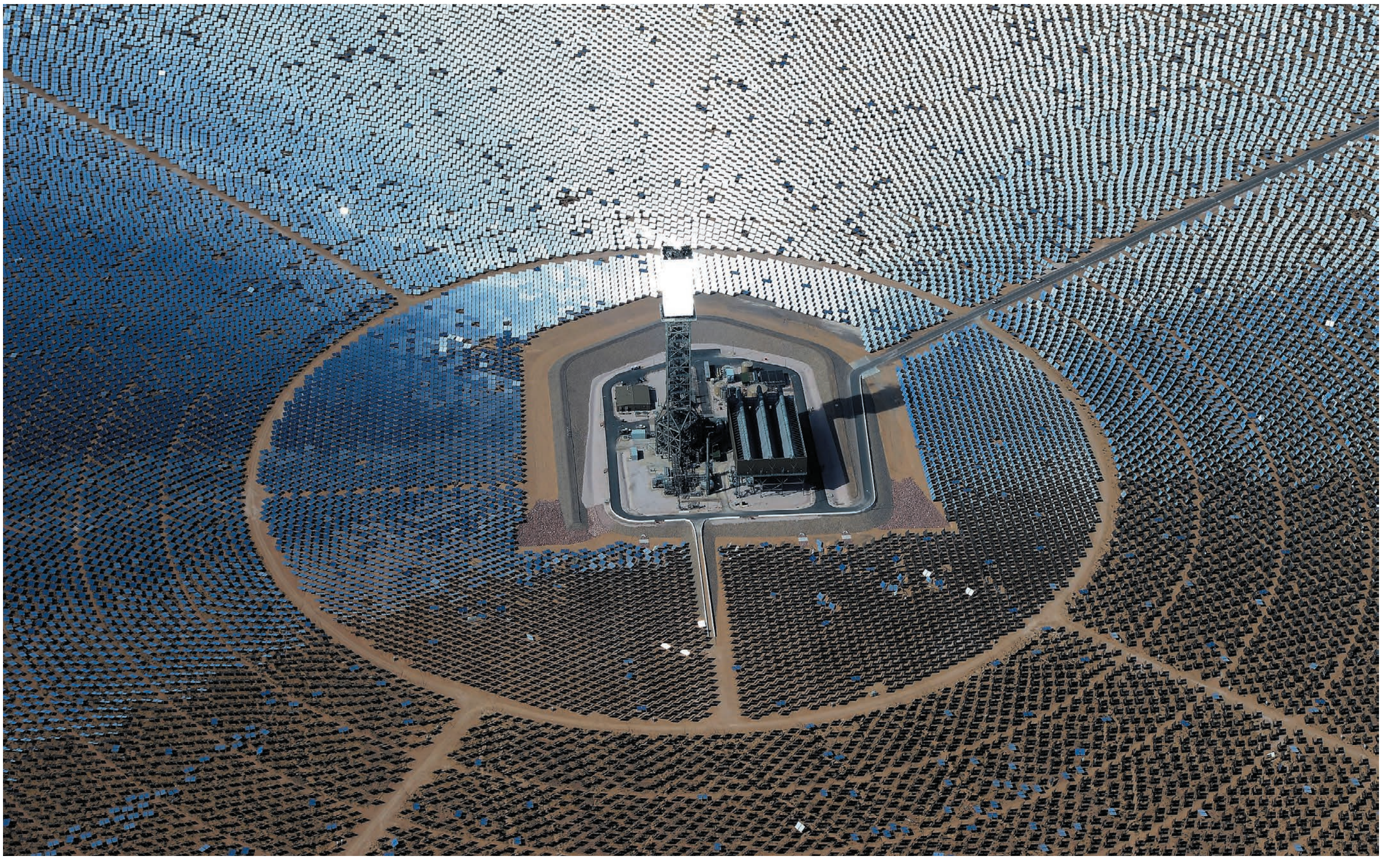
ETHAN MILLER/GETTY

Figure 1 | The Ivanpah Solar Electric Generating System, Las Vegas. Concentrated solar power plants such as this one generate heat by focusing sunlight onto a central tower using mirrors. The heat is then used to drive power cycles for electricity production. Caccia *et al.*[1] report a metal–ceramic composite material designed to make high-temperature heat exchangers — devices needed to enable power cycles in future concentrated solar power plants.

MATERIALS SCIENCE

A composite that takes the heat

A remarkable metal–ceramic composite material has been produced that could aid the development of the next generation of power plants — and might even have a role in curing the world of its addiction to fossil fuels. SEE LETTER P.406

CRAIG TURCHI

Composite materials that combine metals and ceramics have been developed for many different applications, such as use in wear-resistant surfaces for tools and engine parts, electrical components and even dental fillings. On page 406, Caccia *et al.*[1] report a metal–ceramic composite with a combination of properties that makes it suitable for a very different application — in devices known as heat exchangers, which must work at high temperatures in power plants. By enabling highly efficient heat transfer, the new material might allow the realization of a cost-effective electricity-generation process that is currently being developed based on a fluid phase of carbon dioxide known as supercritical CO_2.

Metals and ceramics have been around for centuries, and have their own distinctive properties and applications. For example, bronze and iron have good shock resistance and are malleable enough to be worked into complex shapes such as helmets and horseshoes. Ceramics, such as the materials used to make pottery, can be formed into simple shapes and are prized for their resistance to heat and corrosion. These two classes of material have therefore found disparate applications, and for a long time marched along separate technological paths.

In the mid-twentieth century, the advent of jet engines generated a need for materials that had high resistance to heat and oxidation, the ability to cope with rapid temperature changes, and excellent mechanical strength, exceeding the properties of available metals. The US Air Force funded research to make ceramic–metal composites that had these properties, and the word 'cermet' was coined to describe them. Cermets have since been developed for multiple applications, but, in most cases, they have been used for small parts or surfaces. Caccia *et al.* now report a cermet that can withstand extreme temperatures, high pressures and rapid thermal cycling.

To make this cermet, the authors first produced a preform — a precursor that needs further processing to be turned into the required final object, analogous to the unfired version of a clay pot. The authors compacted tungsten carbide (WC) powder into the approximate shape of the target object and heated it at 1,400 °C for 2 minutes to bond the particles together. They then machined the porous preform to generate the desired final shape.

Next, the authors heated the preform in a chemically reducing atmosphere (a mixture of 4% hydrogen in argon) at 1,100 °C and immersed it in a vat of liquid zirconium and copper (Zr_2Cu) at the same temperature, before removing it and finally heating it at 1,350 °C. This process causes the zirconium to displace the tungsten from the tungsten carbide, producing zirconium carbide (ZrC), tungsten and copper. The liquid copper is forced out of the ZrC matrix as the material solidifies, so that the final object is formed of approximately 58% ZrC ceramic and 36% tungsten metal, with small amounts of residual tungsten carbide and copper. The beauty of the method is that the porous preform is converted into a non-porous ZrC/tungsten composite of the same dimensions (the overall volume change is approximately 1–2%).

The clever manufacturing process is complemented by the robust properties of the final product. Caccia *et al.* find that, at 800 °C, the ZrC/tungsten cermet conducts heat 2.5–3 times better than iron- or nickel-based alloys currently used in high-temperature heat exchangers — which should improve the effectiveness of such devices. Furthermore, the mechanical strength of the ZrC/tungsten cermet is higher than that of nickel-based alloys typically used in high-temperature applications, and is unaffected by temperatures up to at least 800 °C, even when the cermet had previously undergone 10 heating–cooling cycles between room temperature and 800 °C. By contrast, iron alloys (stainless steels) and nickel alloys lose 80% or more of their strength at temperatures between 500 °C and 800 °C (ref. 2).

Heat exchangers transfer the thermal energy generated by a power plant to the working fluid in a thermal engine (such as a steam turbine) that converts heat into mechanical energy. The mechanical energy in turn is used to generate electricity. The overall process of converting heat to electricity is known as a power cycle. The US Department of Energy, along with industrial partners, is currently building a 10-megawatt test facility for a power cycle that uses supercritical CO_2 as the working fluid (see go.nature.com/2pi50mt). This power cycle promises lower costs and greater efficiency for future power plants, compared with currently used power cycles, but requires highly efficient heat exchangers. Caccia and colleagues' paper focuses on heat exchangers that could be used in this power cycle in concentrated solar power plants (which use sunlight concentrated by mirrors to generate electricity; Fig. 1), but the heat exchangers could also be used in advanced nuclear and fossil-fuel-fired power plants.

One technical challenge that must still be addressed concerns the oxidation resistance of the new cermet: the material is prone to oxidation in air at high temperatures such as might be experienced in a power-plant heat exchanger. Supercritical CO_2 is only a weak oxidizing agent, but could still break down the cermet. Caccia *et al.* report that cermet oxidation can be prevented for up to 1,000 hours at 750 °C and at high pressure (20 megapascals) when the material is coated with a thin layer of copper, and if a small amount of carbon monoxide (50 parts per million) is mixed with the supercritical CO_2. Nevertheless, long-term durability must still be proved.

Lastly, the authors' preliminary estimates indicate that the combined costs of raw materials and processing required to make a heat exchanger from the ZrC/tungsten cermet would be lower than for an analogous heat exchanger made from a conventional nickel alloy. Moreover, the cermet device would provide twice the power density — that is, it could be half the size of its nickel-alloy counterpart. The use of such heat exchangers might help to reduce the costs of renewable concentrated solar power, making it economically competitive with fossil-fuel-derived electricity. ■

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1. Caccia, M. *et al. Nature* **562**, 406–409 (2018).
2. ASME Boiler & Pressure Vessel Code, Section II, Part D (2013).

BIOTECHNOLOGY

CRISPR tool puts RNA on the record

The bacterial-defence system CRISPR–Cas can store DNA snippets that correspond to encountered viral RNA sequences. One such system has now been harnessed to record gene expression over time in bacteria. SEE ARTICLE P.380

CHASE L. BEISEL

Determining the gene-expression profile of a cell is crucial to unlocking how its DNA blueprint gives rise to its physical characteristics and behaviours. The standard approach used currently involves RNA sequencing or single-cell imaging techniques that generate detailed snapshots of gene-expression profiles. However, these techniques capture such profiles only at the moment of analysis, and kill the cells. This makes it hard to capture fleeting gene-expression profiles or those that provide a complete picture of cells going through major behavioural or environmental changes. On page 380, Schmidt *et al.*[1] report progress in overcoming this challenge by enlisting a bacterial-defence system that can create a DNA record of specific RNA sequences in a cell.

The CRISPR–Cas bacterial-defence systems are probably best known for their application in genetic engineering to cleave specific DNA sequences[2]. But another feature of these systems is the incorporation of snippets of DNA from unwanted intruders into a bacterium's own genome. These stored sequences provide a permanent 'memory' of infection, which can enable a defensive response if the same sequences are encountered again. The nucleotides are added to the cell's DNA in a configuration called a CRISPR array. The sequence of an array alternates between identical repeat sequences and the incorporated snippets, which are called spacers. As spacers are acquired, the array lengthens, and the positioning of spacers in the array reflects the order in which they were inserted[3].

Almost all CRISPR–Cas systems acquire foreign genetic material by directly capturing DNA from an invader. Some previous work exploited this feature of CRISPR–Cas systems to record information in the form of acquired and stored nucleotide sequences. For instance, one approach[4,5] used CRISPR–Cas-mediated acquisition of externally provided synthetic DNA to capture sequences in a specific order. The particular order of the nucleotides in the spacers was subsequently 'decoded' to link each CRISPR array to pixels in sequential images[5]. Another study[6] used chemical cues from the environment to drive expression of a gene controlling the abundance of a form of circular DNA called a plasmid. As plasmid abundance rose in the cell, the plasmid became the preferred source of DNA snippets for new spacers; this linked the presence of the chemical cue to a stored spacer that matched the plasmid DNA. That study, in particular, set the stage for the use of CRISPR–Cas to record the expression of one or a few genes. Yet it was unclear how this approach could be extended to provide a comprehensive record of the gene-expression profile of a cell.

Schmidt and colleagues devised a creative solution by focusing on CRISPR–Cas systems that capture invading RNA rather than DNA[7] (Fig. 1a). These systems need only two proteins to achieve this feat, with one protein making a DNA version of the RNA sequence