the NATURAL STEP

Dincel Construction System

An evaluation of its contribution to sustainability

By The Natural Step

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The Natural Step is a non-profit organization founded with the vision of a sustainable society. Our mission is to provide decision makers across the globe with a unifying framework for Strategic Sustainable Development. For two decades, The Natural Step has been at the forefront of international research about strategic sustainable development. We have developed a proven, science based framework that helps decision makers and planners identify the gap to full social and ecological sustainability, envision sustainable solutions to the challenges, and identify strategic paths to a more sustainable future.

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This report is authored by David Cook, Richard Blume and Michael Wzdulski from The Natural Step's office in Stockholm. Enquiries about this report can be directed to *chemicals@thenaturalstep.org*.

Cover photos: courtesy of Dincel Construction System.

Introduction by the Inventor of Dincel Construction System

As a structural engineer with over 30 years' experience, I am well aware of the problems with today's construction materials and practices. I am also aware that the world is changing and it is demanding better performance from us all - more people are living in cities, we face increased environmental pressures from a growing population, and safe, affordable housing is essential to improving the lives of billions of people world-wide.

There has been very little innovation in building materials since the invention of Portland cement in the 1800's. Today, concrete is the most common and abundant construction material, despite its failures and inefficiencies. Its brittle nature requires the addition of steel reinforcement, which gives rise to future problems for long term durability (concrete cancer). Producing steel and cement components is energy intensive, and the formwork used to hold wet concrete until it dries requires labour skills, extended time, and a disproportionate amount of timber that is difficult to recycle. Concrete is also porous and requires the introduction of flexible polymer membranes where waterproofing is needed, such as in basements, tanks etc. along with higher levels of cement in the concrete to help protect the steel reinforcement.

When considering the importance of urbanised multi-level apartments in terms of global affordable housing, addressing any limitations in conventional construction systems is crucial. The world's earthquake authorities now recognise that the commonly-used concrete column-slab structural frame, incorporating masonry infill walls, is the most inefficient and in fact dangerous form of construction. This is due to falling masonry walls that cause injuries and fatalities in the event of natural disasters including earthquakes.

Given these challenges, I set out to find a completely different way of constructing buildings. I was looking for ways to maximize the benefits and remove the handicaps of the predominant building materials and construction practices, while maintaining or adding functional advantages. The most important breakthrough I made is in thinking of a building structure as a composite material. By using a polymer to encase the concrete structure, a number of material and construction efficiencies can be made. These include:

- Reductions in cement (40%) and steel (90%) required to build a typical urban multi-level apartment building
- Elimination of timber formwork

- Waterproofing (tested under 6m of water head pressure and certified as waterproof by CSIRO Australia, a worldwide respected government testing authority)
- Maintenance free structures that have increased strength against natural disasters such as flooding, hurricanes and earthquakes (tests by the University of Technology, Sydney, Australia demonstrate an increase in ductility and resiliency behaviour qualifying for magnitude 9 earthquake resistance)
- Faster speed of construction
- Significant improvements in personnel safety during construction
- Building longevity using the unique properties and durability of the composite materials.

It is my belief that the economic cost savings (up to 40% on Australian calculations) offer an affordable solution for providing safe, multi-level dwellings on a global scale and that the technical, social and environmental benefits resulting from these improvements are significant and wide-ranging.

In my investigation I discovered that rigid PVC was today's best choice for the polymer. It is far superior to other polymers in terms of fire properties, and also provides high rigidity and resistance to creep, combined with excellent chemical resistance. Recognizing that the PVC formulation was critical to addressing environmental concerns, I partnered with Chemson Polymer AG to test and refine a winning approach which has been verified by a number of independent studies.

Dincel Construction System is the result of my exploration of these matters over the last 10 years. I am convinced that this innovation can make a significant contribution to global society. For this reason, together with Chemson Polymer AG, we have engaged The Natural Step, a globally respected NGO committed to sustainable development to review our work and provide their opinion.

Burak Dincel, Structural & Civil Engineer
BE MEngSc MIEAust CPEng RPEQ RBPEng NPER

Executive Summary

The conclusion of this study by The Natural Step is that the Dincel Construction System (DCS) offers significant and compelling sustainability advantages for the construction industry. It has benefits over traditional building technologies, and is proven to work in practice. It represents a clear step forward in applying a more sustainable method for one aspect of construction - the building of load-bearing walls - which is found wherever there is a new development.

Given the scale at which global society needs to build new affordable housing, and major urban infrastructures, DCS comes as a very positive innovation. We see no reason why it should not be applied on a global scale provided that the same quality standards are applied.

It results in less energy and raw material being embedded in a new building, particularly through reducing concrete and steel quantities. We have not evaluated those materials in the same depth but all the indications are that DCS will overall use significantly less energy input and fewer raw materials than the concrete or steel reinforcement that it is replacing – a net gain for the environment. It should also mean that no timber is used as formwork for construction of concrete walls and columns. The waste of timber on construction sites is a major inefficiency found almost everywhere, which can be eliminated by the use of DCS.

DCS also offers a range of functional improvements and social benefits over alternative materials and construction techniques. For example, construction safety, economic efficiency, increased lifespan, and reduced asset management during the lifespan, of a building structure. Issues such as concrete cancer, which plague the construction industry and reduces the long term durability of each building, are essentially eliminated using DCS.

There are clear opportunities for DCS to be used in a wide range of applications that meaningfully contribute to sustainable development throughout society. These include the safe and affordable construction of high-rise buildings, submerged tanks and waterproof structures, and grain and water storage facilities. We also see particularly strong benefits in using DCS for the construction of low-cost, earthquake resistant buildings.

As with any material it is the standards applied to sourcing, manufacture, installation, use and post-use that will determine how well DCS contributes to sustainable development. This is particularly true given that DCS relies on PVC – a material that has attracted controversy over the years and which has a particular set of sustainability challenges. It needs to be noted that because of its properties, including durability, PVC lends itself well to this type of application. As well as providing crucial technical properties for the building, it also provides long-term durability (possibly at least 100 years) and the potential for 100% end-of-life resource recovery.

The Natural Step has previously identified a set of overarching challenges and main concerns for generic PVC (commonly available PVC) that need to be overcome in order for it to contribute to sustainability. These are being addressed by DCS in the following way:

- Closed loop application – DCS relies on a zero waste manufacturing process where off-cuts and cut-outs are recombined in a continuous extrusion flow. On-site construction waste is significantly minimised due to supply of exact lengths. At end of the building lifespan, 100% resource recovery is possible from separation of PVC polymer, steel and concrete.
- The DCS PVC formulation used in Australia consists of very low VCM, is classed as 'low VOC by Australian standards (below detection limit) and is derived from ethylene (not carbide).
- The formulation contains no plasticisers and no heavy metal stabilisers.
- Concern for the production of dioxins is addressed at end of the building life with an ambition for 100% recycling rather than PVC incineration.
- In the event of a building fire, independent testing has shown the formulation meets a Group 1 material category with smoke criterion 2.5 times less than the Building Code of Australia's threshold.

These factors should help to clearly differentiate the Dincel formulation from generic PVC. Notwithstanding the above points, care and further work need to be undertaken to: 1) clearly communicate an appreciation of the sustainability challenges that attach to PVC in general and differentiate DCS in that context from the debate 2) address the challenges that are specific to DCS production and use.

We make the following recommendations for DCS to promote and improve its contribution to sustainability:

Communication and stakeholder engagement

1. The DCS sustainability contribution needs to be communicated transparently and in a credible, science-based way to show its benefits while acknowledging generic concerns attached to PVC and demonstrating how they have been addressed.

2. DCS should be the subject of communication and consultation with stakeholders. Such a process should focus on objectives for sustainable construction that aligns with the four TNS system conditions for a sustainable society, seek views on steps that can be taken to improve and allow DCS to be presented and assessed as a step toward those aspirations.

Material Inputs

3. While DCS offers the potential for significant climate change (energy) savings, the reliance on fossil hydrocarbon feedstock is an area that cannot be ignored. A number of measures are suggested.

4. The additives reviewed in this study are an integral part of the DCS PVC formulation and its sustainability contribution. We recommend the formulation be retained as we believe DCS does not stand-up to sustainability scrutiny as well as we have found if more traditional additives are used.

5. The potential for using recycled PVC in the production of DCS should continue to be investigated.

Supply Chain

6. DCS needs to ensure that its suppliers live up to the sustainability ambition through Supplier Sustainability Policies.

7. The risks of dioxin generation in PVC manufacture should be addressed by always ensuring suppliers are using best practice production techniques.

8. Sourcing of titanium – a small component of the DCS PVC formulation - needs to be investigated to understand environmental impacts and any hidden risks in the supply chain. It may be possible for DCS to avoid the use of titanium altogether, and that should be investigated further.

Use and end of life

9. While DCS meets Australia's stringent building codes, the reaction of DCS structures in a large scale urban fire needs more investigation. This is particularly important to address stakeholder concerns about PVC incineration.

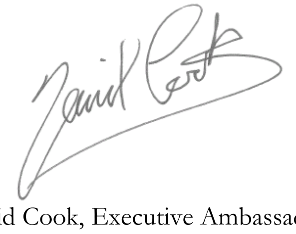
10. While DCS offers the potential for 100% resource recovery, DCS needs to create a clear plan for dealing with DCS-based structures at the end of life, including an auditable system.

Areas for further assessment

11. DCS benefits over competing techniques – for example advantages over concrete and steel - need to be verified in more depth if those advantage are to be used widely. Such comparative studies should be based on the TNS system conditions and apply precisely the same sustainability criteria to provide consistency in benchmarking.

12. We recommend that the overview Sustainability Life Cycle Assessment conducted as part of this study be reviewed and plans be developed to support continual improvement of DCS across its entire life cycle.

13. The implications of DCS eliminating timber in construction formwork should be further investigated to understand the scale of environmental gains possible on a global scale.



David Cook, Executive Ambassador
The Natural Step International

Richard Blume, Senior Advisor
The Natural Step International

About this study

Introduction

This study has been commissioned by Chemson Polymer-Additive AG in collaboration with Dincel Construction System Pty Ltd to evaluate the sustainability contribution of the Dincel Construction System (DCS). DCS is a patented, rigid PVC polymer permanent formwork used to construct concrete buildings. It has been developed and commercialized in Australia with international expansion now planned. The Natural Step was asked to apply its science-based approach to sustainability as a lens for the evaluation. Extensive technical and performance-related studies have already been conducted during the commercialization of DCS and this evaluation relies on them as background information. We have added our sustainability experience, perspectives and methods to give a qualitative viewpoint on DCS sustainability potential and areas for improvement.

Aims and objectives

The proponents of DCS seek to have its credentials reviewed by an external party in order to improve the system where needed, and assist with its promotion. As an NGO dedicated to sustainability, The Natural Step has agreed to undertake the study to examine the sustainability potential of DCS –both risks and opportunities in the short and long term - from a global societal perspective. The desired outcome from the study is a clear and comprehensive statement of the sustainable development contribution possible from DCS including any challenges that need to be overcome. It is envisaged that the findings of this study will be of interest to developers, planners and architects, construction companies, material suppliers and policy-makers.

Approach to the study

The study was conducted between April – September 2012 and involved review of background information such as DCS marketing material and technical reports, followed by interviews and dialogue with the proponents of DCS, with further research where needed.

We have applied the internationally recognized "Framework for Strategic Sustainable Development" promoted by The Natural Step NGO as the foundation for this commentary and drawn on our experience and knowledge of applying it in the chemical and construction industries. A related Sustainability Life Cycle Assessment (SLCA) process was used to look closer at the life cycle of the product system to scan for key issues (see Appendix).

The Framework for Strategic Sustainable Development is an openly published framework for sustainability planning. It includes a peer-reviewed definition of sustainability that includes the following four principles:

In a sustainable society, nature is not subject to systematically increasing...

1. ...concentrations of substances extracted from the earth's crust;
2. ...concentrations of substances produced by society;
3. ...degradation by physical means;

and, in that society...

4. ...people are not subject to conditions that systematically undermine their capacity to meet their needs.

The framework relies on some key assumptions that should be kept in mind when reading this study:

- Sustainability can be defined in scientific terms using the above-mentioned sustainability principles as success criteria.
- Today's products and processes can be evaluated using a gap analysis in relation to those principles for success. This shifts the focus away from studying current problems and incremental improvements to designing for sustainability.
- New innovations and their alternatives can be judged as steps toward alignment with sustainability principles if a full account of the product or service life cycle and wider effects is made.
- When evaluating alternatives, the innovations with the best sustainability potential are not necessarily those with just the lowest footprint today. One must also look at enabling potential and room for improvement as society and technology develop.

For more information visit *www.thenaturalstep.org/our-approach* or *http://www.thenaturalstep.org/slca*

Relevance - Buildings, construction and sustainability

The human population continues to grow, and with it the trend toward increasing urbanization, such that the need for affordable housing and urban infrastructure is of greater importance than ever before. At the same time we are increasingly aware that using more physical resources increases the damaging impact upon the environment and consequently upon society. To meet the need for more buildings in sustainable ways is therefore a considerable challenge.

The predominant building materials and construction approach of today – namely cement-based construction– is known to have a significant contribution to climate change[*], among environmental impacts. As a consequence there is a growing focus on building materials and construction techniques, as evidenced by rating systems such as Green Star, LEED, and BREAM etc. Those responsible for procuring construction projects now face a plethora of sustainability claims from

[*]The cement industry contributes approximately 5% of global CO2 emissions produced by society while the embodied energy of steel used in buildings plays the most significant role in the overall energy intensity of a reinforced concrete building by a factor of 50.

material producers, all competing to claim "green credentials" for their products. Whilst that trend is welcome it also means that we need credible and rigorous evaluations of products with some consistency and stronger sustainability foundations.

Of course there is never just one answer to these issues. We will continue to need a wide range of materials to suit different geographical contexts and cultures. And different regions are at different points along the route to prioritizing sustainable development. Nevertheless we have no time to lose in promoting smarter sustainability choices and helping that mind-set – "how do I get the best from this material in terms of both economic and environmental efficiency"–to become the norm.

In short, there is a clear need and growing focus on improvements in current approaches to construction techniques and material choices. The study and evaluation of sustainable construction materials and methods is therefore of global relevance.

Overview of the Dincel Construction System

What is it?

DCS is a rigid polymer formwork designed for construction of load bearing walls and columns. It was designed in 2001 as an innovative alternative to existing construction techniques that have undergone little or no significant development since they were introduced.

The first DCS prototype was built and sold in August 2006. Iterative testing and development has been done in close partnership with Chemson Asia-Pacific. Universities and national research bodies have been involved in the study of DCS performance characteristics (for details see *http://www.dincelconstructionsystem.com/*).

Today, the waterproof DCS profiles are produced in custom size (per order length) and varying thickness. The polymer formwork module is assembled piece-by-piece, reinforced with steel only where structural shear and flexural actions are required (90% concrete load bearing walls can be unreinforced when DCS is used). It is then filled with concrete to form a load-bearing wall.

DCS is currently commercial and applied only in Australia, with international expansion being planned.

How does it differ / compare to today's alternatives?

The alternative methods for constructing load bearing walls and columns are mainly clay, brick veneer, pre-cast and tilt-up concrete and in-situ concrete. The DCS patent differs in several aspects;

i) It utilizes a polymer formwork to support to the load-bearing structure, resulting in less concrete and steel reinforcement used in the construction, including floor slabs. The choice of polymer is a specific, proprietary formulation of PVC that has been optimized for this construction application.
ii) The formwork is permanent and eliminates the need for temporary timber formwork.
iii) It is light and has a wide applicability range, including applications such as buildings, sea walls, storage tanks (including water, oil, and grain), flood levees, noise barriers and environmental protection walls.
iv) It lowers construction and maintenance costs due to less time being spent in construction, and through elimination of concrete cancer and steel corrosion via encapsulation in the waterproof polymer formwork.
v) DCS requires less labour and lessens dependency on highly skilled craftsmen in assembly. Onsite safety risks are also reduced as a consequence.

vi) By using less concrete and steel reinforcement than a conventional built load bearing structure, less energy and resources are consumed in terms of the afore mentioned materials, resulting in building with a lower embodied energy input.

At first read, DCS promises to deliver a lot of benefits over today's standard practices. However, to be seen as a sustainable development innovation, there are a number of other aspects that need to be investigated, and that is the aim of this assessment by The Natural Step.

Key Materials used in DCS

The DCS polymer formwork is made up of 3 main material components:

i) bulk PVC resin of a desired quality standard:
ii) additives to the PVC resin to achieve desired performance attributes
iii) calcium carbonate filler to complete the formulation.

Steel and concrete are then used (in lesser amounts than in conventional construction) in combination with the DCS formwork to complete the building structure.

The sustainability assessment of DCS therefore focusses on both the use of PVC, its formulation and supply chain etc. and the resultant substitution or dematerialization of other materials such as steel, concrete and timber formwork.

Polymer-encased concrete explained

Composites - a revolution in building materials?

At a conceptual level, we think the use of a plastic polymer to encase concrete is worth exploring further before commenting specifically on the choice and implications of using PVC. From dialogue with the inventor of DCS we understand that the polymer and concrete are acting together as a composite material. We also understand that this is not a solution proposed by the PVC industry but by a structural engineer seeking solutions to problems with conventional reinforced concrete construction materials. Namely:

- Concrete is a brittle material that performs well in compression but not in tension. Hence to limit cracking and retain the integrity of the concrete, steel reinforcing is introduced.
- Steel addresses the performance deficit of concrete but introduces a new challenge. Steel corrodes and despite being embedded in the concrete structure, the porous nature of concrete means that it will eventually be exposed to the elements. Concrete spalling and loss of structural integrity will eventually result as the steel corrodes. This 'concrete cancer' is the single biggest limiting factor on the lifespan of a concrete structure.
- To counter this deficit and improve the life span, engineering design requires significantly higher strength and thicker concrete than would otherwise be warranted.

Encasing the concrete in a polymer sheath approaches these challenges from a different angle:

- It means the elastic properties of a polymer both enhance and substitute for the ductility of steel reinforcing. As the concrete is permanently encased in the formwork, it also means that controlled shrinkage and temperature cracking occurs at the in-built crack inducers of each Dincel panel, thereby eliminating the need for wall joints as well as crack control steel required in concrete walls. Consequently the amount of steel can be reduced by up to 90% for 90% of a typical apartment building walls
- It essentially water-proofs the structure, meaning that any remaining steel is protected indefinitely. Consequently, the building life span can be prolonged (and new types of applications are also possible).
- The cement content of concrete can be dramatically reduced without compromising structural performance. This also opens up new possibilities for concrete replacement with non-conventional and / or recycled materials.
- It also begins to introduce additional functional benefits such as the polymer formwork protecting building occupants from collapsing walls in the event of an earthquake.

For a polymer to be approved for use in building structures it must meet building code requirements for flammability and smoke generation in the event of a fire. DCS has far exceeded the Australian building code requirements which are amongst the most stringent within the construction world. We also understand that this is one of the primary reasons why PVC was chosen in the Dincel Construction System. When longevity, lower cost and fire resistance factors are combined it outperforms any current alternatives.

Benefits claimed by DCS over current practices.

The DCS composite material approach delivers a number of other benefits over current practices. We have not sought to verify all of these benefits and present them here as explained in DCS factsheets and promotional materials:

On-site construction benefits

- Significantly more cost effective and faster.
- Light and easy to be installed by non-skilled labour
- Easily handled by hand, no cranage and provides a solution to access problems.
- Improves work place safety and eliminates the need for scaffolding which can result in significant reductions in constructions accidents.

Building and material performance benefits

- Verified to be waterproof.
- No water damage, damp proof, rot proof.
- No crack, no joint, no concrete cancer.
- Better quality concrete; increased concrete flowability, no air voids, honeycombing or segregation.
- Minimum 100 years life even in salinity and acidic conditions.
- No thermal bridging.
- Termite proof, VOC free.
- Vapour barriers on both faces.
- Stray current protection.
- Mine subsidence areas, steep sites and flood affected land.
- Does not support condensation, mould, mildew and fungus growth.
- Increase in strength against natural disasters such as flooding, hurricanes and earthquakes(tests by University of Technology Sydney Australia demonstrates increase in ductility and resiliency behaviour qualifying for magnitude 9 earthquake resistance)

Design and building innovation potential

- Ready finish.
- Flexible for building curve, arch, wave, circle shaped walls.
- Allows any building dimensions in increments of 50 mm (2 inches). In building interiors where waterproofing not required profiles can be cut to suit any dimension.

Reduced Environmental footprint

- Reduces cement (50% cement replacement has already been used in major Australian buildings with successful trials of 70% cement replacement)
- Reduces steel (Dincel load bearing wall as structural system also significantly reduces steel reinforcement usage in floor slabs as well in comparison to conventional frame systems); significant reduction in embodied energy use leading to significantly less CO2 production.
- Because it is waterproof, Dincel polymer formwork allows for a concrete grade of less than 20 Mpa strength (Australian coastal area durability requirement is for 40 Mpa grade concrete). This will also result in less cement content and the potential use of corals, shale, coal, fly ash, industrial waste, recycled concrete as aggregates in structural concrete making, i.e. much cheaper concrete.
- Elimination of timber formwork results in less resource consumption.
- DCS polymer being VOC free and waterproof, joint free offer solution for indoor air quality, sick building syndrome.
- The minimum life of 100 years in construction offered by DCS is a major step for sustainability.
- Manufacturing is highly efficient using a polymer extrusion process that allows cut-outs to be fed back into the production process, leading to almost zero PVC waste.
- DCS currently achieves 90 % reduction in construction waste associated with the structural components, as DCS is made to order.
- Even with today's technology it offers the potential for 100 % recyclability for PVC, concrete and steel.

PVC as a structural building material?

The DCS invention appears to be one of the first attempts to apply a PVC polymer as an actual structural building material so one could expect that widespread adoption of DCS would result in an expansion of the PVC industry in this segment. The sustainability attributes and issues associated with PVC are therefore of direct relevance to DCS and its proponents should be fully aware of these issues when promoting the DCS invention.

The PVC and sustainability debate

The social and environmental effects of PVC are still heavily debated and there are widely differing views on its use in society amongst stakeholder groups and in different parts of the world. We therefore wish to summarize our views on PVC in general. The implications for DCS are then discussed.

Can PVC play a role in a sustainable society?–PVC, in general, has been heavily opposed by many who regard it as inherently harmful to the environment and / or to human health. In previous assessments we have used The Natural Step Framework for Strategic Sustainable Development to build consensus on current challenges for PVC and explore its overall sustainability potential. We have asked the question *does PVC have a role in a sustainable society?* And our answer is yes - *if* a range of sustainability challenges can be overcome (see details of the challenges below and refer to *PVC and Sustainability: An Evaluation using The Natural Step Framework* for further information)†.

The potential - why does PVC matter? - It is important that the sustainability challenges of PVC are acknowledged and addressed as a matter of priority simply because it is so widely used. PVC is found in countless applications throughout society and even if one wished to, replacing it overnight seems unlikely. There is also no guarantee that alternatives will perform better and they need to be assessed just as rigorously to avoid substituting one set of problems for another. It is also true that PVC has some specific attributes that could usefully be exploited to contribute to sustainable development under certain circumstances. The PVC polymer is cheap, easy to produce, lightweight, strong, durable, inherently flame resistant, has potential to be recycled, and has an inert matrix as its base.

† This work continues as the European PVC industry has scrutinized and adopted the essence of these challenges in its recently launched 10 year voluntary commitment to sustainable development. See *www.vinylplus.eu* or *http://www.naturalstep.org/en/vinylplus-european-pvc-industrys-voluntary-commitment-sustainable-development* for more information.

PVC (and everything else) needs to be used appropriately - Every material has its sustainability challenges, so wise management practices are needed when deciding when and where it is appropriate for use. For some types of application, PVC shows promise while there are other cases where certain PVC formulations should be phased out. For long-life infrastructure society needs durable and subsequently reusable or recyclable materials. Pipes used for clean water supply, and construction materials such as window frames are good examples where rigid PVC can perform better than alternatives from many perspectives (long life span, requires little additional chemical and energy inputs from maintenance, and if recycled, PVC is also likely to have less harmful impact on the environment). In this type of application, the properties of PVC that enable recycling add to its sustainability potential.

Different PVC formulations = different issues – As with all materials there are challenges that arise from the composition of raw materials, and others that stem from the way society makes, uses and disposes of the material. It should also be said that it is not correct to look at PVC as one material. While the PVC molecule itself is always the same, the PVC-based formulations that are used in products can be varied in thousands of ways depending on the additives used to achieve specific properties (e.g. colour, rigidity etc.); these additives may constitute as much as 50% of the mass of some PVC applications. Furthermore, there are different methods of production of the PVC molecule itself which have different 'footprints' (primarily ethylene-based production vs. acetylene-based production, though manufacturing efficiency also varies). The same applies for additives included in a PVC formulation. It would be correct to say that there are 'better' and 'worse' PVC compounds and production processes, and this can be said about most, if not all, materials. The relevant question is under which conditions can PVC be produced, used and managed sustainably?

Today's PVC challenges are not impossible to overcome – Our prior studies and involvement in the PVC and sustainability debate lead us to believe that while the PVC industry faces some significant challenges, they are not impossible to overcome and there is growing momentum for change in the industry. As we are dealing with a material that is ubiquitous and already providing a range of sustainability benefits in many of its common uses, it is important that progress is accelerated through best practice and new innovations. Society needs the PVC industry to make progress, focus on the most appropriate uses, develop alternatives and deal with the challenges of today.

Summary of overall challenges for PVC

The main sustainability challenges for PVC in general have been previously and extensively investigated. For PVC to be used in accordance with sustainability principles the following issues need to be dealt with:

Controlled-loop systems

PVC needs to be produced, used and re-used in controlled-loop systems. This basically means using production, installation and recovery methods that allow for zero emissions of harmful substances, and no waste. It includes recycling and reuse technologies and infrastructure.

Persistent Organic Pollutants

Emissions of persistent organic compounds need to be eliminated from the full life-cycle of PVC. This is one of the more controversial aspects of the material. It arises because the raw materials include chlorine, and many believe that chlorine chemistry will always be bad for the environment. However the industry in some regions has made progress in eliminating emissions of organ-chlorines in manufacturing. And improved reuse and recycling infrastructure can potentially eliminate them from the rest of the life-cycle.

Additives

There are also various additives put into PVC and its products, which can have diverse human health and environmental impacts. This is another controversial area. Each additive has a unique footprint that should be evaluated with care. Additives still used in some parts of the world are banned by legislation in others. Acceptable alternatives are available and more are being developed rapidly. Additives should be either removed completely or substituted with benign alternatives which do not accumulate in nature or do not have significant toxicity impacts for people or other organisms. They also need to aid rather than hinder recycling. There are signs of good progress on this topic.

Climate change and energy

The production and use of PVC products also needs to be done with much less climate change impact and more energy efficiency. And that includes thinking strategically about the choice of basic raw materials. Because of the myriad of sourcing impacts, its non-renewable nature and consequent economic and socio-geopolitical concerns from 'Peak Oil', using oil or gas as one of the two building blocks of the material needs to be challenged and alternatives thoroughly assessed for their own sustainability quotient. That will include looking at so-called "bio-based" feed-stocks. Once again we know that is happening and we can confidently expect more progress.

PVC-related implications for DCS

The above-mentioned sustainability issues associated with PVC have implications for the DCS which cannot be ignored. The implications are as follows:

i) The overall sustainability challenges for PVC in general, as outlined above, must be clearly acknowledged and adequately addressed by DCS if DCS is to be communicated as a sustainability innovation (we interpret what these challenges mean for DCS in the next section of this report).

ii) We note positively that the performance characteristics of a rigid PVC polymer formulation, particularly its durability and recyclability, mean that it is well suited to being used as a structural formwork in buildings. DCS therefore has the potential to be a good case demonstrating appropriate use of PVC. Provided all issues are addressed and necessary safeguards are in place, this particular application of PVC offers enormous societal benefits by revolutionizing the predominant construction technique.

iii) The PVC formulation matters and any adjustment to it could dramatically alter its sustainability quotient, for example by introducing either 'good' or 'bad' additives.

iv) Clearly the right management practices need to be in place to uphold standards and ensure that DCS is used under controlled circumstances. There would be significant sustainability and business risks if a similar PVC-based construction system of lower quality were to become widespread. This point should be dealt with upfront by the innovators of DCS.

Sustainability issues and considerations for DCS

Overview

We have summarized a set of key sustainability issues and considerations that the proponents of DCS should consider when improving and promoting its sustainability contribution. The summary is drawn from two key sources:

1. Our knowledge and prior study of PVC and sustainability-related issues, as summarized in the previous section.
2. A closer review of the DCS product life cycle using a process called Sustainability Life Cycle Assessment (SLCA). This draws upon a desktop study of background documentation provided to us and specific requests for information. See Appendix for details.

Benefits derived from the specific DCS PVC formulation

Given the controversy that has surrounded PVC, the justification for using it must be made clearer. Apart from low cost, durability and recyclability advantages, we see that this particular DCS PVC formulation addresses the generic concerns with PVC and offers the following benefits when used as a construction material:

- → It is does not contain phthalates.
- → It does not contain heavy metal stabilizers.
- → It achieves a Group 1 fire rating under the Building Code of Australia.
- → It generates much less smoke (2.5 times less smoke than the threshold of Building Code of Australia) than other materials in the case of fire.

These are clear areas where DCS can differentiate from the general debate on PVC and demonstrate a formulation that is more suitable as a structural building material.

Commentary on Key Issues

The intrinsic hazard and exposure risks associated with chlorine chemistry

Using a PVC formulation of any kind relies on chlorine chemistry. Chlorine is a hazardous material, though it occurs in great abundance in nature and has been used for many human needs purposes for over a century. It is highly toxic to living organisms and its use introduces an intrinsic hazard that has implications throughout the life cycle. The hazard typically becomes a potential risk to people and planet at two particular points in the PVC life-cycle - in manufacturing and distribution, and again at end of life with the main focus being upon dioxin emissions. Dioxins are a naturally–occurring, and very risky substance with serious human consequences, not to mention environmental degradation[‡].

Manufacturing and distribution - Emission or leakage of chlorine or its derivatives is being tackled by the industry, particularly in Europe. Membrane technology in manufacturing, which significantly reduces the risk, is now more than 50% of the production plants in Europe. Diaphragm and mercury technologies are being phased-out. Similarly there are now very strong rules and standards in the transport of the substance in its hazardous state. Where these practices are in place the occurrence of leakages or spills has been reduced almost to zero.

For DCS, the supply chain risks need to be investigated to ensure best practices are in place.

The production of both steel and to a lesser extent cement, also have a dioxin hazard which, where measured, is recorded as considerably greater than PVC. Reliable global data is hard to find but a comparison of the total DCS package (with reduced cement and steel content) and the traditional methods of using cement and steel would be warranted. The aim would be to assess both dioxin risk as well as other aspects such as embodied energy[§].

End of life - At end of life the chlorine content of PVC is linked to risk of dioxin emissions, since today's disposal practices invariably involve incineration, both planned and unplanned. Applying current best practice to incineration of materials containing PVC at end of life, and increasing the recycling of the material, almost certainly eliminates the risk. However, that technology is not available everywhere.

This emphasizes the importance of thinking now about the way in which DCS structures will be dealt with when buildings are demolished, particularly in different markets. It is necessary to establish now, in consultation with others, a set of standards for dealing with this end-of-life issue.

Equally the efficiency and spread of PVC recycling is a long way from being good enough to eliminate the problems of unregulated burning, be it on beaches in industrializing regions such as in Africa to extract the copper from waste cables, or backyard burning in the US. It is however highly unlikely that DCS structures will find themselves in that kind of situation. It is our conclusion that these problems, whilst very real for PVC in other uses, are manageable and unlikely to affect DCS.

DCS inventors recognise the above facts and as result DCS has been designed to allow at least 90% building walls to be recycled at the end of building life. The DCS system consumes 100% of its own

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[‡] See effects of dioxins here: *http://www.who.int/mediacentre/factsheets/fs225/en/*

[§] DCS Embodied Energy article, as peer reviewed by University of Swinburne – Australia, demonstrates that by reducing steel (90%) and cement (40%), in DCS construction the production of dioxins is significantly reduced in comparison to conventional reinforced concrete slab construction.

waste during production, and can incorporate recyclable PVC waste in its own production, when commercially available at the right quality. This removes the risk of production waste ending up in uncontrolled incineration hence production of dioxins.

Reliance on fossil hydro-carbons as a primary feedstock

The main supply of raw material comes from oil and that is problematic for several reasons (link to climate change, pollution, price volatility, impacts on eco-systems and conflict over sources of supply). The chemicals industry uses a relatively small proportion of the oil currently being drilled and refined, yet it is totally dependent upon that proportion. Little significant progress has been made on alternatives in bulk terms. We know of many initiatives to create bio-mass supply and some of these are going to be successful, but still on a fairly small scale. PVC uses comparatively large amounts of hydro-carbons in its composition as well as the energy used by the industry. Given this situation some mitigating measures need to be addressed by DCS. These are outlined in our recommendations.

The development and selection of benign additives

We believe that sustainable alternatives for additives can be developed and are being developed in various innovative ways across the industry. The pace of replacing known or suspected problematic additives is less than we would like and resistance to change is still strong in parts of the industry. Yet, as with so many breakthroughs to this kind of problem, a few pioneers are researching and addressing this very seriously and they will likely become market leaders. DCS offers an excellent example where a supply chain partnership has resulted in the development of an additive that is much closer to matching sustainability criteria than more traditional approaches. That is a real success story, reflected in the close partnership between Dincel and Chemson. We have detected nothing in the OBS stabilizer package from Chemson that gives concern. That is a breakthrough and clear marker for sustainable development in this industry.

Fire hazard during use phase

As noted above, DCS has demonstrated compliance with building code requirements in terms of smoke development. This is otherwise a problem with commonly used PVC in terms of potential release of dangerous substances when PVC is incinerated. Whilst modern best-practice can deal with many of those concerns, vigilance in dealing with risk from accidental fires is still needed.

This is particularly important in the building industry and for DCS. When PVC is used in buildings on a significant scale we can be sure that an accidental fire will occur somewhere, sometime including burning structures where DCS is installed. Uncontrolled burning could lead to a release of hydrogen chloride and traces of highly toxic dioxins. The science of this effect is not conclusive. The ratio of chlorine quantity to dioxin release is not apparently straightforward. Much depends upon the temperatures reached and the presence of other combustible materials. More research is needed .There is little reliable evidence, for example, concerning human health impacts for people exposed to accidental fires where PVC is present.

DCS has tackled this aspect positively. According to CSIRO- Australia test results of DCS qualified it as a Group 1 Material of Building Code of Australia which means that neither smoke release nor flammability are classed as issues of concern with this technology. In spite of that, the innovators of DCS need to remain aware of the chemical issues of accidental building fires in the overall assessment of the sustainability of the DCS buildings and keep up to date with ongoing research..

PVC actually has some advantages in the case of fire that need to be more widely acknowledged. It does not burn itself, but chars and will be extinguished if left alone without other materials. Consequently, for DCS, its ability to prevent or prolong structural integrity (by encasing the concrete structure and preventing spalling) should be viewed positively.

At the time of writing we have not examined in detail the flame retardant mixture supplied for DCS. At first sight however it appears to offer the following significant advantages from a sustainability perspective:

- To be well within approved limits for ignition, flame and smoke resistances (verified to Australian standards by CSIRO).
- It uses a new formulation of metals avoiding the human health and environmental risks known to be associated with traditional fire retardants.

Recycling infrastructure for closing the resource loop

End of life treatment has already been highlighted as a relevant issue in managing risks associated with chlorine chemistry. However, it is also relevant in a few other regards such as carbon balance, resource efficiency and waste management. For a long-life asset such as a building, these issues may seem well into the future. It is nevertheless critical from a sustainability perspective, that building materials and construction techniques are selected and applied from the outset with resource recovery in mind. This means ensuring the PVC formulation allows for reuse and supporting the development of the infrastructure for end of life treatment where such infrastructure is lacking. Having an answer to these questions will certainly help promote DCS as a well-thought through intergenerational solution.

Achieving excellence in sustainable operations

If DCS is being promoted as a sustainability innovation its proponents will be scrutinised by stakeholders through that lens. The proponent's sustainability profile and commitment is therefore relevant. 'Walking the talk' at production facilities is a particular area where close attention should be given, as here is where direct control exists and where a number of traditional environmental, health and safety issues are relevant. The choice of energy supply, ways in which basic resources are dealt with (water consumption, waste disposal and emissions) will define the character of DCS, even if the major sustainability impacts and gains are elsewhere in the life cycle. A contemporary definition of sustainable operations covers business excellence and extends to ensuring staff understand sustainability, and related goals and decision-making are informed by sustainability principles.

Maintaining standards when going global

Many of the positive aspects of the Dincel technology depend upon the selected supply-chain. The source of the raw materials and the additives in particular, are critical to ongoing sustainability claims. We know that European Vinyl manufacturers have developed a charter of standards which goes a long way to fit sustainability requirements. Compliance with that Charter, or its equivalent, should guarantee that production is carried out with technology that minimizes emissions risk and safeguards transport (including dealing with Vinyl Chloride Monomer (VCM) risks at the workplace and in transport). Buying supplies from sources that do not strive for that kind of standard would easily destroy the credibility of the DCS sustainability claims.

Equally raw material derived from acetylene, including calcium carbide processes from coal, will not support the sustainability message. Therefore the expansion of the Dincel technology beyond Australia must be handled with care. It is becoming clear in large parts of the chemicals industry that global expansion and local success are tricky aims to match. It will be a challenge to keep the high standards of sustainable development that the promoters of DCS are aiming for, at the global scale. Yet we believe that standard setting and maintaining can be achieved. Good partnerships with suppliers and a shared understanding of what is needed will be essential. And as the system gains momentum its originators will need to spend more time on building reliable value-chain systems, including auditing specific key suppliers and end-users.

The pace at which the PVC industry is facing-up to the sustainability challenges is very variable. In Europe we see the most comprehensive progress on all issues, and that is embedded in the VinylPlus programme. By that we mean credible progress on each of the PVC challenges noted above. It is not fast enough nor applied by every part of the industry, yet it is progress to be welcomed. DCS needs to be associated with that kind of progress from the outset. Reliable sourcing of materials and components from the sustainability perspective is essential to DCS's future success.

We know that the inventor and his partners are well aware of these points and have strong intentions to protect the integrity of the DCS technology during global expansion.

Recommendations

To address the issues highlighted in this study we recommend a number of tasks outlined here. We believe these actions are needed to unleash and protect the sustainable development potential of the DCS technology.

1. Transparency and credible communications

If, as we believe is reasonable, the promoters of DCS aim to link the brand to sustainability, then it is essential that it is done thoroughly, scientifically and that the details are not overlooked. Every aspect of DCS will need to be as open to external view as much as possible. It can be expected that it will draw criticism. Most of that criticism will be because it is a "PVC product", hence our emphasis on the generic sustainability challenges of PVC, for which Dincel needs to have credible answers. We know that various bodies involved in trying to further sustainable construction, are not in favour of PVC. Their objections are generic. Ultimately those judging or procuring new buildings need to understand that sustainability advantages lie with this material as opposed to others for some very specific applications in construction, mainly durability, energy efficiency and recyclability. Those attributes also lead to PVC windows, pipes and profiles, being commonly used in construction in many regions. There needs to be more open debate and review of decisions made by standard setting bodies which hinder a sustainable application of any material, where it is otherwise fit-for-purpose. In order to stand on credible ground in that debate, DCS producers need to make sure they have covered all the territory on sustainability, not just the obvious headlines.

2. Constructive Consultation

DCS should be the subject of communication and consultation with stakeholders. By this we mean those involved in the industry – architects, town-planners, construction contractors, engineers, surveyors etc. Such an exercise needs to be designed with emphasis on sharing the sustainability ambition for the construction sector and seeking views on steps that can be taken toward such goals. DCS can then be presented as an innovation that aspires to contribute to sustainability. Each consultation will need careful planning and may be needed each time anew in new places. Before this happens and before publicity is attempted on any serious scale the DCS team in full needs to have a good grounding in the foundations of sustainability, what it really means and how to get on with it. Ill-informed or shallow promotional material will surely damage what may otherwise be a very strong and inspiring innovation.

3. Addressing fossil hydro-carbon feedstocks.

While DCS offers the potential for significant climate change (energy) savings, the reliance on fossil hydrocarbon feedstock is an area that cannot be ignored. This should be addressed through a number of measures:

- → Constantly improve energy efficiency in the supply chain.
- → Seek renewable sources for energy use and transport.

- → Measure and reduce carbon emissions in production and transport
- → Monitor the development of alternatives, including bio-mass for raw materials, and become engaged in that development in appropriate ways.
- → Do everything possible to increase recycling and reuse technologies and practices.

4. Additives.

We recommend that the Chemson supplied additive is retained as an integral part of DCS. In other words we believe that DCS does not stand-up to sustainability scrutiny as well as we have found, if more traditional additives are used or other variations.

5. Recycled content

We also propose that DCS continues to investigate the potential for using recycled PVC in the production of the structure.

6. Supplier Sustainability Policies

All suppliers to DCS need to be aware that it is aiming for sustainable development, and required to submit their own Sustainability Policies for scrutiny. And this should be applied to all suppliers and contractors, from minor to major. Responsible sourcing of materials is vital.

Raw material suppliers in particular need to be asked to explain how their operations match the requirements of industry codes dedicated to sustainability, for example the ECVM Charter in Europe.

We suggest that all suppliers should be required to have relevant ISO management and quality systems in place.

7. Best practice PVC production techniques

No input should be accepted from non-ethylene sources at any stage in the future due to their being greater environmental impacts from the alternative acetylene-based production. Further work is needed to ensure that the differences between best practice techniques are understood and appropriate performance expectations included in supplier requirements.

8 Titanium sourcing

Titanium is involved as a minor additive in the DCS formulation. It needs to be noted that the mining of that substance can have serious consequences for eco-systems and human health. To be as thorough as is needed the original extractor and supplier needs to be checked and evaluated for sustainability issues.

DCS should also consider the total elimination of titanium use. We are informed that the use of titanium within a PVC formulation is needed where cyclic loading is applied, for example in water pipes. As this is not the case for the DCS application and paint protection is required in any case for long term weatherability exposure purposes, the elimination of titanium would appear feasible.

9. Further research on fire hazard

Though DCS clearly meets Australian building code requirements, the reaction of DCS structures in a large scale urban fire needs more investigation than has been possible in this report. A clear communication of the results is warranted, particularly in light of the general interest in PVC and effects of its incineration.

10. Plan for recycling infrastructure

DCS needs to create a clear plan for dealing with the structure at the end of life including an auditable system. This is especially important in developing and emerging economies where standards for end of life disposal are general less well developed.

11. Comparative studies of benefits over competing techniques

Embedded energy/sustainability advantages over concrete and steel need to be verified in more depth if that advantage is to be used widely, as we recommend. Such a study would be based upon the TNS System Conditions and apply precisely the same sustainability criteria to concrete, steel, timber and possibly to other load bearing frame systems.

12. SLCA Review and Development

We recommend that all the detail of the attached SLCA is scrutinized by the DCS team and plans made for each aspect covering supply, production, packaging, transport, installation, maintenance and re-use/recycling.

13. Promote the timber savings further

The use of temporary timber formwork, particularly in the developing world, is likely to be significant. The reduction of timber that could result from widespread application of DCS should therefore be investigated. This is potentially a major aspect which we do not think DCS has fully exploited so far. It will be dependent upon local circumstances to some extent and transporting-in DCS may have logistics handicaps over locally sourced timber. Nevertheless we think the mass-balance advantage must surely lie with DCS and should be followed through.

Appendix - Sustainability life cycle assessment of DCS

Introduction to SLCA

The Natural Step's Sustainability Life Cycle Assessment (SLCA) approach has been used to review the life cycle of the Dincel Construction System (DCS). SLCA helps to define, assess and communicate product sustainability and can be described as an assessment tool and an accompanying process that gives a strategic overview of the full scope of social and ecological sustainability at the product level. It is based on the Framework for Strategic Sustainable Development with its system conditions for sustainability (the four sustainability principles) set against the life cycle stages of a product.

SLCA differs from a traditional life cycle assessment in that the goal is not to identify best available technologies and least harmful alternatives, but rather is to assess opportunities and challenges for a product system in relation to the full scope of sustainability.

Phase 1 - Definition of Goal and Scope

General

The overarching objective is to show how the DCS invention does or could contribute to sustainability in the building and construction industry. A full account would require a broad understanding and inclusion of a wide range of stakeholder views. However, it is beyond the scope of this study to consult widely with stakeholders. Stakeholder views should be sought in due course.

Goal of this SLCA

Intended application(s):	Underpin The Natural Step's commentary of DCS and its sustainability attributes.
Reasons for carrying out the SLCA and decision context:	a) establish a baseline understanding of how DCS currently performs across its life cycle in relation to science-based sustainability principles b) Stimulate discussion about possibilities for future improvement or redesign. c) help the proponents to accurately promote DCS based on its sustainability credentials.
Target audience:	Results are intended to be used by the proponents and are of interest

	to stakeholders in the construction industry, including planners and architects, construction companies, material suppliers and policy-makers. While some information is of a commercial nature, the main study findings are to be made publicly available as part of a third-party commentary by The Natural Step.
Comparisons and/or comparative assertions to be publicly disclosed:	General comments only i.e. no quantification of comparisons.
Commissioner of the study:	Chemson Polymer AG and Dincel Construction System.
Review procedure (if applicable).	N/A for this scope. See recommendations on further review and areas for further investigation.

Scope

Approach to the Assessment - SLCA does not seek to select or quantify impacts in the same way a traditional LCA would. The approach taken is to start with an overview – a birds-eye perspective – and zoom into detail where and when needed to inform decision-making. The aim is to highlight the specific sustainability attributes and challenges that need attention, without muddying the scene with too much detail. Subsequent technical analysis to address any uncertainties may be warranted.

While some commentary is made on DCS in relation to alternatives, this is a non-comparative assessment i.e. alternatives were not scrutinized to the same extent.

We have also sought to align the general SLCA procedure with international standards and guidance on life cycle assessment.

Data quality requirements - We have worked with available information supplied to us and have not sought to verify third party information. Where gaps in information exist we have used professional judgment to help form an overall view (bearing in mind the goal).

Product overview

a)	Product description:	A permanent PVC polymer-based construction formwork to be filled with ready mixed concrete
b)	Functional requirements:	Defined in relation to improving or addressing problems with traditional concrete construction techniques while offering increased social utility.
c)	Social Utility:	Time-saving Material resource efficiency

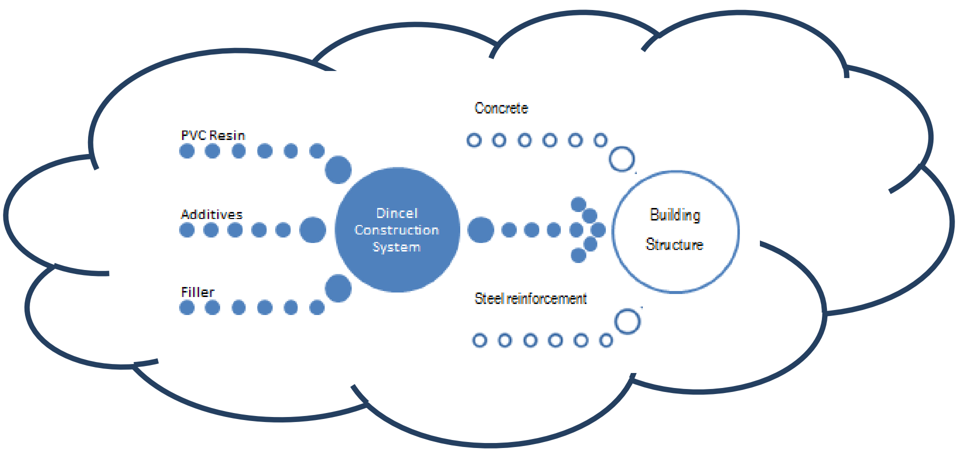
Worker safety

Cost-saving

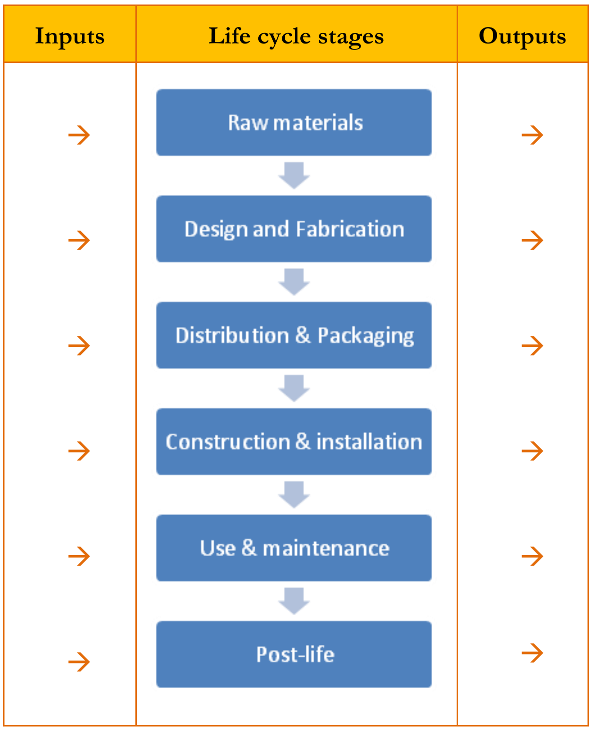
Additional functional benefits

d)	Applications:	Designed for walls and columns in both commercial buildings and low cost housing constructions
e)	Main alternatives:	Concrete buildings constructed with timber formwork. Masonry brick / block wall construction.
f)	Functional unit:	*Space* - Generally, the structure of a standard building where DCS is being used as an alternative to conventional construction techniques. *Time* - Construction time and the lifespan of the building where DCS is applied.
g)	Reference flows:	Resources needed in relation to the functional unit. - 200 apartments in 6 buildings up to 5 storeys over a basement requires17000 m2 of DCS panel. This represents 255 tons of dry blend raw materials. - This is equivalent for 1.275 tons of material use for per apartment, including shared building infrastructure - The quality of complementary material inputs can also be reduced.

The Product system (overview) - The DCS product system can be described simply in terms of the building structure - its material components and the building life cycle. The components include 1) the materials that make up the DCS polymer formwork and 2) other materials needed in the application of DCS (i.e. concrete and steel etc.). Each component has its own complex supply chain which we acknowledge in the study but have not sought to investigate in depth, other than to seeking to understand the main supply chain issues likely to be encountered. The product system is visualized here:



System boundaries - Simplified life cycle stages have been used to organize the main inputs, outputs and throughputs and establish the boundaries for the study:



Impact categories - Rather than seeking to identify, categorize and understand all the impacts, this assessment employs sustainability principles to screen the life cycle stages for known and potential problems, as well as advantages. This helps to focus attention on upstream causes of un-sustainability rather than measure the symptoms.

When considering the possible influence on or by stakeholders, the main categories used are:

- Workers/employees;
- Local community;
- Society (national and global);
- Consumers (covering end-consumers as well as the consumers who are part of each step of the supply chain) and
- Value chain actors (such as construction companies).

Base scenario for the assessment - As DCS is developed and commercialized in Australia, we have considered a typical case to perform the assessment. This is meant only to avoid talking in abstract terms. **Assumptions/Limitations -** DCS has clear applicability outside the Australia and the proponents seek to expand internationally, so we also make note of areas where new challenges may arise due to different applications, environments, markets or geo-political conditions.

Phase 2 - Life Cycle Inventory analysis

The life cycle inventory is a compilation of available information on inputs, outputs and stakeholders in the product system (confidential information excluded).

Summary of main resource inputs, outputs and stakeholders

Stage	Process / component	Inputs	Outputs	Chain considerations (organizational issues)	Stakeholders *
Raw materials	Sourcing of VCM (PCV resin)	K-67 PVC pipe-grade resins produced from ethylene derived VCM. Origin of ethylene: natural gas or crude oil extraction.	Emissions (extraction and transport)	In general the VCM might be considered a commodity. However, we understand that the supplier has a specific process that is integral to the DCS performance requirements. Furthermore, the production process used for ethylene-derived VCM is known to be more environmentally-friendly than acetylene-based VCM production. Process characteristics are therefore important to note. Additive formulations are intellectual property, meaning that 1) the additive supplier is an integral partner in DCS 2) supply chain transparency is difficult to achieve without revealing commercial information. While other OBS stabilizers are on the market, Chemson's additive one-pack uses a dry blend production process. Its footprint differs from other OBS stabilizers where chemical processes are needed.	Australian Vinyl Corporation Hydro carbon supplier
	Sourcing of Additives (stabilizer / 'onepack')	OBS composite stabilizer (heavy metal free) Zinc-based fire-retardant (details are proprietary information) Impact modifier (details are proprietary information) Low level of Titanium Dioxide (a rutile type)			Chemson group Mining/quarry corporations Raw material processing corporations Local residents
	Sourcing of Filler	Calcium Carbonate from a local marble-based source			Omya Australia
Design and fabrication	Plant	Machinery Energy	Emissions Water Solid waste (off-cuts)	Machinery not investigated to determine if the choice or limitations of choice influence DCS sustainability performance.	European machinery suppliers. Energy supplier DCS employees

Distribution & Packaging	Packaging	Wood crates	Solid waste		
	Distribution	Fuel Trucks Equipment	Solid waste Emissions	Distribution is based around production facilities on the east coast, presumably for access to main markets. If international expansion would to occur, by what means would the DCS be delivered? And from where? Note: DCS inventory believes it is ideally suited for local production due to shipping costs, among other things.	Employees
Construction & installation	Sourcing of concrete**	Portland cement (11 percent consisting of lime stone, sand, shale/clay, iron ore) -Sand (26 percent fine aggregate) -Gravel or chrushed stone (41 percent) -Air (6 percent) -Water Energy	Emissions Concrete waste		Construction company. Concrete production industry Local residents near extraction sites
	Sourcing of steel	Coal Iron Energy	Emissions		Construction company /handyman Steel production industry Local residents near extraction sites
	Construction activity	Equipment Fuel	Emissions		On-site workers Local residents near construction site.

**DCS can utilize coal, shale, corals, beach sand, fly-ash and bottom ash to replace conventional aggregate and cement (on locations where these materials are available)

Use & maintenance	Intended use	No inputs needed during use phase	Potential degradation of the DCS polymer over time.		
	Unintended use (e.g. building fire)	Heat	Emissions from combustion		
Post-use	De-assembly	Equipment Transport	Emissions		?
	Recycling	Transport Machinery Energy Any additives?	Emissions Downcycled products Waste products		?

*Stakeholders can be influenced or affected by the product through changes in behaviours, socio-economic processes & capital.

Phase 3 - Life Cycle Assessment using sustainability principles

The following sustainability principles are used to review each life cycle stage.

In a sustainable society, nature is not subject to systematically increasing...

1. ...concentrations of substances extracted from the earth's crust;
2. ...concentrations of substances produced by society;
3. ...degradation by physical means;

and, in that society...

4. ...people are not subject to conditions that systematically undermine their capacity to meet their needs.

Guiding questions used when reviewing the life cycle are:

1. How does DCS relate to the four principles of sustainability?
2. What is being done to address any impacts identified?
3. What more could be done to improve performance?
4. How is DCS a step toward sustainability in relation to current practices?

Note: The assessment represents available knowledge. Not all issues are investigated and some are considered likely issues.

Sustainability Principle 1 - Substances from the earth's crust must not systematically increase in concentration in nature.

Guiding Questions	Life cycle stages					
	Sourcing of raw materials	**Design and fabrication**	**Distribution and packaging**	**Construction and installation**	**Use and maintenance**	**Post use**
How does DCS relate to SP 1?	PVC resin –Emissions associated with fossil based feedstock (Ethylene derived VCM). Mercury from PVC manufacturing (technology being phased out) CO2 emissions from manufacture and transportation of resin, additives and filler to DCS. Dry blend contains Titanium dioxide for better weatherability.	What are the emissions from DCS factory? How much energy does the factory consume? What type of energy?	CO2 emissions from transportation of DCS to site.	CO2 emissions from concrete production CO2 emissions iron ore and steel production …		If PVC is burned, CO2 emissions from fossil hydrocarbons are a net addition to the biosphere, contributing to climate change.

What is being done...;	Sourcing only ethylene-derived VCM is a significant improvement over acetylene-derived VCM. Use of organic-based stabilizer instead of heavy metal stabilizer. Additive processing uses cold mix process (energy save). Design reduces optimizes the concrete pressure on the PVC formwork, meaning the thickness and amount of PVC can be reduced to optimal.	DCS profiles are light (transport/energy advantage).	Per-order manufacture and distribution. (Can also be negative if this results in higher use of energy and resources?)	Goal to make DCS 90% free from steel reinforcement.		Design for resource recovery.
... And what more could be done to improve performance?	Bio-sourced alternatives for PVC resin and additives. Replace metals with alternatives that are not scarce Review the full value chain in terms of origin of flows and conditions of raw material extraction	Use sustainable renewable energy /self-sufficient solutions e.g. solar panels, green energy. Off-set emissions related to DCS operations.	What types of fuel do the trucks use? How efficient are routes and deliveries?			

How is DCS a step toward sustainability in relation to current practices?	The formwork design induces ordered cracking of the concrete, allowing for removal of steel mesh reinforcement.			Less input of steel reinforcement and concrete reduces overall CO2 footprint.		The elimination of steel improves recyclability of construction concrete.

Sustainability Principle 2 - Substances produced by society must not systematically increase in concentration in nature.

Guiding Questions	Life cycle stages					
	Sourcing of raw materials	**Design and fabrication**	**Distribution and packaging**	**Construction and installation**	**Use and maintenance**	**Post use**
How does DCS relate to SP 2?	Sourcing of chlorine feedstock from salt deposits Additives? Dioxin production during VCM manufacture?	There is zero waste PVC product as it is continuously extruded.		Per order length fabrication of PVC formwork dramatically reduces on-site waste.	Dioxins emitted if PVC incinerated in building fires.	Dioxins emitted if PVC incinerated at end of life
What is being done...;		Recycling PVC product - cut-outs are fed back into the process.		Cut-offs can be recycled and fed into other PVC products. Also possible to make new DCS profiles from construction waste	Fire rating exceeds 1, less likely to combust -> substances to accumulate. Titanium content within formulation enhance UV protection to hinder migration of substances.	De-assembled profiles can be recycled.
... And what more could be done to improve performance?	Site visits to raw material extraction points and surroundings to ensure that substances are not emitted in raw material extraction processes					
How is DCS a step toward sustainability in relation to current practices?	Free of phthalates / heavy metals which easily migrate			Can utilize concrete with lower strength, resulting in a resource saving and lower emissions.		

Sustainability Principle 3 – nature must not be systematically degraded by physical means.

Guiding Questions	Life cycle stages					
	Sourcing of raw materials	**Design and fabrication**	**Distribution and packaging**	**Construction and installation**	**Use and maintenance**	**Post use**
How does DCS relate to SP 3?	Ecosystem degradation from fossil feedstock extraction	Ecosystem degradation from plant.	Timber extraction for packaging can lead to deforestation and loss of biodiversity.	Impacts from steel and concrete raw material sourcing.		Potential land use / degradation for waste disposal.
What is being done...;				Designed to use less input for concrete and steel reinforced components.	Fire rating exceeds 1, less likely to combust --> substances to accumulate and affect surroundings, habitat and biodiversity	Recyclable materials puts fewer constraints on natural resources.
... And what more could be done to improve performance?	Site visits to raw material extraction points and surroundings to ensure that mining/quarry operations are executed in a way that restores nature? Renewable feedstock's for PVC resin that does not require fossil fuel extraction.	Use renewable sustainable energy sources at the factory Consider green building for future expansion	Use certified/sustainable sourced wood for the crates		Focus R&D on developing a formula that releases no dioxins when incinerated	What mechanisms are in place to make sure that the DCS profiles do not end up at a landfill?
How is DCS a step toward sustainability in relation to current practices?	Designed to use less resources in terms of concrete and steel reinforcement --> less mining and physical degradation			Eliminates the need for timber formwork. Uses less concrete and steel reinforced components.		Designed to use fewer resources in terms of concrete and steel reinforcement --> less mining and physical degradation.

Sustainability Principle 4 – people must not be subject to conditions that systematically undermine their capacity to meet their needs.

Guiding Questions	**Life cycle stages**					
	Sourcing of raw materials	**Design and fabrication**	**Distribution and packaging**	**Construction and installation**	**Use and maintenance**	**Post use**
How does DCS relate to SP 4?	Health concerns associated with industrial titanium dioxide sourcing and production.	Potential effects on workers from use chlorine chemistry.	Is the material for the wood crates sourced from a location where human needs are met accordingly?		Dioxins emitted in incineration, can cause serious illness as previously stated	
What is being done...;				Integrated conduits mean that trades can work uninterrupted, resulting in time-savings and related resource efficiencies.	Wide applicability that meets human needs: -affordable housing -storage tanks -sea walls -flood levees -irrigation/water management Good earthquake/flooding qualities Fire rating exceeds 1, less likely to combust --> dioxins to accumulate and affect people in various ways	

... And what more could be done to improve performance?					R&D on developing a DCS formula that releases no dioxins when incinerated	Gap between theoretical and actual recycle practices in post-use that may affect human needs where disposed
How is DCS a step toward sustainability in relation to current practices?				Improved construction worker safety.	Highly resilient structure in disaster prone areas. Economic efficiency – lower construction costs and time-savings supports affordable housing.	Improved resource efficiency through use of long life, recyclable materials.

Phase 4 – Interpretation: Summary of key issues and considerations

Here follows a summary of strengths and challenges identified from the life cycle in relation to sustainability principles. Commentary on these issues will be provided in the main report from The Natural Step.

	Sourcing of raw materials	Design & fabrication	Distribution &packaging	Construction & installation	Use &maintenance	Post use
Challenges	Fossil hydrocarbon feedstock Feedstocks rely on chlorine chemistry VCM sourcing and production technique Impacts from sourcing titanium	Ensuring operational excellence with regard to own sustainability footprint, product design suited for sustainability and quality during expansion.			Although DCS meets building code requirements impacts from accidental building fire needs further review and communication	Need to ensure recycling infrastructure for closing the resource loop to become a reality
Strengths	Heavy-metal free stabilizer			Elimination of timber formwork Material savings concrete / steel Safety improvements	Elimination of concrete cancer Long life	

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http://www.dincelconstructionsystem.com/documents/Dincel Wall Fire Assessment.pdf

Construction manual for designers and builders

Dincel Construction System introductory information for The Natural Step

Dincel Wall comparisons
http://www.dincelconstructionsystem.com/documents/Wall Comparisons.pdf

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http://www.dincelconstructionsystem.com/documents/Part 1 Energy Efficiency.pdf

PowerPoint: The Dincel sustainable concrete - PVC system from a PVC sustainability perspective

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