COMMUNITY GEOTHERMAL TECHNOLOGY PROGRAM

EXPERIMENTAL LUMBER DRYING KILN

Conducted by

King Koa

Principal Investigators:

Denver Leaman

Bill Irwin

October 1989

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EXPERIMENTAL LUMBER DRYING KILN

**Final Report
Submitted to the
Community Geothermal Technology Program**

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King Koa

**Principal Investigators:
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Bill Irwin**

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PREFACE

This is a report of work performed for the Community Geothermal Technology Program, a small grant program administered jointly by the Hawaii Natural Energy Institute and the State of Hawaii Department of Business, Economic Development and Tourism.

This project was one of five funded under the pilot phase of the program. The grantees all began in 1986 and completed their work between October 1987 and April 1988. Funds for the pilot phase were provided by the U.S. Department of Energy and the County of Hawaii.

The five Community Geothermal Technology Program projects were the first attempts to make direct use of geothermal heat and by-products in Hawaii. The success of these five grants has encouraged others to consider the use of geothermal energy in their businesses. A second round of grants was awarded in early 1988 and will demonstrate further applications of geothermal heat, brine, and silica.

The opinions expressed in this report are those of the author, and are not necessarily shared by the program administrators, funding agencies, or others involved in the program. Responsibility for the accuracy of the data provided in this report lies with the author.

The enthusiasm, talents, and efforts of the grantees are much appreciated, and I look forward to continuing to work with them and with future recipients of grants from the Community Geothermal Technology Program.

Andrea Gill Beck, Administrator
Community Geothermal Technology Program

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I. INTRODUCTION

A. Background

KING KOA is a partnership engaged in the manufacture of koa wood products. King Koa has been manufacturing products on the Big Island for about six years. Their products are sold in art and craft galleries and fine gift shops throughout Hawaii and in selected stores on the mainland. King Koa's product line includes designer cutting boards and kitchen accessories, furniture, laminated butcher-block counter tops, and hardwood sales. King Koa also offers an automated sanding service to the local wood-working trade.

WILLIAM IRWIN is a partner in King Koa. Bill has knowledge of the woodwork-ing industry and experience as a journeyman electrician.

DENVER LEAMAN is a partner in King Koa. Denver has knowledge of the woodworking industry and experience as a computer programmer.

King Koa learned of the geothermal grant program through the local newspapers. The partnership's production shop was located about three miles from the Natural Energy Laboratory of Hawaii Authority (NELHA) Puna Geothermal Facility, and the use of low-cost steam from this laboratory seemed to be a good opportunity to expand its use of lower priced green and air-dried lumber. By drying its own lumber King Koa could guarantee the quality of its product and reduce material expenditures.

King Koa proposed this experiment for several different reasons. It had been relying on a dehumidifier in a space with a capacity of only about 200 to 250 board feet (BF) to dry the lumber used in the manufacture of its products to equilibrium moisture content (EMC) levels that allowed production of a stable and consistent product for distribution outside Hawaii. This space was not large enough to handle the amount of lumber required for King Koa to keep up its flow of products.

King Koa also saw the need for a reliable, large-scale means of drying thousands of board feet at a time on the island of Hawaii. There are several small-scale dry kiln systems on the island, but none of these existing kilns can handle commercial traffic, and lumber producers and woodworkers continue to rely on private means of drying the lumber that they need.

B. Goals and Objectives

The goals of this project were threefold:

1. To demonstrate the feasibility of using the geothermal waste effluent from the HGP-A well, located at the NELHA Puna Geothermal Facility, as a heat source for a kiln operation to dry locally grown hardwoods;
2. To develop preliminary drying schedules for the proper drying of Hawaiian grown hardwoods; and
3. To develop automatic systems to monitor and control the geothermally heated lumber dry kiln systems.

King Koa proposed accomplishing these goals by constructing an approximately 1,000 BF lumber dry kiln with a computer controlled operating system at the NELHA laboratory, Noi'i O Puna. By keeping measurements of radial (across the rings) and tangential (parallel to the rings) shrinkage and drying-induced defects (i.e., checking and case hardening) in local hardwoods, preliminary drying schedules could be developed.

C. Importance of Kiln Drying

The use of wood-drying kilns allows timber to be processed in a much shorter time with a more consistent result than with air drying. The use of the kiln also allows the finished wood to be taken to a much lower moisture content than if it were air dried. This is an important factor to persons making products in Hawaii to be sold to sources on the mainland.

The equilibrium moisture content (EMC) of the lumber, or the moisture level to which the lumber will stabilize and cease to lose water to the atmosphere, is much lower on the mainland, especially in the winter. If the lumber is air dried to EMC in Hawaii, it will never go much lower than 10 to 11 percent moisture content and may take as long as 18 months to dry to this level. If the products made from this lumber are subjected to a much lower EMC, as would occur outside Hawaii, then the product probably will warp, check, or crack when the wood shrinks. When the EMC is taken down to a level consistent with mainland winter EMCs (i.e., 2 to 4 percent) and then rehumidified to local EMC levels, the product will more easily gain and lose moisture. This prevents most of the problems associated with dramatic changes in EMC.

Kiln drying, however, needs to be done carefully and according to the proper schedule of temperature and relative humidity changes, or the wood may crack or warp. The following are common dry kiln defects that can be avoided, for the most part, by using a drying schedule appropriate to the specific wood being dried. Therefore, much

attention was given to determining appropriate drying schedules for local hardwoods, as discussed later in this report.

- **Surface Checks:** Failures that occur in the wood rays on the flat sawed faces of lumber.
- **End Checks:** Failures in wood rays on end grain surfaces.
- **Warp:** Distortion in shape and form because of differences in radial, tangential, and longitudinal (along the grain) shrinkage.
- **Case-hardening:** The result of drying stresses associated with shrinkage persisting when the wood is dry. The final use of the lumber determines if case-hardening is to be considered a defect. Case-hardened lumber is difficult to machine.

It is interesting that koa, which so closely resembles black walnut in density and grain structure, was not plagued by end checks as walnut is during the drying process.

II. CONCLUSION

Using automatic systems to run and monitor the lumber drying process is both technically and economically feasible. Automatic systems allow for constant monitoring of the kiln conditions with a minimum of human supervision.

The system keeps the dry kiln at optimum temperature and humidity. This allows the lumber to dry in the shortest possible time while keeping drying-induced stresses to a minimum. Lumber was dried in periods ranging from two to six weeks in the kiln, as compared to about 18 months for air drying and six to eight weeks when using King Koa's dehumidified chamber. The economic advantages of automated systems are obvious.

The use of geothermal waste effluent as a heat source to power a lumber dry kiln is feasible technically, but the economics of such a kiln depends on the availability of high temperature geothermal fluids and the use of adequate heat exchanger systems. The lumber dry kiln system at NELHA's Puna Geothermal Facility was designed to run at temperatures of 180° to 185° F. During the experiments at NELHA the dry kiln never reached these temperatures. Installation of a secondary pump in the water circulation system helped increase the kiln temperatures, but did not solve this major problem.

The use of larger, plate-type heat exchangers between the primary fluid and water circulation systems probably would solve the problem. While costing more, the efficiency gained would be essential to the economic operation of a geothermal dry kiln system.

The development of appropriate drying schedules for local hardwoods is possible, but anything other than preliminary schedules was beyond the scope of this project. The collection and drying of local hardwood samples allowed the plotting of shrinkage rates against known mainland species. After studying the drying schedules of known species with similar rates of shrinkage, a best-guess was made at developing schedules for local species. The preliminary drying schedules that were developed for *Eucalyptus robusta*, mango, monkeypod, ohia, and silk oak can be found in Appendix A, Table 1. It should be noted that these are preliminary estimates only and should not be used for commercial drying runs without first running test loads to detect any defects that could occur. King Koa is not liable for damage caused to commercial loads of lumber by use of these drying schedules.

There are several potential benefits that could result from the development of a geothermal powered dry kiln system. The first of these would be the potential for the creation of a lumber drying industry in Hawaii. Hawaii currently imports far more hardwood than it produces locally.

There are also great quantities of lumber that presently go to waste or are used in less economically beneficial ways than would be the case if the lumber were to be utilized to its full potential. Large stands of milo (*Thespesia populnea*) and ohia (*Metrosideros collina*) are commonly bulldozed when sites are developed in coastal and lowland areas in the islands.

The development of a low-cost, efficient drying operation here could allow the Big Island to become a center for the local woodworking industry by providing local craftspeople with a reliable source of kiln-dried lumber in quantities that would allow them to produce finished products on a commercial scale.

A lumber drying facility could also help expand the market for Hawaiian-made wood products by producing lumber that could be utilized in finished products to be sent to the mainland and elsewhere. The air-dried lumber produced here with its approximately 14 percent EMC is unsuitable for production of export products. Kiln-dried lumber would help improve the image of Hawaiian-made wood products.

The centralization of lumber drying using a low-cost energy source would result in a net savings of energy by eliminating some small, inefficient private kilns and by eliminating the long shipping route to mainland kilns. This would also increase the number of jobs in the local hardwood and lumber industries.

There are also possible benefits to the community in areas that do not directly relate to the woodworking or lumber industry. This would be the enhancement of the image of the geothermal resource as something other than a source of electricity. The ongoing controversy of the viability and suitability of the Big Island's geothermal resource for the large scale production of electricity for distribution to an interisland power grid has seriously eroded the public's perception of geothermal as a whole.

Although King Koa continues to endorse the concept of geothermal lumber kilns, the partnership is no longer in a position to pursue this research. It is hoped that other interested parties will investigate the potential of a commercial-scale lumber dry kiln using geothermal heat.

III. DESCRIPTION OF WORK

The NELHA dry kiln experiments contain 3 parts:

1. Development of a dry kiln,
2. Development of automatic control systems, and
3. Development of drying schedules applicable to local hardwoods.

A. Dry Kiln Development

The dry kiln chamber was built at King Koa's shop in Pahoa and transported to the NELHA site by truck.

The kiln chamber was constructed of a wooden 2-inch by 4-inch and 4-inch by 4-inch framework with the outside covered with corrugated tin. The kiln chamber was insulated with four inches of fiberglass insulation with a rating of R11 to help retard heat loss. The inside of the chamber was lined with a 6-mil plastic moisture barrier to prevent moisture inside the kiln chamber from migrating out of, or atmospheric moisture from entering, the chamber. The inside of the chamber was then covered with 1/4-inch external grade plywood.

The inside of the chamber was 12.5 feet long, 4 feet high, and 3.5 feet deep. The volume of the chamber was 175 cubic feet and could accommodate approximately 800 BF of lumber. A load of this size allowed King Koa to continue production on an uninterrupted schedule. The lumber was placed in the kiln lengthwise, and thin strips of wood were placed across the lumber at 18-inch intervals to provide space for an adequate volume of air to circulate through the lumber stock (Figure 1, Experimental Kiln Schematic).

B. Automatic Control System

Air was circulated through the kiln with a 2-1/3 horsepower Dayton #7C039 blower. Since conventional kiln schedules require a minimum 400 cubic foot per minute (cfm) airflow, this blower's rating of 900 cfm guaranteed adherence to a conventional baseline.

Figure 1. Experimental Kiln Schematic

After passing through the lumber stack, the air was returned to the blower for rewarming and recirculation through the lumber. The rewarming took place inside the return air duct. The duct contained a heat exchanger coil composed of 150 feet of 3/8-inch copper tubing fitted with radiating fins.

The hot water provided by NELHA was circulated through this heat exchanger. The water was a low pressure, fresh water loop and was not the primary geothermal fluid from the well. The secondary loop was heated by the primary geothermal fluid loop running through a marine type heat exchanger. The NELHA research facility owns and operates this primary to secondary system.

The system provided water to the kiln with temperatures ranging from 95° to 140° F, with an average temperature of 120° to 125° F.

After connecting the heat exchanger to the hot water supply, it was found that the water circulation through the kiln's heat exchanger coil was not adequate, so an additional hot water circulation pump was attached to the secondary loop to boost circulation. This booster pump helped the situation somewhat because the kiln chamber temperature increased by 5° F.

The return air duct was fitted with a small exhaust blower that was turned on when the control system determined that temperature or humidity was too high at any point in the drying cycle. This air was exhausted directly into the atmosphere.

The input air duct was fitted with a water spray unit that was triggered when the control system determined that the humidity inside the kiln chamber fell below the control level.

The heart of this dry kiln was the computer-operated control system. It was designed to be completely automatic so the kiln would need a minimum amount of supervision. A Leading Edge Model D personal computer fitted with a Strawberry Tree interface card was the controller. Omega instrumentation was used for the digital readouts from the temperature probes and relative humidity monitors. Lignomat instrumentation consisted of the electronics for LIGHUM (lumber moisture content) channel monitors, LIGHUM probes in the lumber, and cables. Other components, such as solid state switches, panel boards, meters, and cabling, were obtained from Granger, SM Industries, Thunder Scientific, Radio Shack, Elinco Electric, Worley, Opto 22, and other suppliers.

The air temperature and the relative humidity inside the kiln chamber and the moisture content of the lumber were continually monitored through probes connected to the interface system.

The moisture content of the lumber was monitored through five channels designated LIGHUM1 to LIGHUM5. These channels measured the electrical resistance of the lumber by applying a small current to twin electrodes inserted into boards at various

positions in the lumber stack. The lower the water content of a hardwood, the higher the electrical resistance becomes. This method gives accurate readings for lumber moisture content (LIGHUM) values below 60 percent.

The temperature of the internal air was measured with a standard RTD thermocouple. The electrical resistance of this thermocouple varies directly with the temperature. The system was designed to control the temperature by turning the water pump on the heat exchanger on or off.

The relative humidity inside the kiln was measured using a probe made by Thunder Scientific. The output voltage of this device is almost linear in relation to the relative humidity (Figure 2). This voltage varies from 0.545 volts at 10 percent humidity to 1.975 volts at 90 percent humidity. These values were calculated at 150° F, as this was assumed to be a mid-range value for temperature in a typical drying run. This channel is designated as RELHUM (relative humidity).

The air blower ran continuously to provide a minimum 400 cfm air flow, but its operation could be controlled by the computer.

C. Drying Schedules

Part of the process involved with trying to best-guess initial drying schedules for native hardwoods is to define some of the physical properties of these woods and compare them to known values of other hardwoods. This was accomplished by taking carefully measured 2.5-inch to 3.5-inch cubes of green lumber samples from Hawaiian woods and oven drying them to zero percent moisture content. The measurements of the dried samples were then compared, and values for radial (R) and tangential (T) shrinkage were calculated (Appendix A, Table 2). Hardwood generally shrinks about 1.5 to 2 times as much parallel to the annual rings (tangentially) as it does across the rings (radially). The shrinkage along the grain (longitudinally) is usually no more than 0.20 percent, but these values were not considered here. The average values for the shrinkages were plotted on a graph with mainland hardwoods of known values. Appendix A, Table 3 lists the mainland hardwood species for which established values of shrinkage are known. These species were used because they have kiln schedules that are well documented. Figure 3 graphs the values calculated for six hardwoods of commercial value in Hawaii plotted with the mainland species listed in Appendix A, Table 3. The results clearly show monkepod to be the most stable with shrinkage values below those of any mainland species. The wood with the greatest calculated shrinkage values was ohia.

An examination of species with similar shrinkage rates gives an approximate indication of what drying schedules to use when starting. For example, koa has a calculated radial shrinkage (R%) loss of 5.4 percent and a calculated tangential shrinkage (T%) loss of 6.1 percent. The closest hardwood on the graph is southern magnolia with an R% loss of 5.4 and a T% loss of 6.6. An examination of the physical properties of these

Figure 2. Thunder Scientific Relative Humidity Probe Output Voltages at Various Humidities

Figure 3. Comparison of Shrinkage Values for Hawaiian Hardwoods

woods shows that magnolia is much denser than koa and that a closer match would be black walnut with an R% loss of 5.5 and a T% loss of 7.8. This species' drying schedule is designated T6D4 and was chosen as an initial schedule for drying runs using koa lumber. Appendix A, Table 4 contains the initial schedule.

D. Discussion of Loads of Wood Dried

LOAD #1: The initial load run through the kiln was first air-dried to 50 percent equilibrium moisture content (EMC). The reason for this was that the chances for kiln-induced drying defects were minimized, and the lumber's moisture content (LIGHUM) values can be accurately determined by the control system only at values lower than 60 percent EMC. This partial drying allowed the proposed drying schedule to be run and monitored to see if it was going to induce gross defects that could be controlled by manipulation of the schedule. The only gross defect observed was slight case-hardening, which was caused by too rapid drying in the first day or so. This problem was resolved by a "warming up" period in which the lumber charge was brought to temperature over 48 hours. The load of 1-inch nominal koa took 15 days to finish drying.

LOAD #2: The second load through the kiln was a load of green koa that was logged from Keauhou Ranch and milled by Winkler Wood Products of Hilo. The 1-inch nominal lumber, dried to 4 percent EMC and conditioned to 6 percent EMC, took 44 days to finish. Some variation found in the final EMC could be attributed to uneven air flow inside the kiln chamber, particularly in the bottom, back layers. This problem was minimized by the addition of small muffin fans inside the chamber to increase air flow in the deficient areas. There was still a small degree of case-hardening that might have been caused by drying the lumber to 4 percent EMC. Holding the charge at increased relative humidity for one day after drying was recommended.

LOAD #3: The third load through the kiln was green 1-inch nominal koa from the same source. This load was dried to 6 percent EMC at slightly higher temperatures than the second load. This increase was caused by the addition of a secondary circulation pump to the heat exchanger system. The load was finished in 31 days and showed almost no case-hardening or other defects.

SILICA LOAD: The kiln chamber was going to be empty for about two weeks while waiting for the next charge of lumber, so it was put to other uses. A 6-mil-thick plastic liner was laid down within the kiln, and large piles of hydrated silica were loaded into the chamber. The kiln was then run at its highest temperature, and the excess moisture was dumped at regular intervals. This silica was being used by another grant project involved in glassmaking. This method of drying proved to be a good one.

LOAD #4: The fourth load of wood through the kiln was also partially air-dried before starting the run. A full load of 2-inch nominal curly koa was chosen. Curly koa is more valuable, and the continuous changes in grain direction tend to minimize potential

warping of the final product. The initial EMC of this lumber was calculated to be 65 to 70 percent. The load took 37 days to bring to a 6 percent EMC. Despite the muffin fans that were added earlier, there was some problem with uneven drying in the lower rear area inside the kiln. The design of the kiln would need to change to insure that a minimum of 400 CF of air is moving through all parts of the kiln.

LOAD #5: The fifth load through the kiln was a partial load (450 board feet) of 1-inch nominal kamani supplemented with 1-inch nominal koa to fill out the charge. This load was run through in 29 days to a 6 percent EMC value for the koa. The kamani suffered from several defects, although it was dried to usable (6 to 8 percent) EMC values. The worst of these defects was surface checking. This defect probably could be cured by increasing the relative humidity inside the kiln and by slowing the drying process somewhat. There was also a small amount of slight case-hardening that would probably not occur if the drying process were slowed.

LOAD #6: The sixth and last charge that was loaded into the kiln never finished its run. The kiln suffered a mechanical problem, and the green 2-inch nominal koa never reached an EMC level that allowed the control system to measure it accurately. A physical calculation of the EMC after a week in the kiln showed it to be about 65 to 70 percent EMC. The failure of the turbine shaft in the secondary circulation pump was caused by a lack of circulation fluid. Sometime during the first weekend of the six-day run, the secondary fluid was never turned on or was inadvertently turned off at the primary heat exchanger, and the impeller shaft and bearing overheated and failed. This terminated the experiment because the acquisition of a new secondary pump was more than time or budget allowed.

IV. PROBLEMS AND CHANGES

Many problems and design changes were encountered early in the project. The first problem encountered was with the RELHUM probe. A probe for the system was constructed from off-the-shelf electronic components and a cellulose wafer whose capacitance changed with the humidity. Initial calibration was attempted using a Styrofoam cooler as a test chamber and a light bulb as a heat source. There appeared to be a large oscillating cycle with a 24-hour period, and all attempts to stop the oscillation failed.

It was finally determined that there were electrical currents being created in the system because one end of the probe's wires was kept at room temperature, while the other end of the wires was kept at constantly higher temperatures. As the temperatures varied from day to night, so did the level of "noise" created by this temperature difference. This problem was corrected by altering the system to include the probe designed by Thunder Scientific.

A similar problem was noticed in the LIGHUM 1 to 5 channels. This problem was minimized by bundling the wires and using the shortest possible leads.

The biggest problem encountered was the lack of high temperatures inside the kiln chamber. The use of standard drying schedules as a baseline requires the temperatures inside the kiln chamber to reach a minimum of 180° to 185° F. Because the temperatures inside the kiln chamber rarely exceeded 125° F, standard tables could not be used, and a control system that operated from another standard had to be established instead.

The control of conditions inside the kiln centers on two factors that are relatively easy to measure and/or control. These are the moisture content of the lumber (LIGHUM) and the relative humidity inside the kiln (RELHUM). The temperature of the kiln was not used as a control, but was used as a reference point instead. The heat was kept at the maximum obtainable to minimize the drying times.

Using the two values, LIGHUM and RELHUM, and a data file (Appendix A, Table 5) a value can be calculated for the wet bulb depression (WETDEP) inside the kiln. The WETDEP is the net difference between the dry bulb temperature and the wet bulb temperature. It measures the amount of moisture that the air can hold at a given relative humidity. The greater the WETDEP, the more moisture the air can hold.

The EMC data file (Appendix A, Table 5) is taken from a standard dry kiln operator's manual. This file is used by the computer to find the WETDEP value inside the kiln. The file is shown as a table consisting of boxes containing two numbers each. The upper number of each pair is the relative humidity value, and the lower number is the calculated equilibrium moisture content (EMC). To read the table, first select a kiln temperature. For example, if the kiln temperature is 120° F, follow the row across the table until the value of RELHUM (the upper number) is equal to kiln conditions, i.e., 60%. The second number in the box shows the EMC value (9.7). Following the column downward yields the WETDEP value of 15° F.

By calculating the maximum WETDEP values allowed for various LIGHUM setpoints, a drying schedule was established that is independent of specific temperature values.

Using this method makes it possible to reduce a standard lumber drying schedule to two variables. For example, the drying schedule chosen for koa (T6D4) (Appendix A, Table 4) can now be written as:

LIGHUM	50%	>40%	>35%	>30%	>25%	>15%	5%
MAX WETDEP	7°	10°	15°	25°	40°	50°	44°

The control system can alter the WETDEP in two ways. By operating the spray injector, water can be added to the air inside the kiln, increasing the RELHUM, which, in effect, decreases the WETDEP. By operating the exhaust blower, the WETDEP can be increased by ridding the system of humidity. The flow chart (Figure 4) shows the logic sequence for the computer controls.

Figure 4. Logic Sequence for Computer Control

To find the optimum exhaust dump time to rid the kiln of excess moisture, test dumps were run. On opening the kiln, both the RELHUM and the kiln temperature fell. The maximum drop occurred between two and four minutes after opening the kiln. After four to five minutes the temperature continued to fall slowly while the RELHUM stabilized. These experimental exhausts showed that five minutes was the longest dump time that could be used to maximize the amount of humidity exhausted while minimizing the temperature loss inside the kiln.

Some problems involved with the low temperatures inside the kiln were solved by installing a hot water booster pump on the secondary water loop, but another approach is needed to resolve this situation completely.

The temperature output from NELHA's primary heat exchanger decreased gradually as the experiment continued, probably because of fouling with precipitated silica. The use of larger, high volume, plate type heat exchangers probably would solve all the problems associated with the low temperatures achieved.

There was also a problem with maintaining a constant heat output from the primary heat exchanger. Figure 5 displays kiln conditions during the four-day run of 2-inch koa from load #4. The fluctuations in temperature could be caused by changes in flow from the geothermal well or from variations in demand at the secondary heat exchanger because more than one project was using this source. Despite this fluctuation, the efforts to dry lumber were still successful. If a larger heat exchanger were used, a more efficient method of moisture dumping from the kiln were found, and better air flow inside the kiln could be developed, then the variation of monitored conditions in the kiln could be minimized. This would greatly increase the effectiveness of the kiln.

There were also problems with uneven drying in the back, bottom areas inside the kiln chamber. This problem could be corrected by using a larger blower and by installing secondary fans and baffles in the rear of the chamber.

There was a small problem with condensation of water in the exhaust duct. Although this did not affect the drying process, it did raise questions about future designs. The use of more insulation on the duct would minimize this condensation.

Future kiln construction could benefit by using this condensation process. A small, finned heat exchanger with cold water circulating through the coil would be a much better way to remove moisture from the kiln without losing the heated air that is moving through the chamber. A catch tray and drain hose would then allow for the removal of the water to a drain.

There was a problem with the spray injection system compromising the temperature readings. The mist entering the return air duct would get onto the RTD thermocouple and

**Figure 5. Kiln Conditions Over a Four-Day Run
(two-hour average values)**

BUDGET SUMMARY

Cost Category	Amount from Grant Funds	Amount from Cost-Share	Total
SALARIES			
Bill Irwin & Denver Leaman @ \$15/hr	\$0.00	\$5175.00	\$5175.00
Subtotal	\$0.00	\$5175.00	\$5175.00
EQUIPMENT			
Computer (Leading Edge)	\$1,581.84	\$0.00	\$1,581.84
Interface (Strawberry Tree)	883.40	0.00	883.40
Instrumentation (Omega)	969.40	0.00	969.40
Instrumentation (Lignomat)	1033.05	0.00	1033.05
Air circulation blower	630.34	0.00	630.34
Instrumentation (other: cables, switches, meters, etc.)	1,072.76	0.00	1,072.76
Subtotal	\$6,170.79	\$0.00	\$6,170.79
SUPPLIES & MATERIALS			
Kiln chamber (lumber, metal, insulation, plastic sheeting)	\$915.50	\$0.00	\$915.50
Electrical supplies	896.17	0.00	896.17
Heat exchanger & plumbing	481.18	0.00	481.18
Programming materials	101.00	64.18	165.18
Office supplies	39.45	0.00	39.45
Lumber for drying	1,535.00	3,000.00	4,535.00
Subtotal	\$3,968.30	\$3,064.18	\$7,032.48
OTHER COSTS			
Administration	\$0.00	\$215.01	\$215.01
Insurance	455.00	0.00	455.00
Shipping	205.91	0.00	205.91
Subtotal	\$660.91	\$215.01	\$875.92
TOTAL	\$10,800.00	\$8,454.19	\$19,254.19

lower the temperature reading because of evaporative heat loss. Moving the spray injector to a point before the heating coils in the air duct would keep the spray off the thermocouple and allow for more rapid evaporation of the injected mist.

The final problem was the corrosion of the equipment, in particular the electronics, due to the presence of H_2S in the air in and around the Noi'i O Puna laboratory. Loss of data on several channels on several occasions was traced to corrosion and corrected. This problem was dealt with by adding a 4-inch diameter PVC intake duct filled with activated charcoal to the top of the control case. A small exhaust blower attached to the end of the case created a negative pressure inside the chamber so air inside the control case was pulled through the duct. The activated charcoal removed the H_2S and minimized the corrosion. Colortec H_2S detector tags were used to monitor exposure to hydrogen sulfide inside the control case. Very little H_2S was detected after the installation of the charcoal filter, and corrosion was virtually eliminated. It was also necessary to repaint the blower motor and duct housings because they experienced severe corrosion. This did not threaten their function but showed the need for good corrosion protection in the geothermal environment.

V. FINANCIAL STATEMENT

The equipment purchased with Community Geothermal Technology Program grant funds included the Leading Edge computer, Strawberry Tree interface, instrumentation, and the air circulation blower. Ownership of the equipment remains with the Community Geothermal Technology Program; it was left at Noi'i O Puna for use in further geothermal research.

The kiln itself was constructed by King Koa with supplies purchased as part of the grant. Therefore, the kiln belongs to King Koa. However, since King Koa will not be able to pursue further research into geothermal dry kilns, ownership of the kiln itself has been transferred to NELHA's Puna Geothermal Facility, for use at Noi'i O Puna with other research projects.

The project budget summary follows.

Appendix A Tables

Table 1. Preliminary Drying Schedules for Five Hardwoods

Note: These are best-guess estimates and are not to be used for commercial drying runs without first running test loads to detect defects.

EUCALYPTUS
(*Eucalyptus robusta*)
T7D3

STEP #	TEMP STEP #	WETDEP STEP #	LIGHUM % AT STEP	KILN TEMP °F	WETDEP °F	WETBULB °F
1	1	1	>50	130	5	125
2	1	2	50	130	7	123
3	1	3	40	130	11	119
4	1	4	35	130	19	111
5	2	5	30	140	35	105
6	3	6	25	150	50	100
7	4	6	20	160	50	90
8	5	6	15	160	50	90
9		EQU	min=4	160	43	117
10		CON	max=6	160	13	147

MANGO
(*Mangifera indica*)
T6C3

STEP #	TEMP STEP#	WETDEP STEP#	LIGHUM% AT STEP	KILN TEMP °F	WETDEP °F	WETBULB °F
1	1	1	>40	120	5	115
2	1	2	40	120	7	113
3	1	3	35	120	11	109
4	2	4	30	130	19	111
5	3	5	25	140	35	105
6	4	6	20	150	50	100
7	5	6	15	180	50	130
8		EQU.	min=4	180	44	136
9		CON.	max=6	180	12	168

Table 1. Preliminary Drying Schedules for Five Hardwoods (cont.)

MONKEYPOD
(*Pithecellobium saman*)
T4F4

STEP #	TEMP STEP#	WETDEP STEP#	LIGHUM% AT STEP	KILN TEMP °F	WETDEP °F	WETBULB °F
1	1	1	>70	110	7	103
2	1	2	70	110	10	100
3	1	3	60	110	15	95
4	1	4	50	110	25	85
5	1	5	40	110	40	70
6	1	6	35	110	50	60
7	2	6	30	120	50	70
8	3	6	25	130	50	80
9	4	6	20	140	50	90
10	5	6	15	180	50	130
11	EQU.		min=4	180	44	136
12	CON.		max=6	180	12	168

OHIA
(*Metrosideros collina*)
T8C4

STEP #	TEMP STEP#	WETDEP STEP#	LIGHUM% AT STEP	KILN TEMP °F	WETDEP °F	WETBULB °F
1	1	1	>40	130	7	123
2	1	2	40	130	10	120
3	1	3	35	130	15	115
4	2	4	30	140	25	115
5	3	5	25	150	40	110
6	4	6	20	160	50	110
7	5	6	15	180	50	130
8	EQU.		min=4	180	44	136
9	CON.		max=6	180	12	168

Table 1. Preliminary Drying Schedules for Five Hardwoods (cont.)

SILK OAK
(*Grevillea robusta*)
T10E4

STEP #	TEMP STEP#	WETDEP STEP#	LIGHUM% AT STEP	KILN TEMP °F	WETDEP °F	WETBULB °F
1	1	1	>60	140	7	133
2	1	2	60	140	10	130
3	1	3	50	140	15	125
4	1	4	40	140	25	115
5	1	5	35	140	40	100
6	2	6	30	150	50	100
7	3	6	25	160	50	110
8	4	6	20	170	50	120
9	5	6	15	180	50	130
10	EQU.		min=4	180	44	136
11	CON.		max=6	180	12	168

Abbreviations:

TEMP	=	Temperature
WETDEP	=	Wet bulb depression inside the kiln, the net difference between the dry bulb temperature and the wet bulb temperature
LIGHUM	=	"Lignin humidity," the moisture content of the lumber, measured by electrical resistance
KILN TEMP	=	Dry bulb temperature inside the kiln
EQU.	=	Equalizing treatment to bring pieces to a nearly uniform LIGHUM
CON.	=	Conditioning treatment to relieve drying stresses

Table 2. Radial and Tangential Shrinkage for Six Hardwoods

EUCALYPTUS
(*Eucalyptus robusta*)
5 samples/3 trees

INCHES	R LOSS	T LOSS	R% LOSS	T% LOSS
3.125	0.188	0.331	6.016	10.592
3.125	0.192	0.335	6.144	10.720
3.000	0.183	0.319	6.100	10.633
2.500	0.150	0.266	6.000	10.640
2.500	0.151	0.263	6.040	10.520
AVERAGE			6.060	10.621

KOA
(*Acacia koa*)
16 samples/4 trees

INCHES	R LOSS	T LOSS	R% LOSS	T% LOSS
3.500	0.184	0.214	5.257	6.114
3.500	0.186	0.218	5.314	6.228
3.500	0.185	0.216	5.285	6.171
3.500	0.184	0.215	5.257	6.142
3.500	0.187	0.218	5.342	6.228
3.500	0.189	0.220	5.400	6.285
3.000	0.164	0.184	5.466	6.133
3.000	0.163	0.181	5.433	6.033
3.000	0.161	0.183	5.366	6.100
3.000	0.162	0.183	5.400	6.100
3.000	0.162	0.176	5.400	5.866
3.000	0.160	0.171	5.333	5.700
2.750	0.154	0.167	5.600	6.072
2.750	0.152	0.170	5.527	6.181
2.750	0.153	0.168	5.563	6.109
2.750	0.150	0.166	5.454	6.036
AVERAGE			5.399	6.095

MANGO
(*Mangifera indica*)
6 samples/2 trees

INCHES	R LOSS	T LOSS	R% LOSS	T% LOSS
3.000	0.085	0.176	2.833	5.866
3.000	0.086	0.175	2.867	5.833
3.000	0.084	0.174	2.800	5.800
2.750	0.081	0.164	2.945	5.963
2.750	0.083	0.163	3.018	5.927
2.750	0.080	0.163	2.909	5.927
AVERAGE			2.895	5.886

Table 2. Radial and Tangential Shrinkage for Six Hardwoods (cont.)

MONKEYPOD
(*Pithecellobium saman*)
8 samples/1 tree

INCHES	R LOSS	T LOSS	R% LOSS	T% LOSS
3.000	0.071	0.136	2.366	4.533
3.000	0.074	0.140	2.466	4.666
3.000	0.072	0.139	2.400	4.633
3.000	0.071	0.137	2.366	4.566
3.000	0.069	0.134	2.300	4.466
3.000	0.070	0.135	2.333	4.500
3.000	0.073	0.139	2.433	4.633
3.000	0.072	0.135	2.400	4.500
AVERAGE			2.383	4.562

OHIA
(*Metrosideros collina*)
5 samples/2 trees

INCHES	R LOSS	T LOSS	R% LOSS	T% LOSS
3.000	0.208	0.365	6.933	12.166
3.000	0.206	0.362	6.866	12.066
3.000	0.205	0.363	6.833	12.100
3.500	0.242	0.424	6.914	12.114
3.500	0.239	0.425	6.828	12.142
AVERAGE			6.875	12.118

SILK OAK
(*Grevillea robusta*)
6 samples/1 tree

INCHES	R LOSS	T LOSS	R% LOSS	T% LOSS
3.125	0.083	0.240	2.66	7.68
3.125	0.084	0.239	2.69	7.65
3.125	0.086	0.244	2.75	7.81
3.125	0.085	0.242	2.72	7.74
3.125	0.083	0.239	2.66	7.65
3.125	0.086	0.244	2.75	7.81
AVERAGE			2.705	7.723

Abbreviations

R LOSS = Radial shrinkage (inches)
T LOSS = Tangential shrinkage (inches)
R% LOSS = Percentage of radial shrinkage
T% LOSS = Percentage of tangential shrinkage

Table 3. Mainland Hardwood Species Shrinkage Values

SPECIES	DRIED TO 0 PERCENT MOISTURE CONTENT		SPECIES	DRIED TO 0 PERCENT MOISTURE CONTENT	
	Radial Shrinkage	Tangential Shrinkage		Radial Shrinkage	Tangential Shrinkage
Alder, red	4.4	7.3	Locust, black	4.6	7.2
Apple	5.9	10.5	Madrone, Pacific	5.6	12.4
Ash:			Magnolia, southern	5.4	6.6
Black	5.0	7.8	Mahogany	3.6	5.0
Green	4.6	7.1	Maple:		
White	4.8	7.8	Black	4.8	9.2
Aspen:			Red	4.0	8.2
Bigtooth	3.3	7.9	Silver	3.0	7.2
Quaking	3.5	6.7	Sugar	4.9	9.5
Basswood, American	6.6	9.3	Oak:		
Beech, American	5.1	11.0	Black	4.5	9.7
Birch:			Bur	4.4	8.8
Paper	6.3	8.6	California black	3.6	6.6
Sweet	6.5	8.5	Chestnut	5.5	9.7
Yellow	7.2	9.2	Live	6.6	9.5
Buckeye, yellow	3.6	8.1	Oregon white	4.2	9.0
Butternut	3.4	6.4	Pin	4.3	9.5
Catalpa, northern	2.5	4.9	Northern red	4.0	8.2
Cherry, black	3.7	7.1	Scarlet	4.6	9.7
Chestnut, American	3.4	6.7	Southern red	4.5	8.7
Cottonwood, black	3.6	8.6	Swamp chestnut	5.2	10.8
Dogwood, flowering	7.4	11.8	Swamp red	5.5	10.6
Elm:			Water	4.2	9.3
American	4.2	9.5	White	5.3	9.0
Rock	4.8	8.1	Willow	5.0	9.6
Slippery	4.9	8.9	Persimmon, common	7.9	11.2
Hackberry	4.8	8.9	Sweetgum	5.2	9.9
Hickory:			Sycamore, American	5.1	7.6
Mockernut	7.8	11.0	Tupelo:		
Pignut	7.2	11.5	Black	4.4	7.7
Shagbark	7.0	10.0	Water	4.2	7.6
Shellbark	7.6	12.6	Walnut, black	5.5	7.8
Holly, American	4.8	9.9	Willow, black	2.6	8.1
Hophornbeam, eastern	8.5	10.0	Yellow poplar	4.0	7.1
Laurel, California	2.9	8.5			

Table 4. Initial Koa Schedule (T6D4)

STEP #	TEMP STEP#	WETDEP STEP#	LIGHUM% AT STEP	KILN TEMP °F	WETDEP °F	WETBULB °F
1	1	1	>50	120	7	113
2	1	2	50	120	10	110
3	1	3	40	120	15	105
4	1	4	35	120	25	95
5	2	5	30	130	40	90
6	3	6	25	140	50	90
7	4	6	20	150	50	100
8	5	6	15	180	50	130
9	EQU.		min=4	180	44	136
10	CON.		max=6	180	12	168

Abbreviations:

TEMP	=	Temperature
WETDEP	=	Wet bulb depression inside the kiln, the net difference between the dry bulb temperature and the wet bulb temperature
LIGHUM	=	"Lignin humidity," the moisture content of the lumber, measured by electrical resistance
KILN TEMP	=	Dry bulb temperature inside the kiln
EQU.	=	Equalizing treatment to bring pieces to a nearly uniform LIGHUM
CON.	=	Conditioning treatment to relieve drying stresses

Appendix B

Photographs

William Irwin and Denver Leaman in front of experimental kiln at Noi'i O Puna.

Experimental Geothermal Lumber Drying Kiln: A) A load of 2" koa lumber in kiln chamber, B) Monitor and control section, C) Air input duct.

Experimental Geothermal Lumber Drying Kiln: A) Kiln chamber, B) Monitor and control system, C) Heat exchanger and air circulation system.

Heat Exchanger and Air Circulation System: A) Heat exchanger, B) Blower, C) Input air duct, D) Return air duct, E) Exhaust blower, F) Water spray unit, G) Temperature probe, H) Hot water circulation pump.

Monitor and Control System: A) Computer, B) Electrical-mechanical control section, C) Temperature and moisture probe section, D) Charcoal air stack.

Monitor and Control System: A) Computer keyboard, B) Electrical-mechanical control section for the blower, heat exchanger, exhaust blower, and spray unit, C) Temperature probe, D) Relative humidity probe, E) Lumber moisture content probes, F) Low voltage power supply for sensor probes.

END

DATE

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3/24/94