them being denied access to the best commercial deals. Addressing these issues will take the traditional energy sector into uncharted territory, requiring new skills, techniques and relationships. This interdisciplinary challenge must combine skills from science, engineering, sociology, product design, and human/computer interfacing (see Smart Meter Set-Up).

PUBLIC ENGAGEMENT
The government has presented an economic case for smart meters and smart grids (see Economic Case). However, there is more to consider than a simple business case. Many people, perhaps most, neither understand nor are interested in how energy reaches them. While energy supply is crucial to society, and interruption brings immediate disruption, users take it for granted. Consequently, the developments led by smart metering are not feasible if consumers reject the idea. While this does not mean that the public have to become enthusiasts, there needs to be a willingness to bother, a curiosity to find out more, and appreciation of the benefits of home automation and smart appliances. The media, wider government and schools will be key influencers, as will engineers and scientists who understand the issues and are willing to communicate their knowledge.

Smart metering deployment will benefit from support from both within the project and without. It will need intellectual fire power, excellent R&D in technical, commercial and social aspects: Considerable gain could come from the active support of individuals, institutions and organisations. Smart metering could be a helpful way to start to raise public awareness of the need to move to a low-carbon energy system.

The challenges are not insignificant, but the rewards for success are high. Smart grids, supported by smart meters, represent the biggest changes in energy management in the UK since the national grid system was introduced. The tasks are complex and multidisciplinary, but the benefits: of securing cleaner energy supplies at lowest cost are potentially far reaching. Indeed, smart meters underpin the success of the government’s low-carbon agenda.

Undoubtedly, there are sceptics, and there are those who, for a variety of reasons, resist change. The move to smart meters and smart grids is, however, evident at an international level. Demonstration and implementation are being pursued actively across the US, China, South Korea and Europe – Italy has already installed more than 10 million smart meters, for example. Early experience has been positive but it also reinforces the importance of excellent project management and winning the hearts and minds of customers and the wider public. This is arguably a landmark development, a first step towards a new energy system and one in which consumers will be active participants for the first time. Support from engineering and science community would be valuable.

While energy supply is crucial to society, and interruption brings immediate disruption, users take it for granted. Consequently, the developments led by smart metering are not feasible if consumers reject the idea. While this does not mean that the public have to become enthusiasts, there needs to be a willingness to bother, a curiosity to find out more, and appreciation of the benefits of home automation and smart appliances. The media, wider government and schools will be key influencers, as will engineers and scientists who understand the issues and are willing to communicate their knowledge.

Smart metering deployment will benefit from support from both within the project and without. It will need intellectual fire power, excellent R&D in technical, commercial and social aspects: Considerable gain could come from the active support of individuals, institutions and organisations. Smart metering could be a helpful way to start to raise public awareness of the need to move to a low-carbon energy system.

The challenges are not insignificant, but the rewards for success are high. Smart grids, supported by smart meters, represent the biggest changes in energy management in the UK since the national grid system was introduced. The tasks are complex and multidisciplinary, but the benefits: of securing cleaner energy supplies at lowest cost are potentially far reaching. Indeed, smart meters underpin the success of the government’s low-carbon agenda.

Undoubtedly, there are sceptics, and there are those who, for a variety of reasons, resist change. The move to smart meters and smart grids is, however, evident at an international level. Demonstration and implementation are being pursued actively across the US, China, South Korea and Europe – Italy has already installed more than 10 million smart meters, for example. Early experience has been positive but it also reinforces the importance of excellent project management and winning the hearts and minds of customers and the wider public. This is arguably a landmark development, a first step towards a new energy system and one in which consumers will be active participants for the first time. Support from engineering and science community would be valuable.

INTERNATIONAL EXPERIENCE

Smart metering and smart grids are high on international energy agendas. Last October, for example, the Obama administration announced a grant of $3.4 billion for energy grid modernisation. This will be matched by industry to create a fund of more than $8 billion.

Smart electricity metering has been implemented nationally in Italy (ENEL had deployed smart meters to 27 million customers by 2005). Sweden and Finland had implemented smart meters by 2009 and deployment is in progress in Victoria, Australia (2.6 million by 2013). In these examples the focus is smart meters and customer interfaces, but not wider smart grid opportunities. In the UK the Energy Demand Research Project is investigating consumer response to improved feedback on energy use. Over 47,000 households are taking part and a further 16,000 households form control groups. Around 17,000 households had both gas and electricity smart meters installed. Interim findings have been published by Ofgem and the trial will complete in March 2011.

While the above developments are encouraging, there have also been some significant difficulties revealed internationally. For example, in the Netherlands in 2007, the government proposed that all 7 million households of the country should have a smart meter by 2013. In 2009 the Dutch government had to back down after consumer groups raised fears about data privacy. In the US, concerns have been raised in regard to possible health effects, the social impact of Time of Use tariffs, and confusion arising from increased energy bills (in fact due to wholesale market price changes but blamed by consumers on their smart meters). An overall message here is the importance of information and explanation to customers from the outset.

Demonstration and implementation are being pursued actively across the US, China, South Korea and Europe.
Concrete can withstand compressive forces very well but not tensile forces. When it is subjected to tension it starts to crack, which is why it is reinforced with steel to withstand the tensile forces.

Properties of concrete and steel reinforce, and develop the concrete. For a biologist to work with civil engineers to incorporate living matter into structural concrete material is in itself a great innovation,” he says.

WHY THE NEED?
Concrete will continue to be the most important building material for infrastructure but most concrete structures are prone to cracking. Tiny cracks on the surface of the concrete make the whole structure vulnerable because water seeps in to degrade the concrete and corrode the steel reinforcement, greatly reducing the lifespan of a structure.

Concrete can withstand compressive forces very well but not tensile forces. When it is subjected to tension it starts to crack, which is why it is reinforced with steel to withstand the tensile forces.

Structures built in a high water environment, such as underground basements and marine structures, are particularly vulnerable to corrosion of steel reinforcement. Motorway bridges are also vulnerable because salts used to de-ice the roads penetrate into the cracks in the structures and can accelerate the corrosion of steel reinforcement. In many civil engineering structures, tensile forces can lead to cracks and these can occur relatively soon after the structure is built.

Repairs of conventional concrete structures usually involve applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great height.

HOW DOES BIOCONCRETE WORK?
Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the surface of concrete structures. Specifically selected types of the bacteria genus Bacillus, along with a calcium salt such as calcium lactate, and nitrogen and phosphorous, are introduced to the concrete. When water is mixed with the concrete, the bacteria germinate and multiply quickly. They convert the nutrients into limestone within several days in the laboratory. Outside, in lower temperatures, the process takes several weeks.

FINDING THE RIGHT BACTERIA
The starting point of the research was to find bacteria capable of surviving in an extreme alkaline environment. Cement and water have a pH value of up to 13 when mixed together, usually an hostile environment for life. Most organisms die in an environment with a pH value of 10 or above. The search concentrated on microbes that thrive in alkaline environments which can be found in natural environments, such as alkaline lakes in Russia, carbonate-rich soils in desert areas of Spain and soda lakes in Egypt.

Samples of endolithic bacteria (bacteria that can live inside stones) were collected along with bacteria found in sediments in the lakes. Strains of the bacteria genus Bacillus were found to thrive in this high alkaline environment. Back at Delft University the bacteria from the samples were grown in a flask of water that would then be used as the part of the water mix for the concrete.

Different types of bacteria were incorporated into a small block of concrete. Each concrete block would be left for two months to set hard. Then the block would be pulverised and the remains tested to see whether the bacteria had survived.

It was found that the only group of bacteria that were able to survive were the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for a better environment to germinate. They would become activated when the concrete starts to crack, food is available, and water seeps into the structure. This process lowers the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated.

Finding a suitable food source for the bacteria that could survive in the concrete took a long time and many different nutrients were tried until it was discovered that calcium lactate was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not interfere with the setting time of the concrete.
The second disadvantage is the cost of self-healing concrete is about double that of conventional concrete, which is presently about €80 euros per cubic metre. Jonkers says: “At around €600 per cubic metre, self-healing concrete would only be a viable product for certain civil engineering structures where the cost of concrete is much higher on account of being much higher quality, for example tunnel linings and marine structures where safety is a big factor – or in structures where there is limited access available for repair and maintenance. In these cases the increase in cost by introducing the self-healing agents should not be too onerous.”

Added to this, if produced on an industrial scale it is thought that the self-healing concrete could come down in cost considerably. If the life of the structure can be extended by 30%, the doubling in the cost of the actual concrete would still save a lot of money in the longer term. The Delft team is currently working on the development of an improved and more economic version of the bacteria based healing agent which is expected to raise concrete costs only by a few euros.

The new self-healing agent being developed will immobilise the sugar-based nutrient during the mixing process. So the team has now developed an alternative self-healing agent with a new shape and form and the way that the bacteria and nutrients would be stored would be totally different.

The new healing agent would comprise only 5-5% of the overall volume and the concrete would therefore be much stronger. The new self-healing agent would be a viable product for most structural concrete applications. The team still has to do a lot of testing which will take another year before the new product is ready for full-scale testing. Jonkers says: “If the cost of the self-healing agent can be brought down sufficiently and the concerns over the long-term effects on the concrete performance properly addressed, then the product could have great potential.”

**INTEREST FROM INDUSTRY**

When the idea of bacteria-mediated concrete was first mooted by US academics in the late 1990s by the research group of Professor Sookie Bang, testing and application of the theory was not taken forward because there was a lack of interest from the commercial engineering sector for such a product.

The R&D process still has some way to go but several big industry players have created partnerships with Delft University to develop applications of self-healing concrete. Investment funding from industry is now forthcoming.

The concept is to engage with one major player from each concrete sector. Delft is therefore developing self-healing concrete products for specific civil engineering markets that would not be in competition with one another. Products will be developed for sectors such as tunnel-lining, structural basement walls, highway bridges, concrete floors and marine structures. Pure concrete products will take two years to develop and products with steel reinforcement will take four years.

**FULL-SCALE TESTING**

Starting this year, there will be full-scale outdoor testing of self-healing concrete structures. A small structure or laboratory test can be conducted within two to four years. Structures will be fitted with some panels of self-healing concrete and others with conventional concrete so that the behaviour of the two can be compared. Cracks will be made in the concrete that are much larger than the ones that have healed up in the laboratory to determine how well and fast they heal over time.

Commercial partners have asked whether the process could be used to repair existing structures. To answer this Delft University has just been awarded funding of €430,000 from the Dutch government. Two postdoctorate scientists will spend two years developing a self-healing system to be applied to existing structures.

To address other concerns laboratory tests are being carried out to accelerate the ageing process of self-healing concrete. The tests will subject the concrete to extreme environments to simulate changing seasons and extreme temperature cycles, wetter periods and dryer periods.

**SOME DISADVANTAGES**

There are two key obstacles that need to be overcome if self-healing concrete is to transform concrete construction in the next decade. The first issue is that the clay pellets holding the self-healing agent comprise 20% of the volume of the concrete. That 20% would normally comprise harder aggregate such as gravel. The clay is much weaker than normal aggregate and this weakens the concrete by 25% and significantly reduces its compressive strength. In many structures this would not be a problem but in specialised applications where higher compressive strength is needed, such as in high-rise buildings, it will not be viable.

The second issue is that the life of the structure is needed, such as in gravel. The clay is much weaker than normal aggregate and this weakens the concrete by 25% and significantly reduces its compressive strength. In many structures this would not be a problem but in specialised applications where higher compressive strength is needed, such as in high-rise buildings, it will not be viable.

The Dutch government has also just awarded €410,000 funding for another research project that will be undertaken into concrete basement walls and pre-cast concrete floors which are vulnerable to groundwater.

Meanwhile, work is proceeding to address concerns from industry as to whether the bacteria can survive dormant for the full service life of the concrete structure. Evidence from the soil samples taken from desert areas and stored in museums shows that the soil still contains live bacteria spores after 200 years.

The research will first two systems. The first technique will see bacteria and nutrients applied to the structure as a self-healing mortar, which can be used to repair large-scale damage. The second technique will see the bacteria and food nutrients dissolved into a liquid that is sprayed onto the surface of the concrete from where it can seep into the cracks.

The Dutch government has also just awarded €410,000 funding for another research project that will be undertaken into concrete basement walls and pre-cast concrete floors which are vulnerable to groundwater.

Meanwhile, work is proceeding to address concerns from industry as to whether the bacteria can survive dormant for the full service life of the concrete structure. Evidence from the soil samples taken from desert areas and stored in museums shows that the soil still contains live bacteria spores after 200 years.

To address other concerns laboratory tests are being carried out to accelerate the ageing process of self-healing concrete. The tests will subject the concrete to extreme environments to simulate changing seasons and extreme temperature cycles, wetter periods and dryer periods.

**SOME DISADVANTAGES**

There are two key obstacles that need to be overcome if self-healing concrete is to transform concrete construction in the next decade. The first issue is that the clay pellets holding the self-healing agent comprise 20% of the volume of the concrete. That 20% would normally comprise harder aggregate such as gravel. The clay is much weaker than normal aggregate and this weakens the concrete by 25% and significantly reduces its compressive strength. In many structures this would not be a problem but in specialised applications where higher compressive strength is needed, such as in high-rise buildings, it will not be viable.