Straight talk with Karen Scrivener on cements, CO_2 and sustainable development

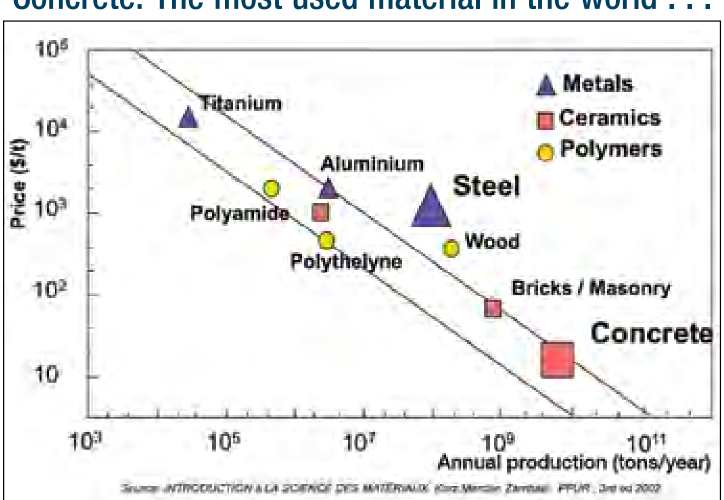
Editor's note: Over the last few years, I have run into a chorus of stories in both the technical and mainstream press bemoaning the carbon dioxide emissions of the cement and concrete industries. It seemed that the "accepted wisdom" was that something was amiss, and the implication was that cement and concrete production needed, well, to be "fixed."

It was a revelation, then, last year when I met Karen Scrivener, a professor at the Swiss Ecole Polytechnique Federale (Lausanne) who was delivering the Della Roy Lecture at the 2011 Advances in Cement-based Materials: Characterization, Processing, Modeling and Sensing meeting. I learned first hand that Scrivener, a founder of a Europe-based collaboration between institutions and industry focusing on strategic problems (Nanocem), is a dynamic and articulate expert on cement and concrete.

More importantly for me, she was the first person I have heard present an aggressive, well-rounded and compelling defense of the critical role of concrete… and at the same time sketch out a realistic set of pathways for materials scientists and engineers to reduce cement's CO_2 footprint while increasing concrete's availability. Read our Q&A and see if you agree.

- Peter Wray

Concrete: The most used material in the world . . .



. . . and the only material which can satisfy the demand for decent housing and infrastructure.

Question: The production of cement and concrete has been associated with the generation of a large percentage of the carbon dioxide emissions in the world. Should the world be trying to develop an alternative construction material?

Scrivener: A lot of people say, "Oh, we shouldn't use concrete. We should be using something else." This is a totally meaningless comment, because it is just not physically possible to produce any other material in such large quantities. That's because of the distribution of resources on Earth. This to me is a really key point.

Concrete is the most used material in the world. Looking forward, especially to the developing regions of the world, it is the only material that can satisfy the demand for decent low-cost housing and infrastructure. Also, concrete is relatively environmentally friendly as measured by CO_2 emissions per ton, which is lower than wood.

But, it's wrong to think there is or could be some competition with wood. The usage of wood worldwide is estimated to be well above replanting levels, so we cannot substantially increase the amount of wood used. Also, while it may be a viable material in temperate climes, in large parts of Africa, India and Asia, there are no significant reserves. There is no way for the Earth to produce enough wood to make any significant replacement of concrete.

Q: So, you are saying there really is no viable alternative to concrete?

A: Yes, and if you use any alternative to concrete, you are going to make things worse. Therefore, the only route we have is to make concrete better.

Q: Is part of the problem that people in the developed countries don't grasp what role concrete plays

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(Credit: Karen Scrivener.)

in the underdeveloped regions of the world?

A: I think so. We all want to have a place to live. We all want to have a road to drive on. And, the only way we can meet these demands is by using more concrete. The real question is, how do we fill the needs of a growing world population that is becoming more and more urbanized? We may not like that, but it's a fact, and we have to deal with it. We can't afford to be like ostriches and stick our head in the sand and pretend this growth is not happening. It is happening.

Obviously, the problem is that CO_2 doesn't just stay in one place. It doesn't stay in China or Africa. It goes everywhere, so we have to have a more holistic approach in tackling this problem. Wherever you are, concrete is the most accessible and least environmentally damaging material.

Q: But, we even hear our colleagues in the materials community long for an alternative to the Portland cement used to make concrete.

A: Yes, even after my lecture at the ACerS–ACBM meeting last year, I heard that someone in the audience suggested that some science funders in the United State think we should give up on Portland cement. That's ludicrous, because, like it or not, Portland cement is the most viable formulation of cement. It's not by coincidence that we have ended up with this formulation, because it is based on years of experience of what are the most widely available materials.

Now, I think we have to look at using other materials to substitute for some of the Portland cement, but it doesn't help to think that we can simply throw it away and start with something new. If you want to look at something else, then you have to start looking at materials that are not widely available and that have hugely different cost structures, and you will quickly find yourself in the same raw materials dilemma where the materials needed are only available in some countries but not others. It would be like the situation with rare earths.

Q: Every so often we see an announcement about a new low-CO_2 cement. Are you saying these aren't viable?

A: Well, let me first say that many of them do work and some of them don't work. But, even if they all worked, it would be a type of solution that only addresses "the tip of the iceberg." They will hardly make a dent, and we are very unlikely to see a new type of clinker that is really going to replace Portland cement by more than 1 or 2 percent.

Q: But you are not saying that nothing can be done about the CO_2 emissions of concrete production, right?

A: Absolutely not. There is a lot that we can do, even with what might appear to be small gains. For example, if we could even save 5 or 10 percent CO_2 on every meter of concrete, it is orders of magnitude more important. In fact, a 10-percent saving in the CO_2 associated with a cubic meter of concrete, which is eminently doable, would be equivalent to removing all the CO_2 emissions associated with steel production. That shows how much impact we can have by research to increase the sustainability of cement and concrete.

Q: Can you explain a little more about your earlier comments about cement composition having to be linked to available resources?

A: Sure. Only eight elements—oxygen, silicon, aluminum, iron, calcium, sodium, potassium and magnesium—make up 98 percent of Earth's crust. Thus, we can forget about making cement out of the other elements that make up the 2 percent. We are forced to look at these eight elements.

Of course, what we'd like to do is to reduce the amount of calcium because calcium more or less correlates exactly with amount of CO_2, because the calcium oxide comes with the decomposition of calcium carbonate. In fact, this limited range of choices is in many ways an advantage, because we already know all the phases that form from these elements and we can systematically evaluate all possible solutions.

The way this has been pursued over the past 20 or 30 years is first of all process optimization. It's worth noting the process of making cement is very close to the optimum, which you can determine from making thermodynamic calculations. In fact, the production is at about 80 percent of theoretical efficiency and that is extremely good.

Also, the cement kiln is very versatile and can accept a wide range of fuels. Many plants operate with more than 80 percent of their fuel coming from waste sources, so we are efficiently using the calorific value of wastes and also efficiently decomposing toxic (organic) materials because of the high flame temperature (2,000°C).

One of the directions going on now to make reductions in CO_2 is to reduce the clinker factor. This means, instead of making cement out of grinding clinker and gypsum, we add more and more of what are known as supplementary cementitious materials. These are often byproducts or waste products from other industries, such as fine limestone, fly ash, blast-furnace slag, silica flume and natural pozzolans.

Now, this has been a very good and successful strategy. So, at least in Europe over the past 20 years or so, manufacturers have reduced the amount of clinker in their cements down to below 75 percent in preblended cements. In other words, they successfully substitute 25 percent of clinker with other materials.

Q: What about in the US?

A: The US goes against this trend, in a sense, because the nation uses a low amount of preblended cements. Instead, SCMs are added at the stage of the concrete mixer. This is not the best practice because it is not as well controlled as production is at a cement plant. This can lead to problems. But, the overall trend is the same.

Q: So is expanding the use of these SCMs the best strategy going forward?

A: This is quite a difficult strategy, because if you look at the amount of supplementary materials available, we see that it is totally dwarfed by the amount of cement produced. Even fly ash—we've all heard about fly ash, and it is probably the most widely available SCM—is produced in very small quantities. There simply isn't enough fly ash worldwide to replace cement in any big amount. And, if we look into where huge demand is going to be coming from, it is going to be coming from underdeveloped countries that lack large amounts of slag and fly ash.

Q: So where are SCMs going to come from?

A: I think we see more and more limestone used, and also are going to see more calcined clays and pozzolans.

But, at the end of the day, what this means is that we are going to see a very diverse range of cements. Cements are going to get more and more diverse—and more and more complicated, because there is no one single answer. But, if we pursue all of these possible sustainability routes in parallel, then I think we have a chance to bring down the CO_2 emissions associated with concrete.

Sustainability can come only from a vastly and increasingly diverse rate of use of cementitious materials, including SCMs, which are adapted to locally available materials. In order to be able to do this, we have to provide end users with understanding and relevant performance tests for them to have confidence in these solutions.

Put another way, what we really want to be able to do is to have the composition of our materials—the cements, the SCMs—and know how they are mixed, the time of curing, temperature, relative humidity, etc., and from this to predict performance. Performance can be on many different levels. Short-term performance like the time it takes to initially set can be quite easy to measure and predict in the laboratory. But, when it comes to properties, such as durability—where we expect structures to last 40–50 years with little maintenance—it is not possible to measure them in the lab.

Therefore, we have to go to an approach based on mechanisms, particularly on microstructure. In fact, we should be able to predict microstructure, based on thermodynamics and kinetics. And, in predicting microstructure, modeling will play a very important role, because the models can help us pull all of this complex information together and have it make sense.

In terms of thermodynamics, we have about 90 percent of what we need. On kinetics, we have more work to do, but progress is now very rapid.

Q: Can you mention more about some of the CO_2-saving materials that might be used?

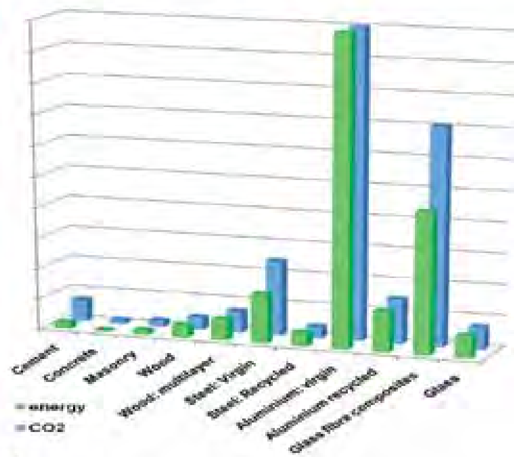
A: If we think in terms of minerals that will hydrate that will really save CO_2, there are certainly calcium aluminate and calcium sulfoaluminate (the mineral name is ye'elimite). These have much lower CO_2 emissions, about 40 percent less. They are also formed at lower temperatures, and they are easier to grind. So, here, you can get net CO_2 savings. But, even so, many of these types of cements currently being studied give only an overall savings of 20–30 percent. But, say, if you are going to put 30-percent fly ash in Portland cement, you are back to the same levels again.

Really, it is important to start making comparisons not to Portland cement but to present-day blended cements, which may contain only 70–80-percent clinker.

But, I think the way it is really going to go is to use calcined clay, because we have almost unlimited amounts of clay. We have had very exciting results

Comparative energy and CO_2 costs

Material	MJ/kg	$kgCO_2/kg$
Cement	4.6	0.83
Concrete	**0.95**	**0.13**
Masonry	3.0	0.22
Wood	8.5	0.46
Wood: multilayer	15	0.81
Steel: virgin	35	2.8
Steel: recycled	9.5	0.43
Aluminium: virgin	218	11.46
Aluminium recycled	28.8	1.69
Glass-fiber composites	100	8.1
Glass	15.7	0.85



And yet,
the enormous volumes used mean that concrete production accounts for about 5–8 percent of the nonnatural CO_2 worldwide.

(Credit: Karen Scrivener.)

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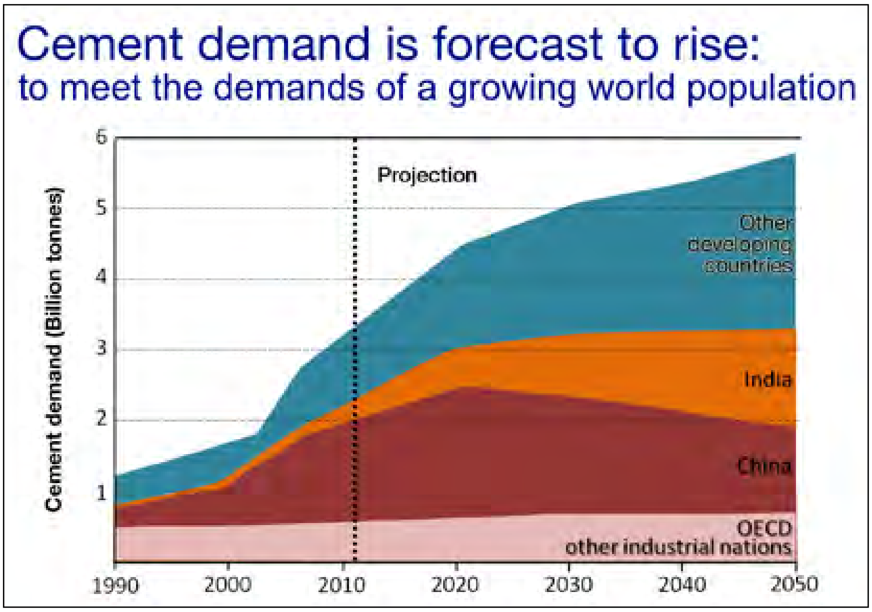

(Credit: Karen Scrivener.)

with calcined clay. We have a program in Cuba where we have shown that you can use low-grade clay. We've be able to show that you can take clay that contains only 30-percent kaolinite and make a blend where you replace 30 percent of the cement and can get the same strength as pure-Portland reference after three days. And, if we make a coupled substitution of calcined clay plus limestone, then we can substitute 60 percent and still get 90 percent of the strength in seven days.

This shows there are a lot of other routes. We have got to stop thinking just in terms of slag and fly ash. I am guilty of that myself. We get stuck on slag because it's a homogeneous material that is easy to study, but slag isn't going to be that important in further reducing CO_2, because there is so little of it available. Of course, where it is available, you can use it at very high replacement rates, but that availability is very localized. And, in the long term, people are going to stop making iron in blast furnaces, because that also contributes to CO_2 emissions.

Q: Your talk at the cements meeting last year was on microstructure and modeling hydration kinetics. Can you briefly explain what this is about, and how it ties into your work with the Nanocem consortium?

A: What we really need to do is to know how the microstructure of concrete is forming. We have this rather miraculous material—if you think about it, you just mix in water and leave it at room temperature and it makes a hard material—but we don't actually understand well what determines those processes. I think we are making very rapid advances, certainly more advances in the past five years than in the previous 50 years. This is what we are doing in my lab and where we are creating the synergy in Europe of having this network of laboratories working together on these problems. When we work together and we have all of the competencies tackling the same problems, we can go much faster.

We are also creating this environment where the industry is pleased to invest in this fundamental work. This industry has been considered low-tech because the science is pretty complicated, and no one company has the resources to change the situation.

So, we bring the companies together in the Nanocem network, where we have five of the world's top six cement companies, including LeFarge, Cemex and Heidelberg, who are responsible for 50 percent of the cement production outside of China. And, if each of them is paying only for part of it, then together they have a global pool that can underwrite part of this research.

In all, there are 11 industrial partners and 22 academic partners in Nanocem, and, by building this consortium, we are bringing about a paradigm change in what type of research can be done.

Q: Are there specific research goals for Nanocem?

A: Yes. The first thing we want to predict with our research is how these materials harden. The second stage of the process, equally important, is predicting how the material will perform over the lifetime of the building or the structure in which the concrete is used. Typically we are talking about lifespans of 50–100 years. Field research isn't very practical, so we have to use the predictive methods coming out of materials science.

We now have, for example, funding from the European Community for 15 linked PhD projects that are jointly addressing the question of water transport, which is the central process by which all degradation mechanisms occur. The idea is to understand this mechanism and how it is affected by different cement types, such as those made with the new low-CO_2 materials. When we achieve this understanding, we are really changing the whole basis on which we can predict its performance.

Q: Are some people surprised by the responsiveness of the industry?

A: Well, business is business, as they say, for the cement and concrete companies, but they really want to be in a sustainable business, and they are probably harmed because they don't have the public relations budgets of, say, the oil industry. But, we have to give them credit for the fact that cement prices are fairly steady and still incredibly cheap. You can still get a ton of cement for around €100. These companies are not making huge profits, and they are constrained about what they can individually do. But my experience is that the management of these companies has a real interest in having a sustainable society.

For more information on Nanocem, visit www.nanocem.org. ■