Cementing Sustainability

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Executive Summary

Concrete engineering has traditionally mainly been concerned with compressive strength. Durability and other issues such as shrinkage and cracking have been of lesser importance. Given the need for sustainable practices within the construction industry brought on by global warming and the inevitable decline from peak oil, a broadening of the debate is appropriate. More consideration needs to be given to the amount of energy that is embodied in structures, the operating efficiency of buildings over their lifetime and the atmospheric impacts of carbon dioxide and other releases.

The obvious reason for re-examining cements is that their manufacture contributes around 10% to global warming (Pearce 1997). Less obvious reasons are the exciting contribution that concretes with improved properties could make to reducing the lifetime energy of buildings and the reduction in transport energies and emissions that would ensue if local low impact materials and wastes found on or near buildings sites were used as aggregates. Transporting stone and sand to batching plants and then to building sites consumes significant energy and would no longer be necessary.

The more urgent reason for re-examination is the fact that the cement and concrete industries are utterly dependent on fossil fuels.

The use of new generation cements such as Eco-Cement to sequester carbon and bind wastes is also canvassed in this paper which defines an exciting, new and holistic approach to sustainability in the context of the cement industry.

Keywords

Materials, built environment, concrete, cement, construction industry, carbon credits, economic, emissions, trading, sequestration, mitigation, abatement, sustainable, sustainability, CO2, concrete, waste, embodied energy, lifetime energy, Eco-Cement, Kyoto.

Redefining Sustainability

The concept of sustainability equates to continued viability. For a process to be continually viable it needs to be a closed loop system. The flow of materials into the process needs to be inexhaustible and the flow out of the process needs to connect to other processes. Processes that use exhaustible inputs or unutilised outputs are unsustainable on an ongoing basis.

Materials used in the construction industry have a huge impact on sustainability. Their production involves changes in chemistry or shape and requires what is referred to as process energy. The logistics of positioning materials at any stage in the process results in the use of transport energy. Process and transport energies are embodied in materials in their final position. The properties of materials and the way in which they are spatially designed define lifetime energies.

Over 90% of all energy used currently results in carbon dioxide (CO_2) releases and cement manufacture is unique in that there are also chemical releases of the gas during the clinkering process.

In addition to considering the properties that relate to the engineering of the building, consideration therefore needs to be given to:

- the embodied energy of materials such as concrete,
- the properties that will determine the operating energy of the building over its lifetime (e.g. thermal insulation/conductivity (solar passive construction), thermal lag times etc.) and
- the release of CO_2 into, and absorption of CO_2 from, the earth's atmosphere.

Become More Sustainable Now or Go Broke

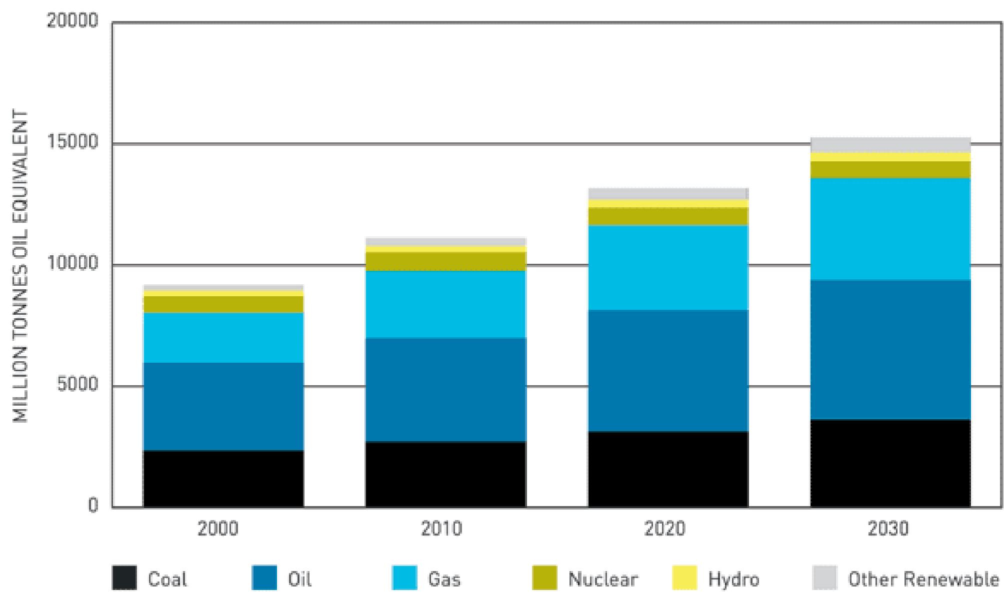

Figure 1 - World Energy Outlook (IEA 2002)

The International Energy Agency (IEA 2002) project global energy use to grow by two-thirds from 2002 to 2030, with fossil fuels meeting more than 90 per cent of that increase. Global greenhouse responses could alter this path, but more likely is a price affect from declining resources particularly of oil.

Most models of oil reserves, production and consumption show peak oil around 2010 (Campbell 2005) and serious undersupply and rapidly escalating prices by 2025.

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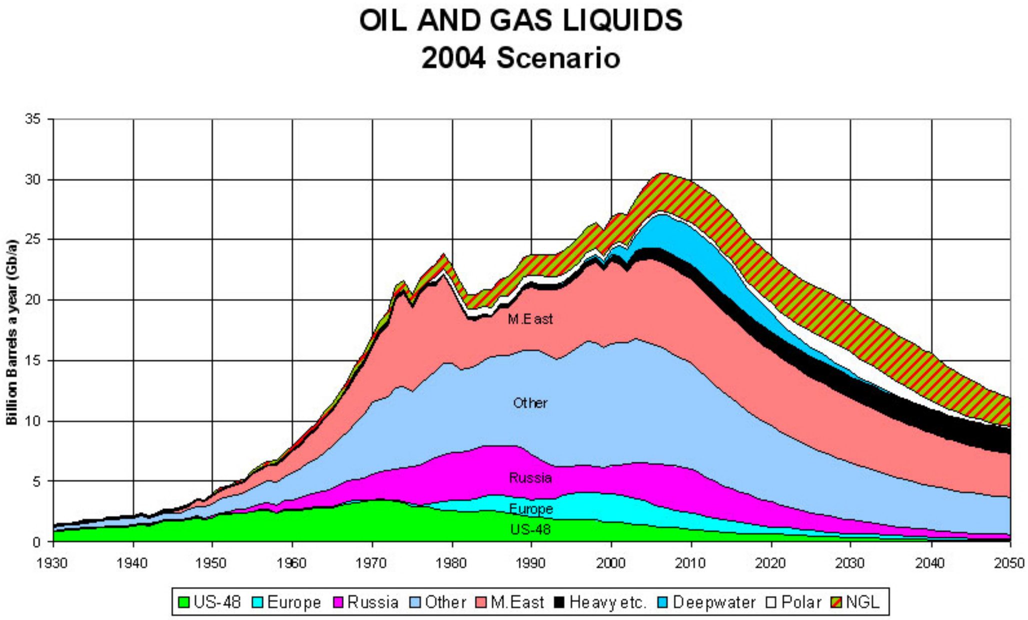

Figure - Peak Oil (Campbell 2004)

Suppliers that act now to reduce and change the energy base of cement and concrete will have an economic advantage as rising oil prices will impact on the price of fossil fuels such as coal which is currently the predominant source of kiln energy The transport energy from quarry to batching plant to site will need to be reconsidered.

Unlike many construction materials, it is fortunately relatively easy to change the energy base of cement and concrete thanks to recent innovations by John Harrison of Tasmania, Australia. This paper will explain how.

Harrison's contributions have been a new non fossil fuel driven kiln technology for making cements that involves capture of chemical releases and binders based on calcium magnesium blends that reduce or even sequester carbon dioxide emissions as well as enable the inclusion of a greater range of localised low impact materials and wastes for their physical as well as chemical properties into concretes for the built environment.

The Way Forward

The built environment encompasses in the order of 70% of all materials flows. Of this concrete is the major proportion at around 15 billion tonnes.

Given this scenario the shift to a more sustainable production and use paradigm will involve the concrete industry as the major participant and require changes reducing embodied and lifetime energies as well as chemical releases.

Urgent sustainability issues such as climate change and waste mean that the industry must evolve. Fortunately rational economic thinking will dictate that the industry does evolve as energy = money on any scale. Other sustainability issues are less obvious such as a need to shift production away from unhealthy organic binders (e.g. formaldehyde).

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There are also other factors driving evolution such as changes in construction methodologies (e.g. the introduction of robotics).

In an industry riddled with prejudice and dogma change will be difficult, but is actually achievable on far greater scales than currently imagined. Manipulable factors include embodied energies, chemical releases and properties.

Changing and Reducing the Energy Base

The concrete industry could be defined as the business of manufacturing and selling binders. Starting with such an open minded definition change will not be so difficult.

Embodied Energies

The embodied energy of a building product such as concrete is the total energy consumed by all of the processes associated with its production, from the acquisition of natural resources to delivery. It includes the mining, manufacturing of materials and equipment, transport of the materials and even the energy consumed in administration.

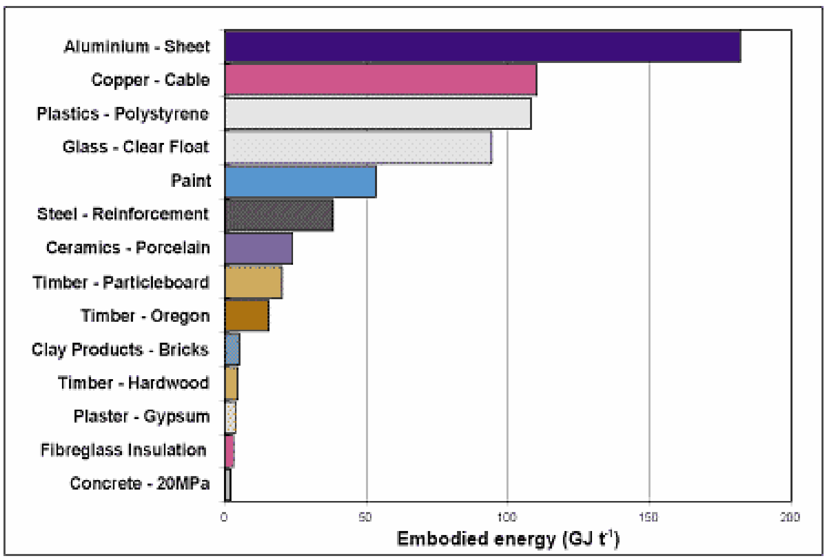

Figure 2 - The Embodied Energy of Building Materials (Tucker 2000)

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The embodied energy of a material is usually measured in Gjt^{-1} ($MjKg^{-1}$). The embodied energy of concrete is relatively low at around 2 Gjt^{-1}. Aluminium by contrast has the highest embodied energy at around 180 Gjt^{-1}. When the total embodied energy in construction is considered however concrete makes the greatest contribution because of the enormous volume used. It follows that small improvements will have a big impact.

Given the fuels scenario presented in this paper, the concrete industry will make more money in the long run by reducing and changing the total energy base. Using energy that is not derived from fossil fuels is not so difficult and for calcining, candidate energies include wind, solar, wave, geothermal and nuclear. For transport more intense lateral thinking is required.

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Calcining Energy

On the 28th June 2005 The European Union announced that the world's largest ever fusion reactor will be built in France, at a total cost of around $12bn. The ultimate goal of the project is to finally crack the problem of how to tap into the immense power of nuclear fusion. Fusion is the same process that goes on in the centre of the sun, and it holds the promise of almost inexhaustible, clean safe energy generation.

Fusion energy will take at least 25 years to develop and until it is safely abundantly available, the concrete industry must focus efforts on reducing the dependency on fossil fuels using other means. Some processes are more adaptable than others and unfortunately Portland cement clinker manufacture requiring over 1400 ^oC is not easily adapted to more efficient use of non fossil fuel energy.

There is however an alternative. Cement is itself a blend of at least four constituents and what Harrison proposes is also blending with it reactive magnesia which has been shown to deliver superior properties and which can be made much more sustainably using non fossil fuel energy.

The lower temperatures required means that calcining magnesite, the main source ore, is more efficient and can be achieved by direct non fossil fuel energy such as in a solar concentrator.

Transport Energies

There are only two ways to reduce the emissions associated with the transport energy component of concrete: change the source of energy away from fossil fuels (as with hybrid and electric vehicles) and/or use less energy by incorporating locally sourced materials as aggregates requiring less transport. Harrison's Tec and Eco-Cement binders are uniquely less reactive, making the latter more feasible.

Concretes of the future will contain more local, low impact materials that have not been transported.

Other means of Reducing Embodied Energies

Recycling of materials reduces their embodied energy, because energy consumed to create the material recycled can be averaged over the number of cycles that have occurred.

Waste materials have zero embodied energy, because the embodied energy is already accounted for in other materials. The inclusion of fly ash in concrete is an example of a waste material that lowers the total embodied energy of the resultant concrete mix – at least until fly ash is no longer considered to be a waste, as is now the case with silica fume.

Concretes are composites that traditionally, but not necessarily use stone and sand as aggregates and, increasingly, fly ash and ground granulated blast furnace slag as supplementary cementitious materials. Many other materials, many of which are wastes, could conceivably be used but current generation cements are too alkaline. The unreactive chemistry of the system proposed by TecEco will change this. Harrison discovered that the main weakness of concrete is the presence of Portlandite which remains indefinitely,

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resulting in a high pH internal environment. Harrison removes Portlandite using the pozzolanic reaction, and replaces it with Brucite, a much less soluble and therefore more stable alkali, thereby substantially reducing the pH and long term reactivity of concrete.

Using TecEco cements an expanded range of recycled and waste materials can therefore be used.

Chemical Releases

When any alkali carbonate is de-carbonated or calcined CO_2 is produced. This release is an inevitable consequence of the stoichiometry of the de-carbonation reaction. It is essential therefore to consider how the gas could be prevented from entering into the atmosphere.

Various direct sequestration processes are being considered. An alternative and adjunct is to change the composition of Portland cement with a view to reducing net releases by substituting components, such as the magnesium oxide proposed by TecEco, that can easily be made in such a way that CO_2 is not released to the atmosphere. Magnesium oxide can be produced at much lower temperatures more efficiently than cement using non fossil fuel energy such as in a solar concentrator.

Properties

The embodied energy of the materials used in a typical energy efficient home lasting say 50 years would be in the order of 30% of the total lifetime and embodied energies and higher if carpet, fit out and white goods were also included.

Concrete is only one component and in one recent example, the K2 building in Melbourne, Australia, contributed only around 1.4% (Flower 2005). More important are the properties that can be imparted to composites such as concrete that reduce lifetime energies.

In the low long term pH formulations proposed by Harrison a very wide range of wastes can be utilised for the physical properties they impart to concretes without delayed reaction problems. Other benefits of recycling include an overall reduction in costs to the extent that wastes that can be acquired at low cost are used. Sawdust as aggregate, for example, is cheap or free, produces concrete that is lightweight, insulating, and easier to cut and drill.

New materials and materials composites can introduce physical properties that result in them being more sustainable in use. The use of insulating concretes is a simple example. There is much room for innovation and significant improvement in the operating efficiency of buildings will be the outcome. Lifetime energy efficiencies have an impact on sustainability by reducing net use of fossil fuels and the associated release of CO_2.

CO_2 Sequestration

The global warming phenomenon requires more action than simply using less energy and producing less CO_2. We actually need a process whereby we can get the CO_2 that is already in the atmosphere back out again on a very large scale at low cost.

Concrete is an ideal candidate for this role because of the huge tonnages involved.

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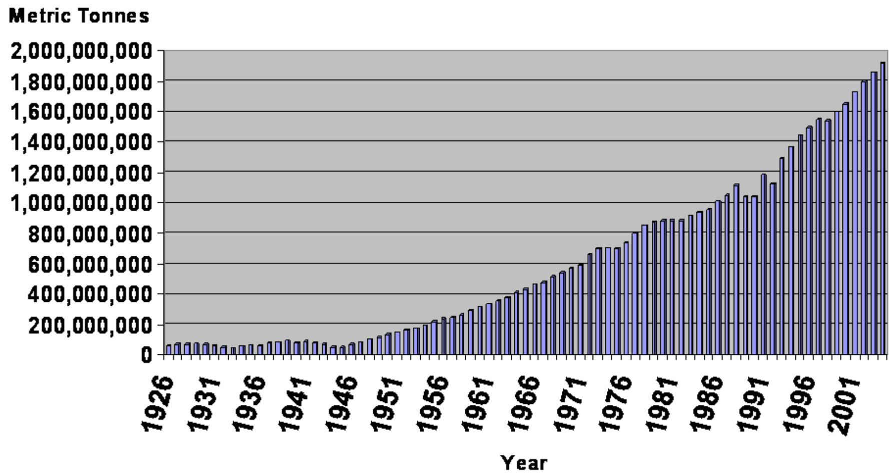

Figure 3 - Concrete Production = Emissions (based on data from USGS 2004)

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Because the CO_2 produced from the calcining of Magnesite ($MgCO_3$) to make reactive Magnesia (MgO) is easily captured and geo-sequestered, significant net sequestration occurs when Eco-Cements absorb atmospheric CO_2 in porous substrates.

TecEco Cement formulations include Tec-Cements, Eco-Cements and Enviro-Cements. Tec-Cements blend reactive magnesia with Portland Cement, but still use PC as the major component and are used for high-performance applications. Eco-Cements have much higher proportions of magnesium carbonate and set by carbonation in porous substrates. Enviro-Cements are a non-porous cement using a similar formula, and are suitable for chemically locking in all manner of toxic and hazardous wastes.

Conclusion

The way we make concrete including how we transport the components, how we use it and what properties we give it is of vital importance to sustainability.

TecEco cements represent a who new tool to lever greater sustainability

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