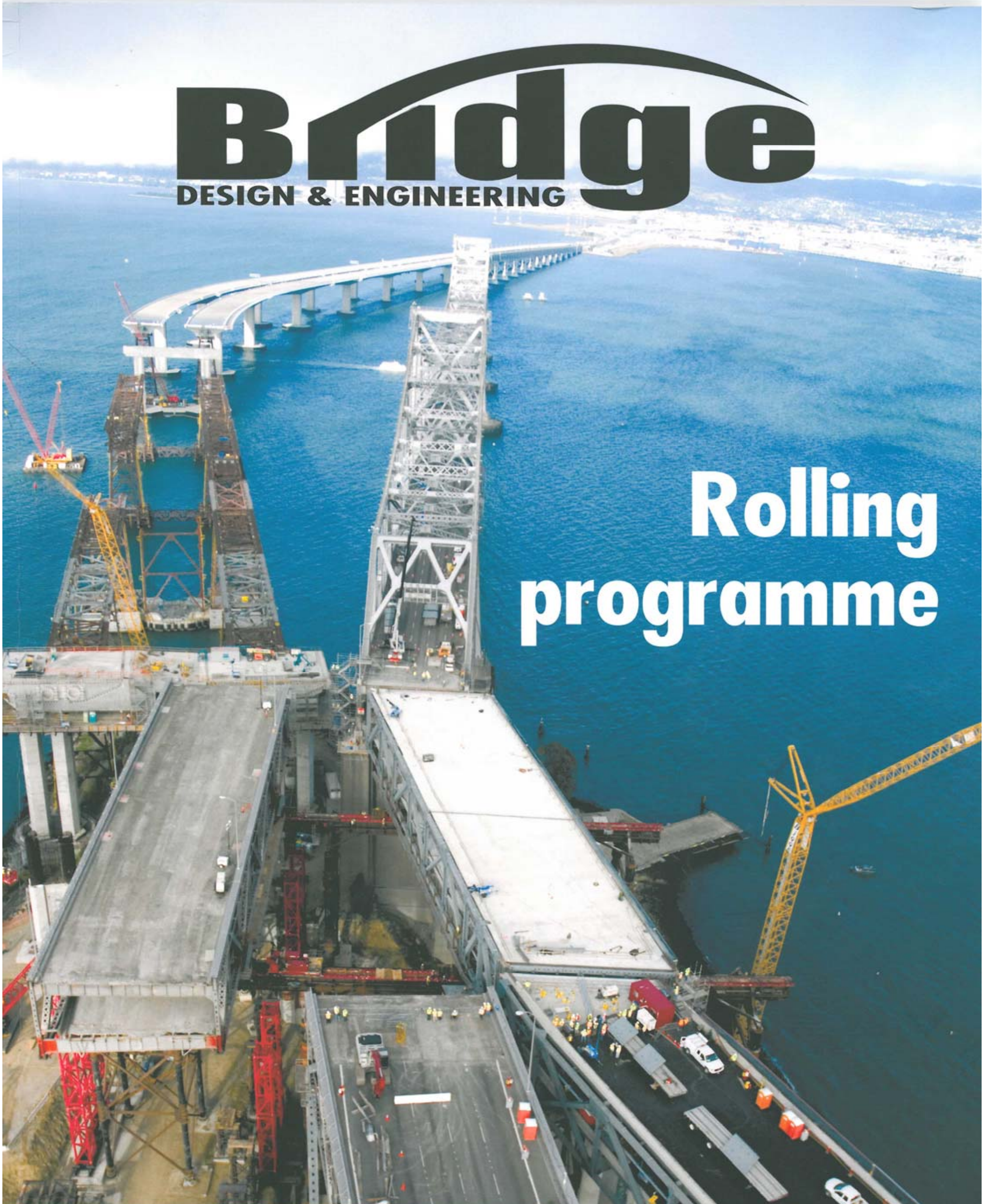
Bridge
DESIGN & ENGINEERING



Rolling programme

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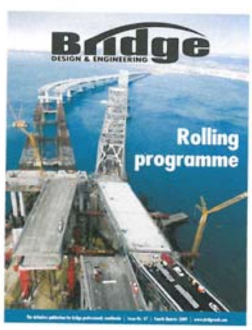

A weekend closure of San Francisco's Bay Bridge enabled a new tie-in span to be rolled into position *(Barrie Rokeach 2009)*

Bridge DESIGN & ENGINEERING

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PARAPET

Reducing energy consumption both in the construction and long-term operation and maintenance of bridges is the theme of one of *Bd&e*'s main reports this issue. Various industry bodies are working to develop a 'green standard' for the bridge industry which will encourage designers in particular to consider the implications of their decisions on the energy needed to build and operate a bridge. This is a consideration which should be central to the decision-making process at all times, in the same way as safety and structural integrity. It should not just be something to think about now, when next month's UN conference on climate change in Copenhagen is the top of the news agenda.

Developing a standard is only the first step in achieving a global move to reduced energy consumption in our sector, but it will offer guidance on what clients, designers and contractors should consider and how changes can be achieved from a practical point of view.

The examples used to illustrate the article demonstrate two very different approaches to reducing energy consumption, but in both cases the central aim is the same.

Ideas such as reducing the energy required to build a bridge by sourcing materials locally are nothing new but in the past this approach has generally been applied to bridges in developing countries where transport of materials is a major obstacle to construction rather than just an additional cost. The way in which designs can be adapted to suit the local materials and workforce – whether on a large scale, such as on the Hooghly Bridge in Calcutta or on a small scale, as practised by charities such as Bridges to Prosperity in their footbridge designs – can offer important lessons to designers in the developed world.

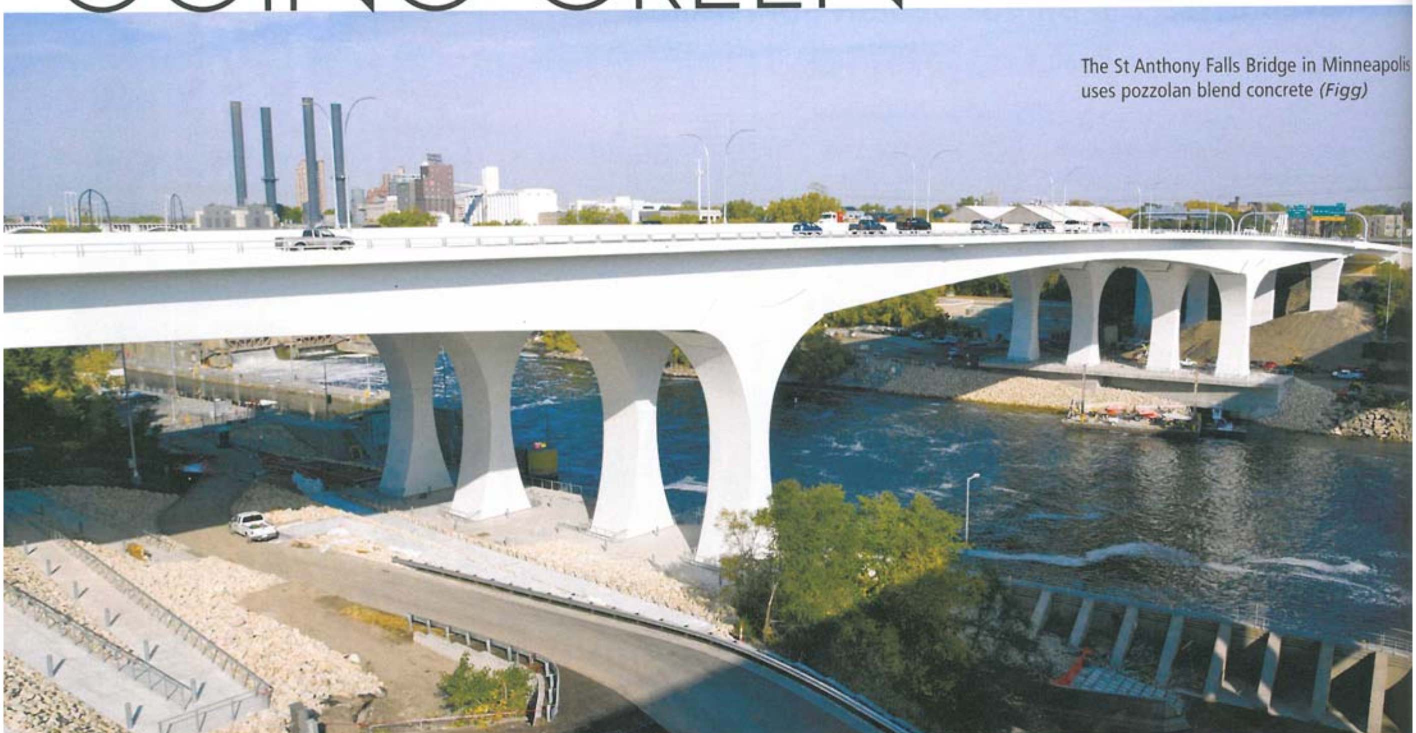
Central to reducing energy consumption in the long term, of course, is the need to build bridges that last longer, and this is something that engineers have always attempted to do. Sometimes their ambitions have been thwarted by budgetary constraints which require clients to choose the cheapest option, other times by increasing traffic demands. While the benefits of advanced composite materials have been recognised for some time, it is only when a technology is developed that can actually undercut traditional materials in terms of construction cost that clients will commit to building more than just a pilot project.

On top of all this is the much more thorny debate about whether building new bridges stimulates additional traffic and hence more CO_2 emissions, potentially wiping out any benefit accrued from other green measures. In some cases it may, but in other cases new bridges offer drivers a shorter route, less congestion and better driving conditions, all of which reduce pollution and they may even offer other incentives for alternative travel options such as improved cycle facilities or lanes devoted to public transportation.

Helena Russell

Next issue is published in February 2010

GOING GREEN



The St Anthony Falls Bridge in Minneapolis uses pozzolan blend concrete *(Figg)*

It is time for the bridge industry to start working towards a 'green' standard by which to design and build bridges. Scott Snelling suggests how this could work

Green design has entered the public consciousness and the mainstream newspapers and magazines. Taxpayers, voters, politicians and policy-makers want to be assured that public funds are being used to build environmentally-friendly infrastructure projects. The American Society of Civil Engineers recently launched an initiative to create a standard for defining and certifying green infrastructure projects and professionals. It is not yet clear when ASCE will be ready to roll-out such a standard or whether another organisation will be first to do so, but they are likely to be very similar to the standards that exist in other industries. The Leadership in Energy & Environmental Design standard certifies green buildings and is administered by the US Green Building Council, a non-profit organisation founded in 1993.

The Sustainable Project Rating Tool was developed by the US Army for its facilities – since 2000 all new army facilities and infrastructure has been built to green standards. The International Federation of Consulting Engineers is developing a Sustainable Construction Assessment Standard and the UK's Institution of Civil Engineers already has its Civil Engineering Environmental Quality Assessment & Award Scheme – both of these are broadly applicable to civil engineering works, but are not bridge-specific.

Greenroads was introduced in the USA this year to certify roadway and pavement projects – it was developed at the University of Washington with funding from the federal US Department of Transportation as well as several state and regional departments. Greenroads documentation states: "A future system focussed on structures [bridges, tunnels and walls] could be incorporated into Greenroads, but none currently exists." Of course such a green standard will need more than just a publisher, it will require a dedicated staff of professionals to audit project applications and documentation. Until this standard is available, however, bridge professionals can apply two primary green strategies to their work.

The first is to maximise the use of recycled materials, the second is to design for minimum life-cycle costs. Bridge owners who wish reduce environmental impacts can incorporate these strategies into requests for proposals for new bridge projects. Designers meanwhile, can use existing specifications for the recycled materials discussed below and may also consider the maintenance implications of their design decisions. Contractors can divert construction waste from landfill, and policy makers should fully fund bridge maintenance programmes in order to prevent wastefully premature rehabilitation and replacement projects.

Green design is about considering the environment as one of the design criteria, and including it as an integral part of the decision-making process on a project. The goals of green design are to reduce life-cycle costs, energy use, greenhouse gas emissions, pollution emissions, waste, and the use of non-renewable resources to sustainable levels. The American Society for Testing & Materials standard E2114 defines that sustainable development should 'meet the needs of the present without compromising the needs of future generations'.

Bridge projects already use many recycled and industrial by-product materials, but there are opportunities to specify more recycled materials while simultaneously reducing costs and increasing performance. Recycled materials that are relevant to bridge projects include steel, concrete, wearing surfaces, reinforced plastic piles, and construction waste.

Steel is already highly recycled and recycleable hence there is no opportunity for bridge engineers to specify green steel. Structural and reinforcing steel in the USA contains some 96% total recycled content (59% post-consumer) as a matter of course. Steel recycling is economically driven by the material's scrap value of approximately 25 cents per pound.

Concrete can be crushed and recycled – downcycled – as aggregate or fill, but has no scrap value, and recycled materials or by-products, such as mine tailings, can be used instead of virgin aggregate. However, the most significant environmental impacts of concrete are associated with cement production – the energy used and greenhouse gas emitted when concrete is produced vary drastically depending on what cement is used.

Portland cement is energy intensive to produce and is estimated to be responsible for 5% of the world's carbon dioxide emissions. China is the world's largest carbon dioxide emitter,

ENERGY EFFICIENCY

One way that bridges can be 'greened' is to reduce their lifetime energy needs – this is particularly relevant to movable bridges, which need energy to open and close them. The Ramspol Bridge near Enst in the Netherlands needs to be completely replaced and DHV has developed an energy-neutral design for the Dutch Directorate General for Public Works & Water Management, which wants to decrease its dependence on fossil fuels and to use energy more efficiently. Certain measures minimise the amount of energy required by the moveable bridge and bridge house, while solar panels are used to provide energy to meet the remaining demand. One way to reduce energy is to increase the bridge's vertical clearance so that it does not need to be opened so frequently.

The existing bridge has a navigation clearance of 5m and the new Ramspol Bridge will have its navigation clearance almost tripled to 13m. Hence it is only for ships higher then 13m that the bridge has to be opened and almost all of the regular inland river traffic will be able to go through the new bridge without it needing to be opened.

Currently the Ramspol bridge opens about 5,000 times per year; its replacement will only need to be opened about 1,800 times per year

Various other energy-saving features ensure that only a very small amount of energy is needed, such as limited installation stand-by power, and using the 'passive house' principles for the bridge control house. These principles include orienting the control house in relation to the sun to optimise solar gain; installing effective thermal insulation and triple glazing, ensuring an airtight building envelope, using heat recovery and solar shading to reduce the heating and cooling demand and make sure that the control house is comfortable in all seasons. In summer the bridge house will remain cool because of its energy-efficient LED lights, night-time ventilation and cooling using river water. With solar collectors for electricity production, the net energy use will be zero.

The solar panels consist of 120m^2 of photovoltaic cells which produce electricity which will be delivered back to the power distribution net. Sufficient energy will be generated via the solar panels to open the bridge about 1,800 times a year. But even when the bridge is not opening or closing, it still needs power for the heating, air conditioning, control systems, observation systems, navigation signs and so on. To reduce its environmental impact, the amount of power required must be reduced as much as possible. For example when there is no-one in the control room all the equipment should be switched off.

DHV has estimated that the energy consumption will be cut from 50,000KWh to just 12,000KWh per year. An emergency power supply using supercapacitors and batteries will enable the bridge to remain functional in the event of a lengthy power outage. The bridge replacement will be carried out as a design-build project, and bidding has just started. It is intended to be open to traffic in 2013.

GETTING CARRIED AWAY

Reducing the amount of energy and materials needed to build a bridge is also a valid way of producing a more 'green' structure. The 'bridge in a backpack' which has been developed by the AEWC Advanced Structures & Composites Center at the University of Maine along with Advanced Infrastructure Technologies meets both these criteria, and unusually, even these pilot projects are already beating traditional construction solutions in price. Two bridges have already been built for Maine DOT using this structural form, which is based on arches made of advanced-composite tubes filled with concrete. The portable size of the unfilled tubes has led to the design being dubbed the 'bridge in a backpack' as they can theoretically be brought to site in this manner.

The pilot project, the 10m-long, 13.4m-wide Neal Bridge in Pittsfield was built last autumn in less than two weeks, and the McGee Bridge replacement in North Anson, Maine took just 12 days to build an 8.5m-long, 7.6m-wide bridge in August this year. Lessons learned from the first project were fed into the design of the second project, enabling the designers to optimise it further and submit the lowest bid for the scheme. The FRP tubes that form the arches can be folded flat and packed away for transport; to ready them for construction, they are inflated and bent to the required profile before being infused with resin and left to set. This process has so far been carried out in the lab for the two bridges already built, but there is no reason it cannot be carried out on site. AIT structural bridge engineer Dan Bannon explains that one of the projects currently bidding for construction next year is a 21m-span bridge in Hampden. "We will have to infuse the tubes on site for this one because we simply don't have any other method of transporting arches of this size."

Once the resin is set, the tubes can be positioned by hand, without the need for lifting equipment. They are cast into concrete footings, and covered over with corrugated FRP decking which is screwed into the tubes and acts as formwork. Self-consolidating concrete is pumped into each tube through a hole at the apex, and concrete is poured onto the decking to form the arch. Construction of the McGee Bridge replacement was completed ahead of schedule, by just five operatives and a mid-size excavator.

Over the next two years, AIT is planning to build six new bridges using this technology, as part of the Maine Composites Initiative programme. Spans range from 7.3m to 21m. At the same time, Bannon says that the team intends to manufacture and test larger-span and larger-diameter arches, and to develop rigid frame and girder designs. Refining the process of on-site manufacturing is another aim, as well as moving towards large-scale production of the units. This is intended to help the new technology become even more competitive with traditional materials.

20% of which is attributed to its cement kilns. The production of Portland cement emits about one ton of carbon dioxide for every ton of cement produced.

Pozzolan cements, meanwhile, effectively require zero energy to produce, and emit no carbon in their production, since they are made of volanic soils or industrial by-products such as fly-ash, blast furnace slag, and silica fume. Typical bridge concrete specifications call for an admixture of 15% pozzolan cement to be blended with 85% Portland cement, but the majority of industrial by-product pozzolans continue to be landfilled and there is opportunity for bridge engineers to economically specify higher percentages of pozzolan cement. Only a proportion of the pozzolans that are landfilled are suitable for use as cement in structural concrete, however. On projects which use standard design-bid-build procurement routes, concrete tends to be the traditional Portland cement-based mixes, from tradition as much as anything else.

But recent design-build projects have seen the successful use of concretes with high percentages of pozzolan cement - up to 85% - because they have proved to be the lowest-priced concrete meeting the required physical properties. The reductions in energy use, greenhouse gas emissions, and landfill have been regarded as happy side-effects. Such concretes may take hours longer to set, but can produce higher strength, lower permeability materials once cured. For example the Cooper River Bridge in Charleston, South Carolina was able to use uncoated rebar to meet its 100-year design life requirement, due to the low permeability of the high pozzolan-blend concrete. Meanwhile the new St Anthony Falls Bridge in Minneapolis, Minnesota used environmentally-friendly pozzolan blend concrete.

Wearing surfaces commonly take advantage of many recycled materials such as, reclaimed asphalt pavement, reclaimed concrete pavement, tyre crumb rubber, shingles, ▶

and more. Using scrap tyre crumb rubber has been found to increase pavement life and reduce road noise. The Greenroads standard favours energy-efficient warm-mix pavements, instead of traditional hot-mixes. The *User's guide for by-products and secondary use products in pavement construction* published by the University of New Hampshire provides a thorough and up-to-date reference to existing standard specifications for recycled materials. Reinforced recycled plastic piles have been successfully used for pier protection fenders on bridge projects. Although the costs per pile are nearly double that of timber, plastic piles have significantly lower life-cycle costs since they absorb more energy and last two to ten times longer.

The proposed standard has a total of six prerequisites and thirty-nine credits grouped into seven categories; materials & resources, alternative transportation, project delivery process, construction activity, maintenance & acess, environment & water, and energy *(see sidebar)*.

These will be used to award credits to bridge projects. All the prerequisites must be met, and a designated minimum point value - 15 credits, for example - will be required before a bridge project can be certified as green. These suggestions are intended as a starting point for further development by a committee of bridge professionals.

The Transportation Research Board's report 290 *Potential impacts of climate change on US Transportation (2008)* states 'there is a need for making changes in [design] standards that focuses first on long-lived facilities, such as bridges'. This report indicates that the solution for dealing with climate change will be a combination of two strategies: adaptation and mitigation. The proposed green bridge standard is part of the mitigation strategy to reduce greenhouse gas emissions that will be deployed in industries across the economy and the world.

Several studies into the construction costs associated with LEED green buildings have found 'there is no significant difference in average [construction] costs for green buildings as compared to non-green buildings'. All sources agree that an initial investment in green building is rewarded many times over during the lifetime of the structure. This comes from lower life cycle costs in the form of decreased energy, water, and waste use.

Twenty-three billion dollars-worth of LEED-certified green buildings were built in the USA in 2007, including nearly three billion dollars-worth of buildings for government agencies. Hundreds of green buildings have been constructed by agencies that own bridges, such as: Virginia DOT, Caltrans, US Army Corps of Engineers, MTA Bridges & Tunnels, Federal DOT, New York City DOT, and the Seattle DOT. Many additional municipalities, including the state of Arizona and the city of Chicago, have created mandates for all new facilities to be built to LEED certified green standards. Hence the proposed green bridge standard has the potential to create an active and growing market.

The proposed standard is a tool that will encourage existing best practices to be used more widely, but it needs government funding and industry support to be developed and implemented ■

Scott Snelling is a mechanical and structural engineer at Hardesty & Hanover

GAINING CREDITS

Materials & resources
Six credits: Use materials that are recycled, recyclable, and industrial by-products. (One credit for recycled material content of 20%, additional credits accumulated over 40%, 60%, 80% and 90%.) Use regionally extracted and manufactured materials. (Defined as 800km radius from the project site).

Alternative transportation
Five credits: Encourage transportation alternatives to single occupancy motor vehicles. Provide pathways for pedestrians and cyclists. Provide designated lanes for buses, light-rail transit, car pools, and low-emission vehicles.

Project delivery process
One prerequisite: Perform bridge life cycle cost analysis in accordance with NCHRP Report 483. Perform life cycle assessments, using the free software eiolca.net, to compare the environmental impacts of competing bridge proposals.
Seven credits: Use design charettes to develop context sensitive solutions. Consider future uses and demolition/salvage of the bridge. Develop innovative designs. Include green design accredited professionals.

Construction activity
Three prerequisites: Divert 75% of the on-site construction and demolition waste from landfills for reuse or recycling (refer to the online Construction Waste Management Database developed by the National Institute of Building Science). Control erosion and stormwater. Prepare a construction noise mitigation plan.
Six credits: Track water and electricity use. Provide on-site environmental awareness training. Reduce fossil fuel use and emissions of the construction equipment.

Maintenance & access
Two credits: Produce a maintenance manual at the time of design, including estimated maintenance activities, frequencies and costs. Provide safe and productive maintenance access.

Environment & water
One prerequisite: Comply with the applicable environmental laws.
Nine credits: Minimise destruction to the local ecology around the bridge site. Minimise erosion, stormwater sedimentation, construction dust, particulate, noise, and light pollution. Minimise the heat island effect. Prefer the redevelopment of brownfield or urban sites instead of developing agricultural or wetland sites. Use native vegetation with no irrigation.

Energy
One prerequisite: Commission the bridge electrical systems after construction to verify that the actual energy used conforms to the design values.
Four credits: Minimise the life cycle costs of the bridge electrical equipment and lighting. Sign a multi-year contract to procure grid-source green electricity.