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U.S. Federal Agency Models Offer Different Visions for Achieving Renewable Fuel Standard (RFS2) Biofuel Volumes

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The Renewable Fuel Standard (RFS2) in the U.S. Energy Independence and Security Act of 2007 (EISA) sets annual volume targets for domestic renewable transportation fuel consumption through 2022, but allows for flexibility in the types of biomass used for biofuels and where and how they are grown. Spatially explicit feedstock scenarios for how the agricultural and forestry sectors can produce sufficient biomass to meet these targets have been developed by the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Agriculture (USDA). Here we compare the models used to generate these scenarios and their underlying assumptions on crop yields, feedstock prices, biofuel conversion efficiencies, land availability, and other critical factors. We find key differences in the amount of land devoted to different biomass sources and their geographic distribution, most notably for perennial grasses. These different visions of land use and management for bioenergy in the U.S. are currently being used both for regulation and to set research funding priorities. Understanding the key assumptions and uncertainties that underlie these scenarios is important for accurate assessment of the potential economic and environmental impacts of RFS2, as well as for optimal design of future energy and agricultural policy.

INTRODUCTION

The Renewable Fuel Standard (RFS2) in the Energy Independence and Security Act of 2007 (EISA) requires annual U.S. consumption of up to 36 billion gallons of biofuels by the year 2022.[1] Of this amount, 15 billion gallons are to be conventional biofuels, most likely met with ethanol from corn grain. The remaining 21 billion gallons are to be advanced biofuels from feedstocks other than corn grain, 16 billion gallons of which are to be cellulosic biofuels derived from cellulose, hemicellulose, or lignin. Feedstocks for these advanced biofuels include plant residues (e.g., corn stover, cereal grain straw, and forestry residues), dedicated energy crops (e.g., switchgrass, energy cane, and hybrid poplar), and other sources of biomass (e.g., municipal solid waste and algae). Another 1 billion gallons of advanced biofuels are to be biomass-based diesel, primarily biodiesel from soybean oil, other vegetable oils, and animal fats. Meeting RFS2 targets would increase the share of renewable fuel by volume to approximately a quarter of U.S. gasoline by 2022.[2]

Producing a sufficient quantity of biomass to meet the biofuel volumes mandated in RFS2 will require millions of acres of land as well as extensive feedstock supply and logistic systems for biomass harvest, transportation, and processing. Recent studies have concluded that wide-scale harvesting of residues from existing cropland and timberland will alone be insufficient to meet biomass production targets.[3] Other land would also need to be converted to the production of dedicated biofuel crops. Biomass production for bioenergy is therefore poised to become a major driver of land use change in the coming decades.

Knowledge of which feedstocks are likely to be used and where they are grown is of great importance for the future development of the biofuels industry. Future demand for biofuels could conceivably be met by any number of combinations of biomass feedstocks. Three federal agencies, the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), and the Department of Energy (DOE), have each produced feedstock production and land use scenarios for meeting RFS2 by 2022.[4−6] These scenarios are influencing public policy discussions, guiding research on the impacts of bioenergy production, and informing future land use planning. However, the scenarios put forth by each agency present very different visions for both land use and industry development, and would likely result in very different economic, environmental, and social consequences.

Despite the relevance of these scenarios to policy, the projections from these three agencies have not been critically compared. Understanding the key differences among them is important for accurate assessment of the potential impacts of RFS2, as well as for optimal design of future energy and agricultural policy. In light of these concerns, the purpose of the paper is to compare and contrast DOE, EPA, and USDA scenarios for feedstock production and land use in 2022. Our intent is not to critique the agency approaches or evaluate the optimal or most probable scenario, as has been done elsewhere.[3,7,8] Rather our objectives are to (1) summarize the modeling approaches taken by each agency, (2) compare their findings in terms of total volumes of biofuel produced from

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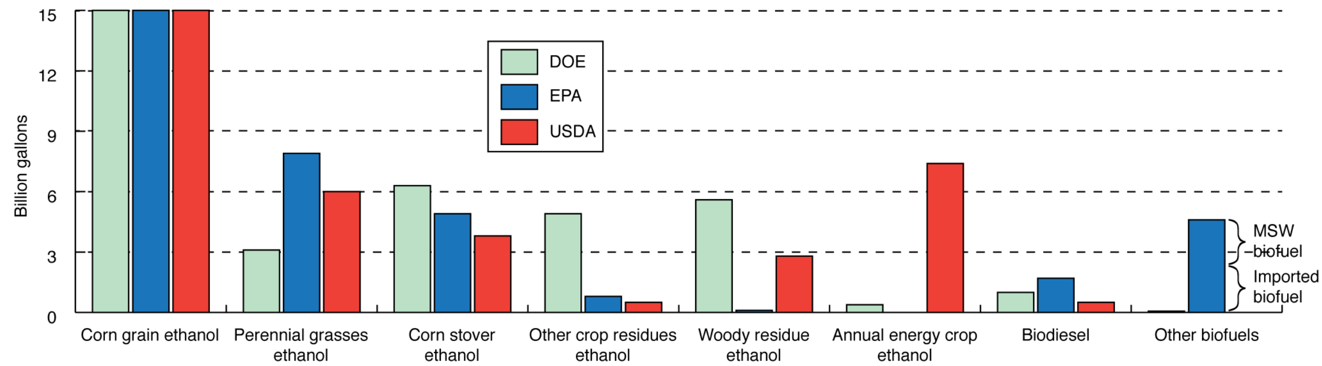

Figure 1. Comparison of DOE, EPA, and USDA, estimates of renewable fuel produced from different feedstocks by 2022.

various feedstocks, the land acreage allocated to perennial grasses and corn stover, and the spatial distribution of corn stover and perennial grass feedstocks across the U.S. landscape, and (3) contrast the key assumptions underlying each agency's projections and how these assumptions may have contributed to differences among the scenarios.

COMPARING MODELING APPROACHES

We compared the modeling approaches employed by DOE, EPA, and USDA to estimate the amount of biomass needed, land acreage required to produce that biomass, and where that biomass would be produced. It is important to note that these scenarios are not necessarily endorsed by the agencies themselves, but rather represent the outputs of agency modeling exercises. All reported data were obtained from agency publications or received directly from the agency per our request.

Both EPA and DOE used economic models of the domestic agricultural and forestry sectors to estimate fuel volumes, commodity prices, and land use trends. EPA used the Forest and Agricultural Sector Optimization Model (FASOM), a long-term economic model that maximizes net present value of welfare over time subject to market, technological, and other constraints.[9] EPA created a scenario where the RFS2 volume requirements were binding, the model solution of which was the mix of feedstocks for each region that would deliver the lowest cost per gallon of fuel produced given projected market conditions. The model estimated equilibrium prices paid at the farm level for different crops based on the market demand for renewable fuels.[9]

DOE also used a simulation model of the agricultural sector, the Policy Analysis System (POLYSYS). POLYSYS is comprised of a system of interdependent modules that simulate crop supply, crop demand and prices, livestock supply and demand, and agricultural income.[10] Key variables manipulated in the model are planted and harvested area, production inputs, yield, exports, costs of production, demand by use, and commodity prices. Unlike EPA, DOE did not assume that the fuel volumes of the RFS2 were binding. Instead, DOE used POLYSYS to estimate the projected quantity of feedstocks that producers would be willing to supply at different biomass prices. Using POLYSYS, DOE produced a series of feedstock production scenarios under varying price and yield assumptions. Model outputs are available online via the DOE Bioenergy Knowledge Discovery Framework (KDF, www.bioenergykdf.net). We downloaded and analyzed fuel volumes for different feedstocks based on DOE-estimated biomass prices from $40 to 60 per dry ton. For our comparative analyses, we selected DOE's model results for a farm gate price of $45 per dry ton of biomass as it was the biomass price that produced a feedstock portfolio that most closely approximated RFS2's 36 billion gallon target. DOE's feedstock volumes for other residues (for example, urban wood waste) and woody residues were not reported at $45, so in this analysis we use a linear approximation between gallons produced at $40 and $50.

In contrast to EPA and DOE, USDA did not use commodity prices and resulting supply curves to predict fuel volumes for their 2022 scenario. Instead, USDA conducted a regional analysis of potential fuel volumes based on assumptions about feedstock availability, energy yields, technology changes, and the costs and production capacity of biorefineries in each region.[4] The goal of the USDA report was to determine if there was sufficient capacity to produce enough feedstock to meet the RFS2 targets and to identify regional infrastructure barriers for producing and refining biomass. For each region, future feedstock production was estimated based on land availability, on suitable crop types based on historical planting data, climate and soil conditions, and on energy yields per acre produced by Agricultural Research Service scientists and industry experts. Feedstock production by region was then coupled with estimates of the number of biorefineries needed to process projected biomass sources. USDA estimated that 527 new biorefineries would need to be built to satisfy RFS2's advanced biofuel targets.[4] Commodity prices were not a major factor in influencing USDA's anticipated feedstock volumes or associated land use change and represent an important difference between their work and that of DOE and EPA.

COMPARING TOTAL FUEL VOLUMES

Each agency model assumes that sufficient biomass will be available in 2022 to meet the mandated annual production target of 36 billion gallons of renewable fuel.[4−6] All three scenarios project 15 billion gallons of corn ethanol, which is the maximum amount of biofuel that can be derived from the starch of corn grain under the provisions of RFS2. Current production of corn ethanol is already close to meeting this target (13.3 billion gallons in 2012),[11] which is mandated to be achieved by 2015.

Also consistent across all three analyses is the importance of perennial grasses, crop residues (particularly corn stover), and woody residues for making up the majority of the RFS2 requirements for advanced biofuels. The three agencies estimates differ, though, on the relative reliance on perennial grasses or agricultural residues to meet biomass volume targets (Figure 1). Both the EPA and the USDA projections rely heavily upon perennial grass feedstocks (7.9 and 6.0 billion gallons, respectively), whereas at $45 per dry ton the DOE model estimates only 3.1 billion gallons of biofuel will be produced from perennial grasses. Rather, the DOE model projects that the majority of advanced biofuel will be derived from crop and woody residues (16.8 billion gallons).

In reporting their results, the agencies organized the potential feedstock resources into similar feedstock categories, (e.g., perennial grasses and annual energy crops). However, while the general categories appear to be similar, the number and types of feedstocks considered in each category varied among the agencies. For example, all the agencies considered "agricultural residues" as a general biofuel feedstock category, but under this category DOE considered fourteen different sources of agricultural residue, whereas USDA considered only two. This discrepancy in part explains why the DOE model projected greater fuel volumes from other crop residues relative to the other agencies. For this paper we created feedstock categories that allowed for the clearest comparison across all three agencies. Most notably we separated corn stover from all other agricultural residues.

COMPARING LAND AREAS FOR SELECT FEEDSTOCKS

Figure 2 compares the total U.S. land acreage for perennial grasses and corn stover in 2022 as estimated in each agency's analysis. All three agency models show that less acreage is required to produce a given volume of fuel from perennial grasses than from corn stover. This is largely because nearly all of the aboveground biomass of perennial grasses can be harvested, but a much smaller fraction of corn stover is available for collection so as to minimize water and wind erosion, and soil carbon loss.[12] It is important to note, however, that land from which corn stover is collected is also producing corn grain, whereas perennial grasses may completely displace land previously used for other purposes. These factors contribute to notable differences in the total land area estimates produced by the agencies. For example, even though its estimate of fuel volume from corn stover in 2022 is the lowest of the three agencies, USDA reports corn stover would be collected from nearly twice as many acres as either DOE or EPA. Both EPA and USDA project more land being devoted to perennial grass production than does DOE.

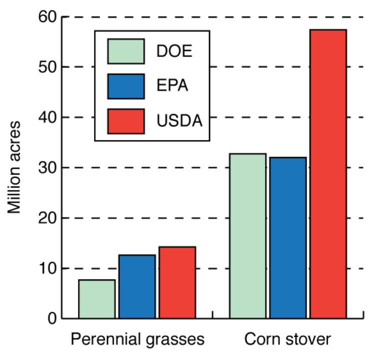

Figure 2. Land area used to produce bioenergy feedstocks in 2022.

COMPARING SPATIAL ALLOCATION OF FEEDSTOCKS

In addition to fuel volumes and land acreage devoted to each feedstock, we also compared the spatial pattern of land use projected by each agency's model due to expansion of bioenergy crops by 2022. Figure 3 shows the spatial allocation of feedstock harvested area across the U.S. landscape for corn stover and perennial grasses. DOE generated county-level data for feedstock production, EPA produced estimates for state or substate regions, and USDA provided estimates at the state level.

The model results from all three agencies show that corn stover and perennial grass production will occur primarily in the Central and Eastern U.S., and less biomass will be produced in the Western states. Both DOE and EPA place the majority of perennial grass production in the Southern Great Plains region including Texas, Kansas, Oklahoma, and Missouri. USDA predicts the most biomass will be generated from the Southeast (50%) and Central (43%) regions of the U.S. For perennial grasses, USDA estimates switchgrass will be produced in areas east of the 100° west meridian, where net primary productivity is greatest in the continental U.S., and primarily south and east of the highest productivity corn-soybean croplands of the Upper Midwest.[13]

The three agencies agree on the spatial distribution of corn stover harvesting for biofuels with a few exceptions. The majority of harvest is predicted to come from existing corn producing states such as Illinois, Iowa, and Nebraska. DOE estimates that at a $45 per dry ton farm gate price, small amounts will be collected across the U.S., nearly wherever corn is grown. Despite reporting broad availability of corn stover and other crop residues across all current corn producing states, the EPA FASOM report estimated future corn stover harvests from only ten Midwestern states.[6] (Notably, corn stover harvest is absent from the Corn Belt states of Minnesota and Wisconsin). This is likely due to the economic optimization model employed by EPA that assumes that even if residues are available, it may not be worth collecting them in all locations depending on the quantity of residue available per acre, the collection and transportation costs, and the local costs of producing and harvesting residues relative to other feedstocks.

Our analysis of acreage totals and distribution is restricted to corn stover and perennial grass feedstocks because data were unavailable for other feedstocks from all three agencies. USDA provided acreage estimates by state for biofuel canola, special oilseed soybean, energy cane, biomass sorghum, straw residues, and timber residues. EPA provided acreage estimates for major commodity crops, some crop residues (i.e., corn, durum wheat, hard red spring wheat, and hard red winter wheat) and hybrid poplar, but did not report or provide acreage estimates for timber residues. DOE provided acreage estimates for all primary agricultural sources (i.e., conventional crops, energy crops, and residues), and provided county level data for tons of biomass produced but did not provide acreage data for forest and secondary residues. Although limitations in access to data prevented us from comparing acreage estimates and spatial distribution of crop and timber residues among scenarios, our analysis of corn stover and perennial grasses represent the two cellulosic feedstock categories with the greatest land use and volume contributions.

COMPARING UNDERLYING ASSUMPTIONS

A comparative analysis of the three alternative scenarios for biomass production in 2022 reveals the importance of key assumptions in influencing total fuel volumes, acres of feedstock harvested, and the distribution of associated land use change. This comparison also highlights the uncertainty

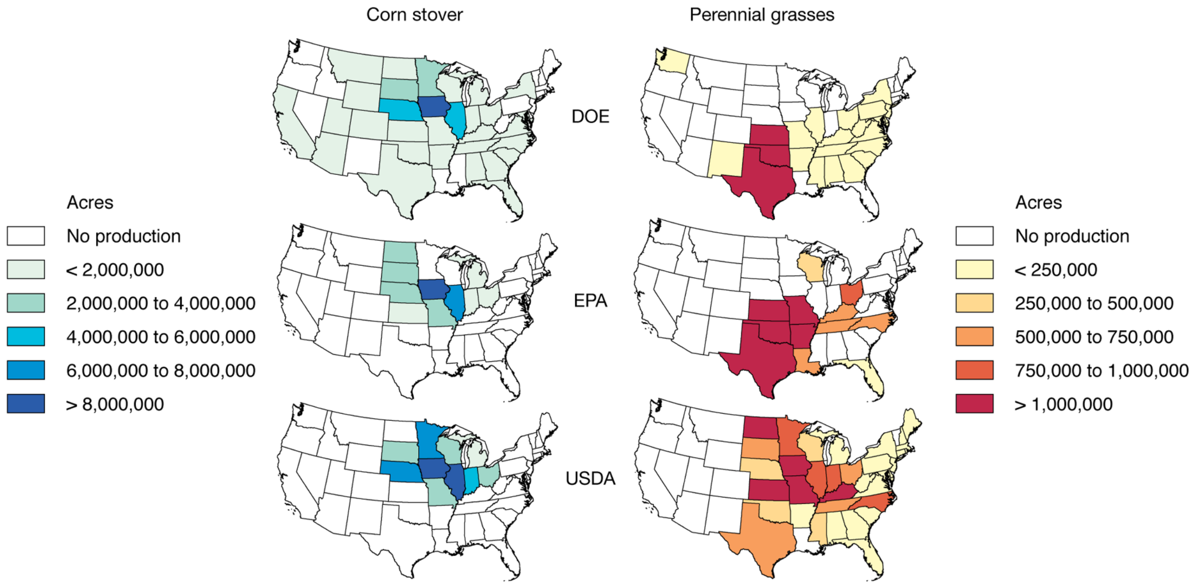

Figure 3. Agency projections of the spatial distribution of corn stover and perennial grasses harvested acres in 2022. State acreage estimates for EPA and USDA were supplied by agency staff. DOE values are from the DOE KDF and represent biomass availability at a $45 per dry ton farm gate price.

Table 1. Key Assumptions Behind Projected Fuel Volumes to Meet 2022 Mandates[a]

	DOE	EPA	USDA
price: corn grain ($ per bushel)	$3.72	$3.60	$3.60
yield: corn grain (bushels per acre)	183	186.3	182.0
price: lignocellulosic biomass ($ per dry ton)	all: $45	perennials: $46.42; corn stover: $39.19; hardwood logging residue: $34.83; softwood logging residue: $27.55	no price restrictions
yield: corn stover (dry tons per acre)	average: 2.8; regional estimates: 1.5−4.38	average: 1.15; regional estimates: 1.2−1.9	average: 1; regional estimates: 0.12−1.29
conversion efficiency: corn stover (gallons ethanol per dry ton)	68[b]	92.3	70
yield: perennial grasses (dry tons per acre)	national average 6; range: 4.1−8	national average 9.1; range: 3.4−9.9	6
conversion efficiency: perennial grasses (gallons ethanol per dry ton)	68[c]	92.3	70[b]
conversion efficiency: forest residues (gallons ethanol per dry ton)	68[c]	hardwood: 101.50; softwood: 92.3	70

[a]Both EPA and USDA express biomass costs in 2007 $ throughout their analyses. DOE uses 2009 $ for agricultural prices and 2007 $ for forestry prices.[3−5] All significant figures are the reported values from agencies. [b]DOE assumes a 20% loss in feedstock between the field and the biorefinery and 85 gallons per dry ton conversion at the facility resulting in an effective conversion efficiency of 68 gallons per dry ton harvested after including all losses. [c]USDA reports 420 gallons of ethanol per acre and an assumed average yield of 6 dry tons per acre.

surrounding potential yields, technological improvements, feedstock prices, and land availability as reflected in the different values used to parametrize each model. Table 1 summarizes assumptions about feedstock prices, yields, and conversion efficiencies employed in each agency's modeling. We note that our interpretation of the reasoning behind each agency's estimates was restricted to the data shared by the agencies or available in public reports.

Yields. Projected yields for commodity crops and dedicated feedstocks strongly influence estimated biofuel volumes and the contribution of different feedstocks to meeting RFS2 goals. Differences among the agency estimates for future perennial grass yields illustrate the uncertainty surrounding the biomass that could be produced regionally through dedicated feedstocks such as switchgrass. The EPA model estimates a national average switchgrass yield in 2022 of 9.1 dry tons per acre (Table 1) based on research by the Pacific Northwest National Laboratory.[14] This yield estimate is considerably higher than yield estimates for switchgrass used by DOE and USDA analyses. EPA's more optimistic yield estimate, coupled with a higher conversion efficiency value for switchgrass biomass, likely contribute to a higher fuel volume projection from perennial grasses compared to the DOE's and USDA's model projections (Figure 1). EPA and DOE based their modeling on regionally specific yields that varied considerably across the U.S. USDA excluded all lands west of the 100° west meridian where yields would be expected to be lower due to limited water availability. Higher estimates of per acre stover yields harvested also contributed to the greater volumes of stover-based renewable fuel generated by DOE models relative to USDA estimates.

The spatial distribution and harvested quantities of crop residues will likely be influenced by crop type, soil fertility, climate, slope, tillage, and other management factors. However, detailed modeling all of site-specific factors was stated to be beyond the scope of these analyses. EPA FASOM modeling calculated residue production based on regional estimates of sustainably removable crop residues that take into account potential erosion and runoff.[6,12] DOE calculated residue removal as a function of crop yield, harvest index (i.e., residue to grain ratio), tillage practice, rotation pattern, and residue retention coefficient.[15,16] The retention coefficient for modeling erosion and soil carbon loss was calculated by DOE at the county level using the Revised Universal Soil Loss Equation (RUSLE2) and the Wind Erosion Equation (WEQ). USDA estimated crop residue availability at the state level based upon grain yield, harvest index, and a specified need to maintain soil carbon and productivity.[12]

All three agencies assumed annual increases in yields of all feedstocks due to technological improvements and plant genetics. EPA and USDA based annual yield increases on historical growth in yields and on USDA projections for yield improvements through 2017, extrapolated out to 2022. EPA yields of dedicated biomass crops were not sensitive to changes in estimated biomass prices. (It is noted as possible that at higher farm gate prices for energy crops, farmers would be more likely to invest in management practices that increase yields.) It is also assumed that crop residue yields and grain yields will increase at the same annual rate.[6] DOE evaluated a baseline scenario and high yield scenarios for corn grain and energy crops. Their baseline scenario for corn assumed 1% per annum increases in yield, while their high yield scenario assumed 2% per annum increases. For energy crops, DOE assumed plantings began in 2014 and subsequent plantings increased in yield based on annual percent increases of 1% in the baseline scenario and of 2%, 3%, and 4% in the high yield scenarios. The effect of price of biomass on yields is not directly modeled by DOE, but improvements in management practices are assumed to be captured in the high yield scenarios.[5] In this study we describe DOE's baseline scenario.

Conversion Efficiencies. Translating fuel volumes into acres of land dedicated to each feedstock requires coupling assumptions about the yields of different crops with the conversion efficiencies required to convert feedstocks into liquid fuel. DOE developed conversion efficiencies from the 2011 Biomass Multi-Year Program Plan.[17] The specific conversion efficiencies were averaged from a number of outputs highlighting the biomass-to-ethanol conversion processes.[5] USDA obtained conversion efficiencies from the DOE Office of Energy Efficiency and Renewable Energy.[4] EPA used a variety of sources for many different types of feedstocks and fuels that fall under the RFS2 mandate. EPA's values for corn stover and perennial grass conversion efficiencies were developed through research at the National Renewable Energy Laboratory (NREL).[6] The EPA model assumes conversion rates will increase over time as cellulosic feedstock conversion technology improves, whereas the DOE and USDA analyses assume no technological change over time.

In their estimates of corn stover availability, USDA used a lower average yield value for corn stover and a lower conversion efficiency value relative to DOE and EPA models. This in part explains why the estimate produced by USDA shows the highest land area but the lowest fuel volume relative to the other scenarios. The EPA model used a higher conversion efficiency for perennial grass and produced the highest estimate of total fuel volume from perennial grasses. Higher conversion efficiency estimates for perennials coupled with higher yield assumptions explain why the difference in fuel volumes for perennial grasses presented in Figure 1 are more pronounced than the difference in total land acreage for perennial grasses in Figure 2. Uncertainty about yields of bioenergy crops coupled with uncertainties about conversion efficiencies and the rate of technological advancement in contribution to yield and conversion rates result in highly variable estimates for volume per unit land ratio for individual biofuel feedstocks. For example, in the DOE model, the average number of gallons of biofuel per acre of corn stover is nearly three times that of the value used in the USDA model. As a result, the DOE model projects that a greater amount of biofuel from corn stover could be produced on half as much land.

Land Availability. In addition to yield and conversion efficiencies, the distribution of crop types on the landscape in each scenario is influenced by assumptions about the availability of different land types to be used for bioenergy production. The EISA definition of renewable biomass restricts dedicated crops, as well as crop and forest residues, to land that was cleared or cultivated before December of 2007 such that the RFS2 targets are not to be met by the clearing of new land.[1] Consistent with this definition, biomass in each agency projection must be met using existing croplands, pasturelands, managed forests, or marginal or unproductive lands. (It is important to note that this does not preclude the possibility of increased demand for biomass inducing land-use change elsewhere via market-mediated effects.) The EPA model estimates that to meet RFS2 targets the amount of idle cropland will decrease, and total cropland acres in the U.S. will increase by 8.1 million acres by 2022 relative to a baseline scenario without RFS2. The USDA analysis assumes a total of 27 million acres of cropland will be needed to meet RFS2 targets by 2022. The DOE model estimates that in 2022, at \$45 per dry ton of biomass, crop residue will be harvested from 46.8 million acres of cropland, and energy crops (e.g., perennial grasses and woody crops) will be harvested from 8.5 million acres.

The agencies differ substantially in their consideration of Conservation Reserve Program lands (CRP) as future resources for bioenergy production. In the USDA scenario, perennials are estimated to displace over 9.5 million acres of lands enrolled in CRP as of 2007, which comprise 67% of their scenario's total perennial grass acreage. The EPA model also allowed any CRP acreage above a minimum requirement of 32 million acres to move into biomass production. The FASOM model estimated that 5.3 million acres of CRP lands will revert to croplands by 2022. In contrast, the DOE scenario does not allow CRP land to transition to bioenergy production. In their assessment of available lands for biomass production, DOE considers all U.S. croplands, as well as pasturelands in counties east of the 100° west meridian. Notably, the DOE report predicts significant conversion of pasture to perennial grass production at higher biomass prices. DOE assumes that losses in total livestock productivity due to conversion of pastureland are compensated by increased grazing intensity or improvement on remaining pasturelands such that for every acre of land taken out of pasture, the effective productivity on another acre of pasture is doubled.[5] The EPA model also estimates a loss in pasture in 2022 as a result of increased demand for switchgrass ethanol.[6]

The USDA report relies less on existing pasturelands and more on less productive corn and soybean acres, along with CRP lands, to meet dedicated feedstock targets. In the USDA scenario, perennials replace 4.7 million acres of less productive corn and soybean acres across the south and eastern edges of the Corn Belt states where yields are typically lower than national averages.[4] All three agencies exclude rangelands from land use conversions to bioenergy feedstock production.

Price. The price of biomass is a major driver of feedstocks production and farmer decision-making about what crops to grow and harvest. However, the treatment of price as a driver of biomass production varied considerably among models. DOE considered multiple prices for biomass in their Billion Ton Update and then solved for which combination of feedstocks would be produced at varying prices.[5] At a low feedstock farm gate price of $40 per dry ton, DOE predicts that little biomass will be generated from perennial grasses and a greater reliance on corn stover due to lower production costs. At a farm gate price of $60 per dry ton of biomass, DOE models assume that perennial grasses will become competitive with pasture and therefore displace 28 million acres of pastureland by 2030.[5] The EPA FASOM model does not provide a graded range of prices as does the DOE model, but it does use different price points for each biomass feedstock ranging from $27.55 per dry ton for softwood logging residue to $46.42 per dry ton for perennial grasses. EPA national average prices for energy crops were estimated by FASOM based on the price at which market demand for feedstocks due to the mandated RFS2 biofuel volumes led to adequate supply.[6] As noted above, USDA did not explicitly model feedstock prices in their regional biomass estimates which may explain why their estimates of biofuels produced from corn stover are lower than for DOE, which assumed a cost advantage of corn stover over perennial grasses at low biomass prices.

■ DISCUSSION

The three scenarios compared here represent alternative futures for biomass production in the U.S. in 2022. These alternative futures agree that meeting RFS2 targets for biofuel consumption will have potentially large effects on land use and land management. However, our analysis of the differences among the agency production scenarios highlights the uncertainty surrounding the composition of feedstocks used to meet the RFS2 mandates and the spatial distribution of these feedstocks across the U.S. agricultural and forestry sectors. For example, both EPA and USDA estimate that more fuel will be produced from perennial grasses such as switchgrass, whereas DOE estimates greater reliance on crop residues. Furthermore, uncertainties surrounding biomass yields and conversion efficiencies have potentially large impacts on both the quantity of fuel produced from different crops and the acres of land needed to meet fuel targets. These uncertainties are amplified by other questions regarding land availability, export growth, technological advancements, and yields of competing crops.

DOE chose to address these uncertainties through the creation of alternative scenarios based on varying assumptions about price and yield growth of dedicated energy crops over time. DOE's high yielding scenarios assume an annual increase in yield of 2%, 3%, or 4% for bioenergy feedstocks. While yield growth at this level may be possible, most field trials and plot studies of switchgrass have not been studied long enough to estimate expected annual increases in yield. It is also worth noting that no scenario with yields below the baseline was presented. The EPA and USDA models likewise neglect possible futures where the EISA requirements are not enforced, yields do not meet expected targets, or the costs of biomass production are prohibitively high due to input costs or competing uses for land. Consideration of such factors could greatly affect the outlook of biofuel production. For instance, a scenario based on the lowest volume estimates of each biofuel category across the agencies (Figure 1) would only generate 23 billion gallons of biofuel per year, or 64% of the RFS2 requirement in 2022. Furthermore, the prices of commodity crops such as corn grain used in the agency predictions, which range for corn from $3.60 to $3.72 per bushel, are considerably lower than actual corn prices since 2007, suggesting agency assumptions about the broad adoption and cost-competitiveness of advanced feedstocks used in model simulations may be overstated.[18]

The federal agency scenarios presented here are already influencing policy and planning decisions for the future of bioenergy development in the U.S. For example, the EPA model results are used in determining which fuels qualify for RFS2 mandates, the DOE analyses are influencing which biorefineries receive federal loan guarantees, and the USDA scenario affects the distribution of funds for biomass production research. Both DOE's and EPA's scenarios have been used as model inputs in recent studies on the environmental and economic effects of bioenergy production.[19−21] Our analysis reveals that these decisions and studies are being made using very different estimates of the types, quantities, and land requirements to meet RFS2 targets.

Many have questioned the likelihood that RFS2 biofuel targets will be met.[3,7] Still, understanding how the agricultural, forestry, and energy industries will work in conjunction with the government to attempt to reach biofuel production goals is of great importance. We hope that our analysis will highlight the range of potential alternative futures for meeting RFS2 goals and bring the differences among agency assumptions and modeling efforts to the forefront of this discussion. Our hope is that the comparisons we present here will help bring the differences and similarities among federal agency modeling efforts to the forefront of this discussion, and in doing so assist in the targeting of research efforts to improve projections of future biomass production and its economic, environmental, and social effects.

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Notes

The authors declare no competing financial interest.

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