Element 5: Application of Rapid Drying Technologies to Streamline the Lumber Manufacturing Process

Applying Rapid Drying Technologies to Canadian SPF Lumber

by

Peter Garrahan, Vincent Lavoie and Diego Elustondo
Research Scientists
Lumber Manufacturing Technology

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1 Objectives

This project was undertaken as part of the research initiative designed to enhance the competitiveness of softwood industry in eastern Canada. Project funding was provided through Natural Resources Canada’s Transformative Technologies Program.

It was initiated to evaluate the potential to use various rapid-drying technologies to dry Canadian SPF dimension lumber. The overall objective of the project is to demonstrate the potential to apply various rapid drying technologies to streamline the drying process and enhance the industry’s ability to target specific final MC requirements and better match this attribute to end user’s needs.

The specific working objectives were as follows:

- Conduct a literature review to identify potential technologies and identify relevant research and development conducted elsewhere in the world.
- Visit research institutes, equipment developers conducting work on rapid drying technologies of relevance.
- Prepare a summary report on the results of the literature review and investigations on current research and equipment development.
- Develop performance data through small-scale laboratory drying trials on various rapid drying technologies of interest.
- Use the performance data to estimate equipment needs and costs for full-scale industrial application.
- Conduct technical and economic pre-feasibility analyses of various rapid-drying technologies and develop a business case for the most promising option(s).
- Prepare a final report with recommendations on “go” or “no-go” for a future research project, including research requirements, projected costs, and funding opportunities.

2 Introduction and background

The softwood lumber production process can be separated into three distinct operations – sawmilling, drying and planing. The sawmilling and planing operations are highly automated and operate in a linear, continuous flow manner. By contrast, basic drying technology has not changed considerably for many years and operates in a batch process, which requires the material to be prepared into stickered packages, placed into inventory and accumulated for processing at the kilns. Drying is therefore the only part of the process where there is an interruption in the flow of material. This adds many steps to the process that increase cost and reduce the recovery of high-grade material. These steps include piling the material on stickers at the sawmill, handling of packages, carrying large inventories of material in process (rough green lumber) and rehandling material between the kilns and planer mill.

Preliminary testing of a RF-based, continuous flow drying technology in conjunction with Hydro Quebec has demonstrated some significant results for the re-drying of kiln “wets”. The results of the re-drying tests raised the possibility to apply this technology to a full “green to dry” drying operation. Other drying
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Technologies such as press drying and ultra-high temperature drying may also have the potential to dramatically reduce drying times and alter the material flow in a lumber mill. These technologies could be used on their own or in conjunction with other technologies to produce a drying rate rapid enough to be developed into an in-line (continuous flow) drying system. Other scenarios to capitalize on these rapid drying technologies will be identified in the process of the technical evaluation.

Current drying technologies inherently result in some degrade to the product. By its nature, a batch drying process will leave some pieces over-dried and other pieces still above the intended target. Procedures are available to minimize this variation but they all involve extending the drying times, which pushes up both capital and operating costs of drying. In an extensive study of industrial drying losses, conducted by FPInnovations, it was documented that almost 16% of pieces were downgraded due to drying. This is a significant and real cost of drying that is often not considered. Current drying operations also involve considerable handling of material that contributes to more losses and damage to the material. Handling and rehandling of packages results in lost and/or damaged boards, and packages that do not provide good support of individual boards during drying.

A non-batch drying process would address many of the issues identified above. There are two basic variations on non-batch lumber drying. The first would be a continuous flow system where the lumber is still arranged into stickered packages. The second would be an in-line process where the boards are singulated and processed individually. The advantage of an in-line process is that each board can be exposed to the drying conditions and drying time needed to achieve the target MC. This would therefore address the most challenging aspect of drying SPF lumber – variability due to inherent differences in the material. The intent of this project is to evaluate the potential to achieve a fully in-line drying process that would be faster than current drying technologies and able to achieve a uniform final MC.

3 Staff

Peter Garrahan Research Scientist, Co-project Leader
Vincent Lavoie Research Scientist, Co-project Leader
Diego Elustondo Research Scientist
Liping Cai Research Scientist
Marc Savard Research Scientist
Guy Labrecque Research Technician
Vit Mlcoch Research Technician
Francis Tanguay Research Technician
Louis Gravel Research Technician

4 Method

4.1 Review of potential rapid drying technologies

With the assistance of the library staff of the Wood Products Division, a review of existing literature was conducted. In conjunction with the literature review, an internet search was conducted to identify more recent work or work underway. Colleagues at other research institutes and universities were consulted to identify any work underway that would be relevant to this project. As part of this process, we became aware of work underway in Austria to develop a detailed technical review of radio frequency (RF)
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technologies as related to lumber drying. As a result of this, a visit and interview was conducted with Prof. Helmuth Resch of the University of Vienna.

A thorough review of work conducted by various equipment manufacturers was done by reviewing website information, identifying technologies of interest, and contacting individual companies. Direct contact with many of these companies was made through attendance at two major equipment exhibitions; the Atlanta International Woodworking Fair (Aug. 2008) and the LIGNA exhibition (May 2009). One equipment manufacturer, USNR, also arranged for a site visit to a mill near Augusta, Georgia that has been instrumental in developing, testing, and implementing a form of continuous dry kiln. This visit was conducted in conjunction with the visit to the Atlanta IWF. Equipment manufacturers have also been helpful in developing budget costs for equipment as used in the economic feasibility analysis.

4.2 Tests of selected rapid drying technologies

4.2.1 Continuous RF drying

Drying by exposure of wood to a radio frequency (RF) field has long been recognized as a means of achieving fast drying rates. Starting in 2001, a program (ElectroBois) was initiated and jointly funded by FPInnovations (Forintek), Hydro Québec, and the Quebec government. One of the objectives of this work was to evaluate a drying technology that combined heating by radio frequency while subjecting the wood to a vacuum (Radio frequency vacuum or RFV). The ÉlectroBois project provided the opportunity to conduct a comprehensive study of this technology through trials in a small, commercial-scale RFV kiln, purchased under this program and located at the Laboratory Technology Energy (LTE), Hydro-Quebec, Shawinigan. The main products tested were hardwood and value-added/appearance-grade softwoods. RFV drying has been applied in the U.S. as a re-drying system in softwood dimension mills.

Therefore, tests were conducted on the RFV system in Shawinigan on using this technology to dry black spruce “wets” after an initial drying in a conventional kiln. A preliminary test was conducted on balsam fir dried from green to dry. Two tests were conducted. The power density used to dry the material was 18 kW/m³. The drying times were 14 hours on the first test from an initial MC of 109% to a final MC of 9% and 13 hours on the second test from an initial MC of 89% to a final MC of 14%. The quality of lumber after drying was acceptable for construction grade lumber. The RFV dry kiln used for these tests did not allow to explore the limits of rapid drying. This system was designed for drying hardwoods and high quality softwood products and was therefore not designed to generate higher wood temperatures and accommodate faster drying rates. This is due to the fixed capacity of the RF generator of the kiln (20 kW) and the minimum lumber volume that the kiln can handle (0.9 m³). As a result, the maximum density attainable was approximately 22 kW/m³. Hydro Québec’s LTE facility also has a continuous RF heating system that they have tested for other (non-wood) heating applications. This drying unit provides the ability to evaluate benefits associated with a wider range of power density. As it is not a batch process, it also offers the opportunity to follow and evaluate the material throughout the trial for changes in moisture and warp. In addition, the system allows for operation at a constant voltage that theoretically should favor better uniformity of moisture content. Such a system, not operating with a vacuum, can also reduce equipment and operating costs due to the lack of a vacuum pump and airtight drying chamber.

The main objective of these preliminary tests was to determine the ultimate speed attainable to dry spruce lumber in a RF field. Those data could then support the techno-economic evaluation summary of this approach to drying. A detailed report¹ has been completed and is available upon request at FPInnovations (French only).

Samples of 16-foot 2x4 were selected from a commercial sawmill production line and were cut to a length of 3.05 meters (10 feet) and taken to the Laboratory of Energy Technologies (LTE) in Shawinigan, QC. Two small sections were taken at 30 cm (1 foot) from each end of each board to determine the initial moisture content (oven-dry method). The remaining 2.44 meter (8 feet) boards were accumulated for test No. 1, and for tests No. 2 to 4, sections of 1.22 m (4 feet) long were prepared.

The equipment used for continuous RF drying is composed of a 50 Ω generator with a variable power output from 0 to 30 kW at a frequency of 13.56 MHz. The wood is carried through the drying chamber on a conveyor around which it is possible to install and modify different electrode configurations. The conveyor has a width of 50 cm and a length of about 5 m. For these tests, the electrodes inside the drying chamber had a surface area of 50 cm by 152 cm. Figure 1 shows the continuous RF dryer used for testing. The chamber is equipped with forced air circulation, heated by electrical resistance heaters inside the dryer to limit moisture condensation and promote moisture wicking.

![Continuous-flow, radio-frequency (RF) heated dryer.](image)

**Figure 1**  Continuous-flow, radio-frequency (RF) heated dryer.

Different strategies were developed for each test to determine optimum operating parameters to achieve the fastest drying time consistent with achieving the required quality. Table 1 presents an overview of parameters used for the various tests.

**Table 1**  Summary of operating conditions for continuous RF drying tests on black spruce

<table>
<thead>
<tr>
<th>Test number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piece length (m)</td>
<td>2.44</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td>Power density (kW/m³)</td>
<td>90</td>
<td>108 to 122</td>
<td>75</td>
<td>93</td>
</tr>
<tr>
<td>Voltage (kV)</td>
<td>1.5 to 2.9</td>
<td>1.5</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

**4.2.2 Press drying**

A supply of green,2x4 white spruce lumber was obtained from a Quebec sawmill. This material was all 8-foot in length and used to prepare matched samples for the press and ultra-high-temperature drying.
trials. The method of sample preparation is show in Figure 2. All test boards were end coated and stored in a cool, high-humidity chamber until needed.

![Diagram showing sample preparation method](image)

**Figure 2** Method of sample preparation for the press and ultra-high-temperature drying trials

Figure 3 shows the press used to conduct the tests on this drying approach. The press surface is approximately 86cm by 86 cm and is heated by steam. This press also has steam injection to help humidify the surface of the wood. The press closing pressure is controlled and this was one of the variables evaluated. The platen temperature and press closing pressure were regulated by a computer control system.

![Image of press](image)

**Figure 3** Press used for press-drying trials on spruce and jack pine
Tests were conducted on 2x4 spruce and jack pine lumber. All samples were trimmed to a length of approximately 61 cm. Eight samples were dried in each test. The boards were pre-surfaced, prior to drying, to achieve better uniformity in thickness and therefore better contact with the press platens. All boards were end coated to minimize any end drying effect. A thermocouple was inserted to the core of one piece in each test to monitor and record core wood temperature. A DC-resistance meter was connected to two pins inserted before drying in one sample to estimate when the final MC was being approached and therefore when to terminate drying.

![Figure 4](image.png)  

**Figure 4**  Press in closed position with thermocouple probe and DC-resistance meter connected to monitor wood core temperature and estimate MC

A summary of the test conditions applied for each drying trial are listed in Table 2. Conditions were adjusted from test to test depending on results of prior trial. The strategy was to try to identify a safe (from the standpoint of lumber quality) drying treatment consistent with achieving a rapid drying time.

### Table 2  Summary of test conditions applied for press drying trials

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Species</th>
<th>Platen Temperature (°C)</th>
<th>Platen Pressure (psi)</th>
<th>Steam Injection Used (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>White spruce</td>
<td>192 – 236</td>
<td>30</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>White spruce</td>
<td>183 – 184</td>
<td>30</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>White spruce</td>
<td>155 – 165</td>
<td>30</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>White spruce</td>
<td>165 – 137</td>
<td>30 to 0</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>White spruce</td>
<td>163 – 136</td>
<td>30 to 0</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>White spruce</td>
<td>120 – 138</td>
<td>30</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>White spruce</td>
<td>79 – 161</td>
<td>17</td>
<td>Y</td>
</tr>
<tr>
<td>8</td>
<td>Jack pine</td>
<td>140</td>
<td>30</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>Jack pine</td>
<td>160</td>
<td>30</td>
<td>N</td>
</tr>
<tr>
<td>10</td>
<td>Jack pine</td>
<td>180</td>
<td>30</td>
<td>N</td>
</tr>
</tbody>
</table>

After drying, each board was cut to obtain oven-dry sections for accurate determination of final MC and to adjust the estimates of initial MC (based on board weight).
4.2.3 Ultra-high temperature drying

A small-scale, laboratory dry kiln was modified to achieve the conditions necessary for the ultra-high temperature (UHT) drying trials. A review of UHT drying applied elsewhere in the world was conducted to set the maximum operating parameters to be targeted with the small-scale kiln. The kiln was able to achieve a maximum dry-bulb temperature of 180° C and airflows up to 8 metres/second (m/s) (approximately 1,600 fpm).

Table 3 Summary of test conditions applied for UHT drying trials

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Species</th>
<th>Maximum DB Temperature (°C)</th>
<th>Airflow (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>White spruce (S1)</td>
<td>160</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>White spruce (S2)</td>
<td>90</td>
<td>3.3 – 4.5</td>
</tr>
<tr>
<td>3</td>
<td>White spruce (S3)</td>
<td>130</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Lodgepole Pine (P1)</td>
<td>160</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Lodgepole Pine (P2)</td>
<td>180</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>Lodgepole Pine (P3)</td>
<td>90</td>
<td>3.3 – 4.5</td>
</tr>
<tr>
<td>7</td>
<td>Lodgepole Pine (P4)</td>
<td>100 - 180</td>
<td>8</td>
</tr>
</tbody>
</table>

Figure 5 shows the kiln that was used for the UHT drying trials. A total of 40 boards were dried per test run. The material was weighed before and after drying and the individual boards re-cut after drying to determine final MC based on the oven-dry method. As shown in Figure 5, two 23 kg weights were applied to the top of the load to provide some restraint during drying. The entire load was weighed continuously during drying by means of a load cell. The weight loss data and final MC determinations were used to develop a drying curve for each charge.

Figure 5 Test charge placed inside of ultra-high temperature kiln
5 Results

5.1 Review of state of the art softwood drying technology

5.1.1 Literature review

In theory, any technology for lumber drying that does not require the use of vacuum or pressure chambers could be suitable for a continuous kiln. The potential drying technologies found in literature as possible candidates for continuous drying without stickers are the following:

1. Pre-treatment to reduce drying time
2. Boiling in oil
3. Solvent drying
4. Infrared radiation
5. Ultrasound
6. Radio frequency
7. Microwaves
8. Convective drying
9. Jet impingement
10. Ultra-high temperature drying
11. Press drying

5.1.1.1 Pre-treatment

Some simple methods have been proposed in the past to improve the drying behavior (“dryability”) of lumber. One method is pre-compression. Pre-compression involves momentarily compressing the green lumber by 2.5 to 20% of the thickness. This results in microscopic internal splits that increase the permeability of the wood. After pre-compressing for example, it was possible to dry yellow birch at high temperature in less than half of the time required with conventional schedules (Simpson 1983-84). In Canada Cech and Goulet, 1968 designed and tested a roller mechanism for in-line compression of green lumber. The equipment produced a transverse lumber compression of around 5 to 7.5% of the lumber thickness, and drying tests with 1 and 2-inch yellow birch showed that lumber pre-compression considerably improved dryability. For the same final quality, pre-compressed lumber was dried in 1/6 of the time required for drying the lumber without pre-treatment.

Chemical drying is another method proposed to facilitate fast drying without degrade. Chemical drying consists of applying a hygroscopic salt over the surface of lumber to help to maintain a relatively high MC at the board surfaces during drying. It has been successfully applied to Douglas-fir (Anderson 1956). For this application, the chemical diffusion into the lumber was to about 1/10 of the thickness, and it required approximately 30 to 45 kg of chemical per Mfbm. From all the tested chemicals, common salt was the most effective in reducing surface checks. Other chemicals investigated include invert sugar, low-grade sugars, diethylene glycol, and a urea formaldehyde (Forest Products Laboratory, 1960).

In general, chemical treatment is not intended to accelerate drying rate, but to prevent case hardening. Chemical treatment can only increase drying rate if schedules that are more aggressive are used to obtain the same final quality (Colgrove, 1956). Recent experiments (Kuryanova et al., 2004) showed that chemical treatment with salt solution can cut the drying time of ash and oak by 2.5 to 3 and 3 to 5 times respectively.
Another method tested at the laboratory level to improve lumber dryability is laser incising. The idea is to reduce the distance that moisture diffuses within the lumber by incising a matrix of holes perpendicular to the lumber surface. It was found that 90 holes/cm² with diameters around 0.3~0.7mm can reduce drying time of 12mm thick maple by 70% (Simpson, 1987). Similarly, 15 holes/cm² of 0.5mm diameter can reduce drying time of 37mm thick red oak and 51mm loblolly pine by approximately 15% to 27% (Kamke and Peralta, 1991). On the negative side, laser incising reduced the strength (modulus of rupture) of oak and loblolly pine by 15% to 46% (Simpson, 1987).

### 5.1.1.2 Boiling in oil

Drying lumber by boiling in oil consists of submerging green lumber in a water repelling liquid (such as petroleum oil, creosote, or molten wax) at a temperature considerably higher than the boiling point of water. Drying softwood lumber with 40~50% initial MC in petrolatum (commercially known as vaseline) at 130~135°C required 4 to 5 hours for 25mm lumber, 11 to 12 hours for 51mm lumber and 16 to 17 h for 66mm thick lumber (Folomin 1956). In two other studies (Forest Products Laboratory, 1956a), 100mm thick southern pine was dried from 77% to 22% MC in 16 hours at 127°C oil temperature, and drying of 25mm and 51mm Douglas-fir lumber required 6 hours and 8 hours respectively.

The result of these experiments showed that boiling in oil may produce severe case hardening, stress and surface checks unless vacuum is used. Since hot oil has no means to condition and equalize the lumber, residual stress caused warping during sawing or machining. Additionally, the lumber absorbed part of the oil during drying. For the cases above, oil retention was around 8.5 kg per Mfbm for 51mm softwood lumber, and 46 liters per Mfbm for the 100mm southern pine. Since the oil is usually inflammable (Forest Products Laboratory, 1956a), any oil retained by the wood may represent an unacceptable fire hazard risk for dimension lumber.

### 5.1.1.3 Solvent drying

Solvent drying is performed by soaking lumber in a hygroscopic liquid that removes moisture by osmosis rather than by water evaporation. Solvent drying has been tested to dry pine by using acetone as the solvent (Anderson 1956). The reported times are 1/2 to 1/4 of the times required in conventional drying, probably because of the more efficient mass transfer mechanism between the solvent and the wood. In terms of quality, it was found that solvent drying increased the strength of ponderosa pine by 5 to 10%, and the dried lumber was practically free of degrade due to cupping, warping and splitting.

Solvent drying with acetone showed that 100mm thick ponderosa pine can be dried in 18 hours in comparison with 72 to 104 hours for conventional drying (Anderson et al., 1962), and 100mm tanoak sapwood can be dried in 30 hours in comparison with 14 days for conventional drying (Anderson and Fearing, 1965). The results also showed that lumber quality after solvent drying was significantly better than traditional kiln drying.

In other experiments (Anderson and Wilke, 1965), 100mm thick redwood with an initial MC of 205 to 223% was solvent dried in acetone at 50°C in 170 to 254 hours or in methanol at 63°C in 100 to 143 hours. The results showed that the lumber was relatively free of honeycomb, collapse, casehardening and end-checks. Solvent drying also reduced chemical stain.

Apparently, the main disadvantage of solvent drying is technological. The solvent absorbed by the lumber must be removed by air drying at approximately 90°C, and then the solvent must be recovered from the air by condensation. In the experiments with redwood, the solvent to wood absorption ratio was 0.18 to 0.23 gallons/lb with acetone and 110 to 160 lb/Mfbm with methanol.
5.1.1.4 Infrared radiation

Infrared drying involves exposing the lumber to a uniform infrared light source. Infrared radiation is absorbed quickly at the surface of the lumber, thus heat transfer is considerably faster than in convective drying. However, infrared radiation only penetrates the surface to a slight degree, thus it does not appear advantageous for drying thick (i.e., 51mm) wood (Forest Products Laboratory, 1956b). In general, infrared drying is not considered a serious candidate for drying dimension lumber because the equilibrium moisture content at the lumber surface cannot be controlled (Espenas, 1954). This creates the potential to overdry the surface and create surface checking.

5.1.1.5 Ultrasound

The possibility of using high-intensity ultrasound for wood drying was tested at a basic laboratory level. In one experiment, 1-inch eucalyptus was dried from green to 20% MC by the application of 20 kHz ultrasonic energy in approximately 1 hour (Neylon, 1978). The temperature generated within the sample during the ultrasonic treatment was approximately 150°C.

Another set of experiments were performed with an experimental laboratory dryer developed for ultrasonic drying of vegetables (Valentino et al., 2002). The results showed that drying with sonic (10 kHz) and ultrasonic energy (20 kHz) at moderate power levels accelerates the wood drying process without any evident wood damage. If ultrasound and infrared radiation are applied simultaneously, these processes complement each other and produce better results. For example, 25mm thick pine samples with an initial MC of 100% were dried in 70 minutes using ultrasound and in 30 minutes using ultrasound combined with infrared radiation.

5.1.1.6 Radio frequency

Radio frequency drying involves heating up the water molecules directly in the wood by exposing the lumber to electromagnetic waves in the order of a 2 to 14 MHz. Electromagnetic energy is mostly absorbed by the water molecules, thus moisture evaporates inside the lumber at temperatures that are higher than the water’s boiling point. Since the boiling point of water at atmospheric conditions is 100°C, continuous RF heating is generally combined with convective surface drying to prevent excessive temperature and pressure increase within the lumber core.

Combined RF and convective drying were applied for drying 51mm thick grand fir with 150% initial MC (Remond and Perre, 2008). The process required:

- 5.9 hours at 166 kW/m³, 75°C dry-bulb and 70°C dew-point temperatures
- 9.4 hours at 95 kW/m³, 80°C dry-bulb and 80°C dew-point temperatures
- 10.8 hours at 77 kW/m³, 90°C dry-bulb and 90°C dew-point temperatures

The results were acceptable for the 10.8-hour drying run, but the 9.4 hour run produced internal checks, and the 5.9-hour run burned the sample. In another experiment, 25mm red oak with an initial MC of 85% was dried in a 13.6 MHz RF field in combination with air circulation at 3 m/s. The experiment created excessive surface checks. As an alternative, the red oak was kiln dried from green to 40% MC in a conventional kiln, and then dried from 40% to 12% in 41 hours without degrade by using combined RF and air circulation.

RF combined with typical dry-bulb temperature schedules was tested by applying the radio frequency energy in pulses of different intensity and spacing (Dean A.R., 1970). The results showed that 25mm low-grade pine can be dried from 93 to 19% MC in 10 hours with similar quality as 19 hours of conventional drying. By contrast, 25mm, high-grade pine dried in 17 hours from 77 to 14% MC resulted in 9% more
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value losses than 49 hours of conventional drying. In the same study, 25mm utile lumber (exotic African wood from the family of the Meliaceae) was dried from 59 to 10% in 9 hours, but showed unacceptable internal checks when compared with 192 hours of conventional drying.

Another study (Miller 1971) combined radio frequency at 2 MHz with conventional drying at 60 to 80°C dry-bulb and 56 to 77°C wet-bulb. The results showed that 51mm white spruce lumber at an initial MC of 55 to 65% required approximately 15 hours drying time in comparison with 60 hours of conventional drying and achieving an equivalent quality (Miller 1971).

To determine the benefits of controlling the lumber temperature during RF drying, RF drying by the method of reaching the water boiling point was compared with RF drying by the method of controlling the lumber temperature with cold humid air (Pratt and Dean 1949). By using radio frequencies of 2, 5, 10 and 15 MHz, the experiments showed that green 51mm beech can be dried in approximately 40 min without much degrade by using the boiling method, but the same method caused considerable internal checks in English oak. When RF was combined with cold humid air, 51mm beach dried from 91% to 13.5% in a few days, and English oak was still difficult to dry because of surface checks.

FPInnovations and Hydro Quebec have conducted tests on continuous RF drying of Eastern SPF. The results and discussion on that work are presented in a later section of this report.

5.1.1.7 Microwave

Microwave drying consists of heating up the water molecules directly inside the lumber by exposing the lumber to microwave radiation with frequencies of 0.434, 0.915, 2.45 or 5.8 GHz (Greaves H. 1998). The main advantage of microwave technology in comparison with RF is that microwave can release hundreds of times more energy than RF without the need for high voltages that can burn the wood. On the negative side, it is difficult to generate a uniform microwave distribution in industrial applications, and there is poor penetration of microwave power into the lumber when the frequency is high. This poor penetration limits the size of lumber or lumber stacks that can be effectively dried with this energy source.

Microwave drying of 41 to 51mm thick pine and spruce at 2.45 GHz and 70°C dry-bulb temperature showed drying rates of 6 to 12 %MC/h when the MC was below the FSP and 12 to 27 %MC/h for wood above the FSP (Antti A.L. 1995). In some cases, there was no checking, but some experiments using high power densities induced the formation of internal checks. Considerable internal checking developed when spruce was dried at an average rate of 43 %MC/h. The core MC was generally lower than the shell, but it tended to equalize at the end of drying.

In another experiment (Lee, 2005), 150mm thick red pine was dried in 30 hours from 77% to 22% MC using 2.45 GHz microwave power and controlled 90°C dry-bulb temperature, but the results showed considerable surface checking. According to the authors, surface checks are caused by the hot air, probably because the experiments did not have control over the air relative humidity. Since volumetric drying starts at the lumber core and convective drying starts at the lumber surfaces, it is expected that combined convective and volumetric drying reduces the MC differences between shell and core. This should help to reduce surface checks (typical of surface drying) and honeycomb (internal checking typical of volumetric drying), but only if volumetric and surface drying are applied at the same rate.

McAlister and Resch (1971) reported that it was possible to dry 25mm thick ponderosa pine without degrade by using a combination of microwave radiation (0.915 and 2.45 GHz) and hot air without humidity control. In these experiments, boards were dried without degrade at 73 %MC/hr using 104°C dry-bulb temperature, and at 9 %MC/hr using 29°C dry-bulb temperature.
For 51mm hemlock and Douglas-fir (clear grade), large scale tests showed that microwave drying combined with 93°C dry-bulb temperature and 100% relative humidity can reduce drying time to 6.2 to 8.7 hours as compared with 9 days for conventional drying (Barnes et al. 1976). In small scale tests, there was however considerable degrade depending on the air relative humidity and the microwave power. The experiments showed that using low relative humidity promoted casehardening and surface checks, and using high relative humidity promoted lumber overheating and internal checking. For 51mm hemlock with an initial MC of 86%, the least amount of degrade was obtained at 100°C dry-bulb temperature, 55% air relative humidity, and 4.6 hours of drying time.

5.1.1.8 Continuous convective drying

Continuous hot air drying without stickers has also been tested as an alternative to conventional kilns. In one experiment, 25mm spruce lumber with an initial MC of approximately 110% was dried in a continuous kiln in approximately 2 hours using dry-bulb temperatures between 114°C and 153°C (Salin J.G. 2005). The fast drying caused considerable casehardening, internal checking, and large internal MC gradients. Additionally, moisture content was not uniform along the board length, and the final standard deviation was approximately 2.4 times higher than the normal SD obtained in conventional drying. Warp was not a problem, probably because of the high temperature that softened the wood.

In another study, 25 to 43mm thick radiata pine lumber was dried in approximately 3 to 4 hours using a dry-bulb temperature of 150°C, the maximum wet-bulb depression attainable, and an air velocity of 10 m/s (Arganbright D.G. 1979). The quality was described as acceptable if the lumber had high permeability and it was not susceptible to collapse.

Another experimental, continuous-roll feed drier (Koch, P. 1974) was used to dry 51mm thick southern pine in 21 hours from 88 to 8% MC at a dry bulb of 115°C and a wet bulb of 70°C. An additional 3 hour conditioning treatment was applied to relieve case hardening. The results showed a considerable reduction in warp in comparison with conventional drying.

Fast drying has also been tested in conventional (batch) kilns for different lumber thicknesses and air temperatures. For example, drying 30mm thick spruce from 70% to 8% in a conventional kiln required approximately 170 minutes at 150°C, 280 to 300 minutes at 130°C, 600 to 900 minutes at 110°C, and 1200 to 1900 min at 90°C (Schneider, 1981). In another experiment, drying 51mm pine from an initial MC of 102 to 121% and using air velocities of 6 and 10 m/s, required 6.5 to 8.5 hours at 149°C, 7.17 to 11 h at 130°C, and 10 to 13 hours at 110°C (Taylor and Mitchell 1987).

5.1.1.9 Jet impingement

Jet impingement drying consists of blowing hot air at high speed perpendicularly to the lumber surfaces. One prototype was designed to work with air temperatures between 100°C and 200°C, and air velocities between 5 and 45 m/s. With this prototype, drying of maple required between 1.2 and 37 hours for thicknesses between 25 and 51mm (Simpson 1983-84). Honeycomb was severe in the pieces. Although high-temperature jet impingement drying caused darkening of the lumber surfaces, this method can dry lumber 10 to 50 times faster than conventional drying (Rosen, 1978a).

Jet drying was also tested on 44mm southern yellow pine and Douglas fir with a dry-bulb temperature between 71°C and 204°C, a wet bulb temperature of approximately 82°C, and air velocities between 15 and 46 m/s (Rosen, 1978b). The results showed that southern pine can be dried in 1.5 to 3.5 hours at dry-bulb temperatures between 150°C and 204°C with minimal degrade. For Douglas fir, the results of jet-drying showed that the heartwood was overdried and the sapwood under-dried. Several combinations of
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high and low temperatures with and without conditioning were tested, but honeycomb and end checking could not be avoided. Jet drying of 44mm thick Douglas fir was not acceptable in terms of lumber quality.

5.1.1.10 Ultra-high temperature drying

Ultra-high temperature drying involves exposing the lumber to a temperature above the wood glass transition point. Glass transition is the scientific term used to describe solid materials changing from rigid to flexible without melting when the temperature increases. The glass transition temperature of dried wood is normally 150°C. Above this temperature, the wood polymer melts and changes into a viscous state that can withstand larger elastic deformations without breaking (US Patent 6910284).

Kiln manufacturers like Mahild, Hildebrand-Brunner and Windsor are already offering ultra-high temperature kilns with dry bulb temperatures of up to 240 to 260°C and they report that drying time can be reduced to a few hours. Windsor for example, indicates that ultra-high temperature drying of structural grade lumber at 160 to 220°C can reduce drying time from 3 to 8 hours.

Thermal modification transforms the lumber into a darker and more stable product that has increased resistance to insect and fungal attack and is less prone to shrinkage and swelling. However, there is still the question of whether high temperature drying affects the structural properties of dimension lumber. It is believed that exposures to temperatures above the glass transition point can considerably reduce the strength of the dried lumber.

5.1.1.11 Press drying

Press drying consists of pressing the lumber between two metallic platens maintained at high temperature. Press drying has been used to dry loblolly pine from 120 to 15% MC by using platen temperatures of 177°C, 213°C, and 246°C (Simpson and Tang 1990). Drying times were less than 20 minutes for 25mm thick boards at 246°C, 85 minutes for 41mm boards at 177°C, and 90 minutes for 51mm boards at 177°C. Boards were essentially free of collapse, surface checks and internal checking. Only occasional short, narrow, and shallow surface checks were noted. Surface darkening was created at 246°C.

In another experiment, 25mm yellow poplar lumber was press dried from an initial MC of 80-100% to 8-10% MC at temperatures that ranged between 121°C and 232°C. Drying required approximately 1 hour, and the final lumber quality was apparently good (Hann 1964). Similarly, Schmidt (1967) press dried 25mm thick European beech from 80 to 8% MC in 1 to 2 hours at temperatures between 150°C and 170°C. The dried beech was relatively free of drying defects.

Hittmeier et al. (1968) press dried 25mm thick European beech from 80 to 7% in 1 to 2 hours at temperatures between 150°C and 170°C. Another nine hard wood species with thicknesses between 12 and 25mm were press dried at 170°C in times ranging from 20 to 200 minutes. In particular, aspen and birch were press dried at 170°C in 80 to 130 min. The main problem was the development of internal checking (honeycomb). In the case of the hardwood, drying defects went from minor to severe as the lumber thickness increased from 25 to 51mm.

To help release stress during press drying, 25mm thick black walnut with 65-67% initial MC was press dried at 121°C using three different strategies, namely, continuous press drying, cycles of 2 hours press drying and 2 hours air drying, and cycles of 2 hours press and 24 hours equalization inside bags (Chen 1978). The cumulative pressing time was 16 hours in all cases, and the result showed that increasing the equalization time between the pressing steps reduced surface checks, collapse and honeycomb. In general, hot-press drying did not produce good quality walnut boards.
An innovative idea was tested by combining 4.5 MHz radio frequency heating with press drying at a maximum press temperature of 110°C. This methodology reduced the drying time of 30mm thick beech with 40-70% initial MC to around 5 minutes (Gefahrt 1970). The results showed a uniform final MC and lumber without internal stress, probably because the simultaneous application of internal and surface heating reduced the drying rate differences between core and shell.

The effect of combining radiofrequency heating with press drying at 68 to 71°C has been tested for drying of 140mm and 165mm thick red pine (Jung et al. 2003). The results showed that under similar conditions, average drying rates increased from 3.30 to 3.63 %/day with only press drying and 4.73 to 7.90 %/day with only radio frequency drying to 11.20 to 16.68 %/day for combined radio frequency and press drying. Even though these tests were performed under vacuum, they showed that combined radiofrequency and press drying reduce drying time, energy consumption, moisture gradients and lumber checks with respect to the other two methods applied independently.

5.1.2 Conclusions from the literature review

There is evidence in this study that lumber with thicknesses smaller than 25mm can be dried with acceptable quality in less than 2 hours by using most of the drying techniques described above. For lumber thicker than 51mm, the same methods seem to require drying times of several hours (Table 4). The limiting factor in any of these drying systems is the capacity of the wood structure to allow moisture to flow. Regardless of how fast the drying method can transfer heat into the lumber, drying is limited by the speed at which moisture can move from inside to outside the lumber. Rapid surface heating can overdry the surface and produce casehardening. Casehardening induces surface checks in the early stages of drying and these may develop into internal checks in the final stages. Rapid volumetric heating does not produce casehardening, but it is more likely to produce internal checks because of the generated temperature, pressure and stress. Pre-treatments are methods to improve dryability, so they can be used before any other drying method to either reduce drying time or increase lumber quality. To show the range of potential drying times that can be achieved with the different drying technologies the results of the literature review are summarized in Table 4.

Table 4 Summary of estimated drying times for 51mm (2-inch) thick softwood lumber using various rapid drying technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Approx. Drying time (hours) (51mm lumber)</th>
<th>Potential problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling in oil</td>
<td>8 - 12</td>
<td>High risk of case hardening / Oil retention</td>
</tr>
<tr>
<td>Solvent drying</td>
<td>--</td>
<td>Mostly tested for 100mm lumber / Solvent drying cycle</td>
</tr>
<tr>
<td>Infrared radiation</td>
<td>--</td>
<td>Impractical for 51mm and thicker lumber</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>--</td>
<td>Only tested at basic laboratory level</td>
</tr>
<tr>
<td>Radio frequency</td>
<td>6 - 12</td>
<td>Risk of honeycombs and wood burns</td>
</tr>
<tr>
<td>Microwaves</td>
<td>4 - 9</td>
<td>Risk of honeycombs / Non-uniform MW distribution</td>
</tr>
<tr>
<td>Convective drying</td>
<td>6 - 13</td>
<td>Risk of case hardening and surface checks</td>
</tr>
<tr>
<td>Jet impingement</td>
<td>2 - 4</td>
<td>High risk of case hardening</td>
</tr>
<tr>
<td>Ultra-high temperature</td>
<td>3 - 8</td>
<td>Thermal modification / Lumber strength reduction</td>
</tr>
<tr>
<td>Press drying</td>
<td>~ 2</td>
<td>Mostly tested for 25mm lumber</td>
</tr>
<tr>
<td>Press drying with RF</td>
<td>&lt; 2</td>
<td>No information found for 51mm lumber</td>
</tr>
</tbody>
</table>
The best results in terms of short drying time with minimum degrade seem to be obtained with press drying, but press drying may not be practical for drying several pieces together when there are small variations in the lumber thickness. Volumetric heating technologies such as radio frequency and microwave seem to be more practical from the mechanical point of view, but it is not clear how a laboratory microwave applicator can be scaled up to a large drying area. To minimize the drying rate differences between core and shell, volumetric heating in rapid drying should be combined with high temperature surface heating.

5.1.3 Influence of drying time on scale of in-line equipment

It is assumed that rapid drying is applied in a continuous process for drying lumber without stickers. Continuous lumber drying with stickers in progressive conventional kilns is a well developed technology that is already widely applied in industry. To dry without stickers, lumber should pass thought the drying area as it moves from the saw to the planer.

Regardless of how many layers of lumber are piled simultaneously without stickers, the minimum area required to dry the lumber is calculated as follows:

\[ A = \frac{V \cdot t}{T} \]

Where:
- **A** = Area required to dry the lumber (Drying area)
- **V** = Volume of lumber dried per unit of time (Lumber production)
- **t** = Time required to dry the lumber depending on the technology (Drying time)
- **T** = Thickness of lumber moving throughout the drying area (One or more layers)

For example, Table 5 indicates the drying area required to replace a 250 Mfbm conventional kiln that dries 2-inch thick by 12 feet long softwood lumber in 40 hours. The table also shows how long the drying area should be if boards are aligned transversally to the direction of the flow.
Table 5  Minimum area and length of a continuous drier to replace a 250 Mfbm conventional kiln that dries 2-inch thick by 12-foot long softwood lumber in 40 hours

<table>
<thead>
<tr>
<th>Drying Time Hr</th>
<th>Drying area m²</th>
<th>Drier length for transverse board flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>290</td>
<td>79</td>
</tr>
<tr>
<td>2</td>
<td>581</td>
<td>159</td>
</tr>
<tr>
<td>3</td>
<td>871</td>
<td>238</td>
</tr>
<tr>
<td>4</td>
<td>1161</td>
<td>318</td>
</tr>
<tr>
<td>5</td>
<td>1452</td>
<td>397</td>
</tr>
<tr>
<td>10</td>
<td>2904</td>
<td>794</td>
</tr>
<tr>
<td>20</td>
<td>5807</td>
<td>1588</td>
</tr>
<tr>
<td>30</td>
<td>8711</td>
<td>2382</td>
</tr>
<tr>
<td>40</td>
<td>11614</td>
<td>3175</td>
</tr>
</tbody>
</table>

As it can be observed, rapid drying of 2-inch softwood lumber taking more than 1 or 2 hours would require drying areas and equipment lengths that would be beyond the scale for practical application in current sawmill environments.

5.1.4 Equipment manufacturers

In May of 2009, a visit was made to the LIGNA Word Fair for the Forestry and Wood Industries, which is held once every two years in Hannover, Germany. This fair provides a unique opportunity to meet with equipment manufacturers from all over the word and is the best attended show of its type both in terms of exhibitors and attendees.

Vincent Lavoie attended on behalf of FPInnovations specifically to gather information relevant to the objectives of this project. The following is a brief, point-form summary of the significant information gathered from this meeting. A detailed trip report can be obtained from FPInnovations upon request (in French only).

- **Ultra high temperature drying**
  - Mahild of Germany and Windsor of New Zealand are the two primary companies identified that are producing commercial, ultra high temperature kilns.
  - Commercial UHT kilns operate at temperatures of 140° C. and higher.
  - Mahild UHT kilns are heated indirectly by a gas burner producing hot air via an air-to-air heat exchanger.
  - Combine high drying temperatures with high airflows of 9 to 13 m/s (approx. 1,800 to 2,600 fpm).
  - UHT is typically followed by a cooling and conditioning treatment that is often done in a separate chamber.
  - Drying time (for 50mm lumber) is in the range of 2 to 6 hours followed by a 2-hour conditioning treatment.
  - All of the UHT kilns produced to date are batch type with either rail loading or side-loading configuration.
Manufacturers report that colour is affected by high drying temperatures, but no significant impact on lumber strength (Note: this may be because of the relatively short exposure time to the maximum operating temperatures).

Mahild has a test facility in Italy, which they offered for our testing purposes.

- Progressive (continuous flow of lumber packages) dry kilns
  - Various configurations of continuous flow dry kilns have existed, especially in Europe, for many years.
  - There are four European companies producing continuous flow dry kilns
  - All European designs are based on the transverse (sideways) flow of packages through the drying chamber.
  - Various manufacturers have different configurations with regard to heating, drying, and cooling zones and airflow patterns.
  - One benefit of all types of continuous flow kilns is the evening out of the energy demand on the thermal energy system.
  - A variation on continuous flow kilns involves longitudinal (lengthways) movement of lumber packages through the drying chamber. There are two companies (USNR and Windsor) producing this type of continuous flow kiln. Further detail on this configuration is provided in the next section.

- Information was gathered on several other technologies which could potentially be applied to an in-line, rapid-drying system. These included technology used in veneer dryers and presses used in the panelboard industry.
  - In one company veneer dryers (Grenzebach) the overall length of the dryer is reduced by splitting the production into 6 decks and slowing the flow rate.
  - Laboratory press drying tests (including those reported in this study) have always been conducted on a batch process. Continuous flow presses have been used in the panel industry for many years. One major manufacturer (Dieffenbacher) was consulted while at the LIGNA exhibition. From an engineering standpoint, they did not see any major issues in constructing a continuous flow drying system. The price for a system would be significantly less than a panelboard application because of the significantly reduced pressure levels.

In September 2009, a visit was made to the Atlanta International Woodworking Fair to gather information and updates from North American kiln manufacturers. Of particular interest was information on the Triple Length continuous kiln configuration. A license for this patented process has been granted to several companies including USNR. In conjunction with the visit to the Atlanta show, a visit was organized to view an early version of an industrial Triple Length kiln located near Appling, Georgia. This visit was conducted with personnel from USNR.

5.1.4.1 Ultra-high temperature drying

5.1.4.1.1 Industrial application of UHT

Most ultra-high temperature drying processes in the world are used to dry softwoods especially pine because most pine species respond well to severe drying conditions. The main client countries for Mahild (UHT manufacturer, met at LIGNA show in 2009) are Australia, New-Zealand, Chile, Argentina, Brazil and Venezuela where radiata pine is present. That technology is not really adapted for other species like spruce and fir. Canadian pines (jack pine and lodgepole pine) are potentially good candidates to be dried by this process.
5.1.4.1.2 UHT manufacturers

There are two main ultra-high temperature (UHT) manufacturers in the world: Windsor (http://www.windsortechnology.biz) of New Zealand and Mahild (www.mahild.de) of Germany. Both of these companies were met and consulted at the world LIGNA show in 2009.

A trip to Europe was arranged, to meet continuous flow kiln manufacturer in November 2010 (a separate trip report is available on request). During that trip a meeting was also arranged to meet once again with the major kiln manufacturer of UHT technology, Mahild. The main objective of that meeting was to discuss the detailed features of the UHT technology manufactured by this company and obtain some information on capital cost for a system suited to Canadian application. A formal proposal for a kiln of 38 m³ capacity was obtained from Mahild. The kiln is a batch type (they can offer both track and side-loading configurations), constructed of Aluminum, with maximum operating temperature of 160° C and approx. airflow of 12.8 m/s. The detailed proposal is presented in Appendix I.

The Mahild UHT proposal was developed for a kiln with capacity to dry approximately 20,000 Mbf/year based on a drying time of 8 hours. This scenario has been established based on a Canadian SPF mill producing 100,000 Mbf/year with 20% of the production being pine. Table 6 shows, for the same annual production, a price comparison between an ultra-high temperature kiln and a conventional kiln.

Table 6 Comparative capital costs for an ultra-high temperature kiln versus a conventional kiln designed to dry the same annual volume based on a 5-fold difference in drying time. This scenario is based on using UHT drying technology for 51mm (2-inch) pine (jack pine or lodgepole pine)

<table>
<thead>
<tr>
<th></th>
<th>Ultra-high temperature</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying time (hours)</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Initial/Final MC (%)</td>
<td>75/18</td>
<td>75/18</td>
</tr>
<tr>
<td>Annual drying production capacity (Mbf)</td>
<td>20,000</td>
<td></td>
</tr>
<tr>
<td>Kiln capacity (m³)</td>
<td>38</td>
<td>190</td>
</tr>
<tr>
<td>Kiln capacity (Mbf)</td>
<td>19</td>
<td>95</td>
</tr>
<tr>
<td>Boiler power (kW)</td>
<td>3250</td>
<td></td>
</tr>
<tr>
<td>Boiler power (BHP)</td>
<td>330</td>
<td></td>
</tr>
<tr>
<td>Kiln price ($US)</td>
<td>356,000</td>
<td>490,000</td>
</tr>
<tr>
<td>Wood waste boiler price ($US)</td>
<td>320,000</td>
<td>320,000</td>
</tr>
<tr>
<td>Total cost ($US)</td>
<td>676,000</td>
<td>810,000</td>
</tr>
</tbody>
</table>

For the same annual dry wood production, UHT equipment is 17% cheaper. The chamber is actually 80% smaller, but there are many fixed costs. For example, the boiler size will be similar for both system and components such as fans, heating coils etc., need to be able to withstand the more severe operating environment and accommodate the faster drying rate.

The main advantage of UHT drying is its flexibility. A smaller kiln means a smaller load so, in theory, it should be easier to prepare charges with uniform material. In the example presented in Table 6 the kiln load is only 1/5th of that required for a conventional kiln. The other factor affecting flexibility is the shorter processing time associated with drying. This is due firstly to the shorter drying time and secondly to the shorter period required to accumulate a kiln.
5.1.4.2 Continuous flow package kilns

5.1.4.2.1 Industrial application of continuous flow

Continuous flow kilns are most commonly used in Scandinavia but are also being employed elsewhere in the world. Most of the current manufacturers of this kiln type were at the LIGNA exhibition in 2009. WSAB, Valutec, Hildebrand and Katres are the main European companies offering this type of drying technology. In North-America, the company USNR offers a counter flow continuous dryer more known under the brand name Triple-Length kiln. In Australia and New Zealand, Windsor Technology also offers continuous flow kilns. The main advantages of this drying technology are better energy efficiency and also better kiln uptime because there’s no need to stop and restart the kiln. The following sections present more details on the USNR and Valutec continuous flow systems.

5.1.4.2.2 Counterflow design continuous kilns in U.S.

The triple length kiln is a concept developed by Andy Pollard of Pollard Lumber. Several years ago, Mr. Pollard came up with an idea to modify one of their existing track kilns into a continuous flow kiln. Pollard Lumber approached USNR to get their assistance in developing the concept into an actual working kiln. The result was the complete rebuild of their existing kiln from the ground up. The original kiln was a double-track kiln approximately 80-ft long. The final product was a 240-ft long, double-track kiln with three zones. The report on the visit to this site along with discussion on the relative merits and potential issues related to applying this technology is provided in Appendix II. Figure 6 is an overhead schematic of the kiln showing the material flow.

![Figure 6 Overhead view of triple length, continuous flow dry kiln (patented process) as designed by Pollard Lumber and manufactured by several kiln companies including USNR and Windsor Technology](image)

5.1.4.2.3 Single direction continuous feed kilns in Europe

One of the biggest European kiln manufactures that supplies continuous flow kilns is Valutec. Representatives of this company were met in Sweden in November 2010 to get more information about their kilns’ characteristics and cost.

The type of continuous flow kilns offered by Valutec are different than the triple length continuous flow kilns described in the previous section. For example, the European designs are based on packages moving in a single (versus counterflow) direction. The chamber is fully sealed with loading doors on both kiln ends and an active heat recovery system. This last characteristic is important in colder climates.
as it helps eliminate condensation and ice build up during winter months. The presence of doors does create some issues when it comes to loading and achieving maximum kiln volume utilization. Drying is achieved by moving bundles from one zone to the next with different drying conditions in each section. For a given product/species, the time per section is regulated and bundles move on a time basis. There are two types of kilns: transverse and longitudinal. The longitudinal feed is the one of most interest for Canadian applications as it does provide more flexibility in package lengths. This feed arrangement is incorporated in the Triple Length kiln configuration described previously.

The resource dried in Sweden that is a mix of Scots pine (Pinus sylvestris) and Norway spruce (Picea abies). It is common practice in Scandinavia, however, to sort these species and process them separately. Valutec guarantees a standard deviation on final moisture content of 10% of the average final moisture content even in their batch type kilns. For a final MC of 15% this would mean a target final SD of 1.5%. That would be a very tight distribution for Canadian SPF lumber, which is typically dried in batch kilns and the species are mixed. The more uniform characteristics of the Scandinavian resource makes it possible to achieve good uniform drying that makes the option of a continuous flow kiln more viable. For Canadian SPF, it would be difficult to avoid overdrying if all the pieces are to be dried below 19%, especially if species are not sorted. In this case adding a redrying option to a continuous flow kiln would help produce a uniform final MC.

During the visit, one of the objectives was to gather information to compare capital cost of continuous flow kiln technology versus traditional batch type kilns. This was to help evaluate applications in a Canadian setting from an economic perspective. The following price comparison has been made between a progressive TC kiln (longitudinal) and traditional batch kilns based on the same output of dry wood per year. Table 7 shows the comparative capital cost for 170 000 m³ (85 000 Mbf) annual dry wood production.

Table 7  Capital cost comparison of equipment between a progressive TC kiln and a traditional batch kiln

<table>
<thead>
<tr>
<th></th>
<th>Progressive TC</th>
<th>Traditional batch kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual dry production (m³)</td>
<td>170 000</td>
<td></td>
</tr>
<tr>
<td>Number of kilns</td>
<td>1</td>
<td>8 of 53 Mbf capacity</td>
</tr>
<tr>
<td>Price per kiln (CAN $)</td>
<td>$3.54 million</td>
<td>$0.54 million</td>
</tr>
<tr>
<td>Total price</td>
<td>$3.54 million</td>
<td>$4.32 million</td>
</tr>
</tbody>
</table>

Progressive kiln TC capital cost, for the same dried volume per year, is less expensive than traditional kilns. In Canada, for conventional kiln, the rough price of the equipment including energy system can be estimated roughly at $8,000 to $10,000/Mbf kiln capacity. The price of Valutec traditional batch kiln corresponds to approximately $10,286/Mbf kiln capacity. On this basis, a progressive TC kiln for the Canadian market would be competitive with the existing technology.

The Valutec Company also manufactures transverse continuous feed kilns called “FB” or “OTC”. Table 8 shows the price comparison for those types of continuous kilns versus the progressive TC type of kiln based on an equivalent annual dry wood production capacity.
### Table 8 Capital cost comparison between progressive TC and transverse progressive (FB or OTC) based on an equivalent annual dry lumber production capacity

<table>
<thead>
<tr>
<th></th>
<th>Progressive TC</th>
<th>Progressive transverse (FB or OTC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual dry production (m³)</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Number of kilns</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Price (CAN $)</td>
<td>$2.15 million</td>
<td>$1.85 million</td>
</tr>
</tbody>
</table>

Progressive transverse kilns are a little bit cheaper that the progressive TC, therefore Valutec’s progressive kilns can be competitive and could be implemented in Canada if all the other characteristics of that type of equipment fit well with the process.

Salin (2006) did a major comparative study within progressive transverse kilns and traditional batch kilns mostly on drying cost and on energy consumption. The conclusions are significant. The energy consumption is reduced by 10-15% for progressive kilns, which can be explained partially by better heat recovery in progressive kilns that is recovered mostly in the first zone (always wet hot air). The drying cost is lower by 20-30% and this can be explained by less energy consumption, but also by the lower capital cost for the progressive kilns for the same volume dried in a given period. The information gathered on capital cost during the visit and presented in the two tables above show that progressive kilns are in fact less expensive than traditional batch kilns for the same amount of wood dried in a period.

### 5.1.5 Meetings with other researchers

In 2009, just prior to the visit to the LIGNA exhibition in Germany, a meeting was held with Professor Helmuth Resch from the University of Natural Resources, Vienna, Austria. Prof. Resch met with Vincent Lavoie of FPInnovations to discuss the work he has performed in his career on high frequency electric current drying of wood. The main objective of this meeting was to share mutual experiences on using radio frequency energy to dry wood. Vincent Lavoie presented a summary of the work done since 2001 by FPInnovations and Hydro-Québec on RFV drying and continuous RF drying/re-drying. Professor Resch has subsequently included most of the results presented by Vincent Lavoie in a new publication called “Drying Wood with High Frequency Electric Current” edited by the Society of Wood Science and Technology published in 2009.

### 5.2 Results of drying trials

#### 5.2.1 Ultra-high temperature drying

##### 5.2.1.1 Drying times

Seven test charges were run. Four charges were comprised strictly of lodgepole pine and the remaining three of white spruce. A range of different drying conditions was tested with the conditions of each being determined after evaluating drying times and quality from the previous test(s). A sample drying schedule and drying curve are presented in Figure 7 for Test No. 2 (lodgepole pine).
As with the press-drying tests, it was difficult to stop drying at a specific MC. As a result, there is some variability in the final MCs listed in Table 9. Despite that, there is a definite trend between maximum drying temperature employed and the drying time observed. This trend is shown in Figure 8. In these tests, both white spruce and lodgepole pine showed a positive relationship between drying temperature and time. Drying times reduce dramatically once the maximum temperatures start to exceed the boiling point.

Table 9  Summary of ultra-high temperature drying results for white spruce and lodgepole pine. Each test included approximately 40 samples

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Species</th>
<th>Max. kiln temp. (°C.)</th>
<th>Initial MC</th>
<th>Final MC</th>
<th>Std. dev. on final MC</th>
<th>Drying time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L. pine</td>
<td>160°</td>
<td>64.9</td>
<td>12.0</td>
<td>2.4</td>
<td>4.3</td>
</tr>
<tr>
<td>2</td>
<td>L. pine</td>
<td>180°</td>
<td>65.4</td>
<td>12.2</td>
<td>2.9</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>L. pine</td>
<td>90°</td>
<td>63.0</td>
<td>13.8</td>
<td>1.8</td>
<td>50.0</td>
</tr>
<tr>
<td>4</td>
<td>L. pine</td>
<td>100 – 180°</td>
<td>62.3</td>
<td>13.7</td>
<td>5.4</td>
<td>5.8</td>
</tr>
<tr>
<td>5</td>
<td>W. spruce</td>
<td>160°</td>
<td>42.4</td>
<td>6.1</td>
<td>1.4</td>
<td>7.5</td>
</tr>
<tr>
<td>6</td>
<td>W. spruce</td>
<td>90°</td>
<td>49.1</td>
<td>9.6</td>
<td>1.7</td>
<td>69.4</td>
</tr>
<tr>
<td>7</td>
<td>W. spruce</td>
<td>130°</td>
<td>46.1</td>
<td>10.1</td>
<td>2.8</td>
<td>20.8</td>
</tr>
</tbody>
</table>
Figure 8  Drying time in at high and ultra-high temperature drying regimes

5.2.1.2 Drying quality

The major concern with drying at ultra-high temperature is the development of internal checking (honeycomb). Figure 9 shows the incidence and severity of the internal checking in two charges of pine and spruce dried under similar conditions. The incidence and severity of checking in lodgepole pine was less than in spruce. Since there were more samples than with the press-drying tests, it was possible to categorize and summarize the results by severity of internal checking. These results are listed in Table 10. Test No. 1 (pine) and Test No. 5 (spruce) were both dried with maximum kiln temperatures of 160° C, but show very different results with regard to the incidence of internal checking.
Figure 9  Internal checking as observed on crosscut sections of spruce (top photo) and pine both dried at a maximum kiln temperature of 160° C

Table 10  Incidence of internal checking by severity in test charges of ultra-high temperature dried spruce and pine

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Species</th>
<th># of Samples Evaluated</th>
<th>Incidence (# of samples) of Internal Checking by Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Lodgepole pine</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Lodgepole pine</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Lodgepole pine</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Lodgepole pine</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>White spruce</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>White spruce</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>White spruce</td>
<td>20</td>
<td>4</td>
</tr>
</tbody>
</table>
5.2.1.3 Equipment considerations and cost

Ultra-high temperature drying is achieved in a chamber that is similar to conventional dry kilns. Due to the temperatures employed and the drying rates achieved, however, the construction and capacity details are different. In short, higher performance materials must be used for most aspects of the construction. In addition, all of the operational functions of the kiln must be sized to accommodate the faster drying rate. These factors drive up the cost of the chamber on a per unit lumber holding capacity. When these prices are factored based on the productive capacity of the equipment, the capital cost comparison with conventional drying becomes more attractive.

The capital cost of a conventional kiln drying on a typical industrial schedule would be approximately $42/Mbf of annual kiln productivity. Through discussions with a kiln manufacturer, we were able to collect some comparative information for a kiln capable of operating at ultra-high temperature. Table 11 shows a comparison of the capital cost based both on the cost per unit of kiln capacity as well as on the cost expressed based on the productive capacity of the kiln. The later is influenced heavily by the assumptions made on drying time.

**Table 11  Capital cost comparison for a conventional dry kiln versus an ultra-high temperature kiln**

<table>
<thead>
<tr>
<th>Kiln Type</th>
<th>Drying Time (hrs)</th>
<th>Capital Cost¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$/Mbf lumber holding capacity</td>
</tr>
<tr>
<td>Conventional</td>
<td>40</td>
<td>$8,500</td>
</tr>
<tr>
<td>Ultra-high temperature</td>
<td>8</td>
<td>$35,600</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>$35,600</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>$35,600</td>
</tr>
</tbody>
</table>

¹ Capital cost estimates include kiln and energy system.

From this basic analysis, there are some distinct economic advantages to be gained from drying more rapidly, even in a batch type kiln. Although a batch kiln does not fit with the concept of continuous flow, by dramatically reducing the drying time, the material flow at a mill can be streamlined. This is explored further in the sections on lean manufacturing.

5.2.2 Press drying

5.2.2.1 Drying times

A DC-resistance moisture meter was used to estimate when the end point was reached during each of the drying trials. Some experience was required to adjust readings for the effect of the high wood temperatures achieved and the moisture gradients created. As a result, there is some variability in the final MC. Table 12 shows a summary of the drying times and final moisture content for all 10 charges.
**Table 12**  Drying times plus initial and final moisture content for press-dried white spruce and jack pine

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Species</th>
<th>Press Temp. Range (°C.)</th>
<th>Initial MC</th>
<th>Final MC</th>
<th>Drying Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>White spruce</td>
<td>192-236</td>
<td>46</td>
<td>2</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>White spruce</td>
<td>183-184</td>
<td>37</td>
<td>13</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>White spruce</td>
<td>155-165</td>
<td>37</td>
<td>17</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>White spruce</td>
<td>165-137</td>
<td>33</td>
<td>18</td>
<td>120</td>
</tr>
<tr>
<td>5</td>
<td>White spruce</td>
<td>163-136</td>
<td>33</td>
<td>20</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>White spruce</td>
<td>120-138</td>
<td>32</td>
<td>14</td>
<td>360</td>
</tr>
<tr>
<td>7</td>
<td>White spruce</td>
<td>79-161</td>
<td>32</td>
<td>17</td>
<td>90</td>
</tr>
<tr>
<td>8</td>
<td>Jack pine</td>
<td>137-141</td>
<td>31</td>
<td>15</td>
<td>120</td>
</tr>
<tr>
<td>9</td>
<td>Jack pine</td>
<td>158-162</td>
<td>30</td>
<td>18</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>Jack pine</td>
<td>178-182</td>
<td>31</td>
<td>12</td>
<td>45</td>
</tr>
</tbody>
</table>

All charges, except Test No. 1 were stopped with a final average MC between 12 and 20%. One of the challenges for any drying system, but even more critical with rapid drying techniques, is determining when to terminate drying. If a rapid drying technique, such as press drying, is to be used as the full drying treatment, it would have to be linked with a sophisticated and accurate on-line moisture sensing system.

Figure 10 shows the relationship between drying time and maximum drying temperature. It is quite clear that spruce responds differently from jack pine. Jack pine is a much more permeable wood and as drying temperature increases, the wood is able to release the moisture vapour generated. With white spruce, there is less of a positive relationship between drying temperature and drying time.

![Figure 10](image-url)  
*Figure 10  Press drying times as related to maximum drying (press platen) temperature*
Due to the rapid heating through direct contact, wood temperatures quickly exceeded the boiling point except for Test No. 7 where the temperature was ramped more gradually. Because of the high internal wood temperature, water was being evaporated within the wood and built up internal pressure. At some points in the process, mini steam explosions could be heard coming from the wood in the press. These steam explosions were more frequent and noticeable with spruce than with pine. This again indicated the limitations in drying spruce too rapidly. This also had implications with regard to wood quality.

For a rapid drying system to be effective, it must be able to move core moisture out quickly and keep moisture gradients as low as possible during the drying process. The moisture gradient was measured by taking shell and core oven-dry MC sections immediately after drying. The moisture gradient present at this time is an indication of the severity of the drying conditions. Table 13 shows the average shell and core MCs for all of the press-dried test charges. Despite having similar initial MCs, the spruce charges had a higher final core MC. The final average core MC for the six spruce test runs (# 2 to 6) was 23.9% versus 22.3% for the three pine charges. The higher core MCs in spruce are likely a contributing factor for interior checking that developed.

### Table 13  Average shell and core MC for press-dried test charges

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Species</th>
<th>Final Average MC</th>
<th>Final Shell MC</th>
<th>Final Core MC</th>
<th>Δ MC (Shell to Core)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>White spruce</td>
<td>2.1</td>
<td>1.6</td>
<td>2.6</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>White spruce</td>
<td>13.0</td>
<td>5.1</td>
<td>21.0</td>
<td>15.9</td>
</tr>
<tr>
<td>3</td>
<td>White spruce</td>
<td>17.5</td>
<td>10.9</td>
<td>25.6</td>
<td>14.7</td>
</tr>
<tr>
<td>4</td>
<td>White spruce</td>
<td>17.7</td>
<td>12.4</td>
<td>27.3</td>
<td>14.9</td>
</tr>
<tr>
<td>5</td>
<td>White spruce</td>
<td>20.2</td>
<td>13.6</td>
<td>26.8</td>
<td>13.2</td>
</tr>
<tr>
<td>6</td>
<td>White spruce</td>
<td>14.3</td>
<td>6.6</td>
<td>17.8</td>
<td>11.2</td>
</tr>
<tr>
<td>7</td>
<td>White spruce</td>
<td>17.0</td>
<td>11.1</td>
<td>24.9</td>
<td>13.8</td>
</tr>
<tr>
<td>8</td>
<td>Jack pine</td>
<td>14.5</td>
<td>9.3</td>
<td>24.1</td>
<td>14.8</td>
</tr>
<tr>
<td>9</td>
<td>Jack pine</td>
<td>17.8</td>
<td>9.5</td>
<td>21.1</td>
<td>11.6</td>
</tr>
<tr>
<td>10</td>
<td>Jack pine</td>
<td>11.6</td>
<td>6.4</td>
<td>22.3</td>
<td>15.9</td>
</tr>
</tbody>
</table>

#### 5.2.2.2 Drying quality

Drying defects can be in the form of warp, stain, and checking (surface and internal). The scope of this study did not allow for full-scale testing of full-sized pieces of lumber. Due to the short length of the samples used (approx. 60 cm.), it was impossible to make any observations with regard to warp. For the most part, colour is not an issue for construction grade lumber. Although the wood was darkened by the exposure to high temperatures, it was not changed appreciably in appearance and this would not affect its marketability.

The significant factor affecting quality was the presence of surface and internal checking. Rapid drying can create severe moisture gradients. The first consequence of this is surface checking as the shell dries below the fibre saturation point as the core remains above. Surface checking was present on a number of samples, but was generally not severe enough on its own to be a downgrading factor for construction grade lumber.

Later during drying, the shell becomes set in a stretched condition and, as the core then dries it starts to shrink and create internal tensile stresses. If these exceed the strength of the wood, internal splits
(honeycomb) will develop. Internal checks were prevalent in all of the tests conducted. Internal checking was more severe and more widespread in spruce than it was in pine. As shown in Figure 11, most spruce samples had some internal checking. As shown in Figure 12, the incidence of internal checking in jack pine was significantly less. Normal seasoning checks (including honeycomb) are not an issue for dimension and stud grade lumber. However, the extent of internal checking on the spruce charges may be a concern with regard to impact on strength, machinability, and workability.

**Figure 11** Typical pattern of internal checking found in press-dried spruce. These samples were from Test No. 5 dried with a maximum platen temperature of 163° C

**Figure 12** Lower incidence and less severe internal checking present in press-dried jack pine. These samples were from Test No. 9 dried with a platen temperature of 160° C
5.2.2.3 Equipment considerations and cost

Press drying equipment is capital intensive when compared to conventional batch type kilns. The only way to recover the extra investment is from the faster drying times and any benefits associated with a faster drying time (see section on lean manufacturing). In this section, the comparisons will be based strictly on the capital cost per unit of production.

A conventional, heat-and-vent kiln operating at temperatures up to 93° C (200° F) is a typical drying system currently used in the SPF industry. At those temperatures, drying times will range from about 30 hours for jack pine, to 50 – 60 hours for black spruce, to 100 hrs plus for balsam fir. Capital cost for a conventional dry kiln operating with an average drying time of 40 hours will be approximately $42/Mbf of annual kiln productivity. The drying times from the press-drying trials described above were used to determine the required size for a press. Cost estimates obtained from a press manufacturer were used to develop a rough estimate of the capital cost of an industrial-scale press-drying system. For spruce with a drying time of 6 hours, the capital cost would be approximately $489/Mbf of annual production. For jack pine with a drying time of 2 hours, the capital cost would be approximately $163/Mbf of annual production. To achieve a capital cost ratio close to that of a conventional drying operation, the press-drying time would need to be reduced to approximately 30 minutes.

In addition to the cost, the size of the equipment is another consideration. Within the context of this project, the objective was to investigate drying technologies that could potentially be implemented in an in-line and continuous flow mode. To achieve this; a continuous press would be the only solution. Multi-opening presses are available; however, they would need to be operated in a batch mode. The estimated press area to achieve 200 million board feet of annual production is as follows:

- 6 hr. drying time (spruce) 6,600 m² of platen area
- 2 hr. drying time (jack pine) 2,200 m² of platen area
- 30 minute drying time 540 m² of platen area

Based on the above, it appears that press drying of construction grade SPF lumber would be unviable from an economic and technical standpoint.

5.2.3 Continuous RF drying

A summary of key results from this study is presented in the following sections.

5.2.3.1 Drying times

Continuous RF drying tests on spruce lumber from green to dry were conducted to establish the maximum attainable speed of drying with this method consistent with obtaining acceptable quality. Quality was assessed on the presence of stress-related defects including internal checks, surface checks, and splits. Warp was the only aspect of quality that was not assessed. A full assessment of warp can only be conducted on full-size lumber with large numbers of samples included. The optimum drying time to achieve good quality in 51mm thick spruce was approximately 2 hours. The power density to achieve this drying time was approximately 93 kW/m³ (voltage 1.2 kV).

5.2.3.2 Drying quality

The quality assessment was mostly qualitative. The main criterion was the presence of observed internal checking because the realization of most of the pieces had a length of 1.22 meters. Very little checking was observed when drying with the operating parameters at a power density of 93 kW/m³ and a voltage of 1.2 kV.
5.2.3.3 Equipment considerations and cost

Some operating parameters were used to determine the total power required to dry an annual production of 200,000 Mbf lumber in an industrial-scale kiln. The RF power required to dry the wood volume would be approximately 16,535 kW. The cost of such drying equipment is estimated at $50 million. The electrical energy cost for drying black spruce is estimated at $22/Mbf based on electricity rate of $0.07 per kWh. The main concerns regarding the feasibility of continuous RF drying of lumber are technical. There are no generators of this size and the only solution would be to combine several units in parallel. Theoretically, it would be necessary to install 110 power-generating units of 150 kW on an electrode surface of about 4000 m², which would be difficult to achieve because each generator must be connected individually with an electrode, requiring 110 electrodes of 37 m² each.

The use of continuous RF drying in the lumber industry should for now be limited only to applications that require drying a fraction of the total volume produced at the plant and/or for situations involving lesser amounts of moisture reduction. For example, one application might be to re-dry components remaining above specification after a first drying cycle. This would require only a small proportion of the total population to be dried and a relatively small reduction in moisture content. RF continuous drying could also be used to dry a proportion of output pre-sorted at the mill. As an example, material that reaches the sawmill in a partially dry condition could be removed from the rest (green portion) of the production and dried separately. Again, the objective would be to deal with only a small proportion of material that requires only a minimal amount of drying.

5.2.4 Continuous RF re-drying

5.2.4.1 Concept of re-drying

The term intentional re-drying refers to a program that deliberately leaves some lumber above the intended final MC to avoid overdrying the majority of material. The material remaining above the intended final MC is then separated and directed to a secondary drying process for re-drying. This approach leads to the following advantages:

- Reduced drying degrade
- Increase productivity of primary drying facility
- Decrease the overall energy consumption
- Eliminate “kiln wet” production
- The potential to assure MC conformity for 100% of production

A continuous RF re-drying process is more attractive than a batch re-drying process primarily because there is no need to re-stack and handle packages of lumber and associated inventories. This type of re-drying system can potentially be linked with various types of primary drying systems including some of the continuous flow package kilns and rapid drying technologies evaluated in this study. One of the problems associated with processing the Canadian SPF lumber mix is that of final MC variability. With an effective way of dealing with “wets”, a wider range of primary drying systems can be considered.

A second comparative study on re-drying (RF continuous vs conventional) was conducted in 2009. Matched boards coming from the same logs were evaluated using a conventional drying approach and an intentional re-drying approach using continuous RF. The complete report² can be obtained from LTE (Hydro-Quebec) upon request (French only).

The main conclusions of the study are the following:

- The trials validated that when re-drying using RF, the rate of drying of wetter pieces is faster than that for the drier pieces. As a result, a narrow range of final MC is achieved.
- For the same final MC for matched samples, there was a reduction in the amount of drying degrade when continuous RF re-drying was employed. The proportion of pieces degraded according to NLGA grading rules was 7% for the continuous RF process and 14% for the conventional process.
- The final MC gradient was more severe (greater difference between shell and core) for pieces re-dried by the conventional process than by the continuous RF process. The surface moisture content was consistently lower on pieces re-dried by the conventional process even when the average final moisture content was higher.
- An in-line moisture scanning system integrated with a continuous RF re-drying system would further improve the final MC distribution.
- Drying degrade observed on pieces re-dried by the continuous RF process was not higher than that observed on pieces re-dried by the conventional process with top restraint of 92 pounds/ft².
- The drying trials have developed data that permit the development of a technical-economical model. The monetary impact of implementing a continuous RF re-drying system has been calculated for a mill with an annual production capacity of 100 MMbf of primarily black spruce dimension lumber. The monetary gains associated with re-drying up to 20% of the production stem from an increase in the proportion of MSR lumber produced, a reduction in drying degrade, a reduction in energy consumption, and an increase in the volume recovery of usable wood. The total of these benefits has been estimated at up to $1.0 million annually in a situation where the existing kilns can already handle the drying capacity needs and $1.6 million when an under capacity situation exists. Given that the equipment cost for this industrial scenario is estimated at $2.0 million, it makes the approach both technically and economically viable.
- Total residence time in the continuous RF kiln to re-dry pieces is estimated at between 14 and 18 minutes depending on the shutdown strategy employed with the primary (conventional) kilns.
- The next step in proving the feasibility of this approach is to develop a semi-industrial scale pilot plant for re-drying “wets” from a commercial primary drying operation.

5.3 Lean manufacturing and drying

5.3.1 Introduction to the principle of lean manufacturing

In December 2010, a workshop was organized in Quebec City on lean manufacturing with specific focus on integrating rapid drying or continuous flow drying technology in industrial operations. This workshop was lead by Gilbert Steinke, an FPInnovations Industrial Advisor and certified lean manufacturing specialist.

Lean manufacturing involves improving efficiency by eliminating steps in the process that either interfere with material flow or do not add value to the final product. Drying is obviously a value-adding step in lumber manufacturing, but the material flow is interrupted significantly when traditional drying practices are employed. In particular, the significant handling steps and inventories involved both between the sawmill and kilns as well as between the kilns and planer mill add significantly to the cost of manufacture and introduce opportunities to lose value. Current batch drying processes are often the bottleneck in the operation due to the inability to match dry lumber output with planer mill production. The main fundamental principles of lean manufacturing are the following:
a. Value added vs Non value added
b. Waste / Muda
c. Value Stream Mapping
d. Visual Management
e. 5 S
f. Setup reduction
g. Quality at the source
h. Pull and Flow
i. Total Productive Maintenance

The lean transformation is intended to lead to growth with minimal capital investment, without increasing employees and in a manner to improve margins.

Traditional drying practices are based on a batch process requiring large inventories of material to be accumulated before and after drying. Traditional drying operations in a sawmill are designed to achieve a given annual production capacity. The most common way to define the equipment needs for a SPF drying operation in Canada is to take the annual production capacity requirement and divide it by a single kiln capacity of between 200 and 300 Mbf.

As a result, many of the activities associated with drying in this manner do not fit well with the concept of lean manufacturing. The multiple handling and inventory steps introduce extra cost and value loss. In drying the only value added operation is what takes place in the kiln(s) itself. Operations that are done before and after the kilns are not value adding steps. Examples of these non value adding steps are stacking, wood handling, inventories, and unstacking. The main waste in the drying operation is associated with the inventories required to keep the kilns operating at capacity.

The lean exercise for this project has focused on the three first fundamental principles. The single principle that has been studied more extensively is that of value stream mapping, which is presented in the next section.

5.3.2 Value stream mapping exercise for a typical SPF drying operation

A value stream map is way of listing all the actions (both value adding and non-value adding) required to bring a product through the main flows essential to every product. Value stream mapping provides a way to visualize the production flow from the customer demand back through to the raw material supply, which is the flow we usually relate to lean manufacturing. It is this area, many have struggled to implement lean methods. A simple way to explain value stream mapping is to follow a product’s production path from customer to raw material supplier, carefully draw a visual representation of every process in the material and information flow and finally ask a set of key questions and draw a future state map of how value should flow. Figure 13 presents the value stream mapping for a typical SPF drying operation based on the hypothesis presented in Table 14.
### Table 14  Hypothesis and assumptions used to develop the value stream map shown in Figure 13

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual volume</strong></td>
<td>150,000 Mbf</td>
</tr>
<tr>
<td><strong>Species</strong></td>
<td>Jack pine</td>
</tr>
<tr>
<td><strong>Weeks of operation per year</strong></td>
<td>50</td>
</tr>
<tr>
<td><strong>Operation days per week (planer mill)</strong></td>
<td>5</td>
</tr>
<tr>
<td><strong>Number of shifts per day (planer mill)</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Production per shift (planer mill)</strong></td>
<td>300 Mbf</td>
</tr>
<tr>
<td><strong>Hours per shift</strong></td>
<td>8</td>
</tr>
<tr>
<td><strong>Time available per year (planer mill)</strong></td>
<td>4,000</td>
</tr>
<tr>
<td><strong>Takt time (available time/costumer need)</strong></td>
<td>96 sec/Mbf</td>
</tr>
<tr>
<td><strong>Drying time</strong></td>
<td>42 hours</td>
</tr>
<tr>
<td><strong>Time available for drying per year with uptime of 94%</strong></td>
<td>7,875 hours</td>
</tr>
<tr>
<td><strong>Required drying capacity (4 kilns)</strong></td>
<td>800 Mbf</td>
</tr>
</tbody>
</table>

![Value Stream Map](image-url)  

**Figure 13 Drying process value stream mapping for a hypothetical industrial drying operation**

As mentioned above, the value stream mapping exercise starts from the customer need. In the above example, it has been established by the annual production requirement for the mill. That permitted the determination of the takt time that is, by definition, the available time divided by the customer demand. In our example, the takt time is 96 s/Mbf. For the drying portion of the operation, the drying time alone requires 189 s/Mbf, which is almost double the takt time for the mill. That is a normal situation and can be explained by the fact that operating time is not balanced between the sawmill, planer mill, and the kilns. The sawmill and the planer mill operate 16 hours per day and 5 days a week comparatively to 7 days, 24 hours/day for the kilns.

The only value-adding operation in the mapping presented in Figure 13 is the drying operation itself. All the inventories are waste and all the handling are non-value adding steps in the process. There are reasons why inventories are created in the actual process and it is not related to the kiln capacity since on
Applying Rapid Drying Technologies to Canadian SPF Lumber

a weekly basis the kilns are able to dry the volume produced by the sawmill. Here are some of the major reasons why inventories (green and dry) are created:

- The sawmill is in a push mode; many products/species are produced
- The kiln capacity is only designed on an annual dry volume need and not to accommodate the varying material flow characteristics coming from the sawmill
- Material must typically be sorted by products, species, and length to produce uniform charges that can be dried on aggressive drying schedules and therefore maximize kiln capacity utilization etc.
- The individual kiln capacities are very large so time is needed to accumulate enough material to form uniform product/species/length charges.
- The planer mill is operated in a batch mode; the same product is surfaced for a given period since it takes time to changeover from one product to another.
- The production of the sawmill/planer mill is not balanced with the drying operation.
- The sales department pulls the production not from the sawmill, but from the green and dry inventories.

As part of this exercise different operating scenarios were evaluated. They were all based on being able to better respond to customer needs in a timely manner. The three scenarios studied are listed below:

1. Batch drying – Reduction of inventories and handling (no green and dry yards)
2. Continuous flow packages – Reduction of inventories and handling (no green and dry yards)
3. Continuous piece by piece (7 days a week, 24 hours operation)

Table 15 presents the impact on production lead time for a current operating scenario versus the three changed operating scenarios listed above.

**Table 15  Value stream mapping production lead time results for different potential scenarios as compared to a typical current operating pattern**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Value added time (drying time)</th>
<th>Total treatment time</th>
<th>Production Lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>189 sec/Mpm</td>
<td>384 sec/Mbf</td>
<td>29.3 shifts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.93 weeks</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>189 sec/Mpm</td>
<td>249 sec/Mbf</td>
<td>5.3 shifts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.53 weeks</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>189 sec/Mpm</td>
<td>249 sec/Mbf</td>
<td>5.5 shifts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.55 weeks</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>201 sec/Mpm</td>
<td>201 sec/Mbf</td>
<td>0 shift</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 week</td>
</tr>
</tbody>
</table>

* Actual scenario consists to batch drying with green and dry yard inventories before and after drying

Table 16 shows that from a client response perspective, current drying operations are not fast. The drying operations alone can delay the final product delivery to the client by 3 weeks. By just eliminating inventories (green and dry) leads to a very significant reduction in response time of 2.4 weeks. In a scenario of continuous piece by piece, drying there is no delay time created by operations before and after drying (as those operations have been eliminated). This is one reason why such a drying method is so fascinating and interesting to explore in the future.
There is time related to a “non lean” operations, but there are also the costs associated with these activities. Information coming from two actual mills has been collected to establish the approximate the actual cost of all the operations presented in Figure 13 for comparison with projected costs for the proposed new operating scenarios. Table 16 presents the cost comparison.

**Table 16 Value stream mapping costs for different potential scenarios compared to a current operating scenario**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total operational cost per year (millions of $s)</th>
<th>Drying cost per year (millions of $s)</th>
<th>Non value operations costs per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>$3.37</td>
<td>$2.25</td>
<td>$1.12</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>$2.68</td>
<td>$2.25</td>
<td>$0.43</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>$2.68</td>
<td>$2.25</td>
<td>$0.43</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>$2.25</td>
<td>$2.25</td>
<td>0</td>
</tr>
</tbody>
</table>

1 Including drying cost and inventory costs (but not including capital, sorting, stackering and unstacking costs)

Information presented in Table 16 shows that there is no operational cost advantage related to using the continuous flow kiln versus a batch kiln. The main advantage (in both cases) is linked to the elimination of the green and dry yards. The cost difference between a current operating situation versus scenarios 1 and 2 is major and represents $688,000 per year for a mill with an annual production capacity of 150,000 Mbf. The elimination of inventory could facilitate the following:

- Balance the flow in a better way between sawmill/planer mill and the kilns (7 days a week with less production per day for the sawmill and the planer mill)
- Modify the cart system (at entrance and exit side of the kiln) to be able to put all the wood coming out the sawmill directly on kiln carts and take all the dry wood from the kiln carts to feed the planer mill. This would require adding carts and staging areas to existing operations.
- Analyze the sawmill output and combine as much as possible products/species/lengths that can be dried together.
- If new kiln investment is necessary, buy flexible equipment that can handle different products/species/length in a short period of time (smaller capacity chambers)

The other major conclusion is that an in-line drying system would eliminate all the operating costs associated with all the non-value adding steps in a batch approach. This could have a major economic impact on the lumber manufacturing industry.

This exercise has demonstrated that lumber production is one process and not 3 different processes (sawmilling, drying and planing). Drying operations are a major bottleneck in the whole process, but sawmilling and planing operations must be evaluated in collaboration with drying. On the planer mill side, there are also changes to be considered. Most planer mills are not flexible enough. Current equipment is typically set for a given product width and thickness for a given time period. This is driven by the fact that changeover times for equipment are long and result in unacceptable loss in production. To accommodate shorter production lead times, planer operations must be more flexible and able to switch from one product to another in a short time. Technology exists to achieve this flexibility. Our estimate of the cost to install such equipment for a typical SPF mill would be approximately $1.0 million.
6 Conclusions

The overall objective for this project was to demonstrate the potential to apply various rapid drying technologies to achieve the benefits associated with the lean manufacturing approach. This not only entailed options for streamlining the drying process, but also enhancing the industry’s ability to target specific final MC requirements and to better match that attribute to end user needs.

6.1 State of the art in rapid drying technology

6.1.1 Literature review

Based on the findings of a review of existing literature and gathering information on the state of the art; the main rapid drying processes that are of interest from an industrial standpoint for SPF lumber are: ultra-high temperature (UHT) drying at temperatures of 140°C and higher, press drying, and radio-frequency drying.

6.1.2 Commercially available equipment – Continuous flow kilns

- Continuous flow, package-loading kilns offer a way to streamline the drying process without changing the drying conditions and drying times as drastically as that associated with the rapid drying technologies that were investigated.
- Various configurations of continuous flow kilns are currently in use in various parts of the world and could readily be converted for Canadian conditions.
- The main advantages realized with this drying technology are better energy efficiency and improved kiln utilization since there is no time lost due to stoppages for loading and unloading.
- When compared based on productive capacity, the capital cost of a continuous flow package kiln is comparable with conventional, batch-loading kilns. The capital cost for a continuous flow package kiln is in the range of $36 to $42/Mbf annual drying capacity.

6.2 Laboratory testing of rapid drying technologies

- Lab tests were conducted on the three rapid drying processes mentioned above, with RF drying evaluated in both primary and re-drying applications.
- Within the SPF grouping, not all species respond the same to rapid drying techniques.
- Press drying and RF drying (as a standalone drying system) are not economically viable.
- Ultra-high temperature is economically and technically viable for pine species from the SPF grouping.
- RF heating is both technically and economically viable when used as a secondary drying system to redry “wets” from a primary drying system.

6.2.1 Ultra-high temperature tests

6.2.1.1 UHT drying tests

- Lodgepole pine responded a lot better than white spruce under UHT drying conditions.
- The shortest drying time achieved on lodgepole pine was 4 hours. Including provision for a conditioning phase, the total estimated drying time is 8 hours.
- All of the UHT drying trials for white spruce resulted in major deterioration of the wood structure mostly in the form of internal checking.
- At a maximum drying temperature of 130°C, white spruce took 21 hours to dry and still developed unacceptable levels of degrade.
Current high temperature drying conditions (up to about 115°C) would appear to be the maximum that this species can tolerate.

6.2.1.2 UHT equipment considerations and costs

- Capital cost investment for UHT has been estimated based on an 8 hour drying time to be approximately $33.80/Mbf annual drying capacity versus $40.40/Mbf annual drying capacity for a conventional kiln drying facility.
- There are some distinct economic advantages to drying more rapidly, even in a batch type kiln. Although a batch kiln does not fit with the concept of continuous flow, by dramatically reducing the drying time, the material flow at a mill can be streamlined.

6.2.2 Press drying tests

- As with the UHT tests, white spruce responded quite differently from jack pine when dried aggressively in a heated press. Jack pine is a much more permeable wood and therefore water vapour does not become trapped in the core and increase internal pressure. Although it is possible to dry white spruce rapidly, the pressures that are generated internally cause rupturing of the wood structure making it unsuitable even for commodity-grade products.
- Internal checking was more severe and more widespread in white spruce than it was in pine.
- A minimum drying time of 2 hours was achieved for jack pine.
- Even at 6 hours drying time for white spruce, the results were not as good as those obtained in 2 hours for jack pine. The optimum press drying time for 51mm white spruce lumber would be longer than 6 hours.

6.2.2.1 Press drying equipment considerations and costs

- Cost estimates obtained from a press manufacturer were used to develop a rough estimate of the capital cost of an industrial-scale press-drying system. For spruce with a drying time of 6 hours, the capital cost would be approximately $489/ Mbf annual drying capacity. For jack pine with a drying time of 2 hours, the capital cost would be approximately $163/Mbf of annual drying capacity. To achieve a capital cost ratio close to that of conventional drying operations, the press-drying time would need to be reduced to approximately 30 minutes.
- Based on the above, it appears that press drying of construction grade SPF lumber would be unviable from an economic and technical standpoint.

6.2.3 Continuous RF drying

6.2.3.1 RF drying tests

- The minimum drying time (maximum speed) that was achieved with this technology in drying from green to dry for spruce is approximately 2 hours for good quality. The power density required to achieve that drying time was 93 kW/m³ at 1.2 kV.

6.2.3.2 Continuous RF drying equipment considerations and costs

- The capital cost of an RF drying facility to dry from green to the required final MC has been estimated at $250/ Mbf annual drying capacity.
- The energy cost to operate such a kiln has been estimated at $22/Mbf.
- The total installed power need for a mill with an annual production of 200,000 Mbf would be 16,535 kW. Since there are no commercial RF generators of this size, it would be necessary to combine several smaller units in parallel. One scenario would be to install 110 power-generating units.
of 150 kW each on an electrode surface of about 4000 m². This would be difficult to achieve since each generator must be connected individually with an electrode, totaling 110 electrodes of 37 m².

- Continuous RF drying of lumber from a green to final MC is therefore not practical from a technical and economic standpoint.
- Continuous RF drying could be considered for applications where the total moisture reduction is less or for instances where there is a need to remove, and separately handle, a small fraction of the population for a specialized drying treatment.

### 6.2.4 Continuous RF redrying

#### 6.2.4.1 Continuous RF drying tests

- Drying trials have validated that RF re-drying can help improve final MC uniformity. Drying rates for wetter pieces were demonstrated to be faster than for the drier pieces. As a result, a narrower range of final MC is achieved.
- Internal checking was not an issue for material re-dried rapidly presumably due to the absence of free water to cause a build-up of internal vapour pressure.
- Drying degrade due to warp was less for material re-dried in a continuous RF kiln. For matched samples dried to similar final MCs, the proportion of pieces downgraded, based on NLGA grading rules, 7% for the RF continuous process versus 14% for conventional process.
- The moisture gradient in material re-dried in a continuous RF kiln was not as severe as that obtained in a conventionally re-dried product. This can help machining of the final product as an overdry shell can cause problems at the planer mill.
- Integrating an in-line moisture metering system would optimize this process and further improve the ability to achieve a uniform final MC.

#### 6.2.4.2 Continuous RF re-drying equipment considerations and costs

- The experimental data collected provided the information required to conduct a pre-feasibility analysis. The monetary impact of implementing this technology was estimated for a sawmill handling roughly 100 MMbf of black spruce on an annual basis. When compared to a typical conventional, batch drying process, the scenario incorporating continuous RF redrying performed better from an economic standpoint. When re-drying up to 20% of the production benefits from this approach were identified. The gains were due to an increase in the proportion of MSR pieces recovered, a reduction in drying degrade (due to warp), a reduction in energy consumption, and an increase in volume recovery. These benefits amount to approximately $1.0 million annually when considering a kiln installation with surplus drying capacity or $1.6 million per year in an under capacity situation. The capital cost for the continuous RF redrying equipment is estimated at $2.0 million. As a result, this option is both technically and economically viable.
- Residence time in the RF kiln to re-dry pieces is estimated at between 14 and 18 minutes depending on the strategy employed at the primary drying stage and MC of wood entering the redry process.
- The next step in demonstrating the feasibility of this process is the development of a semi-industrial pilot plant to prove that the technology can be scaled up and allow the development of a larger database of redrying results for a wider range of products.

### 6.3 Lean manufacturing aspect of the drying operation

Lean manufacturing involves improving efficiency by eliminating steps in the process that either interfere with material flow or do not add value to the final product. Drying is obviously a value-adding step in lumber manufacturing, but the material flow is interrupted significantly when traditional drying practices are employed.
A value stream mapping exercise was conducted to compare traditional drying processes/practices versus various change scenarios. It was apparent that many of the activities associated with traditional drying do not fit well with the concept of lean manufacturing. The multiple handling and inventory steps introduce extra cost and value loss. Here are some major factors contributing to lower efficiency with current practices:

- The sawmill typically operates in a push mode; many products/species are produced based on the material characteristics and manufacturing systems rather than on the demand.
- Kiln capacity is typically designed around annual dry lumber requirements and not to meet the variations encountered daily, weekly, and monthly.
- To meet production targets with limited drying capacity, the strategy is to sort and accumulate material by species and product.
- Individual kiln capacities are typically very large so time and space is needed to build up sufficient volumes of each.
- Planer mills typically operate in a batch mode; the same product is accumulated and then surfaced for a period of time (usually at least one full shift at a time).
- The production capacities and flow rate of material from the sawmill and to the planer mill are not balanced with the drying operations.
- Due to long delays, sales departments operate by pulling from the final product inventories rather than from the production lines.

Several unconventional operating scenarios were identified and evaluated with the objective of improving response to customer needs. The three scenarios studied are listed below:

1. Batch drying – With reduction of inventories and handling (no green and dry yards)
2. Continuous flow package kilns – Reduction of inventories and handling (no green and dry yards)
3. Continuous flow piece by piece drying (7 days a week, 24 hours operation)

Scenarios 1 and 2 were estimated to reduce operating costs for a 150 million board foot mill by $688,000 per year (or $4.60/Mbf) and reduce the lead (response) time by 2.4 weeks. Scenario 3 has the potential to eliminate certain non-value adding steps and thereby reduce operating costs by $1.12 million per year (or $7.45/Mbf) and reduce the lead time by 2.93 weeks.

The reduction or elimination of inventories can be achieved by various means:

- Balance the material flow between sawmill/planer mill and the kilns (one option is to consider operating 7 days a week with less production per day for the sawmill and the planer mill).
- Modify the package handling and kiln loading/unloading systems to minimize the rehandling of material. (One option to consider is to install more tracks and carts in front of the kilns to allow material to be taken directly from the sawmill to the kiln loading area.)
- Analyze the sawmill output and combine as much as possible products/species/lengths that can be dried together.
- When installing new kilns, design in more flexibility to handle different products/species/lengths in a short period (option to consider more and smaller capacity kilns).
7 References

Anderson A.B. 1956. Control of moisture content in special drying processes. Proceedings of the 8th Western Dry Kiln Clubs meeting. Western Dry Kiln Association, Corvallis, Or.


Appendix I

Mahild UHT Kiln Proposal
Proposal no.: 101130-005,

FPInnovations
Vincent Lavois

,

Ph:
Fax:

Attention:
Date:  9.12.2010
Mahild Direct Dial: +49 7022 66925

MAHILD PROPOSAL NO.: 101130-005-1
1 LUMBER DRYING KILN(S)
Type MH 2000 UHT

Mahild High-Efficiency, High-Performance Timber Drying Kilns
Method of Loading: track loading
Design of Main Door: Lifting/ sliding doors on both ends of kiln

MAHILD DRYING TECHNOLOGIES GMBH
Meisenweg 1, Nurtingen, 72622, Germany
Tel: +49 7022 66925
Fax: +49 7022 62121
www.mahild.com
1. Technical Data: (per kiln)

Package dimensions:

<table>
<thead>
<tr>
<th>Width:</th>
<th>2 x 1200 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length:</td>
<td>3 x 2400 mm</td>
</tr>
<tr>
<td>Height:</td>
<td>3 x 1200 mm</td>
</tr>
</tbody>
</table>

Inside dimensions:

<table>
<thead>
<tr>
<th>Width:</th>
<th>5,7 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length:</td>
<td>7,4 m</td>
</tr>
<tr>
<td>Height:</td>
<td>6,6 m</td>
</tr>
</tbody>
</table>

Number of Doors: 1

Inside Door dimensions:

| Width approx: | 7,4 m |
| Height approx: | 4,55 mm |

PA doors: 2

Capacity net approx.: 38 m³

(42 mm thickness, 20 mm stickers, 90 % Utilization)

Species: Pinus

Initial Moisture Content: 75%

Final Moisture Content: 18%

Installed heating capacity: 2806584 kcal/hr, aprox. 3260 kWterm

Average consumption: 1646142 kcal/hr

Kiln Temperature: Max. 160°C

Heating Medium: PHW, max. 10 bar , 180 /180 °C

Heating Piping: Stainless Steel

Reco bath: 15 Kg/m³h, Stainless steel

Humidification: Cold water spray , 100 bar

No of Fans and motors: 4

Electrical Power required: 4 motors x 30 kW each = 120kW

Nominal air speed: Approx. 12,8 m/sec

Total air capacity: 520000 m³/hr

Phase/ Voltage/ Frequency: 3/575V/ 60Hz
2. Kiln Chamber Design

Mahild kiln chambers have an all-aluminium space-frame design, clad with an insulated aluminium double skin.
The pre-fabricated space-frame structure is constructed of heavy-duty, highly corrosion-resistant, aluminium alloy profiles. These profiles are bolted together during installation using stainless steel nuts and bolts. No field welding is required.
The breathable, double-skin, outside walls are 130mm thick. The thermal insulation is Door: 160mm; Outside wall/ roof: 100mm; Centre wall: 100mm, inert mineral wool, treated against moisture absorption.
During installation high temperature silicon sealants, are used to avoid the formation of thermal bridges.

The Mahild kiln design allows for direct attachment of another kiln via a “common wall” and/or the extension of a kiln’s overall length.
The Mahild kiln door is without doubt the best on the market. It is designed for ease of use, strength, and very good seal design. The robust winch system, is simple, easy to maintain, and easy to operate. The door is built with 200mm thick heavy-duty aluminium profiles, clad with the same aluminium double skin as above. The door slides into a closed position, and is lowered via engineered rollers into many anchoring points. The high-temperature, profiled, rubber door gasket is installed into the door profiles to ensure airtight sealing. This gasket is easily replaceable.
Additional parts needed to construct the kiln such as kiln pipe penetrations, electrical penetrations, roof cladding; rain hoods for the vents are included. These parts will ensure the kiln has a good vapour seal. All kiln parts are aluminium and/or stainless steel, and are resistant against the humid conditions, and acids often released when drying wood, therefore no annual maintenance is required.
3. Internal components

Mahild use heavy-duty, truly reversible, high-efficiency axial fans that ensure very even moisture content distribution in the lumber. The fans come pre-assembled, statically and dynamically balanced. They are mounted directly on a SS motor shaft.

The kiln is heated via flanged, heavy-duty, high-efficiency heat exchangers. They are fabricated using high quality, bi-metallic finned pipe. The finned pipe is made using a stainless steel base tube, with cold drawn aluminium fins. The base tube is resistant against alkaline attack from the heating medium. The aluminium fins are resistant to acid-based products with the kiln environment.
All internal kiln pipe work is made of stainless steel; it is included to the outside wall of the kiln and is supplied with a flange.
Kiln heating valves are electrically actuated. Mahild include manual shut off valves.
Mahild utilise a venting system to reach required relative air humidity.
The “false” ceiling consists of an aluminium frame and sheeting. Overhead, unique profile, horizontal baffles are attached to this frame, and ensure uniform airflow.
The motor control centre (MCC) is included. The pre-wired cabinet meets all Canadian standards, and has heavy-duty contactors, overloads, switches, etc.
4. **Mahild Computer Control System**

Mahild’s MM4000 computer control system is specifically designed for the dry kiln user. It has very precise/accurate, fully automatic control of the kiln conditions to maintain timber quality during drying. Novel features are programmed to make the kiln operator’s job easy.

Each heat zone of the kiln is accurately measured using 2 x dry bulb temperature and 1 x wet bulb sensors. Kiln operators can select their pre-set schedules, and the kiln will operate fully automatic.

Mahild MM4000 standard platform is an Allen Bradley PLC, coupled with Citect MMI SCADA package. Options:

a) Networking to client’s requirements
b) Auto-dialler: phone/text when kiln alarms
c) Online support (needs dedicated phone line)
5. **Scope of Supply**

1. Mahild Drying chamber(s), all-aluminium construction, as described (section 2)
   - Main door design: lifting/ sliding doors with door carriers for opening/ closing

2. PA doors per kiln
1. Set of technical equipment (high efficiency fans, special motors, fan baffles)


1. Set of flanged 304 SS high efficiency reco-bath steam generator

1. Set of overhead baffles (extra heavy baffle design)
1. MCC with contactors/ overloads, etc
1. MM4000 Computer control system for 1 kilns. Consisting of:
   - Hardware: Allen Bradley PLC modules
   - Software: Citect licence
   - Instrumentation: 2 x dry bulb sensors, 1 x wet bulb
   - 8 MC% measuring points
   - Field devices: 240VAC

1. Supervisors for the period of mechanical installation
1. Technician for commissioning
1. Set of foundation and erection plans
2. Sets of Technical manuals
1. Packed and delivered CIF Canadian Port,
6. PRICES

1. All-aluminium, high-efficiency, dry kiln
(Mahild Type MH 2000 ACT) USD 356,000.--

Budget Price information:

1. Wood waste boiler for steam, 10 bar
5,5 to/h USD 320,000.—

1. Boiler as above but for thermo oil
USD 380,000.--

7. Exclusions

a) Geo-technical report of foundation area
b) Civil design of foundations
c) Foundations
d) All council permits
e) Customs clearance
f) Delivery to site from wharf
g) Extra tradesmen to install
h) Scaffolding, Crane, & Forklift service
i) Unloading and storage of materials delivered
j) Heat source, and heating medium
k) All connections to energy sources
l) Control room
m) Electrical cabling and wiring
n) Pressure testing if required
o) All taxes in country and state of destination (Import GST)
8. General Conditions

a) Alteration
   We reserve the right to carry out improvements of construction based on research, development and to change technical details and specification to comply with the latest developments and to suit local conditions

b) Prices and Conditions
   All prices are valid 90 days after proposal date. Price adjustments may then be necessary should any change in production costs occurs

c) Delivery
   Ex-works 12-14 weeks

   The delivery time stipulated in the contract will start after the receipt and approval of LOC, provided that all technical and other details have been defined by that time. Should delivery be delayed by any cause beyond our control, the purchaser shall grant the respective extension of time. Partial deliveries shall be allowed
d) **Terms of Payment**

90% irrevocable LOC payable on receipt of shipping documents (B/L)
5% at start of installation, but not later than 3 months after shipment
5% at start-up, but not later than 6 months after shipment

Option:
30% down
60% against shipping docs
5% at start of installation
5% at start-up

e) **Guarantee Period**

The guarantee period 12 months after completion of erection but not longer than 18 months after shipment, pro rata delivery

f) **General Conditions No.188A**

Unless otherwise stated in the quotation, the “General Conditions for the Supply and Erection of Plants and Machinery for Import and Export No.188A prepared under the Auspices of the United Nations Economic Commission for Europe” shall apply so far as the same are not inconsistent with or excepted by the terms of the quotation
g) **Trade terms**
   Trade terms such as FOB, C+F,CIF shall be interpreted according to the international Rules for the Interpretation of Trade Terms (INCOTERMS)

h) **Extent of delivery**
   The extent of the equipment and machinery covered by our quotation excludes all items that are not expressively specified

MAHILD DRYING TECHNOLOGIES

Michael Lausch (President)
General Conditions of warranty and sales

MAHILD warrants the equipment of its own manufacture which it installs, pursuant to this contract, against defective workmanship and materials for a period of one year from the date of shipment providing equipment has been used in the ordinary and normal course as contemplated under this agreement and which our examination shall disclose to our satisfaction to be defective. MAHILD will not be liable for ordinary wear and tear in the use of the equipment. MAHILD’s liability shall be limited to the fixing or replacement of any equipment or its parts F.O.B. shipping points. Any equipment not manufactured by MAHILD will not be covered under this warranty, but MAHILD does hereby assign to purchaser any warranties made available to MAHILD by the manufacturer of the equipment or materials. This warranty is expressly in lieu of all other warranties, expressed or implied, including the warranties of merchantability and fitness for use and of all other obligations or liabilities on our part. We neither assume nor authorize any other person to assume for us any other liability in connection with this contract. This warranty shall not apply to the equipment manufactured and installed by MAHILD if said equipment has been subject to accident, negligence, alteration, abuse or misuse.

MAHILD makes no warranty as to the fitness of the equipment for a particular use and shall not be liable for any direct, indirect or consequential damages in connection with this agreement and/or use of the equipment. Purchaser agrees to indemnify and save harmless seller from and claims or demands against seller for injuries or damages to third parties resulting from purchaser’s use or ownership of the equipment. MAHILD specifically makes no warranties and assumes no responsibility regarding the construction of the dry kiln, buildings or improvements which are performed by other subcontractors or material furnishers even if the same is a part of the contract. Purchaser agrees to look solely to any such subcontractor, architect, engineer, contractor or material furnisher.

MAHILD will not be responsible for costs incurred from work performed by others on MAHILD equipment unless written authorization is given by MAHILD. MAHILD shall not be liable to the purchaser for any loss or damage suffered by the purchaser, directly or indirectly, as a result of MAHILD’s failure to perform or delay in performing, which is a result of circumstances beyond MAHILD’s control.

MAHILD will not be obligated for claims of shortages or errors unless such claim is made promptly on receipt of shipment. MAHILD will not be obligated for claims of back-charges unless they have been approved in advance, in writing by an executive officer of MAHILD.

Purchaser agrees to provide and maintain casualty insurance with extended coverage in the name of the purchaser and MAHILD, as their interest may appear, to the total value of the contract until the equipment is finally accepted and the contract price is paid in full.

The kiln equipment shall remain the property of MAHILD until the contract is paid full.

For late payment the applicable interest rate is 12.5%.

These general terms and warranties cannot be changed or altered except in writing and signed by an officer of MAHILD. This contract shall be construed according to the laws in Germany.

This contract is based on the use of non-union labor.
Appendix II

Trip report – Pollard Lumber
**Pollard Lumber Visit**

Appling, Georgia

**Date of Visit:** August 19, 2008.

**Purpose of Visit:** View and gather information on the Pollard Lumber/USNR drying technology marketed under the name “Triple Length Kiln”

**Present:**
- Peter Garrahan and Vincent Lavoie of FPInnovations
- Jeff Cowley – USNR
- Andy Pollard – Pollard Lumber

**Overview and Description of Process**

The Triple Length Kiln is a concept developed by Andy Pollard of Pollard Lumber. Several years ago Mr. Pollard came up with a idea to modify one of their existing track kilns into a continuous flow kiln. Pollard Lumber approached USNR to get their assistance in developing the concept into an actual working kiln. The result was the complete rebuild of their existing kiln from the ground up. The original kiln was a double-track kiln approximately 80-ft long. The final product was a 240-ft long, double-track kiln with three zones.

Pollard Lumber is a long-established company involved in the manufacture of southern pine lumber producing NLGA grade dimension lumber. As with many mills in this region, the traditional way of drying their lumber has been in high-temperature kilns operating at temperatures up to about 240° F. The Triple Length Kiln is a variation on high-temperature drying as the maximum temperatures that are achieved are in the same range. Drying time in their batch kiln is approximately 24 hours. The lumber typically comes out well over-dried, especially on the surface, and has to sit outside for a period of time prior to processing at the planer mill. In contrast the lumber from the triple length kiln can be fed directly from the kiln to the planer mill.

The lumber packages are fed from opposite ends on the two tracks. Heat from a direct-fired, sawdust burner is pumped into the central part of the kiln and from there infiltrates the two ends of the kiln. Heat entering the central part of the kiln maintains a temperature in this zone of about 240° F. This causes a rapid drying of the material. Since there are no vents in the central part of the kiln and since this section is positively pressured (from the direct-fired burner), hot-humid air is forced towards the two ends of the kiln. The two ends are not heated (there is a provision to add heat, which is not used in Pollard’s application) and as a result the hot-humid air entering these zones is cooled. The cooling of this air raises its relative humidity and the EMC. Eventually the only channel for air to exit the kilns is from the vents and end doors in the two end sections of the kiln. There are no doors on the kiln. Pollard lumber has installed some baffling near the ends but this does not eliminate the escape of air through the ends. Even in a warm climate (it was about 90° F. the day we visited) there is a tremendous amount of condensation taking place near the ends of the kiln, which is coming into contact with the kiln structure, the wood, and is leaking out onto the ground. For a more northerly application, this condensation would have to be controlled to prevent the build-up of ice in these areas.

The best way to consider the impact of the triple length kiln on the lumber is to follow the progress of a bundle of lumber. The attached diagram shows the three zones in the kiln and the flow of lumber. Lumber entering at either end of the kiln is exposed to warm, humid conditions.
The heat in these areas is a function of the infiltration of heat from the central (heated) zone plus the residual heat in the wood that is passing by on the other track. Both of these are essentially free heat in the sense that it would have been energy lost in a conventional drying system. The high humidity (enthalpy) in this zone ensures that the wood is heated quickly and the high EMC ensures a slow initial drying rate with no over-drying of the surface. In this manner the wood is heated gradually up to the operating temperature.

One of the control variables of this kiln is the speed at which the wood moves through the kiln. The kiln at Pollard was operating at a feed rate of approximately 5 to 6 ft per hour. At this rate the residence time in the kiln is from 40 to 50 hours with approximately 15 (+/-) hours in each zone.

After the wood has been warmed in the first zone it passes into the main drying zone. The dry-bulb temperature in this zone is another control variable. At present Pollard is operating at about 240° F. This can be varied in conjunction with the lumber feed rate to achieve different drying conditions. There are no vents in the central section of the kiln so the wet-bulb temperature is a function of the wood MC, drying rate, and the migration of humidity from the central zone to the two end zones of the kiln. This central (drying) zone of the kiln is essentially a high-temperature kiln operating with an air flow rate of about 1100 fpm. The operating practice at Pollard involves achieving a certain exiting air temperature in this central zone as an indication of whether the wood has achieved the required final MC.

The third zone in the kiln is the same as the entering zone but now the lumber is in a cooling mode. Air passing over the lumber continues to create some drying but at a slower rate due to the high EMC. The EMC in the two end zones is usually about 15% but this likely varies considerably within this zone. The air is cooled as it comes into contact with the entering lumber on the other track which contributes to raising the EMC. The dry lumber is now being equalized in the sense that the high EMC allows the surface to equalize at a higher MC and reduces the moisture gradient within boards. As with any equalization process, higher MC boards will (presumably) continue to dry and thereby reduce the final MC variability.

Airflow in the kiln varies between the three zones. As mentioned previously the central, drying zone has an air flow rate of about 1100 fpm. The two end zones are each split along their length with about 900 fpm in the more central end of each zone and about 500 fpm toward the extreme ends of the kiln. Airflow reverses periodically. There is no need for a variable speed drive on this kiln but some sort of soft start system to reduce peak load on start-up after reversals would be desirable.

**Discussion**

This kiln does dry lumber more slowly and under gentler drying conditions than a typical high temperature kiln. These sorts of drying conditions could be achieved in a batch kiln and therefore the improvement in lumber quality would be attainable in a batch kiln. The main advantages of this kiln are as follows:

- By transferring and re-using energy in various parts of the process the net amount of energy to dry wood is reduced. There does not seem to be any hard data to quantify this yet.
- Since the system is a continuous process the heating load on the burner (or boiler) is virtually constant which means a more efficient overall use of the burner (or boiler). The burner capacity can be matched closely to the kiln demand and it can be sized to run at close to its capacity all of the time. This would be a big factor for a residue-fired system.
This kiln inherently creates a relatively mild drying environment. There is no capacity (as in a conventional kiln) to get overly aggressive with the drying conditions.

Wood from the sawmill can be fed directly into the kiln reducing the amount of green inventory. The gentler drying conditions achieved in this kiln make it possible to mix widths with no apparent negative impact on quality. Pollard Lumber mixes all of their lumber widths and as a result have reduced their green inventory to almost zero.

The continuous output from this kiln and the fact that the wood is equalized in the kiln means that the kiln output can be matched closely to the planer mill capacity and the wood can be moved directly from the kiln to the planer mill.

Some issues would need to be resolved for broader application of this technology:

- Since there are no vents in the central section of this kiln, all of the humidity escapes through the vents in the two end sections and the end doors in the form of water vapour or condensate. Condensation is a major problem in that it contributes to kiln corrosion and in a more Northerly application would result in serious icing issues. Some re-engineering to create more of a closed system would be needed.

- The control system is more or less a trial and error system at this time. General operating guidelines have been developed but there are no developed schedules. This is not a serious disadvantage but it does mean that whoever applies this technology must be prepared to develop their own operating procedures.

- This kiln occupies a larger overall footprint than a single or series of batch kilns designed to achieve the same annual production. On the other hand, the cost per square foot of floor area will be less with this type of kiln. The economics associated with applying this technique need to be evaluated.

USNR has built two other Triple Length kilns. One of these is a pole drying application and the other is for another southern pine lumber drying application. This later kiln has just been completed and is located at Rex Lumber in Florida. USNR is planning on conducting some testing on this kiln to develop more quantitative information on its performance.

**Opportunity for FPInnovations and Our Members**

As identified above there are some significant advantages associated with this drying technique. There are also some issues related to applying this technology in Canada. In discussion with USNR staff it became apparent that they are pursuing the further development of this process. They do not have any significant signs of interest from any Canadian producers at this time and have therefore not given too much consideration on how to modify it for our environment. They are open to sharing more information from the testing that they will do in Florida. The next step in evaluating this process would be to gather some information to allow a pre-feasibility analysis of the economics. As we have had a number of enquiries from members on this drying system, it is recommended that a Technology Profile or similar information package be prepared. We should also remain in contact with USNR to stay abreast of any new information they develop on the process and see if an opportunity arises to work with them on modifying the process for a Canadian application or conducting some performance testing.