Potential production and spatial distribution of hybrid poplar as a biofuel crop in Connecticut, USA

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Abstract: The objective of this study was to assess the biomass production potential from hybrid poplars using marginal lands in the state of Connecticut, USA. A land-use suitability model was developed to identify and classify marginal lands in the state that could be used for growing hybrid poplars as a biofuel woody energy crop. The model was built on a geographic information system (GIS) platform, consisting of an exclusion area section, an ecological suitability section, and an economic/land-use suitability section. The model then was used to estimate the total biomass of the land-cover forests, annual biomass from forest and agricultural residues, and in particular the production potential of biomass from hybrid poplars over marginal lands in the state at county level. The results indicated that about 50% of the land in this state is unavailable for hybrid poplar cultivation and that less than 5% is highly suitable. The amount of usable area is highly variable on the county level. Without large-scale land use change, it appears that biofuel production in this state can only be a supplemental resource to the current energy supply.

Keywords: biofuel plants, hybrid poplar, spatial distribution, ethanol production, Connecticut, suitability model, ecological suitability

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1 Introduction

Biofuel is a renewable energy source produced from organic matters, commonly termed as biomass. Biomass can be either utilized through direct combustion or processed into liquid fuels such as ethanol, or gases such as methane[2]. To keep a leading position in global economic development, the USA is pursuing a goal toward national energy independence. Domestically produced biofuels are expected to supplement a substantial portion of the energy for transportation and other energy consumption. Among all the renewable biofuels, the usage of ethanol has increased over fourfold since 2000 and now constitutes over 6% of the total gasoline consumption in the nation. Furthermore, almost all the ethanol is produced from corn and it consumes 20% of the nation’s corn production[8].

The state of Connecticut is far from the US Corn Belt. At the same time, the hilly topography and rocky outcrops also make ethanol production through corn cost-ineffective[10]. Despite of the disadvantages, the state does have some local geographic advantages such as expertise in ornamental horticulture and Christmas tree production[15], and significant and well-distributed areas of second- and third-growth forests that were converted from uncompetitive farmsteads in the 20th century[1]. Hence a possible option for Connecticut is to use other types of lignocellulosic or biofuel crops such as switchgrass, willow, or hybrid poplar. These crops can grow on the abundantly forested lands and marginal lands statewide while utilizing the local expertise in silviculture.

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The ownership and usage types of land are very diverse in Connecticut. The conversion of agricultural or privately-owned forest to biofuel crops ultimately depends on the decision of every individual land holder. The owners must make short-term decisions about crop and land allocations by evaluating the economic suitability of a crop within a land-use planning regulatory environment. According to a marginal land-use allocation model from Lubowski, et al.[12], the least productive land-use, such as fallow or conservation lands are associated with the least productive soil types. These soils have the greatest chance to be converted to substantially different land uses, such as for planting biofuel trees. The highest-value crops are placed in the most productive soils where they have the maximum production potential. Areas already planted with high-value annual crops will tend to stay in that use. Consequently, marginal lands, such as abandoned farms and second-growth forests, are better candidates for lignocellulosic production because the owners are more inclined to broad categorical changes on low-quality lands.

The most commonly used method for assessing the suitability for land use change is the raster-based overlay mapping model which can take different types[13]. Geo-referenced land-use, ecological, and environmental factors are made into individual-attributes maps that carry categorical weights of suitability. The individual maps are then combined into a final suitability map[7]. These models are adaptable and flexible, as they allow users to encode a wide variety of ecological, planning, and topographic information[14]. The agricultural suitability modeling for habitats of various types are completed[3,20]. Ecologically oriented land-use suitability models are used to evaluate the absence/presence of species and habitat suitability using Bayesian logistic[19] or the general linear method[24]. Together with various land-use factors, agricultural suitability is integrated into some applications[4]. Most models employ a sensitivity analysis to evaluate the attribute appropriateness.

Being adaptable and easy to understand, land-use suitability models are dependent on geographic data sets that are often problematic and lack statistical independence among model attributes[13]. In addition, the scale of the available geospatial data may not coincide with the process scale, and the aggregation of data across scales may not capture the "non-linear, emergent, or collective behavior" of the landscape[25]. Feedback loops, which are an important property in environmental models, are often ignored between different process scales[26] and temporal issues are typically ignored in most land-use suitability modeling since the land-use change is normally treated as a single event.

Under a given environmental and climatic condition, a mixture of energy crops could be selected to achieve the highest economic returns and the lowest burden of pest control[27]. We chose the hybrid poplar as the energy crop in this study. This plant was selected because it is regarded as a woody energy crop that suits the local conditions with a superior fossil fuel offset[9] and a rapid growth rate. Poplars have been adapted to the soil and the climate in the state as functional trees. The needed silviculture skills for growing poplars are locally available. Researches have been conducted locally to breed new hybrid poplar species as an energy crop. In the same family (Salicaceae) with willows and cottonwoods, hybrid poplars tend to prefer moist areas, vicinity of streams, and fluvial floodplains[21]. Sites at pH 5-7.5 with adequate water and well-drained soils are best suited for the plant, but it can grow in a wide range of environments owing to high tolerance for site conditions. Hybrid poplars are sensitive to site preparation methods as their productivity is significantly impacted by competition[21]. Mowed plots can have four times of the biomass produced from unmowed plots, which shows the importance of site access[5]. According to DeBell et al.[6], on a 5-7 year rotation the cumulative yields of widely spaced poplars doubled or tripled that of the closely spaced "woodgrass".

Thomas et al.[21] described three levels of cultivation for hybrid poplars. Short-rotation intensive management areas are suitable for areas close to population centers to take the advantages of easy maintenance. Medium intensity management is applicable to areas that are easy to maintain but with more difficult access. Low intensity cultivation, with a much longer return period, is for some restricted site conditions such as those with a steep slope or poor accessibility. Modern poplar hybrids can yield 25 tons of woody biomass per year per hectare in average. This is equivalent to 1 750 gallons of ethanol at a conversion rate of 70 gallons of fuel per ton of woody biomass[17].

The focus of this research was to use a land-use suitability model to evaluate the land availability for conversion to biofuel silviculture in Connecticut and the production potential to supplement petroleum fuels. In particular, we aimed

1) To construct a spatial platform for quantifying feedstock in Connecticut using GIS technology. On this platform, we would establish a comprehensive database of the pertinent attributes of the geography, climate, soil and land use/land cover.

2) To estimate the total amount of biomass storage in the forests and woodlands in Connecticut by identifying and quantifying the total biomass and available feedstock from forest and agricultural residues on the basis of land cover and land use type.

3) To evaluate and map the idle and marginal agricultural lands suitable for growing woody energy crops (*i.e.* hybrid poplars) for lignocelluloses ethanol production.

4) To estimate the potential of biomass production from forest and agricultural residues, and the efficiency of biofuel crop silviculture on the idle and marginal lands in Connecticut.

2 Materials and methods

2.1 Database construction

We acquired data from various sources (see Appendix) relevant to feedstock of biofuel industry. Information fused into the database includes: land use/land cover, digital elevation, slope and aspect, soil type and quality, and climatic variables. Data are all of the best quality and accuracy that can be achieved at the present time. Derived variables and estimations in this study are all based on this database.

2.2 Total biomass storage and availability

Van Aardt, et al.[23] estimated the forest volume and biomass using small-footprint lidar-distributional parameters on a per-segment basis. The amounts of biomass in unit area of different types of forests are shown in Table 1. The total amount of biomass storage in Connecticut was estimated by multiplying the biomass per unit forest area with the total forest area of the three types of forests (deciduous, coniferous and mixed). The forest area was acquired from the National Agricultural Statistics Service Cropland Data, USDA.

Table 1 Volume, biomass and basal area for different types of forest based on Van Aardt, et al. [23]

Forest Type	Parameter	Min.	Max.	Mean	Std. Dev.
Deciduous	Volume /$m^3 \cdot ha^{-1}$	6.94	350.65	156.16	89.32
	Biomass /$mg \cdot ha^{-1}$	11.11	269.01	117.31	62.53
	Basal area/$m^2 \cdot ha^{-1}$	2.3	34.44	15.97	8.21
Coniferous	Volume /$m^3 \cdot ha^{-1}$	8.32	278.99	100.45	66.42
	Biomass /$mg \cdot ha^{-1}$	4.67	81.65	33.66	19.95
	Basal area /$m^2 \cdot ha^{-1}$	2.3	36.73	13.61	8.11
Mixed	Volume /$m^3 \cdot ha^{-1}$	31.68	350.93	156.85	72.6
	Biomass /$mg \cdot ha^{-1}$	20.06	175.75	81.49	38.93
	Basal area /$m^2 \cdot ha^{-1}$	4.59	36.73	16.84	6.68

2.3 Biomass from agriculture and forest residues

Post-harvest agricultural crops leave a significant amount of biomass that can be used to produce biofuel. Similarly, silvicultural forest residues, normally processed on site as wood chips, are also considered a feedstock for biofuel production. The widely accepted values of potential biomass productivity of agricultural crop and forest residues are listed in Table 2[11,16]. The total amount of biomass of such residues in Connecticut was estimated by multiplying the amount per unit area with the respective crop/silviculture area obtained from USDA.

Table 2 Biomass from crop and forest residues based on the study of Pimentel et al.[16] and Lehmann[11]

Source	Residues/$ton \cdot ha^{-1}$
barley	3.5
corn	5.6
cotton	0.5
oats	4
rice	7.4
rye	2.3
sorghum	1.2
soybean	3
wheat winter	3.5
wheat spring	2.3
other	1.1
forest	3.5

2.4 Estimation of potential biomass production

We focused on creating an overlay-type land-use model, with both ecological and land-use components, for quantifying the spatial land distribution suitable for growing hybrid poplars. Several simplifying assumptions were made to reduce the interactions and feedbacks among multiple variables in different domains with variable scales:

1) The analysis was limited to a first order land-use change so that there was no need to model growth and the consequent feedbacks caused by temporal iteration.

2) There were only two major considerations for land-use classification: ecological suitability of hybrid poplars and land-use acceptability with categorical suitability metrics.

3) Land-use allocation was not necessary for each parcel land-owner. Instead, the land-use allocation effects could be lumped with an economic suitability and land-use decision category at a larger scale.

4) Soil polygons and land-use pixels represented “real” data and the inherent heterogeneity was not considered.

5) Mixed-scale data was assumed to be model compatible.

6) Within this study, the attribute weights were sufficient to reflect the suitability for growing hybrid poplars as an energy crop.

With the above assumptions, an overlay-type, land-use suitability model for growing hybrid poplars in Connecticut was developed with raster-based GIS. The model used 30 m by 30 m pixels as the primary modeling scale with land-use, topography and geo-referenced soil data all converted to the same raster size. A suitability rating then was obtained for each pixel based on analysis in the following three sections: 1) excluded areas, 2) ecological suitability, and 3) economic and land-use suitability.

2.4.1 Excluded area sub-section

The excluded area sub-section was to remove from consideration those areas unlikely for hybrid poplars planting, including the urban land, street buffers, hydrological buffers, non-private reserved land, and steep slopes or poor soil areas (Table 3). The urban land category was identified as those pixels the majority of which were covered by urban land. The street buffer (30 m) was intended to mimic a ROW plus a setback for the rear of a lot. This was considered quite representative for Connecticut even for rural areas because houses and farms in rural areas of Connecticut are close to the road. The hydrology buffers were set according to the standard buffer settings used for wetlands and water protection across the state. The non-private land exclusions were for those government-controlled lands unavailable for growing biofuel crops/trees in the near future. The topographic rules were established site limitations in both environmental and economic aspects. Land with steep slopes is hard to utilize and poor soil conditions are not productive for growing any crops/trees.

Table 3 Excluded areas

Attribute	Data source
Urban land	Derived from CLEAR LC
Street buffer (30 m)	Derived from DEP Vector data
Hydrology Pond buffer (30 m) Stream buffer (30 m) Wetlands buffer (30 m)	Derived from DEP Vector data
Non-private lands DEP lands Federal lands Municipal lands	Derived from DEP Vector data
Topography and soils Slope >33% Very rocky soils	Derived from CLEAR 10’DEM

2.4.2 Ecological suitability sub-section

The ecological suitability section was intended to determine the ecological appropriateness of a certain area for hybrid poplars cultivation. The attributes are slope aspect, soil rock content, and soil quality (Table 4A). The slope aspect was weighted towards southern-facing slopes as they get more solar energy and longer growing periods under the year-around wet climate of Connecticut. Two attributes were included for soil quality, i.e. soils with no rocks and land of loam soils.

2.4.3 Economic and land-use suitability sub-section

The final section was a hybrid section of economic suitability and community-level land-use suitability with four attributes (Table 4B) for weights. In land-use allocation modeling, parameterization is very difficult for multi-scale, multi-disciplinary, and spatial-explicit systems. As a consequence, derivative attributes are often used to weight the land that might undergo land-use change. In the economic and land-use suitability sub-section, land-use and land cover attributes were weighted towards marginal lands with forested land cover, because such lands were regarded in general more suitable than those with anthropogenic land cover such as agricultural and turf grass. The slope category weighted the attribute for low and moderate slope areas higher because of their important cultivation benefits for hybrid poplars. The prime farmland classification was an attribute weighted towards marginal lands that would have a better economic gain for growing woody energy crops.

Table 4 Weights of the ecological and economic indices

A: For ecological suitability attributes	Weighted values
Aspect	
North	1
Northwest and northeast	2
East and west	4
South, southeast and southwest	5
Soil	
No rocks	2
Loam soil	2
B: For economic and land-use suitability	
Land-use	
Urban	0
Turf Grass	1
Agricultural	2
Forest	3
Street inclusion area	5
Farmland classification	
Prime farmland	0
Farmland of state wide importance	0
Not prime farm Land	3
Slope	
<8%	5
8-15%	3
>15%	0

2.5 Procedures

The three sections described above were combined using an additive overlay to produce a final suitability map that weighted or eliminated areas for hybrid cultivation in Connecticut. This raster-based, land-use suitability model for hybrid poplar was developed with the ArcMap 9.2 GIS. The GIS was geo-referenced to NAD83, UTM18N coordinate system. All primary geo-referenced data such as vector, raster, and topographic data were acquired from publicly available sources, see Appendix. Attributes were extracted using an SQL database search and then exported separately. All vector data and topographic data were rasterized or resampled to a 30 m × 30 m pixel size to match the satellite derived Connecticut land cover data. Excluded attributes were encoded using a binary encoding and combined in Map Algebra to get a composite exclusion map. The urban land category used a majority rule at the scale of 1 km^2, while buffer layers were processed using the “Expand” function. Slope data were geo-processed in the “Spatial Analyst” function and binned into four categories. Urban land cover map was re-classed to a five-point suitability system. The ecological suitability and economic/land-use suitability sections were combined using a weighted sum overlay to make a suitability map and were re-classified into low, medium, high, and very high suitability. The suitability map is processed using a majority rule for a nearest neighborhood to reduce local variety. The potential biomass production from hybrid poplar cultivation was obtained from the productivity of the poplar species and the areas of the identified marginal lands, weighted by the respective suitability indices. The analysis was also extended to the county level for data presentation.

3 Results and discussion

3.1 Total biomass storage

The total amounts of biomass storage in Connecticut forest are shown in Table 5. The potential heat, electrical and ethanol energy are calculated following the method of Pimentel *et al.*[16]. For reference use, this amount represents the total energy production through all the biomass sources in the state.

Table 5 Biomass storage in forests and woodlands in connecticut

Forests	Total area /ha	Biomass /ton×10^6	Thermal energy equivalent /kcal×10^9	Electrical energy equivalent /kcal×10^9	Ethanol energy equivalent /kcal×10^9
Deciduous	711 541	206.3	333 043	95 212	39 253
Coniferous	40 206	59.2	95 570	27 322	11 264
Mixd	20 545	143.3	231 338	66 136	27 266
Combined	722 292	408.8	659 951	188 670	77 783

3.2 Biomass from forest and agricultural residues

The annual total amounts of biomass from crop and forest residues are shown in Table 6, following the same calculation procedure of Pimentel *et al.*[16]. Converted to ethanol energy equivalent, the potential production of biomass from forest and agricultural residues was about 27.5 million gallons/year for the entire state (data from Shapouri *et al.*[18]), which is about 17.8% of the total ethanol demand of Connecticut. This only works if all the residues are harvested and processed into ethanol, which is obviously not realistic. Assuming a portion of the residues can be collected, transported, and processed, the energy production from forest and agricultural residues will constitute a small number of the total energy assumption.

Table 6 Biomass energy from crop and forest residues in Connecticut

Crop type	Area /ha	Biomass from residue /ton	Heat energy equivalent /kcal ×10^6	Electrical energy equivalent /kcal ×10^6	Ethanol energy equivalent /kcal ×10^6
Deciduous Forest	711 541	2 490 396	4 020 405	1 149 374.5	473 854.5
Evergreen Forest	40 206	140 722	262 551	85 731.5	31 485.4
Mixed Forest	20 545	71 908	134 162	43 808.3	16 088.9
Corn	20 742	116 152	210 817	58 076.2	27 301.7
Alfalfa	54 386	59 831	111 629	36 450.6	13 386.7
Shrubland	29 855	32 844	61 278	20 009.4	7 348.6
Other Hay	20 516	22 570	42 110	13 750.3	5 049.9
Christmas Trees	433	10 699	19 962	6 518.3	2 393.9
Sweet Corn	1 824	10 212	19 054	6 221.6	2 284.9
Pasture/Grass	4 893	5 383	10 044	3 279.6	1 204.4
Tobacco	1 219	1 341	2 502	816.8	300.0
Apples	1 096	1 206	2 250	734.8	269.8
Rye	404	930	1 735	566.5	208.0
Other Crops	827	909	1 697	554.0	203.5
Potatoes	272	299	558	182.2	66.9
Pumpkins	234	257	480	156.8	57.6
Soybeans	85	256	478	156.1	57.3
Squash	150	165	308	100.6	36.9
Peppers	149	164	306	100.1	36.8
Misc. Vegs. & Fruits	146	161	300	97.9	36.0
Eggplants	81	89	167	54.4	20.0
Oats	13	50	97	37.1	10.6
Peaches	27	30	55	18.0	6.6
Grapes	25	27	51	16.7	6.1
Blueberries	25	27	51	16.6	6.1
Other Tree Fruits	23	26	48	15.7	5.8
Durum Wheat	7	26	48	15.5	5.7
Winter Wheat	6	20	38	14.6	4.2
Dry Beans	6	19	36	11.7	4.3
Tomatoes	9	10	18	5.9	2.2
Barley	2	7	13	5.1	1.5
Sod/Grass Seed	6	7	13	4.1	1.5
Sorghum	5	6	10	3.4	1.3
Cranberries	4	5	9	2.8	1.0
Cabbage	4	4	8	2.6	1.0
Asparagus	4	4	8	2.5	0.9
Speltz	3	3	6	1.9	0.7
Sunflower	2	3	5	1.6	0.6
Clover wildflowers	2	2	4	1.1	0.4
Onions	1	2	3	1.0	0.4
Greens	1	1	2	0.7	0.3
Strawberries	1	1	2	0.7	0.3
Combined	909 780	2 966 774	4 903 318	1 426 919.8	581 753.2

Jason Parent *et al*. (unpublished report) used a similar approach to estimate the potential of using forest residues to offset coal use in co-fired power plants in the eastern United States, with a feasible transport distance of 60, 80, and 100 km. Their study indicated that forest residues alone can reduce 2%-3.4% of the current coal usage in the eastern states. This would consequently reduce similar percentages of greenhouse gas and/or pollutants emissions. As shown in Table 6, the forest residues in Connecticut constitute a significant part of biomass that currently is not being used for energy production.

3.3 Idle and marginal land for hybrid poplar production

By identifying marginal lands and scoring their suitability for growing hybrid poplars as an energy crop as described in Section 3, the lands in Connecticut were re-classed into four suitability categories (Table 7). The spatial distribution of the land-suitability is shown in Figure 1. The excluded areas, displayed grey, are delineated lands unavailable for use by land owners for biomass production. About 43% of the land in Connecticut was unavailable, leaving about 57% of the land for potential use for hybrid poplar cultivation. The excluded areas were concentrated in the urban areas or with rough topography. The largest available areas were concentrated in the far northeastern corner and the western part of the state.

Excluding the areas that are controlled by governments and that are difficult to access, the marginal land in the state was fragmented with a significant spatial variation. Binned into the four categories, most of the land was classified as “medium” (23.3%) and “high” (24%). Areas of “low” and “very high” combined only constituted <10% of the total area. The proportions of each category also varied with counties. Heavily urbanized counties (such as Fairfield, Harford and New Haven) tended to have greater area in the excluded category and less for biomass production, while the rural counties (Litchfield, Tolland, and Windham, for example) tended to have more lands suitable for growing hybrid poplars.

Table 7 Suitability categories in Connecticut and its eight counties

County	Area of each category (% of total area)/km^2				
	Excluded	Low	Medium	High	Very high
Fairfield	744.26 (44.8%)	137.24 (8.3%)	408.60 (24.6%)	324.97 (19.5%)	47.40 (2.9%)
Hartford	893.44 (45.9%)	84.82 (4.4%)	376.07 (19.3%)	479.54 (24.7%)	110.62 (5.7%)
Middlesex	407.72 (41.0%)	61.98 (6.2%)	252.83 (25.4%)	238.95 (24.0%)	32.30 (3.3%)
New Haven	732.63 (45.8%)	97.38 (6.1%)	356.80 (22.3%)	344.93 (21.6%)	68.38 (4.3%)
New London	645.58 (36.3%)	97.82 (5.5%)	455.32 (25.0%)	515.56 (29.0%)	75.71 (4.3%)
Litchfield	616.24 (25.2%)	197.25 (8.1%)	826.13 (33.8%)	722.58 (29.5%)	85.18 (3.5%)
Windham	372.23 (27.6%)	64.36 (4.8%)	373.87 (27.7%)	471.71 (35.0%)	67.50 (5.0%)
Tolland	329.96 (30.5%)	55.01 (5.1%)	291.01 (26.9%)	357.86 (33.1%)	47.01 (4.3%)
Combined	6204.86 (43.1%)	804.66 (5.6%)	3378.62 (23.5%)	3458.08 (24.0%)	534.08 (3.7%)

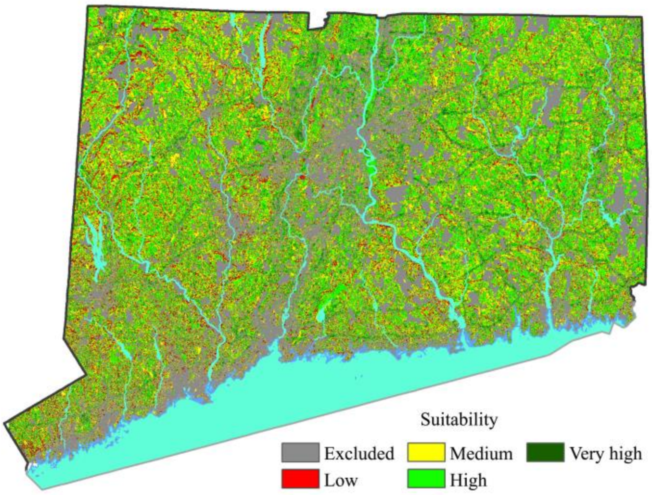

Figure 1 Hybrid poplar suitability map of Connecticut

The results of this research indicated that the distribution of suitable lands for hybrid poplar biofuel production is highly variable within the state in both political and parcel scale. Litchfield, for instance, has about 45% of the highly suitable lands and Fairfield has only 21% in the same category. Although energy policy is developed at the state and federal level, the incentives and infrastructure should be locally targeted at the most suitable communities. For example, Litchfield might be an ideal location to subsidize a processing facility. In addition, environmental and land-use policies should be targeted for the communities with the highest potential impacts. Policy can be groomed to meet the needs of those areas most likely to undergo the largest land-use conversion.

3.4 Economically viable parcels

To find usable parcels of an economically viable size, the two highest weighted categories (high and very high) within the forest land cover areas were all grouped together using the Landscape Fragmentation Tool (University of Connecticut Center for Land Use Education and Research). Grouped areas of under 8 hectares (20 acres) were removed to simulate economically viable parcels. This left 3295 parcels of more than 8 hectares in Connecticut with a mean size of 92 hectares and a standard deviation of 149 hectares. The total area of the parcels is 244 000 hectares, evenly spread throughout the state (shown in Figure 2). The large parcels are abundant in the northern boundary (Tolland) and the eastern part (New London and Windham) of the state.

3.5 Potential production volume of ethanol from hybrid poplars

The maximum amount of ethanol production from hybrid poplars per hectare is about 1 750 gallons/hectare/year. The maximum amount of ethanol production in each county was estimated at this conversion rate and the area of the economically viable lands (usable parcels, >8 hectares), weighted by land suitability. The estimated maximum amounts of energy production from hybrid poplar cultivation are listed in Table 8.

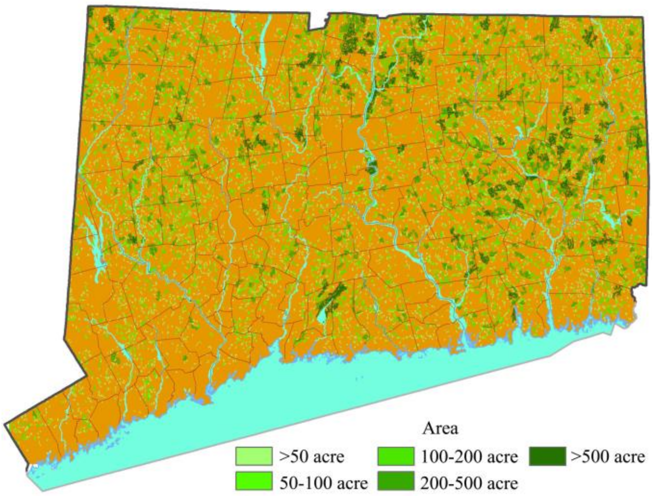

Figure 2 Economically viable lands for hybrid poplars in Connecticut

Table 8 Production potential of ethanol for gasoline replacement

County	Land area /hectares	Potential production /million gal year^{-1}	Proportion to total demand
Fairfield	13 400	23	15%
Hartford	38 100	66	43%
Middlesex	14 100	24	16%
New Haven	21 300	37	24%
New London	38 700	67	43%
Litchfield	51 300	89	57%
Windham	38 700	67	43%
Tolland	28 400	49	32%
Combined	244 000	422	273%

Connecticut currently consumes about 1.55 billion gallons of gasoline a year. Were all the marginal lands used for hybrid poplar for ethanol production, it could provide 27.3% of the fuel consumption. To replace 10% of the demand with ethanol, the state needs about 155 million gallons of ethanol that would demand 90 000 hectares of land to be converted to hybrid poplar plantation, which is over one third of the suitable marginal land area in the state. This estimation was based on the highest production efficiency and optimal climatic conditions. It also assumed that the commodities markets were not distorted by the large land-use changes. However, Connecticut is an urbanized state with rural settings. In addition to developed structures and paved surfaces, the current landscape is characterized by forest, orchards, and to a less extends, facility agriculture. Converting one third of the suitable marginal lands for a 10% fuel replacement seems not a convincing option from both political and ecological perspectives.

4 Conclusions

A suitability model was developed and used to assess the potential of ethanol production by growing hybrid poplars using suitable marginal lands in Connecticut. Among the total land area of the state, 43% was excluded from biofuel production and another 6% was unsuitable with very low productivity. Of that remaining land, about 27% met the definition of suitable land on marginal locations – *i.e.* on a forested land cover assumed to be second growth forest. The number of economically viable parcels is about 244 000 hectares.

For a 10% fuel replacement for the state based on the current fuel consumption, over one third of the total area considered ecologically and economically suitable lands have to be converted for hybrid poplar plantation under the best climatic conditions with the highest efficiency. In the highly urbanized state of Connecticut, converting land of this amount with the current land cover condition for hybrid poplar cultivation is not realistic. Therefore, we conclude that a significant percentage replacement of gasoline with locally grown biofuel crops is very difficult for Connecticut. The same conclusion might apply to the whole east coast. Biofuel from short rotation woody energy crops such as hybrid poplars can only be a supplemental energy source for the current energy supply.

Appendix

Geospatial data was downloaded from these locations for the model:

1) State of Connecticut, Department of Environmental Protection. Information found at GIS Data website http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898 (DEP)

2) University of Connecticut, Center for Land Use Education and Research. Information found at CLEAR Imagery & Data website http://clear.uconn.edu/data.html (CLEAR)

3) The GeoCommunity. Information found at the GIS Data Depot http://data.geocomm.com/

4) United States Department of Agriculture, Natural

Conservation Service. Information found at the Soil Data Mart
http://soildatamart.nrcs.usda.gov/ (SSURGO)

5) United States Department of Agriculture, National Agricultural Statistics Service Cropland Data
http://www.nass.usda.gov/research/Cropland/SARS1a.htm

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