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# Industrial Sustainability of Competing Wood Energy Options in Canada

**Emmanuel K. Ackom · Warren E. Mabee · John N. Saddler**

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**Abstract** The amount of sawmill residue available in Canada to support the emerging cellulosic ethanol industry was examined. A material flow analysis technique was employed to determine the amount of sawmill residue that could possibly be available to the ethanol industry per annum. A combination of two key trends—improved efficiency of lumber recovery and increased uptake of sawmill residues for self-generation and for wood pellet production—have contributed to a declining trend of sawmill residue availability. Approximately $2.3\times10^6$ bone-dry tonnes per year of sawmill residue was estimated to be potentially available to the cellulosic ethanol industry in Canada, yielding 350 million liters per year of cellulosic ethanol using best practices. An additional 2.7 billion liters of cellulosic ethanol might be generated from sawmill residue that is currently used for competing wood energy purposes, including wood pellet generation. Continued competition between bioenergy options will reduce the industrial sustainability of the forest industry. Recommendations for policy reforms towards improved industrial sustainability practices are provided.

**Keywords** Cellulosic ethanol · Wood pellets · Industrial sustainability · Material flow analysis · Sawmill residues

## Introduction

Cellulosic ethanol offers great potential as a partial substitute for petroleum-based fuels. Derived from sustainably produced feedstocks (such as biomass from forestry and

E. K. Ackom (✉) · J. N. Saddler
Forest Products Biotechnology, Faculty of Forestry, University of British Columbia,
4043-2424 Main Mall, Vancouver, British Columbia, Canada, V6T 1Z4
e-mail: emmanuel.ackom@ubc.ca

W. E. Mabee
Queen's Institute for Energy and Environmental Policy, Queen's University, 423-138 Union Street,
Kingston, Ontario, Canada, K7L 4C3
e-mail: warren.mabee@queensu.ca

agricultural operations), cellulosic ethanol is a renewable substitute for petroleum-based transportation fuels. Greenhouse gases (GHGs), including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, have been linked to climate change. Petroleum-based fuels account for 57% of global anthropogenic carbon dioxide equivalent ($CO_2$ equiv.) emissions [1]. Shifting society's reliance on petroleum-based fuels to sustainably derived biomass resources is essential to sustaining modern civilization and achieving GHG emission reductions [2].

Current ethanol production capacity in Canada of $1.7\times10^9$ l/year is derived predominantly from corn and wheat [3]. Cereal crops make up 97% of this production, predominantly corn (75%) and wheat (22%); ethanol from municipal landfill waste represents 2% while lignocellulosic feedstocks such as forest and agricultural residues account for less than 1% of current ethanol production.

In 2008, Bill C-33 [4] introduced renewable fuel mandates for Canada's transportation fuel supply mix, specifying that 5% of gasoline supply should be substituted with ethanol by 2010, and 2% of biodiesel supply by 2012. This will require approximately $2.2\times10^9$ l/year of ethanol production capacity or a 30% rise over current capacity levels. The legislation does not currently specify feedstock or process parameters for renewable fuel production. This differs from renewable fuel standards in the USA or in Europe, which include specific targets for second-generation biofuels including cellulosic ethanol.

There continues to be debate related to the sustainability of cereal-to-ethanol production. Though several authors have suggested a positive environmental benefit from ethanol as a substitute for gasoline [5–9], recent concerns with regard to net energy and carbon balances [10, 11], indirect land use change emissions [12–18], and water consumption [19, 20] are now recognized to be associated with food-derived ethanol production. In some cases, the negative performance reported by individual authors has been refuted by subsequent publications [21]. Most studies that investigate the environmental performance of biofuel systems employ the life cycle analysis (LCA) technique. However, the LCA results reported in these studies seemed to vary for supposedly identical biofuel systems. It was apparent that these variations were likely due to different factors including; geographic location, the year of study, the defined scope or the system boundary for the study, type of feedstock and cultivation practices, the bio-conversion technology employed, the fuel type employed in bio-conversion process, co-product allocation, efficiency of the end-use technology, and the baseline energy system for comparison [5, 22, 23].

While the debate is far from conclusive, the most recent available studies using current data and realistic assumptions have confirmed that GHG emissions savings have been achieved through experience learned by the current corn-based ethanol industry. GHG savings associated with corn ethanol relative to gasoline (based on California's reformulated gasoline blendstock for oxygenate blending GHG intensity) have improved from 27% in 1995 [24] to between 37% and 42% in recent years [25–29].

The debate over unintended environmental impacts linked with cereal-to-ethanol production has resulted in increased interest in other feedstocks, including lignocellulosic biomass from forests and agriculture. While significant technical challenges remain in the conversion of cellulosic material to ethanol, considerable progress has been made in recent years [30]. Both industry and government are actively pursuing opportunities to demonstrate these processes. In the USA alone, at least four full-scale demonstration plants are currently underway [31]. Canada is steward to more than 400 million hectares of forested land, of which 245 million hectares is considered to be productive forest [32]. Sawmill residues generated during wood products processing offer one potential source of wood biomass. These materials have the advantage of being centrally located, and much of the cost for harvest and transport is borne by the primary forest industry, making this material a "lowest-cost" opportunity.

### Industrial Sustainability

The concept of industrial sustainability (IS) evolved from the formal definition of sustainable development formulated at the United Nations Commission on Environment and Development in 1987 [33, 34]. The first collective effort by industry towards sustainability was the formation of the World Business Council on Sustainable Development in 1995, which brought together 160 multinational corporations [35–37]. This led to the definition of industrial sustainability as the production of goods (and services) to satisfy the society's present requirements without jeopardizing future generations' ability to meet their need for similar goods and services. This definition was later expanded by researchers at the University of Cambridge to include the conceptualization and design phases of manufacturing [35, 37].

In the past, industrial activities and economic growth have often been associated with overexploitation of natural resources and environmental degradation. Over the last few decades, public pressure coupled with increasing awareness within industry on the impacts of their activities has resulted in a shift towards better environmental stewardship. The challenge is to achieve the goals of industrial manufacturing, economic growth, and environmental benefits in a socially responsible manner. The development of bioenergy opportunities, including the production of wood pellets and/or cellulosic ethanol, derived from sawmill residues (previously landfilled or burned) could, therefore, be showcased as a practical case study of the IS concept, as residue utilization delivers social, economic, and environmental benefits. Production of solid or liquid fuels from residues from within the existing value chain would not lead to any indirect land use change and thus do not accumulate carbon debt [17, 38].

However, disruptions in feedstock supply upstream could have an adverse impact on the industrial sustainability of the forest-based cellulosic ethanol industry.

Thus, it is important to investigate the competition for this feedstock from other industries. Evaluating the feedstock, therefore, represents a critical first step in developing the knowledge base to support national programs and policies for a sustainable forest-based cellulosic ethanol industry. The work reported here provides information on the amount of sawmill residue that is potentially available to the ethanol industry taking into account the recovery of lumber from the total timber harvest as well as pressures on available sawmill residues from other competing industries, including the wood pellet industry.

## Methodology

Once harvested, logs are first debarked and bucked to an appropriate length at the sawmill. In Canada, most wood is delivered directly to sawmills, while a smaller proportion may be delivered directly to pulpmills. Residues generated during the sawing process include small-dimension sawdust as well as larger-dimension material such as edgings, chips, and shavings. Larger-dimension residues tend to be used in other value-added forest products, including pulp and paper products, wood panels, and other engineered wood products. This study focused on the sawdust and shavings by-products that could be utilized by potential bioenergy producers, including a future cellulosic ethanol industry.

Material flow analysis (MFA) methodology was employed to determine the amount of sawmill residue available to the ethanol industry per annum. MFA is an engineering and economic technique that is defined as the material flows into, within, and out of a system [39–42]. MFA has been applied to investigate manufacturing activities from simple to complex operations with the goal of providing information to support policy development [43–50].

Though physical flows of material are often dictated by economic drivers of change, conventional MFA does not treat these two factors as being mutually dependent [39, 51–54]. However, the impact of policy on industrial systems (for industrial sustainability) would benefit immensely if an established relationship between physical flows and economic drivers is known [32].

MFA is a valued technique in the study of industrial operations and its environmental impact because it is based on systems thinking and reliable data [46, 55].

Application of MFA in this study offered opportunities to track the efficiency of wood utilization in sawmills, and it also provided quantitative data on available residues for use by the potential cellulosic ethanol industry and allied sectors in the value chain. A key goal was to determine whether an industrial activity or value chain could be efficient in resource consumption, which in turn highlights gains in economic, social, and environmental terms [56]. Within the forest sector, better utilization efficiency of our natural resources results in decarbonization*,* defined as the incremental reductions in carbon intensity per unit product [57].

The availability of recent data was limited and is the reason for the selected years (1990–2006) used in the analysis for the study. The timber harvest statistics were obtained from Natural Resources Canada [58], while Canadian lumber production data were retrieved from the Statistics Canada CANSIM [59]. Canada's sawmill residues data on "total residues," "utilized residues," and "available residues" statistics were available for the years 1990, 1998, and 2004 [60, 61]. In estimating for total available residue statistics for year 2006, the ratio of annual sawmill residue generation trends per lumber production for year 2004 was assumed and applied to year 2006 lumber production. Similarly, "utilized residues" and "available residues" amounts for year 2006 were estimated from corresponding residue trends in 2004 statistics.

## Results and Discussion

Total timber harvest in Canada increased 12% over 16 years from $87.8\times10^6$ bone-dried tonnes (BDT) in 1990 to $98.4\times10^6$ BDT in 2006 (see Fig. 1). The trend in timber harvest in Canada followed a gradual but steady growth from 1990 to 1995, after which the curve was cyclic. Timber harvest reached a peak at $112.3\times10^6$ BDT in 2004 [58]. This was largely in response to an increased annual allowable cut following the mountain pine beetle (*Dendroctonus ponderosae*) infestation, which impacted lodgepole pine (*Pinus contorta*) in British Columbia, Canada's largest timber producing province. The mountain pine beetle infestation impacted approximately 130,000 $km^2$ (or $13\times10^6$ha) of interior British Columbia at the end of 2006 [62, 63]. It has been reported that about $435\times10^6 m^3$ of interior BC's lodgepole pine timber have been infested representing $235\times10^6$ BDT [64]. According to the Food and Agriculture Organization of the United Nation, the amount of pulpwood harvested in Canada, as a proportion of total industrial roundwood, has declined from 23% in 1990 to about 13% in 2007 [65]. This means that an increasing amount of wood is being delivered directly to the sawmill. Total lumber production in Canada

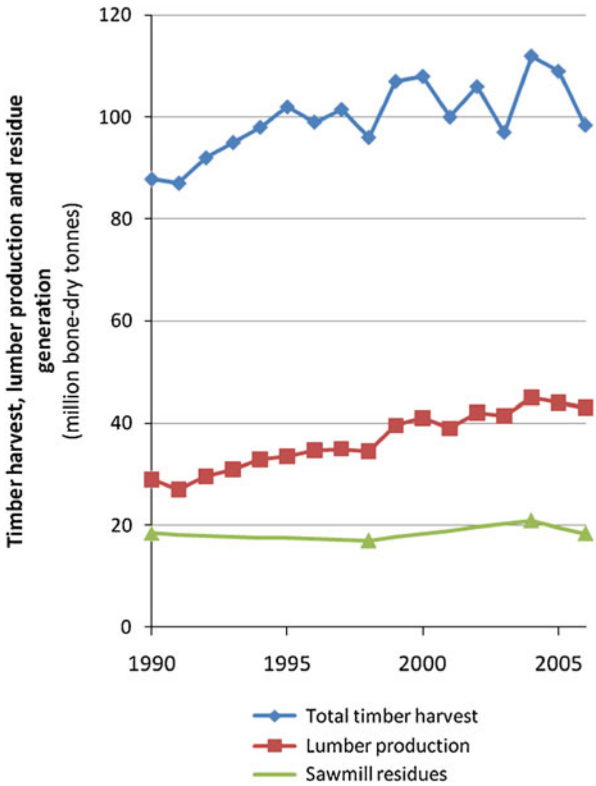


**Fig. 1** Timber harvest, lumber production, and sawmill residue production in Canada [58–61]

increased by 48% between 1990 and 2006, from $28.9\times10^6$ BDT in 1990 to $38.2\times10^6$ BDT in 2006 (as shown in Fig. 1). A linear regression over the 16-year period shows an annual growth rate of $0.9\times10^6$ BDT of lumber production ($r^2$=0.95).

While the total amount of Canadian lumber production increased, the proportion of sawmill residues to lumber production has declined, from about 60% in 1990 to about 46% in 2004. While there is not enough data available to state this decline is statistically significant, it is indicative of improvements to the efficiency of lumber production and supports the theory that efficiency gains in the sawn lumber industry has reduced the overall generation of sawmill residues.

While the efficiency of lumber recovery has likely increased, demand for sawmill residue has also grown. Wood residues are commonly used within the mill to self-generate power, offsetting demand for natural gas or other fossil energy feedstocks. Sawmill residues have also been employed as the primary feedstock for the wood pellet industry in Canada. The growth in wood pellet production in Canada is closely linked with policies in Europe and Asia that favor non-fossil energy sources. A European Community Directive (Directive 2001/77/EC) [66] supporting the use of renewable sources in electricity generation has led to increased demand for pellets, which are primarily used to co-fire coal power plants. Canada is the world's largest exporter of wood pellets. This is due to a relatively abundant supply of sawmill residues, as well as the small size of the domestic pellet market. Canada produced just over 1.3 million tonnes of wood pellets in 2008, which represents a slight drop from the previous year (Wood Pellet Association of Canada 2009; see Fig. 2). However, as is evident in Fig. 2, the capacity for wood pellet production in Canada continues to rise, with an expected $3\times10^6$ BDT of capacity scheduled to be available by 2010. At the same time, world market demand for pellets has been forecasted to reach $13\times10^6$ BDT per year by 2010, a 62% increase over 2006 values of $5\times10^6$ BDT [67]. In response to both self-generation of electricity increases by the sawn lumber industry and the additional growth in wood pellet production, the availability of sawmill residues has decreased significantly, from $9.1\times10^6$ BDT in 1990 to an estimated $2.3\times10^6$ BDT in 2006 (Fig. 2).

## Potential for Ethanol Production from Sawmill Residues

Sawmill residue generation has varied considerably over the period 1990–2006. Material flow analysis based on an input–output basis indicates that the ratio of sawmill residue generated over lumber produced dwindled from 0.64 in 1990 to 0.45 in 2006 (Fig. 1). Additionally, the use of sawmill residues has increased over the same period. These two trends have greatly reduced the amount of “available” residue (as shown in Fig. 3). This in turn has greatly reduced the opportunity to base a cellulosic ethanol industry on sawmill residues.

Estimates of cellulosic ethanol production using sawmill residues have been calculated, using a “best-case” potential yield of 300 l of ethanol/dry tonne of wood feedstock [68], and assuming that only 50% of the sawmill residues available are of high quality (white wood) and, therefore, useful for ethanol production [61]. It should be noted that these

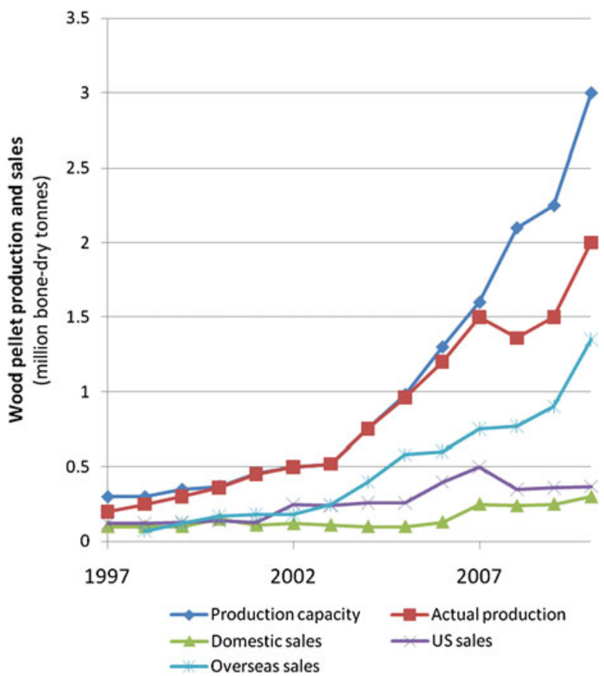


**Fig. 2** Canada’s wood pellet production, capacity, and markets, 1997–2008 and forecasts for 2009–2010 [70]

estimates are based on state-of-the-art technologies. Actual ethanol yields might be lower, and the proportion of high-quality sawmill residues may vary significantly in practice. Using these assumptions, the results of these calculations are shown in Fig. 4.

As stated in the "Introduction," Canadian ethanol production required to meet the mandate described in Bill C-33 is approximately $2.2\times10^{9}$ l/year by 2010. Using the available wood residues from sawmills, the "best case" scenario for ethanol production was $0.35\times10^{9}$ l in 2006, indicating that about 16% of required biofuel could be sourced from sawmill residues (see black bar in Fig. 4). It is clear from Fig. 4 that potential ethanol production would drop significantly over time due to competition for the residue feedstocks.

While the available residues in 2006 could only support about 16% of the required ethanol capacity, it is interesting to note the impact that competition for residue feedstocks and improvements in lumber recovery have had on these potentials over time. For example, in 1990, the amount of residue available for ethanol production was about 49% of the total amount of residue available (see Figs. 3, 4). Increased competition for these residues, which is due to increases in self-generation of power as well as use of residues for wood pellet production, has reduced this proportion to about 13% of total residue production. Thus, if there had been no changes to residue demand in the intervening years, the amount of residue available in 2006 for ethanol production would have been proportionally higher (indicated by the white bar in Fig. 4).

Similarly, the production of total residue as a proportion of total lumber production has declined—from about 64% in 1990 to about 45% in 2006 (see Fig. 1). This is an indication of the overall improvement in efficiency of lumber recovery. If improvements to lumber recovery had not taken place, the amount of residue available in 2006 for ethanol production would have been significantly increased (indicated by the gray bar in Fig. 4).

These results stress the importance of government-led strategies and policies in facilitating access to fiber for emerging bioenergy opportunities. This paper does not

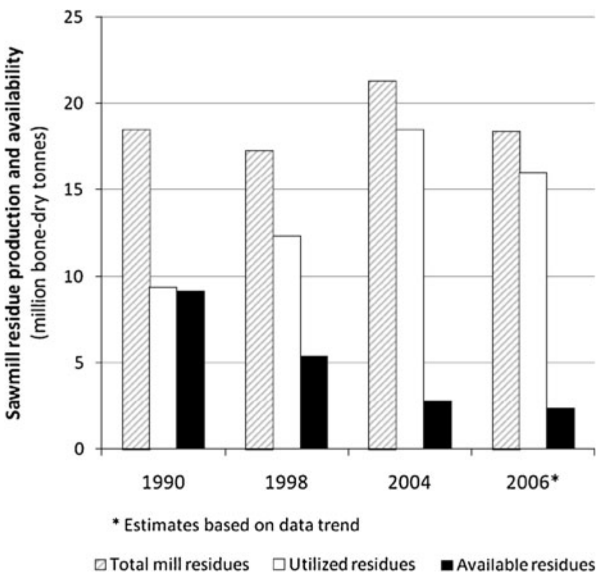


**Fig. 3** Available sawmill residues in Canada 1990–2006 [60, 61]

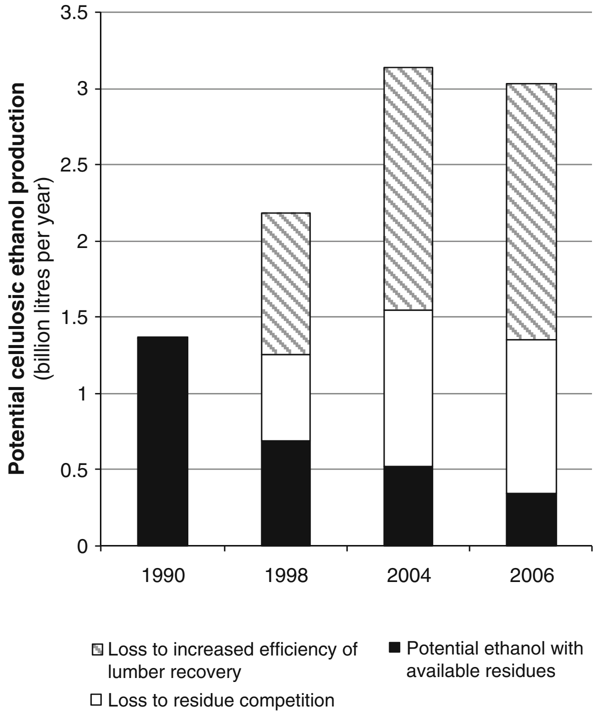


**Fig. 4** Scenarios of ethanol production from sawmill residues in Canada (1990–2006)

intend to suggest in any way that the efficiency gains in lumber recovery and the increased competition for residues for self-generation power and wood pellet production should not have taken place. However, the paper attempts to emphasize the point that strategic policies will be needed to ensure a continuous supply of cheap, low-quality feedstock to support the various competing wood energy options. For example, previous studies have shown that an additional $9.8–46 \times 10^6$ BDT of unutilized forest residues and precommercial thinnings could be readily available to the bioenergy sector in Canada [68]. Deadwood from the ongoing mountain pine beetle outbreak could further increase this potential. The additional cost involved in accessing this available but likely relatively expensive feedstock will require further analysis by a potential forest-based bioethanol industry.

## Industrial Sustainability of Wood-Based Energy Systems

From an industrial sustainability perspective, efficiency gains in the conversion of harvested timber into lumber are a positive development for the forest industry. However, at the same time, these improvements create constraints to feedstock availability for downstream industries, which in turn threatens the industrial sustainability of bioenergy options such as wood pellets or cellulosic ethanol.

Key parameters of industrial sustainability include economic, social, and environmental benefits. Development of the wood pellet industry has resulted in job creation along the value chain from feedstock sourcing to pelletization and shipping, which in turn delivers both economic benefits (new revenue streams) and social benefits (job creation). The introduction of wood pellets has successfully led to effective utilization of sawmill residues which 16 years ago were mainly landfilled or burnt in beehive burners without any energy reclamation. From an environmental perspective, this is clearly an improvement—the use of wood pellets in a furnace or boiler system allows highly efficient energy recovery, offsetting the need for fossil fuels. However, the lack of domestic market development (as shown in Fig. 3) means that a large proportion of wood pellets are shipped overseas. As a result, long-distance transport incurs significant environmental and health burdens, including increased greenhouse gas emissions when compared to shorter-transportation distances that would have occurred if there were major markets for pellets in North America. A recent study suggests a global warming potential of 422 kg of $CO_2$-equivalent per tonne pellets shipped via vessel from the west coast of Canada to Sweden [69]. This analysis suggests that industrial sustainability of the wood pellet industry could be improved by developing policy to support domestic markets for this product.

Similarly, a wood-based cellulosic ethanol industry could potentially lead to substantial improvements to the overall sustainability performance of Canada's forest and forest-product sectors. Development of the cellulosic ethanol industry would deliver new revenue streams and lead to job creation; it would also deliver significant environmental benefits. From an environmental perspective, cellulosic biofuels can be substituted for fossil-derived fuels such as gasoline, which reduces fossil carbon emissions. In comparison to the pellet industry, a market for cellulosic ethanol is available locally. A key advantage of ethanol derived from wood waste (as practiced in Canada) is the potentially high acceptability by society [17].

From an industrial sustainability viewpoint, both wood pellets and cellulosic ethanol have the potential to deliver the full suite of benefits associated with this concept. However, by competing for feedstocks, the ability of either industry to deliver maximum benefit is compromised. It should, however, be noted that though both products are used as fossil fuel substitutes, they, however, have specialized end-use niche applications. For example, while wood pellets provide a substitute for a range of fuels (natural gas, bunker oil, coal) primarily used in stationary applications, cellulosic ethanol is a liquid transportation fuel used within mobile applications. Similarly, the scale of industrial production facilities for wood pellets currently ranges between 50,000 and 100,000 tonnes/year in Canada [70]. While industrial-scale cellulosic ethanol plants have yet to be built, comparable cereal-based facilities produce approximately 200 million liters per year. In a "best case" scenario of ethanol production efficiency, the amount of white wood required would be approximately 667,000 dry tonnes per year [68]. It is recognized that, due to lack of literature specific to the Canadian context, it might be challenging at this stage to directly apply a complete sustainability assessment that evaluates all the environmental, economic, and social aspects of the two processes and products. However, consequential LCA was employed in this particular case. It could be deduced from the results in previous LCA studies on wood pellets [69] that, potentially, cellulosic ethanol offers significant sustainability advantages due to the current GHG emissions associated with long-distance transportation of pellets to Europe and the absence of local pellet markets. Policy intervention that supports cheaper access to fiber and development of local markets for both cellulosic ethanol and pellet industries are, therefore, important. However, in the absence of strong policy direction, the competition for feedstocks between the pellet and cellulosic ethanol industry will continue to intensify based on the rapid growth of the pellet market and industry and the increasing interest in cellulosic feedstocks for ethanol production. This will likely increase feedstock costs and result in financial hardship to both sectors, reducing the industrial sustainability of each option.

## Policy Recommendations

Bioenergy policy in both Canada and the USA are focused on transportation fuels, with little policy direction applied to other wood energy opportunities. In both countries, a series of subsidies and incentives have been used to develop cereal-to-ethanol capacity [71, 72]. In the USA, an effort to increase the cellulosic ethanol fraction in the biofuel mix was set out in the Energy Independence and Security Act of 2007. This legislation sets goals of increasing ethanol production capacity to $132\times10^9$ l/year by 2022, of which $75.6\times10^9$ l must be "advanced biofuels" including cellulosic ethanol [72]. The US total ethanol production target represents a 288% increase over the current production amount of $34\times10^9$ l. In contrast, Canada's renewable fuel mandate (5% ethanol in the gasoline pool, as legislated through Bill C-33) is yet to come into force and does not differentiate between cereal-based and cellulose-based ethanol [4, 71]. Therefore, a key recommendation is the development of a policy roadmap describing the introduction and development of cellulosic ethanol within the Canadian transportation fuel mix.

While no mandate for cellulosic ethanol exists, the Canadian federal government has instituted several programs to promote cellulosic ethanol including:

1. $19.9 million for a Cellulosic Biofuels Network (funded under the Agricultural Bioproducts Innovation Program)
2. $500 million to support large-scale cellulosic ethanol demonstration facilities (NextGen Fuel Fund, administered by Sustainable Development Technology Canada)
3. $19.9 million for various cellulosic ethanol technology projects (funded through the Technology Fund administered by Sustainable Development Technology Canada)
4. Several initiatives created under the Canadian Biomass Innovation Network, including the $230 million ecoENERGY Technology Initiative, the Technology and Innovation Research and Development Initiative, and the Program of Energy Research and Development

The Canadian government has made significant investment into research and development related to cellulosic ethanol. Thus, one recommendation of this paper is that a review of existing projects be used to support the development of a policy roadmap for cellulosic ethanol and that future investments under these programs be used to support the roadmap moving forward.

A range of policy tools might be employed to further cellulosic ethanol within Canada while maintaining or improving the industrial sustainability of the existing forest industry. Targeted incentives, such as tax credits, feed-in tariffs, and infrastructure investment are all mechanisms whereby the government might facilitate greater uptake in cellulosic ethanol production [72]. In addition, existing licensing for publicly owned forest resources (known as forest tenure agreements) might be revised to increase the availability of residues for energy production, without impacting the flow of merchantable timber volumes [68]. Reforms to the tenure system might also allow easier access to standing deadwood impacted by insects or disease, such as lodgepole pine impacted by mountain pine beetle in British Columbia. Another recommendation is that the proposed roadmap for cellulosic ethanol considers a range of policy tools, up to and including forest tenure reform.

Additional key policy recommendation is that a comparative analysis be carried out between competing wood energy systems to determine the best use for sawmill residues and ultimately other forest residues. Quantifying the social, economic, and environmental benefits associated with each competing system is a necessary step to understand the industrial sustainability of these systems. The dwindling sawmill residue availability in

Canada, stemming from factors described in this paper, offers a range of potential industrial sustainability benefits. Historically, resource scarcity had often led to breakthrough innovations [73]. Innovation may be evolutionary (i.e., incremental gains over time) or transformative/disruptive (i.e., innovations that punctuates long periods of business-as-usual) [74, 75]. Developments of multiple wood energy opportunities drawing on sawmills and harvest residues are examples of potentially transformative innovations for the forest sector. However, competition for feedstocks between different wood energy systems will continue to impact the industrial sustainability of these systems until clearer policy goals are defined.

## Conclusions

Two key trends have impacted the availability of sawmill residues in Canada. The efficiency of lumber recovery has increased over the past 16 years, reducing the amount of sawmill residue generated. Sawmill residue generation was approximately 64% of total lumber production in 1990 but fell to 45% of total lumber production in 2006. At the same time, sawmill residues have been increasingly used for both self-generation of energy and for the production of wood pellets. This has reduced the availability of residues at the sawmill site. In 1990, 49% of residue generated was available for use elsewhere, while only 13% was available in 2006.

The development of the wood pellet industry in Canada has largely been driven by the increase in overseas markets for this product. This means that the policy drivers behind the industry are largely external. Canada has not made a significant effort to develop a domestic pellet market to date, although there have been significant financial investment into research and development related to bioenergy and cellulosic ethanol in particular. However, the development of the wood pellet industry has greatly reduced the potential to use sawmill residues to support an early-stage cellulosic ethanol industry.

Given the current availability of sawmill residues, the potential for cellulosic ethanol production in a “best case” scenario was about 0.35 billion liters in 2006. This is approximately 16% of the $2.2 \times 10^9$ billion liters of ethanol required under Canada’s newly introduced renewable fuel mandate. An additional 2.7 billion liters of cellulosic ethanol might be generated from sawmill residue that is currently used for competing wood energy purposes, including wood pellet generation. The potential production of cellulosic ethanol could have been as much as 3.1 billion liters per year, more than enough to meet the mandated ethanol production.

Unlike the USA, Canada’s biofuel policy does not have specific targets for cellulosic ethanol. In view of the growing environmental and social concerns associated with cereal-based ethanol systems globally, it is imperative for Canada’s federal and provincial governments to develop policies that support higher commercial uptake of cellulosic ethanol.

From the perspective of industrial sustainability, both the wood pellet industry and the cellulosic ethanol industry offer a range of benefits. However, a lack of quantitative data makes it difficult to compare the two industries directly. A key recommendation is that a comparative analysis be carried out between competing wood energy systems in order to determine the best use for sawmill residues and ultimately other forest residues.

Sustaining cellulosic ethanol and realizing the full potential of the industry requires immediate policy intervention. As sawmill residues become scarcer, these policies must enable the industry to access relatively inexpensive and available low-grade fiber from sustainable sources, including road side/logging residues and mountain pine beetle infested wood. Maintaining a vibrant forest-based ethanol industry has far-reaching environmental, economic, and social benefits to Canada as well as maintaining the nation's competitiveness internationally. Clearly, feedstock availability and good policy intervention will play key roles in the industrial sustainability of Canada's wood-based cellulosic ethanol industry.

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