A number of studies comparing solar kilns with air drying yards have been performed which concentrate primarily on 1) reduction of drying times and 2) lower final moisture contents (Sharma, 1972; Casin et al., 1969; Maldonado, 1962; Peck, 1962). Most of these studies are conducted in small scale greenhouse type solar kilns, rarely exceeding capacities of 1000 board feet. A very important consideration before these dryers can be used in large commercial operations is their overall economics.

It is the purpose of this paper to examine the costs of solar dry kilns on a commercial scale, using greenhouse type dryers. More specifically, major costs involved are examined and discussed and those areas where the greatest economical potential for improvements may be found are identified.

An example operation is required in order to assess the monetary implications. The drying operation assumed dries 30 million board feet per year of softwood dimension material having an initial moisture content of 100% and a desired final moisture content of 19% or less. The operation consists of those processes shown in Figure 1.

Drying times for solar kilns are dependent on kiln location, species dried and their corresponding thicknesses. In an attempt to use as unbiased drying times as possible the following procedure was followed. Drying times from studies comparing greenhouse type solar drying with air drying techniques were used to compute solar to air drying time ratios. Using these ratios, drying curves were determined from assumed air drying curves. The ratios used are shown in Table 1 and the resulting curves for the solar kiln are shown in Figure 2. The four curves represent the seasonal variation in drying times and therefore are dependent on the time of year lumber is placed in the solar kiln.

Additional cost data used is as follows. Labor cost for the assumed operation is based on the assumption that one hour per day will be spent for every 1.7 MBF capacity and costs $5.20 per hour including fringe benefits. The capital outlay for the solar kilns required is assumed to cost $1.00 per board foot capacity. Annual maintenance is 1.5% of the original capital outlay per year for a 20 year structure life. Electrical consumption is based on that required for conventional kiln drying at 10.5 kWh per MBF per day and costs $0.025/kWh. A 10% interest rate is used with an investment tax credit of 10% also assumed.

Surface requirements for the solar kiln roofs were also based on literature values. This information is needed to
calculate total land requirements. These values found varied widely, from 64.25 ft$^2$ to 223.47 ft$^2$/MBF. The value used, 75.42 ft$^2$/MBF, was an average of the lowest 4 values found for greenhouse type dryers. This produced a total land requirement of 6 acres when access roads are included.

Degrade costs for a drying technique such as solar drying are relatively unknown, hence an initial assumption for its value may be considered useless. Therefore initial costs examined will not include degrade values, however, after comparison with air drying and conventional kiln values a cost effective value can be determined.

The above data were used as input to a computer program discussed in an earlier paper (Smith, 1979), which was designed to determine the costs involved in drying lumber. Cost values for the air drying and conventional kiln drying techniques which were discussed in that paper, under the same mill assumptions, will be used here for comparison purposes. Oil prices from the previous results have been updated to $35.00 per barrel.

Results

The cost of drying lumber in a solar kiln under the conditions outlined above was determined for two cases, 1) using solar kilns only and 2) in combination with a conventional kiln. The results are compared with results for the air drying and conventional kiln drying techniques as shown in Table 2. As can be seen, solar drying by itself costs $45.15 per MBF as compared to $27.50 per MBF for air drying and $43.05 per MBF for drying the same lumber in a conventional kiln. This represents an increase in costs of 61.8% and 4.9% respectively. Costs of lumber dried to a moisture content of 30%, considering the use of a solar kiln as a predryer were determined to be $32.28 per MBF for the solar kiln and $21.90 per MBF for air drying. These resulted in total drying costs of $42.57 per MBF for the solar kiln-conventional kiln combination compared to $30.21 for the air yard-conventional kiln combination, a difference of 40.9% in cost.

These figures indicate that for the situation assumed, solar kiln drying is more expensive than either air drying or conventional kiln drying. Its overall cost decreases by 5.7% when used as a predryer in combination with the conventional kiln. This combination also is 1.1% lower than conventional kiln drying only. The air drying-conventional kiln combination, however, is 29.0% less than the solar kiln-conventional kiln combination which may seriously erode any advantages gained here, unless the air drying space requirements are a limitation. Solar drying requires approximately 55% less area than air drying, but 11 times more than conventional kiln drying.

When the overall cost is broken down by cost factor the major cost deterrents can be more readily identified, Figure 3. Capital investment accounts for the greatest percentage of the total cost, consuming 29.4%, followed by electricity at 21.9% and interest on lumber investment at 14.3%. These top three cost factors all show that the overall higher cost of solar
drying is due to tying up capital and lumber for relatively long periods of time. The high electricity cost stems from the same time factor since the fans are running much longer per unit dry lumber produced. The solar kiln drying time would have to be reduced 37% from that assumed for its overall cost to be competitive with air drying and 11% for it to be competitive with conventional kiln drying.

Degrade, a major cost, has not been considered as yet for reasons of uncertainty as discussed previously. Without proper documentation of values for solar drying, however, it can only be used to determine how much less degrade the solar kiln can allow with respect to that for air drying and conventional kiln drying to at least break even with these techniques. If degrade is defined as the percentage loss of a dry lumber value of $490/MBF, the solar kiln would have to have 3.5% less degrade than air drying and 0.4% less than the conventional kiln, other factors remaining the same. These values, however, cannot be considered in the predrying case since most degrade occurs below the fiber saturation point.

Summary and Conclusions

Commercial solar drying of softwood dimension lumber appears uneconomical at this time under the assumed conditions. They are more cost effective as predryers but are still not as cost competitive as air drying for this purpose. High cost areas result from the relatively long drying times required which on a per MBF basis 1) increases capital cost, 2) increases electrical consumption by fans, and 3) increases inventory cost. Degrade levels which are not known for solar kilns, would have to be substantially lower than for air drying and slightly lower than conventional kiln degrade values for the solar kiln to become cost competitive on this basis.

Decreased drying times may be realized by using solar collectors and storage techniques, but at an increased cost in capital investment. This situation, therefore, would require full examination before the true costs could be determined.

Literature Cited


Table 1. Ratio of Solar to Air Drying Times as Calculated from Drying Curves in the Literature.

<table>
<thead>
<tr>
<th>Source</th>
<th>Species</th>
<th>50%</th>
<th>40%</th>
<th>35%</th>
<th>30%</th>
<th>25%</th>
<th>20%</th>
<th>15%</th>
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</thead>
<tbody>
<tr>
<td>Peck (1962)</td>
<td>4/4 Oak</td>
<td>.596</td>
<td>.542</td>
<td>.523</td>
<td>.468</td>
<td>.477</td>
<td>.461</td>
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<tr>
<td>Sharma (1972)</td>
<td>mixture</td>
<td>--</td>
<td>1.046</td>
<td>.931</td>
<td>.666</td>
<td>.492</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sharma (1972)</td>
<td>hollong</td>
<td>--</td>
<td>.304</td>
<td>.310</td>
<td>--</td>
<td>--</td>
<td>---</td>
<td>.431</td>
</tr>
<tr>
<td>Maldonado (1962)</td>
<td>5/4 Mex. mahog.</td>
<td>.375</td>
<td>.333</td>
<td>.286</td>
<td>.267</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Casin et al. (1969)</td>
<td>Mixture</td>
<td>.651</td>
<td>.598</td>
<td>.541</td>
<td>.570</td>
<td>.558</td>
<td>.390</td>
<td></td>
</tr>
</tbody>
</table>

Mean .596 .584 .539 .490 .452 .510 .411

Table 2. Total Drying Costs Without Degrade

<table>
<thead>
<tr>
<th>Technique</th>
<th>Moisture content range</th>
<th>Cost ($/MBF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar kiln</td>
<td>100%-19%</td>
<td>45.15</td>
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<tr>
<td>Air yard</td>
<td>100%-19%</td>
<td>47.90</td>
</tr>
<tr>
<td>Conventional kiln</td>
<td>100%-19%</td>
<td>43.05</td>
</tr>
<tr>
<td>Solar kiln</td>
<td>100%-30%</td>
<td>32.28</td>
</tr>
<tr>
<td>Air yard</td>
<td>100%-30%</td>
<td>21.90</td>
</tr>
<tr>
<td>Solar kiln-Conv. kiln</td>
<td>100%-30%-19%</td>
<td>42.57</td>
</tr>
<tr>
<td>Air yard-Conv. kiln</td>
<td>100%-30%-19%</td>
<td>30.21</td>
</tr>
</tbody>
</table>
FIGURE 1. PROCESSES INCLUDED IN OPERATION

- GREEN SORT
- HOLDING YARD
- STACKING
- LOADING
- SOLAR KILN
- UNLOADING
- UNSTACKING
- SURFACING
- DRY STORAGE
Figure 2. Solar drying curves.

Figure 3. Solar kiln cost breakdown by cost factor.