Increasing Long Term Storage of Carbon Sequestered in Russian Softwood Logs Through Enhanced Lumber Recovery[1]

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Abstract

The lumber manufacturing industry of the Russian Far East and Siberia was evaluated in order to determine potential improvements in lumber recovery and the corresponding enhancement of temporal carbon storage duration in lumber manufactured from trees harvested from the boreal forest (taiga) of the Russian Far East. The Khorsky DOK lumber mill (in the Russian Far East) was observed to recover approximately 68% lumber from cubic meter round log volume of *Pinus koraiensis*, cut to 22 mm and 50 mm thick random width boards. However, lumber that failed to meet merchantability standards accounted for as much as 34% in their 50 mm thick lumber, and up to 71% in their 22 mm thick lumber. Research demonstrated that better operator training and technological improvements could improve overall lumber recovery. Lumber recovery improvements were evaluated to ascertain long-term carbon storage impacts. Approximately 38.9% of the carbon stored in trees of the boreal forest is transferred into carbon stored in lumber manufactured at this mill complex in the Russian Far East. This carbon sequestration can be increased from 38.9% to 45.6%, or more, with milling improvements to increase lumber recovery, thereby enhancing economic benefits to the manufacturer and simultaneously increasing long-term carbon storage in forest products destined for use in building construction.

Keywords: carbon, lumber recovery, Russian Far East, boreal, taiga, *Pinus koraiensis*

Introduction

Global atmospheric levels of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrus oxide (N_20) have increased from preindustrial concentrations by approximately 30%, 145%, and 15%, respectively (Climate Change 1995). Carbon dioxide concentrations have increased from an estimated 280 parts per million by volume (ppmv) (Bolin et al. 1979) to present day levels of approximately 360 ppmv (Climate Change 1995, Nilsson *et al.* 2000), the highest levels of CO_2 in the last 100,000 years (Climate Change 1995). Increasing concentrations of greenhouse gases are of concern because they can lead to an increase in global warming effects. Mean global surface temperatures have increased by 0.3ºC to 0.6ºC (0.54º-1.08ºF) since the late 1800's and by 0.2ºC to 0.3ºC (0.36º-0.54ºF) in the last 40 years (Climate Change 1995). The past decade has been the warmest in recorded history. It is estimated that average global temperatures could increase by as much as 3.5ºC (6.3ºF) in the next 100 years over those experienced in 1900 (Climate Change 1995). Such global warming could have serious biological, social, and economic consequences.

There are two broad approaches to reducing the increase of carbon dioxide in the atmosphere, and, presumably, mitigating global warming: (1) reducing emissions of greenhouse gases; and (2) removing CO_2 from the atmosphere and sequestering it in long-term storage pools. Both alternatives have received considerable attention in global climate conferences (UNFCCC 1999, Climate Change 1995). Forests are the largest of the long-term terrestrial carbon sinks. There are three general ways to increase the duration that carbon is sequestered by forest ecosystems: 1) increasing forest area through afforestation, 2) increasing the average amount of carbon held on site over multiple rotations using appropriate forest management practices, and 3) converting standing timber to solid wood products that remain in use for prolonged periods, followed by successful reforestation of the harvested forest site. This paper explores the last of these three methods through a case study involving the Russian boreal forest and a Russian sawmill.

Forests are significant global sinks for atmospheric carbon and have the potential to sequester large quantities over standard rotation lengths (Climate Change 1995, Nilsson *et al.* 2000). However, forest ecosystems are not static carbon sinks, but dynamic systems. The basic concept in sequestering carbon in forests is to increase the average carbon content of the forest system and forest products given that carbon is continuously being absorbed by new growth while a portion is released back to the atmosphere from fires, insects, diseases, respiration, and decomposition. The conversion of atmospheric CO_2 to biomass in the form of carbon held in wood fiber is considered by many policy-makers worldwide to be an extremely important mechanism to mitigate global warming. The sequestration of this carbon can be extended if these trees are converted into products with long useful lifetimes; the third option presented above. For example, it is estimated that the half-life of carbon held in structural lumber used in new home construction is 100 years (Skog & Nicholson 1998). Other wood products show promising residence times for prolonged carbon sequestration (Table 1).

A principal factor influencing how much of the carbon removed from forests by logging is transformed into long-term forest products is the efficiency achieved by wood-manufacturing industries in convertinglogs to products (Steele & Wagner 1990). Wood processing techniques that improve the recovery of lumber sawn from round logs increase long-term carbon sequestration because waste material is either burned or converted into short-term products (e.g. paper), thereby rapidly recycling carbon back into the atmosphere.

It should be noted that only a portion of the carbon held in forest ecosystems is held in the bole of a tree. Carbon in the boreal forest zone is also held in other tree parts, in the soil, and in other plants on the landscape. It is estimated that in the boreal forest zone of Southern Finland, carbon distribution in trees, averaged over the life of the rotation, is about 60% in stemwood, 24% in roots, 12% in branches, and 4% in needles (Mäkipää *et al.* 1999). During logging activities, only the carbon stored in the stemwood is removed and converted to wood products and mill waste. Carbon contained in the other parts of a tree remains on-site and may be released back to the atmosphere quickly (if burned) or slowly (through decomposition). While these other carbon release paths are important, we do not address issues related to any of them in this paper.

The Russian Federation encompasses some 1,709.4 million ha (4,223.9 million acres), including approximately 884 million ha (2,184 million acres) occupied by forest ecosystems (Krankina *et al.* 1997, Krankina & Ethington 1995). No other country's forest reserve is larger than the forests existing within the Russian Federation. Russia contains approximately 20% of the world's timber resources and over half of the world's reserve of boreal or taiga forests (Krankina *et al.* 1997). These forests represent an enormous asset to the Russian Federation and the world in reducing atmospheric carbon, especially since the overall carbon balance of the Russian Federation is not currently favorable.

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) called for the development of a full carbon account for each participating country for the year 1990 and projections of levels for 2010 (UNFCCC 1999). The first full carbon account for Russia was completed by the International Institute for Applied Systems Analysis (IIASA) in 2000. This study shows that the Russian Federation made a net contribution of 527 teragrams of carbon (Tg C) to the atmosphere in 1990, and projections for the year 2010 indicate a range of atmospheric contributions of 156-385 Tg C, including energy and industrial sectors (Nilsson *et al.* 2000).

Carbon sequestered in the wood fiber of Russian trees is either recovered through lumber manufacture, or released back to the atmosphere through burning (primary) or decomposition (secondary). Anecdotal evidence and observations suggest that a majority of the wood waste from Russian sawmills in Siberia and the Far East, in the form of mismanufactured lumber and log ends, is used for heating and cooking purposes by mill workers and the surrounding community. The remainder of this wood, along with a majority of other wood waste (saw dust, chips, and bark), is used as landfill or incinerated at the mill without energy recovery. Currently, the Siberian and Far Eastern regions of Russia do not support a pulp-and-paper industry capable of utilizing the waste products created by lumber mills in the region during manufacture. There are no wood-to-energy conversion facilities in the region. Sawmill waste products that, in another country, would be utilized for other products such as paper, fiberboard, or even wood-to-energy are not viable options for sawmills in these regions. Carbon contained in the wood not converted to wood products has a severely limited residence time before being returned to the atmosphere through burning or decomposition. Furthermore, the domestic market for lumber products is very limited as concrete and brick are the primary building materials for Russian construction.

Therefore, the primary outlet for all finished and raw lumber products from the Russian Far East are export markets. The primary markets for RFE lumber includes Japan, Korea, and China. Although reliable numbers do not exist, it is an industry-wide understanding that Russian produced lumber must meet stringent export requirements in order to gain acceptance and have financial benefits. Dependence on this demanding market has two implications. One is that there is little export potential for waste products to offset the meager local markets. The second is that more wood ends up as waste because it does not meet the demanding standards.

Case Background

The goal of the Russian Environmental Partnership Project was to foster sustainable environmental projects that increased long-term carbon sequestration, reduced carbon emissions, and improved economic viability for sustainable business practices in Siberia and the Russian Far East. (The project was funded by the US Agency for International Development-

Moscow, and implemented by Pacific Rim Taiga, Inc. of the USA.) From 1998 through 2000, one aspect of this project was to improve lumber recovery at selected lumber mills in these regions. Enhanced lumber recovery has the double effect of increasing carbon in long-term storage and reducing raw material demands needed to meet product orders. Therefore, increasing the recovery of lumber from round logs in Russia has positive and direct economic and carbon sequestration benefits.

Various components of the Russian lumber processing industry were evaluated from 1998 through 2000 as part of the Russian Environmental Partnership Project. Three sawmills were evaluated; one in Siberia and two in the Russian Far East. Mills were selected based on recommendations from the territorial administrations as being representative of those in the Asian portion of the Russian Federation. The mills processed a variety of softwood species. Included in these studies were Korean pine (*Pinus koraiensis* Siebold & Zucc.), Siberian pine (*Pinus sibirica* DuTour), Siberian larch (*Larix sibirica* Led.*)*, and Gmelina larch (*Larix gmelinii* (Rupr.) Kuzeneva).

This paper presents information and draws conclusions about one of these mills, Khorsky DOK, located in the Russian Far East, Khabarovsk Territory. This mill was regarded by the regional administration and the Forest Industry Technological Institute at Khabarovsk to be one of the largest, most integrated, and technologically advanced sawmills in the Russian Far East territory of Khabarovskii Krai. This research documents inefficiencies in current operations at this mill. It quantifies potential improvements in lumber recovery at this Russian sawmill and draws conclusions about increases of sequestered carbon in durable lumber products as a result of improved lumber recovery.

In the remainder of this paper we present an overview of an evaluation of the Russian mill made by U.S. mill specialists. The mill experts identified a number of sources of inefficiencies at the mill. We document some of the resulting inefficiencies by measuring the accuracy and precision of sawmill cuts for a sample of logs. The sample is compared to a control set to check for biases in sample selection. Measurements of sawmill accuracy are compared to standards as a basis for estimating the potential for improvements in efficiency. Other areas of sawmill operation are also evaluated for efficiency.

Methods

Mill specialists from the U.S. worked with Russian mill management and laborers to evaluate the lumber recovery at Khorsky DOK. That is, they evaluated how each log was sawn (quality and quantity of lumber from logs). The specialists evaluated potential adjustments to equipment and techniques, focusing on the modification of existing equipment. Since capital was a limiting factor, the replacement of saws and major equipment procurement was not considered a realistic option for these companies. All three of the mills were committed to optimizing existing technology. The mill specialists evaluated saw blade sharpening techniques, headrig adjustments, operator experience, and other factors in determining how current lumber recovery could be improved with existing equipment.

Field work at the Khorsky DOK sawmill was completed in January (lumber recovery / sawing accuracy) and February (saw blade sharpening technology), 1999. During the lumber recovery study, 50 Korean pine logs (Table 2) averaging 4.04 meters (13.25 feet) in length were evaluated. Both log end-diameters, inside bark, were measured to determine individual log cubic volume. Volume determinations used the G.O.S.T.[6] scaling rules of Russia. The grades and volume for all lumber produced from the 50 logs were recorded, providing a baseline recovery of lumber from each log. Boards cut from the logs had a rough-cut thickness of 22 mm

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[6] G.O.S.T. means государственный стандарт or the "State Approved Standard" used for all commercial weights, scales, and volumes in Russian commerce.

(0.87 in) and 50 mm (1.97 in), were of variable width, and variable lengths of up to 4 meters (13.1 ft). All of the sampled logs were milled into rough-cut lumber in one shift.

The mill operated three saws at the site evaluated. The headsaw was a Japanese Fuji band saw[7], the second was a twin band resaw, and the third was a single band resaw. The consultants determined that the study was run under normal operating conditions, and that the sawmilling procedures observed were representative of normal operating procedures by mill management. However, it is probable that the mill staff were paying special attention to lumber recovery since they were being evaluated by foreign specialists. Such bias would serve to establish the upper limit of lumber recovery obtained by mill personnel in the absence of adjustments recommended by the consultants.

Two 50 log sets were evaluated to verify how well the sample set represented the average logs processed by the mill. The sample set (Table 2) of Korean pine logs measured a total volume of 26.46 cubic meters (934.30 cubic feet) (G.O.S.T.). Average log volume was approximately 0.53 $\pm$ 0.2 cubic meters (18.71 cubic feet), corresponding to a small-end log diameter in the 38 cm (14.96 in) diameter class. The control set (Table 2) also contained 50 logs with a total volume of 23.94 cubic meters (845.32 cubic feet), and an average log volume before processing of 0.48 $\pm$ 0.27 cubic meters (16.95 cubic feet). The average log diameter of the control set was in the 36 cm (14.17 in) diameter class. There was no statistically significant difference between the two sets of logs (CI=95%), and the logs used for the lumber recovery study were determined to be representative (i.e. not selected with bias) for that mill.

A sample of 100 boards was cut to a target thickness of 24 mm (0.94 in), and a sample of 96 boards was cut to a target thickness of 53 mm (2.09 in). The product to be sold from these sizes included rough-cut, kiln-dried lumber at 22 mm (0.87 in) and 50 mm (1.97 in), respectively.

[7] Fuji Bandsaw, orgin Japan, model unknown.

Thickness was measured at 10 points on each board (Figure 1) using a dial caliper, recorded to an accuracy of 0.1 mm (1/254 in). These measurements were then entered into the USDA Forest Service Lumber Product Size Analysis Program (USDA Forest Service 1990). This computer program was used to assist in determining the degree of top-to-bottom, end-to-end, within-board sawing variation, between-board sawing variation, and total sawing variation. Total sawing variation is a gauge of the magnitude of deviation in lumber thickness produced during milling and is a function of within-board and between-board sawing variation (Steele & Wagner 1986).

Results and Discussion

Critical to the evaluation of the lumber recovery from this mill was the assessment of sawmilling practices in terms of accuracy and precision. These benchmarks of performance were compared with similar results from US sawmills to establish potential ranges of improvements possible.

From the sample of 50 Korean pine logs, the mill recovered (green) a total of 18.08 cubic meters (638.40 cubic feet) of rough-cut lumber, representing a 68.3% recovery from the cubic round log volume.

Data indicated that the between-board variation was beyond the range of measurements observed in other studies in the U.S. (Steele *et al.* 1986) for the boards cut to a target thickness of 24 mm (0.94 in). The within-board variation was 2.3 mm (0.091 in), and between-board variation was 0.65 mm (0.026 in). Total sawing variability was calculated using the sum of the squares of the within-board variation and the between-board variation:

$$TSV = \sqrt{WBV^2 + BBV^2}$$

Where:

TSV = Total Sawing Variation

WBV = Within-Board Variation

BBV = Between-Board Variation

Total sawing variation for the lumber cut to a target thickness of 24 mm (0.94 in) was 2.39 mm (.094 in). A sample of the data set is presented in Table 3.

Between-board variation in the lumber cut to a target of 53 mm (2.09 in) was determined to be less than optimal as well. The within-board variation was 2.8 mm (0.11 in) and the between-board variation was 1.65 mm (0.065 in). Total sawing variation was 3.25 mm (0.128 in).

When calculating how thick to initially cut lumber (operator's target thickness), the mill must employ a simple formula to achieve a target of 95% or more of the total production in the range of acceptable thickness for the product they are manufacturing (Brown 1986). The formula is:

$$\begin{bmatrix} Target \\ Thickness \end{bmatrix} = \begin{pmatrix} Final\ Product \\ Thickness \end{pmatrix} + \begin{pmatrix} Planer \\ Allowance \end{pmatrix} + (Shrinkage) + (1.65\, x\, TSV)$$

Where: 1.65 represents a one sided *student's-T* distribution at the 95% confidence interval.

Both lumber products evaluated in the lumber recovery study at Khorsky DOK were sold without being planed. "Planer Allowance" was therefore set to zero. Shrinkage was set at 2% of initial thickness by the mill management; all measurements were taken green, prior to kiln drying.

A closer examination of this formula reveals that the greater the total sawing variation, the greater the target thickness has to be to insure that an acceptable percent of lumber is within the range of thickness for the final product. The lower the value for the total sawing variation, the closer the target thickness is to the final product thickness, and therefore, less wood wasted during manufacture. The aim of the sawmill is to reduce sawing variation to its minimum maintainable amount and thereby increase lumber recovery on a sustainable basis.

Baseline Lumber Recovery

Considering the 50 mm (1.97 in) thickness product, the target being sought by the rough saw was 53 mm (2.09 in). The actual average thickness obtained from the 970 samples was 53.1 mm (2.09 in) with a standard deviation (across all points) of 1.8 mm (0.07 in). While the mill generally achieved their average target thickness, they were not especially precise in attaining their target. The data indicates that out of the 97 boards cut to a target thickness of 53 mm (2.09 in), 11 of the boards (11.3%) were below the final dry rough thickness of 50 mm (1.97 in) in at least one sample point, and an additional 22 boards (22.7%) were cut to within less than 1.06 mm (0.042 in) of the product specification of 50 mm (critical thickness = final product thickness + shrinkage). The boards cut to less than 50 mm failed to make export quality standards and were either resawn to 22 mm (0.087 in), sold in the domestic market, or wasted. The management of the mill confirmed that the majority of the solid waste was scraped and burned in homes or the mill, while the planer waste and sawdust was burned without energy recovery. The boards cut to within 1.06 mm (0.042 in) of the minimal thickness of 50 mm (1.97 in) were processed, but during kiln drying the shrinkage brought the boards to less than the product size of 50 mm (1.97 in). A total of 33 boards (34%) were mis-manufactured with most of them utilized for domestic products. Given the sawing variation, target thickness should have been 56.4 mm (2.22 in) for this product.

The boards sawn for the 22 mm (0.87 in) product thickness, had similar problems. The target thickness being sought by the rough saw was 24 mm (0.94 in). Considering the 1,000 sample points taken (10 points per board), the actual average thickness obtained was 23.2 mm (0.91 in) with a standard deviation (across all sample points) of 1.0 mm (0.004 in). In this case, the mill was not accurate in achieving their target thickness; they were 0.8 mm (0.031 in), on the average, less than their target. The data indicated that out of the 100 boards cut to an actual average thickness of 23.2 mm (0.913 in), 31 boards (31%) had at least one point on a surface below the finished size of 22 mm (0.087 in), and an additional 40 boards (40%) had a point cut to within less than 0.44 mm (0.017 in) of the critical size of 22 mm (0.087 in). Only one board in the entire sample had all sample points measured at or above 24 mm (0.094 in). The boards cut to less than 22 mm (0.087 in) failed to make product quality standards and were wasted. The boards cut to within 0.5 mm (0.020 in) of the minimal thickness of 22 mm (0.087 in) were processed but during kiln drying the boards shrank below the product specifications. A total of 71 boards (71%) were mis-manufactured and were wasted. The remainder of the boards, only 29%, were consistently thick enough to be kiln dried and remain above the target thickness of 22 mm (0.087 in). Given the sawing variation, target thickness should have been 26.9 mm (1.06 in) for this product.

This high degree of deviation, conceptually seen as thickness fluctuations of the board, and mathematically seen as the total sawing variation, results in reductions in lumber recovery. Consistency in the primary sawing of the boards means that greater accuracy can be exercised in the initial cutting of the logs into lumber. For instance, a high amount of variability, as seen in the 50 mm (1.97 in) thickness boards, means that the operator must cut the board initially to something thicker than the product specifications, for instance, 56.4 mm (2.22 in) when attempting to produce 50 mm (1.97 in) thickness boards. The irregularities and oversize can be surfaced out during planing. If the thickness is more uniform (i.e. lower total sawing variation) then the initial cut can be closer to the final dimensions with only a small amount in addition to be removed during planing. This increase in accuracy, or improvement in recovery, has significant financial benefits to the sawmill and amounts to important improvements in the amount of carbon held in long-term storage as lumber versus carbon held in wood fiber that is wasted as planer dust or mis-manufactured wood products and then released to the atmosphere through burning or decomposition.

Recommendations to Improve Lumber Recovery

After evaluating milling practices, operator know-how, and the technical characteristics of the milling equipment, recommendations were formulated and implemented in a program to improve lumber recovery utilizing existing technology. The subsequent section details the major factors addressed during the consultations with Khorski DOK.

In the process of debarking, the operator was removing not only bark, but a significant degree of wood fiber as well. The equipment, a Rosser head debarker, was being used too aggressively. The impact of this wood loss on the small end of the log resulted in a reduction of recovered lumber. Less aggressive debarking practices were recommended and exercised.

Some irregularities were introduced during sawing at the headrig. The sweeper keeps sawdust and foreign matter from building up on the headrig. On this particular machine, the sweeper malfunctioned and was not repaired. Lack of a track sweeper caused sawdust to accumulate on the carriage, reducing the precision of the cut made by the headrig.

The most significant factor affecting lumber recovery was the saw operator. Saw operation accounted for the vast majority of less than optimal recovery from the logs. To illustrate, log number 9 was a Korean pine log, with a small-end diameter of 38 cm (15 in), possessing 0.53 cubic meters (18.71 cubic feet) volume, grade 2 (G.O.S.T.). While implementing a grade sawing program, the log is opened on the poor face (the first cut). The log is then rotated 180º so that the cut face is against the knees of the carriage. The log is then sawn on the best face until grade diminishes. The log is then rotated 90º and sawing is completed. This particular log had a discernible good face and bad face. The specialists observed the saw operator placing the log on the carriage without adjusting the log position to open the log on its bad face. Instead, the sawyer opened the log on its best face, cutting a slab from clear wood, and leaving the bad face intact. This decision-making process is not consistent with optimizing lumber recovery. Unfortunately, this scenario was repeated on other logs. In some cases, the operator opened the log on a bad face and in other instances the operator opened it on a good face, when a bad one was available. The quality of the log, or the existence of a good or bad face, did not seem to influence the operator's decision on where to open the log for milling.

Within-board sawing variation is due to "wandering" of the saw in the cut. Between-board sawing variation is due to poor saw sets (carriage). On each of the resaw heads, there was no uniform feed rate. Because of the limited ability of the mill's equipment to properly feed the material through the saw, a great deal of variation both within-the-boards and between-the-boards was introduced by the resaws. Repair and maintenance of the resaws is necessary in order to increase lumber recovery at this facility.

It was determined that the headsaw operator and resaw operators should be better informed about lumber grade requirements for their markets and know procedures necessary to maximize the grade of lumber from each log. Thus, operator training would have a positive impact on lumber recovery at this mill. The equipment, although not state-of-the-art, is not inherently defective. A well-trained operator could increase lumber recovery using this equipment over what was observed at the mill complex during the study period.

Installing track cleaners on the headrig carriage would lessen within-board variation. Proper feed rates on all three band saw machines would lessen within-board variation as well. This would be most difficult to accomplish on the third machine as the feed device is inadequate to allow for proper feed, and during the study, cants were forced through the saw by manpower (Figure 2). Repair of the existing equipment would make a substantial improvement in lumber recovery volume and grade.

Saw blade sharpening is a critical factor in the recovery of lumber grade while processing. It also influences consistency of within-board variation (discussed above). The saw blades at Khorsky DOK (and most other Russian sawmills that were evaluated) were not being maintained or sharpened to their potential. An increase to mill production of 5-8% and improved sawing quality would result from implementing a proper bandsaw maintenance program at the facility.

A worker training program was implemented as part of this project that began with a seminar on swedging and shaping, alignment of teeth, leveling, and tensioning of the equipment. Discussions included grinding wheel speeds, and the proper grit and shape of grinding wheels to grind bandsaws. Other improvements included installation of pressure guides on the bandmills, scheduled corrections to blade alignment, and the installation of a laser light guide to assist the headrig operator in determining the best opening face of each log. Installation of a winter time "frost tooth" blade in all bandsaws was recommended for use during winter sawing (when logs are frozen). The outcome of the hands-on training with the mill personnel was an immediate increase in consistency and improved grade recovery from the logs processed.

Improvements in Lumber Recovery

An evaluation of over 400 sawmills in the USA in the early to mid 1980's by Steele et al. (1986) revealed a total sawing variation (converted to millimeters) from 0.508 mm to 0.934 mm (0.02-0.04 in). If we assume this sawing variation to be achievable in the Russian Far East, then we must conclude that the total sawing variations realized by this mill (2.39 mm (.094 in) and 3.25 mm (0.128 in)) are well out of this range of variability. Improvements to the milling procedures in this mill are needed in order to reduce wood waste created from milling, or alternatively increase lumber and carbon recovery.

Using these standards in comparison to those achieved at the Khorsky DOK, permit estimates of lumber recovery through improvements to technical milling aspects (adjustments to equipment) and worker training programs (best-opening-face training, saw sharpening techniques). The most immediate improvement is by decreasing the inaccuracies in sawing that create the high degree of variation seen in the board thickness measurements and evidenced by the total sawing variation calculations.

50 mm Lumber

Approximately 11% of the boards sawn to a target 50 mm (1.97 in) thickness were lost because of inaccuracies in milling that created board thickness points below 50 mm. These errors can be almost entirely eliminated through improvements to equipment and personnel abilities outlined above.

The amount of wood volume lost due to a high degree of variation was calculated based on an average board length of 2 meters (6.56 ft) and width of 20 cm (7.87 in). Using the data collected for the 97 boards milled to a target product thickness of 50 mm (1.97 in), the total volume rough sawn was 2.11 cubic meters (74.50 cubic feet). Of that only 1.94 cubic meters (68.50 cubic feet) was actually contained in the final product (after planing). Thus, 0.17 cubic meters (6.00 cubic feet), or 8.7%, of the final product volume was lost during planing (as shavings). Subtracting the 11 boards that were milled to a thickness below 50 mm (1.97 in) and lost from the grade, the total amount lost to planing and mis-manufacture was 0.40 cubic meters (14.12 cubic feet), or 22.6% of the final product volume.

Adjustments outlined during the evaluation of the mill (equipment and training) would reduce the board thickness variability and, therefore, the total sawing variation. It is expected that the mill can maintain a thickness 95% of the time within a range of 2.0 mm (0.08 in) for all thicknesses, with existing equipment and personnel. For a product dimension of 50 mm (1.97 in) the mill could rough cut 95% of all pieces to a range of 51 mm (2.01 in) to 53 mm (2.09 in), averaging 52 mm (2.05 in), and the remaining 5% within 50-54 mm (1.97-2.13 in). In this improved scenario, the total milled product volume from our sample would be 2.02 cubic meters (71.33 cubic feet). Actual volume of the final product would be 1.94 cubic meters (68.50 cubic feet), resulting in only 4.1% loss to planing, and ostensibly, none to mis-manufacture.

Considering only the losses to planing, the difference between the current observed loss of 8.7% and the potential loss of 4.1%, results in a net improvement of 4.6%. In real terms, for every 100 cubic meters (3,531 cubic feet) of round logs the mill processes, 68.33 cubic meters (2,413 cubic feet) of lumber would be recovered. Through improvements to the manufacture process this could be increased to 71.47 cubic meters (2,524 cubic feet) (4.1% more). Considering the losses due to mis-manufacture and excess losses due to planing, a net improvement of 10.86 cubic meters (383 cubic feet) (10.86%) would result with the improved scenario (from 68.3% to 79.2% recovery).

22 mm Lumber

Using the same criteria as used with the 50 mm (1.97 in) boards, the total volume rough cut to lumber for this product was 0.973 cubic meters (34.36 cubic feet) (in 100 boards). The actual volume of the finished product (100 boards 22x200x2000mm) was 0.88 cubic meters (31.07 cubic feet). That is, 0.093 cubic meters (3.28 cubic feet) (10.6%) were lost to planing. The target loss due to planing, after improvements, is calculated to be only 9.3%, resulting in a 1.3% improvement in lumber recovery. However, with this sample set, an additional 31 boards were mis-manufactured, because the minimum thickness was breached, causing 0.297 cubic meters (10.49 cubic feet) to be discarded for undersize reasons. When combined, the losses to planing and mis-manufacture total 0.390 cubic meters (13.77 cubic feet), or 44.3% of the actual volume of the finished product. By increasing precision to a 2.0 mm (0.08 in) variation on each board the total volume in the rough-cut lumber would have been 0.962 mm (0.038 in) with a loss to planing of 0.082 cubic meters (2.90 cubic feet), or 9.3% of the finished product volume. The 2.0 mm (0.08 in) sawing variation precision would mean that the mill would rough cut 95% of the lumber within the range of 23-25 mm (0.91-0.98 in), averaging 24 mm (0.94 in), and the remaining 5% of the boards rough cut to within 22-26 mm (0.87-1.02 in). The recovery improvement would be a very significant 35.0%.

Additional improvements can be attained. Anecdotal evidence suggests that the mill can increase lumber recovery from the observed 68% of log volume to over 75% of log volume, through the optimal selection of the opening face and adjustments to the debarking process. When combined, the reduction of sawing variation, operator training, and saw blade maintenance could result in lumber recovery improvements from the observed 68% to above 80% at Khorsky DOK.

The specialists conducted lumber recovery studies at 3 mill locations in Siberia and the Far East. One of these performed slightly better than the Khorsky DOK sawmill; however, it was operating two wood-mizer portable sawmills and had a very low daily production. The other was operating a circular saw headrig and had total sawing variation not significantly different from the Khorsky DOK sawmill.

Implications for carbon sequestration

Mäkipää and others (1999) determined that approximately 60% of carbon held in boreal forests is contained in the boles of trees. When trees are harvested and converted to lumber, some portion of the round log is converted to boards. The remainder (wood waste), in Siberia and the Russian Far East, is generally burned. By increasing recovery of lumber from round logs, a direct increase of carbon sequestered in long-term storage can be obtained.

The improvements to lumber manufacturing that lead to improved lumber recovery include better personnel training in operating mill equipment, better maintenance of existing equipment, improved saw sharpening schedules and techniques, and an enhanced overall commitment by mill management to optimizing lumber recovery. Taken together, these efforts will increase the precision of milling and significantly reduce wood waste created during milling. We must consider the conversion of carbon stored in the bole of a tree in the boreal forest to lumber milled from a Russian sawmill. It has been established that approximately 60% of the above ground carbon in the boreal forest is contained in the bole of a tree (Mäkipää *et al.* 1999). We can estimate the logging recovery of stemwood from the forest to be approximately 95% (estimating 5% of stemwood is left in the forest as logging slash), yielding a net recovery of site carbon from trees at approximately 57%. This estimate concurs with research conducted by Shvidenko & Nilsson (reported in Schulze *et al.* 1999) where they determined that approximately 57% of Russian boreal forest carbon was taken from the forest for industrial products such as paper and other wood products. We have demonstrated that current lumber recovery, and therefore carbon recovery, from round logs in this Russian sawmill was 68.3%. These factors combined indicate that the recovery of solid wood and carbon concurrently is approximately 38.9% (0.600 x 0.683 x 0.950 = 0.389). Through milling improvements that increase the sawmill lumber recovery from 68.3% to 80.0%, the conversion of carbon from the tree to marketable lumber can increase from 38.9% to approximately 45.6% (0.600 x 0.800 x 0.950 = 0.456). In other words, improvements to milling practices to increase lumber recovery directly contribute to the amount of carbon transferred from standing trees to lumber (Figure 3). The magnitude of this change causes approximately 6.7% more lumber and carbon to be recovered through reductions to the total sawing variation (or increasing lumber recovery) at this sawmill. Obviously all of the figures used in the calculations of potential improvements in efficiency in this case study are estimates. However, these estimates are robustly representative of obtainable results.

In summary, there is a significant potential for increasing the temporal sequestration interval for atmospheric and terrestrial carbon converted by trees in solid wood and then by man to commercial solid wood products. The exact magnitude of the impact depends on the eventual destinies of the lumber and the waste wood. The longest temporal storage for wood-origin carbon is observed when it is converted from mature trees to lumber products. To understand fully how much additional carbon would be sequestered by conversion to lumber requires an examination of the lumber lifecycle – a study that is beyond the scope of this paper. The other part of the of conversion depends on the alternative destiny of the wasted wood and the nature of the substitutes for the waste material that is otherwise utilized. In the Russian Far East, there are no wood-to-energy conversion facilities currently in operation, so direct electricity production is not a factor. However, some mills use wood waste to heat water that is then used in industrial and private building heating, or even in lumber kilns. If, because of reduced wood waste availability, additional trees are harvested to replace it, or if coal is substituted for the reduced wood waste then the net amount of carbon released to the atmosphere will not be decreased, it will just be replaced and net carbon storage will be reduced when additional trees are cut. Similarly, one must observe the reaction to a reduced amount of wood waste that is otherwise used for home heating and cooking. Is wood waste replaced by increased harvest of wood from the forest or is coal substituted as a heating and cooking source? Where these situations result in a change in fuel supply from sawmill waste to other wood alternatives the net decrease in carbon release to the atmosphere is zero. If it is replaced by coal, then there may be a slight increase in net carbon releases. Pragmatically, the real impact is in that amount of wood waste that is (a) simply burned without energy, heat, or other useful recovery, or is (b) left to decompose (such as saw dust). Such waste wood is decomposing faster, and releasing its carbon sooner, then it would have had it stayed longer in the growing tree. Increases in lumber recovery will cause a direct reduction in the amount of carbon released to the atmosphere where there exists no alternative uses for wood waste created during sawmilling. In every scenario, however, improvements to lumber recovery result in an increase to the carbon storage interval in solid wood that originated as atmospheric and terrestrial carbon.

In point of this discussion, it is important to emphasize that the dominant modification outlined in this research was a reduction in wood waste at the planer. This wood waste is realized as planer-dust produced after sawing (similar to sawdust). It is not a home heating fuel or mill source of energy through burning. It is left to decompose in large piles and landfills or incinerated without energy recovery in any form. Therefore, the secondary impact caused by reducing this waste product will not be seen as an increase in the harvest of other wood products or coal.

While it is not documented in this paper, the efforts to improve lumber recovery also will lead to net increases in revenue and reductions in costs that are greater than the costs of implementing the recommendations. Therefore, increasing lumber recovery has two significant results: increased profitability of the mill and enhanced long-term sequestration of carbon held in forest products. The former should produce incentives for achieving the latter, while both contribute to mitigating global climate change.

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