Alternative Uses for Rice Straw in California

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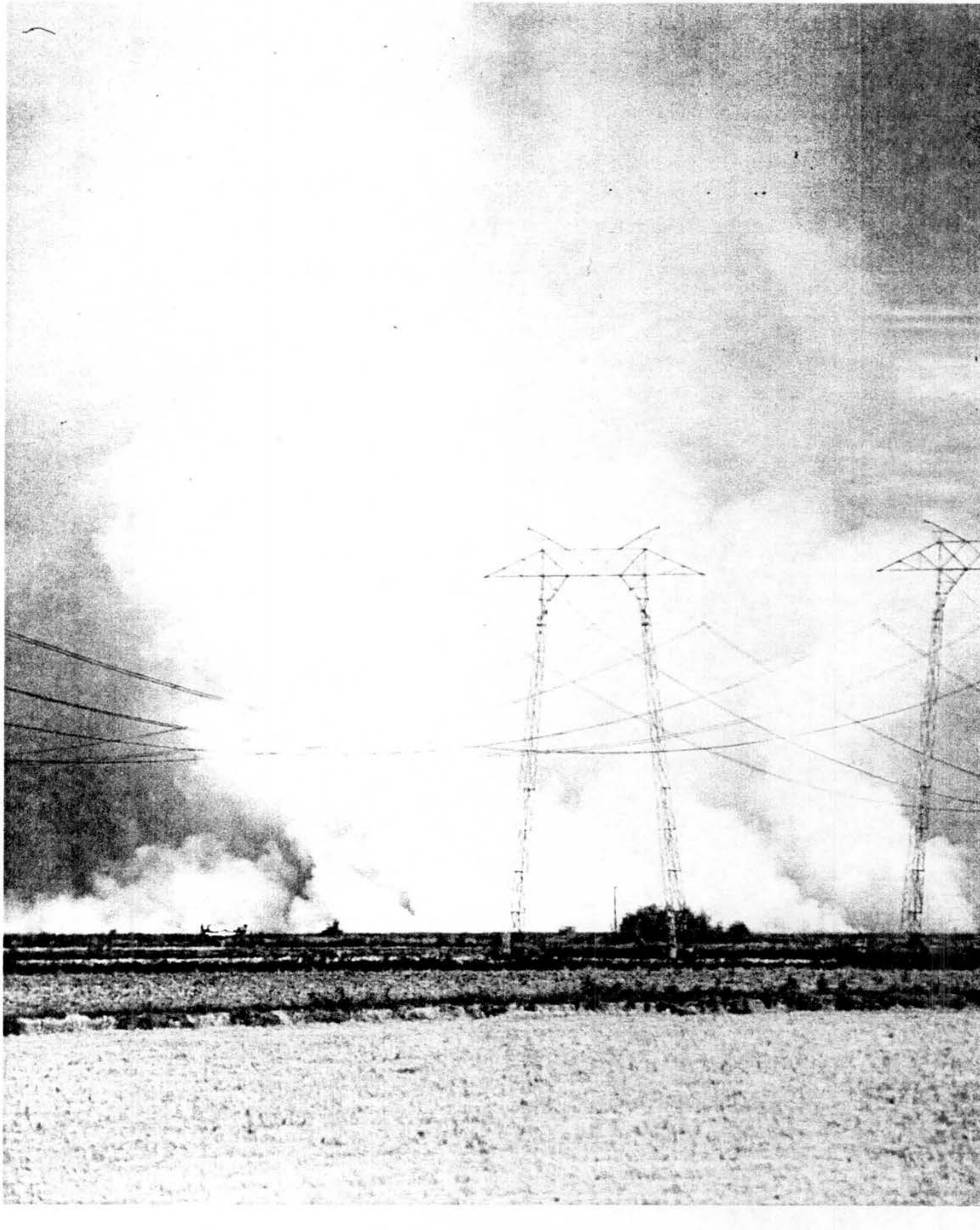

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OVERVIEW: RICE STRAW AND THE ENVIRONMENT

Interconnectedness and complexity are the hallmarks of almost every environmental problem and opportunity including the challenge of rice straw management in California. Although attempts are often made to solve environmental problems by working on single aspects, this rarely works, just as treating symptoms may do little to resolve diseases. The rice straw problem includes the physical systems of the atmosphere, air basins, soils, and local and regional watersheds, and reaches the global scale with concern over atmospheric contribution of methane and implications for global warming. It includes the biological systems of the rice crop, soil organisms, crop pests, and wildlife (both beneficial and harmful). And finally, it includes the economic and social systems of the rice growers, farm families, farm service industries, rural communities, the regional population, rice consumers around the world, fishermen and women, hunters, manufacturers of harvesting equipment, medical services, and potentially, builders and home buyers in the region. Complex linkages between the physical, biological and social systems are well illustrated in the rice straw problem, and like most problems these complex interactions make finding solutions challenging. They also can make it possible to find win-win solutions where multiple parties benefit from improvements in management strategies.

An outline of the rice straw burning problem

Rice production has become an important economic activity in California and in a typical year 400,000 acres of rice are planted (almost 500,000 in 1994). From two to three tons of straw are left per acre after the grain is harvested. The traditional grower practice has been to burn the residue. This is inexpensive, as little as $3 acre, and provides added benefits of reducing weed problems and more critically minimizing rice stem rot and other rice diseases. In recent years 75-135,000 tons of the total of 1-1.5 million tons of rice straw have been burned in the fields in the fall, over the entire year total amount burned can be two to three times as much. The rice straw burning in the fall is spread over a period of weeks or months and is regulated to discourage burning when meteorological conditions are likely to lead to smoke accumulation. Yet even under this careful control the smoke can cause health and safety problems, including asthma, allergies, bronchitis, and respiratory distress. Smoke can also contribute to highway accidents. No detailed epidemiological work-up has been done on the health costs associated with rice straw burning.

Health risks are minor due to burning management, but may be significant locally near burns. These risks include exposure to the various gasses (notably carbon monoxide and nitrous oxides) and particles created by recombination of gasses, ash, and dust raised from the soil surface. These include known carcinogens and mutagens, gasses that are hazardous or lethal at high concentrations, and a range of potentially harmful particles and byproducts of burning. These pollutants and other more dangerous materials are also generated by using firewood to heat homes, automobiles, and wild land and forest fires. Rice straw burning is a contributor, but other sources are more important on a regional basis. Concern has grown recently over the danger posed by small particles (less than 10 microns, PM<10, and more critically particles <2.5 microns). Health studies in other areas have showed a clear relationship between increased particulate levels and increased mortality. Silica content of rice straw is high and the silica rich ash particles may pose a slightly higher risk than other types of ash, but the organic condensates on these particles may be of more concern and would be similar for other types of straw burning. More detailed studies are needed to accurately assess health risks.

Rice straw burning and soil incorporation have global environmental risk implications. The carbon content of rice straw is about 40%, and the burning of 500,000 tons of rice straw may return 200,000 tons of carbon into the atmosphere. This carbon is fixed during the growing season by photosynthesis and there is little net gain. If the straw is incorporated in the soil it increases methane emissions, which are more damaging than the byproducts of burning. Methane is a special concern for global warming, because each methane molecule has 20-25 times the heat capturing potential of a carbon dioxide molecule. Even allowing for the lower level of emissions, the net impact on global warming would be 10-15 times worse than the effects of carbon dioxide from field burning. The use of rice straw for other purposes that would store or sequester carbon would decrease emissions and reduce global warming risks.

The obvious problems associated with rice smoke led to restrictions on burning beginning in 1971 under provisions of the Health and Safety Code, these were revised and made more flexible in the early 1980s. Sacramento Executive Airport records show smoky conditions 24% of the time in October-November in many years, although with restrictions in burning this dropped to less than 4% of the time in October-November, 1990. Current restrictions base allowable burn acres on atmospheric conditions. Predictions of weather conditions and measurements of particulate levels are used by the Air Resources Board to set allowable burn times and amounts. The specific allowable burns are made by the air pollution control districts or their agents. In 1991 an act was passed to phase down rice straw burning by 2000, with the exception of burning essential for disease control.

This has led to increased analysis of options for rice straw management; including field studies by the University of California, this review of uses of rice straw by the Renewable Energy Institute at Cal Poly San Luis Obispo, and many other reports and studies for the Air Resources Board. The University of California studies showed that the economic cost of incorporating straw was high, ranging from $7 to $80 per acre. A complete burn ban and change in management practices could increase growers costs millions of dollars each year. The added cost would be accompanied by increased risk of rice disease buildup and potential damage to crops from methane generated by straw decomposition in the wet soil. These problems have led to an effort to find uses for rice straw that would remove straw from the field and add value to the material.

Global annual methane emissions from rice fields are a major source estimated at as much as 150 million tons, more than the net annual increase in atmospheric methane (see also addendum on methane). Methane production from rice soils is limited if straw levels are low. When rice straw is added to the soil, methane emissions increase 3 to 12 times, with larger emissions when straw is added deeper in the soil. Annual emissions can be correlated with readily mineralizable carbon in soils before flooding. The potential plowdown of straw and flooding of fields for waterfowl would probably generate the most methane.

For the 400,000 acres of rice grown in California current methane generation may exceed 50,000 tons per year. If emissions triple from increasing straw soil incorporation instead of burning this could increase 100,000 tons or more. Although this remains only a tenth of a percent of the global total, this is still significant. As organic matter builds up methane emissions would increase. Anecdotal stories from rice growers suggest increased methane "poisoning" of crops can occur after 3-4 years of plowdown. To offset nitrogen tie-up from straw more nitrogen fertilizer may be needed, but this has also been found to increase methane generation.

The use of non-renewable fuels would also increase as much as 2 gallons per acre for the plowdown, a total of 300-400,000 gallons for the plowdown. But it is likely the health risks in the region would be lower if burning was eliminated.

Solutions

The most environmentally acceptable solution is probably straw harvest and removal. This can reduce methane production, minimize health risks from burning, protect crops from disease carryover and limit risks to global ecosystems. If the straw crop is sequestered it may become a meaningful carbon sink.

The challenge is developing a series of markets and uses for the rice straw to offset harvesting costs. Promising options identified in the Renewable Energy Institute Cal Poly Study include: environmental use for erosion control and dust management, use of straw in mushroom production, straw use in biocomposite materials (i.e. straw panels and structural members made with rice straw and cement or plastics), and use in straw bale buildings. There may also be opportunities in paper production for some types of paper and fiberboard. Other options, not discussed in this report, include ethanol production and treatment to make the straw useful as animal fodder.

The use of straw bales in building is increasing rapidly across the country and in California, including a winery and architect's office in San Luis Obispo, walls of a retail center in Hopland, a mine storage building in San Bernadino County, and homes in Mendocino, San Luis Obispo, Contra Costa, and Inyo Counties. Many more projects including some commercial projects are underway and will be completed this year. Assembly Bill 1314 encouraging straw bale construction passed and was signed by Governor Wilson. This bill encourages local building departments to adopt straw bale building codes. Several counties adopted straw bale building codes in early 1996, including, Napa, Yolo, and Glenn counties. A straw bale sound control wall is slated for testing near Dunnigan.

The state of New Mexico, Pima County and the City of Tucson in Arizona have also developed codes and straw bale buildings are no longer considered unusual. Straw bale building has spread quickly across the United States and around the world and many hundreds of buildings are now in place. The primary markets have been for low cost owner built homes and expensive custom homes, including a 9,000 square foot home currently under construction in Santa Fe that used 4,400 bales.

Many of these alternative uses have potential but will take additional research and time to develop straw harvesting systems and improving markets. Rice straw disposal (incorporation v/s field burning v/s removal) illustrates the importance of reviewing systems implications of policy rather than simply focusing on single-issues. The limited data on many aspects of the rice straw system is also common to most complex environmental problems. If epidemiological studies had been done sooner and more completely the impetus for change would have been stronger and more emphatic. If the full range of impacts and opportunities had been reviewed, perhaps as part of a policy environmental assessment, a more complete picture of policy options and risks could have been developed. If government subsidies for timber harvest were removed the use of biocomposites would increase.

The challenge of rice straw management also illustrates equity problems common to many global resource issues. Although the growers have been forced to change practices to protect the health of the regional population by reducing smoke, the global considerations of methane and carbon emissions to the atmosphere have been ignored. Because these have been neglected alternative consumptive uses have been given limited attention. Reducing emissions from rice straw burning may be much more economical than limiting emissions from other sources, and provide more business opportunities.

Providing the money to improve rice straw utilization should come from a carbon emission fee for agricultural burning (rice straw is not the only source), perhaps beginning with a $3 per ton fee starting in 1996 rising to $6 ton in 2001. Similar charges have proved effective in Europe. One third of this should be allocated for a detailed assessment of respiratory illness epidemiology and costs in the valley. One third would be devoted to improving straw system harvesting and the remaining money would fund a competitive research and demonstration program for alternative uses of rice straw and rice hull ash. This section might provide the money needed to operate research, education, training and business incubation projects such as the Envirosave Research and Training Value Added Technology Center in Redding.

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POTENTIAL USES OF RICE STRAW FOR ENVIRONMENTAL MITIGATION AND ON FARM USE

The market for rice straw for environmental uses is one of the easiest to enter and could absorb large quantities of straw with little change in policy. Uses include: rice straw for erosion control, rice straw for soil improvement and water retention, weed suppression, and site restoration. Many of these uses overlap with agricultural uses.

Rice straw for water erosion control

Rice straw has excellent potential for use in erosion control in the form of mulches. The use of straw mulch to prevent erosion has become a standard acceptable practice over the past several years. Straw mulch protects a site from erosion until plants are established. It also conserves moisture, moderates soil temperature, holds fertilizer (if used), absorbs the impact of rainfall, and provides useful soil organic matter upon decomposition (Versteeg and Earley, 1982; Highfill, 1980). The use of straw as a mulch over wood fiber or other wood products has generally been viewed as providing better results in both site protection and plant encouragement and is much more cost efficient (Jennings & Jarrett, 1984,1985; MacCaskill, 1978; Ross et al., 1990). Gilley et al. (1977) reported that straw mulch reduced erosion of topsoil by over 90%. Rice straw is preferred for many uses because it is less likely to incorporate dry land adapted weed species (OWPS, 1975).

Straw mulch is normally applied at a rate of 2-4 tons per acre. Application can be made by hand or with a mechanical blower. Straw must be anchored into the soil to prevent it from being blown away. This can be accomplished through crimping, disking, rolling or punching it into the soil; by covering it with netting (preferably a biodegradable netting such as coir or jute); or by spraying with a fiber binder (tackifier). Though the use of a glue or tackifier is common in the east, the California Department of Transportation normally uses a roller or puncher to anchor straw mulch on slopes along California's highways.

Tests comparing the costs and effectiveness of numerous erosion control methods were conducted by Burgess Kay at the University of California at Davis (Kay, 1984). A treatment of broadcast seed with a straw mulch applied by blower at 3,000 lb/acre and anchored with 300 lb/acre wood fiber and 60 lb/acre organic binder was the most cost effective at about $1000/acre ($2500/ha) in 1984 dollars (Goldman et al., 1986).

The use of straw wattles for erosion control on steep slopes has come into use over the past several years. These wattles are normally in the form of a nine inch diameter tube that is about twenty-five feet long and weighs approximately thirty pounds. Straw wattles are placed at selected intervals along the face of the slope and pinned in place. Wattles are excellent in slowing runoff, capturing sediment and promoting revegetation. The United States Forest Service presently uses straw wattles for erosion control in burned or other degraded areas.

Vertical mulching, or placing rice straw vertically in the soil may be especially effective for treating problem areas (Bainbridge, 1994). This method provides many benefits, including: slowing water movement; providing open channels for water penetration into the deep soil; safe sites for seeds to catch and sprout; wind breaks to trap seeds and dust; shade and cover for seedlings; and a source of below-ground organic matter to help return the soil ecosystem to health. Experiments have showed that vertical mulch can increase soil moisture storage substantially >20%, (Fairbourn, 1975; Bainbridge, 1995).

An additional benefit to the use of straw mulch as an erosion control method has been outlined by Mostaghimi et al. (1994). Their investigation centered on the effectiveness of different combinations of straw mulch, hydroseed and commercial synthetic polymers in controlling erosion. Results demonstrated that straw mulch not only was best for controlling sediment runoff, but that straw mulch was the most effective technique for reducing both phosphorus and nitrogen losses from the soil. The retention of nutrients is important for forest and agriculture, fisheries and water managers, and water pollution control agencies. The ability of rice straw to help retain nutrients is an excellent selling point.

Barriers and Incentives

Codes and regulations to reduce erosion already require straw mulch in many jurisdictions. California State Parks Department has favored rice straw for many projects and use could be further encouraged on state lands through policy and regulation. Modification to require or encourage the use of rice straw locally on Federal Highways, State Highways and construction projects would increase the market share. The California Department of Transportation manages 230,000 acres of right of way in the state. If 5% were treated each year, 50,000 tons of straw could be utilized annually. It is desirable for straw used for such purposes on or near critical habitats be weed free.

<u>Sediment traps</u>

Despite the best efforts to reduce erosion, some erosion is inevitable and the impacts of erosion are serious and costly throughout California. Rice straw can be used not only for preventive erosion measures, as described above, but also in the reduction of soil loss through erosion that may occur when no preventive measures are implemented or prove inadequate due to high intensity storms. Rice straw bales can be used in the construction of sediment retention structures.

Sediment retention structures do not stop erosion, but trap eroded soil before it can reach a body of water, block culverts and drains, or be dispersed from the original property. As such, sediment retention should be used as a back-up system to erosion prevention systems or until such permanent measures such as landscaping have been accomplished.

Sediment retention structures work by slowing the runoff velocity to allow suspended particles to settle by gravity. Sediment retention structures rarely trap 100% of the runoff sediment, but a 50-75% removal efficiency is acceptable. Straw bales have been shown to provide this level of performance as sediment retention barriers, traps and basins.

The use of straw bales as sediment retention barriers for small areas (i.e. several acres or less) has proven to be both successful and inexpensive (Highfill, 1980). A straw bale barrier can be used to prevent sheet flow or channel flow runoff along exposed slope faces; along the base of a slope; along small drainage ways; and near storm drain inlets. Straw bale barriers are usually best used for slopes with a maximum gradient of 2:1 and a maximum length of 100 ft. or across a small swale where the barrier receives no more than 1 ft^3/sec flow. When a straw bale barrier is constructed, bales should be inserted into the soil approximately 4-6 inches for stability and pinned with two pins per bale. Barriers made of more degradable straw bales have an average life span of about 3-6 months (Goldman et al., 1986), but rice straw bales may last several years in the dry areas of the state. At a restoration site at Red Rock canyon State Park straw bales have lasted for three years.

Straw bales can also be used as check dams (Bogovich, 1992; Miles et al., 1989). A check dam is used to prevent channel erosion by slowing the velocity of the flow. Check dams are used in situations of greater expected flow than sediment barriers and are constructed in a similar fashion to straw bales sediment barriers but with a sturdier construction (i.e. heavier pinning) and a downstream apron to prevent undercutting.

Straw bales are also used for sediment basins and traps (Secor, 1977). A straw bale sediment trap is constructed by placing a line of bales, two or three bales high, in much the same manner as a straw bale sediment barrier. The straw bales must be supported by a wire fence with outlet sections provided to relieve water pressure. Normally a straw bale trap can accommodate a 3-5 acre drainage area and has a life span similar to a straw bale sediment barrier.

A secondary result of straw bale basins and traps is the filtration that occurs as water passes through the straw bales. In situations where water supplies may be polluted through excessive sediment (i.e. fire, flood), straw bale barriers, traps and basins not only capture the sediment, but provide initial filtration of watershed runoff before water enters a reservoir or settling pond. This provides an inexpensive means to avoid costly dredging and drain clearing operations (Miles et al., 1989; Versteeg & Earley, 1982).

Barriers and Incentives

No simple technical guide is available, although various books and articles describe different approaches. Further development of reinforcement methods and apron/spillway designs are needed for straw bale dams for larger gullies and stream channels. Use of straw bale nutrient traps could benefit from field testing, funded by CalEPA, EPA, or the Dept. of Agriculture. Control of biocide runoff and decomposition byproducts should also be evaluated for crops with high pesticide loads. The nutrient traps provide additional opportunity for low-cost compost production.

Wind erosion control

Soil loss through wind related erosion is also a serious problem in many areas of California. This includes not only the loss of soil, but the resultant air pollution caused by airborne particulate matter and the health costs associated with this dust. Particulates are increasingly recognized as a health hazard (Dockery et al., 1993; Schenker, 1993). Particulate matter less than 10 microns in size is able to reach the smallest sections of the lung and is not cleared from these airways. These small particles may be among the most hazardous of all air pollution problems (Dockery et al. 1993).

Dust is also involved in the spread of disease. Valley Fever, which is endemic in parts of California, Arizona and New Mexico (Pappagianis 1988; Rippon 1988; CSDHS 1994), is an infection caused by the soil fungus *Coccidioides immitis*. (Pappagianis, 1988; Rippon, 1988). The arthroconidia, which are infectious, can become airborne in conjunction with dust and remain suspended in air for many hours or days. Dust control in agricultural regions could reduce costly infections and deaths caused by this disease.

Blowing dust has also caused many highway accidents in California. On Thanksgiving weekend, 1991, moderate winds (15-40 mph) caused severe dust and visibility problems on Interstate 5 in Fresno County resulting in a 164 vehicle pileup (Arax 1994). The first settlement with a woman severely burned in the accident cost the state of California $3.4 million dollars. A number of claims against the state still remain unresolved.

Abandoned agricultural land, active and fallowed agricultural land without windbreaks, urban and suburban development, road margins, pipelines, overgrazed range land, off-road vehicle operation, and water transfers all contribute to dust problems. Rice straw mulch and rice straw bale barriers can be used to prevent wind related erosion as well as water erosion.

Abandoned agriculture land is common in the drier parts of the state, including the South San Joaquin, Owens and Antelope Valleys. Particulates in the Antelope Valley exceeded the California 24 hour standard of 50 $\mu g/m^3$ of 10 micron particulates almost 10% of the time in 1992 (California Air Resources Board, 1993). Dust problems from abandoned farmland have also been exacerbated by sheep grazing (Pyle, 1991). Active farmland can also be a serious dust generator, with the state standard exceeded on 24 of 60 observations in Brawley (California Air Resources Board, 1993).

Diversion of water from the Owens Valley to Los Angeles has virtually dried up the once extensive Owens Lake, resulting what is considered to be the most severe dust problem in the nation (Roderick, 1989; Forstenzer, 1992). The winds through the valley now raise large clouds of dust that have caused particulate levels of up to 526 $\mu g/m^3$ in the town of Keeler (California Air Resources Board, 1993). Observations exceeded the State Standard almost 20% of the time. Particulate concentrations greater than 250 $\mu g/m^3$ have also occurred in Olancha and around Mono Lake, another lake affected by water diversion.

In areas with higher wind regimes, dust and sand can also become a physical problem, with drifts and dunes encroaching on highways, housing, farmland, crops, and developments. Removal of sand and dust is expensive and many parts of the state have experienced extensive crop damage from wind blown sand and gravel. Blowing dust and sand cause millions of dollars of damage to vehicles also.

Rice straw is ideal for dust control because it is fibrous, often longer length than wheat or other straws after baling, and highly durable. Dust control can use loose straw, straw flakes, or straw bales depending on goals and site conditions.

For long term dust management, soil loss could be lessened by constructing erosion barriers similar in form to the sediment traps mentioned above. Several barriers, 3-4 bales high and backed by a wire fence, could be constructed perpendicular to the prevailing winds across the dry lake, abandoned agricultural land, or roadside. Such barriers would decrease the wind velocity, reduce particulate matter uptake and also capture soil as the wind eddied around and over the barriers.

An important secondary effect of such a system would be the establishment of microsites for the re-establishment of vegetation. As the straw bales decomposed, the organic matter and nutrients from the bales would mix with the captured soil. These sites could either be seeded with a native seed mix or seeding could rely on the available seed bank from nearby vegetated areas.

The dust problems of Owens Lake are legendary and severe. The deposits on the dry lake basin are readily picked up by winds and carried in intense dust clouds to nearby towns. They are still in sufficient concentrations to be a health hazard more than 100 miles away. The area in and around Owens Lake and the Owens Valley is an example of an area that could profit tremendously from the construction of such barriers. The development of dust control strategies has been limited. Artificial dunes, irrigation and other schemes have been proposed--all would be very expensive. A series of rice bale fences 3-4 bales high, pinned with bamboo or backed by a wire fence, would provide dust control, retain rain and snow, and provide improved microsites for plant establishment. A pilot test on 160 acres is suggested. The bale fences would be 4-5 feet tall and spaced 75 feet apart. This project would require almost 3,200 tons of rice straw. If it proves successful the full treatment of the exposed lake bed might be progressively treated using 40,000 tons per year for more than 30 years.

Dust control along I-5 using rice straw bales would require about 600 tons of straw per mile for a three row fence system. This would be expected to last 10 years, and combined with a planting program would provide almost permanent control of dust in high risk areas. Vertical mulch treatment could be done with less straw at a much lower cost but would also be effective.

Barriers and Incentives

Field testing and cost evaluation are needed for bale fences and vertical mulch. Perhaps testing by CalTrans research lab along I-5 in the southern San Joaquin Valley would be a first step, or this work might be done with students and professors from UC Davis. A test at Owens Lake by the Los Angeles Department of Water and Power would be desirable. The straw might be delivered to site by rice growers in cooperation with the state. The straw bale test barriers could be constructed in cooperation with the Greater Basin Unified Air Pollution Control District that regulates Owens Lake.

Rice straw as an aid in revegetation and site restoration

Rice straw can also be used to aid in the establishment of vegetation. The use of native plants in landscaping and restoration efforts has increased throughout California not only due to an increase in popularity but through the enactment of environmental laws and regulations. Numerous studies have demonstrated the successful use of recalcitrant mulch, such as straw, to favor the growth of native perennials over exotic annuals (Zink and Bainbridge, 1994).

Studies have been conducted on the use of recalcitrant organic matter on both strip mine spoils (Elkins et al., 1984), degraded rangeland (Whitford, 1988), degraded desert and coastal sage scrub (Zink, 1994), and prairies (Morgan, 1994). The addition of straw and bark increased microorganism diversity, established a stable decomposition and mineralization cycle, and improved the physical characteristics of the soil. All these actions led to increased growth of native perennials and a decrease in exotic annuals. Numerous other studies have verified these findings (Ingham et al., 1985; Smith et al., 1986; Schuman & Belden, 1991). Rice straw, being more recalcitrant than wheat or oat straw, is an excellent mulch for aiding in the re-establishment of native perennials along road cuts, pipeline corridors and other construction sites.

Barriers and Incentives

Field tests in a range of native habitats would help sell this use. Ultimate use could be very large. California Department of Transportation is continuing to increase their use of native plants for right of way revegetation. Arranging with CALTRANS to establish and monitor several test sites along their rights of way could go a long way in convincing them on the usefulness of rice straw mulch for native plant establishment. The cooperation of the California Native Plant Society would be helpful in setting up tests plots across California.

et seq Agricultural uses

Rice straw has many uses in agriculture and forestry. The primary uses are likely to be for soil improvement, soil protection and water retention (as with environmental uses), mushroom production, straw bale culture in greenhouses and weed management. Composted straw is most desirable for soil improvement for farm, forestry, and garden use. Mushroom production may have the most potential as a market for large quantities of rice straw.

Soil improvement

Numerous studies have demonstrated that rice straw can be a valuable asset to the agricultural community. The use of rice straw as a mulch on maize crops in Nigeria has been shown to significantly reduce the occurrence of brown spot disease (Osunlaja, 1989). In Japan rice straw mulch has been used to enhance root growth of grapevines (Takahashi, 1988) and to increase tomato plant yields by over 16% in Indonesia (Gunadi & Suwandi, 1988).

A study by Bhagat and Verma (1991) demonstrated that a combination of farmyard manure and incorporation of rice straw into fields of winter wheat in India led to higher grain yields than several other mulch procedures and control. Rice straw was incorporated into the soil at a rate of 5 t/ha^{-1} for a period of five years. The use of incorporated rice straw led to improved soil physical characteristics such as high soil porosity, low bulk density and high water content. similar improvements in grain yields through the use of rice straw have also been reported by Kawata and Seijima (1976) and Bhagat and Acharya (1987, 1988).

Mineralization, the process by which organically bound nutrients are released into the soil as available inorganic minerals, is of primary concern to any agricultural community. Rice straw mulch has been shown to increase mineralization rates in several ways. Shepard et al. (1989) demonstrated that rice straw bundles left in fallow fields increased the diversity and overall number of arthropods, thereby increasing soil microbial activity and, in turn, mineralization. Such an increase in mineralization allows a greater amount of nutrients to become available to plants, resulting in increased crop yields.

Straw mulch benefits saline or other degraded agricultural soil by improving both physical characteristics such as bulk density, aggregation and water infiltration rates, and through its slow release addition of soil organic matter through decomposition.

Table 22.1. Land use in acres

	California
Cropland	10,209,000
Range	17,719,000
Forest	15,073,000

Statistical Abstract US, 1993.

Fifty percent of the California range is in fair to poor condition. Much of the forest land is also in poor condition. More than 8 million acres of range and 4 million acres of forest or land that was previously forest would benefit from application of rice straw mulch and erosion control structures. Despite the great need for environmental protection and improvement work of these lands, little work is done to restore productivity each year. Only about 80,000 acres of forest land improvement are made each year, about half a percent of the area that would benefit from treatment. If rice straw land treatment rates of 2-3 tons per acre are used, the full production of rice straw could be absorbed on either forest or rangeland -- if someone would pay for the transport of the straw. Changes in tax policy that currently discourage active land stewardship could conceivably increase use dramatically and provide many other economic and environmental benefits to the state.

Barriers and Incentives

Low cost straw is important for these low value, long-term payback projects. If large scale straw harvest can reduce cost and increase availability, use of rice straw would increase. Cost disincentives for land stewardship and reforestation should be removed. Changing tax laws to allow current cost charges for improvement activities rather than discounting them till tree harvest would increase use. Increasing user costs for offsite erosion damages and nutrient impacts would also stimulate straw application.

Forestry soil rehabilitation of burned areas

Every year the state of California experiences the destruction caused by forest fires, figure 1. While there is no accurate accounting of the amount of straw used, the California Department of Forestry and the United States Forest Service use straw for erosion control and soil rehabilitation on approximately 5 to 10 percent of the burned area, depending on soil condition, accessibility and steepness. Using the data in figure 1 as a typical 10 year period, and based on an application rate of 1.5 tons per acre, approximately 36,000 ton of straw might be used in an average year.

Barriers and incentives

The amount of rice straw used for rehabilitation of burned land cannot be viewed as a stable demand because yearly damage and conditions caused by forest fires are likely to fluctuate from year to year. However a steady order could be placed to keep rice straw in regional depots to facilitate rapid application after fires.

Straw bale culture

An area in the field of food production that has almost unlimited potential for using rice straw is straw bale greenhouse gardening (Walls, 19__). Straw bales are used as substrates to grow many vegetables under greenhouse conditions. Water and fertilizer is first added to the bales along a slot on top of the bale to initiate decomposition. Once this process has begun, planting of seedlings can begin. Commercial planting techniques allow between 13,000 and 14,000 tomato plants per acre. Tomatoes and cucumbers have been extensively grown in this manner. Rice straw, with its slower decomposition rate than wheat or oat straw, would serve as an excellent substrate on which to grow greenhouse vegetables.

Barriers and Incentives

Lack of current technical information on rice straw response to straw bale culture techniques inhibits use. This would be worth investing in research at local colleges. Straw bale culture provides both the benefit of a marketable crop and compost material.

Mushroom production

Another fairly new field in the area of food production with excellent opportunities for rice straw use is mushroom production. Mushrooms normally grown as a food source, such as *Agaricus bisporus* (Button mushroom), *Pleurotus ostreatus* (Oyster mushroom) and *Lentinellus edodes* (Shiii Take), are decomposers and receive their nutrients from the substrate upon which they grow. The use of straw as a substrate has been much studied over the years (Straatsma et al., 1994; Atkey & Wood, 1983; Chang & Hudson, 1967; Fermor et al., 1985; Gerrits, 1988; Senya, 1988) with reported excellent results. Atthasampunna and Chang (1994) report that the amount of cultivated mushrooms has risen from 2000 tons in 1986 to over 4000 tons in 1990, and is expected to continue increasing at a rapid rate. Pudwell (1993) reported that 400,000 tons of straw was used in 1992 by the commercial mushroom industry in the United Kingdom and the amount continues to increase every year. The compost left after the mushrooms are harvested is used for livestock feed and soil conditioner, increasing the economic value of the straw.

The demand for a cool, dark and stable environment for production could be met by building long straw bale "caves" for production. These could be temporary with a plastic liner or plastered for permanent use. The production of the mushrooms and mushroom "caves" could be very profitable.

Barriers and Incentives

Lack of information on straw bale caves and mushroom culture is probably limiting consideration of this option. The large companies now involved in the mushroom market may respond to mailing of information on the straw resource, local nutrient sources, and straw bale buildings. A test cave would be even more effective. The closeness of the Valley to Sacramento and transport to the Orient (an extremely large mushroom market) is a big plus. In 1993, Honda of North America established commercial mushroom cultivation on its Ohio property with the express purpose of growing Shiii Take mushrooms for export to Japan (Chappell, 1993).

Compost

Composts are complex communities of decomposers and grazers and can provide positive benefits for gardens, field crops, orchards, vineyards, forest and rangeland. Making compost with rice straw may require research to reduce costs. Compost production should be a good outlet for dirty or moldy hay that fails to meet standards for building material or industrial feedstock. Because the C:N ratio in compost is moved closer to the ideal ratio for plant growth by adding nutrients compost can be added to soil in very large quantities, with some market gardeners using more than 20 tons per acre year.

Keeping compost costs low is challenging unless the process also provides waste disposal benefits. The large scale rice hull and poultry waste composting operation at Foster Farms in Livingston converts rice hulls and poultry waste into a popular Organic Soil Amendment. In the Sacramento Valley similar opportunities may exist for composting with dairy waste, feed lot manure, clean small town sewage sludge, and processing wastes. Composting is a natural outcome of mushroom production with straw and mushroom compost is valued by farmers and gardeners. Combining waste manure and rice straw to create high value mushrooms and compost should prove very profitable.

Barriers and Incentives

It would be desirable to do a waste stream search to identify the best sites for composting operations. Benefits of various composting systems could be evaluated and improved.

Perhaps best left to the private market, with a yearly purchase of 1000 thousand tons for CalTrans and other state agency use.

Disease and weed suppression

Rice straw mulch can be used in orchards and vineyards to suppress weeds. Laying in a thick layer of straw is a proven method of weed control. Several inches of straw are added to the surface of the soil. Especially compatible with drip irrigation. Current use is limited by availability and cost of straw. Mulch may need to be held back from tree and crop rows to protect them from mice.

As methyl bromide and other biocides are phased out and become more costly the search for biological solutions for pest problems becomes more essential. Many soil diseases can be suppressed or controlled by stimulating the 'friendly' soil organisms. Springtails (Collembolas) for example, will feed preferentially on pathogenic fungi (Klironomos and Bainbridge, 1995). Increasing the organic matter content of soil and improving aeration usually provide benefits for the plants and the plant symbionts such as mycorrhizal fungi (Allen, 1991).

Increasing the populations of beneficial soil organisms can also suppress or control many invasive weeds. While many crop plants benefit from association with mycorrhizal fungi, weeds can generally grow without them and the fungi may in fact act as pathogens on their roots. For example Allen et al. (1989) found that tumbleweed (Salsola) was attacked by these friendly fungi. Use of rice straw and straw compost on problem weeds is little studied but worth pursuing. Yellow star thistle and other noxious weeds are usually found on degraded soils, and improving the soil may provide better long term control than repeated spraying, tillage, or mowing.

Barriers and Incentives

These applications are little studied despite their potential long term value. This would make a good competitive grants offering for the UC Sustainable Agriculture Education and Research Program. A funding level of $400,000 year could provide rapid answers and many benefits to the State of California. Funded by rice grower assessment and CalEPA, EPA.

REFERENCES CITED

Allen, M.F. 1991. The Ecology of Mycorrhizae. Cambridge, NY 184 p.

Allen, M.F., E.B. Allen, and Freise, C.F. 1989. Responses of the non-mycotrophic plant *Salsola kali* to invasion by vesicular-arbuscular mycorrhizal fungi. New Phytol. 111:45-49.

Arax, M. 1994. Rare spirit of cooperation streamlines I-5 crash suits. Los Angeles Times, March 3, pp. A3, A21.

Atkey, P.T. & D.A. Wood. 1983. An electron microscope study of wheat straw composted as a substrate for the cultivation of the edible mushroom (*Agaricus bisporus*). J. Appl. Bacteriol. 55:293-304.

Atthasampunna, P. & S.T. Chang. 1994. The magic of Mushrooms. UNESCO Courier. Jun., 16-18.

Bainbridge, D.A. 1994. Vertical mulch for site improvement and revegetation. Biology Dept SDSU for the Dept of Transportation, 3 p.

Bainbridge, D.A. 1995. Vertical mulch for site rehabilitation. Restoration and Management Notes (in press).

Bhagat, R.M. & T.S. Verma. 1991. Impact of rice straw management on soil physical properties and wheat yield.. Soil Science. 152(2):108-115.

Bhagat, R.M. & C.L. Acharya. 1987. Effect of soil management on rainfed wheat in northern India. I. Hydrothermal regime and root growth. Soil Tillage Res. 9:65-77.

Bhagat, R.M. & C.L. Acharya. 1988. Soil water dynamics during wheat growth under different soil management practices. J. Indian Soc. Soil Sci. 36:389-396.

Bogovich, W.M. 1992. Twelve Years of Abandoned Mineland Reclamation Activities by the United States Department of Agriculture-Soil Conservation Service in Southwest Pennsylvania. In Land Reclamation: Advances in Research & Technology. ASAE Publication 14-92. American Society of Agricultural Engineers, St. Joseph, Michigan. 1992. p 230-239.

California Air Resources Board. 1993. California Air Quality Data, Summary of 1992 Air Quality Data Gaseous and Particulate Pollutants. v XXIV. Sacramento, CA 151p.

Chang, Y. & H. J. Hudson. 1967. The fungi of wheat straw compost. I Ecological studies Trans. Br. Mycol. Soc. 50:649-666.

Chappell, L. 1993. Pay Dirt. Automotive News. 8 February, p. 3.

CSDHS (California State Department of Health Services). 1994. Coccidioidomycosis. Data Sheets. Division of Communicable Diseases, Surveillance and Statistics Section.

Dockery, D.W., C.A. Pope III, X. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B.G. Ferris, and F.E. Speizer. 1993. An association between air pollution and mortality in six U.S. cities. New England Journal of Medicine 329(24):1753-1759.

Elkins, N.Z., L. W. Parker, E. Aldon & W.G. Whitford. 1984. Responses of soil biota to organc amendments in stripmine spoils in northwestern new Mexico. J. Environ. Qual. 13:215-219.

Fairbourn, M.L. 1975. Field evaluation of microwatersheds and vertical mulch systems. pp. 233-243. In Frasier, G.W. ed. Water Harvesting Symposium, Phoenix Arizona. Agricultural Research Service ARS W-22, Berkeley, CA

Fermor,T.R., P.E. Randle & J.F. Smith. 1985. Compost as a substrate and its preparation. p. 81-109. In P.B. Flegg, D.M. Spencer & D.A. Wood, eds. The biology and technology of the cultivated mushroom. John Wiley & Sons, Ltd. Chichester, united Kingdom.

Forstenzer, M. 1992. Dust to dust. Los Angeles Times, April 10, pp A3.

Gerrits, J.P.G. 1988. Nutrition and compost. p. 29-72. In L.J.L.D. van Griensven, ed. The cultivation of mushrooms. Darlington Mushroom Laboratories, Rustington. United Kingdom.

Gilley, J.E., G.E. Gee, W.O.Willis & R.A.Young. 1977. Runoff and Erosion Characteristics of Surface-Mined Sites in Western North Dakota. Transaction of the American Society of Agricultural Engineers. 20(4)697-700.

Goldman, S.J., K. Jackson & T.A. Bursztynsky. 1986. Erosion and sediment control handbook. Macgraw Hill Book company, New York.

Gunadi, N. 1988. Effects of mulching and plant spacing on growth and yield of tomato var. Berlian. Buletin-Penelitian-Hortikultura. 16(2): 61-66.

Highfill, R.E. 1980. Present Urban Erosion Control Techniques. In: National Conference on Urban Erosion and Sediment Control: Institutions and Technology, October 10-12, 1979, St.

Paul, Minnesota. Environmental Protection Agency Report EPA-905/9-80-002, January, 1980. p 57-67.
Ingham, R.E., J.A. Trofymow, E.R. Ingham & D.C. Coleman. 1985. Interactions of bacteria, fungi and their nematode grazers: effects on nutrient cycling and plant growth. Ecol. Mono. 55:119-140.
Jennings, G.D. & A.R. Jarrett. 1984. Effectiveness of mulching in reducing erosion. ASAE paper No. 84-2556, Am. Soc. Agric. Engrs., St. Joseph, Michigan.
Jennings, G.D. & A.R. Jarrett. 1985. Laboratory evaluation of mulches in reducing erosion. Trans. of the ASAE 28(5):1466-1470.
Kawata, S. & M. Seejima. 1976. The effect of compost application to the paddy yield on the formation of superficial rice roots of rice. Proc. Crop Sci. Soc. Jpn. 45:99-116.
Kay, B. L. 1983. Straw as an erosion control mulch. Agronomy Prog. Report No. 140. University of California, Davis, Agricultural Experimental Station Cooperative Extension, Davis, California.
Klironomos, J. and D. Bainbridge. Collembolas for biocontrol? Forest Nursery Notes January:20-21
MacCaskill, L.P. 1978. Control de erosion mediante dos niveles de densidad de paja en un trumao de lomaje. Agricultura Tecnica (Chile) 38:49-53.
Miles, T. R., J. Burt, K. Hale & Lofton, J. 1989. Emergency Watershed Protection Using Straw Bales. Public Works PUWOAH, Vol. 120, No. 13, p 32-35.
Morgan, J.P. 1994. Soil impoverishment a little known technique holds potential for establishing prairie. Restoration and Management Notes 12(1):55-56.
Mostaghimi, S., T.M. Gidley, T.A. Dillaha & R.A. Cooke. 1994. Effectiveness of different approaches for controlling sediment and nutrient losses from eroded land. J. Soil and Water Cons. 49(6): 615-620.
Osunlaja, S. O. 1989. Effect of organic soil amendments on the incidence of brown spot disease in maize caused by *Physoderma maydis*. J. Basic Microbiol. 29(8):501-505.
OWPS (Office of Water Planning and Standards). 1975. Methods of Quickly Vegetating Soils of Low Productivity, Construction Activity. EPA 440/9-75-006. Environmental Protection Agency, Washington, DC. 465 p.
Pappagianis, D. 1988. The epidemiology of coccidioidomycosis. pp. 199-238 in Current Topics in Medical Mycology. Springer-Verlag, New York, NY.
Pyle, A. 1991. County may dust off permit policy to settle Antelope Valley furor over sheep. Los Angeles Times, March 26, pp. B3.
Pudwell, H. 1993. Straw as a mulch in horticulture and forestry. In: Straw - A valuable raw material. PIRA conference Porceedings.
Rippon, J.W. 1988. Coccidioidomycosis. pp. 433- 473 in Medical Mycology. W.B. Saunders, New York, NY.
Roderick, K. 1989. Owen's Lake dust: Airborne health hazard. Los Angeles Times, April 2, pp I1.
Ross, B. B., T. A. Dillaha III, S. Mostaghimi, C. D. Heatwole and Jim Lewis. 1990. final report: Rainfall simulation for BMP evaluation. Dept. of agric. Eng. virginia Polytech. Inst. and State Univ., Blacksburg.
Schenker, M. 1993. Air pollution and mortality. New England Journal of Medicine 329(24):1807-8.
Schuman, G. E. & S. E. Belden. 1991. Decomposition of wood-residue amendments in revegetated bentonite mine spoils. Soil Sci. Soc. Am. J. 55:76-80.
Secor, T. H. 1978. Controlling Sediment Damage. In: The Freshwater Potomac, Aquatic Communities and Environmental Stresses, Proceedings of a Symposium, January 1977, College Park, Maryland, Flynn, K. C. and Mason, W. T., Eds., 1978. p 174-178, 3 tab. Interstate Commission on the Potomac River Basin, Rockville, MD. Technical Publication 78-2.
Senyah, J. K. 1988. Mushrooms from waste materials. Developments in food microbiology. R. K. robinson ed. 1-22; 67 ref. Barking, Essex, UK. Elsevier Applied Science Publishers Ltd.
Shepard, B. M., H. R. Rapusas & D. B. Estano. 1989.Using rice straw bundles to conserve beneficial arthropod communities in ricefields. International-Rice-Research-Newsletter.14(5):30-31.

Smith, J. A., E. J. dePuit & G. E. Schuman. 1986. Wood residue and fertilizer amendment on bentonite mine spoils: II. Plant species responses. J. Environ. Qual. 15:427-435.

Straatsma, G., R. A. Samson, T. W. Olijnsma, H. J. M. Op Den Camp, J. P. G. Gerrits & L. J. L.D. Van Griensven. 1994. Ecology of thermophilic fungi in mushroom compost, with emphasis on *Scytalidium thermophilum* and growth stimulation of *agaricus bisporus* mycelium. Appl. Environ. Microbiol. 60(2):454-458.

Takahashi, K. 1988. New theories and practices in grapevine cultivation. Agric. and Hort. 63(11):1333-1338.

Walls, I. G. 19__. The Complete book of greenhouse gardening. Quadrangle/new York Times Book Co. New York.

Whitford, W. G., E. F. Aldon, D. W. Freckman, Y. Steinberger & L. W. Parker. 1988. Effects of organic amendments on soil biota on a degraded rangeland. J. Range Man. 42:56-60.

Zink, T.A. 1994. The effects of recalcitrant organic amendment on disturbed coastal sage and creosote scrub habitats of Southern California. Master's thesis. San Diego State University, San Diego. 98p.

Zink, T.A. and D.A. Bainbridge. 1994. Organic Mulch for plant establishment on arid and semi-arid sites. Prepared for the California Department of Transportation as part of the Desert Plants Project, Biology Dept. SDSU. 5p.

RICE STRAW USE IN CONSTRUCTION

<u>Overview</u>

Straw, including rice straw, has been used as a building material for centuries. Straw is used as a reinforcing fiber in the making of bricks and adobe, monolithic earthen walls, and clay -straw walls of various densities (common in central Europe and Japan); plastered bundled barley straw has been used as infill in frame structures; "wattle and daub" walls were once common in Asia; "cob" walls (a type of hand-formed, straw rich brickless adobe) are enjoying a renaissance in Europe, and straw thatches are still used in many areas. Many of these traditional processes are being rediscovered in the United States and training workshops in their techniques for contractors and owner-builders have proliferated in recent years. The insulating properties of straw have long been recognized, and both loose and baled straw have been used to temporarily protect newly placed concrete and foundations from freezing in severe weather (Williams, 1978). The most significant developing uses for rice straw in contemporary California construction, though, are manufactured construction panels (see also composites section) and straw bale construction.

<u>Manufactured Construction Panels (see also §4)</u>

Straw has seen increasing use in manufactured construction panels for dwellings (Wilson, 1995). Both load-bearing structural boards and non-structural compressed straw panels have a growing presence in the construction industry. The 1995 report "A New Industry Emerges: Making Construction Materials from Cellulosic Wastes" (Lorenz, 1995) suggests that farmers may be able to increase their income through farmer-owned cooperative straw board manufacturing. Removing government subsidies for forest products would accelerate this process. A partial listing of 12 existing and forthcoming straw panel manufacturers, including 3 in California, was published in <u>Environmental Building News</u> (Wilson, 1995).

A common structural board is comprised of two sheets of wood-based, oriented strand board sandwiching an insulating interior core of compressed straw, although some structural wall systems have been made of pure straw. A typical non-structural straw panel is compressed to 18 to 20 pounds per cubic foot to produce a straw board 4 feet by 8 feet and 2 inches thick, sealed in a Kraft paper skin; it takes approximately 2 rectangular 44"x16"x24" bales to form one board of this size (Maertens, 1995). Boards of this type (and thinner) will primarily be used for drywall and secondarily for acoustical ceilings and sound control. Double ply or thicker boards may prove to have structural capability, but testing is needed. Straw board can also be used for concrete forming, roof sheathing, and floor decking. Office partition panels, shipping pallets, doors and furniture are additional uses.

Because they can be substituted for conventional wood products, straw-based particle board products can be easily adopted by the building industry, and may experience rapid growth. Mobile home manufacturers are interested in using straw-based panel products because of their sound-insulating qualities, their one-hour fire rating, their durability and cost competitiveness (Lorenz, 1995). National annual waste straw could be made into 5 times the current total U.S. production of all thicknesses of particle board and medium-density fiberboard. This same straw could also be made into structural panels to build 1 million 2,000 square foot 2-story homes, or 2.7 million homes if utilized as straw bales. Pacific Gold Board of Redding, is planning seven manufacturing stations in Sacramento Valley that would each have the capability to utilize 22,000 tons of rice straw per year. They estimate their operations could eliminate the burning of a total of approximately 50,000 acres annually, about 10% of California's rice straw liability (Maertens, 1995).

Straw bale Construction

Residential

The use of baled straw or hay to construct buildings developed in the midwestern United States in the late 1800s and early 1900s, not long after the invention of the baling machine (Bainbridge, 1986, 1987, Bainbridge et al., 1992; Steen et al., 1994). Farmers from the Sand Hills of Nebraska who had no timber or other suitable building materials in the region are credited with creating homes with the baled products of their fields (Welsch, 1970; Smith, 1989; Kay et al., 1990; Freudenberger, 1993b). The current renaissance of this building method is being driven by both housing costs (construction and operating) and environmental issues. Straw bale construction is also attractive as an owner/builder construction technique, with the potential to further reduce building costs (Hammond, 1979; CHMC, 1984; Bainbridge et al., 1993; Freudenberger, 1993a, Reveley, 1993; Everett, 1993; Hawes, 1993). Straw bale building has become common enough to be barely mentioned in passing in building magazines (Whiteley, 1996).

Bales may be used for load bearing walls, non-load bearing walls, insulation or reinforcement purposes. For other than load bearing walls, the roof structure is supported and restrained by posts or other framing attached to the foundation. These can be wood, concrete, or metal with no limitation on height or size. Load bearing straw bale walls require structural connections between the foundation and roof structure which serve two purposes: 1) attaching the roof to resist uplift forces caused by high winds, and; 2) providing lateral resistance to forces from wind or seismic events. Bales used for infill wall panels don't need to be as dense or consistent in size as those used structurally (Wilson, 1995; Bainbridge et al., 1993; Bou-Ali, 1993; Steen et al., 1994).

The smaller straw bales used for building usually range in size from 14 x 18 x 36 inches for two-tie bales (ties are typically either polypropylene or wire) to 16 x 23 x 46 inches for three-tie bales. Bales typically weigh 40 to 90 pounds, depending on size, compaction, moisture content, and type of straw (Wilson, 1995; DOE, 1995). A house with an interior space measuring 35 by 35 feet (1225 sq. ft.) and having 8 foot high walls, would require approximately 228 bales (16 inches x 46 inches) for the exterior walls. At 80 pounds per bale, this would be about 9 tons, or the rice straw from about 3 acres. The length and density of bales can, within some limitations, be tailored to the needs of builders.

In most instances, bales are placed on their flat dimension (i.e., wire or strings on top and bottom) for the most stability and load bearing capacity -- thus each course of bales is 16 inches high. Bales can be produced by standard balers, and bale handling equipment will operate satisfactorily in firm, dry rice fields. Baler capacity should be 7 to 8 tons per hour. Due to the tough and abrasive nature of rice straw, equipment must be in good condition and requires regular maintenance. Limited use of round bales and the larger square bales (31 x 34 x 94 inch and larger) for building has also occurred. Baling rate is about 6 tons per hour for round bales. Large round bales are about 1/4 less dense than rectangular bales and require more storage space per ton of straw (Dobie and Mosley, 1981; Bainbridge et al., 1993).

Although rice straw is more resistant than the common cereal grain straws to decomposition from moisture, the bales should still be protected from excessive exposure to moisture. Elevating the top of the foundation a minimum of 8 inches above the finished exterior grade and the use of exterior plastering or other protective coating are desirable. A moisture barrier is commonly placed between the top of the foundation and the bottom of the bale wall to prevent moisture from migrating up through the foundation into the bottom of the bales. Some builders are using a foam board as the first layer on the slab before the bale assembly begins. This keeps the bale above any moisture from a flooded floor and also keeps the base of the bale warm so moisture from the slab will not condense on the bale base.

Foundations for bale walls are similar to foundations for any other wall system, with the exception of the need to accommodate the added thickness of the walls. Footing depth can often be reduced due to lower loading of the wide walls. The foundation, often of concrete, may also be part of a concrete floor slab (Bainbridge, 1993; Bou Ali, 1993; Steen et al., 1994). Bales are commonly stacked in courses, or tiers, in an overlapping pattern (running bond) like bricks, which helps tie the courses together horizontally -- much like interlocking toy building blocks (Bainbridge et al., 1992; Freudenberger, 1993a; MacDonald and Myhrman, 1994; Steen et al., 1994).

Various methods are used to hold the bales in place and connect them to each other. These include driving pins (wood, metal, or bamboo) down through the courses of bales as the walls are built, and tying or stapling the bales to each other. Tightly fastened stucco net with numerous open ended rectangular pins may also effectively fasten and brace walls. Bracing can also be provided by tightly cross-tying rebar, bamboo or wood to the opposing wall faces.

Frames for doors and windows are typically placed before or during lay up of the bales. Window and door frames may be structural (i.e., top, side and bottom components of the frame are designed to bear weight) or used with lintels (beams across the top of an opening that allow the bales on either side of the opening to bear the weight from above the opening). If lintels are used they should extend sufficiently far into the walls to provide sufficient bearing strength.

Bales may also be mortared together in a matrix construction. This uses more cement, is more labor intensive and time consuming, and is less energy efficient than walls with just stacked and pinned bales (Steen et al., 1994; Gagne, 1986a,b). But the matrix method can make for a stronger wall and even more fire resistant wall assembly, but makes careful planning of utility runs more important. This matrix can be further reinforced with rebar or mesh. A matrix wall on the in or outside of an unreinforced masonry wall to provide insulation and seismic stabilization at the same time.

Bale walls are usually topped with a wooden, plywood, or concrete top plate. This assembly serves as a bond beam or structural element at the top of the wall, to bear and distribute the weight of the roof, give the top of the wall additional lateral strength, and to provide a way to securely attach the roof structure to the walls and in some cases the foundation (Bainbridge, 1986a,b; Bainbridge et al., 1993; Steen et al., 1994).

For load bearing bale walls, since there are no posts or standard framing system, the roof structure must be secured to the foundation by other methods. Various systems have been used including using anchor bolts in the foundation to which sections of threaded rod are attached using coupling nuts, then bales are impaled on the rods and additional rods added until the top of the wall is reached. The rods are run through the roof plate and a large washer and nut secures the roof plate to the wall and foundation. Cables, heavy wires, or various types of plastic and metal straps and cable can also be used to connect the foundation or earth anchors to the roof structure.

Tensioning can be used to load (or pre-stress) the walls for increased structural stability, reduce settling of the bales over time, and speed-up the construction process (by eliminating the time required for settling to take place naturally). For non-load bearing bale walls, the roof and foundation are connected by supporting frame members.

There are also a number of hybrid wall systems being developed which use the bales in a semi-structural way to provide lateral rather than vertical support, or to become load bearing only in certain high load conditions (Steen et al., 1994). Some of these systems may offer construction details and techniques which would be more readily accepted by both code officials and building professionals.

Roof construction for bale buildings can be the same as for conventional construction. The only significant differences relate to roofs on load bearing bale structures because of their reduced capacity to carry highly concentrated point loads. The hip roof is probably most suitable for larger load bearing bale buildings since it offers the advantages of allowing all the exterior walls to be built to the same height and the roof load to be distributed to all four walls. If gable or shed type roofs are used, the gable end or sloped-top walls can either be filled in with normal wood framing or the bale walls can be extended up into the roof framing and the tops of the bales can be trimmed to the roof pitch. Mixing frame and bearing straw bale walls should be done with caution as the potential settling may lead to stress on the fixed framing.

Roofing should provide sufficient overhang to limit rain exposure of the wall structure. Roof overhang and window placement can be designed for seasonal solar radiation capture (winter) or solar control (summer) (Bainbridge et al., 1993; Steen et al., 1994). Straw bales have also been successfully been utilized as roof insulation. Full bales can be supported between I-beam engineered joists, providing a super-insulated roof. Loose straw should be used only if it is fire-proofed or in fire resistant cells.

Architectural research is underway on "roofless" vaulted and domed straw bale structures as well as low-cost, post-tension straw bale roofing systems. These latter systems minimize or eliminate the need for construction wood (wood-frame residential construction in North America is the leading cause of global deforestation) and maximize the use of abundant straw. Steel reinforced straw composite I or V beams may also be developed.

Electrical wiring, plumbing and any environmental systems should be integrated as construction proceeds if embedded into the foundation structure. Above-foundation wiring and plumbing may be placed at nearly any time before plastering. Wiring can easily be placed in the walls and/or between bales or can be surface mounted. Wiring can be fastened in grooves cut into the surface of the bales and electrical boxes are usually fastened to wooden stakes driven into the bales. Conduit is often used but some localities allow use of ROMEX in walls. Special care should be taken with DC electrical systems.

Plumbing is often set in framed sections of interior walls to reduce moisture risks. Plumbing within bale walls is typically run in plastic pipe sleeves that will drain to daylight or isolated from the bale with a moisture barrier to prevent wetting of the bales from leaks or condensation on the outside of cold water pipes (Steen et al., 1994).

Straw bale walls are generally finished with plaster, stucco, gunite, or natural or stabilized mud plaster (Rose, 1995; Bainbridge, 1996). Finishing may be done directly on the exposed straw or over stucco netting and/or wire lath attached to the bales. The use of wire provides additional strength to the wall structure. The typical load bearing building is actually a plaster sandwich with the bales providing little of the strength. Wire attached to the foundation and roof plate can add substantial strength to the wall when plastered (Bou-Ali, 1993; Steen et al., 1994).

Some bale buildings have been finished with wood, shingles, or metal siding on the outside, and wallboard and paneling have been used as interior finishes. The selected finish should be esthetically satisfactory, low toxicity (i.e. asphalt-stabilized mud plaster on exterior only), as well as providing protection from weather, vermin and providing a fire barrier. Typical bale walls are 18-24 inches thick, and have an insulation value ranging from R 43 to 55 (Wilson, 1995; Steen et al., 1994).

The cost of a straw bale home depends on many variables and costs from less than $5 to more than $200 have been reported, ranging from lowest cost owner-built to fancy custom high end. Exterior wall costs typically account for about 15 to 20% of standard construction costs. Bainbridge estimates that a bale wall will cost 1/3 to 1/2 that of a super insulated wall of conventional materials and slightly less than a standard, much more poorly insulated wall (Bainbridge et al., 1993). Owner-builders should be able to realize substantial saving through reduction of labor costs. Walls for an entire house are often erected in a single day.

The demand for rice straw for housing will depend on the rate of penetration into the market. Housing starts are shown in table 1 for the 7 closest counties, almost 10,000 permits were pulled in these counties in 1992. The average combined yearly housing starts for the seven counties listed below was 16,000 between the years 1980 and 1990 (U.S. Bureau of Census, 1994). Housing starts in the West totaled 302,000 and 39,000 mobile homes were placed (U.S. Bureau of the Census, 1993). The low cost possible for owner-built straw bale homes makes it competitive with mobile/modular construction. Farm worker housing is well suited for straw bale construction and several projects are underway or planned in California. Ideally, it will replace the existing older mobile homes in the areas near rice straw production.

Table 1. Housing starts and poverty

	1992 Building permits	Family below poverty line	Mobile home
Butte	351	490	13,500
Colusa	116	430	700
Glenn	113	924	1,400
Sacramento	5,728	25,905	15,000
Solano	1,909	5,194	4,700
Tehama	306	1,762	5,000
Yolo	640	3,200	3.500
7 counties	9,163	37,905	43,800

Source: US Bureau of the Census. 1994.

If market penetration reaches 10%, optimistic but not unrealistic by the year 2000 based on experience in New Mexico and Arizona, then 1,000 straw bale buildings could be built. If the average floor area is 1,400 square feet the exterior bale walls these homes could use 10,000 tons of straw. If interior walls are made of pressed straw panels or cement straw composites they would use 2,000 tons of rice straw. Fiber composite roof shingles made with rice straw could use 1,600 tons and roof decking made of pressed rice panels might consume another 2,000 tons. Fiber composite foundations might consume another 2-5,000 tons. Assuming all rice straw components in all of these homes would use 20,000 tons, or less than 5% of the available straw. A program to encourage replacing mobile homes with energy and resource efficient straw bale homes, 5% per year, could use another 20,000 tons per year in the 7 county area.

If the shipping and distribution develop a market throughout the West the use could rise rapidly. If 5% of the homes built in the West are rice straw bale by the year 2000 then consumption could rise to 300,000 tons per year. If 50% of the mobile homes now placed in the west are replaced by site built straw bale home the use could total 400,000 tons.

Commercial buildings

Bale construction is well suited for commercial space. The high insulation value, noise suppression, economy and durability make bales a promising contender with tilt-up and light frame construction. The use of bales for one and possibly two story light commercial space should be straightforward, using various structural systems for multistory buildings with engineered structural designs.

Larger commercial buildings can also incorporate bale construction. The most obvious candidates are metal and concrete frame structures with the bales used as infill. The super-insulation, thermal mass, and fire resistive properties of plastered bales should prove useful for these structures.

Several commercial and non-residential bale buildings have stood the test of time. These include a large two story straw bale building outside of Lincoln Nebraska, a 3,200 square foot straw bale general store in Glendo, Wyoming built in 1948 and still used for storage, and several churches in the U.S. and Canada (Anon, 1960; Bainbridge et al., 1993; Steen et al., 1994).

Commercial building use is difficult to predict as it will depend more heavily on testing and the potential structural performance issues in larger buildings, particularly in multi-story structures. Bale infill wall panels can be used essentially as curtain walls, non-load bearing exterior walls typical in large multi-story construction. These will have to be demonstrated to be adequate in terms of lateral strength to resist wind and seismic forces. In addition, depending of the type of occupancy, additional testing must be done on flame-spread and smoke development to meet the building and fire code requirements for commercial structures (Eisenberg, 1995a).

Even a small percentage of commercial buildings using straw bale infill could consume large amounts of straw. A modest mid-rise building (40,000 sf) might use 250 tons of rice straw. There are several commercial straw bale projects underway and planned. The new Real Goods, retail store in Hopland, California incorporates a straw bale wall (Real Goods, 1995). A straw bale winery is being finished in San Luis Obispo (Semmes, 1996), an architectural office is in use in Santa Margarita (Bainbridge, 1995), and a professional center has been built in Albuquerque (Blue Mountain Builders, 1996). A farmer's market with straw bale building is proposed for Biggs, California and a straw bale restaurant within a mixed-use retail center in downtown Fresno is planned and ready for code approval (Erganian, 1995). A Value Added Technical Center proposed for Redding, California, associated with Shasta College, would include up to 20,000 square feet of rice straw bale buildings (Pennington, 1995). And a proposed design for a commercial bale building has been prepared for a site in San Bernadino. This structure was competitive in price with conventional tilt-up; it uses a reinforced gunite interior and exterior structural finish system that exceeds the structural requirements (Miller, 1995).

Although schools face special seismic requirements straw bale construction might be especially useful for school construction. The thermal and sound insulating properties are very beneficial and the energy conservation savings are becoming increasingly important. Some of the first uses of bale buildings were for schools in Nebraska (Fowler, 1900).

Thermal retrofits

Another application of straw bale construction for both residential and commercial structures is retrofitting existing buildings to improve their energy efficiency. Thermal retrofits, particularly for uninsulated masonry buildings are very likely to be economically viable. This has been done successfully and represents an opportunity to convert buildings which are enormous energy wasters into energy efficient structures. Applying the bales to the exterior of masonry buildings puts the thermal mass of the walls inside the super-insulated shell, creating an efficient and comfortable living space. Adding additional roof area to cover the thicker walls can be economical for some roof systems, harder and more expensive for others.

Seismic retrofits

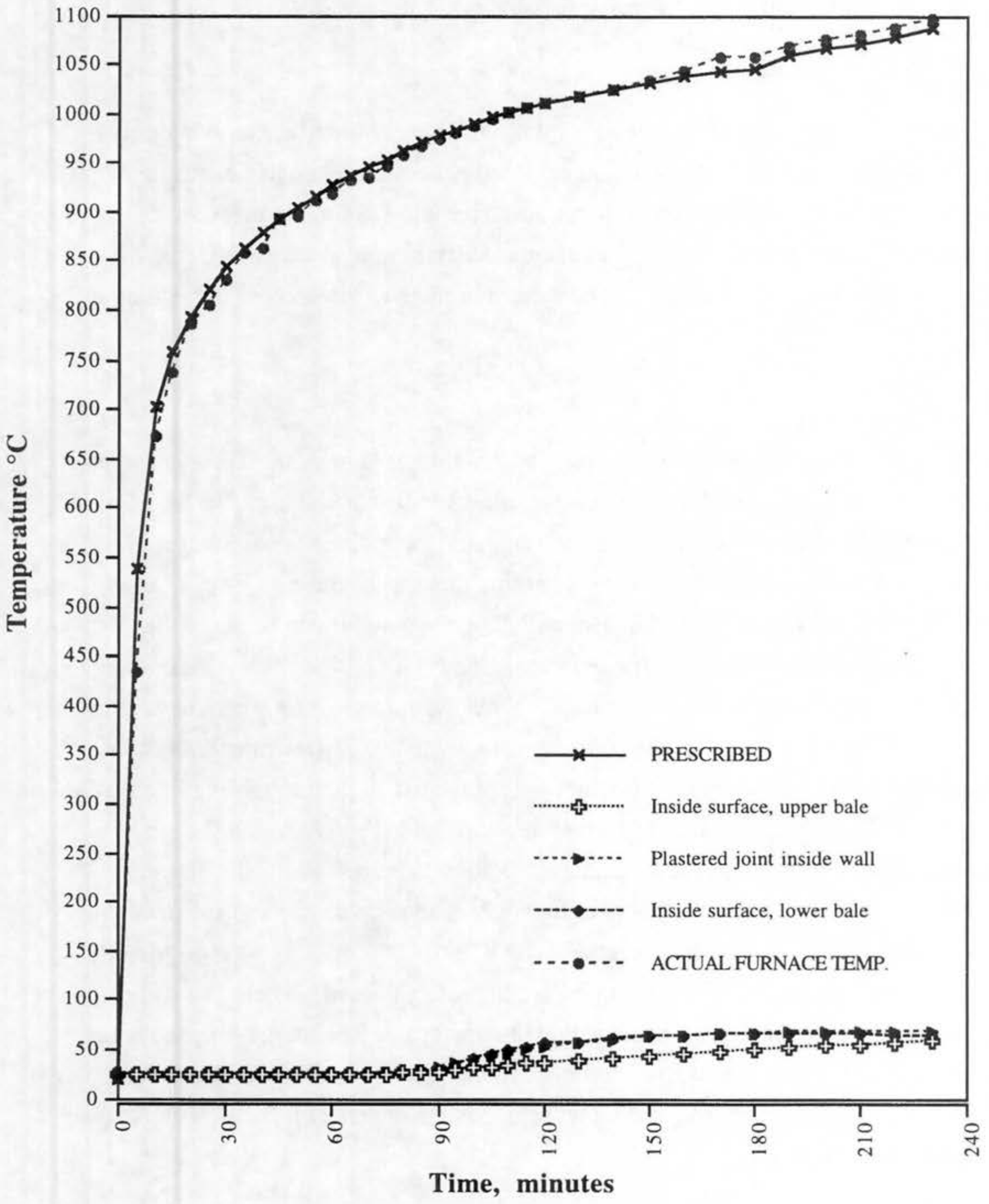
Retrofitting older brick and tilt-up commercial buildings to improve their structural integrity in seismic events should prove attractive. Bales could be added either inside or outside existing walls with a reinforced concrete matrix grid to turn unstable buildings into safer, more pleasant buildings. For unreinforced masonry buildings, a severe safety risk in many areas affected by earthquakes, a bale/bond beam wall system could be used to insulate and reinforce the building at the same time.

Fire safety of straw bale buildings

One of the first concerns everyone expresses about bale buildings is fire risk. Tests in the lab and field have demonstrated the exceptional fire safety of plastered bale buildings. The field test in 1994 included a plastered straw bale bench built at the Haggard/Cooper house near San Luis Obispo, California. The straw bale banco was the only thing that survived the 41 Fire, a fast moving wildfire that consumed more than 40 houses including the wood frame house of the designers of the Noland plastered straw bale house in Lone Pine (Bainbridge, 1994). According to witnesses the flames were 300 feet high and moving like a runaway freight train when they came over the hill. The fire was so hot that even the concrete slabs at the house were ruined, the house was reduced to ash less than 2 inches thick in places, pools of melted aluminum roofing littered the area, and the owners Volkswagen left a trail of molten metal in the driveway. Yet, although decorative glass had melted in the plaster and the integral color was burned white, the plastered straw bale bench was intact. They have built a rice straw bale workshop on site and are finishing a new architectural office, the house will also be rebuilt with bales.

The National Research Council of Canada carried out fire safety tests of plastered straw bales and found them to be better than most conventional building materials. The mortar-encased bales passed the small scale fire test with a maximum temperature rise of only 110°F over four hours, twice the requirement. The plaster surface coating withstood temperatures of up to 1850°F for two hours before a small crack developed.

Fire test data, Plastered straw bales National Research Council, Canada



Tests in New Mexico, following the ASTM E-l 19 Two Hour Fire Test procedures provided similar data, with only 2" of charring where the plaster cracked, and a temperature rise of about 12°F, after more than 2 hours and temperatures of up to 1942° F on the other side of the plastered wall panel. The burn through on a bale wall panel without plaster took 34.5 minutes, and occurred at the vertical seam between two bales. The rest of the bale wall had only charred 8" into the 18" thickness of the wall, despite temperatures in excess of 1550° F (SHB Agra, 1993; Fernandez, 1994). The following quotes from official reports should prove useful in addressing this issue with building officials and fire marshals:

The straw bales/mortar structure wall has proven to be exceptionally resistant to fire. The straw bales hold enough air to provide good insulation value but because they are compacted firmly they don't hold enough air to permit combustion. (Gagne, 1986b).

ASTM tests for fire-resistance have been completed ... The results of these tests have proven that a straw bale infill wall assembly is a far greater fire resistive assembly than a wood frame wall assembly using the same finishes. (Fernandez, 1994).

An ASTM E-119 fire test was conducted at U.C. Berkeley in 1996 by professor Cassandra Adams and her students. Preliminary reports were very positive and further confirmed earlier test data (Eisenberg, 1996e). This test also included a hose stream test for penetration of fire hose, which the wall also passed.

Carefully finished plastered bale buildings with metal roofs, metal soffits, and fire resistant window shutters might prove of great value in areas where brush fires are a major threat.

Like a wood frame house straw bale houses are vulnerable when they are under construction. Unplastered bales will burn, although the compact bales preferred by builders are not very flammable. Fuzzy bales and loose straw are more flammable and grinding and welding should be done with care when there is lots of loose straw on the ground with a fire extinguisher near by. Sites should also be careful maintained to prevent buildup of loose straw.

Plastered straw bale houses, like other rural homes, sometimes burned when struck by lighting or ignited by fierce-burning chimney fires. Fires were commonly carried from the roof and/or ceiling down to the wall. A small structure in Arizona burned in 1996 after a short in the DC wiring set the loose straw ceiling insulation alight (Hofmeister, 1996). This burned quickly but the walls proved very resistant.

A fire break or fire retardent at the top of the wall will help prevent this type of fire. Just as the pioneers reported the relatively air tight and compact walls burned very slowly but were hard to put out. The Martin-Monhardt bale house in Arthur Nebraska was struck by lighting but did not burn.

The only casualty was a box of Kleenex in the dining room.

For building code approval in the United States the best approach is probably to treat the straw bale wall as a 2" thick wire-reinforced concrete or plaster fire wall (ignore the value of the compact and air movement resisting straw bale). Fire safety in a straw bale house requires normal attention to wiring practices and codes and careful detailing of electric box mounting and sealing.

The exposed straw walls of the Eos Institute exhibition eco-house in Anaheim were sprayed with a clear fire retardent at the convention center's request. Fire redardents may be advisable in high risk areas where arson is likely. A boric acid solution can also be prepared and sprayed on bales.

Exterior living spaces

Walls made from straw bales can create wonderful exterior living spaces and protect homes, gardens, and patios. Several contractors have developed businesses building bale walls in New Mexico and a manual is now available (Farrant, 1996). They can be built relatively quickly and they provide excellent sound control. A wall in La Jolla has been built to control noise from a busy street.

These walls can easily incorporate "bancos" or wall seats for intimate seating. They can define spaces which encourage a wide variety of social activities for much less labor and expense than other materials.

Animal shelters and barns

There is little doubt the first shelter built with bales was a barn, and plastered and unplastered bale buildings are still ideal for animal shelters and barns (Shepard, 1920; Promersberger, 1945; Cleland, 1942; Dice, 1947; Johnson, 1982,1987; Bainbridge, 1987,1991; Gergen, 1987; Faller et al., 1990; Tonnensen, 1989). The ease and economy of building with bales made on the site can't be beat, with costs of baling running about $1 per bale. Straw bale use for agricultural buildings has also spread to Mexico, where a bale building is used for a weigh station (Oertega, 1991).

Temporary buildings are most common and widely used. If bales are left unplastered they must be protected with fencing or they may be eaten by animals. Snow fence or chain link can be used to protect the walls. These were described in a series of agricultural extension bulletins from Fargo N.D. in the 1920's and 1930's (Extension Ag Engineer, 1924-1943). Dexter Johnson, a retired agricultural engineer from North Dakota State University, has been researching and promoting temporary bale buildings for prairie farms (Johnson, 1990 a,b,c,d). Test projects and on farm experience has been excellent, with some structures built with the ungainly large round bales.

Temporary bale barn building systems from Blacke Lyon Associates, Norfolk, England, use the large Hesston bales (4 x 4 x 6 ft) with a modular metal frame and plastic roof. These can made in almost any size and erect very quickly. The temporary big bale shelters from Blacke Lyon have been very successful with pigs according to Tony Walkey. Work at Blacke Lyon is currently underway on a twin-roof insulated with straw and packaged space conditioning system.

Bale buildings are particularly effective for pigs, which have comfort requirements similar to humans (Douglas and Langford, 1954; Sorensen, 1982). A pig farmer in Alberta has used very large bale buildings, up to 16,000 sf, and found he could build a temporary bale building for less than the annual interest on a conventional building. At the end of each season the bales were burned to sanitize the site. The size structure built was adjusted year to year based on projected meat prices. Improved comfort increases weight gain, eliminates tail biting and fighting, and improves profits in bale buildings. A much more elegant, but costly, system for piggeries has been proposed in Denmark using a tension roof (Andersen, 1989; Andersen and Homegaard, 1987).

Permanent buildings can be built using any of the methods described earlier. Nebraska style buildings are appropriate for some uses. Pliny Fisk III, from the Center for Maximum Potential Building Systems in Austin Texas developed a model farm for the agriculture department of the state of Texas using truss/bale walls (Tilley, 1991). The project included 5 plastered bale buildings, 3 with sprayed concrete finish and 2 hand troweled. The folded metal lightweight trusses and metal roofs are worth considering for other sites as well.

For farm buildings that require many openings for access of equipment or storage a frame structure with bale infill will be more appropriate. Pole barns, timber frame, and metal frames can all be used. The use of bales for such non-residential structures should pose fewer building code barriers, offering a potential approach for initial implementation and field experimentation with this building system.

Storage buildings

Some of the oldest straw insulated structures known are straw insulated apple storage sheds in England. Arthur Staniforth remarked that these lightweight wood frame structures with lattice walls hung with bundles of straw make a well-ventilated and well-insulated structure that is very good for storing produce. These were once common on estates throughout England, but only a few remain in use. Straw bales have been used for many years to build super-insulated storage sheds for potatoes and other crops (Johnson, 1984; Doughty, 1990; Sparks et al., 1963; Taylor, 1967). These may last for 25 years without plaster. They can be used for many other applications on the farm if they are reinforced with pins and gunited or plastered. The Tree of Life Nursery in California is very pleased with their plastered bale pole barn and seed storage room.

Insulated tanks and quick water storage

Pinned bales could be used to form insulated sprayed concrete tanks or used to contain a plastic pool liner. Careful attention to water-proofing would be necessary for long life in the plastered tank, but even as a form the bales could be cost-effective.

Workshops

Plastered bale construction is ideal for workshops that will be used for manufacturing, wood working, equipment storage and maintenance. The high mass and insulating properties make them pleasant to work in and reduce noise transmission to neighboring properties. Sheds and garages of straw are also a natural. They can quickly and economically provide a very pleasant place to work.

Greenhouses and growing frames

The side and back walls of greenhouses and growing frames can easily be constructed from rice straw bales providing excellent insulation and a growing environment which can be quickly and easily constructed. For temporary structures the bales can be left unplastered and renewed each year. Permanent structures should be plastered and detailed to keep water out of the straw.

Mushroom caves

Another possible non-dwelling use for rice straw bales would be to construct mushroom growing caves. These structures would be super-insulated, so the temperature and humidity could be controlled relatively easily. The use of rice straw bales as the growing medium for mushrooms could prove more durable than wheat or other cereal grain straws, and the utilization of the same material to create the temporary growing structures would simplify the whole process. These artificial caves could be built where the straw is produced, eliminating the need and cost for transporting the bales.

Sound control

Freeway noise is a severe problem in many transportation corridors. Conventional sound control walls are expensive and cannot be built by unskilled labor. Rick Green in Willows is exploring the development of straw bale freeway walls. More than 200 miles of sound control walls have been requested, but the collapse of the state budget has virtually halted construction.

The Oregon Department of Transportation is currently seeking a location for a demonstration straw bale sound wall (Paiva et al., 1995).

Construction of this type will generally require a foundation and means of stabilizing the bales against lateral wind and seismic forces. The extra thickness of bale walls results in better width to height ratios than most conventional wall systems which adds to lateral stability. One method of gaining additional stability is by introducing curves and corners into the wall design, as is often done with masonry walls. This is relatively easy to do with bale walls and may offer a cost-effective alternative for landscape, privacy, and sound control. Plastering or other weather-tight covering would generally be needed. Placement must avoid immersion in water. One other option that has been considered recently is creating 'living' landscape walls, which are low walls built of bales which are wired or fastened together, seeded with appropriate varieties of plants, fertilized and allowed to decompose over time as the plants grow and replace the initial bale structure. Straw bale or straw cement matrix composites would make less costly sound walls possible and much of the labor could be provided by the community that will benefit from the wall.

Straw bale retrofits would also improve quality of life for homes and commercial buildings in noise impacted areas around airports.

Status Of Implementation

Concept

Although the use of straw bales for building is over one hundred years old, it is not yet a standard method for home or other types of construction. While there are many good examples of straw bale homes, both old and new, most have been built under the alternative methods and materials provisions of the various model building codes, or in rural areas where no codes are enforced. For many years straw bale building activity was limited and development proceeded at a slow rate. However, the past several years have seen a rapidly growing interest in this method in the Southwestern United Sates. Interest in other parts of the U.S., Canada, and abroad is growing rapidly. The existence of numerous documented historic straw bale structures and the development of new information and technical resources for straw bale construction are aiding in this growth.

In order for straw bale construction to become widely accepted and used, several barriers must be overcome (Eisenberg, 1996a,b,c). These include: building codes, financing and refinancing, insurance, public perceptions, resale value, seasonal fluctuation in supply of bales, quality control, and lack of knowledge of the method in the design, building, and regulatory industries. These barriers are not independent of each other, and progress in overcoming one will help in dealing with the others.

To effectively address these barriers, several things must happen. First, enough people must be convinced of the need and/or desirability of the method to provide a basis for directing adequate human, technical, and financial resources to work through these problems. Second, excellent examples must be built, widely publicized and open to visit, to allow the general public, as well as the institutional sector, to experience the advantages and benefits offered by straw bale construction. These demonstration projects must clearly show why straw bale construction is a good alternative to conventional construction methods. This can be done by revealing the full range of advantages resulting from building with this material. Third, the institutional obstacles to the development of building codes, the ability to finance and refinance and get insurance must be dealt with to allow easy access. Fourth, there must be adequate supplies of good quality bales available throughout the year, so shortages of bales do not inhibit construction. Finally, There must be enough qualified and knowledgeable architects, designers, engineers, builders and subcontractors, to meet the growing market demand.

Of the barriers mentioned, building codes represent first obstacle. Adoption of codes in many areas and permits for buildings under existing codes are increasingly breaking down the remaining barriers, especially financial and insurance concerns. Virtually every major construction innovation has met with similar resistance and barriers. This includes the introduction of plywood to replace plank sheathing, platform framing to replace balloon framing, non-metallic sheathed electrical cable to replace type bx cable, gypsum wallboard to replace lath and plaster, etc. (Eisenberg, 1995).

The major obstacle in dealing with the building code issues is that there is no large centralized industry which stands to make enough money from building straw bale houses to justify the expenditure of the amount of money required to have all the required testing performed to widely accepted standards in recognized testing labs. The research and testing performed thus far has mostly been carried with very limited budgets and, though well carried out and documented carefully, hasn't always been detailed enough for all building officials to accept. Until much more testing data from accredited labs is available, this issue will continue to be a case by case, official by official process.

Thus, an intensive research agenda must be carried out to provide accurate, verifiable, and detailed information on structural (static and dynamic) properties, thermal performance, fire-resistivity, and moisture-related properties, as well as to analyze the differences and advantages of various wall designs, bale and straw varieties, and attachment methods (Bainbridge and Mhyrman, 1991; Bou-Ali, 1993; Eisenberg, 1993; Hartwell and Theis, 1994; Eisenberg, 1995a,b,1996a).

One essential component of the research and testing agenda is the development of methods to verify the quality and loadbearing capacity of bales on construction sites. Part of this testing will be the development of the accompanying data to correlate compressibility of individual bales to performance of overall wall systems. This will greatly facilitate the acceptance of the method by building officials.

Once completed, the results of this research must be applied to the development of building codes which are reasonable and allow this system to evolve and be optimized. The process of code development for straw bale construction should be designed to ensure that the resulting codes do not preclude the building of high quality, affordable housing. In addition, it is important that codes do not hinder the owner-builder from using this method, since the percentage of straw bale houses built (or partially built) by their owners is likely to remain significantly higher than for houses built using conventional methods. The model code established in Tucson and Pima County, Arizona, which is a combination of prescriptive and performance standards, may offer the basis for code development elsewhere, though local variables will affect regional code development (Eisenberg, 1995b).

It early 1996, Napa, Colusa and Glenn counties adopted straw building provisions (Eisenberg, 1996d). These were made possible by pioneering work by the City of Tucson and Pima County, Arizona which also adopted prescriptive codes for both loadbearing and non-loadbearing straw bale construction in 1996 as an appendix chapter to the 1994 Uniform Building Code (Eisenberg, 1996d; Pima County, 1996; Sayre, 1996). This code does not include the more rigorous seismic considerations that will be required for construction in California. This code was, however the basis of the straw bale construction guidelines in AB 1314, a bill in the California Legislature, adopted in 1995 (Sher, 1995). In addition, the State of Nevada has enacted legislation (Assembly Bill 171) which directs local governing bodies to develop and adopt codes for straw and other resource efficient building materials (Nevada Assembly Bill, 1995).

The State of New Mexico has established guidelines for non-load bearing straw bale construction and issuance of permits has become routine. Although the straw bale code has not been adopted yet in Tucson and Pima County, permits are easily obtained there for both load bearing and non-load bearing straw bale homes. Permits have been issued for straw bale homes in almost every state of the union (Anon, 1995). There are code approved straw bale houses in California, of both load bearing and non-load bearing methods of construction.

In addition, straw bale advocates have been in contact with a number of national and international code officials and have found increasing awareness and acceptance of alternative materials and methods of construction at this level. The late William E. Schlecht, who had served as the Chairman of the ICBO, Chairman of the Council of American Building Officials, and was President and Chairman of the World Organization of Building Officials, and also served as the

Chief Building Official of the City of Pasadena, California, was a strong advocate for straw bale construction and had designed and planned to build a straw bale house for his wife and himself (Eisenberg, 1995b). Several other building officials of national and regional stature have agreed to make themselves available to other building officials to discuss straw bale construction (Eisenberg, 1996c).

Laboratory Testing

The areas in need of further testing and research for the widespread acceptance of straw bale construction are fairly well recognized. Those additional areas, which relate specifically to rice straw, and to the regional building challenges of the State of California, particularly seismic considerations, are also fairly clear. The major research are topics are seismic testing, site determination of structural adequacy of bales, effects of moisture in bale wall systems, and additional fire tests.

Seismic testing

The testing with the largest potential impact on the development of straw bale construction as a significant consumer of rice straw in California is the seismic testing of bale wall systems. Discussions with several structural and civil engineers indicate the potential for straw bale structures to perform very well in high seismic activity areas (Estoup et al., 1995). It is thought that the flexible nature of the bales and the typical methods of connecting bales in a wall system, should give single story load bearing bale structures have the potential to be very safe in seismic events.

This reasoning is based on several factors. First, the width of bales results in walls with higher than normal width to height ratios. This means that the walls should be more stable laterally. Second, the relatively soft and flexible nature of straw bales, and the flexibility of the various systems developed to attach the bales to each other and to the foundation and roof, should result in the ability of the building to move significantly without catastrophic failure. Another potential seismic benefit is the ability of the walls to absorb a large amount of the force applied at the bottom of the wall in a seismic event without transferring this force to the top of the wall. This means that buildings with load bearing bale walls may suffer less of the damage resulting from the transfer of ground motion to the roof structure through the walls. In essence, the bale walls could act as seismic shock absorbers, and, if the connections between bales and between the foundation, walls and the roof are properly designed and built, such a building should be relatively safe in earthquakes (Estoup et al., 1995).

The fairly common practice of using a concrete grade beam on a rubble-filled trench as the foundation for bale buildings may have additional seismic benefits. This type of foundation has found favor among straw bale designers and builders because it requires little or no concrete below grade and therefore reduces the concrete needed. This is important with bale buildings since the extra width of foundation required due to the thickness of the walls is one of the few economic and ecological disadvantages of this building system. Jake Feldman pointed out that this "floating grade beam" foundation may provide seismic isolation for the structure by minimizing the transfer of lateral ground motion to the structure in seismic events. Thus, in certain soil types, the most economical method of constructing the foundations for bale buildings may be seismically best as well (Estoup et al., 1995).

The seismic testing required should include: testing and evaluation of various wall systems; whole structures; component parts including pinning and tie-down systems; door, window and roof plate systems; interior and exterior wall finish systems and attachment methods; and foundation connections.

A proposed seismic research project involves building and monitoring a number of straw bale utility buildings near Parkfield, California. Preliminary discussions have identified a land owner willing to have the buildings on his property, near the epicenter of a recurring seismic event in the area (Work, 1995; Fish, 1995).

A related seismic research project is the potential use of bales for seismic retrofits of masonry structures. The possible structural benefits, when combined with the thermal advantages of bale retrofitting, could prove to be a very attractive option for upgrading existing buildings. If adequate methods of attachment can be developed, it may be possible to significantly strengthen even unreinforced masonry buildings by wrapping them (either inside or outside) with bale wall systems (Estoup et al., 1995). From the standpoint of thermal efficiency, ease of construction, and maximizing usable interior space, exterior positioning of bales is best. Research is needed to determine the viability of this strategy and the optimum placement of the bales. This concept should be evaluated along with the seismic evaluation of new bale construction.

Additional research and testing is needed to develop appropriate wall finishes for buildings with the potential for the amount of movement possible without structural failure of bale wall systems. The use of brittle finishes, such as cement stucco or hard plasters, while adding to the strength of the wall, may also create other problems, not the least of which could be the need to completely re-plaster a building after an earthquake. While preferable to have little repair work, if the building succeeds in protecting its occupants during severe earthquakes, the more superficial, though costly, repair of the finishes may be acceptable. An area of research, related to both seismic effectiveness of bale buildings and the utilization of rice straw is developing rice straw-based wall finishing systems for both interior and exterior applications, which might be more inherently flexible, while providing the bales the physical protection they need. Straw/cement shingles for exterior walls could provide the protection and flexibility, while providing excellent ventilation for the underlying bale wall system.

Site determination of structural adequacy of bales

The development of a simple portable device to measure the compressibility of bales is also a high priority. Though only a part of the larger set of testing projects needed to facilitate the widespread use of straw bale construction, it could have a significant impact. This research project involves both developing the device and then establishing the relationship of the compressibility of bales to the structural performance of bale wall systems.

This is a fairly complex research project, but the potential benefits are enormous. The structural data could be used in both design and analysis of bale structures. The field inspection device would make it much easier to establish the structural quality of bales anywhere.

Making load bearing straw bale building commercially feasible, requires a direct and accurate way to establish that bales are of a minimum structural quality. This presents a series of challenges, which can be addressed in different ways. One approach is the commercial manufacture of bales for construction with a testing and certification program which is satisfactory to the building officials. The advantage would be bales of certified and controlled quality. A major disadvantage is that this process would add considerably to the cost of these bales and, in the end, to the cost of the buildings. Another disadvantage is that the manufacturing facilities would likely be centralized and thus not close either to the source of the straw or the ultimate site at which the bales would be used, adding to the transportation cost and embodied energy of the product.

Because of the advantages inherent in the use of existing baling technology and the potential need to verify the structural quality of bales in the field in any case, this research is important. The actual testing project would require isolating the effects of variables such as types of straw and bales, string tension, density, and moisture content on the structural performance of individual bales. Then the effects of variables in bale wall systems would need to be isolated. These include such things as stacking and pinning methods, tie-down or tensioning systems, and wall finishing systems. Once sufficient test data has been collected, the relationship between compressibility of bales and their structural performance in wall systems could be established.

Completion of this research project should result in a set of allowable design loads for bales meeting certain compressibility and quality criteria. Thus, a designer or owner/builder could easily establish that bales of a given set of characteristics would be capable of performing satisfactorily for specific uses and design loads.

Effects of moisture in bale wall systems

The existence of baled hay and straw buildings dating back to the turn of the century proves the potential durability of this building system. However, questions remain about air and moisture barriers, wall finishes, possible need for breathable wall finishes and design, and potential for deterioration and indoor air quality problems.

The chemical make-up of straw is very similar to that of wood and the behavior of bales in walls should be similar to that of wood in walls, in terms of moisture retention and dissipation, and the deleterious effects of moisture. The differences needs to be studied and better understood. The movement of moisture, the effect of relative humidity and air temperature on moisture in bale walls, the effect of the breathability of wall finishes on the moisture content of straw in bale walls over time, and the seasonal moisture holding capacity of bale walls are all areas which need further study.

Fire testing

Although very satisfactory fire test results have been achieved in Canada and in New Mexico, as noted in the introduction, there is still some resistance to the full acceptance of the superior fire-resistive qualities of bale walls. There have been requests for retesting both bare and plastered straw bale wall assemblies, strictly adhering to ASTM E-119 Fire Test procedures, including Hose Stream Tests, to establish the actual fire rating of these walls. Both the Canadian and New Mexico tests demonstrated fire resistivity in excess of a two hour rating for plastered walls (Gagne, 1986; SHB Agra, 1993). It is believed that the actual rating could be four hours or more. Given the potential for straw bale construction to prove far superior to conventional wood frame construction from a fire safety standpoint, this additional testing could have long term benefits. These include the possibility of preferred insurance rates for added fire safety and a wider market share for buildings in areas particularly susceptible to fire. Additional fire tests on vertically loaded straw bale walls would further acceptance of the method.

A common concern of building officials when considering straw bale construction relates to Smoke Development and Flame Spread ratings for straw bale walls. In the model buildings codes for residential construction there is no such requirement, but it remains an issue of perception and concern among officials when they view the straw bales as insulation. According to the 1994 Uniform Building Code, Volume 1, Section 707.3 which refers to insulation in cavity walls: "When such materials are installed in concealed spaces of types III, IV and V construction flame -

spread and smoke-developed limitations do not apply to facings, provided that the facing is in substantial contact with the unexposed surface of the ceiling, floor, or wall finish." Types III, IV, and V construction are buildings including one and two family residential construction (Eisenberg, 1995). Though the building code exempts most residential types of construction, in order to build multi-family or commercial buildings with bales, these additional tests will need to be carried out. Therefore, this is another area of testing that should be done along with the rest of the fire testing.

Pilot Projects

It is recommended that cooperative efforts be started to create pilot demonstration projects for the various proposed uses of straw bales for construction. A small residential development, using this construction method, could be built patterned after a development currently in the planning phases in Tucson, Arizona (Urban Consortium, 1995).

Pilot straw bale home construction projects could be encouraged at the local level, particularly in rice-producing counties. Governmental funding of straw bale housing evaluation and construction may be feasible. Funding could be generated by a surcharge on rice sales or other broad-based product-related revenues. Following the model being used in Tucson, a coalition of organizations involved in affordable housing, as well as sustainable development groups might come together to help establish such a pilot project in California. There are already some affordable straw bale housing units planned in Northern California and perhaps one of these could serve as a pilot project to demonstrate the viability of this building system.

Additional pilot projects might include seismic and thermal retrofitting of substandard existing housing. HUD has indicated its willingness to use straw bale construction in the 201K and 203K Programs for upgrading and retrofitting existing housing stock. This may provide a source of funding for pilot retrofit projects to explore the costs and feasibility of this technique. As mentioned earlier in this report, there is also the potential for seismic retrofitting with bales and this may also offer an opportunity for funding a pilot project.

At a straw bale construction workshop in September 1995, Dr. Marc A. Weiss, Special Assistant to the Secretary of HUD, expressed the Clinton Administration's interest in supporting the development of this type of innovative approach to affordable housing. He stressed that the greater opportunities for sweat equity, reduced construction costs, and the long term affordability resulting from the energy efficiency make straw bale construction very attractive to HUD for programs such as the National Partners in Homeownership (Weiss, 1995; Housing and Urban Development, 1995).

The Oregon Department of Transportation is exploring the possibility of developing a pilot project using straw bales for highway sound abatement walls (Paiva et al., 1995). Caltrans is testing a similar pilot project using rice straw bales near Dunnigan.

Feasibility of centralized handling

Unless it proves necessary for economic or regulatory reasons, the centralization of the production of rice straw bales, into a commercial facility appears unlikely at this time. Even if it were to prove desirable, the facility required would be little more than a very large covered or enclosed space and some basic baling and material handling equipment. A ban on straw burning in England led to extensive collection and storage of straw by two competing private firms, each handling hundreds of thousands of tons each year. These firms harvest and remove straw from the farm fields for free in exchange for the value of the straw. It is easy to imagine a similar process developing in California.

As straw bale building increases in popularity, it will be necessary to store large quantities of either baled or unbaled straw to accommodate the seasonal nature of the supply of straw. At this stage of development for straw bale construction, the creation of a commercial baling facility is probably not a high priority, although baling adequate supplies and storing them is an activity with commercial potential.

Widespread commercialization

The widespread commercialization of straw bale construction will take time to develop. The creation of straw bale construction guidelines by the passage of Assembly Bill 1314, the completion of testing and research projects, the development of building codes, the successful completion of demonstration projects, the development of optimized construction systems, and the increasing media coverage will all result in market growth. As conventional building systems become less affordable or are recognized to be unsustainable, alternatives such as this will become increasingly attractive to the public and to designers, builders, and the institutions involved in financing and insuring buildings.

There are no other building systems which offer the combination of energy efficiency, aesthetic characteristics and ease of construction at anything close to the cost of straw bale construction. When the viability has been established through testing and high quality demonstration and pilot projects, the market for straw bale buildings should be capable of rapid growth. The increase of interest in alternative building systems by the public, the design and building sectors, and building officials, is an indication of the market pressure to find better ways to build. It is not unreasonable to expect that straw bale construction will capture some of this market. Innovative builders and designers are already pursuing the straw bale market and this should only continue to expand.

Dealing with the building codes issues is very important in establishing acceptance of alternative building systems in the short term (Lorenz, 1995). Completing the research and testing and developing appropriate building codes will be critical elements in the development of the market for straw bale construction.

Barriers

The use of straw bales as building elements presents a set of problems that is unique in the modern system of building technology evaluation. There are some similarities with other systems as well. The two main characteristics that separate straw bales from other materials typically used in construction are, (l) the decentralized production of bales; and (2) the compressibility of the bales. Each of these aspects creates its own set of problems which must be addressed. The ways in which they are similar to problems in other, more accepted methods of construction may aid in overcoming the obstacles to straw bale construction.

The decentralized production of bales is both an advantage and a disadvantage. Because the current technology for producing bales already exists and is well distributed in the exact locations where the raw material is grown, this basic problem has been solved. This means that the bales can be produced from locally grown crops and there is a great reduction in the required transportation to the point of usage of the bales. This reduces both cost and embodied energy of the bales. The embodied energy of rice straw is largely the result of the baling process and transportation of bales from the field. It also provides local economic advantages in that more of the money remains in the local economy.

The disadvantages of having this existing manufacturing capability is that the baling machinery was not designed to produce bales of high uniformity in terms of compaction or size. Additionally, there are numerous types of balers which produce bales with different numbers of ties, dimensions of bales and orientation of the straw within the bales. All of these factors make it difficult to achieve a highly uniform building material with the existing situation.

This lack of uniformity presents a major, but not necessarily unsolvable obstacle to the use of bales as structural building elements. If methods are developed to assess the actual structural characteristics of bales at the building site, the establishment of minimum standards for bales could resolve this issue. While this is different from most other building materials and the way they are manufactured, tested, approved and used, it is not unprecedented. Earthen building systems have a similar variable nature based on the local soil characteristics, manufacturing processes, uses and associated systems. Codes have been developed to accommodate these building systems and the same is possible for straw bale construction.

The benefits of not redesigning and manufacturing balers specifically for construction are significant. The major one is avoiding the need for the research and development process for this equipment and the capital investment required in a basically speculative phase of the development of this technology. Another significant one is the time required to develop and test these balers and bales, in addition to the testing already required to adequately prove the viability of the bale building system to the institutions which regulate construction. Finally, the creation of centralized plants to produce construction grade bales will add substantially to the cost of bales and to the associated cost and energy involved with the distribution and transportation of bales.

Therefore, it appears to make sense to pursue research and testing that will result in establishing site testing of bales to establish that bales meet minimum quality standards for structural uses. The development of higher quality baling equipment is also worth pursuing, if investors can be found to support this activity. Over time, the market may develop sufficiently to warrant such investment.

The other major difference between straw bales and other building systems relates to the compressibility of the bales. This, again is not unprecedented in building systems. The most comparable building system in this regard is log home construction, which also has compression of similar magnitude occurring in the walls of those structures. This compression can be as much as 4 inches, but takes place over a period of several years as the logs dry out, shrink, and adjust to the load they bear. Unlike straw bale walls, there is no way to speed up this process or precompress the walls of a log structure.

This initial compression and the possibility of additional compression occurring over time, are the major concerns expressed about the viability of load bearing bale wall systems. Experience and examination of the historic straw and hay bale buildings has not revealed evidence that there is a long term compression problem. Once the initial compression has taken place, additional compression has apparently not proven to be a problem (Steen et al., 1994).

Compressive testing of individual bales indicates that the bales are elastic in compression and therefore should reach an equilibrium in compression and not continue to compress (Eisenberg, 1993). Various strategies have been devised to post tension or precompress bale walls beyond the maximum design load to alleviate any concerns about additional compression (Hartwell and Theis, 1994). Additional research and testing is required to fully support the results indicated from the initial testing and the evidence from historical structures.

Education has been an important aspect of straw bale development, The EOS Institute erected a full size bale building for the Orange County Home and Garden Show in 1993 (Bayless, 1993). Members of the California Straw Bale Building Association (CASBA) built a demonstration wall for the State Fair in 1995 and the Marin Home and Garden Show in 1996.

Potential for Governmental Action

The two major obstacles most easily addressed by government action to increase utilization of rice straw in construction appear to be institutional acceptance and economics.

The major institutional obstacle to straw bale home construction relates to building codes and general acceptance of the system. Widespread use of the technology requires evaluation and standardization of construction practices. Consumer acceptability needs to be addressed also, but building code acceptance would accelerate this process greatly.

The passage of AB 1314 in the Assembly and Senate and expected signing by the Governor by mid-October 1995 will be a major step in increased credibility for straw bale construction in the State of California (Sher, 1995). This measure is expected to go into effect on January 1, 1996. It will establish minimum voluntary technical construction guidelines for straw bale construction. Local building code jurisdictions will be able to modify and/or adopt the guidelines which are based on the code awaiting final approval in Tucson, Arizona. That code is also expected to go into effect January 1, 1996.

Pilot straw bale home construction projects could be encouraged at the local level, particularly in rice-producing counties through various incentives and easing of certain code restrictions for innovative pilot projects. Governmental funding of straw bale housing evaluation and construction may be feasible. Funding could be generated by a surcharge on rice sales or other broad-based product-related revenues.

Another direct and expeditious government action to encourage alternative uses of rice straw would be economic incentives. The more obvious option appears to be some form of subsidization -- direct funding or tax incentives or some combination of both. Another option may be fee-based revenues from rice and rice products. Whether or not it is reasonable to increase subsidization of rice production may be questioned. As a percentage of growers revenues, subsidization of rice production increased from 28% to 50% between 1982 and 1992. Nonetheless, further subsidization is an option.

Recommendations

a. Straw bale housing could utilize rice straw with a coincidental benefit of lower housing costs, particularly for owner-builders. Major construction cost savings would probably occur only in the owner-builder market due to labor cost savings, in the short term. However, as construction techniques for straw bale wall systems are optimized and contractors become familiar with this building system, costs will drop and this trend should continue for some time. Life-cycle cost savings should be significant, due to lower utility bills and downsized mechanical equipment needed in these superinsulated homes. It is recommended that the major rice growing counties undertake demonstration projects for the construction and evaluation of rural straw bale houses. This should be a joint effort of State and local building and housing agencies and interested private sector parties. Cost-sharing by the State and rice-producing counties seems reasonable.

b. Research and testing of straw bale wall systems should be supported. By establishing the viability of this building system through testing, other major obstacles in the way of widespread acceptance will be influenced. From a practical point of view, research efforts must consider the seasonal production of large quantities of rice straw and the bulky, low density, and abrasive nature of the straw which has economic implications for handling, storage, and shipping.

c. The use of straw bales in other types of construction should be evaluated, e.g., use in agricultural structures, sound barriers, highway dividers. This should be a joint effort of road, highway, building and housing agencies as well as interested private sector parties.

There is little question that straw bale building is an important and effective method for building residential, commercial, institutional and agricultural buildings. It is not suitable for every site and costs are determined in part by shipping distance. But we can expect to see more bale buildings in California.

REFERENCES

Andersen, B.H. 1989. The Danish Solution to Housing Outdoor Pigs. PIGS. 5 (MayJune): 12-13

Andersen, B.H. and P. Homegaard. 1987. *Hytter og klimatelt til alteratiyt svinehold* (Huts and tents for alternative pig husbandry) 5 Nov. Statens Byggesforskingstnst (POB 119 2970, Horsholm, Denmark).

Anon. 1960. Straw bale church in Alberta. Grassland News. New Holland Farm Machinery.

Anon. 1995. Straw bale walls go up at Solar Living Center. Real Goods Catalog p 41.

Bainbridge, D.A. 1986. High performance low cost buildings of straw. Agriculture, Ecosystems, Environment 16:281-284.

Bainbridge, D.A. 1987a. Better homes with gardens. Amandla 1(1):8

Bainbridge, D.A. 1987b. Straw bale construction. Poster presented at the 12th Passive Solar Conference, Portland, Oregon 1987. Portions appeared in the Proceedings of the Conference, American Section International Solar Energy Society, ed. by D.A. Andrejko and J. Hayes. Vol. 12, pp. 250-253. ASISES, Boulder, CO

Bainbridge, D.A. 1993. Plastered straw bale construction. V2a, pp 34:1-8. Conference Proceedings: Straw -- a valuable raw material. PIRA International, Leatherhead Surrey, UK.

Bainbridge, D.A. 1994. Fire safety: field tested in Mother Nature's laboratory. The Last Straw #8:17

Bainbridge, D.A. 1995. Personal communication from San Luis Obispo Solar Group, Ken Haggard and Polly Cooper.

Bainbridge, D.A. 1996. One more crack like that and I'll plaster you. The Last Straw #13:15

Bainbridge, D.A. and M. Myhrman. 1991. Straw bale building systems. Solar World Congress, Denver, CO. vol. 3 part 1. 2611-2616.
Bainbridge, D.A. and W. and A. Steen. 1992. Plastered straw bale construction. Canelo Project. 48p.
Bainbridge, D.A., W. and A. Steen. 1993a. Plastered Straw Bale Construction, 2nd edition, Canelo Project, Elgin, AZ
Bainbridge, D.A., R. Hofmeister and S. MacDonald. 1993b. Roots and revival: working group reports. First National Straw Bale Building Conference. Arthur, Nebraska. Out on Bale, Tucson, AZ 14p.
Bayless, L.E. 1993. Eos Institute Straw Bale Eco-house. Eos Institute, Laguna Beach 4p.
Blue Mountain Builders. 1996. Albuquerque bales for the blues. The Last Straw #14:33-34
Bou-Ali, G. 1993. Straw bales and straw bale wall systems. MS Thesis, Engineering. UofA. Community Information Resource Center, PO Box 42663, Tucson, AZ 85733
Canada Mortgage and Housing Corporation Housing Technology Incentives Program. 1984. An innovative straw bale/mortar building system. Ottawa, Ontario 3p.
Cleland, S.B. 1942 [1941]. Straw sheds. Univ. of Minnesota, Extension Bulletin 227, St. Paul, MN.
Dice, J.R. 1947. Some effects of type of shelter on dairy cattle, ND Agric. Exp. Sta. Bull. 344, (NDSU, Fargo, ND 58102), April.
Dobie, J. and R.H. Mosley. 1981. Straw Harvesting, Collection, Handling and Processing. page 64 in Agricultural Residue Management: A Focus on Rice Straw, A Report of the Residue Management Task Force, University of California.
DOE Energy Efficiency and Renewable Energy. 1995. House of Straw: Straw Bale Construction Comes of Age. U.S. Department of Energy, April. DOE/GO10094-01
Doughty, T. (editor). 1990. Bales form emergency bunker. The Dakota Farmer, p. 31, April 7
Douglas, R.J. and L.H. Langford. 1954. Inexpensive winter shelter for hogs. Bi-Monthly Bulletin. ND Agric. Exp. Sta., 16:4 (Mar-Apr.):139-40.
Editor. 1995. Straw-Bale Structures: Where Are They?", Map, The Last Straw #11:36
Eisenberg, D. 1993. Summary of a Structural Straw Bale Testing Program, Community Information Resource Center, November. Tucson, AZ.
Eisenberg, D. 1995a. Straw Bale Construction and the Building Codes: A Working Paper, Development Center for Appropriate Technology, Tucson, AZ
Eisenberg, D. 1995b. Draft Prescriptive Code for Load bearing and Non-load bearing Straw Bale Construction. Development Center for Appropriate Technology, August, Tucson, AZ.
Eisenberg, D. 1996a. Testing, testing 1,2,3,4. The Last Straw #14:24-25.
Eisenberg, D. 1996b. Building codes and straw bale construction: . The Last Straw #14:6.
Eisenberg, D. 1996c. Code officials speak their minds . The Last Straw #14:4-5.
Eisenberg, D. 1996d. The political arena. The Last Straw #14:11
Eisenberg, D. 1996e. California fire testing. The Last Straw #14:23
Eisenberg, D., M. Myhrman and J. Knox. 1993. Results of a structural straw bale testing program. Community Information Resource Center, PO Box 42663, Tucson, AZ 85733
Erganian, R. 1995. Personal communication.
Estoup, Feldman, Hartwell, Higerd, Lauder, Luckner. 1994/5. Personal Communication with David Eisenberg.
Everett, G. 1993. Straw homes. Mother Earth News Oct/Nov p54
Extension Agricultural Engineer. 1924. Straw shed demountable roof frame, l9'X23', Plank and Wire, Plan # ND B-8-1-1, NDSU, Fargo, ND.
Extension Agricultural Engineer. 1930. Straw Barn for Cattle, 20'28', Endwall Door, Plan ND B-712, NDSU, Fargo, ND.
Extension Agricultural Engineer. 1930. Straw barn for sheep or cattle, 24' X 90', Endwall door, Plan # ND B-711, NDSU, Fargo, ND.
Extension Agricultural Engineer. 1934. Straw barn for poultry, 20'X20', Endwall Door, Plan #

ND B-713, NDSU, Fargo, ND.
Extension Agriculture Engineer. 1943. Special Circular A-54, Straw shed for cattle and sheep. 4p, Extension Service, ND Agric. College, Fargo, ND.
Extension Agriculture Engineer. 1943. Special Circular A-55, Straw shed for poultry, 4p, Extension Service, ND Agric. College, Fargo ND.
Extension Agriculture Engineer. 1943. Straw barn framing 28'X32', Postbeam & Wire Plan # ND 725-3-1, NDSU, Fargo, ND.
Faller, T., Nudell, D., Olson, R., and Stecher, D. 1990. A shed made from straw used for a sheep shelter, 31 st Annual Western Dakota Sheep Day Report, NDSU, February. Hettinger Res./Ext. Center. (POB 507, Hettinger, ND 58639)
Farrant, T. 1996. Working paper for straw bale landscape walls. Out on Bale, Tucson, AZ 30 pages
Fernandez, M.A. 1994. Architect, New Mexico State Construction Industries Division, Report on Straw Bale Construction Activity.
Fish, P. 1995. It's Our Fault. Sunset Magazine, June.
Fowler. 1900. Nebraska School Buildings and Grounds. State Superintendent of Schools.
Freudenberger, R. 1993a. A straw-bale revolution. Backhome Fall:30-31.
Freudenberger, R. 1993b. Standing the test of time. Backhome Fall:34-35.
Gagne, L. 1986a. A Straw Bales/Mortar House Demonstration Project. Canada Mortgage and Housing Corporation, Housing Technology Incentives Program. Ottawa, Ontario 42p.
Gagne, L. 1986b. Report to the Canada Mortgage and Housing Corporation on Straw Bale Demonstration Project.
Gergen, B. 1987. Low-cost calving shed made from straw bales. Farm Show 11:6 (POB 1029, Lakeville, MN, 55044)
Hammond, J. 1979. Straw bale house. Winds of Change, Winter(Feb/Mar):8 (Winters, CA)
Hartwell, R. and R. Theis. 1994. Report on Structural Test Wall for Shenoa Cottage.
Hawes, M. 1993. Straw and solar: a perfect match. Home Power #35: 62-66.
Hofmeister, R. 1996. The end of an experiment. The Last Straw #14:42.
Housing and Urban Development. 1995. The Key to Homeownership: National Partners in Homeownership, pamphlet, U.S. Department of Housing and Urban Development, Washington, DC, June.
Johnson, D.W. 1990a. Straw bales make cheap buildings. Grainews. July:25,42-3, (POB 660, Winnipeg, MB, RC3 3A7)
Johnson, D.W. 1990b. Build yourself a low-cost straw bale barn. Farm Show 14:2 (POB 1029 Lakeville, MN, 55044)
Johnson, D.W. 1990c. Farm buildings using rectangular or round baled roughage. American Society of Agricultural Engineers paper #904550, Presented at the 1990 Winter Meeting. ASAE St. Joseph, MI 4908510p.
Johnson, D.W. 1990d. Old tricks work with new bale shapes. The Dakota Farmer 108:4(Feb 17):34-5 (7900 International Dr., Minneapolis, MN. 55425)
Johnson, H. (editor). 1982. Straw provides low cost shelter for livestock. Farm Show, 6:1
Johnson, H. (editor). 1984. Straw bale grain bins. Farm Show. 8:1-7 (POB 1029, Lakeville, MN 55044)
Johnson, H. (editor). 1987. Round bale shed. Farm Show. 11:6,
Kay, J., D. Anthone, and R. Kay. 1990. Nebraska Historic Building Survey of Arthur County. Nebraska State Historical Society. Lincoln, Nebraska.
Lorenz, D. 1995. A New Industry Emerges: Making Construction Materials From Cellulosic Wastes. Institute for Local Self-Reliance, June.
Maertens, W. 1995. BioFab specifications faxed letter, September.
MacDonald, S. and M. Myhrman. 1994. Build it with bales. Out On Bale, Tucson, AZ 79p.
Miller, J. 1995. personal communication. Design/Build company.
Nevada Assembly Bill 171,1995. Nevada State Legislature, Carson City.

Oertega, A.M. 1991. Sustituyen los ladrillos con paja de trigo!. El Imparcial April 20, Hermasillo, Sonora, Mexico
Ostrowski, H., J. Ostrowski, and T. Argento. nd. The BREBS project: straw-bale rammed earth passive solar bed and breakfast. 3p. Alternative and Conservation Energies, Inc. 1909-10 Ave SW, Calgary, Alberta T3C OK3
Paiva, Shoaps, Phelan. 1995. Oregon Department of Transportation, Personal Communication with David Eisenberg, April.
Pennington, R. 1995. personal communication. developer VATC.
Perry, J.M. 1986. Oldest Building Trade in World Keeps Britons Snug and Dry. Thatchers Use Straw or Reeds to Make Superior Roofs; Drawbacks: Birds and Fire. Wall Street Journal 11/11 [computer abstract].
Pima County Building Codes. 1996. Pima County, Arizona, Prescriptive Standard for Loadbearing Straw-Bale Structures, 201 North Stone, Tucson, AZ, 85701
Promersberger, W.J. 1945. A possible use for North Dakota straw. Bimonthly Bulletin ND Agric. Exp. Sta. 8(1) Sept.-Oct.:14.
Real Goods. 1995. The Last Straw, #11, Summer. page 14. (see also virtually any Real Goods catalog 1995-96),
Reveley, R. 1993. The Song-dog story. Backhome Fall:32-33.
Rose, B. 1995. Recipe exchange. The Last Straw #9:5-6.
Sayre, L. 1996. One from the top. The Last Straw #14:1,6
Semmes, T. 1996. The days of wine and ...straw bales. The Last Straw #13:16.
SHB Agra, Inc. 1993. Report of ASTM Small Scale E-l 19 Fire Test on Uncoated Straw Wall Panels and Stucco Coated Straw Bale Wall Panels.
Shepard, J.H. 1920. Grass fat cattle warmed up on corn fodder with a straw shed as shelter. ND Agric. Exp. Sta. Bull. 140, NDSU, Fargo, ND.
Sher, B. 1995. Assembly Bill 1314, California State Legislature, Sacramento.
Smith, M. 1989?. Baled Hay Houses. pp. 44-45. In Arthur County's 75 years of History, Homesteaders and Homemakers. Arthur County Historical Society Book Committee Arthur Nebraska
Sorenson, D. 1982. Hog barn built with straw bales. Farm Show. 6(6):21
Sparks, W.C., G. McMaster, J.E. Dixon, D.W. Works, and E.B. Wilson. 1963. Idaho potato storages--construction and management. Idaho Agric. Exp. Sta. Bull. No 410, U. of Idaho, Moscow, ID.
Steen, A. and B., D.A. Bainbridge and D. Eisenberg. 1994. The Straw Bale House. Chelsea Green, White River Junction, VT.
Taylor, R. 1967[1963]. Potato Cellar A-Frame Type, Plan No. 734-21, 5 sheets, Agricultural Engineering, U of Idaho, Moscow, ID,
Tilley, R.D. 1991. Blueprint for survival. Architecture May. 64-71
Tonneson, L. 1987. Low-cost shelters from big round bales. The Dakota Farmer, Nov. 7. U.S. Bureau of the Census. 1993. 1990 Census of Population and Housing.
U.S. Bureau of the Census. 1994. County and City Fact Book.
Urban Consortium Energy Task Force/City of Tucson. 1995. Affordable Super insulated Straw Bale Homes Project Summary.
Weiss, M. 1995. Personal Communication with David Eisenberg, September.
Welsch, R.L. 1970. Sandhill baled construction. Keystone Folklore Quarterly 15(1):16-34.
Welsch, R.L. 1973. Baledhay. In: L. Kahn, ed. Shelter. Shelter Publications, Bolinas, California. p. 70.
Whiteley, P.O. 1996. A sanctuary in Tucson's barrio historico. Sunset March p 94
Williams, B. 1978. Reducing Home Building Costs," Craftsman Book Co.
Wilson, A. 1995. Straw: The Next Great Building Material? Environmental Building News 4(3) (May/June)
Work, G. 1995. Personal communication with David Eisenberg.

Electronic sources (Epko, Uhlig, Eisenberg, Bainbridge)

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To subscribe to the Straw-bale Mailing List send the message: <subscribe strawbale> to majordomo@crest.org.

Center for Renewable Energy and Sustainable Technology (CREST):
http://solstice.crest.org/efficiency/Straw_insulation/straw_in.html

(CREST)Strawbale Mailing List Archive 1995
http://solstice.crest.org/efflciency/strawbale-list-archive.old/date.html#start

(CREST)Straw-bale Mailing List Archlive 1996
http://solstice crest.org/efficiency/strawbale-list-archive/index.html

CESD State of California Guidelines for Straw-bale Structures:
http://www.sustainable.doe.gov/codes/ca-strawbale-codes.html

EBN - Straw The Next Great Building Material?:
http://www.ebuild.com.Archives/Features/straw/straw.html

Ecological Architecture: StrawBale Building Technologies:
http://www.west.net/~prince/straw.html

Straw Bale Homes, The E-Zine Of The Straw Bale Community:
http://www complexity.org/mike/straw/

Gary Shea'sStraw bale Resource Guide
straw.http://www.xmission.com/~shea/straw

Home Power #35 Straw and Solar: A Perfect Renewable Match:
http//stores.us.ohio-state.edu/%7Esteen/homepower/straw.html

House of straw. Straw Bale Construction Comes of Age
http://www.eren.doe.gov/EE/strawhouse/

Internet Hay Exchange
http://www.iol.ie/~jrd/hay.html

Tucson and Pima Strawbale Codes
http://www.sustainable.doe.gov/codes/az-strawbale-codes-html

POTENTIAL USE OF RICE STRAW IN COMPOSITE MATERIALS

Composite materials combine more than one material or substance, most commonly a matrix material and reinforcing fibers. The fiber and the matrix will act together if a good bond exists between the resin and the fiber. As loads increase some fibers will reach their breaking points first, and loads will be transferred to other unbroken fibers in a progressive failure, rather than a simultaneous break. Composites can be extremely strong and are also very flexible for manufacturing processes. The development of higher working stresses is largely a question of devising fabrication techniques to make fibers work together to obtain their maximum strength (Parratt, 1972).

Composites have long been used in airplanes and defense, but are gradually making inroads in the automobile industry. Race car builders have long recognized the weight and strength advantages and advanced composites are now extensively used in Formula 1 racing and exotic cars. The 2,380 pound, 854 hp Lotec C1000 (Anon, 1994b) and the 2,425 pound, 627 hp McLaren F1 sports car (Frere, 1994) demonstrate what can be done with composites. The McLaren survived a 30 mph barrier crash test with no structural damage.

In 1993 Amory Lovins suggested that super-efficient, light weight composite cars built with aerospace technology would soon exceed 200 mile per gallon. It happened sooner than he expected when a super car built by students at Western Washington University exceeded 200 mpg equivalent in tests in Los Angeles in 1994. He believes (1994) that hybrid drive systems and components will be sold to local manufacturers, much like current computer clone makers, who could build a car to order in a matter of days out of composite materials.

Glass fibers have been the most common reinforcing materials for composites, but these pose health and environmental problems for disposal and require high energy inputs for manufacturing. More recently higher strength graphite, carbon, and boron fibers have been introduced in manufacturing of consumer items such as golf clubs, bicycle frames, and kit airplanes. Biological fibers and natural or synthetic matrix materials can be used to make composites that are environmentally friendly and strong. Glass fiber reinforced asphalt shingles for example are one of the predominant building wastes hauled to land fills. Every year enough asphalt shingles are thrown away to cover Lake Tahoe. Flax fibers have been replaced glass-fiber in roofing in parts of Europe. Rice straw fibers and stems, which are resistant to decomposition as a result of their high silica content, to 14%, (Walker, nd) and have a relatively high coefficient of friction (Usrey et al., 1992), may also prove suitable.

Plant cell walls and plant structures are natural composite materials with regular arrangement of reinforcing materials (Niklas, 1992). Evolution over millions of years has optimized structural design in many plant structures. Wood is a complex composite material, a fiber reinforced structural foam. It is extensively used and recognized as a structural material, but many other plant components are excellent raw materials for fabricating materials, structures, tools, and equipment. As the price of wood continues to climb, environmental problems with disposal of plastics and glass fiber reinforced materials increase, and the need for developing a market for agricultural fibers including rice straw (as field burning is curtailed), composites will begin to receive long overdue attention. Plant fibers can also be combined with recycled plastic to make a wide range of products.

Plant fibers can be surprisingly strong, Table 1, lightweight and inexpensive. They are more competitive with manufactured fibers than most engineers and manufacturers realize. They are attractive because they have chemically reactive surfaces which make more complete fiber-matrix bonding possible (Bolton, 1991). They can have a high work of fracture, a grass leaf was 4 times tougher than 2024-T6 aluminum (Vincent, 1982; Atkins and Mai, 1985).

Composites using natural fiber should prove safer to handle and work with and more environmentally friendly. Many biocomposite materials can be recycled (composted or digested) or burned, without the residues that are left with glass and carbon fiber composites. Plant fibers can be produced by sustainable agricultural systems (Mitchell and Bainbridge, 1991), with low embodied energy and atmospheric carbon rather than mined "carbon" from petroleum or coal.

Table 1. Specific tensile strength (strength on a weight basis)

Material	MPa
Biofibers	
flax[∂#]	73.3-160
coir[π]	107-173
rice straw[Δ]	105-193
Annealed aluminum[ø]	21
Steel[∂]	25
Fibers	
carbon[#]	171
graphite, intermediate[†]	142
e-glass[†]	136

† Rosato et al., 1991; ø Niklas, 1992; π Balaguru and Shah, 1992; ∂ Stamm, 1964; # Bolton, 1993, Δ Usrey et al., 1992. Measurements are not all from similar tests. Density was estimated where it was not stated.

The mechanical properties of fiber reinforced composites can be predicted and controlled by selecting and specifying matrix material and reinforcing fiber composition and orientation. Virtually any shape can be produced, from simple building materials, to structural angles, channels, I and V beams, and complex moldings and shapes. A new V shaped joist is being manufactured with OSB panels (Wardell, 1995). A similar product could be made with rice straw board.

Reinforcement fiber and form (chopped, felted, woven, braided, etc.) will depend on the performance requirements. Reinforcement-to-matrix material ratios can also be varied to maintain desired weight and strength. Natural fibers may require pretreatment to ensure maximum performance, key issues include selecting matrix materials compatible with the fiber and pretreating or protecting fibers during handling and processing.

Woven fabrics, and expanded fibers may also be of interest. Unwoven reinforcing, including felts and paper, may be effective and economical. Combinations of different fibers (rice and flax for example) may prove desirable. Combinations of different fibers and fabrics can facilitate molding of complex shapes.

While much work on plant fibers has focused on the cellular level and small fragments, there are many advantages from using longer stems and leaves. Longer fibers may help optimize mechanical properties. Natural fibers can be quite long, with individual cells of up to 2.5 cm for flax, and flax line fibers to 900 mm (Gilbertson, 1993). Rice straw could be provided in 50 cm lengths. Stems can be slit or sliced to produce thin, long fibers . Old varieties of rice favored for thatch may make a comeback as industrial feedstocks for biocomposites when longer, more durable fibers are needed. Cross-breeding traditional thatching rice varieties could provide more durable, much longer stems with high yields if markets warrant.

Composites with cementitious materials

More work has been done with composites made with natural fibers and cementitious matrixes than with manufactured or biological resins. Fiber reinforced concrete can be substituted for many wood and timber uses as well as sheet and roofing components. The most appropriate matrix materials are pozzolanas, including rice hull ash, which is up to 93% reactive silica by weight. This high silica content makes rice hull ash an excellent pozzolana (Stulz and Mukerji, 1988). Rice hulls needs to be burned at less than 700°C to remain amorphous and most desirable for pozzolana. Pozzolanas can be used to replace up to 30% of Portland cement without significantly reducing long term strength. Rice hull ash and 30-50% of hydrated lime can be used to make a hydraulic binder known as Ashmoh (RCTT, 1979). Rice hull ash also appears promising in manufacturing refractory or light weight brick silicate materials (Roberts, 1973).

Fiber reinforced cement is regarded as one of if not the most promising roofing materials, and can be produced at low cost, $2-4 per square meter (Stulz and Mukerji, 1988; Gram et al., 1986). Mechanically compacted fiber reinforced concrete contains one part cement, 3-6 parts sand and 1-2% fiber by weight. Pozzolanas are the best binder as they reduced alkalinity improves strength and durability.

Natural fiber reinforced cement roofing is produced as tiles, pantiles, troughs or corrugated sheets (Beck et al., 1987; Evans, 1986; Gram et al., 1984; Gram et al., 1986; Lola, 1985; Parry, 1985). Small beads of wax can be incorporated in the mix, which melts over time and seals the roofing (Gram et al., 1984). Companies including American Cem-Wood (shakes); Eternit (slates, panels); and Fibre-Cem (slates) use cellulose or wood fiber and cement to make roofing (Loken et al., 1994). A draft standard for natural fiber-cement roofing was developed in Sweden (Johansson, 1984).

Straw can be combined with cementitious materials to make building panels. Research in Sweden has refined a method of making cement-bonded straw panels (Hermansson, 1993). Panel density can be adjusted by changing the straw-cement ratio and compression to meet goals for insulation value and strength. Typical panels tested were 90cm x 60cm, 6 cm. Researchers found that soaking straw in a 5% solution of CaCl for 24 hours before fabrication improved performance. Estimated material cost was about $2.80 per square meter for a 10 cm thick panel with a density of 300 kg/m^3.

Straw and rice hulls can also be used to reinforce building block and clay products. INSUL HOLZ-BENSON has introduced the FASWALL system of insulated concrete to the United States. These plant fiber based concrete products are lightweight, have R-values of 11+, can be cut with simple carpenters tools, and can provide construction labor savings of 20% (Midwest Faswall, 1993). Similar products are being developed or manufactured by others including, Hydromix, based in Boulder, Colorado.

Straw has also been combined with building materials to make Strawcrete which has been manufactured and used in Essex England for many years (Edwards, 1993). Straw cement can also be combined to make a easily worked or molded material that is fireproof (Babic, 1993).

Combining rice straw with foamed cement or similar binders may provide high strength, lightweight materials for a wide range of building purposes. Cement can be foamed with a range of organic and inorganic additives. It may be possible to make structural components with fiber reinforced foamed cement,

Straw has long been combined with clay to make insulating infill in the traditional German building method known as *leichtehmbau*.. Ten inch lengths of straw are dipped in a thin clay slurry and packed in wall forms. This fire-resistant, insulating, and environmentally responsible wall system has been used in homes in Texas (Fisk, 1990; Gibson, 1993) and Mexico.

Composites with manufactured resins and materials

Practically all thermoset TS and thermoplastics TP can be used in composites. Glass fiber-reinforced resins were first popularized in the 1950s (outgrowth of the war). Glass fiber and TS polyester combinations currently dominate the market. Other glues and binders can also be used. Building boards made with straw are feasible and are being explored in many areas. Pheno-formaldehyde resins have been used to make fiberboard with rice hulls and cereal straw (Eakin et al., 1982), but rice straw was not tested. Recycled post consumer and phenolic resin board was stronger than wood (Bixby, 1993), and a mixture including rice straw should be tested. Some rice straw is already incorporated in building board in California. Rice straw and wood chips were used to make a medium density fiber-board, but the rice straw was difficult to work with (Report to Rice Growers, 1984). Gridcore™, a pressed fiber panel system (Acello, 1993) would also be a good candidate for rice straw fiber.

Polyester resins can work well with natural fibers. Cotton, linen, and other fibers and polyester resin have been used to build and resurface boats. Work on plastic composites with other natural fibers, including bamboo, may provide useful information (Jain et al., 1993). Scientists at the Biocomposites Center in Wales have found that isocyanates and straw make an exceptionally water resistant fiber (Edwards, 1993).

Composites with recycled plastics

Composites made with rice straw fiber and recycled plastics are perhaps the most promising biocomposite and should be emphasized. Combinations of plant fibers and recycled plastic can make suitable composite materials for many uses. Despite glowing promises in the late 1980's the plastic industry has been unable or unwilling to develop recycling programs for many plastics (Kleiner and Dutton, 1994). While some progress has been made on PET (24% recycled), recycling of LD and LLD polyethylene (0.7%), HD polyethylene (5%), PVC (0.2%), PP (3%), and PS/HIPs (0.8%) is so low it be considered non-existent. More than 11 billion pounds of LD and LLD polyethylene are produced each year, and 8 billion pounds of HDPE and PVC.

Composites of biological fiber and recycled plastic may become important building materials. The Agronomic Systems process uses 70% biofiber and 30% recycled plastic to make a material they call Biocomp. A successful pilot run was made with rice straw from Sutter County. A package plant would utilize 14,000 tons per year.

Recycled plastic "lumber" is becoming more readily available, now manufactured by 30 companies nationwide, with at least 2 in California (California Recycling, Pico Rivera; Durapost, Eagle Recycled, Anaheim). While this plastic "lumber" has many desirable features, waterproof, durable, etc. its use is limited by the high density, which makes it awkward to carry and handle, the slick surfaces, lower strength and a higher coefficient of thermal expansion. TREX, for example, is twice as heavy as wood and can only span 80% of the distance of wood on a deck (Chapdelain, 1994). Combining recycled plastic with rice straw or processed rice straw fiber in the core and in lesser amounts in the matrix could bring density down closer to wood, increase strength, reduce thermal expansion, and provide texture against slipping. .

The composition of straw is similar to wood, Table 2, and the combination should be similar to the mixes developed for plastic and wood fiber (Raj and Kokta, 1991; Maldas and Kokta, 1989; Maldas and Kokta, 1990).

Table 2. Chemical composition in percent

	Cellulose	Hemicellulose	Lignin
Rice straw[1,2]	35	18.7	6-18.5
Wheat[3]	33-40	24-28	10-17
Softwood[3]	40-45	15-20	23-33

[1]Gerber and Van Sacon, 1991; [2] Chawla, 1993; [3] Robson, 1993.

Capturing even a small part of the market would create a very large demand for rice straw. Rice straw and recycled plastic could be used to make studs, headers, and paneling for shipment throughout the west. Because the plastic is being recycled into a building material rather than a food contact product the difficulties in cleaning the waste stream would be minimized.

Biocomposites

Biocomposites are a special class of composites combining natural fibers and natural resins. Natural biocomposites can be exceptionally strong, as anyone who has attempted to open a macadamia (*Macadamia ternifolia*) nut can attest. Macadamia nuts are as hard as annealed aluminum yet resist twice the force for fracture (Niklas, 1992). Many other biocomposites are very strong and resin selections can be made for ultimate strength, elastic modulus, fracture resistance or impact resistance.

Plant cell walls are composites of cellulose, hemicellulose (polysaccharides) and lignin (polyaromatic networks). The reactive hydroxyl groups on the polysaccharides provide a framework from which a wide range of polymers can be built (Bolton, 1993). Polysaccharides may be selected to meet both product and processing demands. Varying degrees of plasticity and biodegradability can be engineered in.

Straw can be compressed and heated to 280°C in a press to make a strong building panel without additives or adhesives. This process was invented in 1935 in Sweden by T. Dieden (Hermanusson, 1993). Stramit Industries in England makes a 5.8 cm thick, 120 cm wide panel in seven lengths, from 227-240 cm. These paper covered panels for interior partition walls have been used in 300,000 structures in England. The production of these panels uses 8,000 tons of straw a year, primarily wheat although rye is preferred and barley is acceptable (Stramit, 1993). An attempt to develop this system was started in Roseville in the 1980's and some material was manufactured, but the company was unable to develop a sufficient market. A company in southern California, Pyramod, intends to use a similar system to manufacture a pyramidal roof system.

Particle Compacting Development (PACO, Ltd.) has developed a method of turning straw into a natural plastic. High lignin content feedstock enables straw to be fabricated into car body components through molding, extrusion, and roll-form extrusion (Edwards, 1993).

Rice straw can be used to make cellulose acetate (McGee, 1980). Cellulose acetate is noted for its attractive appearance, toughness and strength (Rosato et al., 1991). Many other cellulosics and building blocks for industrial material can be extracted from rice straw by biological or chemical processes. Rice straw may also serve as an incubator or feed source for bacterial production of other biomaterials. Work on spider webs, which are super high strength (5x steel, 30 percent more flexible than nylon, 3 times impact strength of Kevlar) is progressing and it is likely these can be manufactured by bacteria in the near future (Graham, 1994). Mustard plants genetically altered to create plastic have been created at the Carnegie Institute for Plant Biology in Palo Alto.

The movement of the biotechnology industry into materials will be one of the hallmarks of the next decade. Biomedical development has been disappointing as a result of the complexity of development and testing medical products. Developing resins for composites will be much easier.

Barriers to use of rice straw fibers in composite materials

The obstacles to widespread use include:

1) ignorance of fiber properties and use, specialization and lack of systems training for engineers involved in manufacturing and research
2) lack of technical materials and readily available reference data
3) limited availability of cleaned, prepared fibers and woven or spun fabric and threads, without the lubricants used to facilitate spinning and weaving
4) limited data on straw harvest and processing
5) compatibility of fibers with matrix materials
6) potential plant cell wall swelling from water uptake by extensive hydroxyl groups.
7) potential reaction with alkalinity in cementitous matrix materials

Removing barriers

1,2. Education and development of technical materials

Technical materials should be collated, compiled and disseminated on paper and in electronic form. This should be done as part of a project to identify key research questions, information gaps, and opportunities. This will help stimulate interest in area colleges and industry.

The defense industry has trained many composite designers, fabricators, and manufacturers. These may well form the nucleus for a biofiber composite revolution. However, these individuals and companies need technical information and support on biofibers and bioresins. While much is already known, additional research is needed.

A biocomposite center should be set up at a local community college, UC Davis. In addition testing programs should be started at UC Berkeley and Cal Poly SLO. The Envirosave Value Added Technical Center proposed for Shasta College (Redding) is right on target for this work (Pennington and Justice, 1995). The community college composite center in the Los Angeles area is worth reviewing. A private rice straw center should also be created to speed implementation.

A competitive grants project for independent research and manufacturing should be established. A competition with substantial prizes for best development of rice fiber based products should be held. This could include student, farmer, and manufacturing divisions. Funding of at least a million dollars a year with priority on rice straw fiber utilization, this might be provided from air pollution credit or carbon tax payments.

3,4. Fiber production and fabric availability

Availability of clean rice straw fiber is primarily a matter of demand. The transition from combines to stripper headers, which leave a longer stem in the field, should make it much easier to obtain clean, long oriented fibers . It is also possible to obtain clean oriented fiber with binder reapers. The equipment for separating, cleaning and processing fibers is improving from year to year and should not prove a serious obstacle.

5. The wax of the cuticle can be removed in processing with solvents, or the resin or plastic may be compounded in a manner that will minimize problems. Woven and spun materials can usually be prepared by washing and rinsing. Weathering can also improve liquid flow into woven and spun materials. Fiber treatment for good coupling may also require additional research. The challenge appears to be developing an appropriate interphase to get good bonding (Garnier, 1993). Quillin (1993) found that stearic acid was once of the best surface modifiers.

6. Past attempts to prevent fiber swelling problems focused on reacting the fiber hydroxyl groups with monofunctional reagents (Bolton, 1993). This can make the modified fiber surfaces more difficult to 'wet' with matrix materials, and can result in the modified fiber and resulting composite being weaker. Improved water resistance and bonding may result if difunctional reagents and methods of controlling reagent reaction can eliminate the fiber hydroxyl groups and form strong (primary valence) bonds with organic matrix materials.

7. The protection of straw fibers from alkalinity has been addressed in various research projects. One of the most effective methods appears to be presoaking and pretreatment. Calcium chloride has given good results with wheat straw (). Shah (1993) found that thin cement reinforced with recycled fiber had good flexural strength, stability and density and had the best initial lifecycle cost v/s commercial available materials.

Summary and conclusion

The potential economic benefits of using rice straw fibers in farming areas beset with economic and environmental problems cannot be underestimated. This is in many ways a new frontier and calls upon the talents and skills of engineers, chemists, botanists, biologists, agronomists, and ecologists. Integrated whole system development will be essential to recognize the full potential of these materials.

With appropriate attention to the opportunities in biological fibers and "natural" resins the transition to safer and environmentally friendly biocomposites can be made. Bioengineering should make it possible to grow plastic resins and reinforcing materials economically and safely. These materials can be used to make lighter, stronger and more durable products that save resources and energy. Long life and eventual recycling can be engineered into these products.

Integrating uses in a straw utilization complex, "Straw Town", would benefit producers and rice growers. Combined use can also create a critical mass to make rice straw harvest, collection, and storage practical. Rice straw harvesters like the two straw harvesting companies working in England, which both handle about 200,000 tons a year, could develop to feed these facilities. While independent companies might be marginal or non-economic, integrating uses could make them all profitable, and minimize waste streams.

For example, an energy facility can provide electricity and steam for construction material fabrication and production. The pozzolanic rice hull ash can be combined with straw fiber to make durable roofing tiles, sheets, and slates. Energy will also be needed to run a straw bioplastic production facility. And fiber can be mixed with recycled plastic to make lumber and panels. Recycled wood fiber could be combined with rice straw fiber 50/50 to make cardboard and paper. Closing the circle will be an essential part of business in the next Century.

References

Acello, R. 1993. La Jollan develops markets for Gridcore™, a wood substitute made from waste products. La Jolla Light March 4, D1,4

Anon. 1986. New building panels reduce cost, increase design flexibility. Construction Data 16(24):1

Anon. 1994a. Lightening strikes. Sports Car International 10(10):16-17

Anon. 1994b. The torquemeister. Sports Car International 10(10):74-78

Atkins, A.G. and Y.W. Mai. 1985. Elastic and Plastic Fracture. John Wiley and Sons, NY

Babic, B.R. 1993. Personal communication, leaflet. Styrocrete©. Oxford, England

Balaguru, P.M. and S.P. Shah. 1992. Fiber Reinforced Cement Composites. McGraw Hill, NY

Beck, V., H.E. Gram and K. Wehrle. 1987. Fibre concrete roofing: towards a mature technology. FCR News, SKAT, St. Gall.

Bixby, G.T. 1993. Recycled cellulose fiber reinforced phenolic composites. MS Thesis, University of Lowell. 87p.

Bolton, J. 1993. Plant fibers: alternatives to man made fibers. BioComposites Center, University of Wales, Bangor 1p.

Chapdelaine, H. 1994. Working with TREX lumber. Journal of Light Construction 12(11):40-41.

Chawla, J.S. 1993. Utilisation of rice straw. Proceedings, International Straw Conference, Royal Agricultural College, Cirencester, UK v2(17):1-20.

Eakin, D.E., M.A. Clark and W.F. Smith. 1982. Evaluation of alternatives to open burning of forest and agricultural residues (other than rice straw) in California. prepared for the California Air Resources Board, Batelle, Pacific Northwest Laboratories, Richland, Wash.

Evans, B. 1986. Understanding Natural Fibre Concrete, Its Application as a Building Material, IT Publications Ltd., London.

Frere, P. 1994. McClaren F1. Road and Track 46(3):82-87

Garnier, G.B. 1993. Cellulose fiber reinforced thermoplastic composites: surface and adhesion characteristics. PhD VPI. 351p.

Gerber, W.D. and V. Sacon. 1993. Paper manufacture in the south of Brazil. Straw : A Valuable raw material. PIRA Conference, Cirincester, England V2: 15

Gilbertson, H.G. 1993. U.K. Seed Flax Fiber. Straw : A Valuable raw material. PIRA Conference, Cirincester, England V3: 14p

Graham, D. 1994. Synthetic spider silk. Technology Review. 97(7):16-17

Gram, H.E., H. Persson, A. Skarendahl. 1984. Natural Fibre Concrete, SAREC Report R2. 1984, Swedish Agency for Research Cooperation with Developing Countries, S-10525 Stockholm.

Gram, H.E., J.P.M. Pany, K. Rhyner, B Schaffner, R. Stulz, K. Wehrle, H. Wehrli. 1986. FCR - Fibre Concrete Roofing, SKAT, St. Gall.

Johansson, L. 1984. Corrugated sheets of natural fibre reinforced concrete : draft standard. 1984. Stockholm : Swedish Council for Building Research, Statens rad for byggnadsforskning (Sweden)).

Kleiner, A. and J. Dutton. 1994. Time to dump plastics recycling? Garbage 6(1):44-51

Lola, C.R. 1985. Fibre Reinforced Concrete Roofing Sheets, Technology Appraisal Report, AT International, Washington, D.C.

Maldas, D. and B.V. Kokta. 1990. Effect of recycling on the mechanical properties of wood fiber polystyrene composites . 1. Chemothermomechanical pulp as a reinforcing filler. Polymer Composites 11(2):77-83.

Maldas, D. and B.V. Kokta. 1989. The effect of aging conditions on the mechanical properties of wood fiber polystyrene composites 1. Chemothermomechanical pulp as a reinforcing filler. Composite Science and Technology. V36 N2:167-182.

Jain, S. U.C. Jindal, and R. Kumar. 1993. Development and fracture mechanisms of the bamboo polyester resin composite. Journal of Material Science Letters. 12(8):558-560.
Jin, B.B., M. Hasuke, K. Murakamik. 1990. Structural characteristics of rice and wheat straw pulp sheets. Mokuzai Gakkaishi 36(3):200-206.
Loken, S., R. Miner, and T. Mumma. 1994. The Guide to Resource Efficient Building Elements. Center for Resourceful Building Technology, Missoula MT.
McLintock, F.A. and A.S. Argon. 1966. Mechanical Behavior of Materials. Addison Wesley, Reading, MA
Midwest Faswall Inc. 1993. Faswall Concrete Systems. personal communication, leaflets. Ottumwa, IA
Mitchell, S.M. and D.A. Bainbridge. 1991. Sustainable Agriculture for California: A Guide to Information. University of California Division of Agriculture and Natural Resources, Publication 3349, Oakland 196p
Niklas, K.J. 1992. Plant Biomechanics. University of Chicago Press, Chicago, IL 607p.
Parratt, N.J. 1972. Fibre Reinforced Materials Technology. Van Nostrand Reinhold, NY
Parry, J. 1985. Fibre Concrete Roofing. Intermediate Technology Workshops, Cradley Heath.
Pennington, R. and W. Justice. 1995. Envirosave Research and Training Value Added Technical Center Proposal. Shasta-Tehama-Trinity Joint Community College District, Redding 35 pages
Quillin, D.T. 1993. Interface characteristics and adhesion in cellulose/polypropylene composites. PhD University of Wisconsin, Madison 165p.
Raj, R.G. and B.V. Kokta. 1991. Reinforcing high density polyethylene with cellulose fibers . 1. The effects of additives on fiber dispersion and mechanical properties. Polymer Engineering and Science 31(18):1358-1362.
RCCT Regional Center for Technology Transfer. 1979. Rice Husk Ash Cement. Joint workshop of UNIDO, ESCAP, RCTT, PCSIR, Bangalore.
Report to the Rice Growers 1969-1984. Economic uses of rice straw, p 19.
Roberts, R.L. 1973. Rice hull utilization. pp. 412-417 In Pomeranz, Y. Industrial Uses of Cereals, American Association of Cereal Chemists, 58th Annual Meeting, St. Louis, Ms, p 73.
Robson, D. and J. Hague. 1993. The properties of straw fibre. pp P#03: 1-19. In Proceedings Straw-A valuable raw material: Volume 1. Pira International, Leatherhead, Surrey, UK. V1: 3, 19p
Rosato, D.V., D.P. DiMattia and D.V. Rosato. 1991. Designing with Plastics and Composites: A Handbook. Von Nostrand Reinhold, NY
Roff, W.J. and J.R. Scott. 1971. Fibres, Films, Plastics and Rubbers. Butterworths, London.
Shah, Z. 1993. Reinforcement of thin cement products with recycled wastepaper fibers. PhD Michigan State University, 243p.
Stramit. 1993. Personal communication, leaflets. Suffolk, U.K.
Stulz, R. and K. Mukerji. 1988. Appropriate Building Materials. Swiss Center for Appropriate Technology, St. Gallen, Switz. 430p.
Usrey, L.J., J.T. Walker and O.J. Loewer. 1992. Physical characteristics of rice straw for harvesting simulation. Food and Process Engineering Trans ASAE 35(3):923-930
Venkataswamy, M.A., C.K.S. Pillai, V.S. Prasad and K.G. Satyanarayana. 1987. The effect of weathering on the mechanical properties of midribs of coconut palms. Journal of Material Science 22:22:3167-72
Vincent, J.V.F. 1982. The mechanical design of grass. Journal of Material Science 17:856-60
Walker, H.G. nd. Chemical composition of rice straw. Western Regional Research Center, Berkeley, CA pp. 75-78.
Wardell, C. 1995. Triangle joists? Popular Science 246(3):71

Paper and packaging materials

Despite some drawbacks, agricultural waste products such as rice straw have great potential for paper and fiberboard production. World paper and pulp production from non-wood fibers was estimated at 15.6 million tons in 1990 (FAO, 1991) out of a total of 1,000 million tons of available cereal straw (O'Brien, 1993). Wheat and rice straw provide 63% of total fiber for China's paper and pulp production (Cheng, 1993), and rice straw paper is also used in other areas (Chawla, 1993; O'Brien, 1993). Rice and other cereal straw were once used in Europe but these uses have declined.

Rice straw is also an acceptable material for many types of paper products, although "rice paper" is not made with rice paper but from the bark of a shrub. In Brazil more than 12 million tons of paper from rice straw are produced every year, a 200 Ton per day plant was being brought on line to make liner board paper and fluting (Gerber and Sacon, 1993). Tests for this mill showed that soda pulp was slightly better than lime pulp treatment. Pure rice straw paper was too brittle, but paper with rice hull fiber included was better. From 25-50% rice straw can be combined with more flexible fibers such as hemp or cotton to improve performance.

New methods of pretreatment for the straw are improving the acceptance of straw fiber for paper and fiberboard. Research is needed on alternative paper production processes from straw, 200 years of work on wood fiber have refined that process but straw has received relatively little attention. Developing equal capability for rice and wheat straw will take time and money. Steam exploded and biologically treated straw might provide better fiber quality at lower prices than traditional methods. Industrial uses require a consistent supply, quality and delivery.

Barriers and Incentives

Rice paper and cardstock would be suitable for many uses. The current shortage of newsprint might encourage exploration of alternative fibers. If fast-food providers used rice-straw paper for place mats a significant demand for paper would result. MacDonalds, for example, serves 18 million meals per day, 1/2 are used in house. This is about 14 tons per day, or 5,000 tons per year. State law might require rice straw paper content for fast food suppliers, file cards and file folders, and boxes for government use.

Rice paper could also be incorporated in many paper blends. The state might require recycled paper for all official use. Manufacturers would need a stable, long-term market to invest in the highly capital intensive paper plants, which may cost more than $2,000 per ton of production capacity. Cardboard was once made in California with rice straw and this worked well, but production ceased in 1989 (Moss et al., 1993).

REFERENCES

Chawla, J.S. 1993. Utilisation of rice straw. Proceedings, International Straw Conference, Royal Agricultural College, Cirencester, UK V2(17):1-20.

Cheng, Z. 1993. Recent developments in China pulp and paper research on wheat straw. Proceedings, International Straw Conference, Royal Agricultural College, Cirencester, UK v2(18):1-23

FAO. 1991. Wood pulp and paper capacities survey 1990-95. United Nations, Rome

Gerber, W.D. and V. Sacon. 1993. Paper manufacture in the south of Brazil. Straw : A Valuable raw material. PIRA Conference, Cirincester, England V2: 15p

Moss, S.J., D. Mitchell, R. McCan, and T. Bayh. 1993. The economic impacts of alternatives to open-field burning of agricultural residues, Foster and Associate, SF. p3-26.

O'Brien, J.P. 1993. Future trends/markets in the straw pulp industry. Straw : A Valuable raw material. PIRA Conference, Cirincester, England V3(47): 12p

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Energy production with straw

Straw and straw bales are increasingly being used to provide heat and energy in the United Kingdom and Europe. Much use in the U.K. is for individual boilers for greenhouse heating and space heating (Teisen, 1987). The Danish systems are the most sophisticated. There are 59 straw fired district heating systems with a total boiler output of 220 megawatts, consuming 270,000 tons of straw a year (Centre of Biomass Activity, 1993). There are also 12,000 small straw and wood fired plants in Denmark, using 450,000 tons of straw per year. These district systems are very efficient because they provide not only electric power, but also hot water for heating buildings and water. The program is subsidized to make it possible to prevent field burning of straw. Emissions are limited by sophisticated burn management.

The larger facilities are computer controlled and utilize the large bales, 4 x 4 x 6 feet. These are stored in a warehouse where they are picked up by an automatic transport system and fed into the boiler. Costs are minimized by this automation, some operate without people on site, with emergency pagers and computer controls linked to home offices.

REFERENCES

Centre of Biomass Technology. 1993. Utilization of biofuels. CBT, Soborg, Denmark 6p

Teisen, P.H. 1987. Straw as a fuel. Farm 2000. Redditch, Worcs. UK

Rice straw harvest

Most uses for rice straw require clean straw. Harvesting should also be done in a way that removes stem rot organisms from the field and does not compact soils. The basic steps are to remove the grain, cut and dry the straw, bale it and remove it. Typically this would involve grain harvest, increasingly with stripper headers which are fast and leave the stem standing; swathing with the machine set to cut at 4-6", run against the direction the straw was harvested.

Straw should be dried for 1-2 days if the weather is clear, then windrowed and baled. The type of baler will depend on end use. This must be done in a timely manner before fields get wet, and drainage must be timed well to get fields as dry as possible for equipment operation. A tracked machine is preferred to minimize ground loading and compaction.

The ASV POSI-TRACK™ combines Kevlar reinforced rubber tracks with a hydraulic drive system to provide loading of only 1.5 pounds per square inch (much less than a human footprint) and can be run in water [ASV (800) 346-5954]. It should have enough power for swathing and baling. Modified balers and bale handlers with flotation wheels or tracks will be helpful.

If the straw is run through a conventional combine it will usually need a longer drying time (4-5 days) and the stems are more likely to be crushed and short. Alternative harvesters could include a combine/binder or binder (tying bundles of straw for environmental uses or long oriented fiber).

The straw or straw bales should be graded and stored off the ground under shelter. This may be as simple as pallets and a quality tarp, but a pole barn or shed is preferred. Bales with weed seeds, rot, or dirt should be marked and separated. Large bales are more likely to be economical. These can be rebelled at the storage site for building and other uses.

As straw burning was phased out in England two companies developed to remove straw from farmers fields. They don't pay for straw or charge for their services. Both handle about 200,000 tons of straw a year, which is stored on old WWII landing fields. Straw is baled in large Hesston balers (4'x4'x6') and then broken down to smaller bales if needed later. A sophisticated and effective home developed system of bales handlers has been created to minimize handling costs.

Processing the straw may include cleaning, sorting, slicing, flaking, orienting fiber, air classification, fractionation, milling, chopping, steam treatment, biological treatment or chemical treatment (Edwards, 1993). Slicing requires less power (Knight, 1993) and may prove more suitable for producing biocomposite materials. Various air/blower, combing, and sorting mechanisms can be used to orient fibers for use in manufacturing.

Biological processing of fibers may prove especially useful. This might require other types of storage and handling. It is possible that an inoculum might be added to the straw as it is harvested for some uses.

REFERENCES

Edwards, C. 1993. Future opportunities. Straw : A Valuable raw material. PIRA Conference, Cirincester, England 3(44):36p

Knight, A. 1993. Preparation of straw for industrial applications/straw slicing. Straw : A Valuable raw material. PIRA Conference, Cirincester, England (8):13p

Straw Bale Information Sources

All materials from Out On Bale and Black Range Films may be purchased from the UNLV Environmental Studies Program. To order contact:

Jan McAdams or Darlene Cartier
UNLV Environmental Studies Program
4505 Maryland Parkway Box 454030
Las Vegas, NV 89154-4030
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University of Nevada Las Vegas (UNLV) Environmental Studies Program Straw Bale Workshop Manual. Includes a copy of Build it With Bales, and a working bibliography.
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Environmental Studies Program
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Cost: $35.00 (includes shipping and handling)

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New Mexico Test Results of the Small Scale E-119 Fire Test on Uncoated Straw Bale Wall Panels and Stucco Coated Wall Panels and the Travers Load Test
Straw Bale Construction Association
31 Old Arroyo Chamiso
Santa Fe, NM 87505
(505) 989-4400
Cost: $25.00

New Mexico Engineer Test and Draft Building Code
Out on Bale, Ltd.
1037 E. Linden Street
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House of Straw
U.S. Department of Energy
1301 Clay Streeet
Rm 1060 North
Oakland, CA 94612
Cost: free

General Information Package
Out on Bale, Ltd.
1037 E Linden Street
Tucson, AZ 85719
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Straw Bale Construction and the Building Codes-A Working Paper
Development Center for Appropriate Technology (DCAT)
P.O. Box 41144
Tucson, AZ 85717
(502)624-6628
Cost: $10.00

The Prescriptive Code for Loadbearing and Non-Loadbearing Straw Bale Structures Adopted by Pima County and the City of Tucson
Development Center for Appropriate Technology (DCAT)
P.O. Box 41144
Tucson, AZ 85717
(502) 624-6628
Cost: $6.00

Straw Bales as a Building Element
Center for Resourceful Building Technology
P.O. Box 100
Missoula, MT 59806
(202) 289-5365
Cost: $8.00

*Earthword (*Quarterly Publication)
Eos Institute
580 Broadway Suite 200
Laguna Beach, CA 92651
(704) 497-1896

Environmental Building News (Bi-monthly newsletter)
RR1 Box 161
Brattleboro, VT 05301
(802) 257-7300

Home Energy
2124 Kittiridge Street #95
Berkely, CA 94704
(510) 524-5405

The Efficient House Sourcebook, Homemade Money; How to Save Money and Dollars in Your Home, A Primer on Sustainable Building RMI Newsletter
Rocky Mountain Institute
1739 Old Snowmass Road
Snowmass, CO 81654-9199
(970) 927-3851
Cost: $10.00

Straw Bale Building: An Introduction
By The Canelo Project
The Canelo Project
HC1 Box 324
Elgin, AZ 85611
(520) 455-5548
Cost: $5.00

Straw Bale Home Design Plans
Sustainable Systems Support
P.O. Box 318
Bisbee, AZ 85603
(520) 432-4292
Cost: $200.00-$400.00

Straw Bale House Plans
By Bob Lanning of Design and Building Consultants
19 East 15th Street
Tucson, AZ 85701
(520) 792-0873

Build it With Bales: A Step by Step Guide to Straw Bale Construction
By S. O. McDonald, Matts Myhrman (illustrations by Orion McDonald)
Out On Bale By Mail
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A Straw Bale Primer
By S.O. MacDonald
P.O. Box 58
Gila, NM 88038

Guidelines to Straw Bale Construction for the Owner/Builder
By Steve Kemble of Sustainable Systems Support
Sustainable Systems Support
P.O. Box 318
Bisbee, AZ 85603
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Cost: $10.00

A Straw Bales/Mortar House Demonstration Project
By Louis Gagne`
Housing Technology Incentives Program
Canada Mortgage and Housing Corporation
Ottawa, Ontario, Canada K1A OP7

Summary of Results of a Structural Straw Bale Testing Program
Based on master's thesis by Ghailene Bou-Ali
Summary written and illustrated by David Eisenberg with Matts Myhrman and Judy Knox
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Tucson, AZ 85719
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Structural Engineering Test Report Summary
Out on Bale-By Mail
1037 E. Linden Street
Tucson, AZ 85719
(520) 624-1673

Straw Bales and Straw Bale Wall Systems
By Ghailene Bou-Ali
Community Information Resource Center
P.O. Box 42663
Tucson, AZ 85733

Come Home to Straw Bale Construction
By Jim Peterson
Resourceful Nest
P.O. Box 641
Livingston, MT 59047
(406) 222-0557

Cut Waste, Not Trees: How to Save Forests, Cut Pollution and Create Jobs
Atossa Soltani and Penelope Whitney (editors)
San Francisco Rainforest Action Network
450 Sansome Street Suite 700
San Francisco, CA 94111
(415) 398-4404
rainforest@igc.apc.org

The Straw Bale House
By David Bainbridge, Bill and Athena Steen, and David Eisenberg
Real Goods
555 Leslie Street
Ukiah, CA 95482-5507
(800) 762-7325
Cost: $30.00

Our Home: Buildings of the Land, March 1994 HUD-1410-CPD
HUD Office of Native American Programs
451 Seventh Street SW Room B133
Washington, D.C. 20410-7000
(202) 755-0032

Straw Bale Portfolio: A Collection of Sixteen Designs for Straw Bale Houses
Out on Bale-By Mail
1037 E. Linden Street
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(520) 624-1673

VIDEOS ON STRAW BALE CONSTRUCTION

Building With Straw, Volume: A Straw Bale Workshop
By Catherine Wanek
Black Range Films
Star Rt. 2, Box 119
Kingston, NM 88042
Cost: $29.00 plus shipping and handling

Out On Bale By Mail
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How to Build Your Elegant Home With Straw Bales
By Sustainable Systems Support
Sustainable Systems Support
P.O box 318
Bisbee, AZ 85603
Cost: $59.00

Out On Bale-By Mail
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Tucson, AZ 85719
(520) 624-1673

Straw Bale Construction
By Kim Thompson
Kim Thompson
RR1 Ship Harbor
Nova Scotia, Canada BOJ 1YO
(902) 845-2750
Cost: $34.00 Canadian

Straw Bale Construction: The Elegant Solution
By Sustainable Systems Support
Sustainable Systems Support
P.O Box 318
Bisbee, AZ 85603
(520) 432-4292
Cost: $33.00

Straw Bales for Shelter
Out On Bale By Mail
1037 E. Linden Street
Tucson, AZ 85719
(520) 624-1673

Straw Bale Construction-Beautiful Sustainable Buildings
By Kim Thompson, Rod Malay, and Richard Robertson
Straw House Herbals
RR 1
Ship Harbor, Nova Scotia, Canada BOJ 1YO
(902) 845-2750
e mail: aa983@ccn.cs.dal.ca

Straw Bale Internet Resources

To Subscribe to the straw bale discussion list, send mail to: majordomo@crest.org with the message: subscribe strawbale. If you would like the digest form (only one messgage of e-mail with all the lists posts included) make the message: subscribe strawbale-digest.

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Alaska Craftsman Home Program
achp@alaska.net

David Bainbridge's Slides on Straw Bale Construction
http://solstice.crest.org/efficiency/straw_insulation/eip/Bainbridge.html

Bennett Engineering
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Center for Renewable Energy and Sustainable Technology (CREST)
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Cross Timbers Permaculture Institute
http://csf.colorado.edu/perma/

Community Eco-design Network
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Energy Efficiency and Renewable Energy Network (EREN)
ENERGYINFO@DELPHI.COM

Environmental Organization Web Directory-Sustainable Development
http://www.webdirectory.com/Sustainable_Development/

Green Sources of Construction Materials
http://www.ran.org/ran/ran_campaigns/wood_con/wood_soures.html

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Resource Guide for Straw Bale Construction
http://www.xmission.com/~shea/straw/

Rod Russell
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Gary Shea's Home Page
http://www.xmission.com/~shea/

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Solstice: Related Resources: Efficiency
http://solstice.crest.org/efficiency/sites.html

Sonoran Strawscapes
kimb@azstarnet.com

Straw Bale Construction
http://www.acs.appstate.edu/~gc11040

Straw Bale House at Swarthmore
http://www.sccs.swarthmore.edu/~ csunamil/straw.html

Straw Bale Hyperlinked Page
http://solstice.crest.org/efficiency/strawbale-list-archive/index.html

Straw Bale Mailing List Archive
http://solstice.crest.org/efficiency/strawbale-list-archive/indez.html

Straw House Herbals Home Page
http://www.cfn.cs.dal.ca/~aa983/strawhouse.html

Sustainable Works
habibg@worldtel.com

Trainer's Choice
jnak@norfolk.infi.net

Todd Woldridge
futon@peak.org

Yellow Mountain Institute
http://curry.edschool.Virginia.EDU:80/Avenue/community/environ/YellowMtn/workshop/strawbale/

Straw Bale Bibliography

Alexander, Christopher, et.al.
A Pattern Language, The Timeless Way of Building, The Production of Houses.
Oxford University Press.

Andersen, B.H. 1989
The Danish Solution to Housing Outdoor Pigs.
Pigs. May-June: 12-13.

Andersen, B.H. and P.Homegaard. 1987.
Hytter og klimatelt til alterativt svinehold
(Huts and Tents for Alternative Pig Husbandry).
5 Nov. Statens Byggesforskingstnst. (POB 119 2970, Horsholm, Denmark).

Anon. 1960 .
A Straw Bale Church in Alberta. Grassland News.
New Holland Farm Machinery.

Argue, R. 1980.
The Well Tempered Home. Renewable Energy in Canada.
Toronto, Ontario, Canada

Aronovsky, S. L. 1947.
Collection of Quality Straw for Strawboard.
Agricultural Engineering. 28 July: 309-10.

Aronovsky, S. K. and J.O. Younger
The Physical Evaluation of Straw and Other Residue Pulps, a Proposed Method.
Paper Trade Journal. May 10: 43-5.

Bainbridge, D. A. 1976.
Planning for Energy Efficiency.
Living Systems. Davis, California.

Bainbridge, D. A. 1986.
High Performance Low Cost Buildings of Straw
Agriculture, Ecosystems, Environment 16: 281-284.

Bainbridge, D. A. 1986.
Straw Bale Construction
Permaculture Journal. 24: 12-13.

Bainbridge, D. A. 1987.
Straw Bale Construction.
Poster presented at the 12th Passive Solar Conference. Portland, Oregon.
Portions appeared in the Precedings of the Conference.
American Section International Energy Society. Volume 12. pp. 250-253.
ASISES. Boulder, Colorado.

Bainbridge, D. A. 1987.
Straw Bale Construction. Working Paper Number Five.
Dry Lands Research Institute. University of California, Riverside, California.

Bainbridge, D. A. 1987.
Better Homes With Gardens
Amandla 1 (1): 8

Bainbridge, D. A. ans M. Myrhman. 1991
Straw Bale Building Systems
Solar World Congress. Denver, Colorado. Volume 3 part 1. 2611-2616.

Bainbridge, D. A., B. and A. Steen. 1993.
Plastered Straw Bale Construction.
The Canelo Project, Elgin, Arizona.

Bainbridge, D.A. 1993.
Plastered Straw Bale Construction.
Conference Proceedings: Straw-A Valuable Raw Material.
PIRA International. Leatherhead Surrey, United Knigdom. V2a. pp 34: 1-8.

Bainbridge, D.A. 1993.
An Introduction to Plastered Straw Bale Construction.
EOS Institute. Laguna Beach, California.

Bainbridge, D.A., R. Hofmeister and S. MacDonald. 1993.
Roots and Revival: Working Group Reports of the First International Straw Bale Building Conference.
Arthur, Nebraska. Out on Bale. Tucson, Arizona

Bainbridge, D. A., B. Steen, A. Steen, and D. Eisenberg. 1994
The Straw Bale House.
Chelsea Green Publishing Company. Brattleboro, Vermont.

Bainbridge, D. A. , L. Bayless, and D. Eisenberg. 1994.
Straw Bale Construction.
California Builder Magazine. June/July: 43-44.

Barden, A. A. III.
Finnish Fireplace Construction Manual.
Maine Heat Wood Company. Norridgewock, Maine.

Barre, H. J. and L. L. Sammett.
Farm Structures.
John Wiley and Sons. New York. p. 614.

Bayless, L. 1993.
EOS Institute Straw Bale Eco-house.
EOS Institute. Laguna Beach, California.

Bio-Integral Resource Center.
Least Toxic Pest Management for Termites.
Bio-Integral Resource Center (BIRC). Berkeley, California.

Bou-Ali, G. 1993.
Straw Bales and Straw Bale Wall Systems.
Masters Thesis, Engineering. University of Arizona.
Community Information Resource Center. Tucson, Arizona

Bower, J. 1991.
The Healhy House.
Carol Publishing Group.

Briggs, P. 1991.
Mortars and Finishes
Old House Journal 19 (4): 35-37.

Brower, S.N. 1988.
Design in Familiar Places: What Makes Home Environments Look Good.
Praeger, New York.

Buckingham, F. 1990.
Round Bays With Hay Quality.
Gainews, May 1992.

Butterfield, B. 1985.
The Straw Manual.
E. and F. N. Spon, London, England.

Canada Mortgage and Housing Corporation Housing Technology Incentives Program. 1984.
An Innovative Straw Bale/Mortar Building System.
Ottawa, Ontario, Canada.

Ching, F. 1991.
Building Construction Illustrated.
Van Nostrand Reinhold, New York.

Cleland, S. B. 1942.
Straw Sheds.
University of Minnesota, Extention Bulletin #227. St.Paul, Minnesota.

Cole, J., and C. Wing. 1976.
From the Ground Up.
Atlantic-Little Brown.

Cole, J., and C. Wing. 1986.
Breaking New Ground.
Atlantic-Little Brown.

Construction Bookstore.
Construction Savvy.
Construction Bookstore. Gainesville, Florida.

Creasy, R. 1982.
The Complete Book of Edible Landscaping.
Sierra Club Books, San Francisco, California.

Dadd, D. L. 1993.
Non-Toxic, Natural and Earthwise.

Darrow, K. and M. Saxenian. 1993.
Appropriate Technology Sourcebook.
Stanford, Connecticut.

Day, C. 1990.
Building With Heart.
Green Books. Devon, England.

Day, C. 1990.
Places of the Soul.
Aquarian/Thorsons (Harper Collins).

Dice, J. R. 1947.
Some Effects of Type Shelter on Dairy Cattle.
ND Agriculture Exp. Sta. Bull. 344, April.

Dickinson, D. 1986.
The Small House: An Artful Guide to Affordable Residential Design.
McGraw-Hill. New York, New York.

Dietz, A. G. H. 1991.
Dwelling House Construction (Fifth Edition).
Cambridge, Massachusettes.

Doolittle, B. 1973.
A Round House of Straw Bales.
Mother Earth News 19: 52-57.

Doughty, T. (editor). 1990.
Bales Form Emergency Bunker.
The Dakota Farmer, p. 31, April 7.

Douglas, R.J. , and L. H. Langford. 1954.
Inexpensive Winter Shelter for Hogs.
Bi-monthly Bulletin. ND Argic. Exp. Sta., 16: 4 (March-April) : 139-40

Eisenberg, D. 1995.
Straw Bale Construction and the Building Codes-a DCAT Working Paper.
Development Center for Appropriate Technology. Tucson, Arizona.

Eisenberg, D., M. Myrhman and J. Knox. 1993.
Results of a Sructural Straw Bale Testing Program.
Community Information Resource Center. Tucson, Arizona.

Ensminger and Olentine. 1978.
Feeds and Nutrition.
Ensminger Publishing Company. Clovis, California.

Everett, G. 1993.
Straw Homes.
Mother Earth News Oct/Nov. pp. 54-57, 75-76.

Extention Agricultural Engineer. 1930.
Straw Barn for Sheep or Cattle, 24' x 90. Endwall door, Plan #ND B-711.
North Dakota State University. Fargo, North Dakota.

Extention Agricultural Engineer. 1930.
Straw Barn for Cattle, 20' x 28'. Endwall door, Plan#ND B-712.
North Dakota State University. Fargo, North Dakota.

Extention Agricultural Engineer. 1934.
Straw Barn for Poultry, 20' x 20'. Endwall door, Plan # ND B-713
North Dakota State University. Fargo, North Dakota.

Extention Agricultural Engineer. 1924.
Straw Shed Demountable Roof Frame, 19' x 23'. Plank & Wire, Plan #ND B-8-11.
North Dakota State University. Fargo, North Dakota.

Extention Agricultural Engineer. 1943.
Strawbarn Farming, 28' 32'. Postbeam and Wire, ND 725-3-1. North Dakota State University. Fargo, North Dakota.

Extention Agricultural Engineer. 1943.
Straw Shed for Cattle and Sheep-Special Circular A-54.
Extention Service, North Dakota Agricultural College. Fargo, North Dakota.

Extention Agricultural Engineer. 1943.
Straw Shed for Poultry-Special Circular A-55.
Extention Service, North Dakota Agricultural College. Fargo, North Dakota.

Faller, T., D. Nudell, R. Olson, and D. Stecher. 1990.
A Shed Made From Straw Used for a Sheep Shelter.
31st Annual Western Dakota Sheep Day Report, NDSU, February.
Hettinger Resource/Extention Center. Hettinger, North Dakota.

Fanger, P.O. 1972.
Thermal Comfort.
McGraw Hill. New York.

Findlay, W. M. 1956.
Oats.
Oliver and Boyd. London, England.

Fish, C. 1988.
Straw Bale House.
Sustainable Living in Dry Lands. 2:2.

Fowler. 1900.
Nebraska School Buildings and Grounds.
State Superintendent of Schools.

Fruedenberger, R. 1993
A Straw Bale Revolution.
Backhome #13. Fall: 30-31.

Fruedenberger, R. 1993.
Standing the Test of Time.
Backhome #13. Fall: 34-35.

Gagne, L. 1986.
A Straw Bales/Mortar House Demonstration Project.
Canada Mortgage and Housing Corporation, Housing Technology Incentives Program.
Ottawa, Ontario, Canada.

Garey, C. C. 1994.
Pioneer Spirits.
Mary Emmerling's Country Magazine. August/September: 42-46.

Gergen, B. 1987.
Low Cost Calving Shed Made From Straw Bales.
Farm Show 11: 6. Lakeville, Minnesota.

Goodman, L.J., 1976.
Low Cost Housing Technology: Problems, Issues, and a Proposed Solution. Strategies for Human Settlement.
University Press of Hawaii. Hawaii.

Gordon, J. E. 1978.
Structures, Or Why Things Don't Fall Down.
Da Capo Press.

Good, C. 1988.
Healthful Houses.
Guaranty Press.

Grandjean, E. 1974.
Ergonomics of the Home.
Hallstead Press. New York, New York.

Grist, D. H. 1986.
Rice.
Longman, London.

Hageman, Jack.
Contractor's Guide to the Building Code.
Craftsman Book Company.

Haggard, K., and G. McMillan. 1993.
Straw Bale Passive Solar Construction.
Solar Today, May/June: 17-20.

Hammond, J. 1979.
Straw Bale House.
Winds of Chance, Winter (Feb/Mar) : 8
Winters, California.

Hammond, W. E. 1950.
A Survey of the Present and Potential Industrial Uses of Straw With Special Reference to Nebraska.
Nebraska Exp. Sta. Bull. No. 401. University of Nebraska. Lincoln,Nebraska.

Harland, Edward. 1994.
Eco-Renovation.
Chelsea Green Publishing Company. White River Junction, Vermont.

Harris, B. J. 1916
The Harris Directory-Recycled Content Building Materials.
Stafford-Harris Incorporated. Seattle, Washington.

Harte, H., and S. Schneider.
Toxics A to Z.

Hawes, M. 1993.
Straw and Solar: A Perfect Renewable Match.
Home Power #35, June/July: 62-66.

Hiles, H. 1930.
Hiles Circular Hanger.
Gothenberg, Nebraska.

Hop, F. 1989.
The Energy-Saving House Design Handbook: Your Super-Guide to Earth Sheltering, Solar Heating and Thermal Construction.
Prentice Hall, New York.

Ivy, R. A., Jr. 1994.
Rural Education.
Architecture, October: 62-65.

Jenkins, B. M., S.Q. Turn, and R. Williams. 1991.
Survey Documents Open Burning in the San Joaquin Valley.
California Agriculture 45 (4) : 12-16.

John Deere Service Training Department. 1983.
Hay and Forage Harvesting.
John Deere, Moline, Illinois.

Johnson, D. W. 1990.
Straw Bales Make Cheap Buildings.
Grainews. July: 25, 42-43. Winnepeg, MB.

Johnson, D. W. 1990.
Build Yourself a Low Cost Straw Bale Barn.
Farm Show 14: 2. Lakeville, Minnesota.

Johnson, D. W. 1990.
Farm Buildings Using Rectangular or Round Baled Roughage.
Paper #904550. Presented at the ASAE 1990 Winter Meeting.
American Society of Agricultural Engineers. St. Joseph, MI.

Johnson, D. W. 1990.
Old Tricks Work With New Bale Shapes.
The Dakota Farmer 108: 4 (Feb 17) : 34-35. Minneapolis, Minnesota.

Johnson, H. (editor). 1984.
Straw Bale Grain Bins.
Farm Show 8: 1-7. Lakeville, Minnesota.

Johnson, H. (editor). 1987.
Round Bale Shed.
Farm Show 11: 6. Lakeville, Minnesota.

Johnson, H. (editor). 1982.
Straw Provides Low Cost Shelter for Livestock.
Farm Show 6:1. Lakeville, Minnesota.

Kahn, L. (editor) 1973.
Shelter.
Shelter Publications.

Kay, J., D. Anthone, and R. Kay. 1990.
Nebraska Historic Building Survey of Arthur County.
Nebraska State Historical Society. Linclon, Nebraska.

Kern, K. 1975.
The Owner Built Home.
Charles Scribner and Sons. New York, New York.

Kidder, T. 1985.
House.
Houghton Mifflin, Boston.

Kilpatrick, J. 1989.
Understanding House Construction.
Home Builder Press of NAHB, Washington, D.C.

Koel, L. 1985.
Carpentry.
American Technical Publishers Incorporated. Alsip, Illinois.

Laporte, R. 1992.
Mooseprint.
Natural House Building Center.

Lathrop, E. C. 1947.
Economics of Straw Utilization.
Agricultural Engineering 28 (July) : 308-10. St. Josephs, MI.

Leonard, W. H., and J. H. Martin. 1963.
Cereal Crops.
MacMillan anc Company. New York.

Leclair, K., and D. Rousseau. 1993.
Environmental by Design.
Vancouver, British Columbia, Canada.

Levy, M. and M. Salvadori. 1992.
Why Buildings Fall Down: How Structures Fail.
W.W. Norton, New York.

Lofton, R.E. 1930.
The Physical Structure of Cornstalks and Wheat Straw.
Paper Trade Journal. 91 (July) : 39-44. TAPPI Section.

Loken, S. 1991.
Resource Efficient Building Materials.
Center for Resopurceful Building Technology. Missoula, Montana.

Loken, S. 1994.
Guide to Resource Efficient Building Elements.
Center for Resourceful Building Technology. Missoula, Montana.

Long, J.T., W.D. Taylor, and T.W. Berry. 1978.
Hay Harvesting Costs in Texas. Texas Agricultural Extention Service Publication B-1171.
College Station, Texas.

MacDonald, S. O. 1991.
A Straw Bale Primer.
Gila, New Mexico.

MacDonald, S. O., and M. Myhrman. 1994.
Build It With Bales-A Step-By-Step Guide to Straw Bale Construction.
Inhabitation Services. Gila, New Mexico, or Out On Bale. Tucson, Arizona.

Mazria, E. 1979.
The Passive Solar Book: A Complete Guide to Passive Home, Greenhouse, and Building Design.
Rodale Press, Emmaus, Pennsylvania.

McDonough, M. 1994.
Eco-Materials.
Metropolitan Home: March/April: 88-89.

McElderry, W., and C. 1979.
Happiness is a Hay House.
Mother Earth News 58: 40-43.

Means, R. E. and J.V. Parcher. 1958.
Foundations for Small Houses in Oklahoma. Engineering Experiment Station Publication 99.
Oklahoma State University, pp. 54, 55.

Merritt, F. S. and J. T. Ricketts. 1994.
Building Design and Construction Handbook.
McGraw-Hill, New York.

Midwest Plans Service.
Designs for Glued Trusses.
Iowa State University. Ames, Iowa.

Mishler, C. (editor).
Rural Builder.
24 (1 Jan) : 94, 103. Krause Publications. Iola, WI.

Mollison, B. C. 1991.
Introduction to Permaculture.
Tagari Publishing, Tyalgum, Australia.

Morrison, F. B. 1957.
Feeds and Feeding.
22nd Edition. Morrison Publishing Company. Ithaca, New York.

Myhrman, M. 1989.
We Just Sort of Stood the Hayfield Up On End.
Earthcare, the Journal of Amaterra.

Myhrman, M. 1990.
Hay, Hay! Could This be the Answer to the Housing Problem?
Green Revolution, 47(2): 1-3.
School of Living. Cochranville, Pennsylvania.

Myhrman, M. 1990.
One Man's Straw Bale Odyssey.
Permaculture Drylands Journal, 10; 8-9, 13.

Myhrman, M. 1990.
Annotated Selective Bibliography.
Out On Bale. Tucson, Arizona.

Myhrman, M. 1991.
Straw Bale Update: Into the Mainstream.
Permaculture Drylands Journal, 14: 3-5.
Education and Research Institute. Tucson, Arizona.

Myhrman, M. 1993.
First Aid Kit for PSB Construction.
Out On Bale. Tucson, Arizona.

Myhrman, M., and S. O. MacDonald. 1994.
Straw Bale Building.
Out On Bale. Tucson, Arizona.

Nisson, J. D. , G. Dutt. 1985.
The Super-insulated Home Book.
John Wiley, New York.

Noble, Allen G. 1984.
Wood, Brick, and Stone the North American Settlement Landscape.
Volume 2: Barns and Farm Structures.
University of Massachusettes Press, Amherst.

Oertega, A. M. 1991.
Sustituyen Los Ladrillos Con Paja De Trigo!
El imparcial April 20. Hermasillo, Sonora, Mexico.

Ostrowski, H., J. Ostrowski, and T. Argento.
The BREBS Project: Straw Bale Rammed Earth Passive Solar Bed and Breakfast.
Alternative and Conservation Energies, Inc. Calgary, Alberta, Canada.

Ott, J. N.
Health and Light.

Passive Solar Industries Council.
Passive Solar Design Strategies.

Pearson, D. 1989.
The Natural House Book.
Simon and Schuster.

Potts, M. 1993.
The Independent Home.
Real Goods. Chelsea Press.

Promersberger, W. J. 1945.
A Possible Use for North Dakota Straw.
North Dakota Agric. Exp. Sta. 8 (1) Sept-Oct: 14.

Reveley, R. 1993.
The Song-dog Story.
Backhome #13, Fall: 32-33.

Reveley, R. 1993.
Standing the Test of Time.
Back Home #13, Fall; 32-33.

Reynolds, M. 1991
Earthship, Volume II: Systems and Components.
Solar Survival Press, Taos, New Mexico.

Ridder, P. 1993.
Building With Straw Bales.
Small Farmers Journal. Winter 17 (1): 72.

Rosenfeld, E. 1994.
The First Little Pig's Revenge-Straw Buildings Make a Comeback.
A1Architect, #1: cover and p. 12.

Roskind, R. 1983.
Before You Build
Ten Speed Press. Berkeley, California

Sardinsky, R. and The Rocky Mountian Institute. 1992
The Efficient House Sourcebook.
The Rocky Mountain Institute. Old Snowmass, Colorado.

Scott, L. and W.C. Scott. 1976.
Recollections of Sheridan County Nebraska.
Sheridan County Historical Society. Rushville, Nebraska. pp. 586-589.

Schaeffer, J. (editor)
Alternative Energy Sourcebook.
Real Goods Trading Corporation. Ukiah, California.

Sheppard, J. H. 1920.
Grass Fat Cattle Warmed Up On Corn Fodder With a Straw Shed As Shelter.
North Dakota Agric. Exp. Sta. Bull. 140, NDSU. Fargo, North Dakota.

Shurcliff, W. 1982.
Super-insulated Houses.
Brickhouse. Andover, Massachusettes.

Smith, M. 1989.
Baled Hay Houses. Arthur County's 75 Years of History, Homesteaders and Homemakers.
Arthur County Historical Society Book Committee. Arthur, Nebraska. pp. 44-45.

Soltani, Atossa and Penelope Whitney (editors)
Cut Waste, Not Trees: How to Save Forests, Cut Pollution and Create Jobs.
San Francisco Rainforest Action Network. San Francisco, CA

Sorenson, D. 1982.
Hog Barn Built With Straw Bales.
Farm Show. 6 (6) : 21.

Sparks, W. C., G. McMaster, J.E. Dixon, D.W. Works, and E.B. Wilson. 1963.
Idaho Potato Storages-Construction and Management.
Idaho Agric. Exp. Sta. Bull. No. 410. University of Idaho. Moscow, Idaho.

Stahl, B.F., and J.L. Smith. 1947.
Treatment for Prevention of Decay in Stacked Straw.
Paper Trade Journal, 125 (24 Dec. 11) : 52-4.

Stiak, J. 1989.
Farmers Playing With Fire.
Sierrra 74 (2) : 92, 93.

Strang, G. 1985.
Straw Bale Studio.
Fine Homebuilding, 12/84-1/85: 70-72.

Stultz, R. 1981.
Appropriate Building Materials.
Intermediate Technology Publications. London, England.

Taylor, R. 1967.
Potato Cellar A -Frame Type, Plan No. 734-21.
Agricultural Engineering. University of Idaho, Moscow, Idaho.

Tibbets, J. M. 1989.
The Earthbuilders' Encyclopedia.
Southwest Solaradobe School.

Tilley, R. D. 1991.
Blueprint for Survival.
Architecture. May: 64-71.

Tonneson, L. 1987.
Low Cost Shelters From Big Round Bales.
The Dakota Farmer, November 7. Minneapolis, Minnesota.

Vale, B. and R. 1991.
Green Architecture.
Little Brown and Company.

Van der Ryn, S. and P. Calthorpe. 1986.
Sustainable Communities.
Sierra Club.

Van Dresser, P. 1976.
A Landscape for Humans.
Lightning Tree. Santa Fe, New Mexico.

Velonis, E. 1984.
Rubble-trench Foundations.
Fine Homebuilding, 12/93-1/84: 66-68.

Venolia, C. 1988.
Healing Environments.
Celestial Arts.

Wallace, A. G. B. 1984.
Thatching.
Fine Homebuilding. August/September: 72-77.

Warren, J. 1984
Building a Fortune
Garnet Publishing Company, Spokane, WA.

Welsch, R. L. 1970.
Sandhill Baled Hay Construction.
Keystone Folklore Quarterly, 15 (1) : 16-34.

Welsch, R. L. 1973.
Baled Hay.
Shelter Publications. Bolinas, California. p. 70

Webster, D. 1977.
How to Save Money When You Build Your Own House: A Guide for People Who Want to Build Their Own House on a Limited Budget.
Traingle Publishing. Rose Hill, Kansas.

Wing, C. 1979.
From the Walls In.
Atlantic-Little Brown.

Wing, C.
House Warming.
Atlantic-Little Brown.

Wright, F. L. 1970.
A Suitable Foundation.
The Natural House. Horizon Press. p. 141.

Wylde, M., A. Baron-Robbins, and S. Clark. 1993
Building for a Lifetime: The Design and Construction of Fully Accessible Homes.
The Taunton Press. Newton, Connecticut.