A Review of Alternative Building Materials in comparison to CMU: Hempcrete, Woodcrete , Papercrete

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**Abstract**

Buildings consume an extraordinary amout of our finite natural resources during their construction and operation. It is imperative we begin to examine more sustainably-produced materials to construct them, as well as lifecycle costs. Concrete is the most widely-used building material in the world, and aggregate forms the majority of its composition. The goal of this research is to compare building materials incorporating renewable aggregate—hempcrete, woodcrete, and papercrete—as alternatives to traditional concrete utilizing nonrenewable aggregates. Comparing and contrasting commercially-available, similar products helps identify feasible applications for these alternatives to concrete that may prove more responsible, sustainable, and cost-effective throughout a building's lifecycle.

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*Keywords: CMU, Hempcrete, Woodcrete, Papercrete, Alternative building material, industrial hemp*

# Introduction

We are rapidly depleting and polluting our finite natural resources, including soil, trees, air, and potable water. The construction industry is the second largest consumer of raw materials, behind only agriculture (Hallady, 2008). In order to lessen the strain on natural resources, it is important to find more sustainable building materials, ideally those which also reduce other negative impacts to our environment. By choosing alternative building materials which have lower embodied energy, such as hempcrete, woodcrete, or papercrete, the building industry can reduce the energy consumed during construction, and future energy consumption during occupancy. Buildings are the single largest users of energy in the United States, accounting for 40% of total energy consumption (eia.gov, 2015).

Building with concrete masonry units (CMU) brings with it a host of environmental challenges. Standard CMU typically consists of a mixture of 14% cement, 42% sand, 42% aggregate (gravel or crushed stone), and 2% water. The production of cement is responsible for 4% to 5% of the world's $CO_2$ emissions, and Greenspec (2017) reports that among all human activities, cement production ranks third in man-made $CO_2$ emissions worldwide (transportation and energy generation ranking first and second respectively). Aggregate is typically blasted or excavated primarily from open mine pits, and is the most mined mineral in the world (The Greenage, 2017). Extracting these various aggregates degrades the landscape, creates dust and noise pollution, destroys the natural beauty of the land, diminishes the opportunity for agriculture, and is often highly dependent on the use of potable water (Greenspec, 2017).

This paper will analyze three alternative building materials to CMU construction in a comparative analysis. They each contain aggregates that are renewable, unlike CMU. Hempcrete incorporates hemp shives and lime, papercrete incorporates waste paper such as junk mail with Portland cement, and woodcrete incorporates wood chips and saw dust with Portland cement. The question posed is which of these materials is most sustainable, which is most cost effective, which one performs the best, and how do they compare to traditional CMU currently used. This paper will compare hempcrete, papercrete, and woodcrete to one another and to the standard use of CMU.

# Literature Review

The three pillars of sustainability encompass economy, society, and the environment. Building materials touch on each of these pillars in various ways. Deciding which construction material best serves these ideals is a challenge in itself. To say one product encompasses all three pillars the best may be a disservice, as each product tends to have its own benefits within these three realms. In instances where products are more viable, local availability and transportation must be considered. It may not be advantageous to source materials from long distances, as the cost and environmental damage this creates might negate embodied energy and operational energy-efficiency benefits, and so must be factored into the equation when determining which product is best suited for a particular project.

Papercrete, hempcrete and woodcrete can replace many applications of concrete, and in some cases other materials, slowing the mining of nonrenewable resources and deforestation. When analyzing both traditional and alternative building materials, there needs to be a consideration of the energy cost and environmental damage involved with excavation, mining, harvesting, and transporting the various raw materials and products, otherwise known as a material's embodied energy.

Open pit mining is the most common procedure to extract aggregate for cement. There are many detrimental environmental impacts in mining and crushing rock for aggregate. These materials have not been disturbed for millennia, and mining them exposes radioactive elements, asbestos-like materials, and metallic dust (Massachusetts Instittue of Technology, 2016). Heavy machinery is required in order to operate a mine, which requires the use of fossil fuels, contributing to $CO_2$ emissions. Damage to the landscape through mining can continue for many years even after mining ceases. Extraction, processing, and waste disposal involve enormous water demands. Nearby water sources often become polluted, contaminated, and depleted due to wastewater processing (Massachusetts Instittue of Technology, 2016).

There are many reasons to examine concrete alternatives, but alternatives must be viable. While the literature review below contains a range of information pertaining to hempcrete, papercrete, and woodcrete, the focus of this research will be narrowed to examine commercially-available building blocks readily comparable to standard concrete masonry units (CMU). This paper will focus on the products of the following companies: Mason Greenstar Blox (papercrete), Just BioFiber (hempcrete), and Faswall (woodcrete). Although each contains a concrete-similar mixture, the primary difference in these products is the aggregate that is incorporated in their mixtures.

## Standard Concrete Masonry Unit (CMU)

Although concrete construction in the form of blocks arguably dates back to the Romans and ancient Egyptians, Ambrose Forster and John Messinger were issued a patent for the concrete block in 1855 (Hall, 2009). The first commercial machine to form concrete blocks was created by Harmon S. Palmer in 1900 (Hall, 2009). This allowed for mass production of CMUs as a building material. CMUs became increasing popular in the United States after they were showcased at the St. Louisiana Purchase Exposition of 1904 (Hall, 2009). The Exposition inspired the United States government to finance the scientific testing of concrete blocks (Hall, 2009), and that testing proved to be a pivotal moment in the United States, spurring the widespread use of concrete blocks as a building material.

Standard CMU typically consists of a mixture of 14% cement, 42% sand, 42% aggregate (ranging from gravel to crushed stone), and 2% water, and standard dimensions are 16" x 8" x 8" (National Concrete Masonry Association, 2013). The aggregate is typically blasted or excavated from open mine pits, and is the most mined mineral in the world (The Greenage, 2017).

**Figure 1. Example of a CMU**

## Hempcrete

Goods from hemp are legal throughout the United States, even though it is largely illegal to grow. Building materials are one area where hemp can excel as a product. Hemp can be harvested up to twice a year, and one acre of industrial hemp produces up to four times as much raw material than traditionally harvested from an acre of trees (Hemp Technologies Collective, 2008-2016). In addition, hemp amends the soil as it grows through phytoremediation (Hemp Technologies Collective, 2008-2016). The crop is drought-tolerant, can grow in virtually any soil, and requires no pesticides (Hemp Technologies Collective, 2008-2016). Hemp can remove massive amounts of $CO_2$ from the atmosphere, converting it to oxygen (Hemp Technologies Collective. 2008-2016). Additionally, hemp is biodegradable, enabling excess materials on a job site to be tilled into the earth, lowering the amount of construction waste (American Lime Technology, 2012).

Hempcrete has recently been traced back to the $6^{th}$ century AD within India's Ellora Caves. The plaster within the caves was analyzed in order to prepare for major restoration work in the caves (Singh, Kumar, and Waghmare, 2015). Although the use of hemp in construction can be dated back this far, more current popularity began to surface in the early 1990s. Hemp can be processed and used to create hempcrete, an alternative to traditional concrete. Hempcrete is a mixture of hemp hurd (shiv), which is the woody material that is found in the center of hemp stalk, and lime blended with water. Hemp crops' primary commodity is their seeds, and the hurd is a byproduct of hemp crops. The lime produces a chemical reaction which creates a binder that adheres hurd particles together. The lime binder has a high pH which makes the product antimicrobial and antifungal. The lime also aids in making the hempcrete mold-resistant.

Hempcrete is often used as an insulation and an infill around wood framing. Walls of a building can be formed by compressing hempcrete between studs, or can be formed into blocks to build walls. These materials create a fire-resistant, pest-resistant, and highly thermal insulated building material (Magwood, 2016). The Queen's University in Canada has tested hempcrete with 19.5 $lb/ft^3$ infill around 2" x 6" wood studs, and determined that this could support three to four times more compressive load than a standard stud wall (Magwood, 2016).

One of the challenges with hempcrete construction is a long drying and setting time. In some climates hempcrete walls have taken as long as several months to fully cure (Elfordy, Lucas, Tancret, Scuddeler, and Goudet, 2008). An additional challenge is that due to the light weight of the shives (~100-50 $kg/m^3$), there is little gravitational compression when casting blocks in the traditional manner, resulting in extremely porous blocks with low mechanical strength properties (Elfordy, Lucas, Tancret, Scuddeler, and Goudet, 2008). Therefore, blocks must be created in less traditional means than standard concrete blocks. One solution to the challenge has been developed in order to inject hempcrete as an infill within wall forms or within block molds. A mixture of lime and shives is mixed and driven into and through a hose by an air compressor. At the end of the hose water is mixed with the dry mixture and the projected into the mold (Elfordy, Lucas, Tancret, Scuddeler, and Goudet, 2008). The water is added at the last moment due to the fact that the shives traditionally absorb an extreme amount of water, which retards the curing process. This process limits the amount of water that can be absorbed, and aids in the carbonation of the lime. The hose then projects the mixture, which due to velocity, compresses it within the mold, increasing the density and strength of the final product. Blocks can be created through this process, or infill can be compacted between traditional wood studs. This creates an insulation that does not require constant energy input, which traditional insulation does, saving on energy consumption costs as well as precious resources (Elfordy, Lucas, Tancret, Scuddeler, and Goudet, 2008).

Per the U.S. Green Building Council (2016), almost 40% of $CO_2$ emissions within the U.S. are produced by buildings alone, higher than the industrial and transportation sectors. Hempcrete is

FIGURE 2 EXAMPLE OF HEMPCRETE BLOW IN

carbon negative due to various factors. The impact begins during the growth of hemp. As hemp grows it absorbs $CO_2$ gases, and it is theorized that “165 kg of carbon can be absorbed and locked up by one cubic meter of hempcrete wall over many decades” (Young, 2005). One could argue the lime used to produce hemp blocks would negate its sustainability; however, it is reported that more $CO_2$ is locked-up in the process of growing and harvesting the hemp than is released in the production of the lime binder used within the mixture. A 2003 study concluded that 716.6 pounds of $CO_2$ are stored within one ton of dried hemp (Magwood, 2016), and 6.88 $lb/ft^3$ of carbon emissions are released in the production of lime binder (Magwood, 2016). Using Lhoist’s Tradical lime instead of cement also contributes to lower $CO_2$ emissions due to the fact that a kiln requires lower temperatures to produce it. According to the Lhoist company, their Tradical Lime based binders also produce “low energy, high carbon capture, durable and high quality products” (Lhoist, 2016). Further impacts on $CO_2$ emissions include the fact that 4.95 tons of $CO_2$ is sequestered annually from a typical 2000 $ft^2$ building insulated with hempcrete (Magwood, 2016).

The life span of a hemp building has been conservatively estimated to last at least 100 years, and when the lifecycle ends the building can be demolished and used as fertilizer, tilling it back into


**FIGURE 3. FIRST HEMP-BASED HOME IN THE UNITED STATES**

the earth (Just Biofiber, 2016). In 2010 a 3,000 $ft^2$ hemp home was built by Push Designs in Asheville, N.C. and was the first hemp home built in the United States. Not only was their focus on building an eco-friendly home, but to also create a building with a material that is non-toxic and improves the indoor air quality. The homeowners have stated that they spend less than $100 per month to cool their home (Koch, 2010).

### *Hempcrete Example*

Just BioFiber is a Canadian company that manufactures interlocking hempcrete blocks for construction. A mixture of the non-fibrous portion of the hemp plant known as hurds (shives), lime, and water make up hempcrete. Just BioFiber's blocks measure 11" x 8" x 21", larger than a CMU, but significantly lighter at 22 pounds (Just BioFiber, 2016). The blocks are fabricated with an interlocking component in order to make installation of their products easier. Blocks can be created by mixing 34% lime-based binder (lime, pozzolanic material, and hydraulic binder), 16% hemp shives, and 50% water (Just BioFiber, 2016).

**FIGURE 4. EXAMPLE OF A HEMPCRETE BLOCK**

## Papercrete

Although often mistaken as a new building material, papercrete was patented in 1928 and made a reappearance in the 1980s (Doril, 2014). A significant benefit of papercrete from a sustainability standpoint is the fact the primary component (50-80%) is comprised of recycled paper products already in circulation, that would otherwise be sent to the landfill. Annually, 48 million tons of paper, which equates to 720 million trees, ends up in landfills in the United States alone (Fuller, 2016). The mixture to create papercrete generally consists of water, Portland cement, and cellulose fiber (recycled paper) (Fuller, 2016). Cellulose materials include newspaper, phone books, junk mail, magazines, lottery tickets and the like. The preferred material is newspaper. This paper material is shredded into a pulp, and then mixed with cement and a two-part organic admixture. The final result is much like adobe, as it is poured into forms, and dried in the sun to create blocks (Fuller, 2016). Like all of the alternative building materials discussed in this research, papercrete has not been approved by the International Code Council, and therefore builders looking to use the material in load-bearing application in areas of the US that require building permits will likely be required to find a structural engineer willing to certify the material meets the structural needs (which may require lab testing). Therefore most builders prefer a post and beam system for load bearing walls in order to ensure the structural integrity of the building, with papercrete serving as in-fill. Papercrete's high thermal resistance value of R-25 may make it desirable even as merely an insulation. This high thermal value aids in lowering the cost of energy consumption throughout the lifecycle of the building.

One consideration when working with papercrete is that until it fully dries, it is susceptible to mold. Papercrete absorbs water, which wicks well into the material. In more humid climates this is especially a challenge, as the product will remain wet and can harbor mold, creating an unhealthy living environment for its inhabitants. One suggestion is to stucco the blocks in order to protect them from the elements, however most experts state that once the product has fully cured it is usually not susceptible to mold. Shrinkage and slow drying times are challenges that can easily be addressed. Adjusting the amount of sand in the mixture will allow shrinkage to be decreased to a minimum. In order to minimize the challenge of slow drying times blocks should be kept from rain during their curing process, and cast in the warm summer months. In addition, it is important to allow the blocks to air dry on all sides as evenly as possible (Hart, 2016).

### Papercrete example

Mason Greenstar, in Mason, Texas, mass-produces papercrete block and is the only commercial producer within the United States (Mason Greenstar, 2016). The owner, Zach Robon, with assistance from Texas Tech University, has performed various tests on his product in order to

**FIGURE 5. EXAMPLE OF A PAPERCRETE BLOCK**

verify its structural integrity. The product is manufactured using the following mixture: 25% Portland cement, 65% recycled paper, and 10% additives (two-part tree resins, surfactants, sodium silicates, accelerators, and air entrainment). An additional benefit to papercrete blocks is their extreme lighrt weight. Their blocks are 8.5 pounds, comparing to standard adobe at 30 pounds, compressed earth at 40 pounds, and light weight concrete weighing 30 pounds (Mason Greenstar, 2016). Mason Greenstar manufactures various papercrete blocks to satisfy different construction goals. Their building block most comparable to CMUs measure 8” x 8” x 16”, which are the dimensions of a standard CMU.

At this time Mason Greenstar is in the initial stages of locating a new facility in Tennessee close to the Kimberly Clark Corporation, in order to more easily access a more reliable source of recycled paper materials (Hargrove, 2017). This will allow for a lower cost, as well as more sustainable access to recycled paper materials without long-haul transportation. When asked what their comparison is to the cost of CMU, their representative Matt Hargrove stated that their product currently costs $.10 to $.15 more per square foot. They do project however that after their facility in Tennessee is opened, their costs should decrease due to the savings on shipping recycled paper. Although their products currently are higher in initial cost than standard CMU, due to their R-value, cost savings are recouped through lower energy bills. They project that homes constructed with their products will save home owners 50% on average in energy bill costs alone (Hargrove, 2017).

Mason Greenstar owner Zach Roben resides in the first home constructed by the company in Mason, Texas which was built in 2002. In order to test how their product performed they did not seal or treat the product in anyway. Mason Greenstar reports that they do not see any challenges or issues with the home since its construction. Many builders, architects and engineers have

FIGURE 6. THE NATION'S FIRST PAPERCRETE HOME

evaluated the building throughout the years in order to investigate the product (Hargrove, 2017). To date an official case study has not been performed on the building.

## Woodcrete

Woodcrete began to develop after WWII. Among the rubble of the aftermath of the war there was an extreme amount of wood waste. In order to dispose of this significant mass of wood waste, it was ground into chips, bonded with cement, formed into building blocks and recycled into new construction (Shelter Works Ltd, 2012). Throughout the years building with woodcrete swept across Europe, Asia, and North America. (Shelter Works Ltd, 2012). Over 1,000 homes have been built in the United States alone.

Woodcrete is a mixture where recycled woodwaste is ground and used as an aggregate in a concrete-similar mix. Woodcrete is comprised of materials such as sawdust, wood chips, and other wood wastes mixed with Tradical lime and water. This diverts construction waste from the landfill. Waste paper is often added to the mixture in order to enhance material characteristics, as well as to ensure a lightweight product with optimal insulation qualities is produced. The paper waste is mixed with water first in order for the paper to absorb the water fully. Although adding waste paper to the mixture provides benefits, it is also somewhat of a hindrance. When adding waste paper to the mixture the density of woodcrete decreases, making the final product a bit less strong in compression (although still more than strong enough to be structurally load-bearing). Another factor that affects the final product is the size of the sawdust/wood waste. 2mm sieves of sawdust are much less dense then 1mm sieves of sawdust particles, changing the overall density of the final woodcrete product (Aigbomian, 2012).  Final steps in preparing wood waste for use in woodcrete include drying the wood particles in an oven at 100° in order to reduce the moisture content of the wood.

### Woodcrete example

Shelter Works, LTD, which is located in Philomath, Oregon, manufactures a woodcrete block called Faswall, which has been in production for over 25 years. Their product is produced by mixing 85% wood chips, primarily from pallets, and 15% Portland cement and water. The mixture is cast into 8" x 12" x 24" woodcrete blocks. Their block units alone provide an R-value of 11.5, however during installation an additional 3" insulation insert can be added within the core, and the remainder of the core filled with concrete. This raises the R-value to 21. When using the additional insulation, the insulated face of the unit is placed toward the exterior side of the wall. Faswall blocks can also be used as load bearing walls, once the units are filled with concrete and reinforced with horizontal and vertical rebar. The installation process does not require the use of mortar: their tongue and grove design allow for the concrete core to form a "post and beam" structural grid, allowing for quicker assembly than standard CMU. In addition

**FIGURE 7. EXAMPLE OF A WOODCRETE BLOCK**

to being larger, Faswall blocks also weigh a little less than standard CMU at 28 pounds, a benefit contractors appreciate. Another benefit to contractors is that the material can be easily cut with hand or power tools on site, and ceramic coated screws can be inserted directly into the blocks. This aids in relatively easy installation of doors and windows, especially in comparison to standard CMU.


## Methods

Research for this paper included a mixed-method approach encompassing both qualitative and quantitative research. Research was conducted through phone interviews and email communication with the various companies concerning their products. In addition, research was conducted through the collection and standardizing of existing test data on the products that was conducted by independent laboratories. This provided a background on these various building materials and enabled them to be compared in as fair a manner as possible.

Lastly, qualitative research methods were implemented by investigating test results from manufacturers and labs. Beyond sustainability, there are many additional concerns regarding building materials within the construction industry. Each of these products have been tested in areas such as R-value, fire resistance, workability, cost, and overall performance. It is often a challenge to engage the construction industry into using products that are not “standard” or “traditional” in nature. The industry as a whole tends to prefer materials with an established record of durability. Having independent test results readily available to the skeptical contractor may help accelerate adoption of these materials. In addition, ease of installation and workability of products are considerations often brought up by contractors as well.

## Data

All comparisons are of the various companies’ materials and blocks that are as closely comparable to one another as possible. Results have been collected from testing that was performed by various entities.

TABLE 1. COMPARATIVE DATA

| | CMU | Hempcrete | Papercrete | Woodcrete |
|---|---|---|---|---|
| Dimensions | 8” x 8” x 16” | 11” x 8” x 21” | 8” x 8” x 16” | 12” x 8” x 24” |
| Weight in pounds | 30 | 22 | 8.5 | 28 |
| R-value | R-2 (R-8 w/foam) | R-27 | R-26 | R-12 (R-21 w/foam) |
| Fire rating in hours | 3 | 1 | 2 | 4 |
| Requires Rebar | Yes | No | Yes | Yes |
| Requires Motor | Yes | Yes | Yes | No |
| Can be cut in field | No | Yes | Yes | Yes |
| Material cost / $ft^2$ of wall area | \$1.46 | \$17.00 | \$1.61 | \$8.37 |
| Mold resistant | Y | Y | Y | Y |
| Pest resistant | Y | Y | Y | Y |

## Discussion

There are many ways to use hempcrete, papercrete, and woodcrete in a building’s structure, and this provided a challenge to compare them to one another and concrete. In order to make a more clear comparison, commercially-available block materials were identified and selected. Note that this does narrow the scope of comparison to these commercially-available blocks, when hempcrete, papercrete, and woodcrete may be utilized in more efficient and cost-effective ways. This would be an ideal focus of further research into these materials.

In order to best compare these products to one another, as well as to traditional concrete/CMU construction it is helpful to study the performance of similar buildings that have been created out of these products. In locating these buildings throughout the world and studying their overall performance energy efficiency, one can analyze the benefits of building with these products individually as well as in comparison to one another. Case studies of these buildings showcase each material’s various benefits. Locating formal case studies proved to be a challenge. To date, the only investigation of these materials in the context of formal case studies has yet to be reviewed. There do exist reports about buildings constructed using these various materials, just not in a comparative case study.

Often, the bottom line in construction is monetary. Sadly this aspect often outweighs all other considerations including environmental sustainability. Not only is there cost in the materials themselves, the lifecycle costs encompass the performance of the product with regard to energy efficiency. This research is to investigate these products and how they perform in terms of embodied energy, operational energy efficiency, and identify any other positive environmental impacts they may have relative to CMU.

R-value is a measurement of a building material’s capacity to resist heat flow from one side to the other (Archtoolbox, 2017). The higher the R-value, the more effective the material is at insulating the building (Archtoolbox, 2017). To homeowners this equates to lower energy bills, but it also has a great impact on the environment. The standard R-value in typical 2” x 6” wood frame construction is an R-19 wall. R-values for these materials are as follows: Standard CMU alone is R-2, however it is becoming more common to fill the cavities of CMU with a more insulative material than standard concrete grout, in order to improve their R-value. In order to make a more fair comparison, adding a Polyurethane foam to the core was brought into consideration. When adding this, the R-value of the polyurethane-filled CMU increases to R-8, still far below the other blocks in this comparison. And it must be noted that filling the cores of CMU with polyurethane adds considerably to the expense, and is often not even possible in many structural applications where the cores are required to be grouted solid for load-bearing walls. In comparison, Faswall alone is R-11.8, and there's an option to add an additional 3" of insulation, with the remainder of the core filled with concrete during construction, increasing the value to R-21 while maintaing structural load-bearing capacity. Mason Greenstar Blox is R-26; and Just BioFiber is R-27. In this comparison all of the alternative materials far surpass the R-value of standard CMU even when adding additional insulation to improve its value. Although a high R-value is a huge asset, additional considerations need to be made in order to improve the building envelope as well.

Building safety is a concern to homeowners and municipalities alike. According to the Center for Disease Control and Prevention over 2,500 people annually die in the United States due to residential fires. To date no building material is fireproof. However building with materials that are fire resistant can aid in saving lives by slowing down fire damage and allowing occupants time to escape a burning home. Fire ratings also show how a fire affects a home's structural abilities. Fire endurance tests are performed in accordance with the American Society for Testing and Materials, ASTM E119-14, Standard Test Methods for Fire Tests of Building Construction and Materials, by various testing laboratories. ASTM states in part: *1.3 This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for the fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.* Fire rating test results for these products: Standard CMU earned a two hour rating (National. 2013), Faswall earned a four hour rating, Mason Green Star Blox earned a two hour rating (Intertek. 2013) and Just BioFiber earned a one hour rating (QAl. 2015).

This research does not take into account the additional cost of various materials required to complete construction with these various products, but instead compares the basic prices of the materials per square foot of wall area. Prices would fluctuate depending on location and distance that materials would need to be delivered, however these factors are taken out of the equation within this research, and the base price is all that is considered at this time.

From a contractor's perspective the workability of a product is often a deciding factor in implementing the material in construction. Often contractors are reluctant to veer away from the standard materials they have historically used. Standard CMU weighs in at thirty pounds and measures 8" x 8" x 16", rebar and mortar are both required during construction, and cutting or reshaping the block on site requires skill and practice. A major selling point to masons building with a material that is similar in nature to CMU is even a small decrease in weight. The sizing of the three products varies: Just BioFiber 11" x 8" x 21", Mason Greenstar 8" x 8" x 16", and Faswall 12" x 8" x 24". All of the alternative products save weight over CMU: Just BioFiber weighs in at 22 pounds, and Faswall 28 pounds, with Mason Greenstar weighing in at a mere 8.5 pounds. All three of these alternative building materials are also able to be more easily cut by standard hand tools or power tools on site. Additionally, in each case screws can be driven into these products more easily as well, simplifying installation of windows and doors. Due to the interlocking technology, no rebar is required when building with Just BioFiber. Faswall does not require mortar due to the tongue and groove design, but they do require rebar for reinforcement. Mason Greenstar Blox and standard CMU require both mortar and rebar reinforcement for load-bearing walls in particular. Mortar and rebar add to the overall cost of construction and this cost is not taken into consideration in the comparison.

# Conclusion

The purpose of this paper is to provide information to better inform people of alternative building materials that can be implemented to aid in preserving the environment as well as provide savings to the occupants through energy savings. The structural requirements and personal preferences determine which of these products is the most desirable product to use. Availability is another aspect that needs to be considered. If materials are not readily available to the area then it is not necessarily advantageous to use these products if the energy use consumed during transportation negates embodied energy benefits or operational energy efficiency. However, considering the considerable energy savings possible through lifecycle costs with these materials, it seems unlikely that transportation alone might offset the lifecycle energy savings.

Each of these products are mold-resistant and pest-resistant. The R-values of these alternative materials exceed traditional CMU significantly, aiding in energy reduction and in turn the impacts of $CO_2$ emissions. The dimensions of the products are roughly similar, however the weight of these products varies drastically from 30 pounds to 8.3 pounds. The workability of the alternative products are a selling point to many contractors. Although the fire rating of CMU is on the upper end of the comparisons of the products, all are rated at a level that makes them each a safe material. The cost of the materials comprises the widest range of difference. Over time, with economies of scale the manufacturing cost could presumably decrease. But importantly, the reduced energy consumption immediately starts working to mitigate manufacturing cost differences as well.

Much further research could be invested in these promising materials time permitting. Further research which may prove particularly beneficial could include comparisons of embodied energy and potential further energy use reductions due to solar reflection. Particularly beneficial would be a thorough evaluation of the cost of these materials after adjusting for building performance and potential energy savings.

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