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Frank M. Howell
Emory University

Jeremy R. Porter
City University of New York-Brooklyn College

Philip B. Mason
Mississippi State University

Troy C. Blanchard
Louisiana State University

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SPATIAL CONTOURS OF POTENTIAL BIOMASS CROP PRODUCTION: AN EXAMINATION OF VARIATIONS BY U.S. REGION[*]

FRANK M. HOWELL

EMORY UNIVERSITY

JEREMY R. PORTER

CITY UNIVERSITY OF NEW YORK – BROOKLYN COLLEGE

PHILIP B. MASON

MISSISSIPPI STATE UNIVERSITY

and

TROY C. BLANCHARD

LOUISIANA STATE UNIVERSITY

ABSTRACT

The recent and projected status of energy production and consumption in the United States, resulting in substantial dependencies upon foreign oil, has continued to provide pressure on domestic energy security. All told, bio-energy systems, and biomass crop production in particular, will be important elements of national security, economic vitality, and public policy. Using biomass crop estimates based upon models developed at the Oak Ridge National Laboratory and the Department of Energy (DOE) National Renewable Energy Laboratory, we identify potential biomass crop production zones using spatial analysis methods. The Midwest and the South are, by far, the largest regions of potential production. Once potential biomass crop yield is made proportional to estimated land and production costs, the South's optimal crop zones fall along the Gulf Coast and Atlantic Seaboard whereas in the Midwest, they are largely in non-metropolitan localities. The implications of these spatial contours for energy policy for alternative biomass crop production are discussed.

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Recent projections of energy production and consumption trends in the United States, which, if accurate, would result in substantial national dependencies upon foreign oil, have continued to exert pressure on domestic energy security. Alternative energy programs such as biomass energy crop systems are currently under development and considerable research and development on them is projected through at least the year 2012 (U.S. Department of Energy 2005). The approach identified by the U.S. Department of Energy (DOE) aims to identify pathways linking fundamental and applied research into an integrated systems plan, using various potential biomass sources as venues of investigation and synchronized development.

In addition, recent allocations of funds concerning the "Reinvestment and Recovery Act" put into action by President Barack Obama and the U.S. government have allocated a substantial amount of money directly to the U.S. Department of Energy's Energy Efficiency and Renewable Energy (EERE) division for the applied research, development, demonstration, and deployment of innovative ideas aimed at pushing forward our ability to harvest clean and renewable energy.

Of the $16.8 billion given the EERE, $2.5 billion is directly allocated to this research, of which $800 million is going directly toward biomass research, $100 million is going to facility and infrastructure improvements at the NREL facility, and $22 million is going to Community Renewable Energy Deployment. While all these initiatives have the potential to ultimately provide a significant bump in technology for the production and deployment of renewable energy, it is the Community Renewable Energy Deployment allocation that is of most interest in the current paper. This interest has risen, causing polar responses among and between communities within the United States in relation to their ability to produce biomass as well as their willingness to accept such production and refinement as a way of life.

Sometimes the development of a bio-economy is fueled by the distinction between a commodity-based agricultural system and a civic-based agricultural system (Lyson and Guptill 2004). In a commodity-based system, the primary goal of agricultural production is the ability to produce food for consumption. However, a civic-based agricultural system is more focused on the production of crops for the immediate local community. Using this framework, which was developed by Lyson and Guptill (2004), the growth and maturation of a local bio-fuel economy is evidently likely to occur in a community with more to gain from such production (i.e., low land conflict, low levels of crop competition, etc.). However, other research has shown that while public investments are important in the development of a profitable economic venture, they do not affect the overall economic development of the local community (Menken and Tolbert 2005). Thus, the simple adoption of a civically based local bio-fuel economy may or may not have positive impacts on the overall economic standing of the community in which the economy develops.

Economic studies of the potential influence of massive biomass crop production on U.S. agriculture (e.g., De La Torre Ugarte et al. 2003) have used commodity-focused models under alternative scenarios to estimate enhanced crop prices nearly 3-14 percent with net farm increases up to $6 billion per year. President Bush identified such alternative fuel programs in his State of the Union addresses in 2006 and 2007 as one of his strategic initiatives for the remainder of his term. As such, federal government policies to stimulate certain biomass crops are almost certainly in the offing. All told, bio-energy systems, and biomass crop production in particular, will be important elements of U.S. national security, economic vitality, and public policy in the future.

With the prospects of such a massive bio-energy sector of the economy on the horizon, we know very little about the potential magnitude, location, and social policy issues arising from it. The "pathway approach" sponsored under the auspices of the DOE largely ignores the social systems that must adapt to make bio-energy a significant and enduring sector of the economy. For instance, as the extant literature shows, transportation costs are crucial economic factors in determining the "break-even" cost for growing biomass alternative fuels. This market force alone will likely create concentrated zones of biomass crop production. Where in the United States will these zones emerge and what will be their proximity to population centers? The locations of these agronomically-optimal biomass crop zones will tell social scientists much about the social policy issues most likely to arise from the emergence of the associated industrial, workforce, and agricultural changes necessary to support the new bio-economy.

The spatial identification of agronomically-optimal biomass crop zones is the main focus of this study. Within this framework we have three objectives: (a) identification of significantly high-likelihood spatial clusters of counties or "zones" for biomass crop production; (b) determination of the proximity of these biomass zones to metropolitan areas; and (c) estimation of the economically optimal crop production zones when crop yield potential is weighed against land-value and production costs to assess patterns of potential land-use conflict in the future. By combining two sets of data estimating overlapping definitions of biomass crop sources, the results provide the best information available with a nationwide scope on where the bio-economy is best likely to develop.

LITERATURE REVIEW

This review of the literature highlights five main topics in hopes of better understanding the role of biomass energy in the United States and its associated consequences and worth. These topics include: (1) agronomic potential for biomass, (2) yield estimates, (3) economic impacts of biomass production, (4) environmental impacts of biomass production and refineries, and (5) social and economic barriers facing the biomass energy industry. The first two topics focus primarily on the climatic and geographic documentation of the optimal areas for the growth of biomass crops. The next two topics introduce some consequences of wide-scale biomass production both economically and environmentally. The final topic, which is most interesting to us as social scientists, concerns the social barriers that currently exist to the implementation of such a bio-economy.

Identification of Agronomic Biomass Potential

Like most crops, biomass production success varies by region due to physical differences in soil quality, temperature, length of growing season, and availability of water (Clifton-Brown, Stampfl, and Jones 2004; van Ittersum and Rabbinge 1997). Accounting for such differences, researchers have identified regions that potentially could successfully produce biomass crops. Walsh et al. (1998) projected that switchgrass will initially be most lucrative in the Lake States, North Plains, South Plains, and Southeast. However, as the market value for switchgrass increases, parts of the Midwest and Northeast are also expected to become large contributors to the production market (Walsh et al. 1998).

Furthermore, researchers have found that optimal seed germination occurs at 77 degrees Fahrenheit and therefore, in colder regions, short-rotation woody crops (SRWC) can be grown successfully using varieties of willow, aspen, and poplar, the robust composition of which resists cold, yet has a relatively rapid growth cycle (Hanson and Johnson 2005; Weih 2004). Based on these parameters, poplar is expected to be most successful in portions of the South (primarily Tennessee and Louisiana), portions of the Midwest (primarily Minnesota), and portions of the upper West Coast (primarily Oregon), while willow is anticipated to be most successful in the Northeast and Lake States (Walsh et al. 1998).

From this assessment it is likely that much of the U.S. will play a role in the impending production of crops for bio-fuel. This is a much different story than the popular one of the future bio-fuel industry revolving around the Midwest dominance of corn-based ethanol fuel. Thus, examining geographic variation to better understand the regional variability that most likely exists is important.

Yield Estimates for Biomass Crops

Estimates of crop yield potentials are important for determining the critical mass of crop output needed for a variety of calculations, including the break-even point in profitability. When considering yield potentials, two major factors are the number of acres available and the proportion of those acres that will be assigned to grow the crop (Graham et al. 1997). Overall, Midwestern states have many more acres of land in agriculture than do other regions. Consequently, that region has the greatest potential to produce the largest gross biomass yields (Graham et al. 1997). However, southern states dedicate many more acres to secondary crops than do states in the Midwest (Graham et al. 1997). Therefore, regions that are not traditionally thought of as producing the largest yields may be more likely to participate in early stages of biomass production because of a history of crop diversity.

Projected yield outcomes for biomass production depend upon adoption assumptions that, at this point, are only suggestive. One study estimated that, within the next half century, switchgrass will occupy as many as 42 million acres in the United States and become the fourth largest crop (De La Torre Ugarte et al. 2003). Other researchers have provided evidence that the agronomic yield of Miscanthus (one type of switchgrass) in Illinois could be potentially twice as large as that produced in Europe (Heaton et al. 2004). Still other studies have projected that the U.S. could produce at least 1.3 billion dry tons of biomass per year using only forestland and agricultural land (Perlack et al. 2005). These yield forecasts provide evidence that biomass may become a serious contender for land currently allocated to more traditional crops, including crops grown solely for animal feed. Thus, land-use conflict associated with the bio-economy is likely to be situated both *within* agriculture and *between* agricultural and other land-uses.

One important question to address is whether there is land that could be used to grow biomass material that is not in competition with traditional crops. One possible source is land under contract with the Conservation Reserve Program (CRP) (Perlack et al. 2005). The CRP is a government program that annually rents farmland from farm operators who participate in 10-15 year contracts to plant permanent vegetation on their cropland (Farm Service Agency 2006). The main objectives of the CRP are to improve soil and water quality, reduce soil erosion, and increase wildlife through land conservation by crop rotation and diversification (Farm Service Agency 2006). Some have estimated that between 17 and 28 million dry tons of biomass could be grown on CRP land (Perlack et al. 2005). This is important because farmers who participate in CRP have already decided to grow permanent vegetation on their land rather than traditional production crops, thus lowering the potential conflict *within* agriculture. Although land allocated to many traditional crops could potentially be used, biomass crops compete most directly with wheat and non-alfalfa and, to a lesser extent, grain sorghum, oats, barley, corn, and soybeans (Walsh et al. 1998).

Perhaps most well documented is the squeeze on the supply of corn and the expected effect it will have in increasing its market price. This result will not only raise the price of ethanol production, but also will affect many facets of animal agriculture overall (Elobeid et al. 2006; Lawrence 2006). Specifically, it is expected that the poultry and pork industries will feel the adverse effects the most because unlike cattle, these animals are unable to eat distiller grains and other solubles (DGS) as part of their feed (Elobeid et al. 2006). However, even among animals that can digest DGS better than others, there are risks involved with using them (i.e., increase of fat, mycotoxin) (Lawrence 2006).

Economic Impacts of Biomass Crop Production

Economists project that switchgrass will be the least expensive biomass crop to grow per dry ton, followed by SRWCs, including hybrid poplar and hybrid willow (De La Torre Ugarte et al. 2003). Moreover, because switchgrass only has to be planted once every 10-20 years, (Heaton et al. 2004) but is harvested annually using common farm machinery (Heaton et al. 2004; Rinehart 2006), it has a relatively low initial investment cost (Heaton et al. 2004). Consequently, it is estimated that up to 99 percent of the land used to grow biomass crops will be dedicated to switchgrass production (De La Torre Ugarte et al. 2003).

The low initial investment makes biomass production likely to be a source of economic revitalization for many rural communities. However, expenses associated with transportation are another factor to consider, as they make it most cost efficient for storage and energy processing facilities to be located near the growing region (Volk et al. 2006). This needed proximity to the "grower" community will increase job opportunities and allow profits from each stage of the production and refinement processes to be spent and re-circulated throughout local businesses (Volk et al. 2006). Storage centers and refineries will need to be built and maintained (Ginder 2006). Transportation services will be developed to transfer materials from the location of the grower, to the interim storage site, and finally to the refinery. Additionally, economic growth in rural areas may occur from federal public investment spending (i.e., to support renewable energy), which has traditionally been an important contributor to economic development in rural areas (Mencken and Tolbert 2005).

However, if ethanol plants continue to be built as quickly as they are projected, there are also negative issues associated with storage and transportation (Ginder 2006; Miranowski 2006). For example, it is estimated that by 2011, Iowa may need to increase grain holdings by 1.4 billion bushels – which is more than the commercial sector is currently able to store (Ginder 2006). Additionally, because bio-fuels are produced in agrestic areas that are distant from major cities where consumers live, ethanol will need to be shipped by rail (Ginder 2006; Miranowski 2006). However, there are few rail cars available to ship ethanol and co-products of ethanol, and some rail car manufacturers are booked for more than two years (Ginder 2006).

Research findings on the overall profitability and economic impact of biomass production are mixed. Some studies have suggested that farmers who choose to grow alternative biomass crops will yield at least the same profits as they would growing traditional crops (Walsh et al. 1998). The largest gains in net farm returns are projected for the Midwest, Northern Plains, Southeast, and Mississippi Delta regions (De La Torre Ugarte et al. 2003). However, studies have also shown that some methods of producing bio-energy are more expensive than others. For instance, bio-fuels processed from corn, canola, and soybeans produce modest profits but require subsidies from the federal government (Samson et al. 2005), something that corn-based plants may be at risk of losing (Gallagher 2006). Other economic challenges that corn-based ethanol plants face are the increasing costs of building and maintaining these plants, the rising costs of corn as a primary input, and the expansion rate of corn-based ethanol plants. These challenges may "erode the ethanol premium over gasoline in the wholesale market" (Gallagher 2006:4).

Furthermore, and in relation to the squeeze in the production of corn, if most of the corn supply is reserved for ethanol manufacturers, production and profits will decrease and lead to a loss of employment in animal-related agriculture (Lawrence 2006). For instance, a 100 million-gallon ethanol plant will employ about 80 people and use the same amount of corn as is used to feed three million hogs and employ more than 800 people (Lawrence 2006). Thus, it is vital to the agricultural sector and the rural communities where bioenergy industries often reside, for bio-fuel producers to find a way to coexist with animal agriculture (Lawrence 2006).

Environmental Impacts of Biomass Crop Production and Refineries

From the preceding section it is evident that the biomass crop-based alternative fuel industry potentially could hold significant economic promise. The same is true of the potential environmental impacts associated with using non-oil-based fuels and the reduction of carbon-based pollutants into the atmosphere. However, negative environmental impacts are also likely.

The energy used to process coal vs. the energy gained is similar to that for switchgrass (Cannell 2003). Yet, one major advantage that biomass energy production has compared with traditional coal-firing methods of production is that biomass emits smaller amounts of carbon and sulfur (English et al. 2004; Jensen et al. 2004). The carbon that switchgrass does emit has been "recycled" (Cannell 2003). After accounting for the carbon the plant uses throughout its life cycle, the carbon released into the atmosphere during the planting, harvesting, and processing stages in biomass production is effectively much less than that of coal (Volk et al. 2006).

Presently, however, scientists are unsure about the carbon that can realistically be reduced by using biomass for energy production. Nevertheless, some evidence suggests that using a partial adoption of biomass may be profitable and help lower emissions. Researchers have found remarkable success in power plants in the southeastern part of the United States using both coal and biomass in a co-firing energy production method at the two and 15 percent levels (English et al. 2004). This co-firing method is seen as a realistic source of energy only if biomass is unavailable at a cost-efficient price, if its use spurs an increase of job opportunities, if its use is competitive with traditional methods of energy production, and if the method is a renewable energy source (English et al. 2004).

The environmental effects from co-firing may be seen as worth the production costs in the future. The demand for ethanol products has increased by more than 400 percent (from 1.5 billion gallons to about 6.5 billion gallons) in the United States during the last six years (Gallagher 2006; Miranowski 2006). This was primarily a result of rising oil prices and supportive state/federal environmental policies and regulations (Miranowski 2006). Specific policies that helped spur this rapid adoption have included state-level bans on polluting fuel additives, ethanol-gasoline blend mandates in areas with problematic air sheds, and tax subsidies to ethanol-gasoline blends (Miranowski 2006). Thus, if energy prices continue to rise, and environmental policies are targeted toward benefiting co-firing plants, the demand for bio-fuels may increase in this sector as well.

Social and Economic Barriers Facing the Biomass Energy Industry

Not surprisingly to social scientists, researchers have found that the greatest barriers facing the implementation of bio-energy production are not technological but social (Roos et al. 1999). At the structural level, these include competition among rivalry bio-energy factories and traditional energy production businesses over the "correct" approach to energy sustainability (Roos et al. 1999). For example, some methods of biomass production are not currently economically competitive with traditional energy production methods (Samson et al. 2005; Volk et al. 2006). These presently cost-inefficient energy industries have to compete not only with traditional energy producers but also with more competitive biomass energy industries (Roos et al. 1999). Consequently, investors may see some emergent technology biomass refineries as too great an investment risk.

On the other end of the traditional marketplace supply and demand continuum, potential investors may be reluctant to make large investments in biomass energy because they may doubt their ability to obtain enough long-term commitments from growers to make secure a profit (Volk et al. 2006). Also, farm operators may be disinclined to adopt biomass crops because they may be unsure of the market demand for them (Volk et al. 2006). One economist has shown that in order for Iowa farmers to grow corn continually, rather than on a rotational basis with soybeans, the price of corn would have to be at least $3/bushel and the price of ethanol would have to stay above $1.50 per gallon (Jolley 2006). However, at current market prices, corn sales must not surpass $4.05/bushel if ethanol is to be profitable (Elobeid et al. 2006). If farmers fear that the price of corn will cross this threshold of profitability, or that the price of oil will fall in the future, they will likely continue growing soybeans because they see them as a proven investment and a smaller risk. Further, farmers may be especially reluctant to switch to short-rotation forestry crops, which have gaps of several years between planting and harvesting, during which the market may change (Volk et al. 2006).

A related concern is whether public demand will be great enough to purchase "green" energy at a higher cost than traditional energy. One study conducted among Tennessee residents found that more than 54 percent of respondents supported the use of electricity from renewable resources, but they were unwilling to pay more for green energy (Jensen et al. 2004). Furthermore, among those who expressed support and a willingness to pay more for energy produced from renewable sources, less than 5 percent purchased electricity from green refineries although most lived in areas where renewable energy was readily available (Jensen et al. 2004). Another study showed that 70 percent of respondents from the western or southwestern states are willing to pay five dollars more per month for renewable energy, whereas only 21 percent were willing to pay 15 percent or more (Farhar 1999).

Studies also suggest that the public is more likely to support green energy made from solar or wind sources than they are to support energy made from biomass crops (Farhar 1999; Jensen et al. 2004). This preference may be a result of greater familiarity with solar or wind power production than biomass energy among survey respondents (Farhar 1999). If so, one of the greatest social barriers to fostering bio-energy may be a lack of adequate knowledge and information about bio-energy among the public. This also applies to the prospective producer sector of farm operators. One study conducted by the Department of Energy found that less than 21 percent of farmers in Tennessee had ever heard of growing switchgrass for energy use (Jensen et al. 2006). Among those who had, 39 percent reported that they would be interested in growing it. However, results from this study need to be viewed cautiously due to a low survey response rate of 24 percent.

A related barrier facing the biomass energy industry is the issue of how to motivate farmers to adopt biomass crops into their planting portfolio. We could identify only a single peer-reviewed study of farm operators about their views on adopting biomass crops for planting. That study used a convenience sample of 52 individuals in Iowa who were involved in agriculture and were interviewed about their knowledge surrounding switchgrass and its use as a source of energy, and their willingness to adopt it as a crop (Hipple and Duffy 2002).

Summary of Research on Biomass Crop Production

At this time, we have only broad outlines of the potential agronomic, economic, environmental, and social impacts associated with industrialized biomass refineries in the United States. There is substantial evidence that biomass energy can become a significant source of green energy marketed at a competitive price. With former President Bush's declaration that biomass-based energy fuels are now a federal priority, there is little doubt that some form of the bio-economy will emerge, perhaps quite rapidly, to lessen the burden of U.S. dependency on foreign energy production. Still, questions remain, many of which will be significantly linked to the locations of each component of the bio-energy industry, as well as to the effects that those locations may have on the local communities, the states in which they are located, and the nation within which the industry fuel distribution sector serves as a critical input source to the rest of the U.S. economy. The present study addresses the location component of the emergent social policy matrix surrounding the new bio-economy.

RESEARCH METHODS

Sources of Data

Data were obtained from several county-level sources concerning the 48 contiguous states. Counties are used as the primary unit of analysis based on data availability. The main sources of biomass crop data come from Graham, Allison, and Becker (1996) at the Oak Ridge National Laboratory (ORNL) and Milbrandt (2005) at the National Renewable Energy Laboratory (NREL). The estimates for biomass crops, switchgrass (SG), and short-rotation woody crops (SRWC), which were produced by Robin Graham and her associates (1996), pertained to 1992. We obtained those data from Dr. Graham and produced similar estimates for 1997 and 2002 using the same procedures but updating the key variables (e.g., CRP acres, harvest acres, etc.) from the successive Censuses of Agriculture. The biomass crop estimates obtained from Milbrandt (2005) were circa 2005.

Both Graham and Milbrandt's data are important in this analysis as they paint different pictures of potential biomass production. The ORNL data provided by Graham provide an estimate of potential biomass production acres from the growth of switchgrass and short-rotation woody crops, whereas the NREL data obtained from Milbrandt take into account the potential effects of harvesting urban residues. Most of the current analysis will examine the ORNL data provided by Graham due to the availability of accompanying variables used in categorizing counties based on their production potential. However, it is important to introduce both data sources to fully understand the different contexts in which biomass is readily and potentially available as well as where these areas are located geographically across the United States. Data on region, metropolitan proximity, county landmass, and total cropland in acres were respectively taken from the Census Bureau, the USDA Economic Research Service, and the Census of Agriculture for 1997 and 2002. The primary categorizations in this analysis focus on regional similarities and differences in the identification of potential and optimal biomass production zones, primarily between the South and the Midwest. On that point, understanding that the use of the U.S. Census' definition of region leaves something to be desired here is important.

For instance, there are large intra-regional variations in the types of climate and soil, as well as proximity to water bodies. However, this analysis is undertaken with these limitations in mind and the understanding that they exist across all regions.

Furthermore, the use of cross-regional metropolitan classifications will help us to control for some of this variation by categorizing counties within each region as metropolitan, adjacent to metropolitan counties, or non-adjacent to metropolitan counties. This classification gives us a good understanding of population concentration, which is commonly thought to cluster near areas rich in natural resources.

Measurement

Potential biomass crop estimates pertain only to switchgrass and short-rotation woody crops (SRWC) such as hybrid poplars and willows, based upon the ORNL model published by Graham et al. (1996), whereas the "total technical biomass resources" available in the county are based upon Milbrandt's work (2005) at NREL. The NREL source contains a broader set of potential biomass sources than simply two major crops, including: agricultural residues from crops and methane from manure management; wood residues from forestry, primary and secondary mills, and urban wood residues; and municipal discards including methane emissions from landfills and domestic wastewater treatment. We briefly summarize the measurement of these variables but more details are available in the source citations for interested readers.

ORNL Data. The total switchgrass (SG) potential based on the ORNL model is expressed in acres as is the total potential for short-rotation woody crops (SRWC). Switchgrass and SRWC acreage overlapped in many areas where soil type and climate are conducive to both crops. We created a variable that represents the total potential biomass acreage in a county by taking the maximum value for SG and SRWC where one of these two crops might have low or no potential crop acreage.

To identify optimal zones for the production of biomass crops in the form of switchgrass and SRWC, three variables in particular are of interest (Graham 1996). First, to be an optimal area for crop production it is assumed that obtaining the land will be economically feasible, or low land rent value. Next, understanding where yield profits are high enough to persuade farmers to convert farming operations to switchgrass and SRWC is important, and lastly knowing where production costs are lowest is important. The combination of these three variables will lead to an ordinal categorization of 'most' to 'least' optimal counties identified for the potential production of biomass crops.

NREL Data. Milbrandt (2005) described the "technical" biomass potential as

> … based on the accessible biomass with respect to constraints of land use, and the majority of the quantity depends on assumptions and factors that relate population to the amount of residue generation. These factors are often local and subject to the level of technology (harvest, collection etc.) available, and vary between [*sic*] different studies. (P. 59)

Using a complex modeling scheme based upon a variety of sources and modeled estimation procedures on each potential source, she produced two data elements of interest to this study: the amount of switchgrass and the total potential biomass from all sources, both expressed in dry tons (see Milbrandt 2005 for more details).

Demographic Controls. County designations for metropolitan proximity used the USDA ERS urban influence taxonomy (Ghelfi and Parker 1997). Counties were collapsed into three groups: metropolitan, non-metropolitan but adjacent to a metro area, and non-metropolitan and non-adjacent. Region corresponds to the four U.S. Census regions (Northeast, Midwest, South, and West). While it is understood that much variation exists within these geographic units, here they will allow for a better understanding of the spatial demography and distribution of potential biomass production zones.[1]

Analytic Procedures

The procedures used are mostly descriptive but some involve a permutation-based significance test in the analysis of significant spatial clusters of counties with high biomass crop potential. Geographic Information Systems (GIS) procedures are used to visualize the spatial distribution of biomass-related variables using an adjacency-based contiguity weight matrix in which all "touching" counties are considered neighbors (Waller and Gotway 2004). This means that any county that shares a border with another county is considered a spatial neighbor in geographic space. A contiguity-based matrix was ultimately chosen because of the gradual changes in landscapes across borders and the arbitrariness of county boundaries, ultimately meaning places closer together are more alike than places far apart.

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[1] The 1993 metropolitan classification system was used in order to provide consistency with a larger project in which this research fits that temporally examines the dispersion of potential biomass from 1992-2002. Furthermore, Porter and Howell (2009) showed that the metropolitan classification of counties themselves changed very little over the decade as only 1.5 percent of all metropolitan counties in 2000 were non-adjacent non-metropolitan in 1990.

Furthermore, a 'queen's' spatial weight matrix was implemented based on the irregular shape of county boundaries and the operationalization of all counties with common borders as neighbors.

The most important single statistic associated with this portion of the analysis is the global Moran's I index, which shows the overall non-random spatial distribution of counties with high biomass production potential based on the implemented weight matrix. Based on this statistic, and the associated tests of power/significance, identifying global clustering patterns, or patterns of non-random spatial distribution, is possible. Within spatial statistics, this index is widely used as a direct indicator of similarity and distance (Waller and Gotway 2004). The statistic is very similar to Pearson's Correlation Coefficient in that it measures an association between N observed values associated with two random variables, Xi and Yi (Waller and Gotway 2004). Here, the only difference is replacing the Xi variable with the Yj neighborhood variable and introducing the weight matrix (ω_{ij}).

This equation produces a statistic in which each unit's (i) interaction with another is taken into account and when neighboring units (indicated by a 1 as the ω_{ij}, as opposed to a zero for non-neighboring units) are statistically significant and similar the Moran's I statistic is positive, meaning areas of closer proximity are often more alike than those far apart (Waller and Gotway 2004). In this instance you would have spatial clustering. To place a significance value on the observed Moran's I statistic, a permutations-based test was conducted to test the null hypothesis: "No spatial association" or "spatial randomness." The test employs a permutations-based approach to test the global index on randomly assigned locations to approximate the distribution of the global index under the null assumption (Waller and Gotway 2004). This examination used a 999 permutations test with a reject region equal to a 0.05 significance level.

To identify statistically significant independent clusters of contiguous "zones" among counties, we used Anselin's LISA (Local Indicator of Spatial Association) statistic (1995), which is based upon the global Moran's I coefficient decomposed into a "local" level that is the county in this study. This local examination repeats the spatial clustering procedure for each neighborhood, which equates to reproduction of the procedure i times (once for each county accompanied by all of its identified neighbors (Waller and Gotway 2004). This procedure ultimately produces a categorical outcome based on the relationship of county i to the remainder of the counties within the j^{th} neighborhood, producing a result that indicates positive spatial clustering (county is significantly like neighbors), negative spatial clustering (county is significantly unlike neighbors), or spatially random distribution (county is not significantly like or unlike its neighbors) (Anselin 1995).

Next, optimal zones of potential biomass production were identified through a rubric aimed at maximizing, in an economically positive fashion, the combination of land rent, production yield, and production costs (all in U.S. dollars) for the ORNL data on switchgrass and SRWC potential. Across these three variables, for both types of crops, an eight-category ordinal scale was developed based on the units' relation to the U.S. median as *higher* or *lower* to identify the most optimal and least optimal counties for potential biomass crop production. In the following section, these are broken down and presented both statistically in tabular form and graphically as two separate maps for each crop type.

Lastly, we also cross-classified biomass-related variables by U.S. region and the county's metropolitan status. Although many factors directly affect crop production, and they vary greatly across vast geographic landscapes, U.S. Census region is used as a general proxy for classifying geographic space based on precedent and a general use within the literature. Furthermore, the variations within U.S. census regions are accounted for somewhat by the simultaneous classification of crop production by metropolitan status, a category that is density and landscape driven.

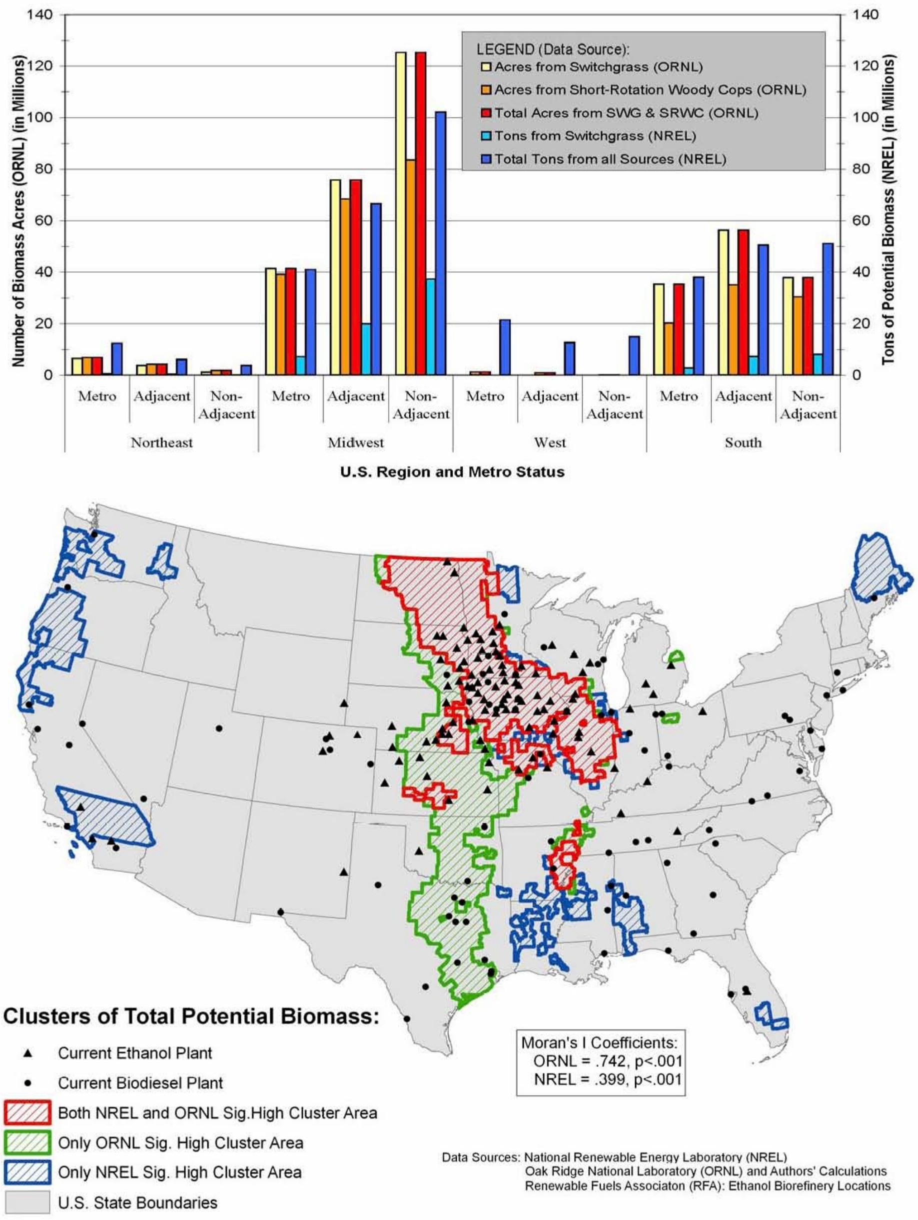
RESULTS

Spatial Demography of Biomass Crop Production

The upper panel of Figure 1 shows the potential for U.S. regions to participate in the crop production component of the bio-economy; this potential is largely restricted to the Midwest and the South. The Northeast could utilize some five to ten million acres for these two biomass crops, mostly concentrated in metropolitan areas, and the West has some two to three million suitable acres, however the Midwest and South, by far, dominate the potential for growing these two biomass crops. The crop-only results are much the same as the tons of potential biomass as measured by the NREL data. However, the metropolitan areas in both the West and Northeast show a greater biomass potential. This is especially true in the West where the tons of potential biomass from NREL sources dwarf the potential from the biomass crops using the ORNL data. This difference is due primarily to the diversity of biomass sources, especially those found in high population centers (urban wood residues, landfill residues, etc.).

Consistent with the report by Thomas and Howell (2003), who found substantial agricultural production within the confines of metropolitan areas, the results in Figure 1 show that between 35 and 40 million acres in either the Midwest or the South could be devoted to bio-energy crop production. The main difference between the South and the Midwest is the latter's relative concentration of biomass crop acreage in rural counties that are not adjacent to large urban population centers. The South's largest potential crop acreage lies in clear proximity to metropolitan areas, a recipe for significant land-use conflict and competition. The NREL estimates are consistent with the spatial patterns in the ORNL estimates in

Figure 1. Spatial demography of potential biomass production



Data Sources: National Renewable Energy Laboratory (NREL)
Oak Ridge National Laboratory (ORNL) and Authors' Calculations
Renewable Fuels Associaton (RFA): Ethanol Biorefinery Locations

the metropolitan proximity and regional totals. This sensitivity analysis using disparate approaches suggests that the general patterns of acres and tons of volume yield complementary estimates.

These results inform us about the total amounts of various biomass sources in the United States, but they do not tell us much about the *locality* of potential production. We used Moran's I and the LISA statistics to determine whether the potential biomass acres and estimated tons of output are randomly or non-randomly clustered across the United States. The global Moran's I test results summarized on the lower panel of Figure 1 show that there are significant, positive, spatially non-random patterns pertaining to the overall geographic distribution of both sources (NREL = .742 and ORNL = .399) of potential biomass production. For both sets of data, there is significant and high positive spatial clustering, indicating that the potential biomass crop production zones are far from a random assortment of counties across the U.S.

The LISA results are also presented in the figure as shaded outlines around groups of counties where specific significant clusters were identified. For ORNL estimates, which contain only switchgrass and short-rotation woody crops, the significant spatial clusters are presented in green; for the NREL estimates, which contain a broader array of potential biomass sources, they are presented in blue. Also, the area in red signifies the overlap in clusters of counties with high potential for biomass production, despite the data source (both ORNL and NREL). Lastly, the locations of bio-refinery plants processing either ethanol or bio-diesel are overlaid on the map to illustrate this sector's spatial proximity to input sources.
For the ORNL data on switchgrass and woody crops, the global Moran's I coefficient is .74, a very large coefficient (see Anselin 1995), quantifying the extreme positive clustering pattern in the map. In other words, counties with high potential biomass acreage are surrounded by counties with high potential biomass acreage. These significant spatial clusters of biomass potential are located in the upper and lower Midwest, in the Heartland, in eastern Texas, and along the Mississippi River Delta. Two pockets of high biomass acreage potential are also observed in South Carolina and in Pennsylvania.

Regarding the broader NREL biomass measure, the distribution has a significant Moran's I coefficient equal to 0.399. It is not as large as the one for the ORNL data but, nevertheless, indicates a high level of spatial clustering (Anselin 1995). While there are indeed significant non-random clusters of potential biomass materials in the upper Midwest and in the South, there are also smaller significant clusters in the Northeast and in the Northwest. Finally, as can also be observed in

Figure 1, the emergent bio-economy as revealed by private-sector investments in bio-refineries is largely locating in these significant clusters of potential biomass crop zones, further evidence of the spatial impact likely to emerge from this industry.

These results do not take into account production costs, competitive land uses, land rents, and so forth (see Downing and Graham 1996; Jolley 2006) in the production of bio-fuels. We now present an optimization assessment of the ORNL data for switchgrass and short-rotation woody crop production, taking into account estimated land rent value and production costs. The more broadly defined NREL data do not contain such details.

Identification of Optimal Biomass Crop Production Zones

In Figure 2, the optimization rules are displayed along with a bar chart of the distribution of acres (in millions) and the number of counties in each region associated with each optimal classification zone. The four zones with *high projected yield* are ranked in the top half of this scheme, each varying as to the land rent value and costs of producing the crop. The bottom half contains varying classifications of costs with *low projected yields.* These categorizations of high and low are based on the global mean for each category and for each crop type respectively.

The most optimal zone is one with low input costs (low land rent and production costs) and high yield, labeled as production classification zone # 1—"Most Optimal." This zone characterizes almost 75 million acres of potential switchgrass and 20 million acres of short-rotation woody crops. The modal production zone is # 4, defined as high yield but also "Expensive Biomass" in terms of high land rental values and production costs; this classification applies to both biomass crops. Finally, areas categorized as having low yield and high associated costs are labeled #8—"Least Optimal." The most optimal, expensive biomass, and least optimal zones are listed in order with the intermittent zones being more arbitrarily placed in between based on some desired and some undesired characteristics.

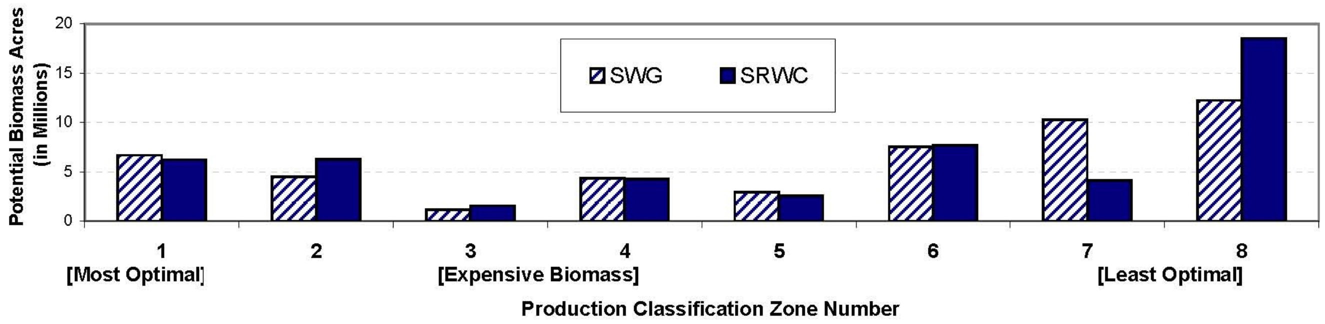
From the figure it is easy to see that the Midwest has a huge advantage concerning the number of counties in the "Most Optimal" zone. Within the region, the vast majority of counties are located in the "Most Optimal" zone, whereas the only other 'player' in the biomass production game, in switchgrass or SRWC production, is the southern region. The South shows promise in that much of its potential lies in highly optimal zone number two with low production costs but high land rents. This could suggest spatial clustering around metropolitan areas.

Figure 2. Optimization breakdown and descriptives of production classification zones*

Economic and Production Optimization Classification Scheme

	Optimization Variables			Number of Counties in Classification Zone by U.S. Region									
Variable	Rent	Yield	Production Costs	SWG Optimal Zone					SRWC Optimal Zone				
Median SWG	$50.73/acre	$35.84/dry ton	$1216.44/acre/yr.										
Median SRWC	$50.73/acre	$65.62/dry ton	$1443.40/acre/yr.	Northeast	Midwest	West	South	Total	Northeast	Midwest	West	South	Total
Classification Zone #													
1 (Most Optimal)	**Low**	**High**	**Low**	**0**	**615**	**0**	**62**	**677**	**11**	**615**	**35**	**5**	**666**
2	High	High	High	39	96	0	123	258	5	4	0	209	218
3	Low	High	Low	0	55	0	0	55	13	50	0	0	63
4 (Expensive Biomass)	**High**	**High**	**High**	**0**	**84**	**0**	**94**	**178**	**0**	**21**	**0**	**125**	**146**
5	Low	Low	Low	0	19	0	101	120	47	75	0	23	145
6	Low	Low	High	39	4	196	244	483	15	40	161	293	509
7	High	Low	Low	0	22	0	290	312	82	84	0	24	190
8 (Least Optimal)	**High**	**Low**	**High**	**139**	**160**	**218**	**0**	**517**	**44**	**166**	**414**	**710**	**1,334**

Number of Acres of Total Potential Biomass from Switchgrass (SWG) and Short-Rotation Woody Crops (SRWC) by Production Classification Zone



* Low and high cutpoints based in relation to the U.S. median of the specific variable.

This is examined in greater detail in Table 1. The results from the table show that, again, the region with the greatest number and percentage of counties in the "Most Optimal" zone is the Midwest. Furthermore, these counties are often distributed fairly evenly across all three metropolitan status types. On the other hand, the counties in the high production zones in the South are often metropolitan counties. Hence, the initial perceived association between higher land rents for the more optimal southern zones of biomass crop production. Beyond the biophysical limitations that disadvantage the Northeast and the West in the development of a bio-economy, there are definite within-region patterns that advantage the Midwest over the South, given its relative lack of urban influence. Although this is addressed briefly in the discussion section, the impact of urban influence is beyond the scope of this paper and should be addressed in future research.

Spatial Illustration of Optimal Biomass Crop Production Zones

The overall picture for growing switchgrass, amortized against principal input costs, shifts from what was obtained from simply considering potential yields. In Figure 3, the production zone classifications show that the most optimal zone (# 1) is spatially concentrated in the upper Midwest, in Kansas, along the Gulf Coast, and on the Eastern Seaboard. There are also pockets of counties throughout the eastern half of the United States meeting the criteria in this classification zone. The more expensive high yield classification (# 4) are often in the Midwest where it is the higher land rent values and crop production costs that reduce the high acreage with potential for biomass crops to a slightly less optimal status for switchgrass.

The optimized outlook for short-rotation woody crops is shown in Figure 4. Whereas the Midwest often dominated the most optimal classification (# 1) for switchgrass, it is the Southeast, long a dominant forest region, which has the highest concentrations of this class of counties. Most of the zone 1 counties are located adjacent to metropolitan areas (see clustered bar chart in Figure 4). The most "expensive" but high yield class (# 4) are often in the Midwest. Thus, in both switchgrass (Figure 3) and short-rotation woody crops (Figure 4), the Midwest is likely to face higher input cost factors than is the Southeast.

DISCUSSION

The 'bio-economy' is on a trajectory to become institutionalized into the national economy of the U.S. Federal stimuli, in both research and development and prospective programs under the existing Farm Bill and related legislation, and private investments make this a reasonable projection. With the prospects of a

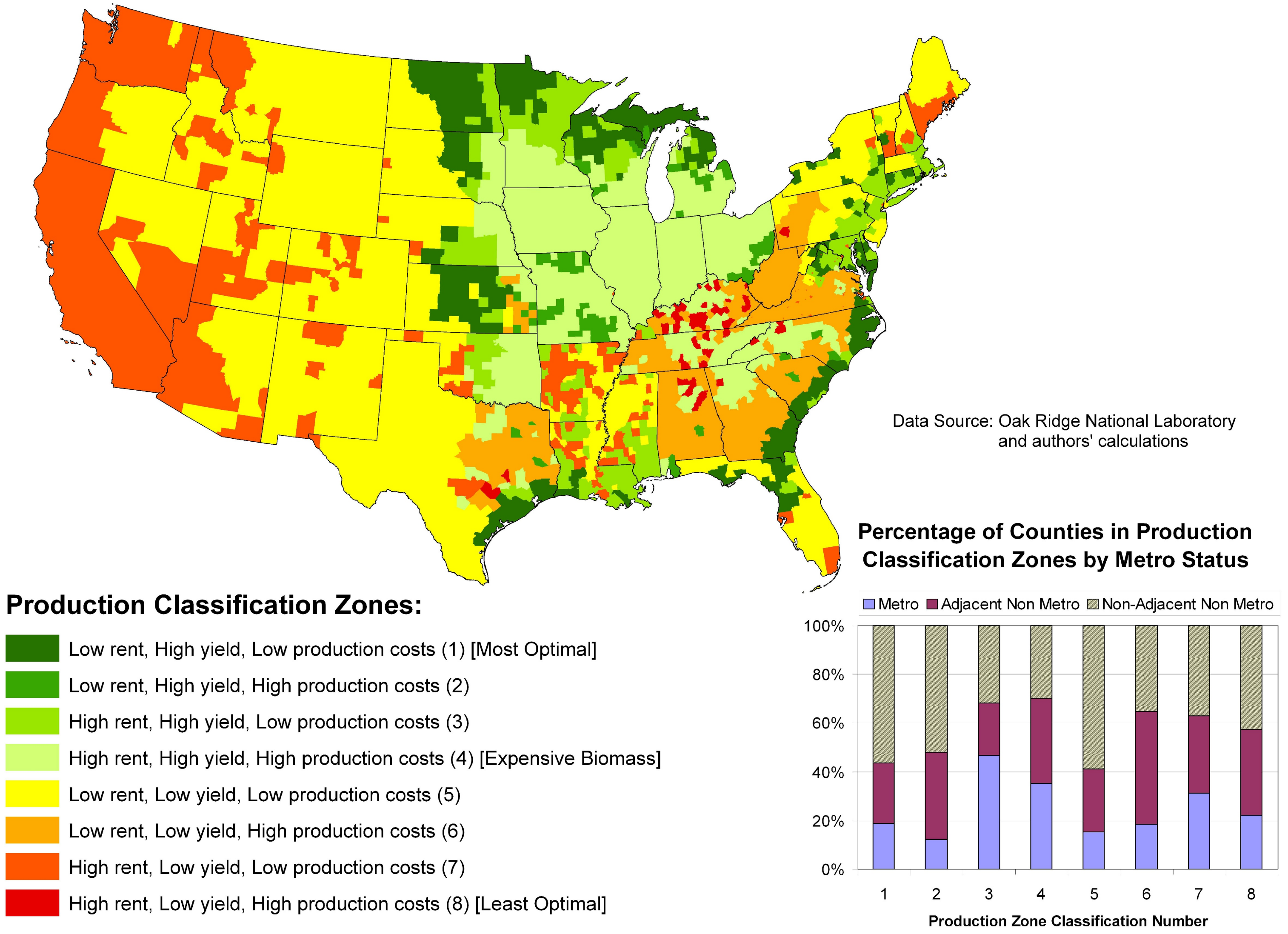
Table 1. Comparison of Count and Percent of Counties by Optimal Production Zones Between the Midwest and South Regions and Metro Status.

	Switchgrass											
	Region and Metropolitan Proximity											
	South (n = 1,374)						Midwest (n = 1,055)					
Optimization Categories	Metro		Adjacent		Non-Adjacent		Metro		Adjacent		Non-Adjacent	
	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%
1 (Most Optimal).....	36	2.6	0	0.0	11	0.8	190	18.0	224	21.2	201	19.1
2..................	76	5.5	36	2.6	11	0.8	17	1.6	23	2.2	56	5.3
3..................	0	0.0	0	0.0	0	0.0	4	0.4	18	1.7	33	3.1
4 (Expensive)........	29	2.1	29	2.1	36	2.6	4	0.4	14	1.3	66	6.3
5..................	36	2.6	33	2.4	32	2.3	3	0.3	5	0.5	11	1.0
6..................	67	4.9	79	5.7	98	7.1	0	0.0	1	0.1	3	0.3
7..................	54	3.9	136	9.9	100	7.3	0	0.0	9	0.9	13	1.2
8 (Least Optimal).....	83	6.0	192	14.0	200	14.6	3	0.3	15	1.4	142	13.5
Total...............	381	27.7	505	36.8	488	35.5	211	20.9	309	29.3	525	49.8

TABLE 1. *CONTINUED.*

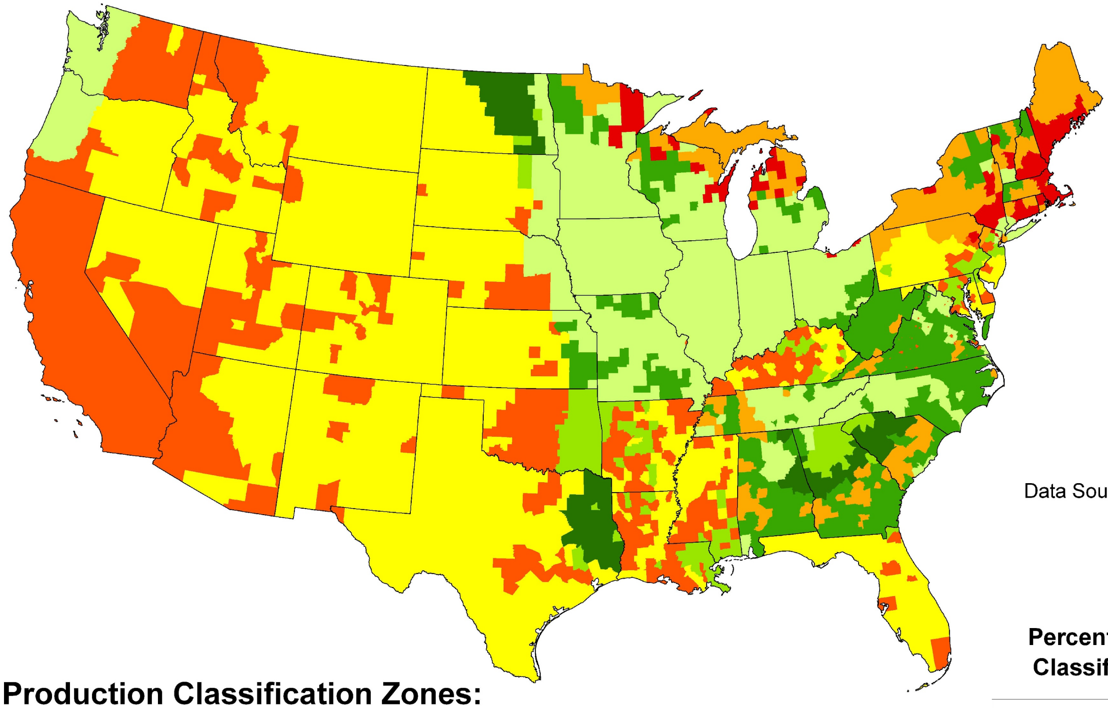
	SHORT-ROTATION WOODY CROPS											
	REGIONAL AND METROPOLITAN PROXIMITY											
	SOUTH (n = 1,374)						MIDWEST (n = 1,055)					
	METRO		ADJACENT		NON-ADJACENT		METRO		ADJACENT		NON-ADJACENT	
Optimization Categories	NUM	%	NUM	%	NUM	%	NUM	%	NUM	%	NUM	%
1 (Most Optimal).....	5	0.4	0	0.0	0	0.0	192	18.2	221	20.9	202	19.1
2....................	109	7.9	58	4.2	42	3.1	0	0.0	1	0.1	3	0.3
3....................	0	0.0	0	0.0	0	0.0	5	0.5	20	1.9	25	2.4
4 (Expensive)........	33	2.4	65	4.7	27	2.0	0	0.0	3	0.3	18	1.7
5....................	7	0.5	9	0.7	7	0.5	16	1.5	27	2.6	32	3.0
6....................	94	6.8	96	7.0	103	7.5	2	0.2	4	0.4	34	3.2
7....................	3	0.2	12	0.9	9	0.7	2	0.2	18	1.7	64	6.1
8 (Least Optimal).....	130	9.5	280	20.4	300	21.8	4	0.4	15	1.4	0	0.0
Total...............	381	27.7	505	36.8	488	35.5	221	20.9	309	29.3	525	49.8

Figure 3. Switchgrass optimal production zones based on rent, yield price & production costs



Data Source: Oak Ridge National Laboratory and authors' calculations

Figure 4. Short-Rotation Woody Crop optimal production zones based on rent, yield price & production costs

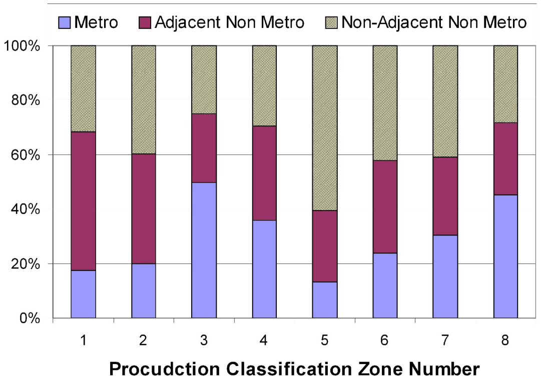


Production Classification Zones:

- 🟩 Low rent, High yield, Low production costs (1) [Most Optimal]
- 🟩 Low rent, High yield, High production costs (2)
- 🟩 High rent, High yield, Low production costs (3)
- 🟩 High rent, High yield, High production costs (4) [Expensive Biomass]
- 🟨 Low rent, Low yield, Low production costs (5)
- 🟧 Low rent, Low yield, High production costs (6)
- 🟧 High rent, Low yield, Low production costs (7)
- 🟥 High rent, Low yield, High production costs (8) [Least Optimal]

Data Source: Oak Ridge National Laboratory and authors' calculations

Percentage of Counties in Production Classification Zones by Metro Status



bio-energy sector of the economy looming on the national horizon, we know very little about the potential social policy issues that will quickly come into play as a result. In the U.S. State of the Union addresses for 2006 and 2007, President Bush twice articulated the importance of federal stimuli for growing a bio-fuels industry for national security interests surrounding sustainable energy resources. Very few specific policy issues, other than research-and-development investments, have been identified on the national scene.

With the premise that sound social policy is partially based upon the best available facts, we have argued that knowing *where* biomass energy crops are most likely to be grown effectively is predicated on several factors. One is the agronomic potential of a locality to grow specific, identified biomass crops. Switchgrass and short-rotation woody crops are the key crops being touted for their biomass potential, with switchgrass likely being the dominant crop-of-choice (De La Torre Ugarte et al. 2003). Another factor is that of local "input costs" for growing biomass crops, largely the land rent value and productions costs. A third factor involves the potential linkages with local and regional sectors of the economy that will facilitate the clustering of biomass crop zones, short-term storage facilities, and refineries. A fourth factor involves the potential impacts on local communities, ranging from economic to environmental, including concerns about whether the bio-energy sector can become sustainable over time.

We identified the spatial contours of agronomic potential for key biomass production zones in our analysis. They are primarily centered in the Midwest and the South for switchgrass and short-rotation forestry crops. Using a broader definition for biomass potential---involving methane recovery from landfills, crop residues, and so forth---we have shown that the West and Northeast, especially in metropolitan areas, can generate significant amounts of biomass material inputs for alternative energy production.

The two dominant regions exhibit very different pictures regarding metropolitan proximity. In the Midwest, rural areas in non-metropolitan counties that are not adjacent to urban centers have the largest acreage suited for these biomass crops. Likewise, the results from table 1 report that nearly 20 percent of these counties are in the 'most optimal' biomass production zone. Furthermore, the Midwest has an equally large percentage of its total counties, identified as adjacent to metro counties, in the 'most optimal' zone (21.2 percent). In comparison, there are relatively fewer counties in the 'expensive biomass' zones in the Midwest for all metropolitan status types.

In contrast, the non-metropolitan counties adjacent to urban population centers constitute the dominant locale of prime acreage for biomass crop production in the South; however, no counties were identified within the 'most optimal' zone. This is primarily because population redistribution and suburbanization take place in these adjacent counties, driving up land rent prices.

The patterns for these two regions could suggest different social policy scenarios, especially for the South. This region has experienced tremendous population and development growth in the past three decades and this is likely to continue (Frey 1987; Frey and Spear 1992; Fuguitt, Heaton, and Lichter1988; Lichter and Fuguitt 1982; Lichter, Fuguitt, and Heaton 1985). Thus, conflict over land use in the non-metropolitan adjacent counties of the South looms on the horizon.

Our study also provided a crude assessment of the most economically effective zones for switchgrass and short-rotation woody crops in the United States. This analysis showed how society moderates physical space as these "optimized" biomass crop production zones reflect local land value and labor costs. The most optimal counties have relatively high yields (above the median), low land rent values, and low production costs. The converse for yield, land values, and production costs reflects the least optimal localities. We observed that the dominant profile for U.S. counties is what we might term "expensive" biomass crop acreage: high yield estimates but also high land rent and production costs. These total some 170 million acres of either switchgrass or short-rotation woody crops. The counties meeting the most optimal profile total some 70 million acres of switchgrass but only 20 million acres of short-rotation forestry crops. The concentrations of these "optimal" zones show two distinctive spatial patterns. Significant portions of these zones are located near the coastal areas of the Gulf of Mexico and the south Atlantic seaboard. These areas are some of the most rapidly developing lands in the United States and they are fragile ecosystems as well. Another optimal area, as noted before, is in the suburban locales adjacent to urban centers of the South.

While this analysis is assumed to be a thorough and comprehensive study of the available data and literature on the topic at hand, it is only so based on the limited work performed in the area thus far. This limitation is directly related to the fact that, as a discipline, we are still in the early and formative stages of research concerning the social implications of biomass production. Furthermore, the same can be said about the more general area of biomass fuel production in a larger sense. Directly related to this project, the data available reflected several limitations. Most important, the project was limited in available data and required the authors to choose from the few available sources (Graham et al.1996; Milbrandt 2005).

Each of these sources is important as they represent some of the seminal work on alternative fuel production. However, they represent only a starting pointing, to which we hope that this analysis has meaningfully contributed. In fairness to the data used in this examination, noting that both sources used surpass acceptable standards based on the rigidity of their development and documentation is important.

The results paint a picture of bio-energy development for the immediate future that begs for serious discussions of the social policy elements surrounding it. The competition for land-use in the bio-economy appears at the core of the major social policy issues that the biomass sector will face. Within the South there is an excellent, yet difficult to implement, opportunity for economic growth from what looks to be an impending boom in alternative fuel production over the next decades. The unique issue facing the South is the potential to grow such fuel sources coupled with the higher density, in relation to the Midwest, and the inevitable land conflict that will accompany such an endeavor. In this sense the Midwest has a clear advantage and may, in fact, hold the upper hand regarding such fuel production.

On this point, several potential future research opportunities follow this examination. While we hope to have set a precedent in the literature through the identification of high production and optimal zones, this study does not necessarily contribute to the broader work on the social implications of such production. It does, however, lay the groundwork for these future analyses. Logical follow-up work could include the identification of threats to housing developments, increasing farm land prices, and changes in subsidy distribution, among many other factors that could potentially affect the livelihoods of many rural residents. This is an especially interesting development for the high production areas in the South, where ‘threats’ from the ever increasing and dispersing population seem inevitable.

Furthermore, while our analysis has taken a contiguous counties approach to identifying spatial clusters of high biomass crop production, understanding the effects of spatial weight matrices on the development of these clusters is important. For example, is a contiguous or distance-based matrix more efficient and what are the differences? Theoretically, it seems that the weight matrix employed in this examination is a good proxy for the efficient identification of an agronomically optimal bio-zone, due to the arbitrary county boundaries and the stasis landscape across counties. However, continuing to push this analysis forward through continued spatial modeling of differing neighborhood definitions is important. On this point, future work should comparatively examine the identification of spatial clusters based on several differing spatial neighborhood definitions.

The dominance of the Midwest in the optimal biomass crop zones identified in this study begs questions of William Frey's "command-and-control" centers (1987) in the new bio-economy. Where will the corporate control of the creation of wealth in the bio-economy reside? Will, for instance, the Midwest become the "backyard" for Chicago as the historian William Cronon (1991) described in his historiography, *Nature's Metropolis*? Can Des Moines, IA or Minneapolis-St. Paul, MN become the "Houston" (TX) of the new bio-economy as the latter has been in the fossil-fuel economy?

However, from an alternative point of view the South may have incentives of its own. For instance, currently the FDA is interested in finding ways of 'righting' the wrong they have admitted to, in court, concerning their past discriminatory practices of providing loan and subsidy monies to farmers. Biomass production in the South may allow for the proverbial "killing of two birds with one stone" by allowing for the involvement of disadvantaged black farmers across the black belt in the production of these alternative sources of fuel. Simultaneously, this would advance the technology and knowledge concerning the use of such fuel sources through its continued production and development. Although it is understood that the black farming community constitutes only a small share of the total, the point here is only that the ability to repair such social ills while potentially profiting economically does not present itself often and should be taken advantage of when possible. In this respect, the understanding of the relationship between racial diversity and the proximity of places to potential biomass production centers should be further explored to better understand the implication of social policy on group-specific outcomes.

The beginning of the quest for these and other answers is identifying the spatial contours of where biomass can be most effectively grown, in what proximity to both production and urban centers, and how "within-agriculture" (competition for traditional crop space) and "between-agriculture" (competitive land-uses) conflict can be managed for sustainability. While this study certainly implies several potential consequences (both positive and negative) of biomass crop production, it is beyond its scope to account for such consequences in-depth. However, by presenting a method for the identification of such production zones, future work can examine these outcomes, including potential economic boons for communities, the impact of closely situated dense population clusters, and so forth. These types of social policy issues must be addressed and understood as the sustainability of this emergent industrial sector will not be likely unless the social policy elements arising from the science-and-engineering thrusts into alternative bio-energy solutions are effectively identified, carefully evaluated, and thoroughly vetted through an open process where all elements of the stakeholder-set are involved. We hope this study has contributed to that initial discussion.

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