# Bio-SIPs: a deeper shade of Green?

## Jacqueline McIntosh<sup>1</sup>, Mark Harrington<sup>2</sup>

<sup>1</sup>Victoria University of Wellington, Wellington, New Zealand <sup>2</sup> Victoria University of Wellington, Wellington, New Zealand

ABSTRACT: A relatively recent innovation in building component systems for housing, Structural Insulated Panels systems (SIPs) are fast gaining popularity in North America and Europe. A prefabricated structural element, SIPs can be used for walls, roofs and floors without the requirement for framing. Hailed as a 'green building product' and promoted as environmentally sustainable, the Structural Insulation Panel Association claims in its website that SIPs create a 'green' home through:

- Energy efficiency and renewable energy
- Waste reduction during the construction process
- Creation of healthy indoor environments

While these claims have validity when SIPs are compared to light timber framed construction, SIPs still have a high environmental footprint, are not biodegradable and typically contain chemicals that are considered hazardous.

This paper looks at emerging research into 'BioSIPs', biologically based Structural Insulated Panel systems, to compare the attributes and assess the disadvantages of these potentially new 'green' building components. It does this by comparing the performance of a typical Structural Insulated Panel system with a variety of BioSIPs. It then goes on to consider which components of SIPs could be improved on and identifies how this could be achieved in the context of the New Zealand environment.

Key Words: SIPs, Bio-SIP, Kiwi-SIP, sustainability, green building products

## INTRODUCTION

Structurally Insulated Panels, or SIPs, appear set to revolutionise the North American building industry. Touted as a 'green building product' and promoted as environmentally sustainable, Structural Insulation Panel Association (SIPA) claim that SIPs create a 'green building' through; energy efficiency and renewable resources; waste reduction during the construction process; and through the creation of healthy indoor environments. In 2003 SIPs contributed 1% of all new residential construction in the USA, growing by 10% in 2004 and then by 23% to 2005 (from 8,515 to 10,485 new SIPs homes--SIPA webpage). In the UK, Canada, Europe, Central America, Japan, and many other countries SIPs construction has seen acceptance and is growing in use with more recent press coverage on the internet, television home building programs and in magazines and journals.

A simple system of interlocking insulated panels, SIPs are composed of a sandwich assembly of wood and plastic, most typically engineered wood for the facing panels and a polyfoam core. This composition is structurally analogous to an I-beam, providing structural strength and enabling load-bearing construction. They can be used for floors, walls and roofs in residential and commercial buildings to a height of two stories, without the need for framing.

SIPs currently are not imported, manufactured or used in New Zealand. While there are a variety reasons for this, one key issue is New Zealand's limited production of the component parts of the SIPs panels. As we investigate this new building component further and consider its suitability for New Zealand, we are conscious of the imperative to seek more ecologically friendly materials, raising the question as to whether SIPs have the potential to be even 'greener'? This paper reviews the characteristics of traditional SIPs, it then dissects them into their component parts while reflecting on the various measures of sustainability. Following a search of the literature for the various options for greener, biological components and assemblies, it identifies some problems to provide a framework and some options for further research and design.

#### **BACKGROUND**

Structurally Insulated Panel systems (SIPs) have been in existence in some form or another since Frank Lloyd Wright used SIP-like panels in the 1930s<sup>1</sup>. Interest in SIPs has grown due to the introduction of more streamlined assembly technology; the reduction in construction time; the subsequent reduction in labour costs; and most recently, the 'green building' attributes of the system. With the continued development and improvements in SIPs manufacturing and design and the recent history of steadily increasing growth of SIPs manufactured buildings, the SIPs industry in the US has moved from the experimental stage and can now be considered a sustained growth industry.

In addition to the sustainable qualities of traditional SIPs, detailed later in this paper, the demonstrated success of SIPs in situations of natural disaster has further added to their appeal (Schwind 2006). This has been noted in a variety of disasters including the earthquakes in Japan (Kobe 1993) and Northridge California, recent hurricanes in southeastern USA (Hurricanes Andrew and Iniki) and performance in world record snowfalls in the Cascade and Rocky Mountains. The advantages of the reduced construction time for SIPs homes also demonstrates their added value in the face of civil emergency, most recently following Hurricane Katrina when the USA Federal Emergency Management Agency (FEMA) dispatched 25,000 Building America Structural Insulated Panel (BASIP) homes for temporary housing (Schwind 2006).

#### STRUCTURAL INSULATED PANELS

Structurally Insulated Panels consist of only two main components:

- 1. facing panels, usually engineered wood panels which serve as interior and exterior boards, most commonly either oriented strand board (OSB) or plywood; and
- 2. an insulating core, usually made of polyurethane (PUR) or expanded polystyrene (EPS), or less commonly, polyisocyanurate (PIR).

Other minor components include: adhesives used in the making of the panels, predominately formaldehyde based glues; expanding foams used at the junction points between panels; and finally adhesives between the panel and the core. (refer Fig. 1).

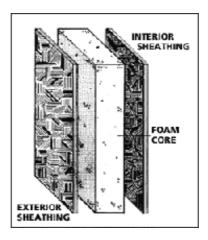


Figure 1: 3D sketch of SIP components. (SIPA, 2007)

SIPs construction represents a centralisation of the building manufacturing process. Instead of on-site production, SIPs are manufactured in the factory, cut to the size demanded by the individual design, then shipped to the site ready for quick assembly. As well as providing a base for interior and exterior claddings, the primary functions of the panels are to:

Provide structural support resisting gravity and lateral loads. Resistance is provided by the panel
acting like an I-Beam. The Oriented Strand Board (OSB) or Plywood acts as the flange while the
polystyrene core acts as the web. (The panels can also act as structural diaphragms)

<sup>&</sup>lt;sup>1</sup> though Alden B. Dow, son of the founder of Dow Chemical Co., is recognised as designing the first SIP homes in 1932 with plywood and Styrofoam.

- Moderate the interior environment by insulating against extremes in temperature.
- Provide secondary water tightness through the various components. The OSB, polystyrene and expanding foam provide water tightness between the exterior and interior environment.

SIPs have been successful due to their efficiency in providing high levels of insulation as well as the speed at which a SIPs building can be erected - a great advantage in economies with high labour rates. However they have some disadvantages which are less well publicised probably due to the promotional nature of much of the early literature. These include:

- formaldehyde based adhesives which have known disadvantages including off-gassing, which is mainly an issue with phenol rather than urea based adhesives;
- inability of EPS to breakdown in the environment post-demolition;
- the quantities of thick black smoke produced by EPS in a fire (Baker 2002).

## 1. Performance of Engineered Wood/Oriented Strand Board facings

The typical SIP uses OSB as the interior and exterior skin or facing material. To provide appropriate structural resistance the two skins/facings must have the same properties. In North America, the individual panels are typically 11 mm thick, are composed from spruce, pine, fir or other woods with the same or superior mechanical properties and density to meet strength, stiffness, density and tension requirements set out by regulating authorities. OSB is typically produced in standard sheet sizes related to press sizes, which work with existing building modules and ceiling heights. Commonly the density of OSB is 640kg/m³ (Structural Board Association 2004).

In terms of overall performance, the insulation values of OSB are negligible. The cross fibre layering of the timber pieces combined with the addition of wax and resins produces a stable water-resistant end product. Most OSB plants use formaldehyde for adhesive, which has known disadvantages including off-gassing. This includes the adhesive used in the manufacture of the OSB and in fixing core insulations to it. The majority of formaldehyde emission from wood composites is restricted to the curing stage. However, low level formaldehyde emissions can result from a breakdown of the resin as a result of hydrolysis (damp). Formaldehyde is a carcinogen and exposure may cause skin, respiratory and pulmonary complications. Due to the water resistance properties of OSB the sheets are highly durable; however, if the panels are left sitting in water, they can swell which affects their structural performance. Hence construction detailing must avoid situations where the production is exposed to sustained water emersion.

#### 2. Performance of the Insulating Core

The typical SIPs core insulation materials are Polystyrene (PS), Expanded Polystyrene (EPS) or Polyurethane (PUR) and its derivative polyisocyanurate (PIR) all of which are manufactured as mineral oil by-products. The blowing agents used to expand or extrude EPS, PS, PUR and PIR are most commonly pentane and carbon dioxide. EPS is highly flammable and often treated with inorganic additives to reduce its flammability. PUR and PIR do not support combustion, but emit toxic fumes when subjected to constant flame. In light of their manufacture from petrochemical substances which are potentially damaging to the environment, the plastic foam interior of the panel raises issues of sustainability<sup>2</sup>. There are also issues of increasing price of these core materials due to the finite quantity of petroleum resources and their depletion. Finally, there is the difficulty in obtaining plastic foams as well as the high cost of shipping due to plastic foam volume to weight ratios. (The alternative—importing the beads and expanding them locally means that the resulting gasses are also released locally.)

Because standard plastic foams are derived from petrochemicals, they have a very high embodied energy. The extruding agent, petane affects the central nervous system and causes irritation to skin, eyes and respiratory tract on exposure. However, very little trace of the pentane is left behind after the curing time. The  $CO_2$  used for expansion/extrusion is usually recovered from existing commercial or industrial sources so is not further contributing to the high  $CO_2$  in the atmosphere. Once expanded, the foams contain 95% air and only 5% of the plastic, so very little of the material is actually used in the making of SIPs. When the PS deteriorates, it releases gases under ultra-violet light, however little to no UV penetrates the panels once manufactured.

In terms of performance, the insulating core must be relatively light weight, such that the weight of the core does not make the panel so heavy as to be unwieldy during erection. The weight of polystyrene EPS, which is the most commonly used core insulation is relatively light, weighing 1.5lb/ft³ (24.03kg/m³), but is still heavier than spray polyurethane foam which weighs only 0.5lb/ft³ (8.01kg/m³) (James 2003)³. The core must be sufficiently rigid to resist the pressure of pressing the panels. Spray polyurethane foam allows around 20% greater structural loadings than EPS alternatives. One of the advantages is the flexibility of the system which helps avoid cracking during deflection. In terms of thermal resistance, extruded expanded polystyrene has an R value or 5.0, while molded expanded polystyrene an R value of 3.8 - 4.4 and spray polyurethane foam has an R-value of 3.6 (James 2003)⁴. Both EPS and polystyrene resist water penetration.

Sustainability needs to be reviewed with two aspects in mind with regard to EPS. On one hand the product provides such high levels of insulation that the heating and cooling loads on building are significantly reduced – a positive for the environment. On the other hand EPS is non biodegradable and consequently post demolition disposal is an issue. Another concern is the smoke the polystyrene produces in a fire, which is thick, black and in greater quantities than that produced from conventional stick timber construction (Baker 2002). There has been much discussion regarding polyfoam materials in mostly metal sheathed products in the UK. Anecdotal information suggests (BRANZ) The fire service is unable to effectively fight these fires due to toxicity and heat and as a result most of the buildings are unable to be saved. Chemical and plastics developments seek to resolve some of these issues but in doing so produce a lesser product in terms of insulation. For this reason the EPS must be sufficiently protected from fire for a suitable length of time by the panel skins or fire retardant agents.

To minimise the impact on the environment, there have been recent initiatives in the US, Australia and NZ to use recycled polystyrene. Both PUR and PIR can be recycled through melting and regrinding. Currently, most PU waste goes to landfill where it is non-biodegradable. PIR is stronger and more stable than PUR, but is also more expensive, so used less often. It is unclear how much recycled foam is used by manufacturers as the majority of manufacturers reportedly use new foam plastics.

The sustainable advantages of SIPs over conventional stick and timber framing include its superior:

- Thermal insulation qualities;
- Airtightness of construction controlling draughts and unwanted air leakage;
- Minimal waste during the pre manufacturing, manufacturing and construction process.

Concerns associated with SIPs include the problems associated with the disposal of the product post-demolition, health concerns with formaldehyde adhesives and ventilation of virtually airtight buildings. BioSIPs look at the use of alternative products with the goal of maintaining the advantageous qualities of the product as well as addressing any weaknesses, perceived or actual, with the conventional SIPs.

## **BIOLOGICALLY BASED STRUCTURAL INSULATED PANELS (BIO-SIPS)**

The term BioSIPs refers to green SIPs that are composed of biologically based renewable, rather than non-renewable resources. Green materials also address the impacts and affordability of the product over its lifetime. To compare we sought a quantifiable indicator of performance to measure their sustainability. The search for sustainability measures is topical — many nations, states/provinces and authorities are working to develop their own. Among the numerous systems are:

- British Research Establishment Environmental Assessment Method BREEAM
- Building Environmental Assessment Criteria (Canada) BEPAC
- US Green Building Council's Leadership in Energy and Environmental Design Green Building Rating System – LEED
- Energy Performance of Buildings Directive (UK) EPBD
- Green Builder Program (International) GBP

Most recently, in April 2007 of this year, the Green Building Council of New Zealand announced a measurement system for New Zealand. Modelled on the Australian example, the NZ Green Building Council is relatively new and is still in the process of developing some of the elements of the system, but

2

<sup>&</sup>lt;sup>3</sup> Converted from American units

<sup>&</sup>lt;sup>4</sup> Ibid

it is expected that the issues will be similar to those experienced overseas. Each of the programs has its advocates and all have their critics but all use some or all of the following broad areas as a standard for measuring sustainable building products;

- Energy efficiency and renewable energy;
- Conservation of materials and resources, or resource efficiency;
- Material toxicity and emissions/ Indoor environmental air quality;
- Waste reduction.

Compared to traditional light timber framing, SIPs are reputed to be superior with respect to sustainability on all four indicators. In our comparision of SIPs and bioSIPs we have used data from manufacturers' publications. No primary testing has been carried out.

More specifically, in terms of:

- 1. **Energy Efficiency:** The thermal qualities of the bioSIP should be capable of meeting or exceeding the R-values of the traditional SIP, helping to minimize energy consumption.
- 2. Conservation of materials and resources. This can be accomplished in various ways. For a BioSIP, it is achieved through using locally available materials, not requiring significant transportation to the project site. Alternatively, they could be from materials that have been harvested from sustainably managed sources. Other forms of resource efficiency are achieved through utilising materials that have a high level of identifiably recycled content or have been salvaged, refurbished or remanufactured or through manufacturing processes that are resource efficient (minimizing waste, energy efficient and reducing greenhouse gases). Finally, resource efficiency also relates to durability, where long lasting products require less frequent replacement or maintenance. Durability and life span will be considered and while it is difficult to establish a general life span for many products, conclusions can be made with reference to aspects likely to cause concern.
- 3. Material toxicity and emissions/indoor environmental quality This criteria generally relates to the indoor environmental qualities that can be enhanced through using materials that are low or non-toxic, emiting few or no carcinogens, volativel organic compounds (VOC's), irritants or reproductive toxicants. Or products that are moisture resistant, inhibiting biological contaminants in buildings.
- 4. **Waste reduction:** In-factory manufacturing advantages SIPs and BioSIPs over conventional light timber framing in terms of waste.

The performance criteria for BioSIPs are greater than those of simply 'green building', they also extend to those performance qualities that are necessary for the constructability success of SIPs. Aspects to be considered include:

- a. Panel Size should ideally be able to work with other building claddings and products which tend to be produced in 1200 x 2400mm sheets (600mm modules). Large format panels would be suitable for industrial and commercial buildings —however the 600mm module should still be acknowledged;
- b. The weight of the panel is an important criteria considering easy transportation and erection;
- c. The structural integrity, with regard to maintaining an I-beam form of resistance through the panel;
- d. Resistance to fire both the spread of flames and the materials flammability, as well as the smoke developed index;

Producing the 'perfect' bioSIP will become a balancing act between these criteria — as some contradict the ideals of others.

#### **BIO SIPS: SURFACE PANEL OPTIONS**

Bio-SIPs have the ability to provide a highly effective insulating material while addressing environmental concerns in relation to the safe disposal of the product post-demolition. The use of composites combines the strengths of several materials into a single new assembly. This can be achieved both through the composition of the panel as a whole, but also within each of the component parts.

It is advantageous to have the exterior facings panels as light as possible for a number of reasons. Firstly it helps the structural load on other parts of the building. For example, a lightweight roof is easier to

support than a concrete tile roof. Secondly, the panels are easier to handle and manoeuvre on site which provides the opportunities for larger panels to be produced. Thirdly, the transportation of the panels becomes more economical and sustainable as less fuel is required to move the lighter panel. Like a carefully designed yacht or aircraft the structural design of the panels needs to explore the areas where weight can be removed. At the same time the panels need to remain reasonably generic to reduce their production costs. Having reviewed the standard OSB skins, we will now consider the other options for facing materials.

#### Honeycomb bio-based board

Honeycomb bio-based boards use a process called engineered moulded fibre technology, or EMF. EMF uses cellulose sources such as waste paper, wood waste, and agricultural by-products which are moulded into structural layers. These structural layers form the boards used to sandwich layers of high R-value, expanded, soy-based foam insulation (Architecture of the CU 'Bio-sip' 2005). The system has been explored by the U.S. Department of Agriculture Forest Products and the University of Colorado during the development of a Bio-sip as part of their house design for the 2005 Solar Decathlon. Through this production method, waste material is recycled resulting in high levels of resource efficiency. The manufacturers claim low toxicity levels with virtually no VOC's. While the panels are a standard size, they are lighter in weight than OSB.

The panels designed for the Solar Decathlon deviated from the conventional denotation of a SIPs by including top and bottom timber plates, as well as stud like framing at the panel connections. The CU BioSIPs team explain this, "We will seam together our SIPs with an I-Beam type stud at every four foot increment between SIPs. These are made from simple 2x4's (45 x 90mm in NZ) and OSB glued together to make an I-beam shape that will slip into the adjacent SIP's. Unlike traditional SIP's, our panels will also be attached by a top and bottom 2x6 (45 x 135mm in NZ) plate which will run the length of each wall. The beauty of this system is the light weight, extreme insulation (135mm = approx. R 4 NZ) and the gridcore surfaces are of finish quality, they can be painted just like drywall!" (Architecture of the CU 'Bio-sip' 2005). While structural integrity of the entire assembly is superior to that of the OSB panel, it requires additional framing.



Source: (Architecture of the CU 'Bio-sip' 2005)

**Figure 2:** Image of the bio-SIP developed for the University of Colorado's 2005 Solar Decathlon.

The honey comb structure provides benefits for the panels weight. However, additional requirements for weather proofing the product appears to be the major drawback. The facing panel, commonly clad with a plaster or adobe render, then requires a polyurethane based sealant, providing only a single line of defence against the elements. Design measures such as deep eaves and high nib walls at the base could be adopted to protect the panel from moisture. Alternatively light weight rain screen could address this problem.

## **Fibre Cement Board**

Fibre cement board was developed in the early 1980's in response to the demand for alternative reinforcing materials to create asbestos free cement based building products. Made from a mixture of cellulose fibre from sustainable, renewable plantation grown radiata pine trees, Portland cement, sand and water with small amounts of chemical additives to help the process, fibre cement building panels will not burn, are resistant to permanent water and insect damage. The panels are considered a highly

durable, low maintenance product and when installed according to manufacturer directions are resistant to rotting and warping.

Advantages associated with the product are: sheets that are produced to standard construction sizes of 2400 x 1200mm and 2440 x 1220mm for metric and standard markets respectively; and excellent fire resistance. The disadvantages are, the relatively heavy weight of the product (heavier than OSB, Honeycomb board and plywood) and the inclusion of Portland cement as well as the chemical additives (http://www.jameshardie.com.au).

#### **Plywood**

Structural plywood is manufactured from rotary peeled *pinus radiata* veneers from sustainable, renewable plantation timber which is then bonded with phenol formaldehyde resin adhesive. Untreated structural plywood may be used in interior dry situations, (i.e. protected from the weather or dampness). However, for exterior use, or internal environments exposed to high humidity or condensation, or where the moisture content of the plywood or timber next to it could exceed 18% moisture content the timber is default treated with the chemical cocktail Copper Chromium Arsenic (CCA) to protect from insects, fungi and fire. Other specifying options include LOSP (Light organic solvent preservative) which commonly includes TBTN (Tributyltin napthenate) treatment, which are considered healthier options. Anecdotal evidence suggests there are issues about residual solvents causing problems. For health and safety reasons, CCA was phased out of use in the USA in 2004 and is to be phased out of Canada, the UK and Australia soon. However, it become more common in NZ building after untreated timber was found to contribute to the damage from recent leaky buildings in New Zealand.

The basic ply bracing sheet is 7mm thick and is produced in standard construction sheet sizes (refer table #1). As the product is timber it makes for easy fixing, and the stability of the plywood sheet allows fixings to be made close to the sheet edge. When used together – in applications such as the skins of wall, roof or floor panels – the sheets resist load through diaphragm action.

With reference to weather tightness it has been mentioned above that ply must be treated for situations where it will be exposed to moisture. In addition ply acts as a rigid air barrier.

#### **Comparing Panel Skins**

The various options for SIPs panel skins have very different characteristics, key elements are outlined in Table 1 below. Data has been sourced from manufacturers' publications and no primary testing has been carried out.

COMPARING P	ANEL SKINS						
	Resource efficiency	Health	Insulation Values (R-values – NZ)		Size, mm	Weight Kg/m2	Source
			Manf. Value	Calculated value			
OSB	Efficient 90% tree utility, can use low grade timber	Contains formaldehyde	0.1	0.16	2400 x 1200, 2700 x 1200,	8.34	(Structural Board Association 2004)
Honeycomb bio board	Very efficient	No VOCs.	n/a	n/a	1220 x 2440 (8' x 4')	0.65	(www.sonoco.com 2007)
Fibre Cement board	Moderately Efficient	Some Portland cement contains cement additives.	0.2	0.25	2400 x 1200mm & 2440 x 1220mm	14.65	(PermaBase Cement board 2007)
Plywood	Efficient	TBTN (Tributyltin napthenate) preservative treatment. Contains formaldehyde	0.1	0.123	2440 x 1200, 2745 x 1200,	4	(Carter Holt Harvey 2007)

Table 1: Comparison of Panel Skin characteristics

To summarise, the OSB is generally good in every aspect excepting the use of formaldehyde glues which likely explains its popularity in SIPs production. The experimental honeycomb board also performs well across the range of sustainable criteria, with the exception of weathertightness. Fibre cement board performs well in terms of durability and weather tightness but is heavy and contains some undesirable toxins. Eco-ply is an average performer across all criteria, but excels in no one aspect.

#### **BIO SIPS: INSULATING CORE OPTIONS**

The range of agri-products which can be used in the manufacture of bio-SIPs include soy, wheat, corn, jute, bamboo, wood and waste paper and most recently willow and mushrooms. Non-biological suitable recycled content includes glass, metals and plastics. As the SIPs facing panel relies on a degree of rigidity from the insulation to separate and support the two skins some products can be ruled out immediately. These include fibreglass and wool batts, mineral wool, and loose blown insulation. The majority of biologically based insulations have been developed as forms of spray polyurethane foams.

#### Sov based foam

Soy based insulation was developed as a low cost, sustainable, alternative to polyurethane spray-on foam made from mineral oil by co-polymerisation of a disocynate with a polyol. The product relies on an oil which can be extracted from the soy bean and replaces the polyol component of polyurethane. Like polyurethane, the soy based insulation expands to fill a void and then sets as a flexible solid, sized to the facing panels and can be sprayed into cavities without the need for extra propellant chemicals as the carbon dioxide produced as a side product fufills this role. In the manufacture of bio-SIPs the soy insulation is sprayed into the cavity of the panel after cardboard conduit is placed within the panel for the electrical cabling. Lightweight, the expanding qualities provide greater structural performance, in the order of 20%, over the status quo polystyrene. The soy oil is used as a water resistant component and given that soy is grown and not chemically produced there are associated sustainability benefits in addition soy based foam is associated with a reduction of Volatile Organic Compounds (VOCs) (Knowles 2006). Research chemists at Virginia Tech advise that less than 7% of soy oil is attractive to bio organism as food.

Due to its recent development, long term experimental data of the soy based insulation is not available, however current use indicates that levels of comfort and insulation are similar to other forms of foam insulation. Also, it tends to respond better in fire than traditional spray foam insulations which is petroleum based. The structure of the insulation means that it is more capable of biodegrading when disposed of.

## **Corn Based Foam**

An alternative to soy is a **corn based foam**. Available data relating to the properties of corn insulation are less than comprehensive. What has been established is that corn based foam has a more expensive production process than soy in the US, which has contributed to the focus on soy products (Knowles 2006).

In New Zealand, Biopolymer Network (lead scientist Michael Witt from SCION) has recently invented and developed a CO2 foamed biopolymer using as the base polymer polylactic acid (PLA). PLA is a sustainable, commercially available biofoam made from polysaccharides (dextrose derivatives) derived from Indian corn in a fermentation process (via lactic acid) followed by a polyermisation. The Biopolymer Network foam which has a density and insulation similar to polystyrene, is an alternative to synthetic commodity foam products as it is generated from plants and not mineral oil. Accordingly, it has almost no ozone depletion potential and only a small global warming potential. It is reported to have one of the best life cycle costing analysis figures and does not need expensive equipment (SCION 2007).



Fig 3: Biopolymer Network foam (SCION 2007)

## SB07 Conference Paper number: 067 Willow based foam

In July of this year, NZ based Genesis Research and Development Corporation reported the successful production of an expanded polyurethane foam produced from a sustainably grown common shrubby willow which thrives in areas of low value land. The natural lignin has been tested for thermal conductivity and density and is also reported to be very similar to polystyrene in terms of both density and insulation value. Due to the newness of this new product, limited information is available.

#### Recycled cellulosic waste foams

Emerging research is also focussed on utilising waste bio based materials, in particular the development of a foam material from waste cellulosic products, such as papermill sludge, wood chips, wood particles, sawdust, waste paper or cardboard scraps. The foam is made by reacting together a polyisocyanate, a catalyst, and a cellulosic material. This research is still new and further information was unavailable; however as polyisocyanates originate from mineral oil, a product related to polyurethane and the soy based foams (see above) is expected (Burgueno 2005).

## Straw / Agriboard

Another material which has been considered for the insulation core of the bio-SIP is straw, which if densely packed can provide the structure and insulation for the panel. Straw is a 'green' product which is readily available and is sustainable. It is difficult to establish consistent structural properties however one aspect remains the same, that is the straw needs to be densely packed. Weight of the straw insulation is 320g per m² of 150mm thick insulation, when dry. Panel size is limited by the skin dimensions and flexural strength properties. Thermal data varies and is inconsistent but are consistently less than EPS. Fire has always been a concern surrounding the use of straw in construction. However, as with the structural properties the fire properties improve when the straw is densely packed. Straw insulation does not resist moisture, and exposed to moisture with out the ability for it to dry out will cause major problems including dampness and rot.

An example of this product was developed for SIPs in Wichita, USA, where they use a system of three layers of densely packed straw with adhesive layers between to bind the straw fibres together. The panels then utilise OSB skins for structure and weather tightness. The glue is produced as a by product from heating the straw as was developed in the New York Institute of Technology team of the Solar Decathlon design 2007 (<a href="http://iris.nyit.edu/solardecathlon">http://iris.nyit.edu/solardecathlon</a>). Issues to be aware of range from vermin proofing the straw to ensuring the straw is densely packed to avoid a quicker spread of flames than desirable in a fire.

## **Comparing Core Insulation Materials**

The various options for SIPs core insulation materials are more similar in their characteristics than the facing panel skins, key elements are outlined in Table 2 below. Data has been sourced from manufacturers' publications and no primary testing has been carried out.

COMPARING INSU	LATING CORE MATERIA	ALS					
	Resource efficiency	Health	Insulation Values (R-values NZ)		Panel Size	Weight Kg/m2	Source
			Manf. value	Calculated value	0.20		
Polyurethene foam	Petrochemical base	Acceptable	3.6	2.25	n/a	5.38	Modern materials, Nov 2006
Molded polystyrene	Petrochemical base	Production emissions.	3.8 – 4.4		n/a	10.75	(James 2003)
Extruded/expande d polystyrene	Petrochemical base	Production emissions. Inability to breakdown post demolition	4 - 5.0	2.57	n/a	16.14	(James 2003)
Soy based foam	Improvement on a conventional polyurethane foam.		3.6	n/a	n/a	5.38	Modern materials, Nov 2006
Willow based foam	Very efficient			n/a			
Agriboard	Very efficient	Low VOCs	25.4	1.29	8'or 9'x 8'or 24'	68.47	(www.agriboard.com 2007)

Table 2: Comparison of Insulating Core Material characteristics

To summarise, in terms of insulation value the petrochemical based foams are relatively similar. There are essentially two types of foam based BioSIPs: those that are mineral oil based and those that are plant based. The bio based foams are very similar to the petrochemical foams in terms of performance and offer similar energy efficiency and light weight without the reliance on non-renewable petrochemicals. However, within the biobased foams, there are distinct differences. The soy, willow and celluloseic foams still utilize some amounts of petrochemicals (approximately 50% per formula) whereas the New Zealand PLA based foam is entirely plant based. In contrast to the biofoams, the Agriboard product is distinctly different; resource efficient and with limited toxicity it has comparable insulation values. But Agriboard is extremely heavy, which will have ongoing and inherent structural complications due to the dead load.

While conventional SIPs have some inherent problems which Bio-SIPs seek to resolve, some Bio-SIPs in themselves create new ones. These include rodents which are attracted to the 'food' based products; weather tightness and water damage.

#### CONCLUSION

While some research seeking improvement in the interior and exterior skins of the SIPs using recycled paper or agricultural fibres to form greener board products, such as the honeycomb structured board produced in the University of Colorado and Forest Products Research development of a Bio-SIP for the 2005 Solar Decathlon, the majority of BioSIPs research has been directed towards improving the insulating core material of the SIPs panels. In particular, the development common agricultural products such as soy, or corn oil in the production of a blown insulation product which forms a flexible solid. Compressed straw has also been explored as an alternative for the insulating core, but with limited success relative to the developments in biological spray polyurethanes.

Bio-SIPs appear to be able to successfully replace petroleum based insulation, with bio-based products. They do this while maintaining similar levels of insulation and structural resistance. In addition to the environmental benefits of the more sustainable SIP they also alter the fire safety performance, as the EPS used in the conventional SIP, while not increasing the risk of fire, produces larger amounts of thick black smoke than alternative methods of construction.

Common issues found across the Bio-SIPs include weather tightness and rodent proofing. It appears that Bio-SIPs currently in use rely on a sealer coat to the face of the external skin sealant to prevent moisture moving through the panel. Rodent proofing relies on details which prevent vermin entering the panels, with areas requiring close attention including voids created for the services. Of course these are not issues particular to Bio-SIPs, but many forms of construction; as a result there are standard ways of resolving them. Solutions include: vermin proofing openings to prevent rodents gaining access to the materials; applying waterproof layers in the construction of the Bio-SIP to stop water penetrating from the exterior to the interior; and adding top and bottom plates to allow for fixing due to the altered insulation material.

## **DISCUSSION**

While people will sometimes move to an environmental product if it performs the same as, and costs the same as (or costs up to 5% more) than existing items in general, for a sustainable product to be successful it needs to not only have benefits for the environment, but also perform better and more cost effectively than other products on the market. By utilising the construction and production techniques of a SIP, BioSIPs can be a familiar construction technique for the designers and trades people involved. As a result BioSIPs do not burden economies, with additional training costs or high labour rates. By requiring a new construction technique to be understood. BioSIPs must be customised for the agri-crops most easily and cheaply grown locally to produce the most sustainable outcome. Soy, corn and other agricultural byproducts have been used in the creation of the BioSIP because of their availability in North America where the research and prototypes have been carried out. Obviously if replicated in New Zealand, potentially alternative materials would need to be sourced - and such an investigation could take place alongside the sourcing of materials and production techniques for SIPs generally.

Another major component to be resolved is the interior and exterior skins. It has been mentioned that the quality of timber produced in New Zealand does not lend itself to the production of oriented strandboard, which essentially relies on low quality timbers being glued together. Instead New Zealand has developed a range of engineered timber products based around a synergy between plywood and laminated veneer lumber. Due to the structural properties of the New Zealand timber being comparatively good it would make sense to utilise these in providing the structure for the SIP. Blown plant oil based insulation to the

panel cavity would enhance the structural characteristics while providing a water resisting barrier. The skins of the panel have options of recycled paper products which - as was noted in the University of Colorado's Bio-SIP development - depending on the form and lattice of the sheet can improve structural performance and reduce weight.

Prototypes for a New Zealand SIP would require testing for the New Zealand environment. While New Zealand's requirements for wind, earthquake and weather tightness will be experienced by other locations in the world their means of compliance with building codes will differ. A starting point would involve tests similar to those conducted by Forest Products Laboratory and the University of Colorado in their initial development of the Bio-SIP in North America followed by a full life cycle costing exercise. Trial structures could then be constructed to evaluate other areas of performance.

Challenges facing the development of a Bio-based SIP for the New Zealand construction industry include: working with the available production and construction techniques existing in the industry; sourcing suitable bio or recycled products available locally; and conforming to relevant means of building compliance. The insulation product presents challenges for the production of a Bio-SIP in New Zealand as the use of oil based blown insulation is not widespread. Rigid EPS insulation as used in the conventional SIP is used less frequently locally than in Europe and North America. New Zealand, currently in its infancy of exploring the possibility of SIPs as a construction method, has the advantage of producing Bio-SIPs as the mainstream product for the industry rather than a 'green' alternative to an existing system, which is the case in North America.

#### **ACKNOWLEDGMENTS**

Special thanks to Dr. Michael Witt of SCION, New Zealand, Dr Thomas Borrmann, of the School of Chemistry, Victoria University of Wellington, Carrie Guthrie of BRANZ and John Gray, School of Architecture, Victoria University of Wellington

#### **REFERENCES**

Architecture of the CU 'Bio-sip' (04 June 2007) http://www.solardecathlon.org/pdfs/techreport05/co\_architecture\_report.pdf

Baker, Gregory. B (2002) Performance of Expanded Polystyrene Insulated Panels exposed to radiant heat, University of Canterbury, Christchurch

BioSIPs (04 June 2007) http://www.newportpartnersllc.com/technologies/biosips.html

Burgueno, Rigoberto, Quagliata, Mario J, et al. *Load-bearing natural fiber composite cellular beams and panels* Composites Part A: Applied Science and Manufacturing, Volume 35, Issue 6, June 2005, Pages 645 – 656

Burgueno, Rigoberto, Quagliata, Mario J, et al. Sustainable Cellular Biocomposite from Natural Fibers and Unsaturated Polyester Resin for Housing Panel Applications Journal of Polymers and the Environment, June 2005.

Carter Holt Harvey Wood Products, http://www.woodproducts.chh.com/, August 2007

Childs, Jim (2000) Building with Structural Insulated Panels (SIPs), The Taunton Press, Newtown, Connecticut

Insulation with a twist. (July 2004) Building Design & Construction, 45, pS-23(1)

Is the UK competing to make new engineers? (2006) www.energy-focus.com

James, Mary, & Wyatt, Edward. (Sept-Oct 2003) Natural insulation products: soft on the environment--and sometimes even soft to the touch--natural insulation products are filling a growing market niche. Home Energy, 20, p30(3)

Knowles, Mason (Nov 2006) SPF Beyond Insulation, Modern materials, U.S.A.

Maynard, Nigel F. (March 2007) Blue-ribbon panels. Residential Architect, 11, p75(1)

McIntosh, J and C. Guthrie, (Sept 2007) 'Structural Insulated Panels: A Sustainable Option for House Construction in New Zealand' XXXV World Housing Congress, Melbourne Australia

McDonald, H (ed), BRANZ House Insulation Guide, BRANZ Ltd, 1995

Molinaro, Hope. (Dec 2005) Agricultural-based SPF foam for insulating your home. Plastics Engineering, 61, p10(1)

Nabar, Yogaraj, Narayan, Ramani, & Schindler, Melvin. (April 2006) *Twin-screw extrusion production and characterization of starch foam products for use in cushioning and insulation applications.* Polymer Engineering and Science, 46, p438(14)

PermaBase Cement Board, *Construction Guide*, <a href="http://www.nationalgypsum.com/literature/gypsumconstructionguide/PermaBase.pdf">http://www.nationalgypsum.com/literature/gypsumconstructionguide/PermaBase.pdf</a>, 2007

Schultz, Neil, Fire & Flammability Handbook, Van Nostrand Reinhold Company: New York, 1985.

SIPA (July 2007) http://www.sips.org.html

Structural Board Association, OSB in Wood Frame Construction, http://www.osbguide.com/pdfs/TM422.pdf, 2004.

Zold, Andras & Steven Szokolay, Thermal Insulation: Design Tools and Techniques, Plea notes: Australia, 1997