Energy Policy 59 (2013) 329–340

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

# Lignocellulosic ethanol production from woody biomass: The impact of facility siting on competitiveness

James D. Stephen [a,b,*], Warren E. Mabee [b,1], Jack N. Saddler [a,2]

[a] Department of Wood Science, University of British Columbia, 2424 Main Mall, Vancouver, British Columbia, Canada V6T 1Z4
[b] School of Policy Studies, Queen's University, 138 Union Street, Kingston, Ontario, Canada K7L 3N6

## HIGHLIGHTS

- Lignocellulosic ethanol production costs vary notably by region.
- Feedstock cost is the primary site-specific production cost variable.
- Woody feedstocks in North America have a higher cost than those in Brazil.
- Use of Brazilian eucalyptus resulted in the lowest MESP for considered feedstocks.
- MESP ranged from $<\$0.75\ L^{-1}$ to $>\$1.00\ L^{-1}$.

## ARTICLE INFO

*Article history:*
Received 11 May 2012
Accepted 22 March 2013
Available online 23 April 2013

*Keywords:*
Biorefinery
Lignocellulose
Ethanol

## ABSTRACT

Just as temperate region pulp and paper companies need to compete with Brazilian eucalyptus pulp producers, lignocellulosic biofuel producers in North America and Europe, in the absence of protectionist trade policies, will need to be competitive with tropical and sub-tropical biofuel producers. This work sought to determine the impact of lignocellulosic ethanol biorefinery siting on economic performance and minimum ethanol selling price (MESP) for both east and west coast North American fuel markets. Facility sites included the pine-dominated Pacific Northwest Interior, the mixed deciduous forest of Ontario and New York, and the Brazilian state of Espírito Santo. Feedstock scenarios included both plantation (poplar, willow, and eucalyptus, respectively) and managed forest harvest. Site specific variables in the techno-economic model included delivered feedstock cost, ethanol delivery cost, cost of capital, construction cost, labour cost, electricity revenues (and co-product credits), and taxes, insurance, and permits. Despite the long shipping distance from Brazil to North American east and west coast markets, the MESP for Brazilian-produced eucalyptus lignocellulosic ethanol, modelled at $\$0.74\ L^{-1}$, was notably lower than that of all North American-produced cases at $\$0.83–1.02\ L^{-1}$.



## 1. Introduction

Many jurisdictions around the world are competing to attract renewable energy and clean technology companies, with an emphasis on creating ‘green-collar’ jobs (Renner et al., 2008). Of particular interest for regions historically dependent upon forestry and agriculture industries are biomass biorefineries, which can potentially produce energy, chemicals, and materials in addition to liquid fuels such as ethanol. These facilities promise large numbers of jobs in feedstock production/management, feedstock and product transportation and handling, and plant operations. Unlike solar or wind electricity industries, a large proportion of the jobs created in the biofuels industry are ongoing operation and maintenance jobs that last the lifetime of the facility (Wei et al., 2010).

Ethanol produced from lignocellulosic biomass is often referred to as advanced or ‘second generation’ biofuel, while corn- or sugarcane-based ethanol is referred to as conventional or ‘first generation’. The second generation fuels are promoted as environmentally, economically (for the operating company), and morally superior to conventional biofuels (Tilman et al., 2009; Williams et al., 2009). Whereas conventional corn ethanol is estimated to have a net greenhouse gas reduction of approximately 12–13% relative to baseline gasoline (Farrell et al., 2006; Hill et al., 2006), dependent upon feedstock and processing conditions, lignocellulosic ethanol is expected to have greenhouse

* Corresponding author at: School of Policy Studies, Queen's University, 138 Union Street, Kingston, Ontario, Canada K7L 3N6
Tel.: +1 613 532 7079; fax: +1 613 249 7487.
*E-mail addresses:* jstephen@tlbio.com (J.D. Stephen), warren.mabee@queensu.ca (W.E. Mabee), jack.saddler@ubc.ca (J.N. Saddler).
[1] Tel.: +1 613 533 6000x77092; fax: +1 613 533 2135.
[2] Tel.: +1 604 822 9741; fax: +1 604 822 8157.

0301-4215/$ - see front matter 
http://dx.doi.org/10.1016/j.enpol.2013.03.043

gas reductions exceeding 80% (Fleming et al., 2006; Sheehan et al., 2004). This is in the same range as commercial sugarcane ethanol, which has estimated reductions of 75–85% (Luo et al., 2008; Wang et al., 2008). It is also anticipated that lignocellulosic ethanol will require reduced water withdrawals and consumption compared to corn ethanol, particularly relative to fuel produced from irrigated crops (King and Webber, 2008). Lignocellulose may also have a lower market price on a per tonne basis than corn or sugarcane, although recent work has shown that feedstock cost is not significantly lower for woody biomass than for corn as a contributor to minimum ethanol selling price (MESP) (Stephen et al., 2012). Finally, moral concerns with conventional biofuels, in particular corn ethanol, have focused on direct competition for feedstock between fuel and food markets (Food and Agriculture Organization, 2008; Piesse and Thirle, 2009).

The authors have previously shown that it will be difficult for woody feedstock lignocellulosic ethanol to compete economically on a cost-of-production basis with conventional ethanol produced from corn and sugarcane in the short term without substantial support subsidies (Stephen et al., 2012). Even when considering higher-value emerging fuels such as biobutanol and hydrocarbon biofuels, the primary comparative metric of monomer sugar cost still puts lignocellulosic feedstocks at a disadvantage (Stephen et al., 2012). However, given the push towards lignocellulosic ethanol and the desire for job creation, it is important to identify the conditions that would make production most economical and which jurisdictions have an opportunity for long-term, sustainable job creation. Substantial government investments, such as the CA $500 million Sustainable Development Technology Canada NextGen Biofuels Fund (Sustainable Development Technology Canada, 2011) and hundreds of millions of dollars allocated for commercial biorefineries by the United States Department of Energy (United States Department of Energy, 2007, 2009), have been made with the goal of reducing production costs and increasing commercial feasibility.

For businesses comparing jurisdictions for manufacturing or chemical processing operations, labour is typically the most significant contributor to location-specific costs (KPMG LLC, 2010). However, biomass, due to its low energy density, is not traditionally transported long distances without preprocessing and therefore feedstock (raw material) is a location-specific cost component critical to the biofuel production industry (Uslu et al., 2008). Since feedstock is typically the largest variable and operating cost for a biorefinery (Boerrigter, 2006; Humbird et al., 2011; Sims et al., 2008), regardless of the technology platform used, it is also the largest contributor to location-specific costs (Huang et al., 2009; Stephen et al., 2010a). Other major location-specific biofuel production cost components include raw material transportation cost (including associated labour cost), cost of capital, cost of construction, income and other taxes, utilities (energy and water), and government and insurance fees (KPMG LLC, 2010). When determining the ability to compete in a target market, physical proximity to that market is an essential consideration for large-volume commodity producers, and hence transportation cost of product(s) is an additional factor that must be taken into account (Uslu et al., 2008; Zhang et al., 2010). Finally, the exchange rate must be considered if inter-country trade is involved, which affects all cost components and can greatly impact competitiveness of production (Chen et al., 2010).

Previously, we have determined that advanced lignocellulosic biofuel facilities are likely to resemble pulp mills in terms of scale, feedstock supply, and logistical structures (Stephen et al., 2010b). Therefore, it is worthwhile considering trends in the pulp industry for implications and lessons for lignocellulosic biofuels, particularly those utilizing woody feedstocks. Of particular importance is the general pulp industry trend of increasing southern hemisphere production and stable or declining production in northern hemisphere countries. Although labour savings contribute to the lower cost of production in countries such as Brazil and Chile, the greatest factor by far is cost of feedstock (Greenbaum, 2008). Eucalyptus can be grown in 7-year rotations in Brazil (Walter et al., 2006), while hardwood and softwood forest rotations in Canada range from 50 to 90 years. Brazil is already the world's largest short-fibre pulp producer, having risen to the third largest producer overall, and is expanding rapidly (Chadwick, 2007; Food and Agriculture Organization, 2009). The ability to utilize short rotation eucalyptus as a feedstock has enabled Brazilian pulp and paper mills to achieve much greater economies-of-scale than their northern hemisphere counterparts (Faleiros, 2010; Stephen et al., 2010b). While the largest Brazilian pulping complex exceeds 2.3 million tonnes (Mt) pulp per year and the largest individual mill is 1.5 Mt, the average mill capacity in Canada is 200,000 t (t) pulp (Faleiros, 2010; Fibria, 2012; Kirby, 2006; Yakabuski, 2007).

Pulp companies in Brazil and other tropical nations benefit from being vertically integrated; owning their own land, growing and harvesting their own fibre, and then processing that fibre at their mills. Comparatively, companies with operations in temperate and subtropical climates have little or a negative financial benefit from land ownership and vertical integration due to low productivity (Cubbage et al., 2007). Even in the relatively rapid-growth U.S. south-east, land expectation values do not support investment in land purchases (Cubbage et al., 2007). In other words, it is lower cost for pulp companies to purchase fibre from landowners than to grow the trees themselves. Not controlling feedstock directly poses a substantial operating risk for a large biorefinery requiring potentially millions of tonnes of biomass per year. Nevertheless, this multi-million tonne per year capacity, which enables large economies-of-scale and lower production costs, is the competition faced by Canadian pulp mills and biorefineries.

Difficulty competing in challenging traditional markets has forced Canadian pulp and forestry companies to investigate alternatives or co-products such as lignocellulosic ethanol (Browne et al., 2011). However, the question of forest sector competitiveness must apply to both pulp and new products such as ethanol. Given the push towards advanced lignocellulosic biofuels in countries such as Canada and the United States, it must be determined whether domestic production is economically competitive in a world with global trade. As a renewable resource, it is possible to dramatically increase production of biofuels worldwide if justified by market prices and demand. Therefore, the purpose of this work was to determine the ability of domestic lignocellulosic ethanol producers to compete economically with tropical producers in North American markets.

## 2. Study design and assumptions

This study sought to compare the cost of production and delivery of lignocellulosic ethanol for North American and Brazilian producers. The metric for comparison was the cost including freight (CIF) minimum ethanol selling price (MESP) of ethanol delivered to two Canadian markets, Montréal and Vancouver–the second and third largest cities in Canada respectively. Both cities have year-round port access for accepting Panamax-sized ships, a key criterion for selection. The study involved the creation of six lignocellulosic ethanol production scenarios—two at each of three potential production sites—which are presented in Table 1. A lignocellulosic ethanol production techno-economic spreadsheet model was created to determine the MESP. Steam explosion, followed by enzymatic hydrolysis and fermentation by *Saccharomyces cerevisiae* (brewer's yeast), was chosen to be the preferred