Technology

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1. Introduction

Technology has been defined as the use and knowledge of humanity's tools and crafts (McGinn 1991) and it is an important component in determining a nation's, firm's or sector's competitiveness. Technology is a major determinant of the competitiveness of the Canadian forest sector as it influences many aspects of the industry.

By adopting a value-chain approach, technological impacts may be categorised as occurring within three domains:

- the forest;
- the manufacturing sector;
- the market place.

Within the forest, there have been many technological innovations in plant breeding, silviculture, harvesting and other areas that have significantly improved the productivity of both the forest and the workforce. Technology adoption within the manufacturing sector has resulted in the substitution of capital for labour and material with fewer jobs and improved products yields per unit roundwood. The development of competitive, or parallel, technologies also has an important influence on the sector's competitiveness in the market place. For example, in North America, the ongoing market penetration of electronic media has greatly affected the demand for some print media and consequently reduced the consumption of some paper grades.

Technological innovation therefore has the potential to substantially influence the amount and type of wood fibre consumed by the forest products sector to satisfy market demand, the number of jobs created, and the costs of growing, harvesting and transporting roundwood. In future, innovations will create new market and non-market opportunities for Canadian forests.

This paper provides an overview of the technology driver. Initially, it considers technology in the broad context of Canadian forestry by outlining the interactions between technology and the other drivers. Second, the historical impacts of technological innovation over the last four decades are described. Finally, the possible future impacts of technology are examined by considering four alternative scenarios.

2. Technology in the Context of Canada's Forests and Forest Sector

Technology has the greatest impact on drivers directly associated with the forest value chain, such as wood supply/demand and industry profitability (Table A1). In these areas, the impacts of technology have been and will continue to be substantial. Technology also interacts strongly with global energy supply/demand and climate change, although the technological developments in these areas are likely to have a less direct impact on technological innovation within the forest sector.

Since the industrial revolution, there has been a significant interaction between societal values and technology. In recent years this has manifested itself in the development of neo-Luddism, which may be considered to be a modern movement of opposition to technological development (Jones 2006). This concept is explored in greater detail below.

Technological development is influenced by a diverse range of factors (Table A2), several of which are beyond the scope of the Future Forests Project. Industry profitability is an important driver of technological development. For those sectors that produce commodity products, continued investment in technology to increase throughput, substitute capital for labour and decrease unit costs are important elements in maintaining global competitiveness. Technology may also strongly affect the wood supply/demand driver in several ways. It is a key element in developing the process innovations that are essential to maintaining the competitiveness of the sector in global markets (Schaan and Anderson 2002). Historically, technological developments have also resulted in improved yields of product per unit roundwood input.

Societal values have strongly influenced the implementation of several technological developments, especially those associated with biotechnology and biomedical technology. For example, the use of genetically modified organisms (GMOs) in forestry and agriculture is a source of significant debate and concern within society and different nations have adopted varying responses to these issues. One notable example is the differing approaches developed by the US and the EU to the use of GMOs in agriculture. In a forest-management context, the Forest Stewardship Council will not certify any forest where GMOs are used. Societal values are therefore likely to play an important role in determining whether some advanced technologies may be used and there will be significant variations in national responses to these issues.

Climate change and global energy demand will result in major technological innovations over the next fifty years. Several of these developments, such as economic processes for converting lignocellulosic materials to fuel and materials, may have significant implications for the forest sector.

3. A Look-back: Technology since 1960

Sector overview

Over the last 40 years, the Canadian forest sector's GDP has increased from approximately $(C1997) 12 billion to about $(C1997) 30 billion (Statistics Canada 2007). Despite this increase, the sector has grown more slowly than the total Canadian economy. The sector's GDP contribution to the national economy has consequently decreased from about 5% in the early 1960's to approximately 2.5% in 2006 (Statistics Canada 2007). From 1961 to 2003, the harvest volume doubled from about 90 million $m^3.year^{-1}$ to over 180 million $m^3.year^{-1}$. Over this period, the GDP contribution and the harvest volume were highly correlated and, on average, 1.0 m^3 of roundwood harvest contributed $(C1997) 142 to the Canadian economy (Statistics Canada 2007).

Technology has therefore had little impact in creating more value per unit volume of roundwood processed over the last forty years. This likely results from the Canadian forest products sector's traditional focus on commodity products and pursuit of a low-cost strategy concentrated on increasing rates of fibre throughput and obtaining the highest product yields from the feedstock.

The forest domain

Over the last fifty years there have been major technological achievements in tree breeding and biotechnology, forest management and harvesting. Conventional breeding was initially used for tree improvement with the breeding targets generally being improved growth rate and form (Walter et al. 1998). More recently, advanced biotechnologies have been applied to trees with the goal of improving growth rate, wood properties and quality, pest resistance, stress tolerance and herbicide resistance (Tang and Newton 2003). These technologies have been used both to support conventional breeding and to develop transgenic trees, the first of which was produced in 1987 (Fillatti et al. 1987). In comparison to agricultural biotechnology, genetic engineering of trees is lagging behind because of the difficulties of tissue culture/regeneration and the long generation times for the species involved (Walter et al. 1998). However, supporters of tree biotechnology consider that it will drive forestry to enter a new era of productivity and quality. In contrast, others see no place for GMOs in natural ecosystems.

The forest resource has been subject to important innovations in management and harvesting. Many of the major advances in managing natural forests have been both conceptual and technological. For example, the use of sophisticated decision-support systems that integrate remote sensing, GIS and visualization tools have greatly improved the frameworks used to support forest management decisions (Sayer et al. 2005). Technology has also played a major role in the intensive management of industrial plantation forests which have, over the last forty years, become an increasingly important supplier of industrial roundwood. In 2000, plantations provided 35% of global industrial roundwood supply and this value is predicted to increase to 46% by 2040 (Miller and Ogle 2000). These developments are expected to reduce gradually the wood supply required from natural forests with the expectation that many natural forests will be managed for a more diverse set of values than fibre supply. Intensification of forest management can increase growth rates five-fold in comparison to non-managed forest, which allows the forestland for fibre supply to be focused on a smaller, more productive area. This intensification also provides logistical benefits though shorter transport distances (see Sedjo (1997) for a review of the major technological developments in this area).

There have also been major developments in timber harvesting and forest engineering, with sophisticated harvesting equipment having been developed to improve safety and increase productivity. Two important innovations have been the processor and the forwarder. The processor is designed to fell the tree, remove the limbs, cut the trunk into desired lengths, and to stack the wood in small piles. The forwarder is designed to move the logs from the pile to the road or a pick-up deck from where the logs can be transported directly by truck to the mill (Sedjo 1997).

Such technological innovations within the forest have a major influence on productivity and labour requirements and resulted in forestry and logging having the greatest reduction in labour inputs of any forest subsector between 1961 and 2005 (Figure 1). Over this period, labour inputs declined by 36% and productivity increased three-fold (Statistics Canada 2007). In contrast, a consideration of labour inputs to the entire forest sector (i.e. forestry and logging, wood products manufacturing and pulp and paper) reveals that the total hours worked have been remarkably consistent since the early 1960s, averaging 640 million hours.year^{-1} (Figure 1). The increase in labour in the manufacturing sector has therefore offset the reduction in labour inputs within the forest.

The manufacturing sector

Although technological developments have been widely researched in other manufacturing sectors, relatively little is known about the level of innovation of the forest products industry (Crespell et al. 2006). However, technological innovations in the industry are known to have strongly focussed on increasing mill productivity (Stier, 1980; Greber and White, 1982) and that these developments have influenced mill size, the number of mills and the volume and type of roundwood used to meet market demand.

The investment of capital into more advanced technology, such as laser-guided sawing and computerized log breakdown systems has enabled the Canadian lumber manufacturing industry to increase the recovery of sawnwood from logs. For example, the average lumber recovery factor (LRF) for BC increased by 17% from 232 bf.m^{-3} in 1990 to 272 bf.m^{-3} in 2005 (Ackom and McFarlane 2006; BC MoF, 2006). This improvement in LRF directly affects the amount of lumber produced per unit of roundwood harvested. The increased recovery of lumber also has implications for residue, especially chip production as increased lumber recovery necessarily decreases whitewood residue production. It is estimated that whitewood residues from the BC sawmilling sector were reduced by 5.6 million m^3 over the same period.

There has also been a trend towards fewer, larger mills as the sector has used economies of scale to reduce manufacturing costs. The recently constructed supermills typically have total manufacturing costs that are about 64% of those for a small mill. The increased number of large mills has resulted in lower number of total mills. For example, between 1990 and 2005, the number of medium and large-sized mills in BC decreased by 24% and the average mill's capacity increased by 43% (BC MoF 2006). Between 2003 and 2005, 122 mills were permanently closed across Canada with significant consequences for many forest dependent communities (Parkins and White 2007).

The increased levels of technology deployed within the mills have also affected the labour inputs with different trends being observed for the wood products manufacturing (WPM) and pulp and paper (PP) sectors. Labour input to the PP subsector increased from the early 1960s to 1974.

Subsequently, it exhibited a steady decline so that by 2005 the labour input was slightly less than that in 1961 (Figure 1). During this period, the PP productivity approximately doubled (Statistics Canada 2007). The WPM subsector exhibited a more cyclical labour input trend (Figure 1) in response to commodity cycles driven by the US housing market. WPM was the only subsector to show an increase in the total hours worked, with a 33% increase occurring between 1961 and 2005 (Figure 1). WPM productivity also increased the greatest, by a factor of 3 (Statistics Canada 2007).

In addition to increased product recovery, new technology may also facilitate the use of different forest resources. For example, the transition from the supremacy of plywood to the dominance of OSB (oriented strandboard) manufacturing in the North American structural panels sector has had important forestry implications. Over the last 50 years, the timber resource has changed in many ways with much of the timber now available being smaller and of lower quality than that utilized previously. Douglas fir was generally the preferred species for plywood manufacturing because of its strength properties, and high-quality peeler logs, which are needed to produce the sanded and specialty plywood grades, were amongst the most valuable timber harvested (McKeever and Meyer 1983). In contrast, the development of OSB enabled a smaller and lower quality resource, including hardwoods, to be used for structural panel production. Trees as small as 10 cm in diameter may be used to make OSB (Wiedenbeck et al. 2003) enabling the use of northern species, such as aspen, that were previously uneconomic to harvest. Also, the lower cost of this resource enabled the fibre costs for OSB production to be significantly reduced over plywood.

OSB manufacturing also converts the roundwood input into finished product more efficiently than plywood manufacturing. Typically, an OSB mill is able to process about 77% of the roundwood input into final product while a plywood mill is generally able to convert 51% of the peeler logs to panel output (Kline, 2005; Wilson and Sakimoto, 2005).These yield differences mean that the OSB can satisfy the market demand for structural panels with a smaller roundwood harvest than plywood. The increased use of OSB in the North American housing market over the last 25 years has therefore had important consequences for the Canadian forest resource. Using the average yield factors cited above, the roundwood requirements for satisfying the demand for structural panels with 100% plywood and those required for the current mixture of OSB and plywood can be calculated. In 2005, the increased product yield from OSB meant that approximately 7 million $m^3.year^{-1}$ less roundwood were required to meet the market demand for structural panels. The development of OSB has therefore had significant consequences for Canadian forestry by providing an economic use for previously unutilized northern species such as aspen, by increasing the volume of panels produced per unit roundwood harvested, and by constraining the demand for the high-quality peeler logs required to manufacture plywood.

The market place

In North America, the growth of electronic media has had a significant impact on markets for several paper products, especially newsprint, with a 16% decrease in per-capita newsprint consumption occurring between 1975 and 2005 (NPA 2007). Recovery and reuse of waste paper may also be considered to be a parallel technological development that reduces the consumptive pressure on virgin forest resources. In 2005, the paper recycling rate in the United States reached 51%, equivalent to 25.7 million tons of paper (AF&PA 2007). Such high recycling levels significantly affect the amounts of wood and fiber required for paper production in the United States (Ince 1998).

Technological developments in the North American housing sector also have implications for Canadian forestry because of the amount of forest products destined for this market. For example, recent studies have shown that new flooring systems using engineered wood products (EWP) require approximately half the volume of wood compared to conventional lumber floors (Schuler 2005). In addition, EWP can generally be manufactured from reduced volumes of lower quality roundwood while attaining performance properties equal to, or greater than, lumber. Clearly, if innovations such as novel EWP-based building systems obtain a significant market share, they will reduce the amount, and change the type, of roundwood required to satisfy consumptive needs.

Technological innovation also has the potential to increase pressure on forest ecosystems by creating new market opportunities for forest-based industries. The lignocellulosic biorefinery is an important example of such a development that is presently attracting significant attention. The biorefinery concept is explored in more detail in the companion paper on “Energy”. The salient points to consider here are that concerns over climate change and energy security are driving several countries to explore the production of energy and materials from renewable agricultural or forest sources. While it is presently easier and cheaper to produce bioenergy and biomaterials from agricultural products, concern over food supply and price is driving the long-term examination of the potential to obtain such products from lignocellulosic materials. If these research and development efforts are successful, new industries will be seeking cheap, low-grade fibre from forest ecosystems, thereby increasing the consumptive pressure on the ecosystem.

In summary, technology has had a significant influence on Canadian forests by:

- Affecting the type of roundwood harvested;
- Influencing the volume of roundwood required to satisfy market demands;
- Reducing the labour requirements per unit roundwood;
- Decreasing the number mills; and
- Affecting the stability of numerous forest-dependent communities.

4. A Look-ahead: Future Scenarios for Technology Impacts on the Canadian Forest Sector to 2050

This paper considers four potential scenarios:

1. Business as usual; this is an extrapolation of trends that have occurred over the previous forty years.
2. Value added; this assumes that the Canadian forest products sector restructures and uses advanced technologies to produce a diverse range of higher-value products that utilize the intrinsic high-quality fibre available in many Canadian forests.
3. Forest Bioeconomy; this assumes that technological innovations will enable Canadian forests to be a source of energy and materials for North America. Significant innovations

will be required to make this scenario feasible.

4. Ecosystem services; this assumes that globally rare resources associated with forest landscapes will become more highly valued and innovations will occur to attribute value and to manage the ecosystems to maximise these values.

Each of these scenarios is examined below.

Business as Usual

In this scenario, Canadian forestry continues to be focussed on the production of commodity products. Global competition continues the momentum to build fewer larger mills that employ fewer people per unit of product manufactured. Structural wood products eventually dominate forest products manufacturing and the increasing recovery obtained from the roundwood reduces the whitewood residues available for the pulp and paper industry. This subsector struggles to be economic in the face of the challenge from large southern hemisphere and Asian mills. The sector continues to confront the boom-and-bust cycles that characterise the commodity arena and it persist in its focus on cost control. Economic utilization of whitewood residues is a key concern for the entire sector. Engineered wood products gradually assume a greater importance. Technological advances in breeding and forest management increase the total harvest to about 270 million $m^3.year^{-1}$ and there is increasing utilization of lower-value species. The harvest patterns are more cyclical in response to increased impacts of pests and diseases. The outbreaks periodically create substantial volumes of low-quality fibre that create challenges for the solid-wood sector to process economically. Such outbreaks also have significant impacts on forest-dependent communities. The importance of the forest products sector within Canada gradually diminishes as its GDP contribution and employment grow slower than average for the economy. There are fewer forest-dependent communities.

Value Added

In this scenario, the Canadian forest products sector becomes restructured to focus on value recovery rather than volume and to operate on a more cooperative, community-focussed manner. It develops a diverse range of higher-value markets based on the intrinsic fibre quality of the resource. Innovation has produced smart tools to measure resource quality in the forest easily and allocate the roundwood to its highest value use. Smaller manufacturers of niche products are able to use advanced technologies and source the high-quality fibre needed to satisfy high-value markets. The manufacture of commodity products is less important although the lower quality resource and residues are used to produce commodities or energy. Clusters of niche manufacturing expertise develop and operate alongside commodity producers. The total harvest reduces to about 120-140 million $m^3.year^{-1}$ and the lower harvest facilitates the development of service-oriented community-focussed forestry. Fewer, but more stable, forest-dependent communities evolve and forestry's importance within the Canadian economy continues to diminish.

Forest Bioeconomy

In this scenario, severe climate change combined with a desire to obtain renewable energy and replace materials that are presently derived from petrochemicals drive the development of a global bioeconomy. Concerns over food supply and security result in innovations that target the production of bioenergy and biomaterials from agricultural residues and forest-based fibre. The sector focuses on commodity products and uses as much of the forest resource as it can access. The solid-wood sector becomes a fractionation process that allocates the roundwood to its highest-value commodity use. The residues from this subsector are then utilized by a rejuvenated pulp and paper industry which operates large biorefineries that produce energy and biomaterials to meet North American market needs. The bioeconomy focusses on commodity products and economies of scale will be important. Consequently, there are fewer forest-dependent communities although the sector GDP contribution increases. New companies that have traditionally participated in the petrochemical sector will engage and rejuvenate the forest sector. Severe climate change causes regular pest and disease outbreaks with consequent large variations in the amount of fibre available from the forest. Industry removes as much fibre as economically feasible, including residues that are presently left to decay within the forest. The harvest increases to 300-440 million $m^3.year^{-1}$ and there are significant impacts on biodiversity and ecosystem stability. The oscillations in harvest volumes created by pest and disease outbreaks result in industry and community instability.

Ecosystem Services

Here it is assumed that climate change and changing societal values create global markets for several forest ecosystem services, such as water, carbon and biodiversity. Innovations occur that permit the valuation and trade of such services. Forests are managed to maximize the value of these goods, mitigate the impacts of severe climate change and timber extraction is significantly reduced. Vibrant communities develop throughout the forest areas and these communities have the responsibility, expertise and tools to managing their local natural resources. Timber is extracted on a small scale for high-value artisanal and cultural uses and the national harvest decreases to about 30-40 million $m^3.year^{-1}$.

4. Conclusions

Technological innovation is an important element in determining the competitiveness of the Canadian forest sector. Historically, this sector has focussed on commodity products and followed a low-cost strategy based on increasing rates of fibre throughput and obtaining the highest product yields. These developments have been successful in increasing the yield of products manufactured per unit of roundwood processed and therefore require less roundwood to satisfy a given market demand. They have also enabled previously unused species to be utilized for commodity manufacturing, thereby reducing consumptive pressure on old-growth forests.

Four scenarios were explored to show how technology may influence the future of the Canadian forest sector. It is evident that technology should be viewed as a tool that enables alternative futures to be captured and become real. Without significant technological development, several of the possible futures outlined above will not eventuate. With such development, a range of promising futures is available. The major actors in society should determine the most desirable future for Canadian forests and use the necessary processes and tools to seek that future. Technology is but a means to an end.

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Appendix

Table A1: Influences of technology on other drivers

Driver	**How Technology Affects the Driver**
Climate Change	New technologies will be developed to mitigate or facilitate adaptation to climate change. Several of these developments, such as carbon trading, may significantly affect forests, forest products manufacturing and markets.
Wood Supply/Demand	Technology, especially plant biotechnologies, plantation and silvicultural technologies are likely to significantly influence global wood supply. Technology also strongly influences the demand for forest products and competing materials.
Geopolitics	Minor interaction.
Global Energy	Global energy supply and consumption will be strongly affected by the technological innovations.
Governance	Negligible interaction
Aboriginal Empowerment	Little direct influence.
Ecosystem Health	Moderate influence. Technology may result in improved or decreased ecosystem health.
Conflict over Resources	Moderate influence. Technology may result in increased or decreased competition for resources.
Societal Values	Significant. Neo-Luddite values are one response to the increasing impact of technology on society. Also the implementation of some biotechnological developments has been constrained by several states in response to societal values.
Demographics	Negligible influence.
Industry profitability	Technology has a significant interaction with industry profitability. Technology is a major factor in industry competiveness and profitability is a prerequisite for technological investment.

Table A2: Influences of other drivers on technology

Driver	How the Driver May Affect Technology
Climate Change	Climate change mitigation and adaptation pressures will drive the development of new technologies. Several of these technologies may impact the forestry sector, broadly defined.
Wood Supply/Demand	There is a strong link, at global and regional scales, between wood supply, manufacturing capacity, technological innovation and product demand. Advanced manufacturing technologies are generally able to produce an increased yield of product per unit roundwood input, thereby satisfying a given market demand from a lower harvest volume
Geopolitics	Minor interaction. In recent years, advanced technologies have been implemented in all geopolitical areas. Some geopolitical areas are more willing than others to implement contentious advanced biotechnologies.
Global Energy	Pressures to increase sustainable and secure energy supplies will drive the development of several novel technologies to produce energy form forest based materials. Concern over embodied fossil fuel energy in products will facilitate increased consumption of forest products.
Governance	Moderate interaction. Security over fibre access is a major issue for companies investing in technology. Various trade disputes have argued that governance influences sector profitability and therefore the ability to invest in advanced technologies.
Aboriginal Empowerment	Minor influence.
Ecosystem Health	Minor influence.
Conflict over Resources	Competition for resources will usually stimulate the development of technology.
Societal Values	Significant influence. For example, the deployment of genetically modified organisms (GMO) within the food and forestry sectors has been resisted by several groups within western societies and legislated against within some nations. Neo-luddites oppose the introduction of advanced technologies on several grounds. These values are not uniform within society nor among various geopolitical blocs.
Demographics	Minor influence.

Industry Profitability	Significant influence. The profitability and scale of an industry greatly affects its ability to generate the capital and knowledge required to install and effectively use advanced technologies.

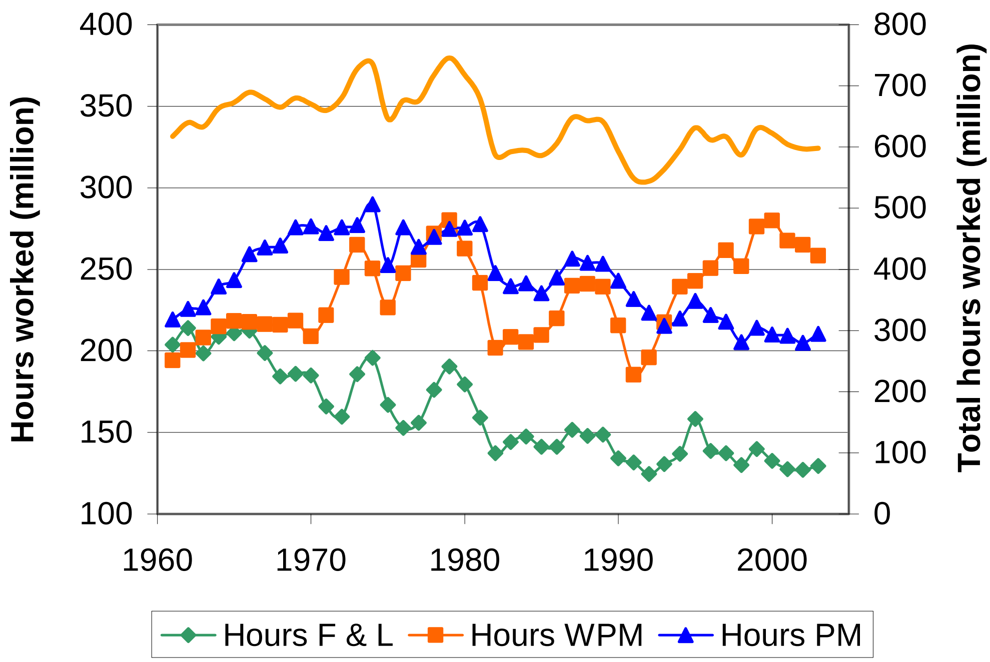

Figure 1: Annual hours worked within each subsector of the forest industry and the total hours worked within the sector (Statistics Canada 2007). Key: F&L = Forestry and logging; WPM = Wood products manufacturing; PM = Paper manufacturing.