Skilled Labor Preference, Cellulosic Biofuel Facility Location, and Economic Impacts in the Southeastern US

D.M. Lambert, B.C. English, R.J. Menard, B. Wilson, L. He, T.E. Yu, K. Jensen

Department of Agricultural and Resource Economics

The University of Tennessee Institute of Agriculture

308E Morgan Hall, 2621 Morgan Circle

Knoxville, TN 37996-4518

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*Corresponding author: dmlambert@utk.edu

Abstract

This research applies recent developments in the analysis of firm location determinants, applying local geographic concentration indices to determine and the extent to which clustering influences the location decisions of cellulosic biofuel facilities. We focus on ethanol production from switchgrass and drop-in fuels made through pyrolysis. The economic sectors analyzed would be involved in the extraction, production, and distribution of intermediate and final fuel products, and the financing of businesses supporting these activities. We augment a cost-minimizing site location model with information about local employment patterns that would be engaged with a switchgrass-based cellulosic fuel sector. Employment concentration is determined using recent developments in the derivation of the traditional location quotient as a maximum likelihood estimator. The null hypotheses are that differences arising from advantages associated with each county are not different. Rejection of this hypothesis suggests that some sites have comparative advantage with respect to location advantage. The null hypothesis also suggests that the inclusion of labor concentration information in the overall cost structure will not impact the distribution of facilities. Region-wide economic impacts that follow the addition of multiple facilities are not expected to be different after inclusion of the employment location quotients as site suitability criteria.

Key words: cellulosic ethanol, pyrolysis, switchgrass, facility siting, employment concentration

JEL Classification: Q1, Q4

Introduction

The development of the renewable energy sector is expected to become an important economic driver of local and regional economies. This expectation is based on energy production targets set by federal and state governments to encourage the expansion of renewable energy industries. Federal mandates promoting a sustainable and secure future for the Nation's energy supply set goals for the production of biomass fuels from non-grain materials. The Energy Policy Act of 2005, a significant energy policy landmark, required that 7.5 billion gallons of fuel come from renewable sources. Two years later, the Energy Independence and Security Act (EISA) mandated that 36 billion gallons per year of biofuels be produced in the United States by 2022, with 21 billion required to be from advanced biofuels. Advanced biofuels are defined as a renewable fuel (other than ethanol derived from corn starch) with lifecycle greenhouse gas emissions (GHG) meeting a 50 percent reduction over baseline GHG lifecycle emissions. Cellulosic materials from "dedicated energy crops" such as switchgrass, corn stover, wheat straw, sweet sorghum, poplar, willow, and wood waste products will be needed to meet these biofuels production targets (De La Torre Ugarte et al., 2007). Least-cost sites will reflect a balance between transportation, payroll, service access and technical support, and feedstock costs.

This research applies recent developments in the measurement and analysis of industry concentration and firm location theory, applying local geographic concentration indices to determine if the businesses comprising the cellulosic ethanol and pyrolysis are clustered, and the extent to which clustering influences the site location preferences of facilities. The sectors analyzed encompass the extraction, production, and distribution of intermediate and final biofuel products, and the financing of businesses supporting these activities. The analysis is at the county level, focusing on the Southeastern United States (AL, FL, GA, KY, MS, NC, SC, TN, and VA,

n = 841) using 2010 data sources. Prior research shows that the Southeastern U.S. will be a key supply region for biomass feedstocks from dedicated energy crops such as switchgrass (Perlack and Stokes, 2011; English et al., 2006). Hence, our determination of cellulosic ethanol and pyrolysis clustering and the influence of clustering on site location focuses on the Southeastern U.S.

Methods

We augment a cost-minimizing site location model, BioFlame (Wilson, 2009; Lambert et al., 2014) with information about the relative concentration of jobs making up the switchgrass-based ethanol and pyrolysis sectors. Employment concentration is determined using recent developments in the derivation of the traditional location quotient (LQ) as a maximum likelihood estimator. The methodology proposed by Guimarães, Figueiredo, and Woodward (2009) (GFW) facilitates testable hypotheses about the geographic distribution of sector concentration across counties while retaining observational equivalence to the standard LQ. The null hypotheses are that differences arising from labor concentrated in the supporting sectors associated with each county are similar (H0: LQ < 1). Rejection of this hypothesis suggests a county has comparative advantage with respect to location. The null hypothesis also suggests that the inclusion of labor concentration information (e.g., potentially lower search and training costs) into the overall cost structure will not affect the site selection decisions of facilities. Region-wide economic impacts that follow the addition of multiple facilities are not expected to be different after inclusion of the employment location quotients as site suitability criteria.

BioFlame Facility Location Model

The facility location model BioFlame is currently calibrated for 16 Southeastern states. BioFlame has been used to explore the economic impacts of preprocessing facilities for a potential commercial-size switchgrass biofuel plant in East Tennessee (Wilson, 2009; Yu et al., 2011), and the least cost locations of cellulosic ethanol facilities using switchgrass as feedstock (Lambert et al., 2014). BioFlame operates on GIS architecture consisting of three components—site suitability, feedstock availability, and land conversion. Road networks, pipelines, transmission lines, and other geo-spatial layers are used to identify potential cellulosic refinery locations (ESRI, 2008). Given an annual target output level (millions of gallons) for an individual facility, BioFlame estimates; 1) source locations for the feedstock supply to the facility, 2) the annual cost of procuring and transporting feedstock, and 3) number of facilities a region can support. The algorithm combines a number of GIS functions and database management operations to determine the facility locations minimizing the plant-gate cost of feedstock. The shortest path to every potential feedstock supply unit along the transportation network is determined and used to generate a least-cost transportation layer. A hierarchy of primary, secondary, and tertiary roads (categorized based on the speed limits of each road type) is used to generate paths between nodes. County-level budgets, acreages, and prices are used to calculate a break-even price above which farmers would convert traditional crops to dedicated energy crops. The feedstock supply analysis subsequently evaluates the costs of siting a facility in the set of all candidate sites in a region. Transportation and farmgate costs are minimized at the preferred site.

The siting algorithm supports single or multiple facilities. We hypothesize that processing facilities will locate to minimize competition with other biomass refineries (e.g., Zhang and

Sexton, 2000; Alvarez et al., 2000). First-movers select the least-costs sites, characterized by abundant supply of feedstock, superior transport infrastructure, availability of business support services, and the requisite skilled labor for plant operations and management. The site selection of the first-mover impacts the distribution of low-cost sites that could be selected by subsequent entrants. The location decision of the second firm is conditional upon the site selection decision of the first; and because plant capacity is a function of cost, and costs are site-specific, the scale of the firms entering the feedstock market later will be impacted by the first. Thus, the site selection decision and scale of the *n*-th firm entering is conditional upon the location decision of firm $n - 1$. The process continues until all available least-cost sites are exhausted, or until demand markets are saturated. The physical infrastructure and land suitability constraints embedded in BioFlame are modified to reflect the distribution of labor that would be employed by the sectors comprising the cellulosic fuel industries considered here.

According to the EIA, 681.2 trillion Btu generated from petroleum are required on an annual basis. There are approximately 115,000 Btu/gallon of gasoline. A 50% replacement rate translates into a supply target of 10.5 billion gallons of cellulosic-based fuel produced in the region. Assuming a conversion factor of 80 gal ethanol/t of cellulose, feedstock demand for switchgrass is projected to be 16,375,000 t of biomass. The most current techno-economic data suggests an upper capacity limit of 80.3 million gallons/year, operating at 96% efficiency. This translates into 147 cellulosic ethanol plants locating in Southeastern region to reach the 50% replacement rate.

Achieving the same target for bio-oils produced using pyrolysis requires additional assumptions with respect to technology scale. We consider three capacity levels to reflect these differences; 36.4, 53.2, and 59.5 million gallons per year capacity. Achieving the 10.5 bgy target would require 287, 198, and 177 cellulosic pyrolysis facilities. Conversion technology specification for pyrolysis and cellulosic ethanol are based on Wright et al. (2010) and Humbird et al. (2011).

Table 1 summarizes the parameters under which the site location models were estimated to generate switchgrass feedstock supply curves for bio-oils (produced by pyrolysis) and cellulosic ethanol. Feedstock supply curves for industry demands are generated taking into consideration firm preferences for choosing sites with labor skilled in the supporting sectors of the biorefinery, and in the absence of this constraint. Presumably, sites where labor is concentrated would be indicative of locations where backward linkages to sectors supporting biorefinery would be relatively dense. Thus, the economic impacts may be larger because leakage would be moderated in terms of demands for services and capital. On the other hand, transportation costs may increase because sites harboring skilled labor may not necessarily have comparative advantages with respect to feedstock growing conditions.

Hypothesis Testing of Employment Location Quotients

Location quotients are frequently used in economic base analyses to compare local economies to other economies (Shaffer, Deller, and Marcouiller, 2004). Guimarães, Figueiredo, and Woodward used location quotients to evaluate manufacturing industry localization in Connecticut. Riddington, Gibson, and Anderson (2006) employed location quotients for a Scottish enterprise in a comparison with the gravity model and survey approaches. Location quotients have also been used in evaluation of renewable energy in the Appalachian region (Jensen, et al. 2010).

A variety of methods and indicators can be used to calculate location concentration indices, but employment-based LQs are common. The employment location quotient is measured as the employment share of a given industry in a location divided by the employment share of that industry across a wider region. The usual interpretation is that if the index is greater than one, then (1) that location is competitive in terms of attracting firm investment, (2) the industry is concentrated in that location or region, and (3) regional economic impacts are likely to emanate from these areas as export activities expand (Isserman, 1977).

Despite the popular appeal of LQs, the statistical criterion supporting conclusions that might be inferred from the index is tenuous (Guimarães, Figueiredo, and Woodward, 2009). GFW maintain that without a theoretical structure reflecting firm objectives to the index it is difficult to disambiguate industry concentration that occurs by chance alone from industry concentration arising from the natural advantages of a given location (e.g., an abundant resource base, transport infrastructure, and access to agglomeration economies). Without theoretical grounding, they argue, it is impossible to account for the inherent randomness of firm location activities using location quotients.

This research applies GFW's statistical procedure to test the extent to which firms making up the cellulosic ethanol and pyrolysis sectors are geographically concentrated. The hypotheses are derived from a probability-based firm location model developed by GFW in 2007, which expands upon Ellison and Glaeser's (1997) seminal article on industry concentration measurement. Within this framework, probabilistic statements about localization economies can be made with the location quotient. GFW develop a Wald statistic to test the null hypothesis that an industry is non-localized in a given location. The intuition is that if a significant portion of the location quotients are around one, then the industry is not geographically concentrated. Lack of concentration is inversely proportional to costs savings enjoyed by firms with access to localization economies.

The LQs are calculated using the 2010 IMPLAN employment data bases. Hypotheses about these indexes are tested using GFW's a maximum likelihood procedure. The null hypothesis is that the industries analyzed are not localized in a given county. Rejection of the null hypothesis suggests the presence of scale economies, wherein the average fixed costs of operations are expected to be lower, which in turn could increase the competiveness of a location and the probability that firms associated with the industry sector will locate there. Results of the statistical analysis are integrated into BioFlame's resource database at the county level. In the LQ scenarios, firms are constrained to consider locations where location quotients exceed 1.

The 2010 IMPLAN model is used to determine the aggregate economic impacts to the region under each scenario (Lindall and Olson, 2009). Key indicators include: (1) impacts from investment and (2) impacts that are recurring due to facility operation. Impacts from conversion of energy and those occurring backwards in the supply chain are also measured, including changes in revenue earned by farmers and/or landowners. When land is removed from another use, the net decrease in economic activity from that enterprise is accounted for.

Results and Discussion

The mean of the cellulosic ethanol employment location quotients was 0.95 ($\pm$ 0.21 standard deviations), with a minimum (maximum) LQ of 0.16 (1.40) (Figure 1). The mean of the LQ for the pyrolysis sector was similar (0.96) but with a wider variance (standard deviation, 0.26; minimum, 0.03, maximum, 1.73). About 50% of the counties exhibited location quotients exceeding 1 for both industries (Figure 2). The geographic distribution of the cellulosic ethanol raw location quotients were most concentrated in the Western North Carolina/East Tennessee region, and along the cost of South Carolina. The distribution of the pyrolysis location quotients was more dispersed. Location quotients typically separate economic activity into two broad categories; basic and non-basic. Basic sectors export goods from a region and the non-basic sectors comprised of industries supporting the basic sectors. Regions with comparative advantage in terms of the basic sectors can be identified by comparing the share of jobs in a given location and sector to the regional or national average. On average, at the county level it appears that aggregation of sectors comprising what would ostensibly define the cellulosic ethanol industry exhibit some degree of "comparative" or "natural advantage" with respect to accessing skilled labor or existing support services.

The apparent clustering of the LQ for the cellulosic ethanol sector was confirmed by distribution of the counties where the null hypothesis ($LQ \leq 1$) was rejected at the 5% level of significance (Figure 2). Comparative advantage with respect to the cellulosic ethanol industry was exhibited in 159 counties (out of 841). Compared with cellulosic ethanol biorefineries, counties with pyrolysis LQs exceeding 1 were more uniformly dispersed across counties (n = 144, or 17% of the counties). Given these results, it appears that including the employment information as a constraint in the site suitability criteria will influence the location of facilities. The constraint imposed during the site selection optimization criterion was a decision rule that disqualified potential locations if the employment location quotient was less than one in the site's respective county.

Constraining the location of firms increased the overall costs of feedstock supply for cellulosic ethanol and pyrolysis (Figure 3). The site-constrained and unconstrained feedstock supply curves of the cellulosic ethanol industry were statistically similar (Kolmogorov-Smirnoff test, 5% level), but the aggregate (variable) costs of feedstock acquisition were higher in the unconstrained case, reflecting the effect of eliminating the low-cost, high feedstock productivity sites in favor of access to labor skilled in supporting industries. The result suggests that the distribution of jobs engaged in the supporting sectors of the cellulosic ethanol and pyrolysis industries overlap (to some extent) with the distribution of land and terrain favorable to switchgrass supply and transportation. The feedstock supply curve for the pyrolysis industry was generally flatter, suggesting that relatively more switchgrass is required to support this industry at specified targets. Aggregate industry variable costs of feedstock supply were comparatively higher for the pyrolysis industry. The 10.5 bgy target was not obtained in the constrained case for pyrolysis, reflecting the relatively dispersed nature of counties with workforces engaged in the sectors supporting pyrolysis refinery operations.

Firm preferences for a workforce skilled in the sectors supporting the cellulosic ethanol and pyrolysis industries impact the spatial destitution of the feedstock sheds and the location of facilities (Figure 4). In all scenarios, as the premium on low cost sites increases, facilities ostensibly locate in sites already occupied by a facility. In practice, once a hexagon is selected (the fundamental unit of analysis in BioFlame, a 5 km^2 polygon), it is eliminated from the choice set. What appears in Figure 4 are firms locating in hexagons neighboring a hexagon occupied by a facility in a previous iteration. The interpretation is that these composite sites represent single facilities operating at scales larger than the parameters used to calibrate the location model.

Aggregate economic impacts were modest, ranging from +0.73% (cellulosic ethanol, LQ constrained) to +1.09% (pyrolysis, unconstrained) in total industry output (TIO) (Table 2). The impacts on TIO, jobs, and total value added (TVA) were highest under the pyrolysis-baseline scenario, presumably because of denser connections to local economies for this industry. Impacts were lowest for the pyrolysis-constrained scenario because the aggregate industry production target was not achieved. The distributions of the indicators were not significantly different from each other, or the reference distributions of TIO, jobs, and TVA, evaluated at the BEA level (Kolmogorov-Smirnoff test, 5% level). Locating sites where labor skilled in these technologies is concentrated increases industry costs and moderates economic impacts when 100% targets are achieved. This difference appears to be driven by trade-offs between acres of corn, soybean, and cotton converted to biomass. Future analyses will investigate the trade-off between lower training costs and higher feedstock procurement costs. The analysis could also be extended to examine partial fulfillment of RFS2 mandates.

Table 1. Scenarios used to generate facility distributions and industry supply curves

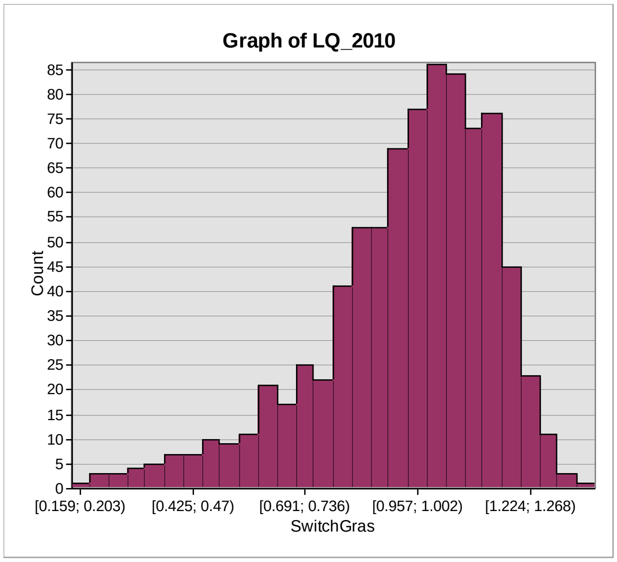
Cellulosic EtOH	Pyrolysis
• Target: 10.5 bgy advanced fuel in the Southeast • Switchgrass • Ethanol • 75 mgy facility capacity • 22%, 31%, 50%, 100% target achieved • Unconstrained/LQ constrained	• Target: 10.5 bgy advanced fuel in the Southeast • Switchgrass • Bio oils • 36.4 mgy, 52.5 mgy, 59.5 mgy capacity • 100% target achieved • Unconstrained/LQ constrained

Table 2. Aggregate economic impacts

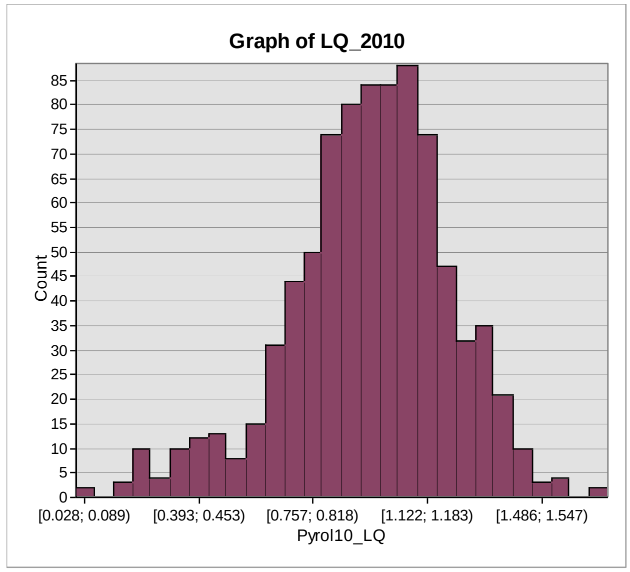
Aggregate economy (2010 $'s)	Total industry output (TIO) /1	Jobs 2/	Total value added (TVA) /1
Baseline economy	6.172	46,509	3.590
Cellulosic EtOH-Baseline	+0.77%	+0.97%	+0.84%
Cellulosic EtOH-LQ constrained	+0.73%	+0.90%	+0.81%
	TIO /1	Jobs 2/	TVA /1
Pyrolysis-Baseline	+1.09%	+1.25%	+1.17%
Pyrolysis-LQ constrained	+0.54%	+0.64%	+0.58%

Notes:

Evaluated at 100% target of 10.5 bgy; 75 mgy cellulosic ethanol (147 facilities); 36.4 mgy pyrolysis/bio-oils (287 facilities); 1/trillions of dollars; 2/ 1,000s of jobs.



Cellulosic ethanol



Pryrolysis

Figure 1. Distribution of employment location quotients.

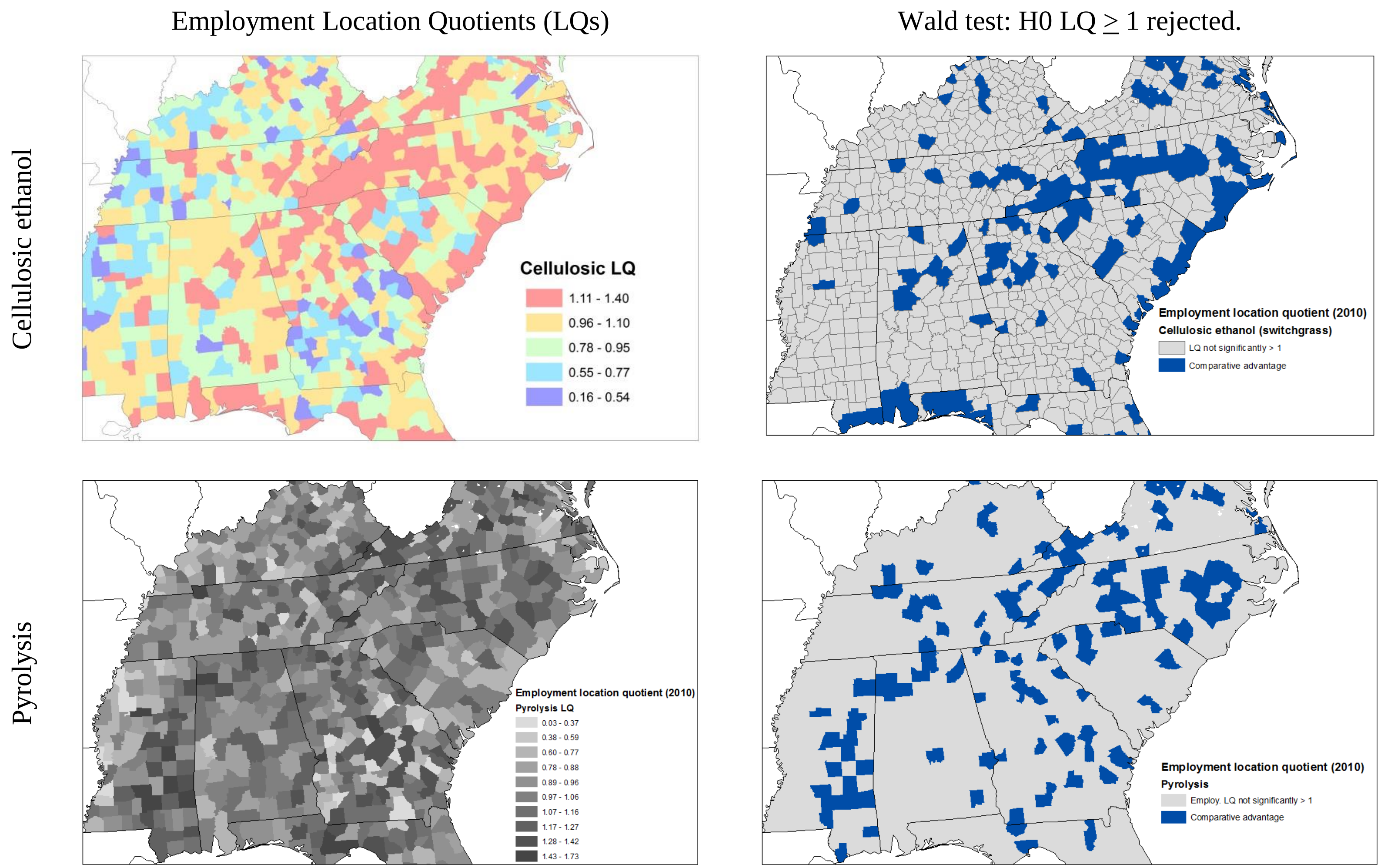


Figure 2. Distribution of employment location quotients and counties with employment location quotients exceeding 1.

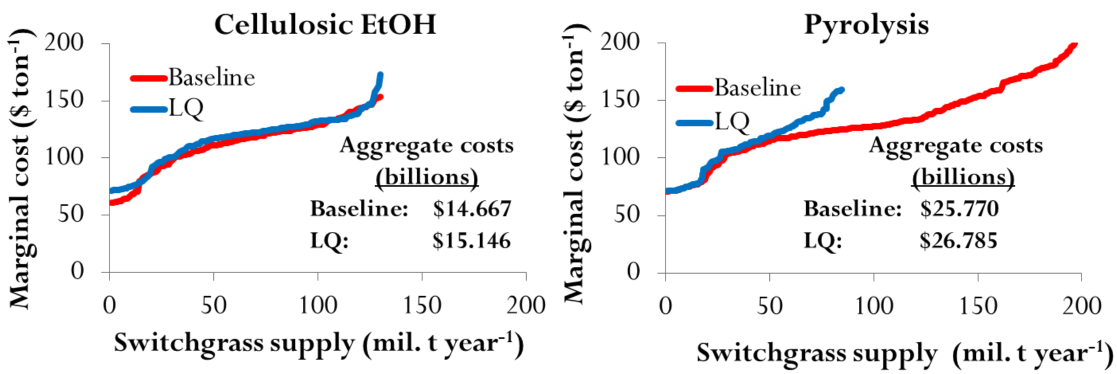


Figure 3. Feedstock (switchgrass) supply curves

Cellulosic ethanol (switchgrass feedstock) Pyrolysis (switchgrass feedstock)

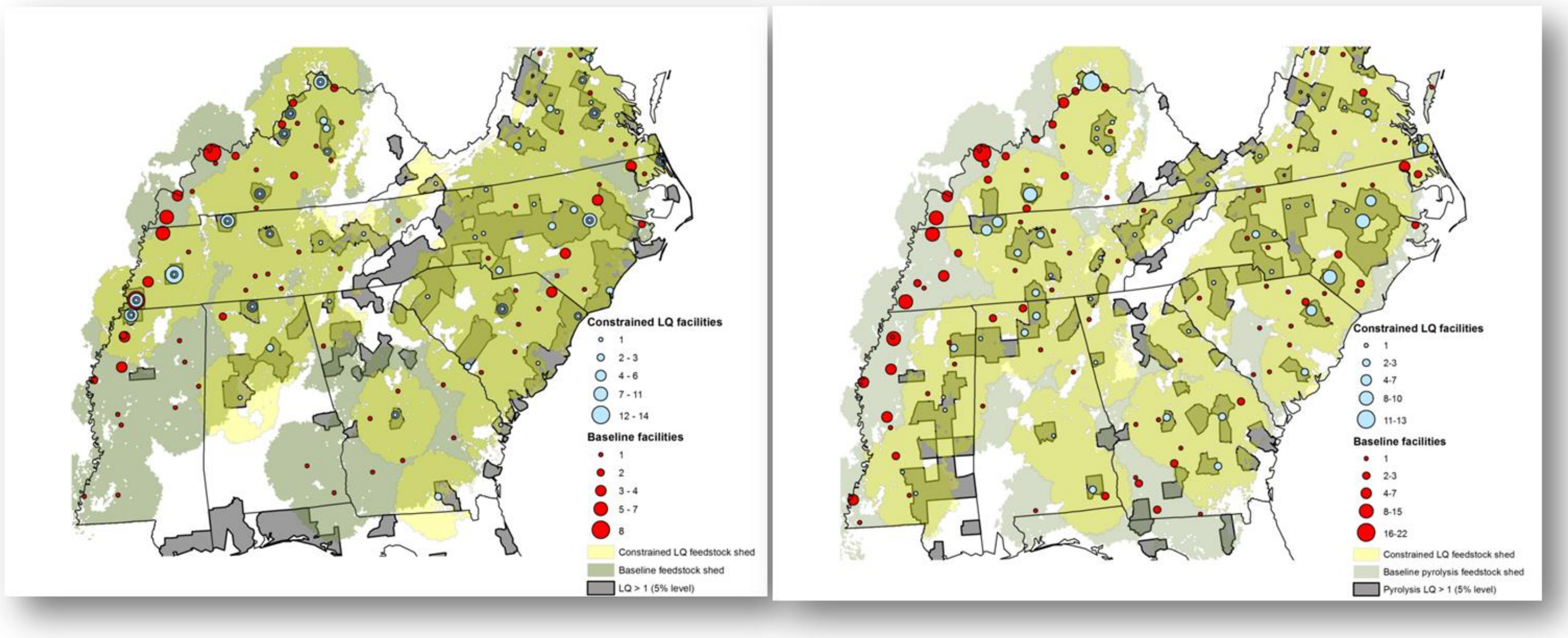


Figure 4. Distribution of feedstock sheds, facility location, and counties with employment location quotients exceeding 1

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