THE ROLE OF MATERIALS IN SUSTAINABLE CONSTRUCTION

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A more holistic solution to global warming not only includes reductions in energy consumption but sequestration on a massive scale. This paper describes the potential of materials and particularly materials in the built environment to deliver not only greater sequestration but conversion of many wastes to resources, solving two major problems facing the globe today.

All materials are ultimately derived from the bio-geo-sphere. They are everything between the take and waste and are the key to sustainability. The choice of materials for construction controls whole of life cycle impacts such as emissions, gross take, properties of wastes returned to the bio-geo-sphere, use of recycled wastes and their own recylability. Materials also strongly influence lifetime energies, user comfort and durability.

The built environment encompasses the major proportion of all materials flows and is our footprint on the planet. The materials we use strongly influence linkages with the wider bio-geo sphere and must be significantly changed to improve sustainability. An example of such a paradigm technology shift would be to incorporate carbon as a component of durable building materials as well as many other wastes for their physical properties. By making carbon a resource in construction we would be mimicking nature as substantial quantities of carbon were used during previous epochs of global warming to form carbonate sediments, coal and petroleum.

End users would not discern any detrimental changes, architects would have a much wider range of material composites with different properties to select materials from and the process would easily be made economic underpinning the legally imposed cost of carbon by the Kyoto treaty with real economic value.

By making sustainability an economic process then economic forces will be able to be relied upon to deliver the massive sequestration and waste utilisation required to save the planet from further significant climate change.
The TecEco kiln, tec, eco and enviro-cements will have a major role in changing the technical paradigms in the above manner.

KEYWORDS

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

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OVERVIEW

For the last several billion years nature has nurtured the planet evolving complex eco-systems (the biosphere) that conserve and recycle energy and materials.

Much is to be learned from the study of mature climax eco-systems which demonstrate complex web-like integration, conserving energy all of which is ultimately derived from the sun as it flows through the system and materials which are constantly recycled, the waste from one natural metabolism being the input of another.

Plants and animals live together in mutually interdependent ways that become increasingly specialized developing mechanisms for regulation preventing overgrowth or dominance. The wonder of nature is the complexity of this interdependence and how extremely efficient it is at recycling the nutrients essential to life.

Occasional aberrations are triggered climatically, by fire, cataclysmic events or some other way. Species are wiped out (as were the dinosaurs) and new species or groups of species appear to take over. In the past however the biosphere has always come back into to a balance characterized by complexity and integration but this can take thousands and sometimes millions of years.

Along came humans. In the last hundred years or so and for the first time in geological history we have become masters of the destiny of the rather unique blue green planet we live on.

We are like no other cataclysmic event yet we are responsible for many of the changes affecting the geosphere-biosphere from salinity, de-forestation and pollution to the global carbon dioxide balance.

Climate change is the most visible result - storms, droughts, floods and the like are rising in frequency and severity and the consensus is that we are to blame.

In nature climax communities are stable. Our presence on the planet is non-climax, non stable and non sustainable. Driven by our intelligence, greed and arguably, cheap fossil fuel energy and like a new predator before which no living thing can stand we are taking over. We are however the agents of our own eventual doom. We are choking and poisoning ourselves - slowly. It's a bit like the old agar dish experiment from biology at school - remember how it works? You put a spec of bacteria in the middle of a food supply loaded in agar jelly and behold - the bacteria grows in a ring to the edge of the dish dying in the middle as the poisons it has released in its world (the dish) kill it. There is no escape. We are so ignorant that few understand the flows checks and balances vital to the maintenance of the biosphere as a whole. There will be a natural correction. Will it involve our own extinction? Should we wait to find out?

First the village smithy, then James Watt and the steam engine followed by oil, abundant energy and thousands if not millions of innovations later and we have a tiger by the tail called the techno-process. It is bigger than we are, more ubiquitous, far reaching and in its name some five or six hundred billion tonnes of matter is moved about the planet to create the twenty or thirty billion tonnes of new materials we actually use every year.

The tremendous appetite of the techno-process is irreversibly changing the planet. The earth that nurtures us has limits that we have now most certainly exceeded.

Resources are supplied by the geosphere-biosphere one way or another and are not infinite. Needs change and the things we make out of materials wear out. Eventually everything is thrown away. All this activity has an impact on the planet and it seems vital earth systems are unable to cope and are rapidly going out of balance. It appears impossible for humans to correct the problem on such a large scale.

What options does that leave us? Kyoto is a symbolic start but that is all. What does nature teach us?

Economics could perhaps be defined as the set of common behaviors that string together our interactions for survival. It is about the application of resources to needs. Economics drives both the techno-process and nature – both are based on survival but there are some fundamental differences between our techno-process and natural systems. Nature uniquely embraces integration and balance, seen as desirable by economists but unfortunately missing from the techno-process. Economists should study ecology for a few clues about where we are going wrong.

The cataclysmic event in our evolution has been the development of machines energized by fossil fuels. The resulting techno-process is simple, linear, non-integrated and arguably non-climax. Linear systems cannot be balanced because they cannot possibly contribute as much as they take. Climax eco-systems in the biosphere are on the other hand are characterized by complex integration and balance.

Efficiency is important for profit which drives the allocation of resources. Unfortunately we only seem to understand efficiency in a linear sense, not an integrated one. The greatest proponent of efficiency, Henry Ford developed a linear production line to which resources were delivered. There was no concern for resource issues beyond the factory gate – that was somebody else’s problem or nature would provide. Enterprise based efficiency espoused by Henry Ford neglects the value of the natural capital or the planet as a whole.

Climax ecologies are characterized by extremely efficient systems in which all processes are integrated. For example a leaf is technically designed to minimize water loss and maximize photosynthetic production. When the leaf falls to the ground it is eaten by bugs, grubs and bacteria and eventually it provides nutrients for the trees above it in what is a highly efficient process that retains embodied energy from the sun and recycles materials indefinitely.

Liquid and gaseous fossil fuels are now running out and the techno-process cannot continue the way it has in the past. The planet is in crisis. It is time for change so the total net consumption of energy and materials is much less. Can the intelligence of the computer chip provide the connections to close the loops in our linear techno-process, can we invent new materials that do not have such an impact on the planet. Can we live in harmony with the planet? These are the big questions.

The only driving force humans answer to on a large scale is economics, but like a mirror, economics is really only a measurable reflection of how we really are, how we think and act. Economics is the driver of the techno-process. Technology however defines what moves through it and how. In this simple understanding lies the clue. Maybe we can redefine materials so economics drives more sustainable processes? Can we re-invent our physical world? In my view we are going to have to if we want to survive.

Natural climax eco-systems involve conservation of energy and materials, integration and thus recycling and provide the example as to how this could be done.

How can we mimic nature and yet still obey the rules of economics?

Can we harness economic forces to bring about change in what is a linear, substantially un-integrated techno-process1 and develop a more sustainable regional industrial ecology which conserves materials and energy in the system as a whole, to a desirable extent complements nature and that is highly integrated with much more recycling and re-use.

Technology, which primitively used created the industrial revolution and the linear techno-process can be turned to the greater cause of producing an industrial ecology which is integrated and efficient and which has minimal impact on the planet. The need is obvious. Technology is the means. Linked with the will we may yet reduce our footprint on the planet until it is hardly noticeable. As part of this a paradigm shift in the technology underlying materials is required.

The opportunity for change is greatest in the built environment which after all encompasses the greatest materials flows on the planet with the largest take and waste impacts. Taking into account infrastructure governments are uniquely the largest constructors on the planet and have the opportunity, if not the responsibility to encourage and implement new technologies that will make the difference.

Architects engineers and specifiers are uniquely positioned to take advantage of the changes that are occurring and drag the rest of the supply chain into delivering sustainability.

MAJOR THEMES

1. Sustainability is a goal not a benchmark.
2. There is a techno-process describing our activities on the planet of taking resources, manipulating molecules, making new “things”, using these “things” and eventually throwing them “away”.
   A special case of the techno-process is the extraction and burning of fossil fuels.
3. Materials are everything between the take and waste
4. By re-engineering materials we can reduce the volume and impact of the take and waste.
5. The built environment offers enormous opportunities for re-engineering materials and improving sustainability.
6. The only way to make any of the above happen on a global scales is economically

THEME STATEMENT

The technology paradigm defines what is or is not a resource in an economic system that drives materials flows through the techno-process. By harnessing basic human psychology through cultural change to achieve greater demand for sustainable outcomes delivered by evolving and changing techno-processes that sustainably deliver cost effective solutions economics

THE KYOTO TREATY

On the 16th February 2005 the 1997 Kyoto Protocol, drawn up in Kyoto, Japan in 1997 to implement the United Nations Framework Convention for Climate Change, finally became international law.

Signatory countries are legally bound to reduce worldwide emissions of six greenhouse gases (collectively) by an average of 5.2% below their 1990 levels by the period 2008-2012.

For the protocol to become law it needed to be ratified by countries accounting for at least 55% of 1990 carbon dioxide emissions. The key to ratification came when Russia, which accounted for 17% of 1990 emissions, signed up to the agreement on 5th November 2004. Ratification of the agreement means Kyoto will receive support from participating countries that emit 61.6% of carbon dioxide emissions.

Member countries have developed their own methods to meet targets. The EU for example has established quotas and a market to buy and sell credits. Unfortunately however some major emitters have not joined making it difficult for resident companies to trade their credits. The official view in the US and Australia is that it would ruin their economies. The Australian government has developed its own scheme called "The National Greenhouse Strategy" that will attempt to reduce emissions by only 10.1% by 2012, which is an 8% increase on 1990 levels.

It will be a difficult task for most of the member countries to meet their Kyoto targets and already nations are falling behind. Spain and Portugal in the EU were 40.5% above 1990 levels in 2002. Canada, one of the first countries to sign, has increased emissions by 20% since 1990, and they have no clear plan to reach their target. The Japanese are also uncertain about how they will reach their 6% target by 2012.

THE ROLE OF THE CONSTRUCTION INDUSTRY

Under Kyoto member countries have agreed to reduce net emissions. This means that as well as a reduction in emissions there is a role for sequestration. The protocol does not concern wastes but as wastes have

- [1] Take, manipulate use and waste.

embodied energies it is arguable that recycling represents reductions in new energy usage.

Construction is the biggest business on the planet and accounts for some 70% of all materials flows. The construction industry impacts on the wider environment in a number of ways.

A high proportion of pollution incidents occur in the industry. Construction and demolition waste alone represent a high but unknown proportion of total waste. Too many buildings are environmentally inefficient and do not make best use of limited resources such as energy and water. The energy used in constructing, occupying and operating buildings represents a high proportion of all greenhouse gas emissions in industrialized countries2.

The built environment is our footprint on the planet. This paper explains how we can reduce our footprint and profitably make the built environment much more sustainable ensuring our long term survival.

There are a number of opportunities that come to mind:

- Reducing the energy it takes to run buildings (lifetime energy).
- Reducing the high level of waste in construction
- Utilizing wastes to make construction materials
- Reducing emissions during the production of construction materials
- Sequestering carbon by utilizing carbon containing materials
- Using more durable materials for construction

Reducing the Lifetime energy of Buildings

Cites, and the buildings of which they are comprised, consume a large proportion of the total energy produced within developed countries. Much of this energy is derived from fossil fuels that produce emissions. The need to reduce the energy consumed by residential and commercial buildings is now widely recognised. This has been acknowledged by Australian and many other governments and has resulted in strategies intended to increase the efficiency of building construction and operation. I will not go into this area as it is already well understood and the subject matter of many conferences.

Reducing the High Level of Waste in Construction

Waste management in many countries is in a state of anarchy with no effective plan in place to maximize recycling and minimize waste. Statistics are hard to obtain and not collected on a uniform basis. Some countries claim a high proportion of waste recycling but more thorough investigation reveals that this usually only relates to municipal waste which is a low proportion of the total. There is also a growing trade whereby problem wastes not meeting regulatory requirements in one country are exported to another with less stringent requirements.

Building wastes in industrialised countries probably account for 15-40% of all wastes going to landfill. According to Maria Atkinson of the Green Building Council of Australia the figure in Australia is around 40% (Atkinson 2003).

The EU lead the world in improving these appalling statistics. Regulation (EC) No 2150/2002 of the European Parliament on waste statistics was adopted in November 2002 and published in the Official Journal of the European Communities in December 2002. The objective of this Regulation is to establish a framework for the production of European Union-wide statistics on the generation, recovery and disposal of waste.

The high level of waste on building sites can be improved and the main drivers will be cost recovery and changes in construction materials and methods.

There is value in wastes and as recovery methods improve using them as inputs will reduce costs. The use of robotics in construction will allow the exact delivery of the correct amount of material as does an ink jet printer to a sheet of paper, new methods of reinforcing such as the tech tendon method invented by me will reduce cut off and wastage of steel. Eventually, in developed countries at least, buildings will be robotically constructed on site or off site in factories with much less overall wastage. New materials will continue to be invented with next use in mind such as eco-cement concretes that can be recycled back into eco-cements and aggregates.

Utilizing Wastes to Make Construction Materials

Using more supplementary cementitious materials is a major objective of the Portland cement industry and widely documented as such as for example in “The cement sustainability initiative, our agenda for action”(WBCSD 2002). Fly ash (pfa) and ground vitrified blast furnace slag (gbfs) are mainly used and are wastes from other industries. Pfa by itself does not have cementing properties whilst gbfs does.

To the extend to which less PC is required and no further energy is used because of their use they are more sustainable.

- [2] Unfortunately there is a paucity of statistics and it is very hard to compare as measurement criteria vary.

Carbon wastes such as sawdust and timber from construction if taken to landfill eventually becomes methane which is a greenhouse gas 21 times worse than CO2. It would be better to reduce this kind of waste (see Reducing the High Level of Waste in Construction above). As an alternative they could be used to create new building materials that permanently sequester the carbon component. Examples include products made with sawdust/chips and wood waste such as building panels and many sound reflecting or insulating panels. A recent breakthrough has been the invention of tec, enviro and eco-cements by my company which being low alkali reduce reaction problems with organic materials.

Non organic wastes including building materials or other wastes taken to landfill can also be used and the concrete industry is already utilizing high proportions of pozzolanic industrial wastes. Again, TecEco cements contribute by allowing even greater proportions to be used.

Many wastes can contribute physical property values. Take plastics for example which are collectively light in weight, have tensile strength and low conductance. Tec, eco and enviro-cements will allow a wide range of wastes to be used for their physical property rather than chemical composition and as over two tonnes of concrete is produced for every man woman and child on the planet there is huge scope.

Reducing Emissions during the Production of Construction Materials

Building materials use energy during their manufacture and are said to have embodied energy.

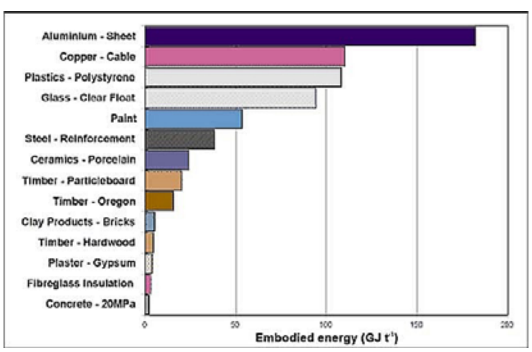

Figure 1 - Embodied Energy of Building Materials (Tucker 2000)

Unfortunately the concept of embodied energy does not include chemical releases of gases as is the case for example with the manufacture of Portland cement.

In almost every industry tremendous savings in the energy required to produce things have resulted in cost savings and greater sustainability

Concrete

As of 2004 some 2 billion tonnes of Portland Cement (OPC) were produced globally (USGS 2004) (see Figure 2), enough to produce over 7 cubic km of concrete per year or over two tonnes or one cubic metre per person on the planet.

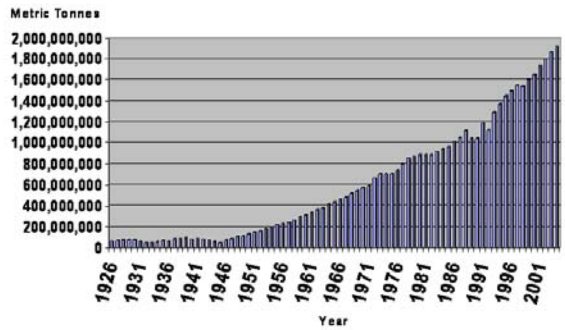

Figure 2 - Cement Production = Carbon Dioxide Emissions from Cement Production 1926-2002 (Van Oss, Hendriks et al. 2003)

As a consequence of the huge volume of Portland cement manufactured, considerable energy is consumed (see Figure 3 - Embodied Energy in Buildings (Tucker 2000)) resulting in CO2 emissions. The gas is also released chemically from the calcination of limestone used in the manufacturing process.

Various figures are given in the literature for the intensity of carbon emission with Portland cement production and these range from 0.74 tonnes CO2 / tonne cement (Hendriks, Worrell et al. 2002) to as high as 1.24 tonne determined by researchers at the Oak Ridge National Laboratories (Wilson 1993) and 1.30 tonne (Tucker 2002). The figure of one tonne of carbon dioxide for every tonne of Portland cement manufactured (Pearce 1997) given by New Scientist Magazine is generally accepted. Production thus equates to emissions (See Figure 2).

Because of the huge volume used, Portland cement concrete is the biggest single contributor to embodied energy in most buildings. As a consequence Portland cement concretes account for more embodied energy than any other material in the construction sector (Tucker 2000).

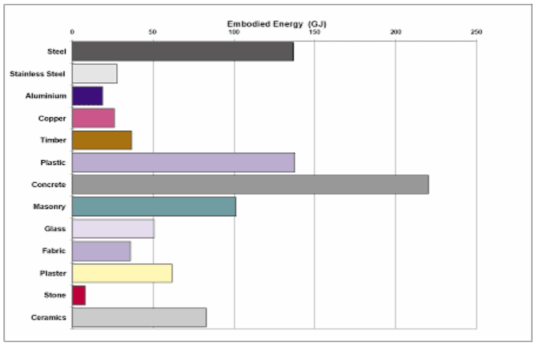

Figure 3 - Embodied Energy in Buildings (Tucker 2000)

Because of the huge quantities made Portland cement is also one the biggest single contributors to the greenhouse effect after the burning of fossil fuels, accounting for between 5% (Hendriks, Worrell et al. 2002) and 10% (Pearce 1997) of global anthropogenic CO2 emissions.

Global production of cement is likely to increase significantly over the coming decades as:

- Global population grows;
- GDP grows3;
- Urban development continues; and
- Industrialisation increases.

Associated with such huge usage and growing demand is the enormous potential for improvement in properties and sustainability.

The challenge is to reduce net embodied energy and chemical releases. One obvious direction is to utilize more renewable energy and especially non carbon cycle renewable energy such as solar and solar derived energy. Another is to eliminate gaseous emissions.

For concrete, the most widely used construction material, future improvements will involve capturing gases during manufacture and this is easiest for a magnesium component as demonstrated by TecEco, my company using kiln technology characterized by calcination and grinding in a closed system and the use of non fossil fuel energy.

Geopolymers are also of relevance as they are essentially made from fly ash and other pozzolans and caustic alkalis. To the extent that fly ash remains a waste they are therefore more sustainable. Unfortunately metakaolins and other kandoxi, also generally required,are not wastes and require energy to make.

Sequestering Carbon by Utilizing Carbon Containing Compounds

During earth's geological history large tonnages of carbon were put away as limestone and other carbonates and as coal and petroleum by the activity of plants and animals.

Sequestering carbon in the built environment mimics nature in that carbon is used in the homes or skeletal structures of most plants and animals.

Carbon can be used as components of building materials in basically two ways:

As a Fiber, Filler or Massing Component

The use of waste organic fibres such as discussed above is becoming increasing popular. For example James Hardie Industries manufacture a product called Villaboard which includes wood fibre. In the US there are currently many papercrete homes being built. Another interesting product is Zelfo which is a plastic like material made from cellulose and potentially from wood waste.

The use of carbon is not limited to cellulose and derivatives. Previously mentioned was the example of plastics and other companies have made use of rubber waste.

As a Binder

The concept of using carbon as a binder is not new. After all ancient and modern carbonating lime mortars are based on this principle. TecEco have now taken the concept a lot further with the development of eco-cement which is based on blending reactive magnesium oxide with other hydraulic cements. Magnesium is a small lightweight atom and the carbonates that form contain proportionally a lot of CO2 and are stronger. The use of eco-cements in construction, particularly in conjunction with the previously mentioned closed system kiln also invented by TecEco would result in sequestration on a massive scale. As Fred Pearce reported in New Scientist Magazine (Pearce 2002), "There is a way to make our city streets as green as the Amazon rainforest".

Getting the Aggregates Right

Lime mortars are actually very common; unfortunately however the sands that are being used are suitable for hydraulic binders not carbonating binders. If the right sands were used additional strength would ensue as the result of proper carbonation. Papers on this subject are available for download from the TecEco web site.

Building using more Durable Materials

[3] Especially in China, India and other so called underdeveloped countries.

Building materials are not as durable as they could be and in the future it would make sense to improve durability, not only because buildings that last longer do not have to be replaced as often, but because if we are to incorporate wastes in building materials the less often they are recycled and these wastes potentially concentrated – the better.

The TecEco cement technology substantially improves the durability of concrete.

Taking Advantage of Kyoto

To take advantage of the trading opportunities offered under Kyoto the construction industry will need to overcome a number of hurdles.

The first hurdle is the conservatism that has plagued the industry for many years. Industry participants will need to embrace new technologies, ideas and performance based standards.

The concrete industry is particularly trapped by tunnel vision resulting in a fixation on Portland cement because of the quirks of history and the fact that it is, relative to what has been previously been available, a good binder (well almost anyway). Participants need to realize they are in the glue business. Organic binders are going out of favour because many such as urea and phenol formaldehyde have been linked to cancer. Pure mineral binders are much safer4. There are a big range of mineral binders as one glance at sedimentary rocks should teach us and many have specific advantages. Industry managers need to understand that what is gray is not necessarily great and all they make will not be what goes out the gate in years to come.

There are strong drivers for change that will need to be embraced. These include robotics, the need to utilize wastes of all kinds, to reduce embodied energies, lifetime energies and emissions and, of course, the Kyoto factor. Many of these drivers will are also supported by sound economics.

If we are to house the world more cheaply and effectively, remembering there are many who still do not have a proper home, then we are going to have to use what is available and cheap locally and wastes are usually inexpensive. In some countries labour will be inexpensive but in others robotics will be required to achieve these goals.

In this new paradigm of robots buildings like the new Eureka building in Melbourne, Australia would go up with a central structural core but all around would be built with robots squeezing out a cementitious composite with a consistency a bit like toothpaste that will be smoothed off with little robo paddles. This technique is being developed by many people all over the world and I suspect the most advanced is Behrokh Khoshnevis at the University of Southern California.

We need to think at the supply and waste end when we design building materials – not just about the materials utility phase in the middle. Making the built environment not only a repository for recyclable resources (referred to as waste) but a huge carbon sink is an alternative that is politically viable as it potentially results in economic benefits.

By including carbon, materials are potentially carbon sinks; by including wastes many impacts at the end of the supply chain are solved.

Toxic and hazardous waste technology and concrete technology will merge because the fact is the standards on risks associated with using wastes and the pressures to do so are both rising rapidly. Even now it no longer makes sense to just encapsulate waste materials in a concrete and bury them. They have to be so safe that we may as well make useful product out of them.

Having said this it is important to remember that the objective is to get CO2 out of the air. To achieve this we really need to support what is an artificial price for carbon introduced by the treaty with a real underlying and hopefully one day dominating value.

We have to find ways to get CO2 out of the air that everybody everywhere uses because they result in tangible economic benefits. We cannot expect people to live more sustainably because it is the right thing to do. If some governments are waiting for a technical revolution the size of the one started by James Watt then they had better stop their procrastination and talk to me because TecEco technology is one of these ways.

TecEco technology will make concretes more sustainable and, as in the long run, sustainability and profit are actually the same direction, there is nothing to fear from them!

Finding 3 under the heading Transport and Urban Design of the recent ISOS conference in Australia applies globally. It stated in part. "…The Federal Government should promote Australian building innovations (e.g. eco-cement) that contribute global solutions towards sustainability; provide more sustainable city innovation R&D funds; and re-direct

- [4] Note however as there have also been some warnings about plasticisers and various other organic additives to concrete. It follows that if you could get to the end result without them is would be better some housing and transport funds towards sustainable cities demonstration projects5."

CONCLUSION

The role of materials for greater sustainability is discussed. A number of ways are suggested to make the construction industry more sustainable including reducing the energy it takes to run buildings (lifetime energy), reducing the high level of waste in construction, utilizing wastes to make construction materials, reducing emissions during the production of building materials, sequestering carbon by utilizing carbon containing materials and building using more durable materials. There are no economic disadvantages of any of these methods and some, such a reducing embodied energies are clearly economic. Underlying all is technological change, particularly in relation to materials.

Materials are the key to sustainability in the built environment and innovative new materials will allow architects and engineers to build structures that have greater value as they are more pleasing to use, live in or look at, healthier for us and much more sustainable.

Huge quantities of materials are used. Their choice profoundly affects many value properties relevant to sustainability including weight, embodied energies, fuel related and chemical emissions, lifetime energies, user comfort and health, use of recycled wastes, durability, recyclability and the properties of wastes returned to the geosphere-biosphere.

A holistic approach to sustainability in which all things possible are done is most likely to work and the built environment offers tremendous opportunities for the cultural and technical changes required.

Exciting new benchmark technologies such tec and eco-cements offer a way forward and of solving the two greatest problems on the planet of global warming and waste.

The direction is clear, technology can help us change the techno process. By doing so the process becomes more economic and thus self propelled with less government intervention.

Technology can make it possible to achieve a far greater measure of sustainability, to economically reduce, re-use and recycle. The potential multipliers from spending on research and development are huge.

As Fred Pearce reported in New Scientist Magazine (Pearce 2002), "There is a way to make our city streets as green as the Amazon rainforest".

- [5] ISOS Conference, 14th November Canberra, ACT, Australia communique downloadable from http://www.isosconference.org.au/entry.html.

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