**ABSTRACT**

**Key Words:** biofuel, biorefinery siting, forest residues, feedstock supply, feedstock variability, feedstock cost

1. **INTRODUCTION**

Biofuels are becoming an increasingly important source of energy because of their potential to reduce dependency on fossil fuels, thereby reducing greenhouse gas emissions (IEA Bioenergy 2013). Moreover, second generation biofuel provides the benefit of avoiding competition with food production by using lignocellulosic biomass – often in the form of agriculture and forest residues – as feedstock (source?). Forest residues are generated as by-products of conventional forest harvesting operations, and include the tree tops, branches and non-merchantable logs. These residues are typically left behind in slash piles, which are burned during winter to mitigate against the risk of wildfires. Canada has a developed forestry sector that produces approximately 20 million t[oven dried]yr-1 of forest residues (Dymond et al. 2010).

Despite the potential to produce biofuels from forest residues, such use is limited to a few highly subsidized pilot projects. Indeed, several operational and economic challenges hinder the utilization of forest residues. These challenges are related to: (1) capital investments in biorefineries, (2) geographical distance between feedstock and markets, and (3) concerns surrounding feedstock availability (Shabani et al. 2013). The purpose of our study is to explore concerns surrounding this third challenge – feedstock availability – by evaluating annual variability in commercial stemwood harvest in the province of Alberta, Canada.

A number of studies have shown that collection and transportation costs are arguably the biggest constraint to widespread use of forest residues in bioenergy systems (Ralevic et al 2003, Wood and Layzell 2003, Kumar et al. 2003, Rummer 2007, Aulakh 2008). Availability of forest residues for a biorefinery largely depend on commercial harvesting operations and the production of traditional forest products. Fluctuations in the volume of stemwood harvested for forest products could have a direct impact on residues available for biofuels. Major factors, such as the 2008 housing crisis and the ongoing softwood lumber dispute with the United States have resulted in sawmill closures and reductions in forest harvesting activities (De Avillez 2014, Spelter 2009). This relationship between volatile sawlog harvests and subsequent residue variability is explored in detail by Niquidet and Friesen (2014) @ who model forest residue supply in Alberta as a direct function of lumber prices. Given that biomass feedstock accounts for 40 to 60% of a biorefinery’s total costs (Stephen et al. 2012), reliable feedstock supplies and costs over the life of the biorefinery are important factors to consider when deciding where to locate the biorefinery.

Though past studies regarding biorefinery locations have greatly improved our understanding of feedstock availability and constraints, one key area that has largely been omitted is considerations of feedstock supply variability over time. Commercial stemwood harvests vary year-to-year, largely based on market conditions for forest products. Since a forest-residue based biorefinery is dependent on stemwood harvesting for feedstock, any variability in harvesting directly influences the volume of residues that would be available. Therefore, considering the variability associated with feedstocks in different locations could be important in choosing the optimal site for locating a biorefinery

Although not related to a biorefinery siting decision, some studies have considered variable feedstock supplies when investigating whether and when to expand the production of bioenergy from burning residues (Bolkesjo et al. 2006; Buongiorno et al. 2011; Galik et al. 2009; Moiseyev et al. 2011). Other studies have explored the context of variable supplies when making decisions about capital investments in forest residue-based biorefineries (Cambero et al 2015, Chen and Fay 2011, Papapostolou and Kondili 2011). Variable feedstock supplies are also shown to affect capital investment decisions related to: investing in a residue preprocessing facility (Chen and Fay 2011), types of storage infrastructure for biorefinery feedstocks (Papapostolou and Kondili 2011), as well as whether to invest in biofuels versus bioenergy, and when to invest in processing facilities (Cambero et al. 2015).

There has been a number of studies conducted regarding siting decisions for forest residue-based biorefineries – see Johnston et al (2012) for a review of these studies – however, we are aware of no study that considered stemwood harvest variability and its subsequent effect on forest residue variability. Therefore, our study contributes to the literature by considering variability in forest residue feedstock supplies. More specifically, we analyze how this variability affects the cost of delivering residue, and then use these cost estimates to inform the decision on where to locate a biorefinery.

We consider co-locating the biorefinery adjacent to either a sawmill or a pulpmill. Co-locating with existing facilities and making use of established infrastructure and transportation systems can reduce many of the costs associated with establishing a new biorefinery (Browne et al., 2012; Saddler et al., 2012; Benjamin et al., 2009; Towers, et al., 2007). The decision to co-locate a biorefinery near a sawmill or pulpmill should be informed by how stable the respective residue supplies are. The facility with a more stable stemwood harvest would generate a more stable supply of forest residues that could be collected from the nearby harvested areas.

The objectives of our study are …… Our approach incorporates variable feedstock availability into decision making, and our results provide important information for assessing the potential for a forest residue-based biofuel industry in Alberta.

The remainder of the paper is as follows: The next section describes …….

**OTHER POTENTIALLY USEFUL TIDBITS…**

The need to go outside its normal delivery zone in bad years is similar to a scenario in the agriculture residue feedstock supply literature, called the the “derisked” scenario, whereby a buffer area outside the normal supply zone is contracted to provide residues during years when residue supply is low (Golecha and Gan 2016).

Residue variability is an important source of risk for a forest residue-based biorefinery. Being dependent upon stemwood harvests for the generation of residues can lead to cost variability over the long operating life of a biorefinery, making it is important to have a comprehensive feedstock risk management program. If the conversion technology allows it, biorefineries could consider creating a portfolio of different sources of residues. Such a portfolio approach might consider locating the biorefinery where it could also access agricultural residues during periods when availability of forest residues is low. We plan to investigate feedstock portfolios in future research.

Modern biorefineries can expect to breakeven financially with delivered biomass costs of approximately $80 (US$60) t[oven dried]-1 (Steeper 2021) . Studies have shown that forest policy reforms could reduce delivered forest residue costs by incenting plantations of fast-growing tree species on lands close to pulpmill locations (Shooshtarian et al. 2021, Anderson et al. 2012). Other important factors will be advances in biorefinery technology and increases in biofuel prices. In Canada, governments impact biofuel prices by setting renewable fuel mandates and paying subsidies for biofuel production (Campbell et al., 2016). The continuation of these mandates and subsidies will likely be an important factor for the emergence of a second-generation (“advanced”) biofuel sector. Also, the Government of Canada's Clean Fuel Standard, which is proposed to come into force in 2022 (Government of Canada, 2020), is expected to improve the economics of advanced biofuel production.

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# **REFERENCES**

1. Alberta Government n.d., Forest Management Plans - Overview*,* viewed May 2019, < <https://www.alberta.ca/forest-management-plans-overview.aspx>/>.
2. Alberta Innovates Bio Solutions 2013. Recommendations to build Alberta’s bioeconomy. http://bio.albertainnovates.ca/media/57924/bioe\_final\_report\_web\_may2013.pdf. Accessed June 14, 2019.
3. Aulakh, J. 2008. Implementing residue chippers on harvesting operations for biomass recovery. Masters of sciences thesis. Auburn, AL: Auburn University.
4. Benoit, L. 2008. Canada’s forest industry: Recognizing the challenges and opportunities. Report of the Standing Committee on Natural Resources. <http://www.parl.gc.ca/content/hoc/Committee/392/RNNR/>Reports/RP3534643/rnnrrp03/rnnrrp03-e.pdf. Accessed June 14 2019
5. Cantelon, R. and J. Rustad. 2011. BC bio-economy. <http://www.gov.bc>.ca/jtst/down/bio\_economy\_report\_final.pdf. Accessed June 14, 2019
6. Bolkesjo, T.F., Tromborg, E., and Solberg, B. 2006. Bioenergy from the forest sector: economic potential and interactions with timber and forest products markets in Norway. Scandinavian Journal of Forest Resources. 21(2): 175–185.
7. Bouchier, R, J., [Stanton](https://www.thecanadianencyclopedia.ca/en/author/c-r-stanton), C.R. and [Kuhlberg](https://www.thecanadianencyclopedia.ca/en/author/mark-kuhlberg), M. (2015). Forestry. The Canadian Encyclopedia. [online] Avaialbelat: <https://www.thecanadianencyclopedia.ca/en/article/forestry>. [Accessed 03/08/2019]
8. Bradley D. Canada report on bioenergy, 2010. (Available from: <http://www.canbio.ca/upload/documents/> canada-report-on-bioenergy-2010-sept-15-2010.pdf). Accessed March 24, 2019.
9. Buongiorno, J., Raunikar, R., and Zhu, S. 2011. Consequences of increasing bioenergy demand on wood and forests: an application of the global forest products model. Journal of Forest Economics, 17(2): 214–229.
10. Cambero, C, Sowlati, T., Marinescu, M. and Röser, D. 2015. Strategic optimization of forest residues to bioenergy and biofuel supply chain. International Journal of Energy Resources. 39:439–452.
11. Canadian Forest Service. Biomass, bioenergy and bioproducts. (Available from: http://cfs.nrcan.gc.ca/ pages/65). Accessed February 13, 2019.
12. Chen, W. and Fan, Y. 2012. Bioethanol supply chain system planning under supply and demand uncertainties. Transportation. Research.48, 150–164.
13. Johnson, D., Jenkins, T. and Zhang, F. 2012. Methods for optimally locating a forest biomass-to-biofuel facility, Biofuels, 3:4, 489-503
14. Demirbas, F., Balat, M. and Balat H. 2009. Potential contribution of biomass to the sustainable energy development. Energy Conversion and Management; 50(7):1746–1760.
15. Dymond, C., Titus, D., Stinson, G. and Kurz, W. 2010. Future quantities and spatial distribution of harvesting residue and dead wood from natural disturbances in Canada. Forest Ecology and Management. 260(2):181–192.
16. Engineering ToolBox, (2004). *Densities of Wood Species*. [online] Available at: https://www.engineeringtoolbox.com/wood-density-d\_40.html [Accessed 27/07/2019].
17. Galik, C.S., Abt, R., and Wu, Y. 2009. Forest biomass supply in the southeastern United States – implications for industrial roundwood and bioenergy production. Journal of Forestry 107(2): 69–77.
18. Gronowska, M., Joshi, S. and MacLean, H. L. 2009. A review of U.S. and Canadian biomass supply studies. BioResources. 4(1):341e69.
19. Huang, H., Stephen ,J. and Douglas, P. 1992. Comparison of nonlinear height–diameter functions for major Alberta tree species. Canadian Journal of Forest Research. 22: 1297-1304
20. Husch, B., Miller, C.I., and T.W. Beers. 1982. Forest Mensuration. Wiley. New York. 402 p.
21. IEA Bioenergy. Potential contribution of bioenergy to the world’s future energy demand. 1. IEA bioenergy. Potential contribution of bioenergy to the world’s future energy demand. (Available from: <http://www>.ieabioenergy.com/MediaItem.aspx?id=5586) Accessed March 11, 2019.
22. Jones, G., Loeffler, D., Butler, E., Hummel, S. and Chung, W. 2013. The financial feasibility of delivering forest treatment residues to bioenergy facilities over arrange of diesel fuel and delivered biomass process. Biomass Bioenergy. 48: 171-180.
23. Kim, J., Realff M. J. and Lee J. H., 2011. Optimal design and global sensitivity analysis of biomass supply chain networks for biofuels under uncertainty. Computers and Chemical Engineering*.* 35, 1738–1751 (2011).
24. Kumar, A., Cameron, J.B. and Flynn, P.C. 2003 Biomass power cost and optimum size in western Canada. Biomass Bioenergy. 24: 445-464.
25. Moiseyev, A., Solberg, B., Kallio, A.M.I., and Lindner, M. 2011. An economic analysis of the potential contribution of forest biomass to the EU RES target and its implications for the EU forest industries. Journal of Forest Economics 17(2): 197–213.
26. Niquidet, K., Stennes, B., and van Kooten, G.C. 2012. Bioenergy from mountain pine beetle timber and forest residuals: a cost analysis. Canadian Journal of Agricultural Economics 60(2): 195–210.
27. Niquidet, K. and Friesen, D. 2014. Bioenergy potential from wood residuals in Alberta: a positive mathematical programming approach. Canadian Journal of Forest Resources. 44: 1586–1594.
28. Papapostolou, C and Kondili, J.K. 2011. Development and implementation of an optimization model for biofuels supply chain. Energy36, 6019–6026.
29. Ralevic, P., Karau, J., Smith, T., Richardson, J. 2007 IEA Bioenergy Task 31 Country Report: Canada December 2008. Available from: <http://www.ieabioenergytask43.org/>
30. Rummer, R. 2007. Harvesting and transportation of Forest biomass. Unpubl Rep. Available from:, http://www.weedcenter. org/mrwc/cig/documents/.
31. Röser D, Asikainen A, Stupak I, Pasanen K. Forest energy resources and potentials. In Sustainable Use of Forest Biomass for Energy: A Synthesis with Focus on the Baltic and Nordic Region, Röser D, Asikainen A, Raulund-Rasmussen K, Stupak I (eds). Springer: Dordrecht, The Netherlands, 2008; 9–28.
32. Ryans, M. and Cormier, D. 2009. Opportunities and challanges to biomass harvesting e operational perspective. FPinnovation, FERIC. Presentation for CIF Rocky Mountain Section. Edmonton: Bioeconomy and Forestry.
33. Shabani, N., Akhtari, S. and Sowlati, T. 2013. Value chain optimization of forest biomass for bioenergy production: a review. Renewable & Sustainable Energy Reviews. 23:299–311.
34. Spelter, H., McKeever, D., and Toth, D. 2009. Profile 2009: softwood sawmills in the United States and Canada. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, Res. Pap. FPL-RP-659. Available from www. treesearch.fs.fed.us/pubs/34525 [accessed 13 September 2018].
35. Stephan, J.D., Sokhansanj, S., Bi, X., Sowlati, T., Kloeck, T., Townley-Smith, L., and Stumborg, M.A. 2010. Analysis of biomass feedstock availability and variability for the Peace River region of Alberta, Canada. Biosystems Engineering. 105: 103–111.
36. Wood, S. and D. Layzell. 2003. A Canadian biomass inventory: Feedstocks for a bio-based Economy, Final Report. BIOCAP Canada Foundation, Kingston, Ontario, Canada. 42 pp
37. Volpe S. 2011 FPInterface e BiOS. FERIC Advantage report 13(1).