The Rice Hull House

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ABSTRACT

The rice hulls are unique within nature. They contain approximately 20% opaline silica in combination with a large amount of the phenyl propanoid structural polymer called lignin. This abundant agricultural waste has all of the properties one could ever expect of some of the best insulating materials. Recent ASTM testing conducted R&D Services of Cookville, Tennessee, reveals that rice hulls do not flame or smolder very easily, they are highly resistant to moisture penetration and fungal decomposition, they do not transfer heat very well, they do not smell or emit gases, and they are not corrosive with respect to aluminum, copper or steel. In their raw and unprocessed state, rice hulls constitute a Class A or Class I insulation material, and therefore, they can be used very economically to insulate the wall, floor and roof cavities of a super-insulated Rice Hull House. This paper also explains how the structure of such a house can be fashioned out of a variety of engineered lumber products derived from sugarcane rind.

PAPER

When nature decided how to package a grain of rice, she wrapped this tiny bundle of nutrients with what is often referred to as a "biogenic opal."[1] The chemical structure of the rice hull, containing amorphous silica bound to water, closely resembles that of the opal, and this gives the rice hull some fairly amazing properties. Nowhere could we ever find a cereal by-product so low in protein and available carbohydrates, and yet, at the same time, so high in crude fiber, crude ash and silica.[2] Of all cereal by-products, the rice hull has the lowest percentage of total digestible nutrients (less than10%).[3]

The rice hull contains approximately 20% opaline silica in combination with a large amount of the phenyl propanoid structural polymer called lignin. Such a high percentage of silica is very unusual within nature,[4] and this intimate blend of silica and lignin makes the rice hull not only resistant to water penetration and fungal

[1] See Velupillai, L., Mahin, D.B., Warshaw, J.W., and Wailes, E.J. 1996. A Study of the Market for Rice Husk-to-Energy Systems and Equipment, p.24, Louisiana State Agricultural Center. "In nature, silica (SiO_2) occurs as seven distinct polymorphs: quartz, cristobalite, tridymite, coesite, stishovite, lechatelerite (silica glass), and opal; the latter two are amorphous." Drees, L., Wilding, L., Smeck, N., and Senkayi, A. 1989. Minerals in Soil Environments (2nd Edition), p. 913. "Opal is a hydrated silica polymorph ($SiO_2 \cdot nH_2O$)." Ibid, p. 921.
[2] See Rice-Husk Ash Cements: Their Development and Applications, United Nations Industrial Development Organization, Vienna, pp. 12-13.
[3] See Juliano, B.1985. Rice: Chemistry and Technology, p. 695.

decomposition, but also resistant to the best efforts of man to dispose of it. Since rice is grown on every continent except Antarctica, since it ranks second only to wheat in terms of worldwide area and production,[5] and since the hull represents on average about 20% of the rough harvested weight of rice,[6] our planet ends up with an abundance of this scaly residue.

More than 100,000,000 metric tons of rice hulls are generated each year throughout the world.[7] In 1995, the United States produced about 1,260,000 metric tons of rice hulls[8] at about 50 mills[9] located in Louisiana, Texas, Arkansas, Missouri, Mississippi, Florida and California. Since most mills store rough rice and process it on a daily basis, fresh dry hulls are available throughout the year. Since hulls do not biodegrade or burn very easily, they are sometimes available free-of-charge.[10]

The hull is a very tough and abrasive packaging material, consisting of two interlocking halves. It encapsulates the tiny space vacated by the milled grain, and in proximity to a myriad of other hulls, it forms a thermal barrier that compares well with that of excellent insulating materials.[11] Thermal resistance tests on whole rice hulls indicate R-values greater than 3.0 per inch.[12] If the R-value of rice hulls is so favorable, why have they not been used extensively to insulate residential and commercial structures?[13]

Perhaps our scientists and engineers focus only on creating materials and products that can be labeled and marketed as proprietary. Perhaps the humble use of the rice hull as an insulation material does not sufficiently inspire the scientific or commercial imagination. But why focus on man-made products when natural materials abound? Surely there must

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4 "No other plant offal even approaches the amount of silica found in rice husks." Beagle, E.C. 1978. FOA Agricultural Services Bulletin 31, p. 8.
5 See Velupillai (1996), p.1.
6 See ibid., p. 15. See Beagle (1978), pp. 6. "Percentages of husk in paddy vary widely, but 20% can be taken as a fair average." Ibid, p. 25.
7 See Velupillai (1996), p. 15.
8 See ibid., p. 44.
9 See ibid., p. 37. For a listing of some rice mills in the United States, see http://www.ricecafe.com/newlinks2.htm or ftp://www.usarice.com/publish/member1.htm.
10 "Husks typically sell for about $6/ton, although one mill indicated that it has sold husks for prices ranging from $2 to $20 per ton." Velupillai (1996), p. 45.
11 See Velupillai (1996), p. 16.
12 "Rice hull has a thermal conductivity of about 0.0359 $W/(m\cdot°C)$; the values compare well with the thermal conductivity of excellent insulating materials (Houston, 1972)." Juliano (1985), p, 696. The thermal conductivity of rice hull ash is reported to be 0.062 $W\cdot m^{-1}\cdot K^{-1}$. See UNIDO, p. 21. A more recent test done by R&D services of Cookville, Tennessee, indicates a 3.024 R-per-inch.
13 Although charred rice hulls have been sold as an insulation material in loose-fill applications under the trademark name of "Mehabit," it is hard to find evidence that fresh hulls have been used for this purpose. See Beagle (1978), p. 132.

be some profound and obvious reason that makes the raw rice hull unsuitable to serve as an insulation material.

Do rice hulls burn? Yes they do, but with difficulty, as Eldon Beagle once so elegantly explained:

> The peculiar silica-cellulose 'drinking-straw bundle' structural arrangement of the husks results in an object that does not burn or even liberate heat in a manner resembling that of any organic substance. These minute silica-crested tubular structures offer an inherent resistance to burning. Often they seal off and prevent the thorough, uniform burning essential to obtaining a desired end-product."[14]

Anyone who has tried to set a match to loose rice hulls understands how difficult they are to burn. Since air cannot flow freely through a pile of rice hulls to provide the oxygen needed to sustain rapid combustion, they do not easily and cleanly combust. The bulk density of loose rice hulls is similar to that of baled straw, and anyone who has tried to burn a bale of straw understands the problem associated with the availability of oxygen. But the simple availability of oxygen does not explain everything.

As we have noted above, the high percentage of opaline silica within rice hulls is most unusual in comparison to other plant materials, and some scientists say that during the combustion of rice hulls, the silica ash may form a "cocoon" that prevents oxygen from reaching the carbon inside. Other scientists speculate that, since silica and carbon may be partially bonded at the molecular level, silicon carbide is formed during high-temperature combustion, and that the presence of this heat-resisting ceramic impedes the easy combustion of the rice hull.[15] Still other scientists say that at certain temperatures, the molecular bond between the silica and carbon in the hull is actually strengthened, thereby preventing the thorough and uniform burning of the hull.[16] In any case, even if we do manage to ignite a pile a rice hull, we find that it tends to smolder rather than flame.

> Rice husks are flame retarding and, at ordinary temperatures, self-extinguishing. A lighted match, tossed onto a pile of rice husks will generally burn out without producing a self-sustaining flame in the husks.[17]

Conventional cellulose insulation necessitates the addition of large quantities of flame and smolder retardants. The concentration of flame and smolder retardant chemicals

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[14]Beagle (1978), p. 8. "The high percentage of silica in rice hulls and the peculiar silica-cellulose structure impede uniform and thorough burning of the hulls in a combustion process." Velupillai (1996), p. 18. "Of all biomass combustion, the combustion of rice hulls (and straw) is particularly difficult because of the high ash content." Ibid., p. 23. "Eldon Beagle set a pile of rice hulls 300'x500'x50' on fire and they burned for six months." Ibid., p. 24. "However, husk cannot be burnt easily or cleanly with excess air, and energy recovery is very low as the heat produced cannot be utilized in a beneficial manner." Ibid., p. 25.

[15] See ibid., p. 24.

[16] From a conversation with Carl D. Simpson of Riceland Foods, Inc.

[17] Beagle (1978), p. 9, quoted from Burrows (109A).

(such as boric acid, sodium borate, ammonium sulfate, aluminum sulfate, aluminum trihydrate, mono- or di-ammonium phosphate) in conventional cellulose insulation may reach as high as 40% by weight.[18] These chemicals are expensive to purchase and prepare, and the cellulosic fiber must undergo extensive preparation to receive them.

Surprisingly, rice hulls require no flame or smolder retardants. Nature has freely given to this agricultural waste product all of the combustion properties needed to pass the Critical Radiant Flux Test (ASTM C739/E970-89), the Smoldering Combustion Test (ASTM C739, Section 14), and the Surface Burning Characteristics Test (ASTM E84). Recent testing done by R&D Services indicates an average Critical Radiant Flux (CRF) of 0.29 W/cm^2, a smoldering combustion weight loss between 0.03% and 0.07%, a Flame Spread Index (FSI) of 10 and a Smoke Development Index (SDI) of 50. Since US building codes require an FSI of 25 or less, and an SDI of 450 or less, we see that the rice hull easily passed these tests. In its raw and unprocessed state, the rice hull constitutes a Class A or Class I insulation material.

All organic materials will absorb or release moisture until they come into equilibrium with the relative humidity of the surrounding air. The high concentration of opaline silica on the outer surface of the rice hull impedes the atmospheric transfer of moisture into the hull. Also, 2.1% to 6.0% of the rice hull consists of a biopolyester called cutin,[19] which, in combination with a wax produced by the rice plant, forms a highly impermeable barrier. Nature employs several very effective strategies to protect the kernel of rice from the water and high humidity generally associated with the cultivation and growth of this plant.

Consequently, studies done on rice hulls at 25°C indicate that the equilibrium moisture content of rice hulls at 50% relative humidity is at or below 10%, while at 90% relative humidity, the equilibrium moisture content of rice hulls remains at or below 15%.[20] A Moisture Vapor Sorption Test (ASTM C739, Section 12) conducted by R&D Services indicates a gain in weight of only 3.23%. This is well below the moisture content needed to sustain the growth of fungi and mold.

The ASTM Standard Specification for cellulose insulation requires a 28-day test for resistance to fungal growth (see section 10 of ASTM C1497, ASTM C1338, Section 6.6 of ASTM C1149 or Section 11 of ASTM C739). Following these standards, R&D Services inoculated rice hulls with five different fungal species, and the rice hulls passed these tests without the addition of fungicides or any other chemicals.

The high concentration of opaline silica on the outer surface of the rice hull also establishes the effective hardness of the rice hull at roughly the same values as reported

[18] "The concentrations of chemicals commonly added in commercial cellulosic insulation normally range from 10 to 40% by weight. Chemicals commonly used are boric acid, sodium borate, ammonium sulfate, aluminum sulfate, aluminum trihydrate, mono- or di-ammonium phosphate." Service Bulletin entitled "Borates for Fire Retardancy in Cellulosic Materials," p. 5, prepared by US Borax.
[19] See Juliano (1985), p. 695. Regarding cutin, see http://wcb.ucr.edu/wcb/schools/CNAS/bpsc/agomezpo/3/modules/page34.html
[20] See Juliano (1985), p. 707.

for opal (6 on the Mohs scale).[21] However, due to the presence of lignin within the rice hull, this hardness is tempered with flexibility and elasticity. Since the rice hull is hard and yet elastic, it resists settling and compression far better than shredded newspapers. The settling of cellulose insulation in a wall cavity can reduce its installed height by as much as 25%. For this reason it is often necessary to stabilize cellulose insulation by means of polyvinyl acetate or an acrylic adhesive. None of these stabilizing compounds are needed with rice hulls, if firmly vibrated or packed into a wall cavity.

Ordinarily loose rice hulls have an angle of repose of about 35 degrees.[22] But once firmly packed into a wall cavity, their tiny tips, edges and hairs interlock to achieve a negative angle of repose. Due to this peculiar bonding of rice hulls under mild pressure, they stabilize in a very uniform manner, and no further settling is possible. Also, since it is not necessary to add fire-retardants, fungicides or any other chemicals to the rice hull, R&D Services has determined that this benign and stable biomass does not emit offensive odors (ASTM C739). Likewise, R&D Services determined that rice hulls do not corrode aluminum, copper or steel (ASTM C739, Section 9).

With rice hulls, we need not engage in a mining or manufacturing process that generates air pollution, water pollution or erosion.[23] With rice hulls, we need not engage in a manufacturing process that depletes our reserves of fossil fuels (as with polystyrene,[24] polyisocyanurate and polyurethane insulation). With rice hulls, we do not use chlorine-based chemicals such as phosgene, propylene chlorohydrin[25] or any ozone-depleting chlorofluorocarbons.[26] With rice hulls, we do not use urea formaldehyde, and surely none of the phenol formaldehyde used in most fiberglass insulation.[27] With rice hulls, we do not have to worry about the irritability or cacinogenicity of dust and fibers.[28] Moreover, those with acute chemical sensitivity should not have to worry about the offgassing associated with binders in batt insulation, with ink in recycled newspaper or with VOCs released from foam insulation.[29] Since rice hulls require no shredding, hammer-milling, fluffing, fiberizing, binding or stabilizing, they possess, surely in those states where hulls are available, far less embodied energy than even cellulose insulation.[30] Since rice hulls do not burn very easily, they require no flame or smolder retardants, and since they are so

[21] See Juliano (1985), p. 696.
[22] See Juliano (1985), p. 28.
[23]Much of the comparative language of this paragraph is taken from Environmental Building News – Insulation Materials: Environmental Comparisons, at http://www.buildinggreen.com/features/ins/insulation.html.
[24] "The styrene used in polystyrene insulation is identified by the EPA as a possible carcinogen, mutagen, chronic toxin, and environmental toxin. Further, it is produced from benzene, another chemical with both environmental and health concerns." Ibid, p. 5.
[25] "To manufacture isocyanate, a precursor of polyisocyanurate and polyurethane insulation, two chlorine-based chemicals are used: phosgene and propylene chlorohydrin." Ibid., pp 4-5.
[26] "The most significant pollutants found in insulation materials are chlorine-based chemicals that destroy the earth's protective ozone layer." Ibid., p. 5.
[27] "Most fiberglass insulation is produced using a phenol formaldehyde (PF) binder to hold the fibers together." Ibid., p. 5.
[28] "Growing health concerns about glass fiber" are discussed on p. 10 of ibid.
[29] See ibid., pp. 10-11.
[30] Embodied energy is defined as "the energy required to produce and transport materials." Ibid., p. 8.

tough and durable, nothing prevents them from being used and recycled over and over again.

Perhaps the most significant cost associated with the utilization of the rice hull is its transport. At a bulk density of about 9 lbs. per ft^3,[31] loose hulls can be transported at roughly the same cost as baled straw. However, to reduce the cost of transport, rice hulls can be compressed to as much as 25 lbs. per ft^3 without destroying their elasticity.[32] They readily bounce back to their original density once the force of compression is removed.

But to transport rice hulls economically, it would not be necessary to compress rice hulls to a density of 25 lbs/ft^3. At a density of only 14.50 lbs/ft^3, a standard 53-foot trailer attains optimal transport efficiency at its maximum legal weight of 24 tons. Those living less than 200 miles from rice mills should have a hard time justifying the use of any other type of insulation material. When many mills reluctantly sell rice hulls for less than $5.00 dollars per ton, the argument in favor of rice hulls becomes extremely compelling.

Supposing we are convinced that rice hulls offer many advantages over conventional insulating materials, how should we go about constructing a super-insulated house employing rice hulls? Supposing further that we wanted to build the structure of this house almost entirely out of waste materials, how should we proceed? Since loose rice hulls, unlike bales of straw, have no structural value, how should we build the floor, wall and roof cavities of a rice hull house?

The technology that would allow us to create floor, wall and roof systems out of low-grade cellulosic materials already exists. Companies such as Georgia-Pacific, Louisiana Pacific, Weyerhaeuser and Boise specialize in a variety of engineered lumber products such as I-joists, laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), oriented strand lumber (OSL), glued laminated timber (GLULAM), etc. These engineered wood products offer a broad range of advantages over traditional solid-sawn lumber.

They are free of knots and other imperfections. They do not shrink, crown, twist, bow, split, check or warp. They are stronger, stiffer, lighter, straighter and far more precise than solid-sawn lumber. They can be engineered to span relatively long distances, with far more load-carrying capacity per unit of weight. Architects can design structures with far more livable and useful space, builders are not confronted with discard and waste, and carpenters find them easy to cut and install.

Currently aspen is the primary raw material used to manufacture many of these engineered lumber products. Aspen grows in forests, and up until now, the destruction of these forests has been an inevitable consequence of making engineered lumber.

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[31] See Juliano (1985), p. 696, Velupillai (1996), p. 16, Beagle (1978), p. 8.
[32] “Hull can be readily compressed to about 0.4 g/cm^3, and grinding increases bulk density two to four times.” Juliano (1985), p. 696.

But there is another tree that could be used to make engineered lumber, and the utilization of this tree would not entail the destruction of our native forests. It is a highly invasive tree that has spread throughout the Gulf States. It is called the Chinese Tallow tree.

The Chinese Tallow tree is adaptable to a wide range of soil and light conditions. From highlands to lowlands, from inland areas to marshes, from fresh water soils to saline-sodic soils, from hills to flood plains, from open prairies to closed canopy forests, from pine forests to cypress swamps, from rural areas to densely populated urban areas, it vigorously competes with native vegetation.. The Tallow tree quickly becomes the dominant plant in the area it invades, causing large-scale ecosystem modification by displacing not only native vegetation but also a lot of the wildlife that co-evolved alongside it. Once it is well established, it appears almost impossible to eradicate. Unless we find some way to work in harmony with this formidable enemy, it will surely defeat us.

One way to control its proliferation would be to harvest it periodically from wild stands. This abundant cellulosic biomass can be engineered into a variety of structural members that can be used to make the floor, wall and roof trusses of this rice hull house. The Tallow tree is rich in oil-bearing seed that makes an excellent biodiesel, and its biomass can be used to make methanol.[33]

As citizens in a large industrial society, we find it hard to do things that really make a difference. In choosing to build a structure derived in large measure from agricultural waste materials, not only do we do that which is right with respect to the environment, but we also fashion for ourselves a structure far superior to anything conventionally available. This super-insulated rice hull house, when correctly designed, [34] should be considerably cheaper to build than a conventional structure, while continuously benefiting its owner with utility bills never exceeding on average more than one US dollar per day.

Therefore, why build conventionally when it is far cheaper and far more sensible in every respect to do otherwise? Up until now, we could always take refuge in the fact that as long as we are unaware of the possible, we could not make it happen. But this is not so much about duty and obligation, as it is about finding new and exciting ways of responding creatively to the awesome and overwhelming beauty within our Universe.

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[33] See http://www.thebiopod.com/pages/pages/tallow.html

[34] "Thick enough insulation and good enough windows can eliminate the need for a furnace, which represents an investment of more capital than those efficiency measures cost. Better appliances help eliminate the cooling system, too, saving more capital cost… The only moderately more efficient house and car do cost more to build, but when designed as whole systems, the *super*efficient house and car can often cost less than the original, unimproved versions." Hawkens, P., Lovins, A., and Lovins, H. 1999. Natural Capitalism, p. 114, Boston: Little, Brown and Company.

Appendix

The First Rice Hull House

The first rice hull house, completed February, 2004, was initially the home of Paul and Ly Olivier. Randolph Speyrer now lives there and has embellished the interior in a truly magnificent way. Located in the historic steamboat town of Washington, Louisiana, right across from the magnificent Magnolia Ridge Plantation,[35] this house is indistinguishable from houses built in the area more than 150 years ago. Many of the building techniques described in this paper have been applied in the construction of this home.[36]

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[35] See http://www.cajuntravel.com/washington.html

[36] For more information on this rice hull construction technique, see: http://www.esrla.com/shotgun/frame.htm