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Advanced Technology Fund Research Grant: Final Report

12/15/2010

Dear PPAB Assistance Committee,

Through the CDPHE grant, the CU BioSIP team has been able to pursue our research with the highest level of scientific freedom. Because of the grant review committee's support, encouragement, trust, and confidence, the team has been able to achieve even greater successes and advancements in the work than anticipated. For this opportunity, the CU BioSIP team thanks the CDPHE for its funding support and for the trust extended throughout the grant work.

The CU BioSIP team believes that the materials and products developed through this grant funding will help fill a critical market need while creating valuable clean-tech, green-tech jobs and industry for Colorado.

The following is our final report for the "Recycling Solid Waste into High Performance Environmental, Structural Insulated Panels" project.

Sincerely,

Julee Herdt, Project Manager
and the
CU BioSIP Team

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III. GRANT PROJECT INFORMATION

I. ORGANIZATION INFORMATION

Agency Name: CU-Denver

Project Title: Recycling Solid Waste into High Performance Environmental, Structural Insulated Panels

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II. WORK PLAN

Deliverable	Completion Date	Comments (if deliverable was not completed, please explain why or progress made)
Recycle waste fiber analyses	3/30/2008	
Pricing; Manufacturing analyses	5/9/2008	
Milestone Subtask: Waste diversion quantified	5/9/2008	
Economic Impact; Waste feedstock analyses	5/9/2008	
Milestone Subtask: Fiber finite element modeling	9/30/2008	
Milestone Subtask: Bench Top Prototypes	10/15/2008	
Milestone Subtask: Full-scale molds, panels	4/30/2009	
Computer modeling, design of structure	12/19/2008	
Business consortium: Locate pilot plant	12/15/2008	
Business Plan; Publication updating; Leeds comp	12/15/2008	
Milestone Subtask: Factory insulation, cam locks	7/31/2009	
BioSIP recycled product manual outline	2/28/2009	
Presentation to State of Colorado grant team	10/27/2009	
Milestone Subtask: Structural tests	2/25/2010	
Milestone Subtask: Transfer technology	7/19/2010	
Code, structure evaluations; Quantify design	7/9/2010	
Construct structure: Analyze methods: PV install	10/31/2010	
Develop project publication; Next state funding	10/31/2010	
Presentation to State, potential investors	10/28/2010	
Milestone Subtask: Testing and monitoring	10/31/2010, Ongoing	Monitoring equipment for indoor/outdoor temperature data and building energy production/consumption has been installed. Data will be available online in 2011. A professional energy audit of the BioSIP Research Structure will also be completed in 2011.
Weather and humidity analyses	9/30/2010, Ongoing	EMF moisture resistance property testing has been completed. Results will be used to determine best strategies for next stage research and development. On-site BioSIP weathering properties are on-going and will continue to be monitored throughout the building's lifespan.

III. GRANT PROJECT INFORMATION

1. Executive Summary

"Recycling Solid Waste into High-Performance, Environmental, Structural Insulated Panels", or the "CU BioSIP project", focuses on the technical and economic feasibility of using post-consumer and agricultural waste fibers as feedstock for developing environmentally-sound, economically-viable, high-performance, and cost-competitive building products called "BioSIPs."

Newly-invented **BioSIPs** are biologically-derived wall, floor, and roof "Structural Insulated Panels" (SIPS). BioSIPs are fabricated from diverted wastepaper and other recycled fibers through a highly energy-efficient, patent-pending production process. Constructing with BioSIPs can lessen U.S. dependence on solid wood and petroleum-based construction while diverting large volumes of solid waste into solutions for clean-tech business growth and jobs for the State of Colorado, now and into the future.

Post-consumer wastepaper bales at EcoCycle, Boulder. Paper waste such as this, and agricultural waste fibers, are the main feedstock for newly-invented BioSIP products developed through this grant.

The CU BioSIP project included fiber science and research resulting in patent pending, code-compliant, environmentally-sound BioSIP wall, floor, and roof panels.

These panels in combination with other environmentally-derived materials were used in design and construction of the solar-powered BioSIP Research Structure.

The BioSIP project resulted in successful --

- **Material science and research** of diverted waste fibers as feedstock for BioSIP panels.
- **Engineering and testing** of full-scale BioSIP panels using ASTM test criteria.
- **Filing of two provisional patents** for BioSIP technology and related fabrication process inventions. And, this was the first architecture patent in CU history.
- **Tech transfer** of BioSIP technology from CU to the newly formed company, BioSIPs, Inc, which was created at the outset of the grant.
- **A Business Plan and pro forma**; investment funding; and strategic partnerships to carry BioSIPs forward to commercialization (as on-going steps beyond this grant).
- **A full-scale BioSIP testing and monitoring prototype building** to demonstrate diverted waste transformed into valuable new building products and methods.

The State of Colorado BioSIP grant shows:

Recycling of Colorado's solid waste into valuable new environmental products for clean-tech business, industry, and green-collar jobs.

CU-invented, high-performance sustainable materials for constructing many types of energy-efficient buildings including residences, commercial-, office-, industrial-, and other architectural structures.

An example of government, universities, business and industry working together to create eco-friendly products for a stronger, healthier Colorado, nation, and world.

The grant was conducted at the University of Colorado under the direction of Project Manager, Professor and Architect, Julee Herdt in collaboration with Senior Researcher and Co-Principal Investigator Kellen Schauermann. Fiber and material science investigations were conducted in collaboration with the U.S. Department of Agriculture, Forest Products Laboratory (USDA FPL) through a Cooperative Research and Development Agreement (CRADA).

The University of Colorado, the location of the grant project.

The US Department of Agriculture, Forest Products Laboratory, Madison, Wisconsin is the location of the fiber science research partner's lab and testing facilities.

BioSIP team members John Hunt (left) and Kellen Schauermann shown working at the USDA FPL on the project CRADA.

2. Project Description and Overview

The CU BioSIP project is important to recycling in Colorado because it demonstrates BioSIPs, Inc as a new clean-tech business model for Colorado-technologies and a company that can divert large and on-going amounts of solid waste into value-added products. Based on results from this grant, BioSIPs, Inc and associated spin-off companies and businesses can generate new green collar jobs, rural and urban economic opportunities, while growing a stronger, more competitive Colorado (and U.S.) economy.

The CU BioSIP project will help:

1. **Divert** Colorado's post-consumer-, agricultural-, forest and other waste fibers into valuable new products (the majority of the state's post-consumer wastepaper is currently shipped out-of-state due to lack of in-state markets).
2. **Establish** Colorado as a leader in yet another environmental discipline, which is that of biobased, petroleum-reduced, low-embodied energy building product manufacturing and construction. And, since BioSIP buildings are more thermally-sound and require less energy to operate than traditional stick-framed buildings, BioSIPs will also have positive effects on carbon emission reductions in Colorado.
3. **Support** CU's advancement as a leading environmental research institution while transferring CU-based BioSIP technology into new commercially viable products.
4. **Lead** to other Colorado spin-off eco-businesses such as anaerobic digestion and energy production, and use of unwanted biomass by-products for BioSIP production.
5. **Result** in new jobs to stimulate Colorado's economy in areas such as: *Manufacturing; Post-consumer waste recycling and sorting; Business, management, and administration; Fiber science and research; Architectural design; Product design and engineering; CAD and computer science to support product design; Marketing and sales; Graphic design; Building construction, and others*.

3. Recycling Impact in Colorado

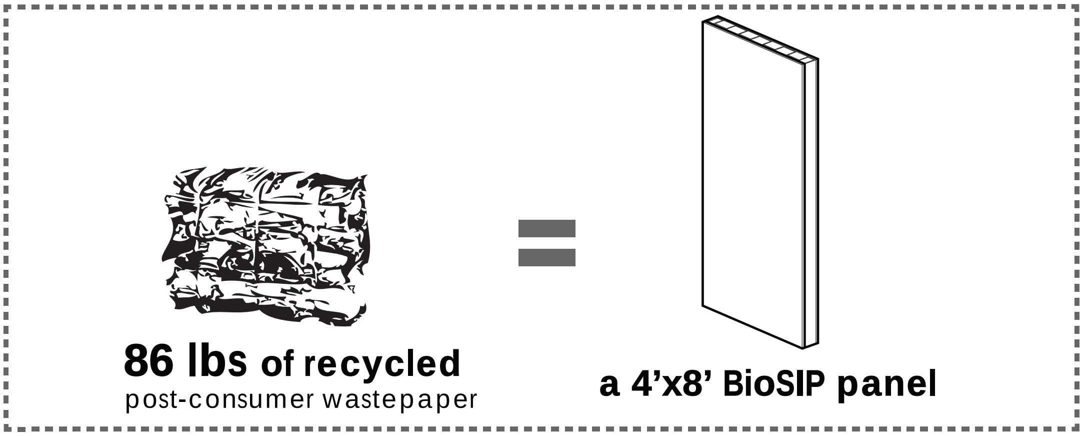
Waste fibers used in the CDPHE project for BioSIPs

The main waste fiber sources used in the CU-BioSIP project were post-consumer, corrugated containers (OCC), and agricultural by-product waste; however, many other types and sources of waste fibers can be used to make BioSIP products such as forest waste, construction wood waste, all types of paper waste, and plants of different types and varieties. The BioSIP team even used wastepaper and construction waste generated while working on this grant for fabrication of BioSIP prototype panels used to build the research structure.

Waste diversion from BioSIPs

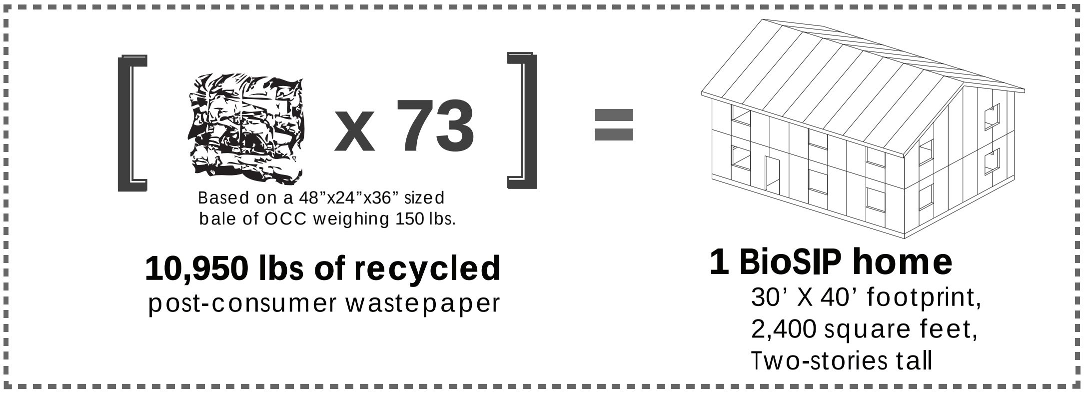
The following waste diversion statistics were calculated using software developed by the grant team for determining recycled fiber quantities in various BioSIP products while also balancing desired BioSIP product characteristics, fabrication costs, and manufacturing profitability.

Potential for OCC waste fiber diversion through BioSIP Manufacturing



Recycled waste fibers used to create a standard BioSIP home

Colorado OCC diversion for a BioSIP home that is approximately 2,400 square feet, two stories tall:



And, assuming a modest calculation showing BioSIPs, Inc producing panels for the following number of homes, the diverted waste volumes indicating "Economies of Scale" could be:
31 homes per month = **339,450 pounds or 169.7 tons of waste fibers per month**

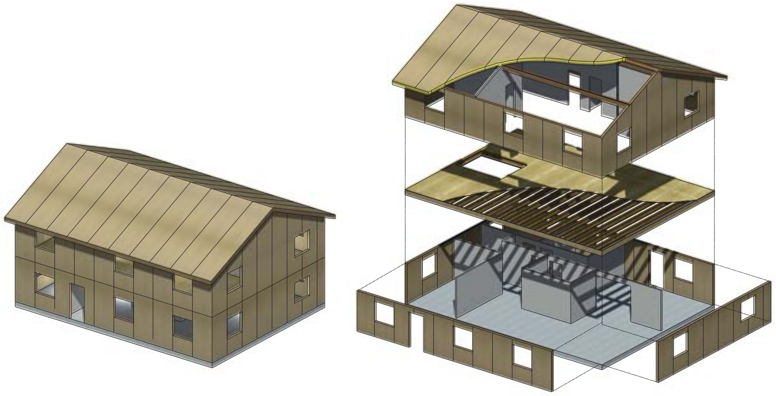
And assuming: 31 homes per month x 12 months per year =
4,073,400 pounds or 2,037 tons of diverted, waste fiber could be recycled into value-added BioSIP products for residential construction alone.

But before we go further --

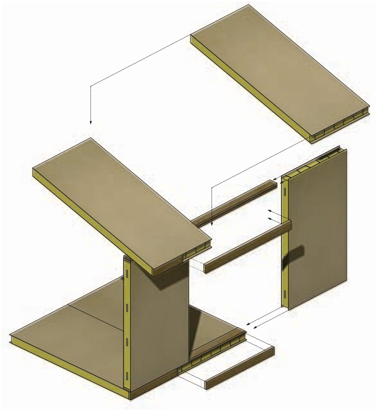
What are SIPs?
SIPs are modular, sandwich construction panels produced in a factory and shipped to a building site for rapid assembly. A recent study shows that SIP construction reduces on-site construction time by one-half when compared to stick framing.

The SIP method originated at the FPL in 1935 as a modular building system in which framing members and insulation are sandwiched between wood sheathing with the sheathing designed to carry a percentage of a wall's structural load. This is referred to as a "stressed skin SIP" and is the current, standard method of SIP fabrication.

Julee Herdt has worked with the FPL since 1992 on developing environmental building materials from a range of waste fibers. Today, Julee Herdt and Kellen Schauermann are working with FPL researchers to develop new SIP technology through their BioSIP invention. And, they are developing BioSIPs as a 3D core system with smooth exterior skins, all of which are produced from waste fibers in a SIP design with improvements over the standard sandwich panel invention.



Axonometric view of a home built from BioSIPs; assembled view (right), exploded view (left).



Axonometric wall section showing
BioSIP floor, wall, and roof panels.

In general, SIPs provide:

- "All-in-one" integrated structure and insulation
- Energy and cost efficiency
- Improvements over stick framing in thermal, moisture, and mildew resistance
- Superior structural performance (including seismic)
- Faster construction time than standard wood framing

In 2006 the total residential home building market was approximately $455 billion with:

- SIP construction taking $890 million, or 2% of this market share

SIPS show consistent growth despite a declining housing market with sales as follows:

- 4.7% in 2007
- 6% in 2006
- 12% in 2005
- 9% in 2004

What are BioSIPs?

An improvement over standard SIPs since BioSIPs have:

- **Higher R-values** through super-insulating, no-VOC, high-density polyurethane foam (the “greenest” foam insulation product available)
- **Superior embodied-energy ratings** (less energy to make BioSIPs)
- **Superior** transverse bending strength resulting in increased allowable roof spans and loads
- **Proprietary 3D core** design with internal “access chase” for easily inserting or placing building components such as electrical, plumbing, and supplemental structural supports into BioSIP walls, floors, and roofs.
- **Potential for thinner exterior wall panels** yielding more interior “real estate”
- **Green building points** and credits through programs such as LEED
- **Clean-tech manufacturing** methods using diverted waste, closed-loop water systems, and recycling of manufacturing feedstocks into new BioSIP products
- **Lower shipping costs** through a lighter-weight product; “flat-pak” shipping; and computer-aided, remote fabrication
- **No petroleum in their fiberboard skins (and 3D core)** compared to the petroleum-based OSB skins of standard SIPs

BioSIPs are a **structurally and environmentally sound building system** creating safer environments for living and working.

BioSIPs with structural 3D core encapsulated in high r-value insulation (R-7 per inch)

Standard sandwich panel SIP with two layers of OSB sandwiching a layer of expanded polystyrene insulation (R-3.5 per inch)

4. Description of work completed

Science: Applied Research, Testing, and Prototype Fabrication

In this phase of the CU BioSIP grant project, the team demonstrated the technical feasibility of using post-consumer waste for BioSIP wall, floor, and roof panel inventions.

Main goals were:

1. Analyses of waste fibers in order to scientifically study, select and determine recycled post-consumer feedstocks for optimum BioSIP performance characteristics
2. Development of finite element modeling software to achieve material input efficiencies for BioSIP structural, thermal, water- and fire-retardance characteristics
3. Fabrication of BioSIP prototypes for structural (compressive, bending, shear, and fastener attachment strengths), thermal (r-value), moisture, and flammability testing
4. Design and construction of full-scale BioSIP panel prototypes and systems joinery
5. Structural testing of full-scale BioSIP panel prototypes using building code criteria
6. Development of: “BioSIPs: A Manual for Professionals and Practitioners”

This phase of the CU BioSIP research, fiber and material science developed using three-dimensional engineered molded fiber (EMF) technology originally developed by the Forest Products Laboratory (FPL) and advanced by the BioSIP team.

EMF technology is a method in which waste fibers are hydro-pulped to produce slurries, which are then poured into flat or three-dimensional molds. Hot-pressing, with or without supplemental adhesives, yields inter-fiber bonds and resulting strong, fiber boards.

In the BioSIP project, the CU team collaborated with the FPL to further advance EMF technology in creation of 3D waste fiber geometries suitable for structural applications, and specifically, BioSIP building materials. The work was conducted through a “Collaborative Research and Development Agreement, or “CRADA”, and resulted in the invention of new, cost-effective methods for producing flat and three-dimensional EMF BioSIPs using standard tools and digital fabrication techniques. The work also resulted in recycled fiberboard material shapes and configurations that were previously not possible using EMF technology.

Additionally, the CU team developed methods for encapsulating 3D EMF configurations in super-insulating construction foam (the most environmentally-benign insulation available on the market), resulting in the basic BioSIP panel system. The team then developed variations on the basic BioSIP panel and flat fiberboard designs to generate interior wall partition products, structural insulated headers, and a range of other recycled fiberboard building products.

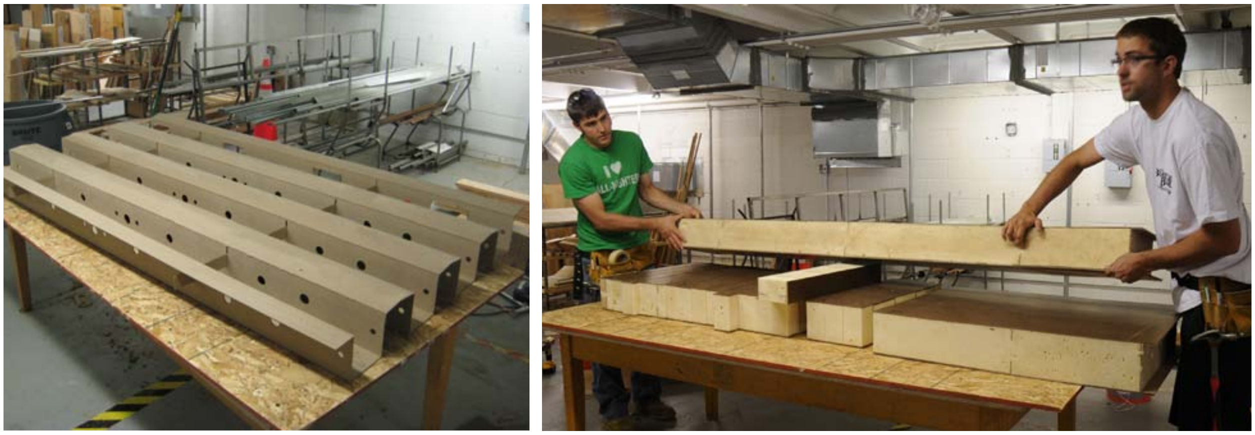
Computer model of a 3D EMF corrugated substrate.

How BioSIPs are Made

To make a BioSIP panel…

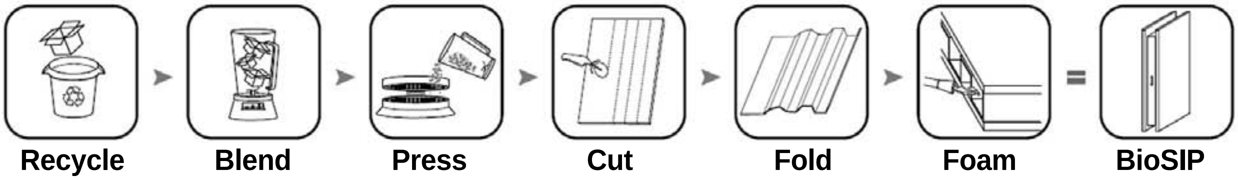
…bio-based wastes and recycled fibers such as post-consumer paper-, wood- and fiber-based agricultural wastes are sorted then pulverized (pulped) in water using a hydro-pulper, which is similar to a large, industrial-strength blender.

The resulting fiber pulp is blended using patented processes that maximize fiber bond strengths without the need for any additives. This proprietary mixture is then pressed into flat fiberboard sheets of desired dimensions.



The flat fiberboards are then given 3D shapes that form the unique BioSIP structural core material. Insulation, cam locks, and smooth fiberboard “skins” are integrated with the 3D fiberboard cores and the finished BioSIPs are ready for use.

Or, in an easy graphical analogy:



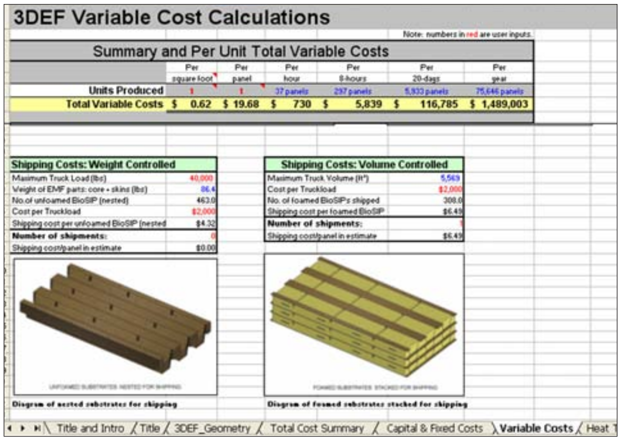
5. Summary of Unanticipated Outcomes or Roadblocks

At the outset of the BioSIP project the greatest challenge for success, as defined in the project proposal was anticipated as *"…balancing panel performance characteristics in a cost-competitive SIP product."*

Research developments using digital fabrication and methodologies

To manage and offset this challenge the team developed a proprietary software package that allowed adjustment of BioSIP design performance variables to balance: *the most efficient use of OCC fiber material in a lightweight, strong, high-performance (thermal, construction site adaptability), energy-efficient, cost-competitive, environmentally-sound SIP design.*

The software allowed the team to complete "finite element modeling" (computer-based studies) so that fiber processing variables and structural properties could be balanced prior to fabrication and testing of full-scale BioSIPs. The software also allowed study of not only fiber characteristics (recycled fiber blends, types, and volumes needed in the ideal BioSIP design configuration), but it also allowed design and analysis of 3D BioSIP shapes and structures meeting product performance characteristics in unique patent-pending, corrugated core designs with desired product cost and profit outcomes.



3DEF Variable Cost Calculations

Note: numbers in red are user inputs.

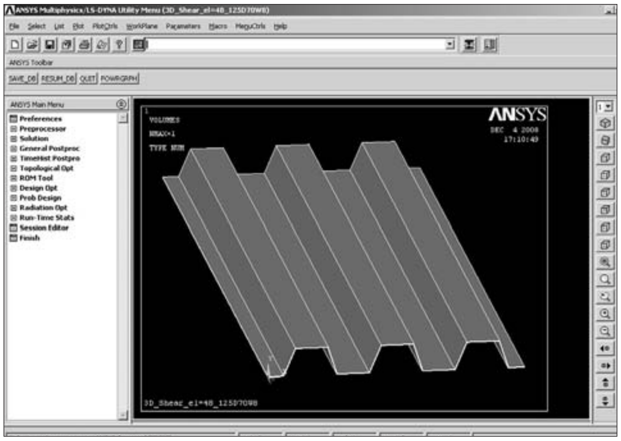
Summary and Per Unit Total Variable Costs

	Per square foot	Per panel	Per hour	Per 8-hours	Per 20-days	Per year
Units Produced	1	1	37 panels	297 panels	5,933 panels	75,646 panels
Total Variable Costs	$ 0.62	$ 19.68	$ 730	$ 5,839	$ 116,785	$ 1,489,003

Shipping Costs: Weight Controlled	
Maximum Truck Load (lbs)	40,000
Weight of EMF parts: core + skins (lbs)	86.4
No. of unfoamed BioSIP (nested)	463.0
Cost per Truckload	$2,000
Shipping cost per unfoamed BioSIP (nested	$4.32
Number of shipments:	0
Shipping cost/panel in estimate	$0.00

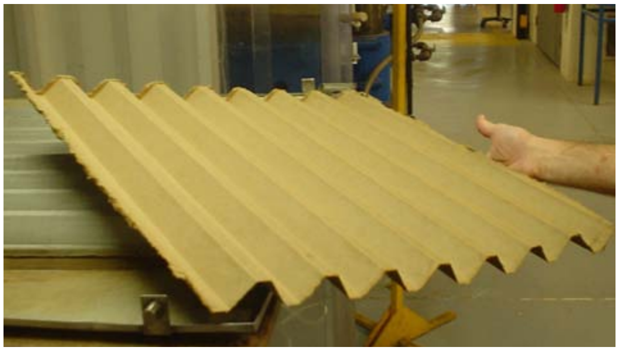
Shipping Costs: Volume Controlled	
Maximum Truck Volume (ft³)	5,569
Cost per Truckload	$2,000
No. of foamed BioSIPs shipped	308.0
Shipping cost per foamed BioSIP	$6.49
Number of shipments:	
Shipping cost/panel in estimate	$6.49

The BioSIP software was developed from EMF software originally created by the Forest Products Laboratory (FPL). The CU team modified and advanced this software for BioSIP invention, design, and development.

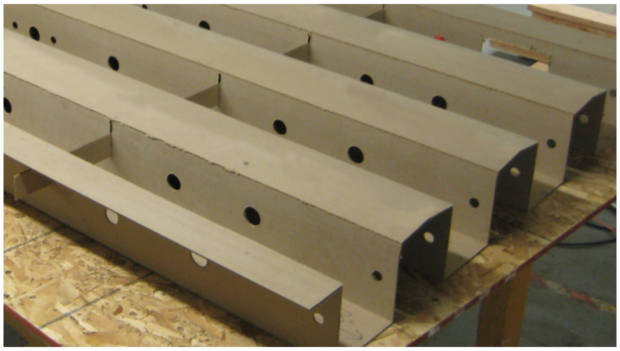


The CU team worked with the FPL to develop BioSIP computer models for "finite element analysis", or "FEA", using ANSYS software. FEA allows product characteristics to be input into a computer program so that the computer can help aid in product design.

As the grant research proceeded the team discovered and developed new fabrication possibilities that allowed shifting away from more complex and costly fiber molding techniques to state-of-the-art, computerized digital fabrication methods.



Early examples of EMF fiberboards in which 3D corrugations were produced using metal molds. This process proved to be more costly for BioSIP fabrication than the team's later-developed, digitally-produced, computer fabrication methodologies.



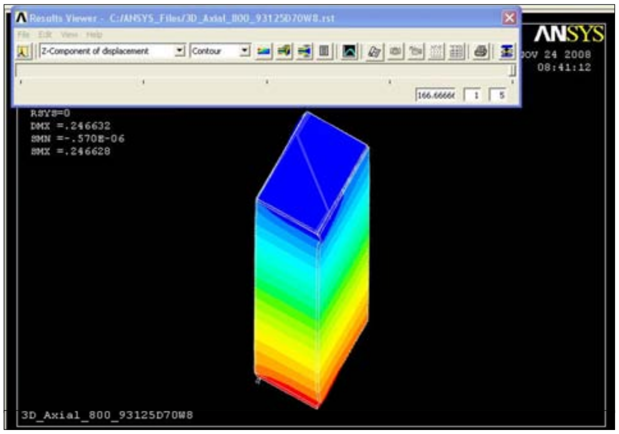
Patent-pending, digitally fabricated BioSIP material was developed in later stages of the grant as a more cost and resource efficient method for BioSIP fabrication.

6. Measures and Indicators Used

BioSIPs were developed in compliance with International Building Code (IBC) and International Residential Code) criteria for Structural Insulated Panels.

Finite Element Analysis

Computer simulated testing was conducted to determine ideal fiber properties and substrate (flat fiberboard) designs prior to full-scale fabrication and testing of BioSIP floor, wall, and roof panels.



```
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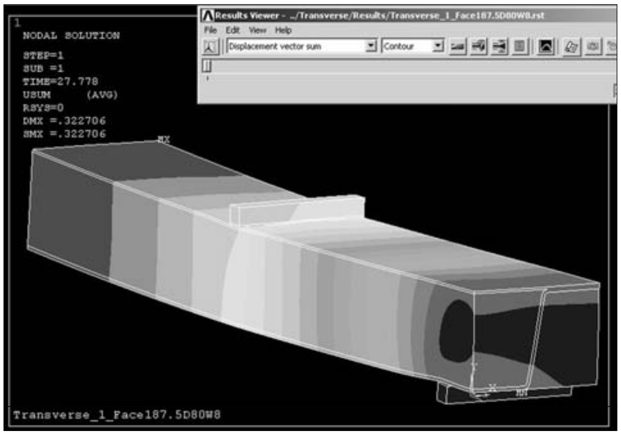
SMN =-.570E-06
SMX =.246628
```

Isometric view of 3D ANSYS model of a BioSIP fiberboard substrate being tested under axial loading conditions. Axial loading includes building forces that are applied vertically, or downward, on a wall or column. The various colors indicate levels of deflection within the BioSIP substrate as it is being tested. Blue indicates areas where maximum deflection occurs.



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NODAL SOLUTION

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SUB =1
TIME=27.778
USUM      (AVG)
RSYS=0
DMX =.322706
SMX =.322706
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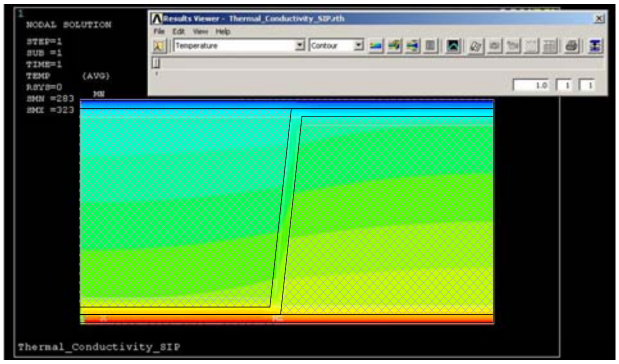
Isometric view of ANSYS computer model showing one 3D section of a BioSIP fiberboard core under two-point transverse loading conditions. Transverse loads are those building loads applied perpendicular to a wall. The test simulation indicated that BioSIPs would have a greater resistance to bending loads than standard SIPs.



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1
NODAL SOLUTION

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SUB =1
TIME=1
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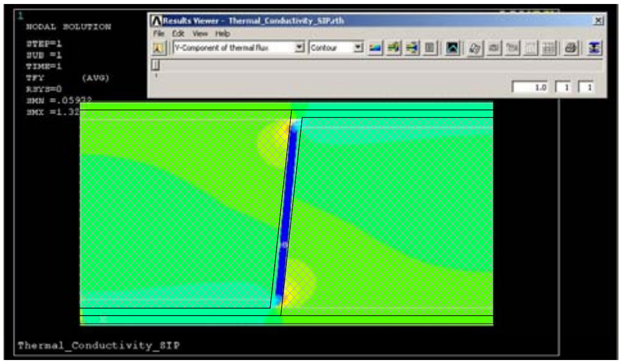
RSYS=0
SMN =283
SMX =323
```

ANSYS simulation of a BioSIP panel assembly undergoing thermal conductivity testing. Thermal conductivity is a building material's ability to transfer heat. Temperature variations are indicated in color with blue signifying cold exterior temperatures, red indicating warm interior building conditions. BioSIPs are fabricated using high-performance insulation and are therefore, super energy-efficient.



```
1
NODAL SOLUTION

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SUB =1
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TFY       (AVG)
RSYS=0
SMN =.0593
SMX =1.32
```

ANSYS simulation of heat transfer through BioSIP core. Test results indicate that negligible heat transfer occurs at these points and that BioSIPs will demonstrate 4-5 times less overall heat loss through thermal bridging than standard stick frame construction. Thermal bridging is transfer of temperatures through a material from inside to outside of a building.

BioSIP structural tests

BioSIP prototypes developed through the grant were tested at CU engineering's Fast Hybrid Testing Facility ("Smash Lab") lab using ASTM and International Building Code criteria. The BioSIP team's testing protocols and procedures were overseen by CU technicians and lab manager, Mike Eck.

Tests conducted on full-scale, 2'x8', and 4'x8' BioSIP prototypes included:
ASTM-E72, Section 9 - Axial Compression Loading Test
ASTM-E72, Section 11 -Transverse Loading Test
ASTM-E72, Section 14 Racking Load Test

7. Summary of Findings and Results

Loading a BioSIP test panel into the axial compression testing equipment

Overall summary of Testing Results

- BioSIPs were tested and yielded successful results for ASTM required SIP test methods in axial compression, racking, and transverse loading Refer to the *"BioSIP Structural Testing Report"* for a detailed analysis of test results.
- BioSIP EMF material was tested at the USDA FPL and met code required flammability and water resistance criteria.
- The BioSIP EMF material (flat boards) developed through the grant exhibit superior strength compared to existing hardboard and fiberboard products.

Successful Results of the BioSIP Axial Compression Load Testing

BioSIP axial loading tests indicate that BioSIPs will likely exceed existing SIP manufacturers' panel strengths in actual product certification tests and that BioSIPs will be among the strongest structural insulated panels in the marketplace. Additionally, BioSIPs are stable in withstanding increasing compressive loads over time.

Successful Results of the BioSIP Transverse Bending Load Testing

The transverse loading tests indicate that BioSIPs will significantly exceed existing SIP manufacturers' panel strengths making BioSIPs among the strongest structural insulated panels in the marketplace.

BioSIP undergoing the transverse bending load test.

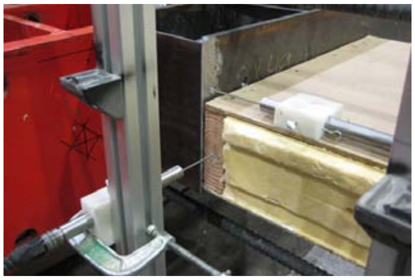
Kellen Schauermann (right) and Mike Eck (CU Smash Lab Manager) discussing BioSIP transverse bending test results.

All of the testing was monitored by computer software developed specifically for recording and analyzing BioSIP test data.

Successful Results of the BioSIP Racking Shear Load Testing

Test results show that BioSIPs will be comparable to existing SIP panels' racking strengths in actual product certification testing and that BioSIPs will be among the strongest structural insulated panels in the marketplace.

BioSIP test panel set up for racking shear load testing at CU's Fast Hybrid Testing Lab.



Strategically placed sensors were used to monitor results of the structural testing.

Detail view of the failure location along wood sill plate attached to the BioSIP test panel.

Business: Creating BioSIPs, Inc; Technology Transfer

In 2008, at the commencement of the grant, Julee Herdt and Kellen Schauermann co-founded BioSIPs, Inc. as a Colorado-based C-corporation with the goal of commercializing BioSIP technology under exclusive licensing from CU.

Don Leonard, a business strategist with extensive, successful experience in renewable energy start-ups joined BioSIPs, Inc as Acting CEO and business advisor. Together, Herdt, Schauermann, and Leonard established BioSIPs, Inc's company mission as follows:

To be the premier designer, developer and global provider of innovative sustainable building systems and products that utilize recycled waste materials and energy-efficient production processes.

BioSIP's vision is a future world that is intolerant of waste and is committed to preservation of the Earth's natural capital through widespread adoption of sustainable building materials and practices.

The company's overarching business goal is commercialization of BioSIP technology and products which set new standards for cost-effective, energy-efficient and environmentally-friendly building design and construction, while creating new industry and jobs in the United States and globally.

For additional information about BioSIPs, Inc, refer to: www.biosips.com

Did You Know?

Consumer demand for "green" products has grown 41% from 2004 to 2009 to just over $722 billion dollars in the U.S. alone. Green product sales are expected to continue to grow nearly 20% in the next two years, according to leading research firm Mintel.

Source: National Eco Wholesale website

Tech Transfer of BioSIP technology from CU to BioSIPs, Inc

CU's Technology Transfer Office supported the BioSIP project throughout the grant. Tech Transfer's mission is to *"…aggressively pursue, protect, package, and license to businesses the intellectual property generated from CU-based research enterprises and to serve faculty, staff, and students seeking to create such intellectual property."* The BioSIP project is the first-ever cross-campus collaboration between the College of Architecture and Planning and Technology Transfer, resulting in the first architecture patents in CU's history.

BioSIPs, Inc has continued to negotiate with CU's Tech Transfer Office to secure exclusive licensing for commercialization of the BioSIP technology. On September 23, 2010, the Company and CU's Technology Transfer Officer executed the Exclusive Option Agreement granting BioSIPs, Inc the right to negotiate the Exclusive Licensing Agreement for commercialization of the BioSIP technology. Under this licensing agreement, CU will receive royalty income from BioSIPs' sales to help fund on-going environmental research and scholarships. Julee Herdt and Kellen Schauermann will continue to conduct environmental research and material science at CU while pursuing BioSIP commercialization and concurrently developing technologies and patents outside CU and through BioSIPs, Inc.

BioSIP patents

The initial BioSIP provisional patent was filed in 2007 with the U.S. Patent Office under the title: “Environmental Structural Insulated Panels” with Julee Herdt and Kellen Schauermann as co-Inventors. Additional provisional patents for BioSIPs have since been filed to accommodate continued research and development of the BioSIP technology. A second provisional patent, also developed during the BioSIP grant project and entitled “Cut-Fold-Shape Technology for Engineered Molded Fiber Panels”, was filed in December 2010. This second provisional patent provides protection for proprietary computer software and processes used in design and fabrication of a broad spectrum of unique two- and three-dimensional BioSIP and other EMF product applications (e.g., construction, furniture, containers, packaging, etc.). Utility patents for both provisional patents will be filed in 2011.

On-going business developments

BioSIPs, Inc is negotiating its first strategic partnership for product manufacturing and business development with a Colorado-based SIP manufacturer known for producing cost-effective, high quality, energy-efficient, easy-to-assemble, modular building components. The company collaborated with the BioSIP team in summer 2009 on production of BioSIP prototype wall, floor and roof panels. These initial BioSIP prototypes were produced using the strategic partner’s standard SIP foaming equipment (with required manufacturing adjustments made by the BioSIP team).

BioSIPs, Inc is currently collaborating with Hafele International, a renowned hardware company, to design and test Hafele fastening systems in combination with BioSIP fiberboard materials for interior architecture and furniture designs. Hafele plans to work with BioSIPs, Inc to help introduce BioSIP products to commercial furniture manufacturers seeking a sustainable fiberboard as replacement to medium density fiberboard (mdf) and particleboard products.

Fundraising for BioSIPs, Inc beyond the grant

BioSIPs, Inc raised its first $75,000 seed money in summer 2010 and is currently raising capital investment funding for commercialization of BioSIP products to begin in 2011.

Computer rendering of the BioSIP Research Structure. The building serves as a testing and monitoring station for grant-developed materials as well as an educational tool for promoting waste diversion and eco-friendly architecture and construction practices.

The BioSIP Research and Demonstration Building

The BioSIP Research Structure is a solar-powered testing and monitoring structure constructed from BioSIP wall, floor, and roof panels produced through this grant in combination with a range of other environmental products. The building is 18' in length by 10' wide by approximately 15' in height.

Concept model, 1:96 scale

Presentation model, 1:8 scale

Constructed BioSIP Research Structure

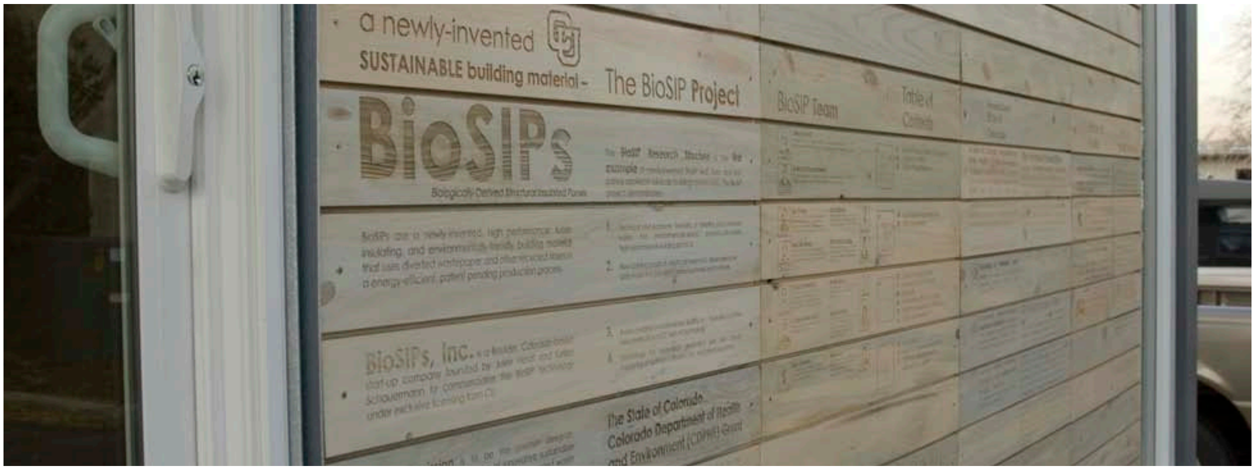
As a successful CDPHE waste diversion grant product, this building demonstrates:

- The technical and economic feasibility of diverting post-consumer waste into environmentally-sound, economically-viable, high-performance BioSIP wall, floor, and roof products.
- Interior architectural details and furniture from BioSIP 100% waste fiberboards.
- Beetle kill forest waste as building siding and a value-added Colorado diverted waste fiber product.
- The value of CDPHE funding and support for advancement of Colorado-based technologies that will create important new building products from diverted waste and associated clean-tech industry and jobs for a healthier future.

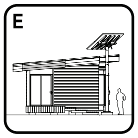
Building Graphics

The story of the CDPHE-funded CU BioSIP diverted waste project is laser-etched in the beetle kill siding so that the public can learn the value of this project by simply visiting the building. The project is located at 3640 Walnut Street, Boulder, CO 80301.

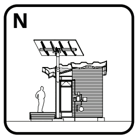
The project website is www.biosipresearchstructure.com.



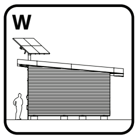
Laser-etched methods were developed by the team so that each elevation of the building tells a piece of the CU BioSIP grant story.



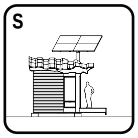
01 Research Support: State of Colorado
02 A History of BioSIPs
03 Origin of the SIP Method



04 Solar Engineering: Simple Solar
05 Solar Power System

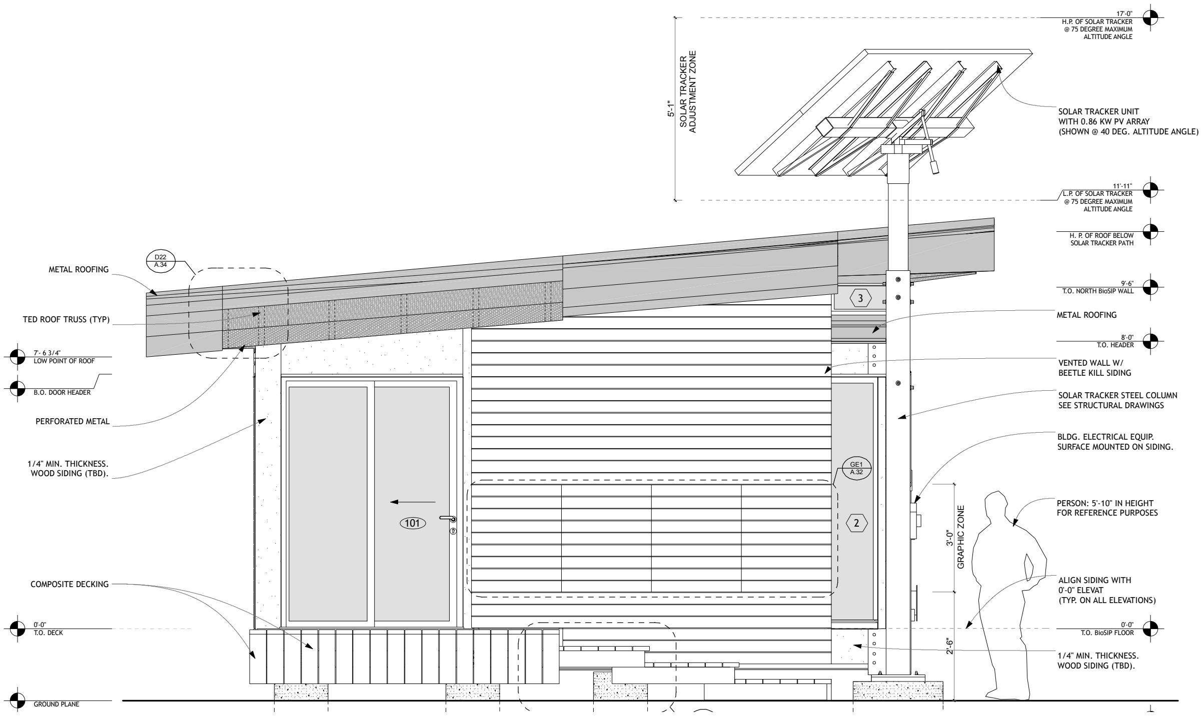


06 Diverted Colorado Waste
07 Potential for OCC Diversion
08 Beetle Kill
09 Photo Voltaic (PV) Solar Energy
10 BioSIP Prototype Factory Fabrication
11 Project Collaborators



12 Vented Roof
13 BioSIP, Inc. Business Opportunities
14 The Project Site:
National Eco Wholesale, Inc. (NEW)

East Elevation



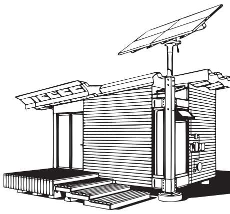
The building's east elevation provides information about the grant project, the history of SIPs and BioSIPs, project waste diversion statistics, and environmental benefits of building with BioSIPs.

BioSIP Research Structure, Diverted Consumer Waste

[ x 25] =

This is based on a 48"x24"x36" sized bale of OCC weighing 150 lbs.

3,710 lbs of recycled post-consumer waste paper



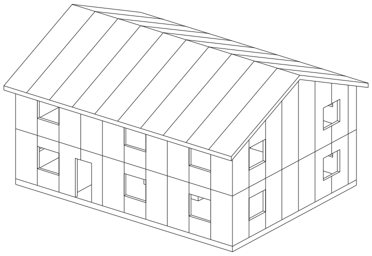
BioSIP Research Structure

Wall, floor, and roof BioSIP panels	=	**2,285 lbs** of post-consumer waste
CNC fabricated trusses for roof	=	**625 lbs** of post-consumer waste and salvaged wood framing from ReSource
Furniture, interior finishes, and ceiling materials	=	**800 lbs** of post-consumer waste

Environmental benefits of utilizing diverted consumer waste

According to data from the American Forest and Paper Association, a typical home built with BioSIPs would provide environmental benefits by conserving the equivalent of:

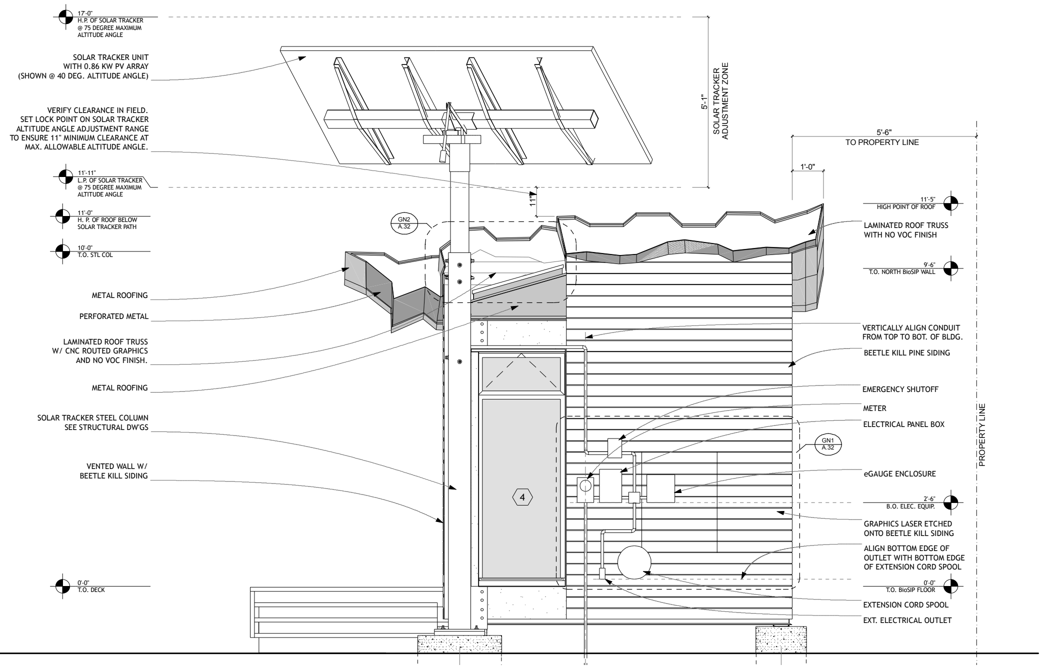
1 BioSIP home:
30' x 40' footprint,
<u>two-stories tall =</u>
2,400 square feet



=

93	trees (35 ft tall)
11	barrels of oil (enough to run an avg. car for **6,900** miles)
22,450	kilowatts of energy (enough to power the average home for 33 months)
18	cubic yards of landfill space
329	pounds of CO2-generated air pollution

North Elevation



PV (Photo Voltaic) solar energy to power the BioSIP Research Structure

The Heimbold Foundation provided a renewable energy in education grant so that CU students could learn hands-on solar system design, installation, use, and monitoring. The Heimbold Foundation also funded the purchase and installation of the project's solar tracking collection system.

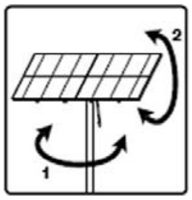


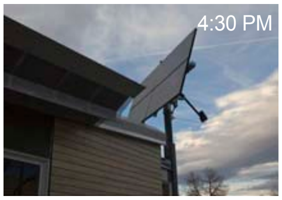


Environmental benefits of renewable energy

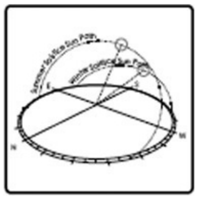
The BioSIP Research Structure produces 142 kilowatt hours of electricity per month as an alternative to standard grid-tied electrical energy use. This supports a healthier environment, reduced CO2 production, and the equivalent of:

Solar Tracking Methods

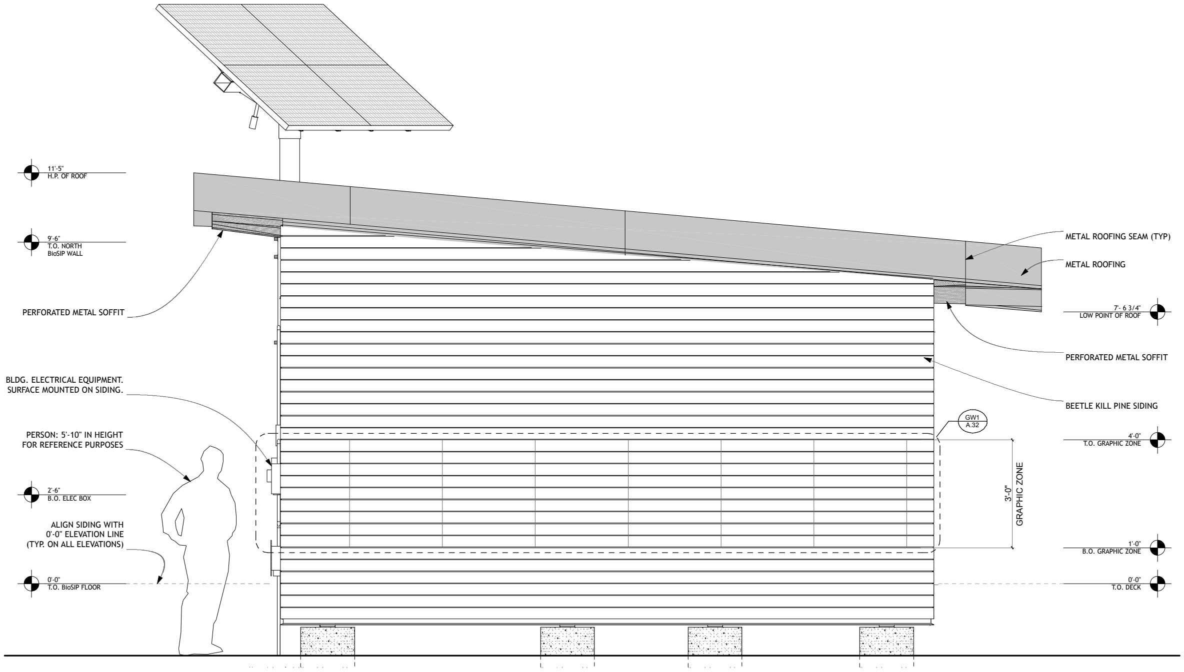


1. Tilting the PV panels left to right is called **"azimuth tracking"**. Azimuth tracking means the PV panels adjust during the day by turning east to west so they are always facing the sun. This is similar to the way a flower directs its petals toward sunlight.



2. Tilting the PV panels forward to backward is called **"elevational tracking"**. Elevational tracking involves tilting the PV panels on a seasonal basis. Since the sun is lower in the sky in winter than summer, the tracking system adjusts the panels in a more upright, or forward, position during the winter, and a more flat, or backward, position during the summer. This helps produce maximum solar efficiency throughout the year.

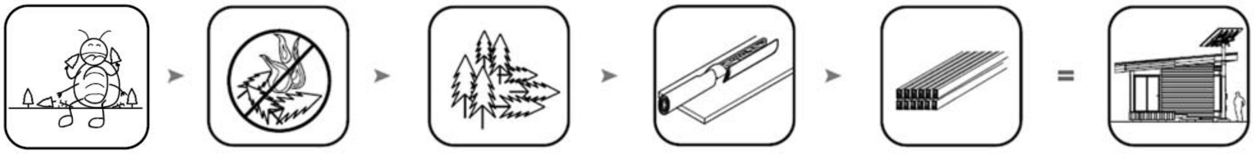
West Elevation



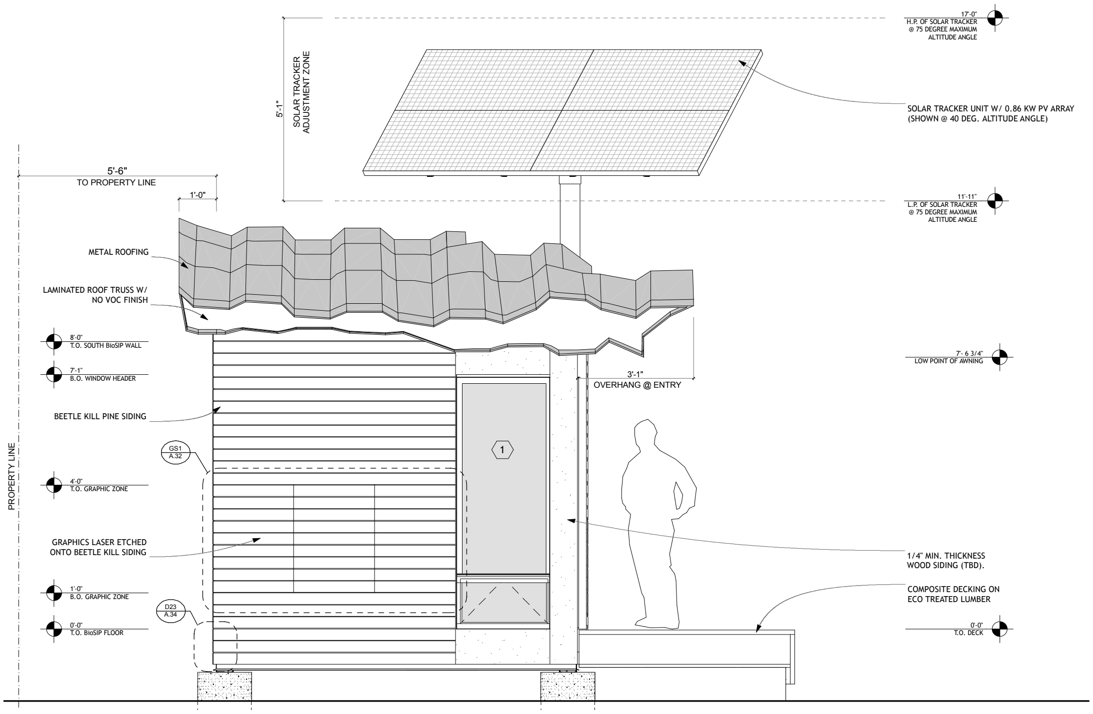
The building's west elevation provides statistics about potential for Colorado solid waste diversion through BioSIP production. This elevation also lists project collaborators and included project educational information such as beetle kill pine forest waste info.

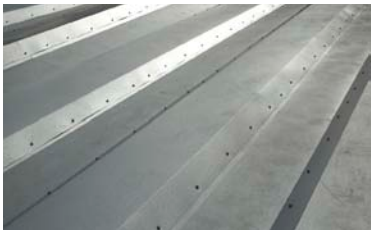
Beetle Kill Pine

The BioSIP Research Structure's exterior siding was fabricated from Colorado beetle kill pine tree salvage. Even while forest officials and communities work together, the Mountain Pine Beetle devastation continues. By removing large percentages of beetle-killed trees from forests, this wood waste can be converted into valuable construction material. And, by removing certain amounts of beetle-killed pine trees from forest floors, a potential forest fire fuel is eliminated.



South Elevation





Vented Roof

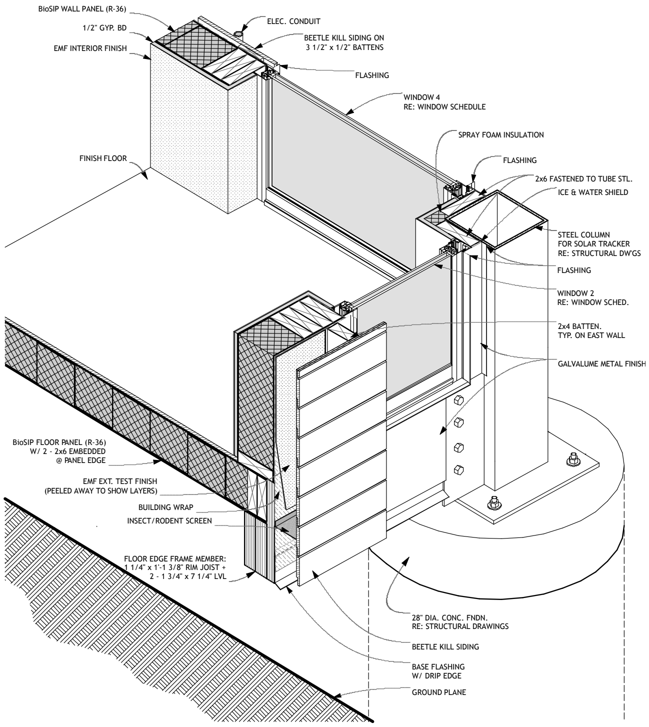
The 3D ripples of the building's recycled steel roof form an underlying air cavity below that enhances **air movement** across the weatherproofed BioSIP roof enclosure.

The ripples also prevent the sun's rays from hitting directly on the BioSIP roof panels, which contributes to cooler indoor building temperatures in the summer. The **airfoil roof can be thought of as an insulating hat for the building.**

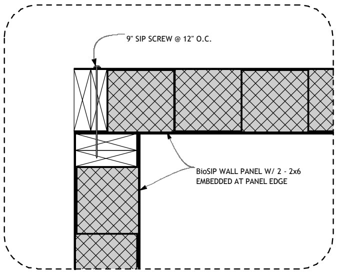
Project Site

The research structure is located at National Eco Wholesale, Inc. (NEW) and Ellie's headquarters in Boulder. NEW, a Boulder-based company, is the nation's first specialty distributor of exclusively natural and sustainable products. The company was founded in 2009 by Steve Savage, CEO and president, who has a national reputation as a successful green building entrepreneur, pioneer, and leader. NEW and Ellie's will be one of the first distributors of BioSIP products.

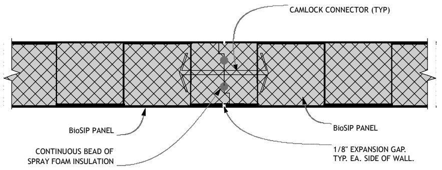
Construction Drawings



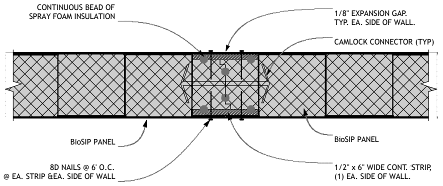
AXONOMETRIC DETAIL @ NORTHEAST CORNER
SHOWING CONSTRUCTION W/ FINISHES APPLIED
D3



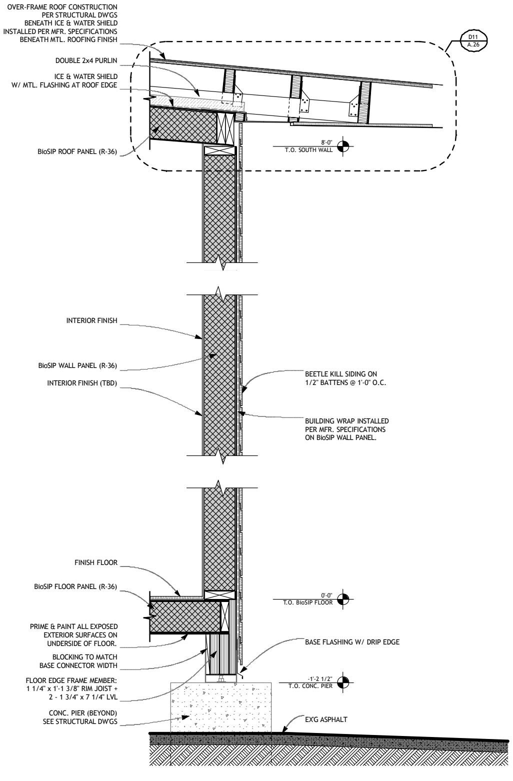
BioSIP CORNER DETAIL
SCALE: 1 1/2" = 1'-0"
D13



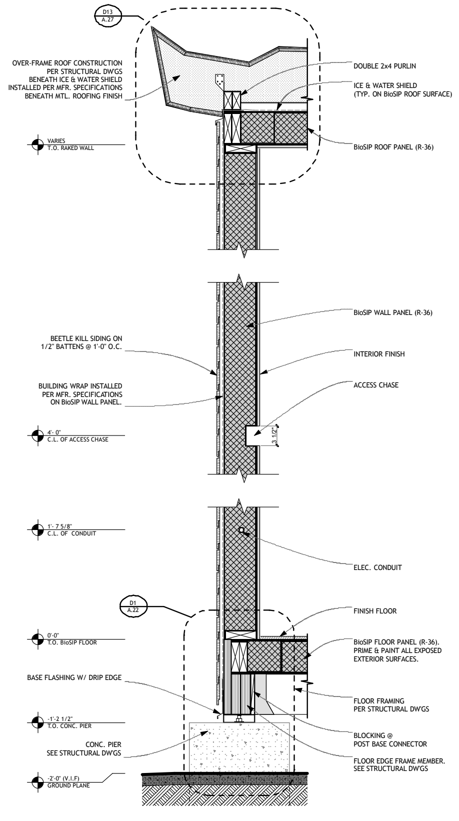
ROOF-TO-ROOF BioSIP CONNECTIONS
SCALE: 1 1/2" = 1'-0"
D18



WALL-TO-WALL VERTICAL BioSIP CONNECTION
SCALE: 1 1/2" = 1'-0"
D17



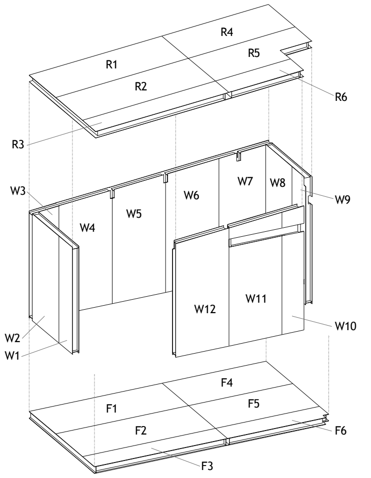
WALL SECTION 1: SOUTH WALL
SCALE: 3/4" = 1'-0"
WS1



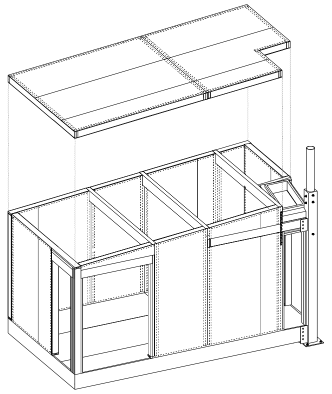
WALL SECTION 2: WEST WALL
SCALE: 3/4" = 1'-0"
WS2

BioSIP Fabrication and Installation

The BioSIP Research Structure was designed and built by the CU BioSIP grant team with assistance from CU architecture students. BioSIP wall, floor, and roof panels were fabricated by the BioSIP team at CU and were factory-foamed at ICS-Rocky Mountain. The foamed BioSIP panels were then delivered to the project site for quick on-site assembly by the BioSIP team.



BioSIP LAYOUT DIAGRAM
FRAMING REMOVED FOR CLARITY



BioSIPs W/ FRAMING INTEGRATED
SEE STRUCTURAL DRAWINGS

Time lapse showing the BioSIP installation process

Construction Process



Prefabricated solar tracker column being set onto concrete foundation (above left). Final dimensions were verified before BioSIP floor panels were set in place (above middle). Kellen Schauermann checking precision of BioSIP wall panel during installation (above right).


Construction team installing BioSIP wall panels (above left). Special thanks to Michael Honaker, Keaton Schauermann, Mathew Doner, and Drew Doner for their volunteer efforts during the two-day BioSIP wall, floor, and roof installation.

Eric Doner routing electrical wires through BioSIP prefabricated conduit channels prior to BioSIP roof panel installation (above right).



BioSIP Research Structure with BioSIP floor, wall, and roof panel enclosure in place and ready for installation of exterior finishes (above left). CU Bachelor of Environmental Design (B.ENVD) student, Patrick Westfeldt, installing prefabricated roof trusses on BioSIP roof panel enclosure (above center). Roof trusses were fabricated by the CU BioSIP team using diverted waste sources and digital fabrication methods.

Roof trusses installed and ready for the sheathing and metal roof finish (above right).

Research Structure with weather barrier installed; metal roof installation in progress (above left). CU Bachelor of Environmental Design students Cullen Taub and Patrick Westfeldt working with Eric Doner to install metal roof finish (above right).

Patrick Westfeldt and Eric Doner standing beneath solar tracker and PV array (above left). Installation of beetle kill siding on building's west elevation (above middle). Kellen Schauermann and Julee Herdt discussing color and finish options with Ryan Chivers (Artesano, LLC) for the eco-mortar finish used around the entry area (above right).

Completed BioSIP Research Structure (above left). BioSIP team members Julee Herdt, Kellen Schauermann, Eric Doner, and Patrick Westfeldt presenting the BioSIP Research Structure to the grant advisory committee on October 28, 2010 (above right).

The BioSIP Research Structure shows:

- BioSIPs as a SIP with performance and environmental improvements over current SIP products.
- Interior walls fabricated from a range of post-consumer and agricultural fiber mixes to allow viewers to see and touch the BioSIP fiberboard materials.
- A range of eco-friendly materials made from diverted waste sources



- BioSIP "Truth Wall" showing conduit routing- and framing member channels. These are a few of BioSIP's proprietary characteristics.
- An exposed window header reveals BioSIP's unique corrugated core.
- View looking upward through the skylight to the moving solar tracker.



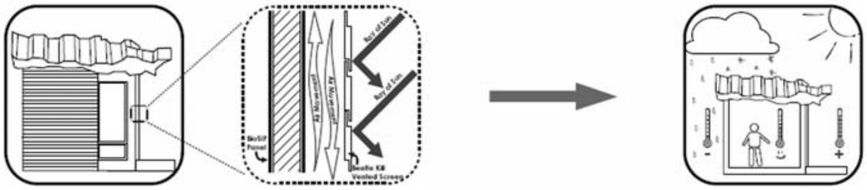
And, the research structure demonstrates BioSIPs as a petroleum-reduced construction method for lower embodied energy and lowered carbon emission design. For example, BioSIPs:

- Use less petroleum in manufacture than standard SIPs.
- Result in buildings requiring less energy to heat and cool.
- Will help lessen U.S. dependence on solid wood and petroleum-based materials and methods.

On-site testing and monitoring of the BioSIP Research Structure

BioSIP Research Structure tasks that are currently underway and will continue beyond the grant into product commercialization:

- BioSIP wall, floor, and roof product testing and monitoring
- Weather and humidity analyses
- Thermal analyses (through a professional energy audit of the building)



The BioSIP Research Structure's interior temperatures, relative humidity, and exterior site temperatures are measured on an on-going basis to allow the BioSIP team to monitor BioSIP wall, floor, and roof assembly performances over time.

A BioSIP Research Structure "Open House" will be held the first quarter of 2011 following completion of interior architectural developments and furniture applications. The BioSIP interior architecture and furniture developments will continue as work separate from this grant.

8. Continuing Research and Development

The BioSIP team has determined the next critical research step prior to commercialization to be:

1. Introduction of unique proprietary, natural additives for achieving long-term product durability (for increased moisture and fire resistance).

In order to achieve this next step, the team has organized the following research collaboration team:

- USDA Forest Products Lab (for fiber science)
- Natural Resource Research Institute (for fiber chemistry)
- Industry partners (a paper products manufacturer; a local SIP manufacturer)

Initial steps for this research have begun with promising results shown to date. Funding for completion of this final research stage will be obtained in early 2011. BioSIP commercialization will then follow.

9. Communication to Colorado Businesses and Communities

The BioSIP Research Structure serves as an educational tool and will be the location of a variety of environmental events that will be open to the public. The building's exterior graphics (laser etched into the beetle kill siding) allow the public to read and learn about the CDPHE grant project at any time.

BioSIPs, Inc is founded on the team's international and national credentials. Based on these BioSIPs, Inc will:

1. Capitalize on the qualifications of the Company founders and management team to sustain the project and move BioSIP products to commercialization;
2. Create partnering relationships with green architects, developers, manufacturers and builders to get BioSIP products into the marketplace,
3. Advance BioSIP science, technology and commercial production processes to keep BioSIPs, Inc at the forefront of environmental building material research development and application.

The BioSIP project is built on a history of national and international awards, grants, publications, and recognitions including:

- State of Colorado, Governor's Energy Office
- U.S. Department of Agriculture
- US Department of Energy
- International Solar Energy Society
- American Solar Energy Society
- National Home Builders Association
- American Institute of Architects
- U.S. Department of Housing and Urban Development, HUD
- PATH, Partnerships for Advancing Technologies in Housing
- National Geothermal Heat Pump Consortium
- Small Business Innovations Research Grants, USDA
- University of Colorado

CU's 2005 Solar Decathlon home was constructed with first-generation BioSIPs, a standard sandwich panel SIP invention.

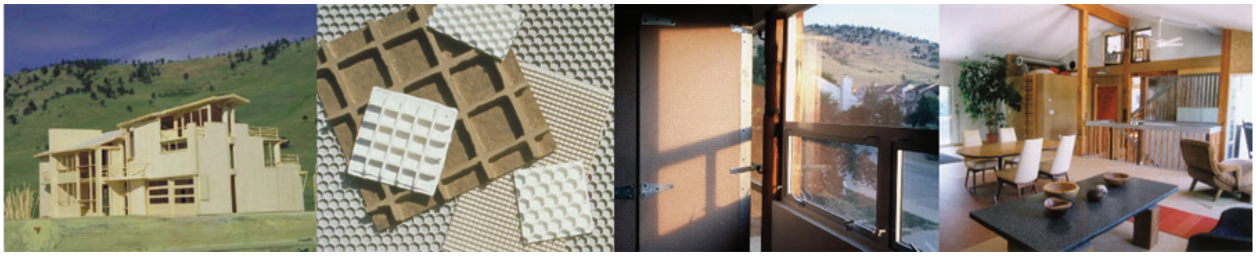

CU's trophies for the 2002 and 2005 first place, internationally award-winning Solar Decathlon projects.


Biobased interior of the 2005 CU Solar D home – constructed using first-generation BioSIPs integrated with a range of other petroleum-reduced building products.

First Generation BioSIPs as basis for this grant

CU's first place, 2005 CU Solar Decathlon solar home design and construction were based on Architecture Faculty Advisor Julee Herdt's engineered fiber research with the USDA FPL. For the project, the initial BioSIP invention was developed and led the way for Julee Herdt and Kellen Schauermann's new corrugated core BioSIP as a product of the CDPHE grant.

Julee Herdt was also the Architecture Advisor for CU's first-place-winning 2002 CU Solar Decathlon project. This project was constructed using standard SIPs combined with a wide range of environmental materials and was based on Herdt's SIP-constructed "Farmhouse" project – a low-embodied energy building that served as an early case study for development of first-generation BioSIPs.


The biobased, SIP-constructed "Farmhouse" by Julee Herdt

The CU BioSIP, CDPHE project is also founded on a previous collaboration with the U.S. Department of Housing and Urban Development Office, Partnerships for Advancing Technologies in Housing (PATH). PATH is a federal agency dedicated to *"… accelerating the commercialization and use of technologies that radically improve the quality, durability, energy efficiency, environmental performance, and affordability of America's housing market."* In 2005, at the international Solar Decathlon Competition, PATH selected BioSIPs from hundreds of new technologies developed throughout the U.S. as a product that the agency wanted to support. PATH called BioSIPs a *"…technology with potential to change the way America builds."* In 2006, prior to the CDPHE grant, Julee Herdt and Kellen Schauermann worked with PATH on BioSIP product marketing, focus group studies, and product design strategies. Ideas developed through this collaboration were applied in the CDPHE grant.

10. Financial Summary

	Grant Funds Spent	Matching/In Kind Amount (University of Colorado)	Matching/In Kind Amount (BioSIPs, Inc)	Total Amount
Personnel Salaries & Wages	$81,259.56	$48,050.64	-	$129,310.20
Fringe Benefits	$10,574.23	$16,776.53	-	$27,350.76
Tuition/Fees	-	-	-	-
Travel Costs	$8,236.99	-	-	$8,236.99
Materials/Supplies/Equipment (under $5,000)	$29,736.46	$1,075.45	$3,569.48	$34,381.39
Equipment Purchases (over $5,000)	-	$7,000.00	-	$7,000.00
Contractors/Subcontractors	$71,817.70	-	$ 42,880.06	$114,697.76
Consultants	-	-	-	-
Training/Educational classes	-	-	-	-
Marketing/Advertising	-	-	-	-
Other Direct Costs	$2,520.91	-	$407.40	$2,928.31
Indirect Costs	$36,084.13	-	-	$36,084.13
Total Project Cost:	$240,229.98	$72,902.62	$46,856.94	$359,989.54

Total award amount: $240,245

11. Final Conclusion

Through the CDPHE grant funding, the CU BioSIP Team was able to advance a technology that will allow large volumes of diverted waste to be recycled into viable, value-added building products. Now, at the conclusion of this grant, the CU BioSIP team would like to offer their continued support to the CDPHE team by allowing this successful project to serve the Advanced Technology Fund program as a tool for future presentations and demonstrations of the Colorado waste-diversion grant program.

BioSIP Structural Testing Report

March 5, 2010

State of Colorado Advanced Technology Fund Research Grant
CRS Chapter 370 Article 19.7 25-16.5-105(2)(b)
Colorado Department of Public Health & Environment, CDPHE

Project title:
Recycling Solid Waste into High-Performance, Environmental, Structural Insulated Panels

Project Lead: CU College of Architecture and Planning:
Julee Herdt, Principal Investigator
Professor of Architecture, Licensed Architect,
College of Architecture and Planning
BioSIP "Inventor of Record"

Kellen Schauermann, Co-Principal Investigator
Structural Testing Coordinator
College of Architecture and Planning
BioSIP "Inventor of Record"

Eric Doner, Research Assistant
College of Architecture and Planning

CU Technology Transfer
Kate Tallman, Director, UCB/UCCS

BioSIP Structural Testing Location:
College of Engineering and Applied Sciences
Civil, Environmental, & Architectural Engineering
Fast Hybrid Testing Laboratory
Michael Eck, Laboratory Operations Manager

BioSIP prototype set up for racking shear load testing at CU's Fast Hybrid Testing Laboratory, January 2010

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BioSIP Structural Testing Goals

The BioSIP structural testing goals sought through the State of Colorado grant were three-fold and as follows. They were to:

1. Determine whether BioSIP wall, floor, and roof, structural insulated panels developed through the State of Colorado grant meet and/or exceed SIP strengths for loading standards established by the American Society of Testing Materials (ASTM) and the ICC Evaluation Service, Inc.

2. Provide structural verification of BioSIP wall, floor, and roof panels so that BioSIPs developed through the grant can be applied in construction of the BioSIP Research Structure, a grant "Deliverable."

3. Determine whether a thinner BioSIP panel facing material could be used to achieve required panel strengths since a thinner facing material would result in lowered manufacturing inputs and product shipping costs. The BioSIP panel faces designed for the physical testing prototypes were based on the team's Finite Element Analysis (FEA) software applications. And, since the team's FEA research indicated that the BioSIP corrugated structural cores would carry the majority of structural forces for the BioSIP system -- rather than the skins carrying significant load -- a thinner skin could possibly be used for future panel design (standard SIP panels are designed to carry the majority of structural forces through their skins).

The BioSIP physical testing to be performed was expected to indicate whether the FEA-generated panel skin strengths coincided with the actual strengths or whether variations between the two could mean reduced overall, future panel skin designs.

Overall Successful Results of the BioSIP Tests

1. As described in the following report, BioSIP panels exceeded required SIP strengths and loading standards as established by the American Society of Testing Materials (ASTM) and the ICC Evaluation Service, Inc.

2. A licensed structural engineer's stamp can now be obtained to verify that the BioSIP wall, floor, and roof panels produced through the State of Colorado grant can be applied in construction of the BioSIP Research Structure.

3. Based on higher-than-required loading capacities of the BioSIP prototypes it is likely that future BioSIP panel skins can be designed as thinner substrates than those used in the testing.

Testing Location

Testing was conducted at CU's College of Engineering and Applied Sciences, Civil, Environmental, & Architectural Engineering, Fast Hybrid Testing Laboratory. Laboratory Operations Manager, Michael Eck advised on testing procedures and protocol and was present at all times during the BioSIP structural testing.

Testing methodology was coordinated based on ASTM criteria. Whenever lab constraints prevented the exact duplication of ASTM methodology, an appropriate alternative was developed in collaboration with, and was approved by, Michael Eck.

BioSIP Researcher Kellen Schauermann coordinated the testing and was assisted by team member, Eric Doner, BioSIP Research Assistant. Principal Investigator, Julee Herdt was present during certain parts of the tests.

BioSIP Structural Testing Categories

Building material testing standards are established by certification organizations that specify materials' required structural capacities for carrying dead and live loads such as those exerted due to wind, snow, seismic, and other conditions.

Axial compressive load tests are conducted in order to determine a material's capacity to withstand loads pressing in a downward direction. Transverse bending tests determine a material's ability to withstand a load applied perpendicularly to the plane of its longitudinal axis, such as a wind load acting on a building's walls. Racking load tests indicate a material's ability to withstand asymmetrical forces traveling through it, especially in diagonal directions.

In order to determine structural capacities of the BioSIP invention produced through the State of Colorado grant, the following tests were performed:

- **Axial compressive load testing**. Completed October/November 2009
- **Racking (shear) load testing.** Completed January/February 2010.
- **Transverse (bending) load testing.** Completed February 2010.

Overall BioSIP Testing Criteria

1. ICC Evaluation Service, Inc. "Acceptance Criteria for Sandwich Panels: AC04", approved in June 2007, provides a definition of and standards for SIPs under the International Building Code and Residential Building Codes and outlines SIP testing criteria, standards, and protocol.

2. The American Standards for Testing Materials (ASTM) International Designations, "Standard Test Methods of Conducting Strength Tests of Panels for Building Construction", published May 1, 2005 establishes testing criteria for building panel products. The following ASTM testing criteria were used as BioSIP testing protocol:

Axial Compressive Load Testing Criteria:
ASTM E72-05, Section 9

Transverse Bending Load Test criteria:
ASTM E72-05, Section 11

Racking Shear Load Test criteria
ASTM E72-05, Section 14

BioSIP Prototypes for Structural Testing

To complete the BioSIP axial, transverse, and racking tests a series of BioSIP testing prototypes were designed using ANSYS software developed through the State grant. The prototypes were then fabricated based on Herdt-Schauermann's provisionally-patented, corrugated core BioSIP panel design. The prototypes included high-density polyurethane foam insulation encapsulating the panel cores and 1/8" thick skins for the opposing panel faces. The prototypes were fabricated from Old Corrugated Container (OCC) feedstock. See Fig. 0.1 for an illustrative depiction of the BioSIP prototype assemblies.

The BioSIP testing prototypes also included an integrated wood frame sill- and header plate at the respective tops and bottoms of the test panels. Construction adhesive was used to join the framing lumber to the BioSIPs. Then, 8d nails were shot through the panel faces and into the lumber at 6" on center using a pneumatic nail gun. This attachment method simulates on-site construction methods and requirements.

The BioSIP prototypes were tested in the following sizes:
- 24" x 96" x 6" panels
- 48" x 96" x 6" panels

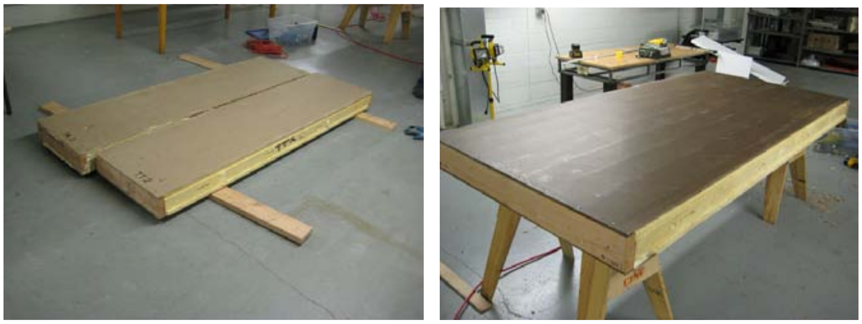


Photo 0.1: Example BioSIP physical testing prototypes as follows: 24"x96" prototype (left) and 48"x96" prototype.

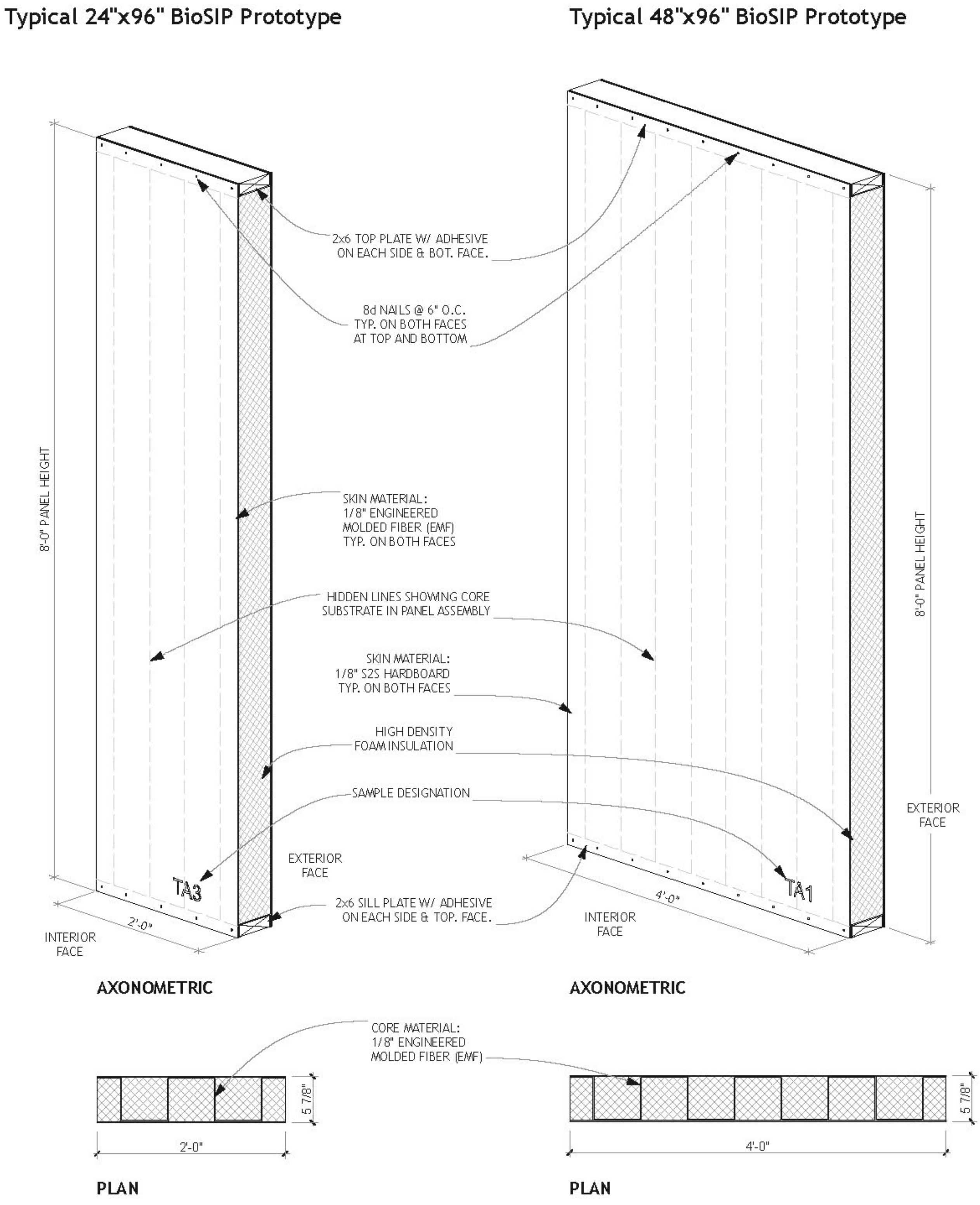


Figure 0.1: BioSIP Prototypes

PART 1: BioSIP Axial Compressive Load Testing

- BioSIPs were tested in axial loading in an MTS 1000-kip universal testing machine. (MTS Systems Corporation is the manufacturer of the test machinery. This machinery is regularly checked and calibrated to certify that it performs to certification standards).

- Steel I-beams were secured to the top and bottom of the BioSIP axial testing prototypes for even distribution of axial loads applied by the testing actuator.

- The BioSIP prototypes were loaded into the testing equipment via a crane and with manual assistance. Axial loads applied by the actuator were increased at a rate of 0.0315 inch/sec (0.8 mm/s), pausing at 0.025 inch increments over a period of 2.5 minutes.

- A testing prototype was fabricated for each axial test. The prototypes were then tested to panel failure.

- Data for panel deformation (shortening in axial direction) and lateral deflection were recorded during the testing process. The only variation from ASTM methodology was that external strain gauges were not employed, as the 1000 kip MTS actuator possessed an internal displacement measuring device to record panel shortening.

- A dial micrometer was mounted on a stand and used to measure lateral deflections at the mid-height of each test panel. See Photo 1.1.

- Photos 1.1-1.5 provide documentation of the test set up and testing process.

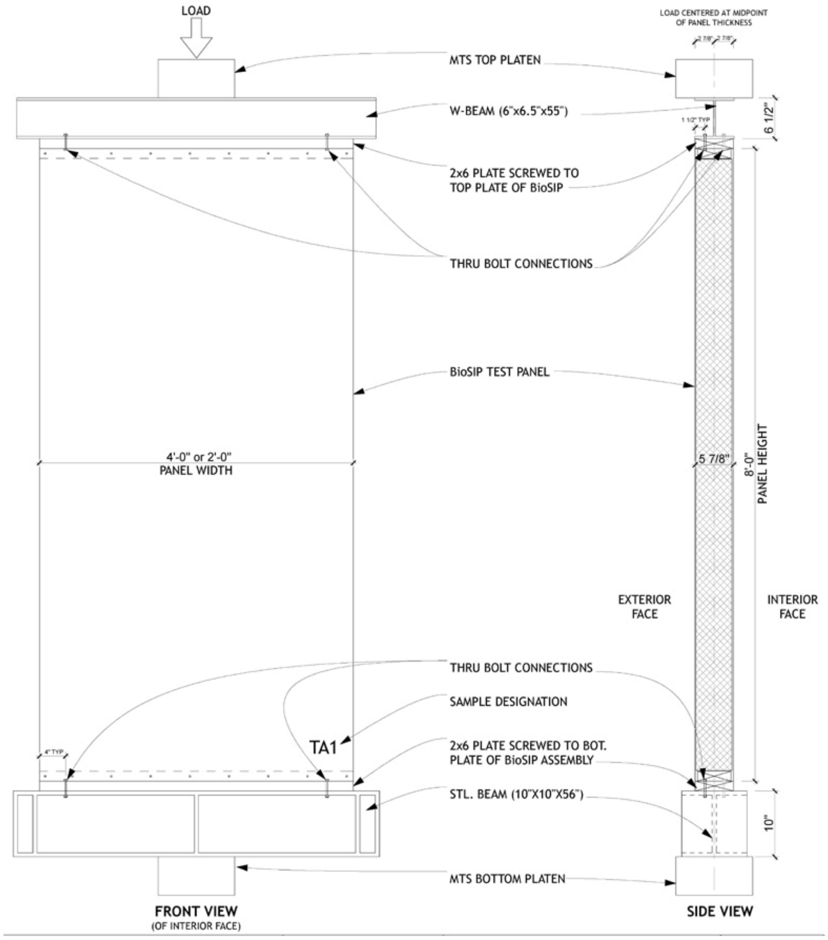


Figure 1.1: Axonometric drawing depicting Axial Compression Test Setup

Axial Test Results for BioSIP panels:

Table 1.1: Results for Axial Compressive Loads vs. Deflections for individual BioSIP test panels

Axial #1 (TR2, 2x8)				
Time	Load		Vert Displ at Ends	Hor Defl at Mid-Ht
min	lbs	plf	inch	inch
0.0	72	36	0.0000	0.0000
3.5	597	298	0.0024	0.0000
6.5	896	448	0.0126	0.0000
16.0	1,311	656	0.0299	0.0000
18.0	1,824	912	0.0445	0.0000
20.0	2,490	1,245	0.0598	0.0000
23.0	3,149	1,574	0.0744	0.0000
26.0	3,863	1,932	0.0896	0.0080
29.0	4,724	2,362	0.1049	0.0100
33.5	5,151	2,576	0.1148	0.0120
35.5	5,792	2,896	0.1249	0.0160
37.5	6,104	3,052	0.1305	0.0180
39.5	6,342	3,171	0.1346	0.0180
42.5	7,416	3,708	0.1572	0.0200
46.5	8,992	4,496	0.1830	0.0220
51.0	9,797	4,899	0.1998	0.0250
53.5	11,324	5,662	0.2236	0.0290
58.0	13,070	6,535	0.2564	0.0380
63.0	15,402	7,701	0.3042	0.0430
68.5	17,637	8,818	0.3603	0.0790
69.0	17,838	8,919	0.3680	0.0790

Axial #2 (TT3, 2x8)				
Time	Load		Vert Displ at Ends	Hor Defl at Mid-Ht
min	lbs	plf	inch	inch
0.0	914	457	0.0000	0.0000
2.0	1,763	881	0.0121	0.0050
6.0	2,831	1,416	0.0270	0.0100
10.0	3,802	1,901	0.0423	0.0130
13.0	4,919	2,460	0.0574	0.0180
16.0	5,969	2,985	0.0720	0.0200
19.0	7,105	3,553	0.0875	0.0240
22.0	8,070	4,035	0.1024	0.0280
24.5	8,662	4,331	0.1094	0.0300
27.5	9,407	4,703	0.1199	0.0320
30.5	9,871	4,935	0.1272	0.0340
34.5	11,550	5,775	0.1469	0.0400
37.0	12,789	6,395	0.1613	0.0450
40.0	14,096	7,048	0.1773	0.0500
43.0	14,950	7,475	0.1926	0.0570
46.5	16,428	8,214	0.2119	0.0630
50.5	17,826	8,913	0.2319	0.0710
54.0	19,377	9,688	0.2518	0.0800
57.5	21,147	10,574	0.2758	0.0930
61.5	22,960	11,480	0.2996	0.1020
66.0	25,329	12,665	0.3319	0.1100
70.5	26,758	13,379	0.3618	0.1210
75.0	28,223	14,111	0.3920	0.1300
78.3	28,711	14,356	0.4133	0.1320

Axial #3 (TT1, 4x8)				
Time	Load		Vert Displ at Ends	Hor Defl at Mid-Ht
min	lbs	plf	inch	inch
0.0	212	53	0.0000	0.0000
4.0	1,659	415	0.0200	0.0100
7.0	2,825	706	0.0352	0.0150
10.0	4,181	1,045	0.0514	0.0200
13.5	5,896	1,474	0.0720	0.0260
16.5	7,117	1,779	0.0859	0.0300
19.5	8,540	2,135	0.1014	0.0360
22.0	9,474	2,368	0.1104	0.0400
24.5	10,194	2,549	0.1182	0.0420
27.0	10,921	2,730	0.1271	0.0430
30.0	12,569	3,142	0.1425	0.0500
33.5	14,303	3,576	0.1606	0.0580
36.5	15,836	3,959	0.1761	0.0620
39.5	17,136	4,284	0.1910	0.0650
42.5	19,242	4,811	0.2113	0.0750
45.5	20,793	5,198	0.2270	0.0820
49.0	22,973	5,743	0.2501	0.0900
53.5	25,183	6,296	0.2753	0.0950
58.0	27,155	6,789	0.3000	0.1010
62.0	29,279	7,320	0.3310	0.1100
66.0	31,147	7,787	0.3606	0.1150
71.0	33,278	8,320	0.3915	0.1260
75.0	36,691	9,173	0.4234	0.1260
80.0	41,703	10,426	0.4737	0.1430
80.2	41,935	10,484	0.4761	0.1430

Note: Axial #1 tests employed a slightly different set-up than Axial #2 and Axial #3 and this resulted in the latter tests yielding lower load-to-displacement readings. This is because Axial #1 was the initial BioSIP prototype test and by request of the testing lab staff, a safety mechanism was installed in order to prevent displacement of the panel from the testing equipment in the event of a catastrophic failure. The safety mechanism employed was a 2x6 wood framing member attached to the top and bottom of the Axial #1 BioSIP test prototype so that a bolted connection could be achieved between the prototype and the steel beam at the top and bottom of the prototype (the steel beam held the prototype to the actuator).

Axial #1 tests yielded higher-than-expected vertical displacement readings and a lowering of the test samples load/deflection ratio. It was determined that the lowered performance of the prototype was likely due to the installation of the wood plate safety mechanisms. Therefore, in subsequent Axial #2 and Axial #3 tests, a lower profile, 1/4" steel plate was installed at the top and bottom of the test panels to eliminate unwanted displacement. See Photo 1.2.

Table 1.2: Axial Compression Results at Key Points for Determining Allowable Loads

Load does not include the weight of the load beam or the self weight of the test panel

Test Name	Sample Name	Panel Properties		Load at 0.125" Defl.		Max Load		Defl. at Max Load		**Failure Characteristics**
		Size (in)	(lbs)	(lbs)	(plf)	(lbs)	(plf)	Vert (in)	Horz (in)	Test samples failed by a combination of the skins cracking and buckling near the fasteners at the top and bottom of the panel.
Axial 1*	TR2	24" x 96"	68.5	5,823	2,911	17,838	8,919	0.3680	0.0790	
Axial 2	TT 3	24" x 96"	68.5	9,694	4,847	28,711	14,356	0.4133	0.1300	
Axial 3	TT1	48" x 96"	127.5	10,884	2,721	41,935	10,484	0.4761	0.1430	
* see note above	**Test Standard: ASTM E72, Section 9 - Compressive Load**									

Figure 1.2a: Results for Compressive Load (lbs) vs. End Deflections (in)

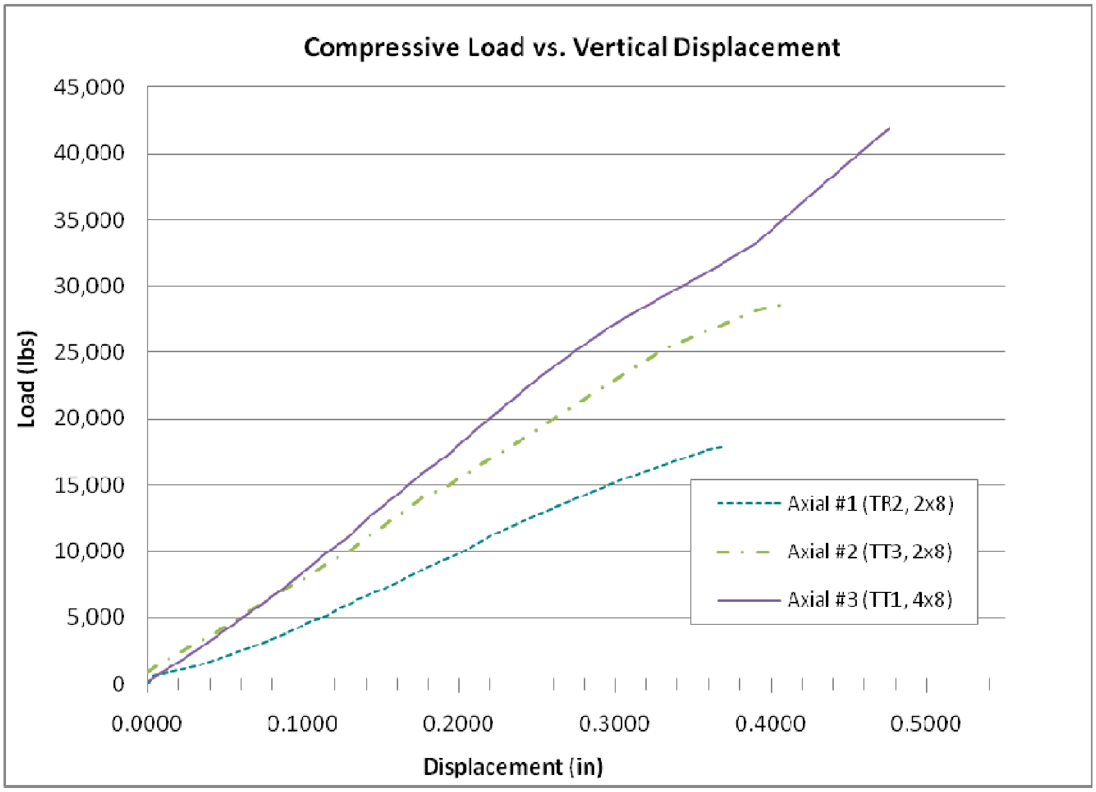


Figure 1.2b: Results for Compressive Load (plf) vs. End Deflections (in)

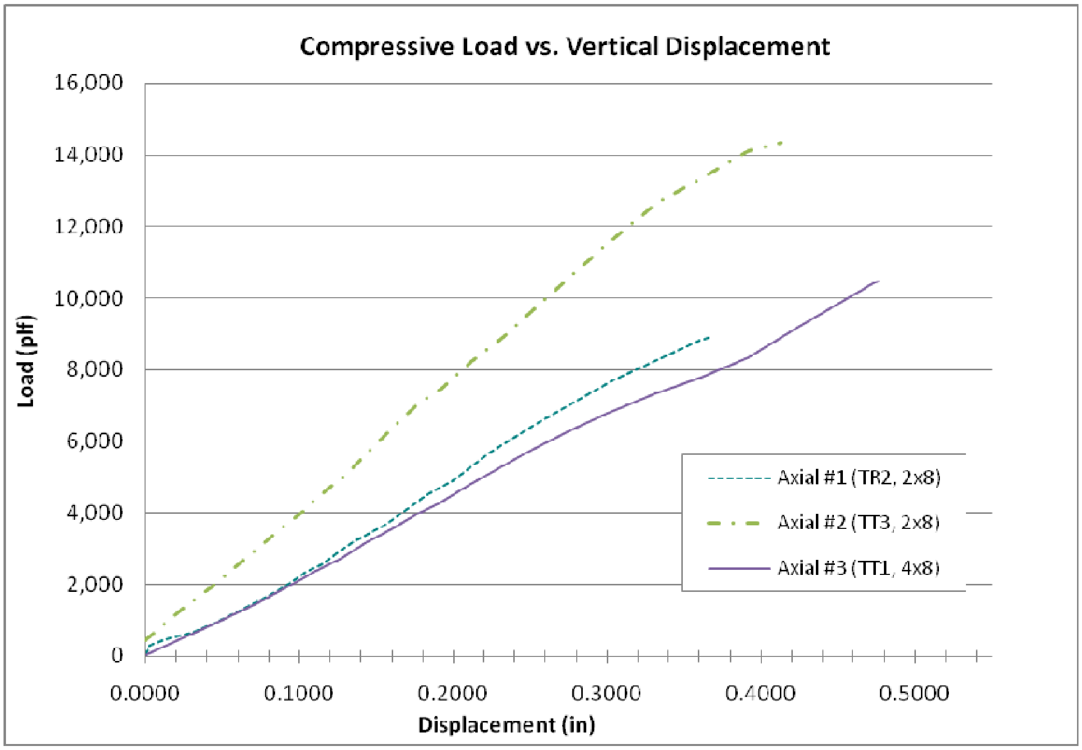


Figure 1.3a: Results for Compressive Load (lbs) vs. Lateral Deflection (in)

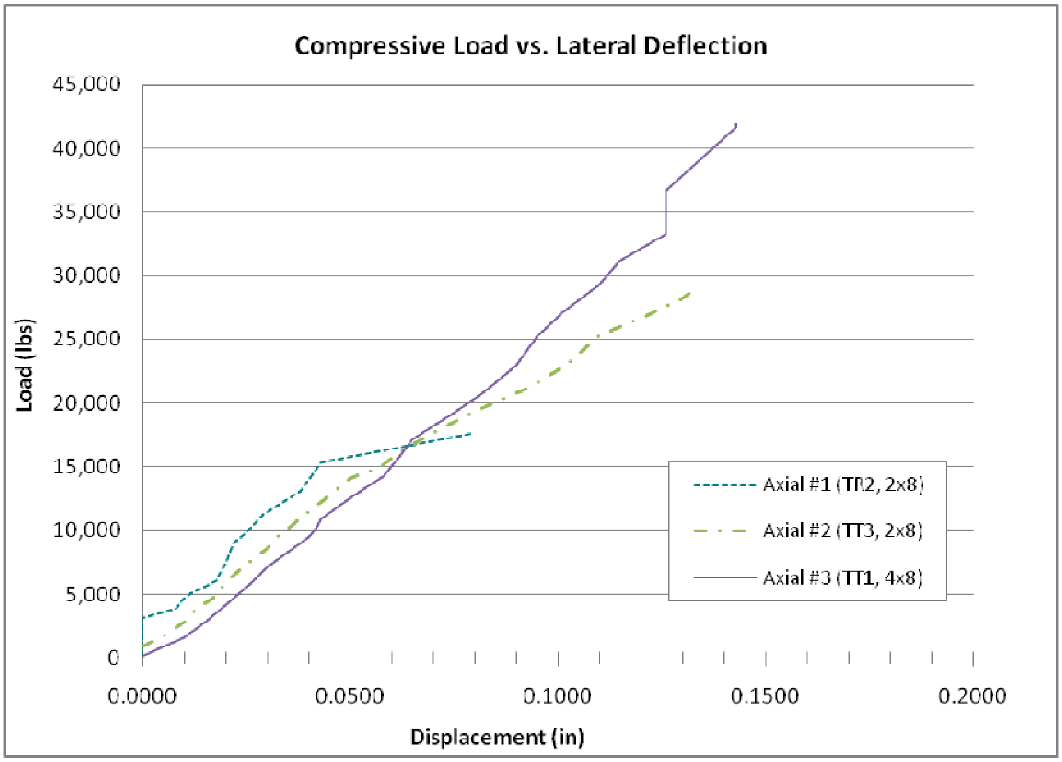
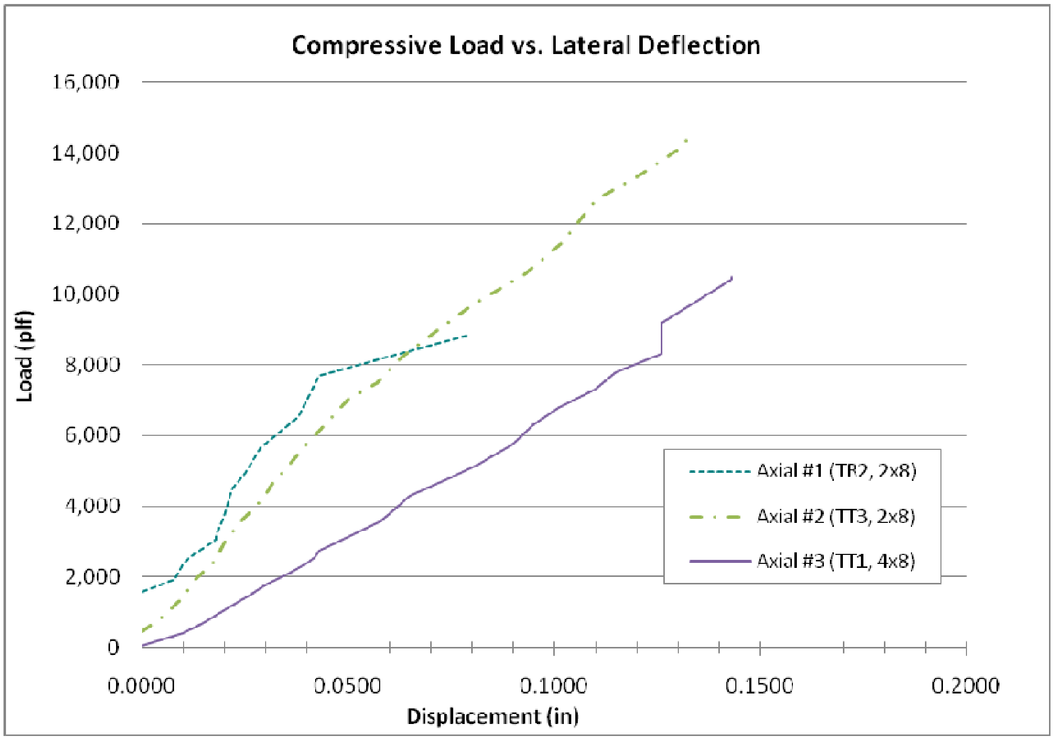


Figure 1.3b: Results for Compressive Load (plf) vs. Lateral Deflection (in)



Successful Overall Results of the BioSIP Axial Compressive Load Tests

BioSIP axial loading tests indicate that BioSIPs should exceed existing SIP manufacturers' panel strengths in actual product certification tests and that BioSIPs will be among the strongest structural insulated panels in the marketplace.

Summary of the Axial Compressive Load Tests:

Axial loading tests shown in Figs. 1.2a, 1.2b, 1.3a, and 1.3b are close in range indicating that BioSIPs are stable in withstanding increasing compressive loads over time. And,

- In testing to failure, the prototypes ultimately failed through a combination of cracking and buckling of the skins near the 8d steel nail connectors at both the tops and bottoms of the panels. Photos 1.3-1.5 provide visual documentation of the testing process and panel failure locations.
- According to ICC criteria, SIP allowable axial loads are determined from the compressive load at which a net axial deformation of 0.125 inch occurs in the panel or the ultimate load divided by a factor of safety of 4, whichever is lower. Table 1.3 provides a summary of this calculation and shows appropriate allowable load capacities for BioSIPs.
- Table 1.4 summarizes BioSIP testing loads, deflections, and strain results at calculated maximum allowable loads.

The BioSIP axial load testing goals were achieved as follows:

Prior to the BioSIP axial physical testing, and based on BioSIP FEA analyses and research into existing SIP product strengths, the BioSIP team set a goal of achieving 3,164 pounds per linear foot (plf) allowable load in axial compression. Results of the BioSIP physical testing show that:

- The 24" x 96" BioSIP testing prototypes yielded allowable loads of 3,589 plf, and thereby exceeded the team's goal by 425 plf.
- The 48" x 96" BioSIP prototypes yielded an allowable load of 2,621 plf.

Table 1.3: Calculated Allowable Loads for BioSIPs in Axial Compression

24" x 96" panels with EMF skins			48" x 96" panels with hardboard skins		
Data based on test Axial #2	Failure Load,	Allowable Load,	Data based on test Axial #3	Failure Load,	Allowable Load,
	P_f	$P_a = P_f$ / SF*		P_f	$P_a = P_f$ / SF*
	plf	plf		plf	plf
	14,356	3,589		10,484	2,621
	Load at 0.125" Defl.	Use the data from above b/c it is the smaller of the two allowable loads		Load at 0.125" Defl.	Use the data from above b/c it is the smaller of the two allowable loads
	P_{def}			P_{def}	
	plf			plf	
	4,847			2,721	
	Allowable Load =	**3,589 plf**		**Allowable Load =**	**2,621 plf**

* A safety factor (SF) of 4.0 was applied to failure load according sec 4.4.2 of "Acceptance Criteria for Sandwich Panels"

Table 1.4: Strains and Deflections at Allowable Loads

24" x 96" panels with EMF skins					48" x 96" panels with hardboard skins				
Allowable Line Load, P_a	Vertical Deflection	Strain	Lateral Deflection		Allowable Line Load, P_a	Vertical Deflection	Strain	Lateral Deflection	
plf	in	in/in	in	as L/xxxx	plf	in	in/in	in	as L/xxxx
3,589	0.0898	0.094%	0.0240	L/4000	2,621	0.1210	0.126%	0.0430	L/2232

Documentation of the BioSIP Axial Compressive Load Tests

Photo 1.1 BioSIP axial test sample being loaded into MTS 1000-kip universal testing machine (left). Dial micrometer measuring BioSIP deflection at mid-height (right).

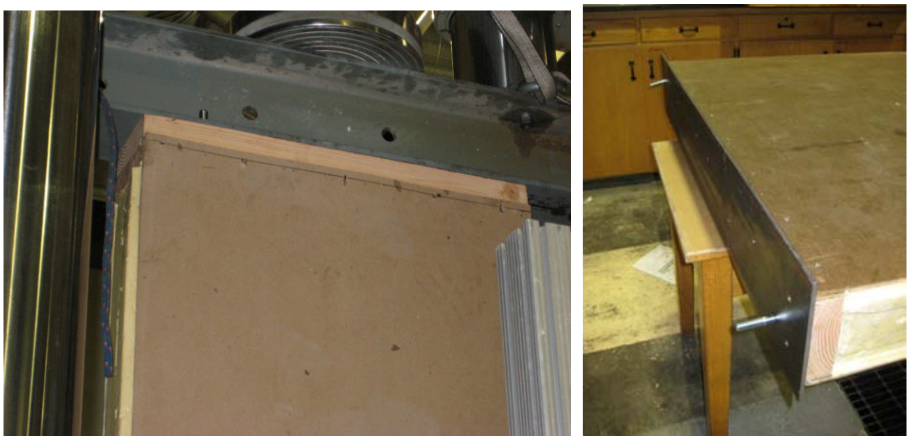


Photo 1.2: Axial #1(left) and Axial #2, Axial #3 (right) depict the variations in testing as described above in Table 1.1: "Results for Axial Compressive Loads vs. Deflections for individual BioSIP test panels." The Axial #1 test employed wood framing safety mechanisms at test panel top and bottom, whereas Axial #2 and Axial #3 employed a lower profile, 1/4" steel plate at test panel top and bottom.

Photo 1.3: **Axial #1 (left) and Axial #3 (right) load testing in progress.**

Photo 1.4: BioSIP team and lab staff monitoring in-progress axial load testing.

Photo 1.5: Detail showing failure of BioSIP Axial #2 test prototypes at: (left) interior face of panel skin at sill plate connection, and (right) at exterior face of panel skin at sill plate connection.

PART 2: TRANSVERSE BENDING LOAD TESTING

- BioSIP prototypes were tested according to ASTM E72-05, Section 11, with one exception being that the test specimen was oriented horizontally (instead of vertically) for logistical reasons based on available equipment and space in the testing lab. See Fig. 2.1. Lab Operations Monitor Mike Eck verified that testing in this orientation was acceptable and would yield equivalent results as would testing in the vertical direction.

- The BioSIP prototypes were placed (elevated off the floor) with their top and bottom surfaces bearing against the curved diameter of two, 3.5” diameter, schedule 40 steel pipes so that there was an unsupported span of 92 inches. The two-point (quarter span) loading method was used according to ASTM methodology.

- Transverse loads were then applied to the BioSIP prototypes using a 22-kip MTS actuator mounted to cast concrete sections that were held in place to the lab floor by tensioned steel rods. All loads were applied in "displacement mode" at a rate of 0.0625 inch/sec, pausing at 500 lb increments over a period of 2.5 minutes. Prototypes were tested until panel failure.

- Data for mid-point deflection of the BioSIP testing prototypes were recorded by a measuring device placed internally in the actuator. Real-time readings of the transverse loading reactions of the BioSIP prototypes were also recorded by an externally mounted linear variable differential transformer (LVDT). Absolute displacement of the BioSIP prototypes, caused by the transverse load being placed on it, was recorded by the actuator while the externally mounted LVDT recorded the mid-point deflection. The final displacement was the sum of the actuator and LVDT readings.

- See Photos 2.1 through 2.5 below for documentation of the BioSIP transverse load test set up, process, and data.

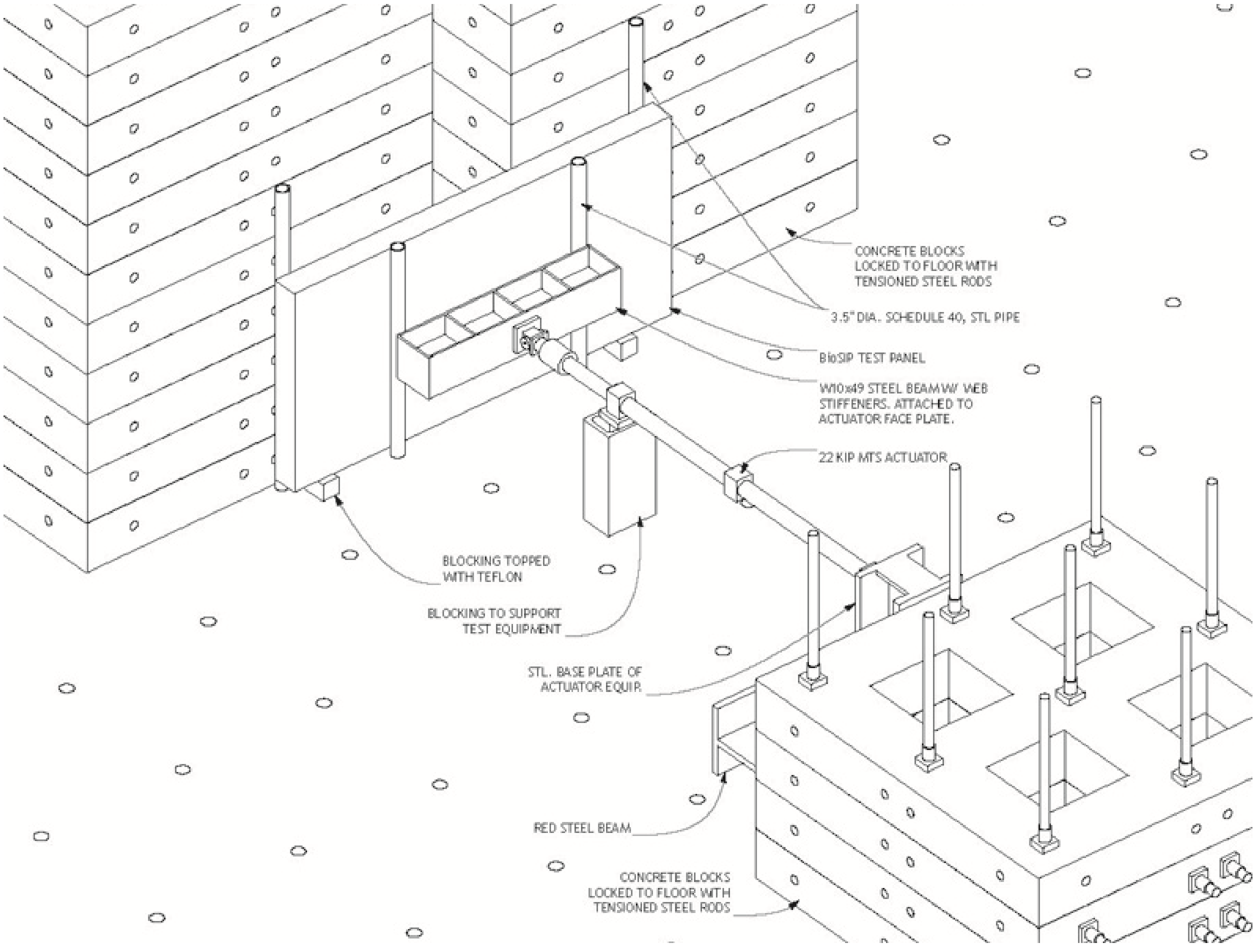


Figure 2.1: Transverse Bending Test Setup

Transverse Bending Test Results for BioSIP panels:

Table 2.1: Results for Transverse Load vs. Deflections for individual BioSIP test panels

Bending #1 (TA3, 2x8)			
Time	Load		Deflection
min	lbs	lbs/sf	inch
0.00	160	10	0.0000
1.50	281	18	0.0140
5.00	507	32	0.0396
9.50	776	48	0.0711
12.00	996	62	0.0955
13.50	1,500	94	0.1499
15.50	1,761	110	0.1790
16.00	2,011	126	0.2075
19.00	2,493	156	0.2630
21.00	2,605	163	0.2763
24.00	3,198	200	0.3435
27.00	3,760	235	0.4080
30.00	4,348	272	0.4762
34.00	4,839	302	0.5372
37.00	5,127	320	0.5760
40.00	5,659	354	0.6430
41.00	5,973	373	0.6828
44.00	6,068	379	0.6991
45.50	6,447	403	0.7498
48.00	6,849	428	0.7984
51.00	7,254	453	0.8594
51.50	7,515	469.7	0.8933
56.00	7,959	497.4	0.9794
59.00	8,352	522	1.0480
60.50	8,686	542.9	1.1406
62.00	8,805	550.3	1.2301

Bending #2 (TA2, 2x8)			
Time	Load		Deflection
min	lbs	lbs/sf	inch
0.00	97	6.0	0.0000
2.00	515	32.2	0.0594
4.50	1,012	63.2	0.1225
7.00	1,142	71.4	0.1384
8.00	1,502	93.9	0.1841
11.00	1,996	124.7	0.2465
13.50	2,538	158.6	0.3105
14.50	3,008	188.0	0.3676
18.00	3,385	211.6	0.4144
20.00	3,960	247.5	0.4889
21.50	4,212	263.3	0.5176
23.00	4,999	312.4	0.6147
26.00	5,524	345.2	0.6848
27.00	5,997	374.8	0.7490
30.50	6,294	393.4	0.8025
32.00	6,997	437.3	0.9035
35.50	7,563	472.7	0.9966
37.50	7,948	496.8	1.1265
40.00	7,622	476.4	1.1611
43.00	8,229	514.3	1.2695
44.33	8,446	527.9	1.3534

Bending #3 (TA1, 4x8)			
Time	Load		Deflection
min	lbs	lbs/sf	inch
0.00	10	0.3	0.0000
0.50	156	4.9	0.0171
1.00	276	8.6	0.0657
1.50	327	10.2	0.1013
2.50	507	15.9	0.1660
5.00	1,003	31.4	0.2047
8.00	1,537	48.0	0.2411
10.50	2,023	63.2	0.2712
13.00	2,469	77.1	0.2994
13.50	2,915	91.1	0.3259
16.50	3,558	111.2	0.3679
17.00	3,965	123.9	0.4012
18.00	4,720	147.5	0.4642
18.50	5,010	156.5	0.4893
22.00	5,442	170.0	0.5274
22.50	5,854	182.9	0.5608
23.50	6,609	206.5	0.6247
24.50	7,037	219.9	0.6646
27.00	7,633	238.5	0.7162
27.50	8,011	250.3	0.7479
28.00	8,444	263.9	0.7834
29.00	9,049	282.8	0.8379
32.00	9,545	298.3	0.8894
33.00	10,198	318.7	0.9485
34.00	10,842	338.8	1.0090
34.50	10,985	343.3	1.0289
36.50	10,753	336.0	1.0293
39.17	11,029	344.7	1.0722

Table 2.2: Transverse Bending Test Results

Load does not include the weight of the load beam or the self weight of the test panel

Test Name	Sample Name	Panel Properties		Unsupported Span	Max Load		Defl. at Max Load
		Size (in)	Weight (lbs)	inch	lbs	lbs/sf	inch
Bending #1	TA3	24" x 96"	69.0	92.0	8,805	550	1.23
Bending #2	TA2	24" x 96"	68.5	92.0	8,446	528	1.35
Bending #3	TA1	48" x 96"	127.0	92.0	11,029	345	1.07
Test Standard: ASTM E72, Section 11 - Transverse Load							
Failure Characteristics							
Test samples failed by severe bending and buckling of the skin along the load beam.							

Figure 2.2a: Results for Transverse Load (lbs) vs. Deflection (in)

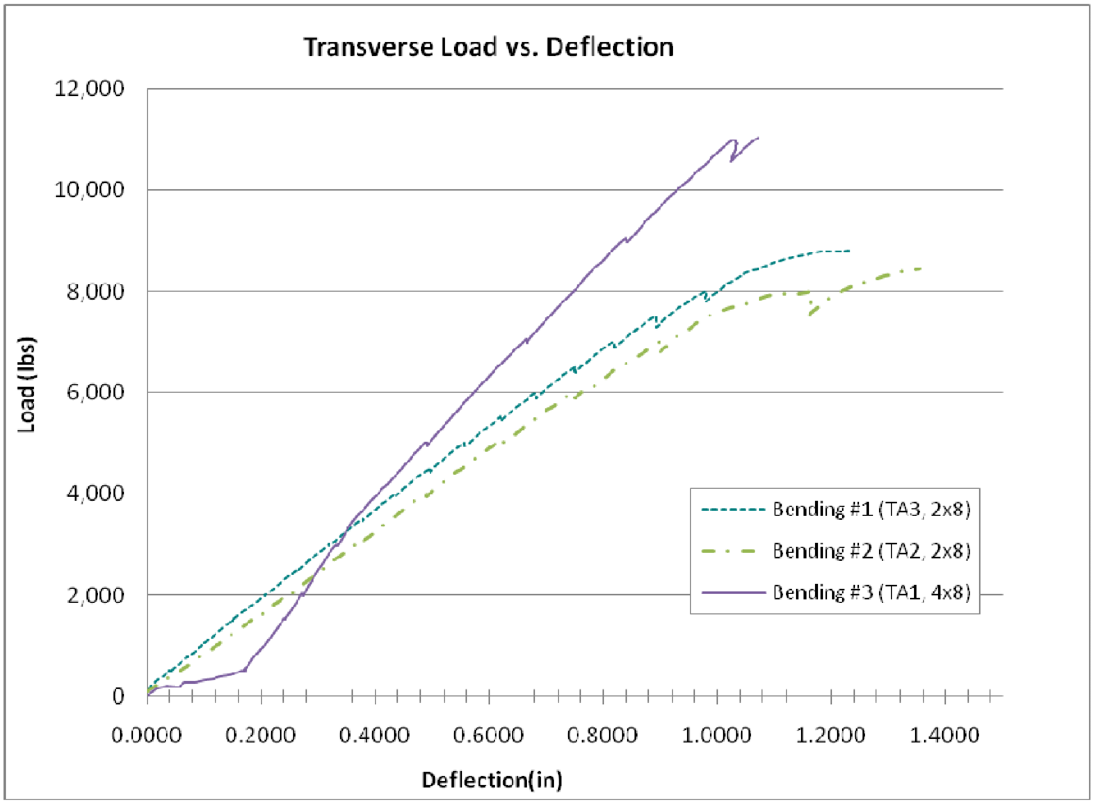
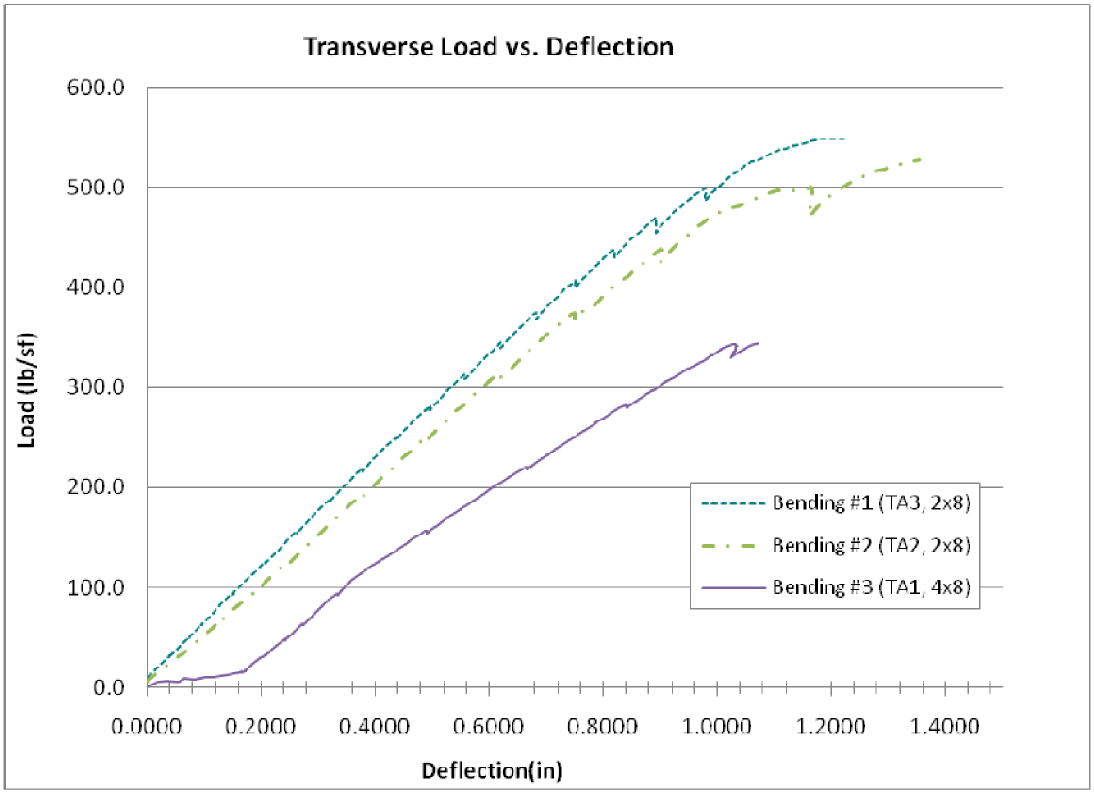


Figure 2.2b: Results for Transverse Load (lbs/sf) vs. Deflection (in)



Successful Overall Results of the BioSIP Transverse Bending Load Tests

The transverse loading tests indicate that BioSIPs will significantly exceed existing SIP manufacturers' panel strengths making BioSIPs among the strongest structural insulated panels in the marketplace.

Summary of the BioSIP Transverse Bending Load Tests:

Results indicated in Figs. 2.2a and 2.2b show that all test samples are close in range and that BioSIPs remain stable under an increase of transverse loads over time. The lower sloped portion shown in Bending #3 (between 0.0-0.2 inches) was caused by settling of the test setup during the initial loading; following settling, the slope returned to normal beginning at 0.200 inches to panel failure.

- The prototypes ultimately failed due to extreme bending and buckling of the panels along the steel member that acted as the quarter-point load applicator. Photos 2.1-2.5 provide visual documentation of the testing process and panel failure locations.
- According to ICC criteria, the allowable transverse loads are determined from the ultimate load to be applied divided by a safety factor of 4, and at L/180, L/240, and L/360 deflection points. Table 2.3 provides a summary of these calculations and shows appropriate allowable transverse load capacities of BioSIPs.
- Table 2.4 summarizes BioSIP stiffness calculations.

The BioSIP transverse load testing goals were achieved as follows:

Based on BioSIP FEA analyses and research into existing SIP product strengths, the BioSIP team set a goal of achieving 60 pounds per square foot (lbs/sf) allowable load in transverse bending. Results of the BioSIP physical testing show that:

- The 24" x 96" BioSIP testing prototypes yielded allowable loads of 135 lbs/sf, and thereby exceeded the team's goal by 75 lbs/sf.
- The 48" x 96" BioSIP prototypes yielded an allowable load of 86 lbs/sf, and thereby exceeded the team's goal by 11 lbs/sf.

<table>
<tr><th colspan="10">Table 2.3: Results at Key Deflection Limits</th></tr>
<tr><th colspan="5">24" x 96" panels with EMF skins</th><th colspan="5">48" x 96" panels with hardboard skins</th></tr>
<tr><td colspan="5">Based on average results from Bending #1 & Bending #2</td><td colspan="5">Based on results from Bending #3</td></tr>
<tr><td>Initial Defl.</td><td colspan="2">Load</td><td colspan="2">Deflection</td><td>Initial Defl.</td><td colspan="2">Load</td><td colspan="2">Deflection</td></tr>
<tr><td>inch</td><td colspan="2">lbs/sf</td><td colspan="2">inch</td><td>inch</td><td colspan="2">lbs/sf</td><td colspan="2">inch</td></tr>
<tr><td>L/180</td><td colspan="2">272</td><td colspan="2">0.51</td><td>L/180</td><td colspan="2">161</td><td colspan="2">0.51</td></tr>
<tr><td>L/240</td><td colspan="2">204</td><td colspan="2">0.38</td><td>L/240</td><td colspan="2">116</td><td colspan="2">0.38</td></tr>
<tr><td>L/360</td><td colspan="2">143</td><td colspan="2">0.26</td><td>L/360</td><td colspan="2">59</td><td colspan="2">0.26</td></tr>
<tr><td rowspan="3">Allowable Load, P_a</td><td colspan="2">Failure Load, P_f</td><td colspan="2">Allowable Load, $P_a = P_f / SF$*</td><td rowspan="3">Allowable Load, P_a</td><td colspan="2">Failure Load, P_f</td><td colspan="2">Allowable Load, $P_a = P_f / SF$*</td></tr>
<tr><td>lb</td><td>lbs/sf</td><td>lb</td><td>lbs/sf</td><td>lb</td><td>lbs/sf</td><td>lb</td><td>lbs/sf</td></tr>
<tr><td>8,625</td><td>539</td><td>2,156</td><td>135</td><td>11,029</td><td>345</td><td>2,757</td><td>86</td></tr>
<tr><td colspan="10">* A safety factor (SF) of 4.0 was applied to failure load according sec 4.2.4 of "Acceptance Criteria for Sandwich Panels"</td></tr>
</table>

<table>
<tr><th colspan="6">Table 2.4: Average Flexural "Stiffness" Values</th></tr>
<tr><th colspan="3">24" x 96" panels with EMF skins</th><th colspan="3">48" x 96" panels with hardboard skins</th></tr>
<tr><td colspan="3">Based on average results from Bending #1 & Bending #2</td><td colspan="3">Based on results from Bending #3</td></tr>
<tr><td>Load, P</td><td>Deflection, d</td><td>Stiffness, k=P/d</td><td>Load, P</td><td>Deflection, d</td><td>Stiffness, k=P/d</td></tr>
<tr><td>lbs</td><td>inch</td><td>lb/in</td><td>lbs</td><td>inch</td><td>lb/in</td></tr>
<tr><td>4313</td><td>0.503</td><td>8,576</td><td>5576</td><td>0.538</td><td>10,356</td></tr>
<tr><td colspan="6">The stiffness ("k" values) represent the average load required to generate 1" of deflection and can be seen as the slopes of the load/deflection curves. The load and deflection values were selected approximately halfway to the ultimate load.</td></tr>
</table>

Documentation of the BioSIP Transverse Bending Load Tests

Photo 2.1: BioSIP transverse bending prototypes shown undergoing Bending #1 (left) and Bending #3 (right).

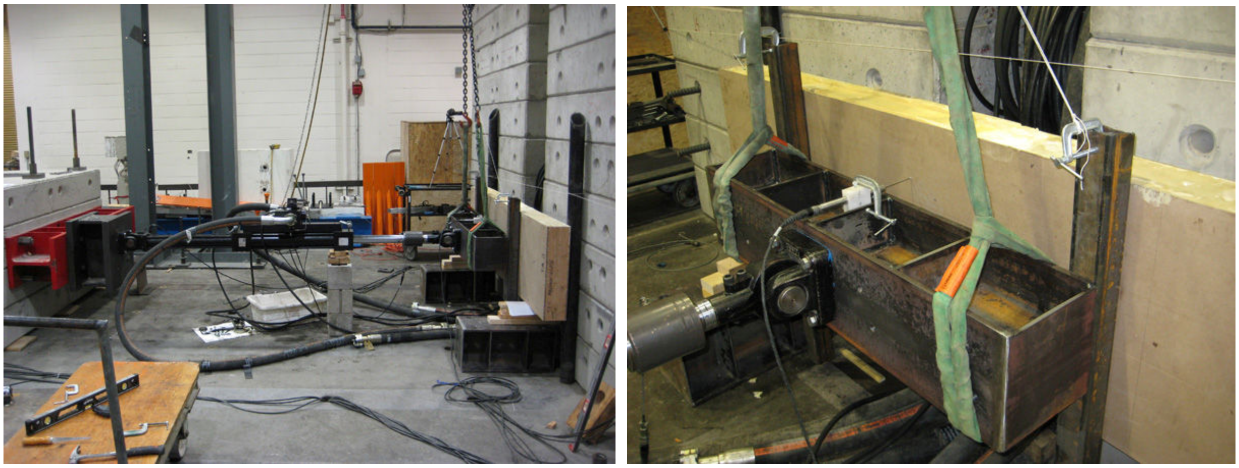


Photo 2.2: Side-view of BioSIP transverse bending test setup (left). Close-up of externally mounted LVDT (right).

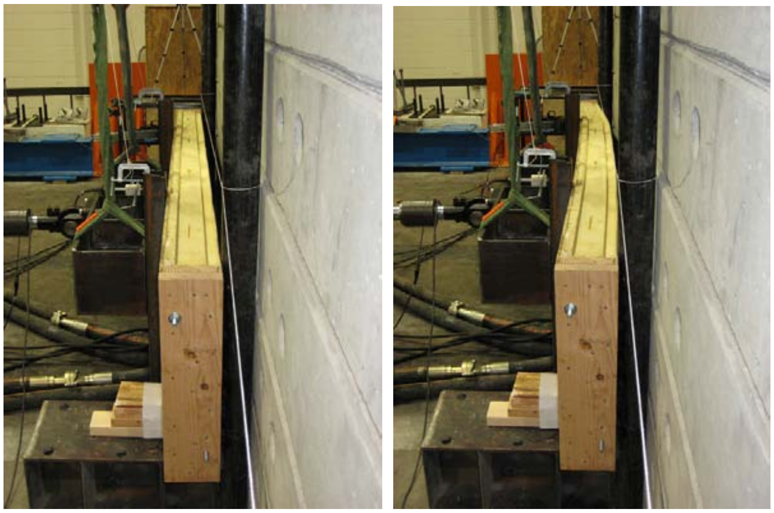


Photo 2.3: BioSIP transverse bending prototype prior to testing (left) and shown at testing-to-failure position at (right).

Photo 2.4: Close-up of BioSIP prototype at testing-to-failure position for Bending #3 (left) and Bending #2 (right).

Photo 2.5: Kellen Schauermann and Michael Eck monitoring testing in progress (left) and discussing panel failure (right).

PART 3: RACKING SHEAR LOAD TESTING

- BioSIP prototypes were tested according to ASTM E72-05, Section 14. Since the BioSIP team does not yet have full fabrication capabilities, it was not possible to conduct the test on an ASTM-prescribed 8 foot by 8 foot wall sample. Instead, the racking shear load test was conducted on individual 2' x 8' and 4' x 8' BioSIP panels.

- The BioSIP racking load test was performed by placing the testing prototype horizontally (and elevated off of the floor) and by rigidly affixing one 4' panel side to an anchored cast concrete section. A lateral force was then applied to the opposite 8' side of the BioSIP prototype using a 22 kip MTS actuator. See Fig. 3.1.

- Loads were then applied in displacement mode to the BioSIP prototype test panel at a rate of 100 lbs/min. Each BioSIP test sample was loaded according to the ASTM standard as follows:

  - Loaded up to 200 lbs (50 plf), then load removed back to 0 lbs.
  - Loaded up to 400 lbs (100 plf), then load removed back to 0 lbs.
  - Loaded up to 600 lbs (150 plf), then load removed back to 0 lbs.
  - BioSIP prototype then loaded to failure

- Deflection of the BioSIP prototype was measured and recorded with three externally mounted linear variable differential transformers (LVDTs) placed at the following locations:
  - Upper left corner of the test sample for measuring uplift (Uplift).
  - Upper left face of BioSIP prototype for measuring slippage (Slip).
  - Lower right corner of prototype and opposite of the actuator for measuring total movement (Drift).

  Net displacement of the BioSIP prototype in racking shear was then calculated by: $D_{net} = Drift - Uplift - Slip$

- Refer to Figures 3.1 through 3.5 for documentation of the BioSIP racking shear test set-up, process, and results.

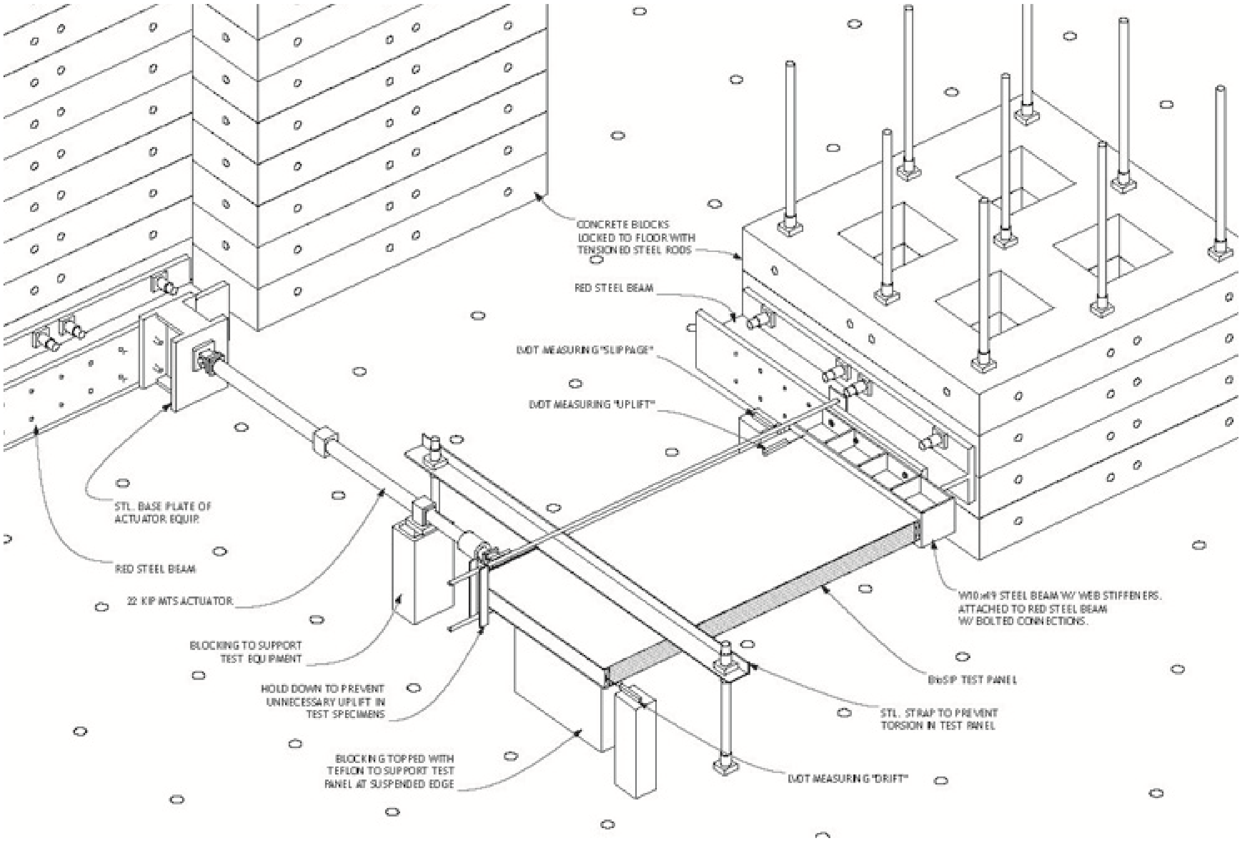


Figure 3.1: Racking Shear Test Setup

Racking Shear Test Results for BioSIP panels:

Table 3.1: Results for Racking Load vs. Deflections for individual BioSIP test panels

Racking #1 (TT2, 2x8)				Racking #2 (TR1, 4x8)			
Time	Load		Deflection	Time	Load		Deflection
min	lbs	plf	inch	min	lbs	plf	inch
0.00	-13.3	-6.7	0.0000	0.00	-3.7	-0.9	**0.0000**
1.50	42.1	21.0	0.0278	1.00	86.2	21.5	**0.0070**
2.50	141.0	70.5	0.1100	2.00	236.0	59.0	**0.0244**
3.50	200.1	100.1	0.1490	3.00	400.7	100.2	**0.0461**
4.50	144.9	72.5	0.1345	4.00	263.2	65.8	**0.0339**
5.50	44.7	22.3	0.0572	4.83	95.8	23.9	**0.0151**
6.00	0.6	0.3	0.0175	5.50	0.0	0.0	**0.0021**
7.00	98.5	49.2	0.0790	6.50	182.8	45.7	**0.0207**
9.00	299.0	149.5	0.2132	7.50	383.0	95.7	**0.0451**
10.00	400.0	200.0	0.2903	8.50	582.7	145.7	**0.0715**
11.00	364.8	182.4	0.2853	9.58	800.4	200.1	**0.0999**
13.00	164.3	82.2	0.1791	11.00	535.9	134.0	**0.0755**
14.00	64.3	32.2	0.0881	12.00	336.2	84.1	**0.0514**
15.00	-0.5	-0.2	0.0255	13.00	135.9	34.0	**0.0248**
16.00	81.2	40.6	0.0767	13.80	-0.2	-0.1	**0.0046**
18.00	281.2	140.6	0.2381	15.50	152.7	38.2	**0.0198**
19.00	381.2	190.6	0.2828	16.50	323.7	80.9	**0.0406**
20.00	482.0	241.0	0.3551	18.00	569.7	142.4	**0.0733**
21.50	600.8	300.4	0.4504	19.50	836.8	209.2	**0.1064**
23.00	520.9	260.4	0.4368	22.20	1200.2	300.1	**0.1572**
24.50	369.2	184.6	0.3572	24.00	906.7	226.7	**0.1320**
27.00	118.5	59.2	0.1656	25.50	604.1	151.0	**0.0958**
28.50	-0.2	-0.1	0.0434	27.00	304.1	76.0	**0.0559**
30.00	97.5	48.8	0.1099	28.50	3.9	1.0	**0.0125**
31.00	197.7	98.9	0.1984	31.50	192.4	48.1	**0.0303**
32.00	297.5	148.8	0.2730	32.50	365.4	91.4	**0.0522**
33.50	448.7	224.3	0.3606	34.00	616.3	154.1	**0.0854**
34.50	548.8	274.4	0.4255	35.50	872.1	218.0	**0.1185**
34.98	593.7	296.8	0.4550	38.00	1270.1	317.5	**0.1700**
35.00	-65.8	-32.9	-0.0032	41.50	1595.6	398.9	**0.2251**
37.50	121.7	60.9	0.1634	46.50	2020.4	505.1	**0.3310**
42.00	572.3	286.1	0.6585	51.00	2399.0	599.7	**0.4246**
46.00	968.6	484.3	1.0275	57.00	2713.4	678.4	**0.5316**
47.00	1069.9	535.0	1.1360	60.50	2905.6	726.4	**0.6019**
50.00	1377.5	688.8	1.4692	65.50	3161.1	790.3	**0.6875**
52.50	1560.0	780.0	1.6975	71.00	3392.3	848.1	**0.7810**
53.00	1611.1	805.6	1.7565	77.00	3547.1	886.8	**0.8816**
53.50	1699.1	849.5	1.9045	79.00	3665.3	916.3	**0.9219**

Table 3.2: Racking Shear Test Results

						Deflection (in) at Max Load			
	Sample	Panel Properties		Max Load		Drift	Uplift	Slip	Net Defl.
Test Name	Name	Size (in)	Weight (lbs)	lbs	plf	inch	inch	inch	inch
Racking #1	TT2	24" x 96"	68.5	1,699	850	2.20	0.27	0.02	1.90
Racking #2	TR1	48" x 96"	121.0	3,665	916	1.27	0.30	0.05	0.92
Test Standard: ASTM E72, Section 14 - Racking Load									
Failure Characteristics									
Panels failed by some combination of lifting/tearing of the sill plate; the skin tearing around nails on the sill plates; crushing of foam near load source; and separation of foam from skin and BioSIP EMF end plates									

Figure 3.2a: Results for Racking Load (lbs) vs. Deflection (in)

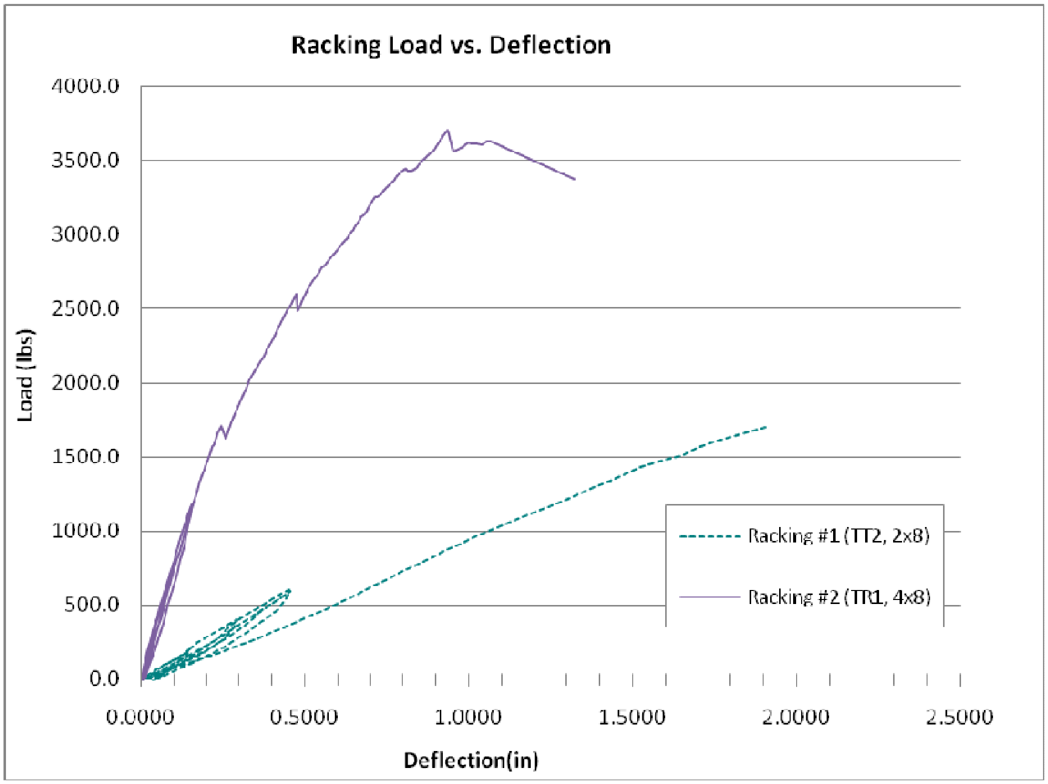
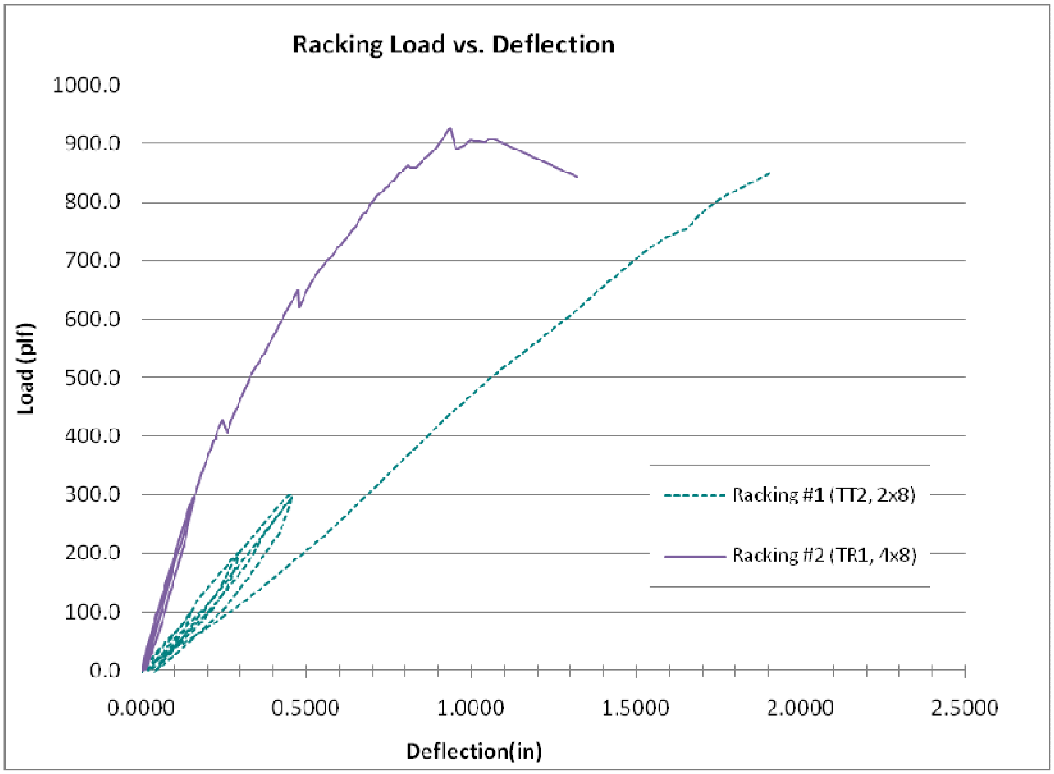


Figure 3.2b: Results for Racking Load (plf) vs. Deflection (in)



Successful Results of the BioSIP Racking Shear Load Tests

The BioSIP racking shear loading tests indicate that BioSIPs will be comparable against SIP manufacturers panel racking strengths in actual product certification testing and that BioSIPs will be among the strongest structural insulated panels in the marketplace.

Summary of the BioSIP Racking Shear Load Tests:

- The BioSIP testing prototypes were tested to failure and ultimately failed due to combinations of:
    - Lifting/tearing of the sill plate from steel beam
    - Panel skin tearing around nail heads where the panel was attached to the sill plates
    - Crushing of BioSIP panel foam near load source
    - Separation of foam from skin and the panel's EMF end plates. Photos 3.4 and 3.5 provide visual documentation of these panel failure locations.
- According to ICC criteria, allowable SIP racking load is determined from the ultimate load divided by a safety factor of 4, or, by the racking load at which a net deflection of 0.125 inch occurs, or, whichever of the two is lower. Table 3.3 provides a summary of this calculation and shows appropriate allowable racking load capacities for BioSIPs.
- Table 3.4 summarizes BioSIP deflection results at the allowable loads.

The BioSIP racking load testing goals were achieved as follows:

Based on BioSIP FEA analyses and research into existing SIP product strengths, the BioSIP team set a goal of achieving 300 pounds per linear foot (plf) allowable load in racking load. Results of the BioSIP physical testing show that:

- The 24" x 96" BioSIP testing prototypes yielded an allowable load of 212 plf based on panel failure load divided by a safety factor of 4. Deflection considerations reduced the allowable load to 79 plf.
- The 48" x 96" BioSIP prototypes yielded an allowable load of 229 plf.

The major factor causing the decreased allowable load values for the test results was attributed to the proportions of the individual BioSIP panels as follows:

The 2’ x 8’ and 4’ x 8’ BioSIP prototypes have a 4:1 and 2:1 height-to-length ratio compared to the 1:1 ratio of an 8’ x 8’ assembly undergoing similar racking load testing (which was the basis of the 300 plf goal). This gave the BioSIP test prototypes a considerable disadvantage in a one-to-one numerical comparison. For example, imagine how much easier it is to push something over that is tall and skinny versus something that is short and wide. Results in Fig. 3.2b, support the BioSIP shear load testing conclusions and show an increased steepness in the load/deflection slope for Racking #2 (4’ x 8’) compared to Racking #1 (2’ x 8’).

Therefore, the BioSIP team concludes that the racking load results indicate that BioSIPs will be comparable to existing SIP manufacturers’ panel strengths once they are tested for actual product certification testing (as in an 8’ x 8’ assembly).

Table 3.3: Calculated Allowable Racking Loads

24" x 96" panels with EMF skins					48" x 96" panels with hardboard skins				
Based on results from Racking #1					Based on results from Racking #2				
Ultimate Load Calculation	Failure Load, P_f		Allowable Load, $P_a = P_f / SF$*		Ultimate Load Calculation	Failure Load, P_f		Allowable Load, $P_a = P_f / SF$*	
	lb	plf	lb	plf		lb	plf	lb	plf
	1,699	850	425	212		3,665	916	916	229
Net Deflection Calculation	Net Deflection		Allowable Load,		Net Deflection Calculation	Net Deflection		Allowable Load,	
	inch		lb	plf		inch		lb	plf
	0.125		158	79		0.125		984	246
Allowable Load = 158 lbs, 79 plf					**Allowable Load = 916 lbs, 229 plf**				
* A safety factor (SF) of 4.0 was applied to failure load according sec 4.5.2 of "Acceptance Criteria for Sandwich Panels"									

Table 3.4: Deflection Results at Allowable Loads

24" x 96" panels with EMF skins			48" x 96" panels with hardboard skins		
Based on results from Racking #1			Based on results from Racking #2		
Allowable Load		Deflection	Allowable Load		Deflection
lbs	plf	inch	lbs	plf	inch
158	79	0.1254	916	229	0.1157

Documentation of the BioSIP Racking Shear Load Tests

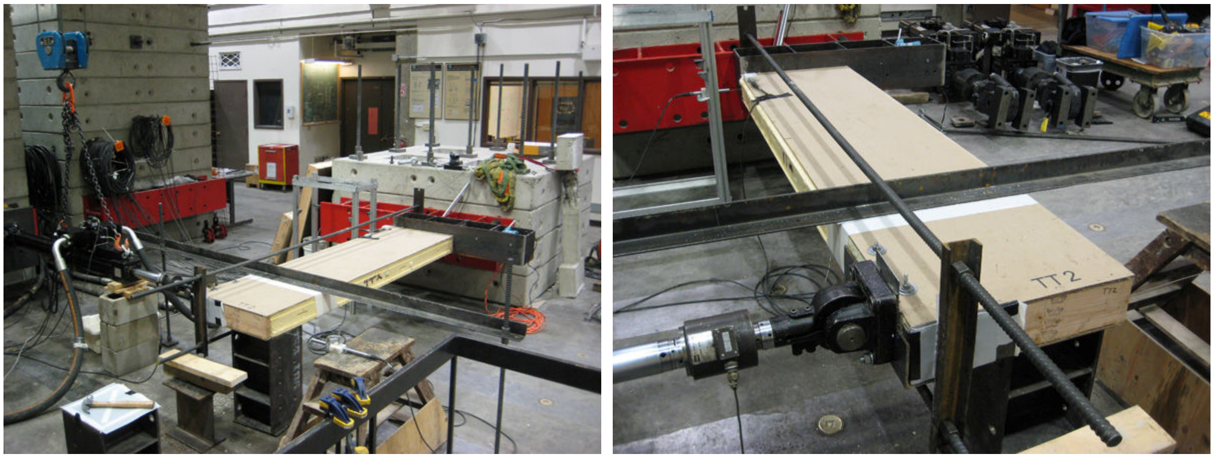


Photo 3.1: BioSIP prototypes shown in Racking #1 shear test configuration.

Photo 3.2: BioSIP prototypes shown in Racking #2 shear test configuration.

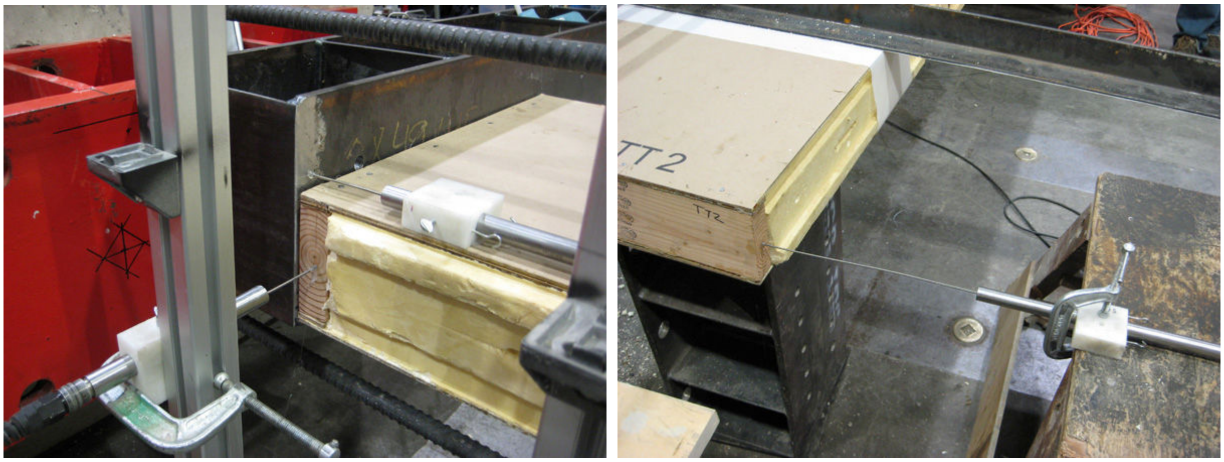


Photo 3.3: Locations of linear variable differential transformers (LVDTs), measuring slippage and uplift (left) and drift (right) as described in " PART 3: RACKING SHEAR LOAD TESTING".

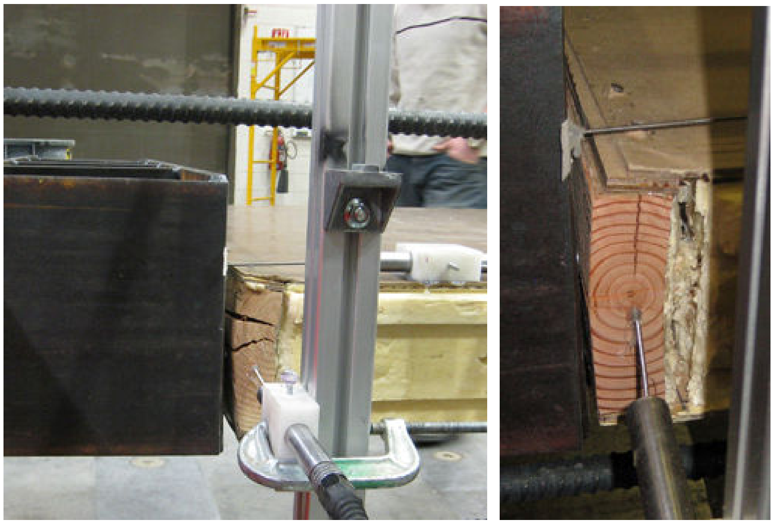


Photo 3.4: BioSIP Racking #2 test prototype shown in testing-to-failure of sill plate assembly (left). BioSIP Racking #1 prototype shown in testing-to-failure of sill plate (right).

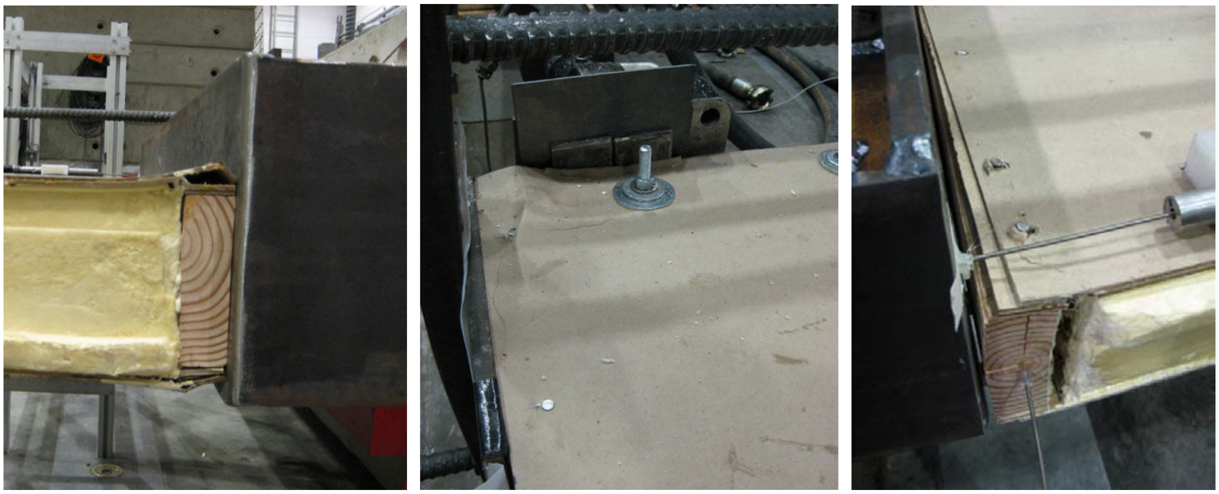


Photo 3.5: Close-up of BioSIP Racking #1 and Racking #2 sill plates at testing-to-failure.