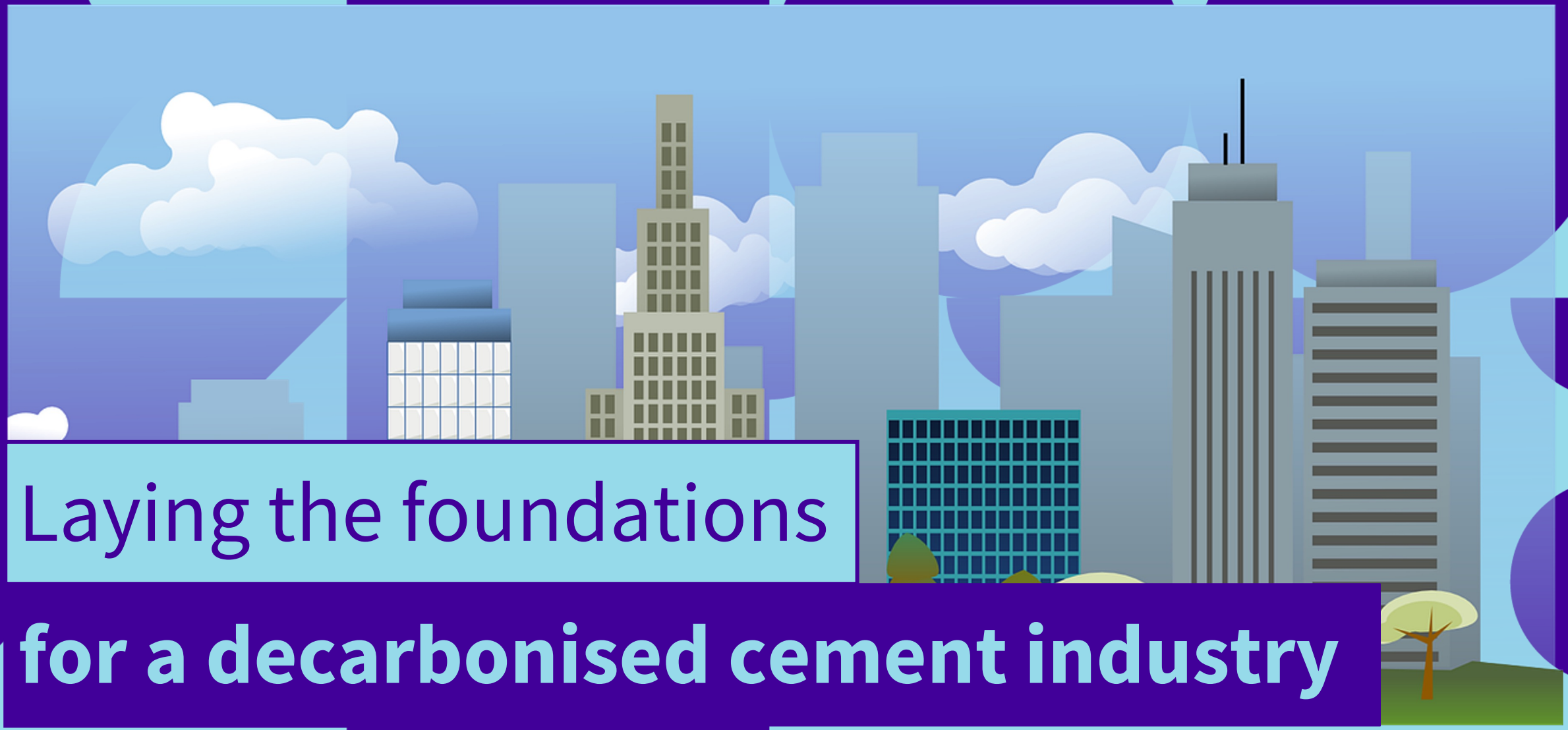
University of Sheffield

Materials -
a SUBJECT
that MATTERs

Dr John Provis

Structural Materials.



Laying the foundations

for a decarbonised cement industry

What is Materials Science and Engineering?

MSE is defined as an ‘interdisciplinary subject, bridging the physics and chemistry of matter towards engineering applications and industrial manufacturing processes.’ The programme content spans from foundations in physics and chemistry to the mechanical, electrical, magnetic, and optical properties of materials, and the design, manufacture and applications of metals, alloys, ceramics, polymers, composites, and biomaterials.

MSE continues to establish itself amongst engineering disciplines and is offered as a degree course across the UK at the Universities of Birmingham, Cambridge, Imperial College London, Leeds, Loughborough, Manchester, Oxford, Queen Mary, Sheffield and Swansea, as well as Materials Chemistry being offered at St Andrews and Glasgow.

Key Learning outcomes

Why is the cement industry currently not sustainable?

To make 1 tonne of cement we currently release 800 kg of CO_2!

This means that, because **we produce 4 billion tonnes of cement worldwide every year**, the cement industry is contributing to 3.2 billion tonnes of CO_2 emissions annually- that's 4-5 times more than the aerospace industry! [1]

What are the ways in which we are looking at making the cement industry more sustainable?

Looking at improvements at every stage of the process…

1. **Separating the carbon dioxide from the limestone before production.** The CO_2 separated would be sequestered and removed in a controlled manner so that the resulting calcium oxide would be used instead of the limestone to produce cement. This would mean that no CO_2 would be released from the chimney of the cement plant and that carbon capture and storage would not be required post-process.

1. **The temperature of thermal processes could be reduced.** Could the cement be produced at 1250 degrees rather than 1400 degrees as a way of saving energy? This requires research into the modification of properties and the crystallisation of phases within the material to enable scientists to design a cement which performs as well as the original but can be produced at a lower temperature.

1. **Designing novel chemistries** for cements. These cement compositions would not be based off limestone and other conventional raw materials. For example, magnesia-based cements.

GCSE Chemistry topics this episode could be taught alongside…

Limestone and building materials

- Removing CO_2 from limestone.

Chemistry of the atmosphere

- CO_2 as a greenhouse gas and global climate change.

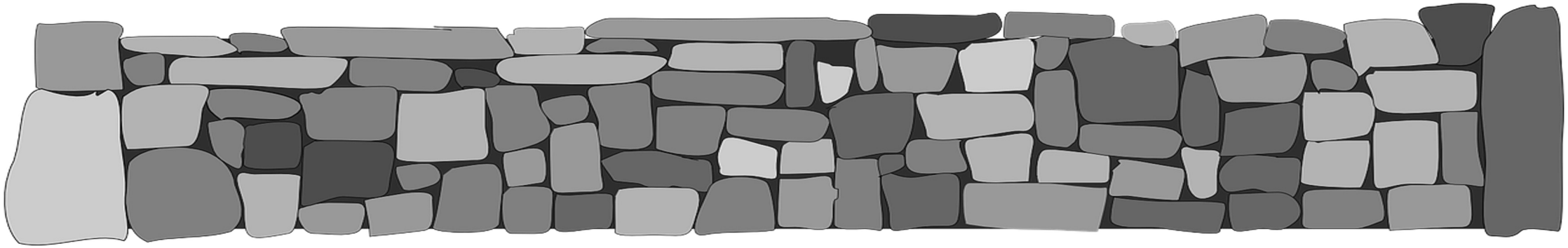
How does this episode go beyond the curriculum?
Reactions of cements and cement hydration…

Students have been taught the basics about limestone, cement, mortar and concrete.

The episode talks about removing the CO_2 from limestone and using calcium oxide in production.

This involves heating the limestone (calcium carbonate) to drive off carbon dioxide gas leaving behind lime, the base calcium oxide. Therefore, the reaction is a **thermal decomposition reaction.**

$CaCO_3\,(s) \rightarrow CaO\,(s) + CO_2\,(g)$



Hydration is another chemical reaction used in the production process which takes place between cement and water. Portland cement is mixed with sand, gravel and water to produce concrete.

Cement powder is **anhydrous** (meaning without water). It's hydration (reaction with water) involves many different reactions, which often occur at the same time and are mainly **exothermic**, meaning they generate heat.

The products of the hydration reactions gradually bond together the individual components of the concrete to form a solid mass and so the process is often termed as the **hardening** process.

The products are termed "hydration products." In concrete (or other cementitious materials) there are typically four main types:

- Calcium silicate hydrate: this is the main reaction product and is the main source of concrete strength.
- Calcium hydroxide
- AFm and AFt phases: these are two groups of minerals that occur in cement, and elsewhere. The definitions of these phases are complex.
- Hydrogarnet

Atmospheric pollutants and carbon capture, utilisation, and storage

John talks towards the end of the episode about what carbon capture and storage is.

Carbon capture and storage is a process in which CO_2 can be prevented from being released into the atmosphere as a pollutant.

The method involves capturing the CO_2 directly from the atmosphere, or from large point sources such as power generation or industrial facilities that use fuels such as fossil fuels and biomass. If the CO_2 cannot be used on-site, it is compressed and transported typically by pipeline, ship, truck or rail to be used for other useful applications or to be permanently stored by injection into deep geological formations like depleted oil and gas reservoirs which trap the gas.

There are currently around 35 commercial facilities which are using carbon capture, utilisation and storage to industrial processes, fuel transformation and power generation as a way of reducing emissions.
[2]

Key definitions

Carbon sequestration

The storage of carbon in a place where it will remain for a long period of time.

Types of sequestration include:

'Geological', where CO_2 is captured and buried underground.

'Biological', where CO_2 is absorbed during the growth of plants and trees.

The carbonation of concrete is also sequestration, as is the production of concrete using CO_2 .

Cement

A material used to join others, as a means of providing structural stability.

In the context of concrete, cement refers to finely ground inorganic material that forms a paste when mixed with water and which sets and hardens through the hydration process.

After hardening, cementitious material retains it's strength and stability even under water.

Portland cement

A mixture of compounds formed from the oxides of calcium (CaO), silicon (SiO_2), aluminium (Al_2 O_3) and iron (Fe_2 O_3), predominantly comprising hydraulic calcium silicates.

It is produced by grinding Portland Cement clinker with a source of calcium sulphate to leave a fine powder.

Other cements

A term used for potential alternatives to existing general purpose cements.

The suitability of these 'other cements' is not yet established in the UK concrete standard BS 8500.

Questions to think about

Why is cement a hard material to replace?
Cement being hard to replace is partly a matter of its huge production scale, partly because of its versatility - being castable is a huge advantage over a lot of competing materials that must be mechanically formed.

Is it possible that wood could someday replace concrete as our go-to building material?
Wood is the renewable resource that carries the lowest carbon footprint of any comparable building material.
Part of the problem of wood is flammability, partly is that it's bendy, partly that it's not castable - it's not really a 1:1 comparison with cement/concrete for a lot of reasons, but it's worth mentioning because it can lead to a good discussion.

Questions to think about

To improve sustainability what materials could we add to our cement mix to replace the materials in our traditional Portland cement?

Replace them with materials that result from industrial processes or things we produce from natural resources at lower temperatures.

For example, the Portland cement in a Cementitious mixture could be replaced by industrial wastes and by-products such as blast furnace slag or the ash produced from coal fired power stations. This means they are replaced by lower emissions materials. Dr Provis is then currently researching what he can combine a cement made mostly from lower emissions materials with to make a robust concrete!

“Cement is the most underappreciated material that we think of worldwide”

Dr John Provis.

Discussion Topics

As humans, what are the things we make the most of everyday in the world?

We make fresh drinking water the most. Cement comes second to that! The only thing we make more of than cement is fresh water, we produce more cement every day than we do food!

We produce 3-4 billion tonnes of cement every year, to imagine that there is around 7 billion people in the world, that means we produce more than 1 kg of cement per person in the world every single day![3]

What are the challenges with making the cement industry more sustainable?

The scale of the industry. It can be overwhelming for production methods and chemistries to be changed across the industry. Despite being a challenge, why may the large scale introduce an advantage experimentally?

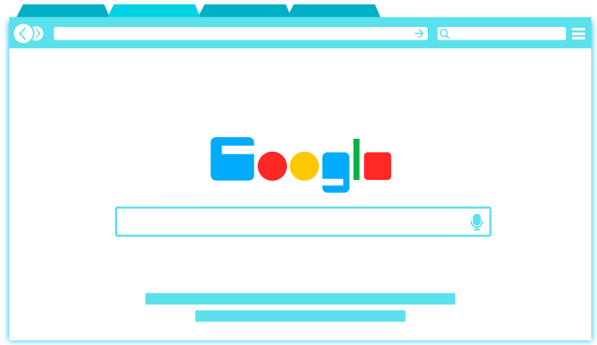
If we change how we design the material and how it may feel and behave for the workers who oversee handling the physical cement in the final stages of a product's quality control, then this means that workers may need to be re-trained as their years of 'on the job' experience will no longer be useful.

Additional Resources

Cement practical

Royal Society of Chemistry Education

https://edu.rsc.org/resources/making-concrete/2022.article



Low Carbon Concrete Roadmap

https://www.ice.org.uk/media/200i0yqd/2022-04-26-low-carbon-concrete-routemap-final_rev.pdf

REFERENCED FACTS

[1]https://www.polytechnique-insights.com/en/braincamps/industry/how-to-reduce-the-carbon-footprint-of-the-construction-industry/we-can-reduce-co2-emissions-from-cement-by-a-factor-of-10/

[2] https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage

[3]https://www.imperial.ac.uk/news/221654/best-ways-carbon-emissions-from-cement/