LAND USE AND GREENHOUSE GAS MITIGATION EFFECTS OF BIOFUEL POLICIES†

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Concerns about energy security, reduced dependence on exhaustible fossil fuels, and climate change have led to significant policy support for biofuels, particularly for cellulosic biofuels. The Biomass Crop Assistance Program (BCAP) and volumetric tax credits for biofuels seek to supplement the Renewable Fuel Standard (RFS) and provide incentives for producing and blending cellulosic biofuels. This Article examines the effects of these policies on the mix of biofuels produced, food and fuel prices, and consumption and greenhouse gas (GHG) emissions as compared to the RFS alone. It also examines the effects of two performance-based policies that target incentives based on the GHG intensity of fuels. This Article finds that the BCAP and volumetric tax credits together lead to biofuel production that exceeds the minimum required by the RFS by 26% and to a significant transition away from corn ethanol and toward cellulosic biofuels. They also reduce GHG emissions by 3% and gasoline consumption by 100 billion liters relative to the level with the RFS alone. These subsidy policies are costly for the government and for the economy, however, imposing a welfare cost of $122 billion over the 2007–2022 period. Replacing these payments by subsidies based on carbon credits generated by a feedstock relative to gasoline, though less costly, does not create significant incentives to change the mix of biofuels beyond the levels mandated by the RFS. In contrast to these subsidy policies, supplementing the RFS with a $30 per metric ton of

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carbon dioxide equivalent emissions carbon price instrument is found to achieve the 3% reduction in GHG emissions with a gain in social welfare and lower costs to the government relative to the RFS alone.

I. INTRODUCTION

Concerns about energy security, reduced dependence on exhaustible fossil fuels, and climate change have led to significant policy support for biofuels in recent years. Recognition of the adverse impacts on food and feed prices and of increased reliance on food-based feedstocks has led to increasing interest in promoting the production of advanced biofuels from renewable biomass other than corn kernel starch. Advanced biofuels, defined as those obtained from renewable biomass from various sources, including crop or forest residues and dedicated energy crops, have the potential to increase biofuel yields per unit of land, reduce the need for diversion of cropland from food and feed production, and lead to greater greenhouse gas (GHG) emission reductions per unit of fuel than corn ethanol. Although a commercially viable technology for converting biomass to fuel has yet to be developed, it is expected that these advanced biofuels will be costly to produce and be economically competitive only at high oil prices.

Various forms of energy and farm policy support are being provided to induce the production of advanced biofuels. Foremost among these policies is the Energy Independence and Security Act (EISA) of 2007,[1] which established the Renewable Fuel Standard (RFS)[2] that seeks to provide an assurance of demand in order to accelerate the innovation needed to transition to a low carbon transportation sector.[3] The RFS sets annual targets for the blending of specific categories of biofuels with transportation fuel;[4] these categories are defined on the basis of the feedstock used and the GHG intensity of the biofuel, with the share of advanced biofuels in annual biofuel production increasing over time to 58% by 2022.[5]

To accelerate the production of advanced biofuels and reduce their costs to fuel blenders and consumers of mandated quantities, the Food, Conservation, and Energy Act (FCEA) of 2008[6] provides various types of financial support to grow and harvest renewable biomass and blend advanced biofuels with gasoline.[7] One form of support is volumetric tax

1. Energy Independence and Security Act of 2007, Pub. L. No. 110-140, 121 Stat. 1492.
2. *Id.* § 202, at 1521–28 (codified at 42 U.S.C. § 7545(o) (Supp. II 2009)).
3. *See* 42 U.S.C. § 7545(o)(2)(A)(i).
4. Energy Independence and Security Act § 202(a)(2) (codified at 42 U.S.C. § 7545(o)(2)(B)(i)).
5. *See id.* (codified at 42 U.S.C. § 7545(o)(2)(B)(i)(I)–(II)).
6. Food, Conservation, and Energy Act of 2008, Pub. L. No. 110-246, 122 Stat. 1651.
7. *Id.* § 15,321(a) (codified at I.R.C. § 40(a)(4)).

credits for blending biofuels with gasoline.[8] The per liter tax credit is higher for advanced biofuels than for corn ethanol.[9] With a binding mandate, the tax credits create incentives for blending biofuels with gasoline and lower the cost of fuel to consumers. A higher tax credit for advanced biofuels could also shift the mix of biofuels to meet the mandate toward advanced biofuels by making them competitive with corn ethanol.

The FCEA seeks also to directly encourage the production of biomass for advanced biofuels. A key source of renewable biomass is expected to be dedicated energy crops, typically long-lived perennials that involve significant up front fixed costs of establishment, as well as lags between establishment and first harvest times during which landowners have to forego potential income from other uses of that land.[10] The lag between planting and harvesting of dedicated energy crops require coordination between producers, biorefineries, and blenders and forward planning to plant the energy crops before they are needed. Landowners, on the other hand, have incentives to delay planting these crops; uncertainty about biomass prices over the lifetime of these crops together with high upfront costs creates an incentive for producers to wait until the expected returns are high enough to provide an option value premium.[11] The decision to invest in these crops also suffers from the "chicken-and-egg" dilemma, since producers are likely to delay investment in these crops until there is a biomass conversion facility that will purchase the biomass, and investment in conversion facilities is unlikely in the absence of an assured supply of feedstock.

The FCEA seeks to overcome these barriers and accelerate production of new feedstocks by authorizing the Biomass Crop Assistance Program (BCAP), which provides establishment and annual (E&A) payments to producers of energy crops.[12] These include cost-share payments for establishing dedicated energy crops in designated project areas and annual payments to cover the foregone income from alternative uses of the land.[13] BCAP also provides payments to cover the costs of collecting, harvesting, storing, and transporting (CHST) eligible material to quali-

8. *Id.* § 15,321(b)(1) (codified at 2 I.R.C. § 40(b)(6)), *amended by* Health Care and Education Reconciliation Act of 2010, Pub. L. No. 111-152, § 1408(a), 124 Stat. 1029, 1067 (to be codified at 2 I.R.C. § 40(b)(6)(E)(iii)).

9. *See* Food, Conservation, and Energy Act § 15,321(b)(1) (codified at I.R.C. § 40(b)(6)(B)).

10. *See* Madhu Khanna, *Cellulosic Biofuels: Are They Economically Viable and Environmentally Sustainable?*, CHOICES: MAG. FOOD, FARM & RESOURCE ISSUES, 3d Quarter 2008, at 16.

11. *See generally* Feng Song, Jinhua Zhao & Scott M. Swinton, *Switching to Perennial Energy Crops Under Uncertainty and Costly Reversibility* (Mich. State Univ. Dep't of Agric., Food & Res. Econ., Staff Paper No. 2009-14), *available at* http://purl.umn.edu/56195.

12. Food, Conservation, and Energy Act sec. 9001, § 9011 (codified at 7 U.S.C. § 8111 (Supp. III 2010)).

13. *Id.* sec. 9001, § 9011(c)(5) (codified at 7 U.S.C. § 8111(c)(5)).

fied biomass conversion facilities for production of heat, power, or advanced biofuels.[14]

The U.S. Department of Agriculture (USDA) has only partially implemented the BCAP program, and no payments have been made to producers for establishing dedicated energy crops as of October 19, 2010.[15] A BCAP notice of funds availability (NOFA) was announced in June 2009 for CHST payments followed by a draft programmatic environmental impact statement of alternative ways of implementing BCAP.[16] The USDA reports that $243 million has been spent as of October 19, 2010; most of this (about $203 million) was spent on subsidizing the collection of federal and non-federal woody forest biomass residues.[17] The NOFA was cancelled in February 2010 when a proposed rule for implementing BCAP was announced and made available for public comment.[18] A final rule to implement BCAP was published on October 27, 2010.[19]

The final rule provides eligibility criteria for materials that can receive a CHST payment and the criteria for eligibility and selection of project areas to receive the E&A payments.[20] It also provides an alternative to CHST payments (which is on a uniform per ton basis for all feedstocks), including developing a payment rate based directly on the value of carbon emissions mitigated by a feedstock relative to the fossil fuel it replaces.[21]

The various types of crop residues and energy crops considered here differ in their yields per unit of land as well as in the environmental benefits they provide.[22] Table 1 shows the biofuel yields per unit of land from various feedstocks and their GHG intensity. Uniform volumetric tax credits for all cellulosic biofuels and uniform matching per ton payments for feedstock are likely to encourage the production of feedstocks with the highest yields per unit of land. These subsidies could also

14. *Id.* sec. 9001, § 9011(d) (codified at 7 U.S.C. § 8111(d)).

15. FARM SERV. AGENCY, U.S. DEP'T OF AGRIC., BCAP CHST COMPONENT REPORT (2010), http://www.fsa.usda.gov/Internet/FSA_File/bcap_chst_component_report.pdf.

16. Notice of Funds Availability (NOFA) for the Collection, Harvest, Storage, and Transportation of Eligible Material, 74 Fed. Reg. 27,767 (June 11, 2009); FARM SERV. AGENCY, U.S. DEP'T OF AGRIC., PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT (2010), http://www.fsa.usda.gov/Internet/FSA_File/bcapfinalpeis062510.pdf.

17. FARM SERV. AGENCY, *supra* note 15.

18. Biomass Crop Assistance Program, 75 Fed. Reg. 6264 (proposed Feb. 8, 2010) (to be codified at 7 C.F.R. pt. 1450).

19. Biomass Crop Assistance Program, 75 Fed. Reg. 66,202 (Oct. 27, 2010) (to be codified at 7 C.F.R. pt. 1450); *Biomass Crop Assistance Program for FSA*, FARM SERVICE AGENCY, http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap (last modified Jan. 6, 2011).

20. Biomass Crop Assistance Program, 75 Fed. Reg. at 66,235–36, 66,240 (to be codified at 7 C.F.R. §§ 1450.2, .201).

21. *Id.* at 66,204–05.

22. *See* Khanna, *supra* note 10, at 17; Xiaoguang Chen, Haixiao Huang, Madhu Khanna & Hayri Önal, *Meeting the Mandate for Biofuels: Implications for Land Use, Food and Fuel Prices* 1–2 (Nat'l Bureau of Econ. Research, Working Paper No. 16697, 2011), *available at* http://www.nber.org/papers/w16697.

change the mix of biofuels beyond the mandated levels in favor of advanced biofuels. These subsidies, however, do not distinguish among advanced biofuels based on their GHG intensity and other environmental benefits they provide; nor are the subsidy rates based on considerations of the value of those environmental benefits. Although these volumetric and per-ton subsidies do create incentives for a transition from corn ethanol to advanced biofuels (with lower GHG intensity), they may not induce consumption of advanced biofuels that have a lower carbon footprint. Moreover, biofuel subsidies create perverse incentives to increase fuel consumption because they lower the price of blended fuel, which could offset some or all of the benefits of substituting biofuels with low GHG intensity.[23]

The first purpose of this Article is to analyze the effects of BCAP (with E&A and CHST payments) and volumetric tax credits on the mix of biofuels produced, gasoline consumption, and GHG emissions as compared to the RFS alone. In particular, we examine the extent to which these subsidies induce the production of biofuels, specifically advanced biofuels, beyond the minimum levels required by the RFS. We also analyze the implications of these subsidies for fuel prices and fuel consumption and examine the possibility of unintended consequences undermining the energy security and GHG reduction benefits they are intended to achieve.

Second, we assess the economic costs these subsidy policies impose for the fuel and agricultural sectors after considering their welfare effects on producers and consumers in the two sectors and on government revenues. At a minimum, the subsidies described above would benefit fuel blenders and consumers by lowering the cost of advanced biofuels used to meet the mandate and benefit biomass producers. To the extent that these subsidies encourage the production of feedstocks that generate higher biofuel yields per unit of land, they reduce the competition for land between food and fuel, and, therefore, also benefit agricultural consumers. These potential benefits have to be compared against the costs of subsidies for the government and for gasoline producers; thus, their net economic benefits relative to no subsidies is an empirical issue that is investigated here.

Third, we examine the implications of replacing biofuels subsidies with alternative performance-based policies that are targeted specifically at rewarding one of the external benefits from biofuels, namely, reducing GHG emissions from the transportation sector. A carbon price is the most direct and cost-effective approach to reducing GHG emissions. A carbon price by itself, however, would need to be extremely high to create incentives for blending high-cost advanced biofuels. Moreover, a carbon price would not provide the assurance of long-term demand for

23. *See* Madhu Khanna, Amy W. Ando & Farzad Taheripour, *Welfare Effects and Unintended Consequences of Ethanol Subsidies*, 30 REV. AGRIC. ECON. 411, 416 (2008).

biofuels or create the opportunities for learning by doing with cumulative experience as the RFS does. Therefore, we examine the effects of supplementing the RFS with two alternative carbon-based policy instruments, one that imposes a carbon price on all fuels including gasoline and another that replaces CHST payments of BCAP and the volumetric tax credits with carbon credit–based payments. Both policies create incentives to switch toward less GHG intensive fuels, but a carbon-price instrument also raises the cost of all fuels and therefore creates incentives for fuel conservation.

We undertake this analysis using a dynamic, multi-market equilibrium model, the Biofuel and Environmental Policy Analysis Model (BEPAM), which determines the impact of the above mentioned policies on markets for fuel, biofuel, food and feed crops, and livestock for the period 2007–2022. The BEPAM considers biofuels produced from corn and several cellulosic feedstocks as well as ethanol imports from Brazil and Caribbean countries. The model treats each Crop Reporting District (CRD) as a decision-making unit where crop yields, costs of crop and livestock production, land availability, and GHG emissions differ across CRDs. Food and fuel prices are endogenously determined by the model for each year of the planning horizon and used to update price expectations, cropland acreage, and land-use choices for the subsequent year. Life cycle analysis is used to estimate the GHG intensity of alternative fuels and emissions at the CRD level.

II. PREVIOUS LITERATURE

A number of studies have examined the effects of a volumetric tax credit on corn ethanol on fuel and food prices and social welfare using stylized models. Gardner estimates the deadweight losses of a tax credit as opposed to a direct deficiency payment subsidizing corn producers.[24] Rajagopal et al. show that the tax credit lowers the world price of gasoline by 3% and can result in a net gain in social welfare for the United States if the loss to U.S. gasoline producers is small.[25] The study by de Gorter and Just analyzes the interaction effects of an ethanol tax credit with farm subsidies.[26] They find that the existing corn ethanol tax credit leads to a $1.3 billion loss in social welfare because of the costs to the government and the loss in surplus of corn consumers due to higher prices.[27]

24. Bruce Gardner, *Fuel Ethanol Subsidies and Farm Price Support*, J. AGRIC. & FOOD INDUS. ORG. (Dec. 10, 2007), http://www.bepress.com/jafio/vol5/iss2/art4/.

25. D. Rajagopal, S.E. Sexton, D. Roland-Holst & D. Zilberman, *Challenge of Biofuel: Filling the Tank Without Emptying the Stomach?*, ENVTL. RES. LETTERS, 3 tbl.2 (Nov. 30, 2007), http://dx.doi.org/10.1088/1748-9326/2/4/044004.

26. Harry de Gorter & David R. Just, *The Welfare Economics of a Biofuel Tax Credit and the Interaction Effects with Price Contingent Farm Subsidies*, 91 AM. J. AGRIC. ECON. 477, 477 (2009).

27. *Id.* at 485.

A few studies have considered the external effects of the corn ethanol tax credit. Vedenov and Wetzstein find that the optimal subsidy for ethanol should be positive because it improves fuel security and has a multiplier effect on incomes and thus tax revenues for the government.[28] Khanna et al. examine its effect on GHG emissions and find that it has a negligible effect (0.1% relative to a no-ethanol tax credit baseline) because it increases vehicle miles traveled.[29] It also lowers social welfare by $0.5 billion relative to a no-ethanol tax credit baseline.[30] Ando et al. and de Gorter and Just examine the effects of the ethanol tax credit together with the RFS and show that the tax credit lowers the cost of fuel and leads to an increase in gasoline consumption relative to the RFS alone.[31] As a result, the former study also shows that the tax credit offsets a part of the reduction in GHG emissions that would have been achieved by the RFS otherwise.[32] There are several partial and general equilibrium simulation models that have examined the effects of biofuel production in the United States on land use, food, and fuel prices.[33] These studies focus primarily on analyzing the effects of the RFS and have not examined the effects of tax credits and BCAP, which is the purpose of this Article.[34] To address this issue we use a mathematical model that simulates market equilibrium in commodity and fuel markets, including biofuels. Following the policy background below, we describe the model and the database used in our analysis, which is followed by empirical results and a discussion of their policy implications.

III. POLICY BACKGROUND

EISA modified the volumes of biofuels required previously under the Energy Policy Act of 2005[35] (which was 28.4 billion liters in 2012[36]) and mandates a five-fold increase in their levels.[37] The RFS established by EISA also mandates the volume for specific categories of renewable

28. Dmitry Vedenov & Michael Wetzstein, *Toward an Optimal U.S. Ethanol Fuel Subsidy*, 30 ENERGY ECON. 2073, 2085–86 (2008).

29. *See* Khanna et al., *supra* note 23, at 418 tbl.1.

30. *Id.* at 417.

31. Amy W. Ando, Madhu Khanna & Farzad Taheripour, *Market and Social Welfare Effects of the Renewable Fuels Standard*, *in* HANDBOOK OF BIOENERGY ECONOMICS AND POLICY 233, 247 (Madhu Khanna, Jürgen Scheffran & David Zilberman eds., 2010); Harry de Gorter & David R. Just, *The Law of Unintended Consequences: How the U.S. Biofuel Tax Credit with a Mandate Subsidizes Oil Consumption and Has No Impact on Ethanol Consumption* 2 (Cornell Univ. Dep't of Applied Econ. & Mgmt., Working Paper No. 2007-20, 2008), *available at* http://ssrn.com/abstract=1024525.

32. Ando et al., *supra* note 31, at 247.

33. For a review of these studies, see Chen et al., *supra* note 22, at 4–7.

34. *Id.*

35. Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat. 594.

36. *Id.* § 1501, at 1069–70 (codified at 42 U.S.C. § 7545(o)(2)(B)(i) (2006 & Supp. II 2009)), *amended by* Energy Independence and Security Act of 2007, Pub. L. No. 110-140, § 202(a)(2), 121 Stat. 1492, 1522–23 (codified at 42 U.S.C. § 7545(o)(2)(B)(i)).

37. *Compare* 42 U.S.C. § 7545(o)(2)(B)(i) (2006), *with* 42 U.S.C. § 7545(o)(2)(B)(i) (Supp. II 2009).

fuels to be produced from 'renewable biomass,' defined as planted crops and crop residues from cleared or cultivated agricultural land before the enactment of EISA, woody biomass, animal wastes, animal byproducts, and algae.[38] The categories of renewable fuels include cellulosic biofuels, biomass-based diesel, advanced biofuels, and total renewable fuels.[39]

The volume requirements in EISA are nested within one another, so that the advanced biofuel requirement includes fuel that meets either the cellulosic biofuel or the biomass-based diesel requirements, and the total renewable fuel requirement includes fuel that meets the advanced biofuel requirement.[40] The RFS requires the total renewable fuel production to be at least 136 billion liters in 2022.[41] The amount of advanced biofuels in this must be at least 79 billion liters, of which at least 60.5 billion liters should be cellulosic biofuels.[42] The remaining portion of total renewable fuel not met with advanced biofuels is allowed to be corn-based ethanol.[43] EISA sets an upper limit of 57 billion liters annually for corn ethanol in 2015 and beyond.[44] There is no specific corn-ethanol mandated volume; thus, any advanced biofuel produced above and beyond the advanced biofuel requirements could reduce the amount of corn ethanol needed to meet the total RFS. The RFS quantity mandates imply a maximum cumulative production of 744 billion liters of corn ethanol over the 2009–2022 period and at least 420.7 billion liters of advanced biofuels.[45]

Advanced biofuels specifically exclude ethanol derived from corn starch;[46] they include other types of ethanol derived from renewable biomass, including ethanol made from cellulose, hemicellulose, lignin, sugar or any starch other than corn starch,[47] as long as it achieves a life cycle GHG emission displacement of at least 50%, compared to the gasoline or diesel fuel it displaces.[48] Sugarcane ethanol imported from Brazil qualifies as an advanced biofuel.[49] Cellulosic biofuel is renewable fuel, not necessarily ethanol, derived from any cellulose, hemicellulose, or lignin each of which must originate from renewable biomass.[50] It must also achieve a life cycle GHG emission reduction of at least 60%, compared to the gasoline or diesel fuel it displaces.[51] Life cycle GHG emissions in-

38. *See* Energy Independence and Security Act §§ 201, 202(a)(2) (codified at 42 U.S.C. § 7545(o)(1)(I), (2)(B)(i)(I) (Supp. II 2009)).
39. *Id.* § 201 (codified at 42 U.S.C. § 7545(o)(1)).
40. *Id.* § 202(a)(2) (codified at 42 U.S.C. § 7545(o)(2)(B)(i)).
41. *Id.* (codified at 42 U.S.C. § 7545(o)(2)(B)(i)(I)).
42. *Id.* (codified at 42 U.S.C. § 7545(o)(2)(B)(i)(II)–(III)).
43. *See id.* (codified at 42 U.S.C. § 7545(o)(2)(B)(i)).
44. *See id.* (codified at 42 U.S.C. § 7545(o)(2)(B)(i)(I)–(II)).
45. *See id.*
46. *Id.* § 201 (codified at 42 U.S.C. § 7545(o)(1)(B)(i)).
47. *Id.* (codified at 42 U.S.C. § 7545(o)(1)(B)(ii)).
48. *Id.* (codified at 42 U.S.C. § 7545(o)(1)(C)–(D)).
49. *See id.* (codified at 42 U.S.C. § 7545(o)(1)(B)(ii)(II)).
50. *Id.* (codified at 42 U.S.C. § 7545(o)(1)(E)).
51. *Id.*

clude direct emissions from all stages of fuel and feedstock production, delivery of feedstock to refinery, conversion from biomass to biofuels and distribution of it, and the use of finished fuel by the ultimate consumers.[52] It also includes indirect emissions from land use changes.[53]

EISA limits the crops and crop residues used to produce renewable fuels to those grown on land cleared or cultivated at any time prior to December 19, 2007, that is to agricultural land that has been either actively managed or fallowed and non-forested.[54] It also requires that forest-related slash and tree thinnings used for renewable fuel production pursuant to the Act be harvested from non-federal forestlands.[55] Agricultural land is defined as cropland, pastureland, and land under the Conservation Reserve Program (CRP) that has been retired from crop production.[56] The FCEA limits the acreage enrolled in the CRP to 13 million hectares for 2010–2012.[57] The regulatory impact analysis of the RFS precludes the use of land enrolled in the CRP for growing dedicated energy crops for biofuel production.[58]

Federal fuel excise-tax credits for renewable fuel have been present for decades.[59] The tax credit for corn ethanol peaked at $0.16 per liter in 1984, reduced to $0.14 per liter in 1990, and was phased down to $0.13 per liter between 1998 and 2005.[60] The FCEA provides tax credits for blending biofuels with gasoline; the tax credit for corn ethanol was further decreased to $0.12 per liter and is currently authorized until December 2010.[61] The tax credit of $0.27 per liter for cellulosic biofuels has been available since December 31, 2008, and is authorized until January 1, 2013; it is given to blenders that blend cellulosic biofuels with gasoline.[62] It also requires that cellulosic biofuels be produced and consumed in the United States.[63]

In addition to biofuel mandates and volumetric tax credits, the United States imposes trade barriers to restrict the imports of sugarcane ethanol from Brazil. The biofuel trade policy includes a 2.5% ad valo-

52. *Id.* (codified at 42 U.S.C. § 7545(o)(1)(H)).

53. *Id.*

54. *Id.* (codified at 42 U.S.C. § 7545(o)(1)(I)(i)).

55. *Id.* (codified at 42 U.S.C. § 7545(o)(1)(I)(iv)).

56. Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program, 75 Fed. Reg. 14,670, 14,692 (Mar. 26, 2010); Food, Conservation, and Energy Act of 2008, Pub. L. No. 110-246, sec. 2301, § 1238E(b)(1)(A), 122 Stat. 1651, 1770 (codified at 16 U.S.C. § 3838e(b)(1)(A) (Supp. III 2010)).

57. *Id.* sec. 2103(3) (codified at 16 U.S.C. § 3831(d)).

58. U.S. ENVTL. PROT. AGENCY, EPA-420-R-10-006, RENEWABLE FUEL STANDARD PROGRAM (RFS2) REGULATORY IMPACT ANALYSIS 32 (2010), http://www.epa.gov/otaq/renewablefuels/420r10006.pdf.

59. *See* Wallace E. Tyner, *The US Ethanol and Biofuels Boom: Its Origins, Current Status, and Future Prospects*, 58 BIOSCIENCE 646, 646 (2008).

60. *Id.* at 646–47.

61. Food, Conservation, and Energy Act § 15,331(a)(1)(c) (codified at I.R.C. § 40(h)(2)).

62. *Id.* § 15,321(b) (codified at I.R.C. § 40(b)(6)(B), (H)).

63. *Id.* § 15,321(d) (codified at I.R.C. § 40(d)(6)).

rem tariff and a tariff of $0.14 per liter (authorized until January 2011).[64] An exception to the tariff is the agreement of the Caribbean Basin Initiative (CBI) initiated by the 1983 Caribbean Basin Economic Recovery Act.[65] Under this agreement, ethanol produced from at least 50% agricultural feedstocks grown in CBI countries is admitted into the United States free of duty.[66] If the local feedstock content is lower than the requirement, a tariff rate quota will be applied to the quantity of duty-free ethanol.[67] In any case, duty-free ethanol from CBI countries is restricted to no more than 7% of the U.S. ethanol consumption.[68] To take advantage of this tariff-free policy, hydrous ethanol produced in other counties, like Brazil or European countries, can be imported to a CBI country and exported to the United States after dehydration.[69] In 2007, total imports accounted for roughly 6% of U.S. consumption (25.7 billion liters), with about 40% of the import from Brazil and approximately 60% routed through CBI countries to avoid the import tariff.[70] CBI countries, however, have never reached the ceiling on "their ethanol quota, partly due to insufficient capacity."[71]

To facilitate biomass-based energy production, BCAP is authorized by the FCEA to financially assist biomass producers with the cost of CHST of biomass and provide payments to match those received from the conversion facility.[72] Eligible material owners receive a matching CHST payment at a rate of $1 for each $1 per dry ton of biomass paid by the qualified biomass conversion facility.[73] The maximum amount of matching payment is up to $45 per dry (short) ton with zero moisture and the payment may continue for up to two years to a particular participant after the first payment is issued.[74] Biomass eligible for BCAP matching payments includes materials, pre-commercial thinnings, or invasive species collected from both public and private lands that are byproducts of preventive treatments, not used for higher-value products, and are harvested in accordance with applicable law and land management plans.[75]

64. *See* BRENT D. YACOBUCCI, CONG. RESEARCH SERV., RS 21930, ETHANOL IMPORTS AND THE CARIBBEAN BASIN INITIATIVE 3 & n.4 (2008), http://ncseonline.org/NLE/CRSreports/08Apr/RS21930.pdf.

65. Caribbean Basin Economic Recovery Act, Pub. L. No. 98-67, tit II, 97 Stat. 384 (1983); *see also* YACOBUCCI, *supra* note 64, at 4.

66. *See* YACOBUCCI, *supra* note 64, at 4.

67. *See id.*

68. *See id.*

69. *See id.*

70. *See id.* at 3 & fig.1.

71. *JAMAICA: Jamaica Seeking to Boost Ethanol Production for Export Under CBI*, CARIBBEAN DAILY NEWS (Nov. 25, 2009), http://www.caribbeandailynews.com/jamaica-jamaicaseeking-to-boost-ethanol-production-for-export-under-cbi/.

72. Food, Conservation, and Energy Act of 2008, Pub. L. No. 110-246, sec. 9001, § 9011, 122 Stat. 1651, 2089–93 (codified at 7 U.S.C. § 8111 (Supp. III 2010)).

73. *Id.* sec. 9001, § 9011(d)(2)(B) (codified at 7 U.S.C. § 8111(d)(2)(B)).

74. *See id.*

75. *Id.* sec. 9001, §§ 9001(12), 9011(a)(6)(A) (codified at 7 U.S.C. §§ 8101(12), 8111(a)(6)(A)).

Additionally, BCAP provides E&A payments to biomass producers that plant perennial energy crops on eligible land that is located within a designated project area and is not federal- or state-owned land.[76] Annual crops are not eligible crops for E&A payments.[77] The establishment payment can cover up to 75% of the establishment costs of eligible non-woody and woody perennial biomass crops.[78] Cost items that may be covered include seed and stock costs, planting costs, site preparation costs for nonindustrial forest land, and other costs such as temporary irrigation.[79]

Additionally, annual payments are to be provided at rates needed to ensure sufficient participation in the designated project areas and can be provided for up to fifteen years of crop production.[80] We interpret these annual payments as covering the opportunity cost of using land for bioenergy crops. The BCAP rule states that the basis for annual payment determination includes a "weighted average soil rental rate for cropland" and the "applicable marginal pastureland rental rate for all other land except for nonindustrial private forest land," whose annual payments will be based on "the average county rental rate for cropland as adjusted for forest land productivity."[81] These annual payments are also intended to cover any lost income due to crop failure or closure of a biomass conversion facility.[82] Annual payments could be reduced for various reasons (to avoid duplicate benefits), including the use of contracted biomass crop for purposes other than energy production, violation of a term of the contract, delivery of the biomass to a conversion facility, or receipt of a matching payment.[83] The rule states that payment reductions could be equal to 25% of the authorized annual payment[84] but not necessarily a full reduction because the purpose of the program is to encourage biomass production.[85]

Whereas the rule implies that annual payments could continue at some level over the life of a perennial crop (up to fifteen years), our analysis of BCAP includes annual payments to cover the foregone profits from the land converted to perennial energy crops only during the establishment years. This is because we assume that the purpose of these annual payments is to compensate farmers for lost annual income during those years and thereby reduce the fixed upfront costs of investment in perennial grasses and incentives to delay investment. Our estimates of

76. *Id.* sec. 9001, § 9011(a)(5), (c)(5)(A) (codified at 7 U.S.C. § 8111(a)(5), (c)(5)(A)).
77. *Id.* sec. 9001, § 9011(a)(4) (codified at 7 U.S.C. § 8111(a)(4)).
78. *Id.* sec. 9001, § 9011(c)(5)(B) (codified at 7 U.S.C. § 8111(c)(5)(B)).
79. *Id.*
80. Biomass Crop Assistance Program, 75 Fed. Reg. 66,202, 66,241 (Oct. 27, 2010) (to be codified at 7 C.F.R. § 1450.205(a)).
81. *Id.* at 66,242 (to be codified at 7 C.F.R. § 1450.214(b)).
82. *See id.*
83. *Id.* (to be codified at 7 C.F.R. § 1450.214(f)).
84. *Id.* (to be codified at 7 C.F.R. § 1450.214(f)(1)(iii)).
85. *Id.* at 66,237 (to be codified at 7 C.F.R. § 1450.3(a)(1)).

the costs of BCAP and its incentive effects will be underestimates if annual payments are made for a longer duration. On the other hand, we do not impose a budget constraint for the implementation of BCAP. To the extent that available funds to implement BCAP are smaller than those projected as being required to support all profit-maximizing landowners that seek to voluntarily participate, our estimates of the incentive effects of BCAP could be overestimates.

IV. DESCRIPTION OF MODEL

In order to address the issues mentioned above, we apply a multimarket, multiperiod, price-endogenous, nonlinear mathematical programming model that simulates the U.S. agricultural and fuel sectors and formation of market equilibrium in the commodity markets, including trade with the rest of the world, referred to as the BEPAM. The BEPAM incorporates producers' and consumers' behavior when simulating the formation of market equilibrium. Market-clearing prices and quantities of major crop commodities, biomass crops, and transportation fuels are determined by the model in a simultaneous way. We consider a representative consumer that demands crop and livestock products and vehicle kilometers traveled (VKT). The behavior of the consumer is characterized by linear demand functions for each of these commodities and for VKT. Demand for VKT is a function of a weighted average of alternative fuel prices. The primary crop commodities are consumed either domestically or traded with the rest of the world (exported or imported), processed to consumer products (such as oil and fuel), or directly fed to various animal categories. Likewise, livestock commodities are either consumed domestically or traded with the rest of the world. Like domestic commodity demand functions, export demand functions and import supply functions for tradable commodities are also specified assuming linear price-quantity relationships. Both domestic and export demand functions are shifted exogenously over time due to increased demand resulting from population and income growth. We solve for equilibrium prices and quantities in each of the markets considered here by maximizing the sum of producers' and consumers' surpluses subject to material balance constraints equating supply and demand of individual commodities, regional resource use and availability constraints, and technological constraints underlying crop production. With the assumption of linear functional forms, this approach leads to a quadratic programming model that determines the optimal land allocation for production of food and feed commodities and energy crops in such a way that the optimum supplies by producers are consistent with the market prices that consumers would be willing to pay for fuel, biofuel, food and feed, and livestock commodities. Takayama and Judge and McCarl and

Spreen explain why this approach establishes simultaneous market equilibria.[86]

Given that the U.S. biofuels policies are stated for the period 2007–2022, we consider a multiperiod planning horizon and find the market equilibrium prices and supply and demand quantities for each year of the above period considering year-to-year dynamic relationships between resource availability and planting decisions for traditional row crops, dedicated energy crops, and livestock activities, all of which compete for agricultural land. The crops and livestock sectors are linked to each other through two factors. First, crop production provides feed (grains and byproducts of processing corn and oilseeds for ethanol and oil, respectively) to the livestock sector. Second, the two agricultural production activities compete for land because grazing land needed by dairy and beef cattle can also be used for crop production, particularly feedstock for biofuels production.

The fuel sector includes petroleum-based gasoline and ethanol produced from corn and cellulosic feedstock. As biofuels, we consider only the ethanol demanded by light-duty vehicles and assume these vehicles consume a blend of gasoline and ethanol with limited substitution possibility. We formulate an aggregate kilometers demand function for the entire vehicle fleet, where the demand for VKT is related to the price of the fuel blend, which in turn depends on the prices of gasoline and ethanol and their shares in the blend. Like the other demand functions, the demand for VKT is also shifted upwards over time. The amount of VKT is determined by the amount of gasoline and ethanol consumed. We assume that this relationship is represented by a constant elasticity of supply (CES) production function. The CES function is calibrated for the base year assuming a known elasticity of substitution between ethanol and gasoline, the observed base year prices and quantities of these fuels, and the observed VKT. The model incorporates a domestic supply function and an import supply function for gasoline, both are specified as linear functions. For biofuels, the equilibrium amount of supply is determined through the interaction and competition between biofuel feedstocks (corn and cellulosic biomass obtained from perennial grasses, such as switchgrass and miscanthus, and crop and forest residues) and conventional row crops. The prices and shares of transportation fuels in the fuel blend are determined endogenously by the model depending on the marginal costs of production and supply adjusted for fuel efficiency.

The BEPAM has a fine spatial disaggregation compared to other models analyzing the economic implications of biofuel production.[87] As the spatial decision units, the model uses CRD (each being a cluster of

86. *See generally* TAKASHI TAKAYAMA & GEORGE G. JUDGE, SPATIAL AND TEMPORAL PRICE AND ALLOCATION MODELS (1971); Bruce A. McCarl & Thomas H. Spreen, *Price Endogenous Mathematical Programming as a Tool for Sector Analysis*, 62 AM. J. AGRIC. ECON. 87 (1980).

87. *See* Chen et al., *supra* note 22, at 6–7.

about ten counties on average) in forty-one contiguous U.S. states in five major regions. We assume that each CRD is represented by an aggregate producer who makes planting decisions to maximize total net returns under the resource availability and production technology constraints (crop rotation possibilities, dynamics of perennial crops, etc.) specified for that CRD. Both crop- and livestock-production activities are represented using constant input-output relationships (Leontief production functions) and constant cost coefficients. We estimate and use region-specific cropland supply functions to allow cropland expansion through the conversion of marginal lands that are not currently being used for crop production. The cropland supply response is based on econometrically estimated elasticities that relate cropland acreage to a composite crop price index.[88]

A shortcoming of programming models used for economic analysis is the likelihood of obtaining optimal corner solutions, which imply extreme product specialization. This is unrealistic particularly for agricultural supply responses because even at fine regional scale farmers' acreage plans typically include a mix of crops. Diversification is necessary because of agronomic reasons (fertilizer requirements and pest related yield effects of continuous cropping) and income risk considerations (a crop portfolio provides better risk management against price and yield, thus income, uncertainty). To avoid specialized crop patterns, one or very few crops produced by all producers in a given region, we employ an extended form of the crop-mix approach introduced by McCarl.[89] When modeling farms' planting decisions, this approach restricts the crop pattern in each region to a weighted average of the "historical" crop mixes in that region. This implies that planting decisions obtained from the model under altered market conditions has to be something like (a blend of) the historically observed planting patterns. Under "normal changes" in market conditions this approach works well and produces meaningful model solutions. In an era when a large amount of land needs to be diverted from conventional crop production to the production of energy crops, however, which consequently implies a significant change in the acreage of conventional crops, the historical crop mixes may not be truly representative for farmers' supply responses.[90] To address this issue, besides the crop mixes observed historically we also gen-

88. Haixiao Huang & Madhu Khanna, An Econometric Analysis of U.S. Crop Yield and Cropland Acreage: Implications for the Impact of Climate Change 32 tbl.4 (May 3, 2010) (unpublished manuscript), *available at* http://ageconsearch.umn.edu/handle/61527.

89. *See generally* Bruce A. McCarl, *Cropping Activities in Agricultural Sector Models: A Methodological Proposal*, 64 AM. J. AGRIC. ECON. 768 (1982). For a theoretical foundation of this approach, see generally Hayri Önal, Bruce A. McCarl, Wade L. Griffin, Gary Matlock & Jerry Clark, *A Bioeconomic Analysis of the Texas Shrimp Fishery and Its Optimal Management*, 73 AM. J. AGRIC. ECON. 1161 (1991).

90. To accommodate planting bioenergy crops and unprecedented changes in crop prices in the future, forest and agricultural sector optimization model allows crop acreage to deviate at most by 10% from the observed historical mixes.

erate a number of "hypothetical crop mixes" for each region and then restrict the regional acreage responses to a weighted average of both historical and hypothetical mixes. Each historical or hypothetical mix is an array of land allocations that can occur in a given region if commodity prices are favorable. When generating hypothetical mixes we rely on statistically estimated crop acreage elasticities[91] used along with a set of systematically varied hypothetical crop prices. Such mixes offer a planting flexibility beyond the observed levels and allow potential land uses that might occur in response to the projected expansion in the biofuels industry and related increases in corn and cellulosic biomass production.

The perennial nature of energy crops switchgrass and miscanthus requires a special treatment of these crops because, instead of annual net returns, farmers would consider a continued income stream over years, which depends on annual variable costs and yields and fixed startup costs of establishing these crops. This is fundamentally different from net return consideration when making planting decisions for annual crops. Furthermore, because we consider a finite horizon in the model, the economic value of a standing biomass crop beyond the terminal year of the planning horizon (i.e., the present value of net returns after the terminal year until the productive life of the energy crop) needs to be taken into account when making production decisions. Otherwise, returns obtained over a few years may not cover the production costs (including fixed and variable costs) and therefore for the last few years of the planning horizon the model would not produce a solution that includes perennial crops in it. To address this issue, we use a ten-year rolling horizon where for each year of the 2007–2022 period, the model determines crop production decisions and the corresponding dynamic market equilibrium for the next ten years starting with the year under consideration. After each run, we take the production decisions and the associated market equilibrium for the first year of the ten-year period, and use this information to update some of the key model parameters, such as the overall crop price index and expected prices, land supplies in each region, and crop yields for major crops. We then run the model again for another ten-year period starting with the subsequent year and thus have a rolling horizon.

The endogenous variables determined by the model include: (1) gasoline, biofuel, and commodity prices; (2) production, consumption, export and import quantities of commodities, gasoline, and biofuels; and (3) land allocations and production practices for row crops and perennial crops (namely, rotation, tillage, and irrigation options) for each year of the 2007–2022 planning horizon and for each region. The model also calculates ex post economic welfare measures including producers'

91. These elasticities are estimated econometrically using historical county-specific data on individual crop acreages for the period 1977–2007 as described in Huang & Khanna, *supra* note 88, at 27 tbl.1.

and consumers' surpluses, government revenues and costs, net welfare effects, and environmental impact indicators including GHG emissions.

We consider two types of land, existing cropland and idle land and pastureland that can be used for conventional crops and bioenergy crops. A change in crop prices triggers changes at the extensive margin and leads to a shift in acreage between cropland and idle land and pastureland. The remaining idle land and pastureland can be used for bioenergy crops, but this occurs at a conversion cost. In the absence of an empirically-based estimate of the ease of conversion of marginal land for perennial grass production, for each CRD we assume a specific conversion cost that is equal to the returns from the land by producing the least profitable annual crop in that CRD. This ensures consistency with the intuitive decision rule for land conversion, namely in a land market equilibrium all lands with non-negative excess profits from annual crop production vis-à-vis bioenergy feedstock production would be utilized for annual crop production. As annual crop prices increase, the cost of conversion increases also; the "supply curve" for idle marginal land is, therefore, upward sloping.

V. DATA

The simulation model uses CRD-specific data on costs of producing crops, livestock, biofuel feedstocks, yields of conventional and bioenergy crops, and land availability. We estimate the rotation-, tillage-, and irrigation-specific costs of production in 2007 prices for fifteen row crops (corn, soybeans, wheat, rice, sorghum, oats, barley, cotton, peanuts, potatoes, sugarbeets, sugarcane, tobacco, rye, and corn silage), alfalfa, and two perennial grasses (switchgrass and miscanthus) at the CRD level. The model also includes several primary livestock commodities as well as secondary livestock and crop commodities. Feedstocks used for biofuel production in the model include corn, corn stover, wheat straw, forest residues, miscanthus, and switchgrass. Sugarcane ethanol imports are possible from Brazil and the Caribbean countries, subject to the tariff policy.

The two dedicated bioenergy crops considered here, switchgrass and miscanthus, have been identified as among the best choices because of their high-yield potential, adaptability to a wide range of growing conditions, and environmental benefits in the United States and Europe.[92] In the absence of long-term observed yields for switchgrass and miscan-

92. *See* CARLA A. GUNDERSON ET AL., U.S. DEP'T OF ENERGY, ORNL/TM-2007/183, EXPLORING POTENTIAL U.S. SWITCHGRASS PRODUCTION FOR LIGNOCELLULOSIC ETHANOL 2–4 (2008), *available at* http://digitalcommons.unl.edu/usdoepub/16/; Emily A. Heaton, Frank G. Dohleman & Stephen P. Long, *Meeting US Biofuel Goals with Less Land: The Potential of Miscanthus*, 14 GLOBAL CHANGE BIOLOGY 2000, 2009–11 (2008); Iris Lewandowski, Jonathan M.O. Scurlock, Eva Lindvall & Myrsini Christou, *The Development and Current Status of Perennial Rhizomatous Grasses as Energy Crops in the US and Europe*, 25 BIOMASS & BIOENERGY 335, 341–48 (2003).

thus, we use a crop productivity model, MISCANMOD, to simulate the yields of miscanthus and switchgrass.[93] These yields differ across CRDs due to differences in climate, soil moisture, and length of growing season. Costs of producing these crops differ during the establishment phase and during the subsequent maintenance period of the crop. Assumptions about the lifetime of these crops, the length of their establishment phase, input requirements, and yields, are described in Chen.[94] These crops are assumed to be equally productive on regular cropland and on marginal land.[95] We describe the methods for estimating CRD-specific costs of producing these crops in Jain.[96] We consider two alternative scenarios for these costs. The scenarios differ in their assumptions about nutrient requirements, ease of establishment of the grasses and harvest related loss in yields, and costs of harvesting per metric ton. In each case, these costs differ over the life of the crop and across CRDs due to differences in yields, costs of field operations, input prices, and implicit opportunity cost of land. The benchmark scenario considers relatively low cost of production. We examine the implications of high production costs, particularly of miscanthus, in the sensitivity analysis.

The yields of conventional crops in each CRD in 2007 are represented by the historical five-year average (2003–2007) yield per hectare for that CRD under dryland and irrigated land.[97] The yields of corn, soybeans, and wheat are assumed to grow over time at trend rates estimated using historical data. These yields are also assumed to be price-elastic with the price elasticities estimated econometrically. The trend rates and elasticities used in the model and more details of the econometric estimation methods can be found in Huang and Khanna.[98] We adjust crop yields per hectare based on crop rotations for each CRD and incorporate fifteen crop rotation possibilities for each region of the United States from USDA/ERS.[99] Corn stover and wheat straw yields for each CRD are obtained based on a 1:1 and 1:1.5 grain-to-residue ratio of dry matter of crop grain to dry matter of crop residues, respectively, and 15% moisture content in the grain reported in Sheehan et al., Wilcke and

93. *See* Atul K. Jain, Madhu Khanna, Matthew Erickson & Haixiao Huang, *An Integrated Biogeochemical and Economic Analysis of Bioenergy Crops in the Midwestern United States*, 2 GLOBAL CHANGE BIOLOGY: BIOENERGY 217, 218 (2010).

94. Chen et al., *supra* note 22, at 25–27.

95. *See* G.E. Varvel, K.P. Vogel, R.B. Mitchell, R.F. Follett & J.M. Kimble, *Comparison of Corn and Switchgrass on Marginal Soils for Bioenergy*, 32 BIOMASS & BIOENERGY 18, 19–20 (2008).

96. Jain et al., *supra* note 93, at 219–25.

97. Data available at National Agricultural Statistics Service, *Quick Stats*, U.S. DEP'T AGRIC., http://quickstats.nass.usda.gov/ (last visited Dec. 28, 2010).

98. *See generally* Huang & Khanna, *supra* note 88.

99. MERRITT PADGITT, DORIS NEWTON, RENATA PENN & CARMEN SANDRETTO, ECON. RESEARCH SERV., U.S. DEP'T OF AGRIC., STAT. BULL. NO. SB969, PRODUCTION PRACTICES FOR MAJOR CROPS IN U.S. AGRICULTURE, 1990–97, at 53–63 (2000), *available at* http://www.ers.usda.gov/publications/sb969/.

Wyatt, and Graham et al.[100] Similar to Malcolm, we assume that 50% of the residue can be removed from fields if no-till or conservation tillage is practiced and 30% can be removed if till or conventional tillage is used.[101] We use the industry average yields and costs of conversion of corn to ethanol and estimate the corresponding data for cellulosic biomass based on Wallace et al. and the Environmental Protection Agency (EPA).[102]

We construct crop budgets for commercial crops for each CRD by compiling crop budgets obtained from state extension services. These crop budgets differ by rotation, tillage, and irrigation practices.[103] The costs of harvesting corn stover and wheat straw in each CRD are also estimated, as reported in Chen et al.,[104] including the cost of fertilizer, as nutrients and soil organic matter are lost due to crop residue removal.[105] We include costs of transporting biomass to a conversion facility located fifty kilometers away from the production source. Costs of collecting forest residues are obtained from the Biomass Research and Development Board.[106]

Details about the livestock products considered, determinants of their supply, and costs of production are described in Chen et al.[107] The production of livestock requires feed crops, soymeal, and Distiller's Dried Grains with Solubles to provide grain and protein.[108] We deter-

100. R.L. Graham, R. Nelson, J. Sheehan, R.D. Perlack & L.L. Wright, *Current and Potential U.S. Corn Stover Supplies*, 99 AGRONOMY J. 1, 2, 6 (2007); John Sheehan et al., *Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol*, J. INDUS. ECOLOGY, July 2003, at 117, 124; William Wilcke & Gary Wyatt, FS-M1080, *Grain Storage Tips: Factors and Formulas for Crop Drying, Storage and Handling*, U. MINN. EXTENSION (May 2002), http://www.extension.umn.edu/specializations/cropsystems/M1080-FS.pdf.

101. *See* Scott A. Malcolm, *Weaning off Corn: Crop Residues and the Transition to Cellulosic Ethanol*, *in* TRANSITION TO A BIO ECONOMY: ENVIRONMENTAL AND RURAL DEVELOPMENT IMPACTS 123, 126 (Madhu Khanna ed., 2008), *available at* http://ageconsearch.umn.edu/handle/53500.

102. U.S. ENVTL. PROT. AGENCY, *supra* note 58; ROBERT WALLACE ET AL., U.S. DEP'T OF AGRIC. & U.S. DEP'T OF ENERGY, NREL/TP-510-37092 & USDA-ARS 1935-41000-055-00D, FEASIBILITY STUDY FOR CO-LOCATING AND INTEGRATING ETHANOL PRODUCTION PLANTS FROM CORN STARCH AND LIGNOCELLULOSIC FEEDSTOCKS (2005), http://www.nrel.gov/docs/fy05osti/37092.pdf.

> Ethanol yield from corn grain is 417.3 liters of denatured ethanol per metric ton of corn while cellulosic biofuel yield from a[] . . . stand alone plant is estimated as 330.5 liters per metric ton of dry matter of biomass. The cost of conversion of corn grain to ethanol is estimated as $0.20 per liter in 2007 prices . . . while the non-feedstock costs of producing cellulosic ethanol are estimated as $0.37 per liter in 2007 prices.

Chen et al., *supra* note 22, at 33 (citations omitted) (citing U.S. ENVTL. PROT. AGENCY, *supra* note 58 and WALLACE ET AL., *supra*). These costs and those of sugarcane ethanol are assumed to decline as the cumulative production of each type of biofuel increases, as described in Chen et al. *Id.* at 33–34.

103. *See* Chen et al., *supra* note 22, at 29.

104. *Id.* at 30.

105. *See* Sheehan et al., *supra* note 100, at 122; Charles S. Wortmann, Robert N. Klein, Wallace W. Wilhelm & Charles Shapiro, G1846, *Harvesting Crop Residues*, U. NEB.–LINCOLN EXTENSION (May 2008), http://elkhorn.unl.edu/epublic/live/g1846/build/g1846.pdf.

106. BIOMASS RESEARCH & DEV. INITIATIVE, INCREASING FEEDSTOCK PRODUCTION FOR BIOFUELS: ECONOMIC DRIVERS, ENVIRONMENTAL IMPLICATIONS, AND THE ROLE OF RESEARCH (n.d.), http://www.usbiomassboard.gov/pdfs/8_Increasing_Biofuels_Feedstock_Production.pdf.

107. Chen et al., *supra* note 22, at 31–34.

108. *See id.* at 31.

mine the feed rations for each type of livestock based on prices and nutrient contents of these inputs. In the crop sector, the demand for primary crops is determined not only by the direct demand for food production and other uses, but by the indirect demand for secondary commodities also.[109] The conversion rates from primary crop commodities to processed commodities, and the conversion costs and the methods for calibrating the domestic demand, export demand, and import supply functions for all commodities are described in Chen et al.[110] We shift domestic and export demand curves and import supply curves exogenously over time to capture the increase in demand due to growth in population and income.[111]

The fuel sector includes a demand function for VKT, production function for VKT, and supply functions of domestic gasoline and gasoline for the rest of the world. The calibration of these functions relies on data on consumption of kilometers, fuel consumption, and fuel prices for 2007, as well as estimates of the elasticity of demand for kilometers, elasticity of substitution between gasoline and biofuels, and elasticities of supply of gasoline produced domestically and imported from the rest of the world.[112] Data on ethanol imports including excess supply elasticities, prices of sugarcane ethanol in Brazil and CBI countries, and life cycle GHG emissions of sugarcane ethanol are described in Chen et al.[113]

We consider four categories of land types: idle cropland, cropland pasture, pasture, and forestland pasture. Land availability for each type of land for each CRD is obtained from USDA/NASS.[114] Assumptions about the possibilities for conversion of land across different types and the costs of land conversion are described in Chen et al.[115] Land enrolled in the CRP is maintained at thirteen million hectares from 2008 onwards.[116] Due to concerns about the effect of expansion of bioenergy crop production on subsurface hydrology and on biodiversity, we impose a 25% limit on land that can be allocated for the production of bioenergy crops in each CRD.[117] We examine the sensitivity of model results to a reduction in this limit from 25% to 10%.[118]

We conduct a life cycle analysis of the above-ground carbon dioxide equivalent emissions (CO_2e) generated from all the crop and biofuel

109. *See id.*
110. *Id.* at 31–34.
111. *See id.* at 32.
112. *See id.* at 32–33.
113. *Id.* at 33–34.
114. *Quick Stats*, *supra* note 97. "In 2007, the availability of pastureland and forestland pasture is estimated to be 155 [million hectares] and 10.5 [million hectares], respectively while that of idle cropland is 15 [million hectares] and of cropland pasture is 13 [million hectares]." Chen et al., *supra* note 22, at 30–31.
115. Chen et al., *supra* note 22, at 12–13.
116. *See id.* at 31.
117. *See id.* at 13.
118. *See id.*

production using the same fertilizer application rates assumed to construct their costs of production. The CO_2e emissions are estimated by aggregating the major GHGs emitted, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), using their one-hundred-year global warming potential factors. We include the CO_2e generated from various inputs and machinery used in the production of each feedstock, the energy used to produce and transport those inputs to the farm, and the energy used to transport the feedstock to a biorefinery, convert the feedstock to biofuel, and transport the biofuel for final consumption net of coproduct credits using emissions factors for agricultural inputs, machinery, refinery processes, and transportation from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model.[119] We exclude soil carbon sequestration by the cropping activities considered here as well as emissions due to indirect land use change caused by the diversion of cropland to biofuel production. The carbon emissions of sugarcane ethanol at U.S. ports are obtained from Crago et al.[120] The estimates for carbon emissions from corn ethanol emissions are obtained assuming one-third wet and two-thirds dry mill facilities.[121]

VI. RESULTS

We examine the effects of five policy scenarios on the agricultural and fuel sectors, all of which include the RFS. Scenario (1) considers the RFS only. The RFS is simulated as a binding mandate with its nested volumetric requirements as specified in EISA. Scenario (2) considers the RFS with BCAP. In simulating the effects of BCAP we consider the E&A payments for the first two years for miscanthus and for the first year for switchgrass (because these crops are assumed to yield 100% of their maximum yield thereafter). CHST payments are provided at a rate of $45 per (short) ton with zero moisture for the following two years for each of these crops and for the first two years for any acreage from which crop or forest residues are harvested. Scenario (3) includes the volumetric tax credits for corn ethanol and cellulosic ethanol in addition to the E&A and CHST payments from BCAP.

Furthermore, we consider Scenario (4) in which all BCAP payments and volumetric tax credits are replaced by a carbon tax on all fuels. We set the carbon tax at the rate needed to achieve the same level of GHG

119. *See GREET Model: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model*, ARGONNE NAT'L LAB., http://greet.es.anl.gov/main (last visited Dec. 28, 2010).

120. Christine L. Crago, Madhu Khanna, Jason Barton, Eduardo Giuliani & Weber Amaral, *Competitiveness of Brazilian Sugarcane Ethanol Compared to US Corn Ethanol*, 38 ENERGY POL'Y 7404, 7411–12 (2010).

121. This estimate assumes the conversion rate of corn to ethanol of 10.6 liters per bushel of corn for all facilities. Energy use in the refinery is assumed to be 2.7% from coal, 79.2% from natural gas, and about 8% from electricity. These emission estimates do not include emissions during ethanol distribution.

emissions as achieved by the RFS and existing biofuel subsidies. Although such a policy is expected to be a cost-effective approach to reducing GHG emissions, it may not provide the same level of incentives for switching from gasoline to biofuels (particularly cellulosic biofuels) as existing biofuel subsidies do. Finally, in Scenario (5) we replace the uniform CHST payments and volumetric tax credits rate with payment rates that are based on carbon credits generated by the feedstock relative to gasoline. The value of carbon is kept at the level determined in Scenario (4) and its implications for the level of GHG reduction achieved relative to the RFS alone are examined. In all scenarios considered here, we include a fuel tax on gasoline and biofuels, which is set at $0.10 per liter.

Our findings on the impact of these policies on allocation of cropland are presented in Table 2, whereas Table 3 shows the results for production and prices of key crop and livestock commodities. Tables 4 and 5 present the impact of these policies on the fuel sector and on social welfare, respectively. We calculate the changes in cumulative discounted social welfare under alternative biofuel policies relative to the RFS alone over the 2007–2022 period. Social welfare is measured here by the sum of domestic consumers' and producers' surpluses generated (net of any taxes, but including subsidies) in the agricultural and transportation fuel sectors and government revenues due to fuel taxes and subsidies over the period 2007–2022. This measure of welfare does not include the value of environmental benefits, such as those from reducing GHG emissions and those from enhanced energy security by reducing gasoline imports, in each of these policy scenarios. Although a complete social cost-benefit analysis of these policies that includes monetized values for each of these benefits is outside the scope of this Article, we can examine the incremental cost-effectiveness of these policies in achieving each of these benefits, if that were the only motivation for these policies. This is presented in Table 5. Table 6 contains the results of the sensitivity analysis.

A. Scenario (1): The RFS

With corn ethanol produced at its maximum allowable level of 56 billion liters from 2015 and beyond, corn ethanol could constitute a maximum of two-thirds of the cumulative biofuel production over 2007–2022, with the remaining met by advanced biofuels at the mandated minimum level. Due to the nested volumetric provisions of the RFS, however, advanced biofuels can potentially meet more of the mandate than the minimum level if they can compete with corn ethanol. Given the assumptions about the rate of decline in costs of producing advanced biofuels from cellulosic feedstocks in the United States and sugarcane ethanol in Brazil as described above, we find that the RFS would lead to the production of about 613 billion liters of corn ethanol (instead of the maximum allowable level of 801 billion liters) and 608 billion liters of advanced biofuels, including 38 billion liters of sugarcane ethanol imports over the 2007–2022 period. This would increase the cumulative production of corn ethanol by 107% relative to business-as-usual over this period. The cellulosic biofuels (570 billion liters cumulative) are largely produced using miscanthus (49%) and forest residues (22%), with the rest produced using switchgrass, corn stover, and wheat straw. The RFS would also increase in the volumetric share of ethanol in total fuel consumption to 21% in 2022.

The RFS leads to an increase in total cropland by 6% (6.9 million hectares), most of which is due to increased corn production to produce the additional corn ethanol. Land under corn in 2022 increases by 16% (about 4.7 million hectares) compared to the land requirement in the absence of the RFS. With a high yielding grass like miscanthus, planting only 4.4 million hectares of miscanthus and 3 million hectares of switchgrass would be sufficient to produce the required amount of cellulosic biofuels. Of this 7.4 million hectares under bioenergy crops, only 0.4 million hectares is converted from cropland and about 7 million hectares is from currently idle cropland or cropland pasture. Thus, a total 12.1 million hectares is required for biofuel production, of which about 5 million hectares is converted from acreage previously under other crops (including soybeans, wheat, rice, cotton, and pasture), accounting for 4% of the 121.5 million hectares of cropland in 2007 and the remaining 7.1 million hectares is obtained from changes at the extensive margin. Corn stover and wheat straw would be harvested from 10% and 5% of the land under corn and wheat, respectively, in 2022.

Acreage under bioenergy crops changes over the 2007–2022 period under the mandate as shown in Figure 1(a). Acreages under miscanthus and switchgrass are about the same in 2012, with each being less than 1 million hectares. As the mandate for cellulosic biofuels increases, the land under miscanthus expands rapidly to over 4 million hectares in 2022 whereas the land under switchgrass expands more slowly to 3 million hectares in 2022 because of its relatively higher costs of production and lower yields relative to miscanthus. In addition, we find that the mix of cellulosic feedstocks differs considerably across regions. Figure 2 shows that corn stover is harvested mainly in the Plain States (Kansas, Nebraska, North Dakota, and South Dakota) in 2022 whereas 80% of wheat straw acreage is collected in the Western States (including Arizona, California, Idaho, Oregon, and Utah). About half of the switchgrass acreage in 2022 is in Texas and 15% is in Missouri. Miscanthus is more competitive than switchgrass in terms of break-even costs of production, and its production is fairly concentrated in the Great Plains (Oklahoma), the Midwest, and along lower reaches of the Mississippi River. Crop and fuel production and prices under the RFS are shown in Tables 2 and 3.

B. Scenario (2): The RFS with BCAP

The provision of BCAP payments for the production of bioenergy crops has the potential to significantly change the mix of feedstocks used for biofuels in two ways. First, it makes cellulosic ethanol competitive with corn ethanol and sugarcane ethanol and reduces cumulative corn ethanol production from 613 billion liters under the RFS alone to 249 billion liters. Cumulative cellulosic ethanol production increases by 64%, from 570 billion liters to 938 billion liters, over the 2007–2022 period relative to the mandate alone. Second, it increases the share of miscanthus in cumulative advanced biofuels (cellulosic biofuels plus sugarcane ethanol) from 49% under the mandate alone to 76%, while the share of switchgrass shrinks from 18% under the mandate alone to 12%. That is because BCAP payments enhance the competitiveness of miscanthus relative to switchgrass by reducing the high establishment costs of miscanthus. Additionally, the uniform per ton matching payments reward high-yielding feedstocks, like miscanthus. The volumetric shares of ethanol imports and biofuel produced from forest residues in cumulative advanced biofuels fall from 6% and 22% under a mandate alone to 4% and 7%, respectively.

The BCAP-induced change in the mix of biofuels produced from corn and other cellulosic feedstocks significantly affects the total cropland and land under various crops compared to the RFS alone. An increase in biofuels produced from miscanthus leads to land under miscanthus increasing from 4.4 million hectares under the mandate alone to 10.8 million hectares. Of the 6.4 million hectares of additional land under miscanthus, 1 million hectares is converted from switchgrass, reducing land under switchgrass from 3 million hectares under the mandate alone to 2 million hectares. The reduction in corn ethanol (relative to the RFS) also reduces the acreage under corn by 7.2 million hectares, of which about 5 million hectares is diverted to other conventional crops while the rest is diverted to the production of miscanthus. In addition, 3.2 million hectares of idle/cropland pasture is converted for the production of miscanthus. Due to the expansion of acreage under miscanthus, total cropland increases by 1.3 million hectares relative to the RFS alone. The increase in production of biofuels from miscanthus slightly shrinks the acreage needed for corn stover and wheat straw collection, to 4% of corn acres and 0.3% of wheat acres in 2022. Acreage under soybeans, wheat, rice, cotton, and pasture and their production in 2022 are higher with BCAP and the RFS than with the RFS alone.

With BCAP, miscanthus acreage increases while switchgrass acreage declines in all rain fed regions. Moreover, as shown in Figure 1(a), BCAP also makes the production of switchgrass and miscanthus viable earlier than under the RFS alone. Miscanthus acreage increases from 0.2 million hectares in 2010 to more than 10 million hectares in 2022, whereas switchgrass starts with 0.6 million hectares in 2010, but levels off and even declines in later years after 2016. This is because miscanthus and switchgrass compete for marginal land in the same locations, and BCAP increases the relative profitability of miscanthus.

The BCAP-induced increase in the production of cellulosic biofuels alleviates the adverse impact of the mandate on the prices of crop and livestock commodities. Corn and soybean prices in 2022 would be 22% and 16% lower, respectively, than under the mandate alone scenario, while beef prices in 2022 would be 6% lower. The BCAP payments result in consumer prices of $0.65 per liter for corn ethanol and cellulosic ethanol that are significantly lower than those under the mandate alone scenario, while the price of gasoline is marginally higher due to increased demand for fuel than under the mandate alone. Relative to the RFS alone scenario, cumulative VKT over the 2007–2022 period increases by 48 billion kilometers (less than 0.1%), while gasoline consumption increases by 5.1 billion liters (0.06%). The BCAP payments lower the overall cost of fuel and hence the cost per kilometer by 1%. The increase in fuel consumption from miscanthus reduces GHG emissions by 1% relative to the mandate alone.

The discounted cost of BCAP to the government is $46 billion, half of this is for the E&A payments and half for CHST payments. The loss in social welfare as compared to the RFS alone is $66 billion. Although BCAP reduces GHG emissions by 0.3 billion metric tons, it does increase gasoline consumption by 5 billion liters (2007–2022) compared to the RFS alone and, therefore, reduces the contribution of the RFS to energy security. The implied welfare cost per metric ton of GHG emissions reduced by BCAP (if the entire cost is attributed to a single environmental benefit) is $216 per metric ton of CO_2e.

C. Scenario (3): Biofuel Mandate with BCAP and Volumetric Tax Credits

In the presence of the biofuel mandates and BCAP payments, the provision of tax credits for biofuels reduces the price of cellulosic biofuels in 2022 to $0.38 per liter, significantly lower than that for corn ethanol ($0.54 per liter). This increases the consumption of cellulosic biofuels to 1384 billion liters over 2007–2022, which is more than twice the level under the mandate alone (608 billion liters) and substantially higher than under the mandate with BCAP (938 billion liters). The tax credits also increase the shares of miscanthus and switchgrass in the consumption of total biofuels from 25% and 9% under the mandate alone to 67% and 11%, respectively. The volumetric shares of ethanol imports and biofuel produced from forest residues in total biofuels fall from 3% and 11% under a mandate alone to 1% and 10%, respectively. The amount of biofuels produced from crop residues (corn stover and wheat straw) account for 2% of the total biofuels over 2007–2022, close to the level under the mandate alone. Higher corn ethanol prices result in a further reduction in the cumulative corn ethanol consumption from 613 billion liters under a mandate alone to 130 billion liters, accounting for only 8% of the total biofuel consumption. The total biofuel consumption over 2007–2022, however, is still raised from the minimum mandated level of 1221 billion liters to 1536 billion liters due to the tax credits.

The tax credits increase miscanthus acreage to 13.5 million hectares, higher than that under the mandate alone (4.4 million hectares) and the mandate and BCAP (10.75 million hectares); switchgrass acreage increases to 2.32 million hectares, higher than that under the RFS and BCAP (2.02 million hectares) but lower than that under the RFS alone (3.03 million hectares). The reduction in corn ethanol (relative to the RFS) shrinks corn acreage by 9 million hectares, of which about 4.4 million hectares is converted to miscanthus and the rest is allocated to soybeans, wheat, cotton, rice, sorghum, and barley. The shares of corn and wheat acres from which residues are collected in 2022 remains at low levels of 7% and 0.4%, respectively, due to their low yields relative to other feedstocks. Corn and soybean prices in 2022 are 24% and 16% lower, respectively, than the prices under the mandate alone scenario and the price of beef decreases by 6% because of the lowered feed prices. Figure 1(a) shows that the volumetric tax credits shift the acreage under miscanthus and switchgrass in each of the years (2010–2022) relative to the RFS and BCAP. The increase in acreage is much greater for miscanthus than for switchgrass and the acreage under switchgrass levels off after 2011.

Figure 2 shows that the provision of BCAP and volumetric tax credits reduce the acreage under the low-yielding feedstocks, including the corn stover acreage in the upper Plain States and wheat straw acreage in the West. Figure 3 shows also that these subsidies expand the acreage of miscanthus against switchgrass, making it competitive in the upper Midwest and in the Plain States, while switchgrass production is concentrated in Wisconsin, Minnesota, North Dakota, and in the South (Texas, Mississippi, Louisiana, and Florida).

Cumulative biofuel consumption over 2007–2022 exceeds the mandated level by 315 billion liters. That further reduces the consumption of gasoline by 100 billion liters relative to the mandate alone. The total fuel consumption (including biofuels), however, is higher under this scenario than in Scenarios (1) and (2) because the volumetric tax credits lead to biofuel production levels that exceed the RFS by 26%. The volumetric share of biofuels in the total fuel consumption rises from 13% under a mandate alone to 16%. The tax credits also lower the overall cost of VKT in 2022 by 9% and thus increase VKT in 2022 by 2% relative to the mandate alone. Consequently, GHG emissions under this scenario decrease by 3% relative to the RFS alone due to decreased carbon intensity of the blended fuel. The BCAP payments and volumetric tax credits cost $330 billion and lower social welfare relative to the RFS alone by $121 billion (0.7%). The implied cost of reducing GHG emissions by 0.84 billion metric tons is $144 per metric ton of CO_2e. They also reduce cumulative gasoline consumption by 100 billion liters, indicating a cost of $1.2 per liter of gasoline reduced.

D. Scenario (4): Biofuel Mandate with a Carbon Price Instrument

The carbon price instrument considered here could be implemented as a carbon tax or a cap-and-trade policy that provides tradable allowances to energy producers and generates a market price for carbon. In either case, a carbon price would raise the marginal costs (per liter) of gasoline and biofuels by the amount of the carbon price times the GHG intensity per liter of the fuel, creating incentives to switch to less GHG intensive fuels. By raising the costs of all fuels, it would also raise the cost of VKT and create incentives for reducing VKT and fuel consumption. Although the biofuel mandates and subsidies create mechanisms to switch to biofuels, they differ from a carbon price instrument in that they lower rather than raise the price of VKT.

The price of carbon can be determined in several ways. Ideally, it should be based on the value of marginal environmental damages caused by GHG emissions. Parry and Small find that this ranges between $2.5 and $366 per metric ton of CO_2 with a central value of $92 per metric ton of CO_2.[122] Under a cap-and-trade policy this would be determined by the level at which the cap is set at any point in time. Here we determine the price of CO_2 which, together with the RFS, would achieve the same level of emissions reduction as the RFS by implementing BCAP and volumetric tax credits. We find this price to be $30 per metric ton of CO_2e by systematically increasing this price from low levels until we found the price that lowered GHG emissions to the same level as with the RFS and all subsidies.

Climate change legislation has yet to be enacted in the United States. The two bills introduced in 2009 by the Senate and the House both placed caps on the overall amount of GHG emissions allowed from all capped entities and allowed capped entities to trade allowances.[123] The capped sectors included transportation and electricity sectors but agriculture is excluded in both bills.[124] Estimates of the market price of allowances over the 2009–2020 period differ across the two bills but are expected to be lower than $30 per ton of CO_2e with the upper bound set by the price at which allowances held in a strategic reserve will be auc-

122. *See* Ian W.H. Parry & Kenneth A. Small, *Does Britain or the United States Have the Right Gasoline Tax?*, 95 AM. ECON. REV. 1276, 1282 (2005).

123. American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. § 114 (as passed by House of Representatives, June 26, 2009); Clean Energy Jobs and American Power Act, S. 1733, 111th Cong. § 125 (2009).

124. H.R. 2454 § 114; S. 1733 § 125.

tioned.[125] Hence, the price determined above is a reasonable estimate of the price likely to prevail under a national cap-and-trade policy.

We find that as compared to the RFS alone, the addition of a $30 per metric ton price on CO_2e lowers the cumulative volume of corn ethanol produced from 613 billion liters to 476 billion liters and raises the volume of biofuels from miscanthus and corn stover, accordingly. The total GHG emissions decrease by 3% as compared to the RFS alone, as in Scenario (3). Unlike Scenario (3), which achieves this reduction by exceeding the mandate and producing an additional 26% of all biofuels (but at the same time lowering the cost of VKT and raising VKT by 2% relative to the RFS alone), the carbon price raises the cost of VKT and lowers VKT by 0.3% relative to the RFS alone. The total gasoline consumption falls by 1.5% under this scenario as compared to the RFS alone and is 3% below that in Scenario (3) with biofuel subsidies.

The total land requirement to meet crop and fuel production needs is marginally lower than that under the RFS alone, mainly due to lower corn ethanol production. It is also 1.3% lower than that in Scenario (3) with the biofuel subsidies, due to the lower cellulosic ethanol production. The crop and livestock prices are lower than those under the RFS alone and higher than those in Scenario (3) with the biofuel subsidies. Fuel prices under this policy are similar to those with the RFS alone despite the addition of a carbon price per unit of fuels. Figure 1(b) shows the trends in acreage of miscanthus and switchgrass under this scenario. Throughout the entire planning horizon the acreages of miscanthus and corn from which stover is collected are higher, whereas switchgrass acreage is lower than the corresponding findings under the RFS alone.

Figures 2(c) and 3(c) show the regions in the United States where crop residue and perennial grass production would be viable under the RFS with carbon price. The carbon price policy makes miscanthus production viable in the upper Midwest and the northern Plains. Areas under other feedstocks are broadly similar to those under the RFS alone.

A carbon price instrument if implemented as a carbon tax would raise the discounted value of cumulative government revenue by $621 billion. As compared to Scenario (3), government revenues would be $951 billion higher. If implemented as a tradable permit price it would not generate revenue for the government but would increase profits for entities that sell carbon allowances, which could be biofuel producers. This policy also results in higher social welfare relative to the RFS alone ($208 billion, 1.2%) and relative to the RFS with all biofuel subsidies ($330 billion, 2%). It therefore not only leads to a 3% reduction in GHG emissions, a reduction in gasoline consumption by 1.5% while increasing cellulosic biofuels by 137 billion liters (24%) compared to the RFS alone,

125. OFFICE OF ATMOSPHERIC PROGRAMS, U.S. ENVTL. PROT. AGENCY, ECONOMIC IMPACTS OF S. 1733: THE CLEAN ENERGY JOBS AND AMERICAN POWER ACT OF 2009, at 18 (2009), http://www.epa.gov/climatechange/economics/pdfs/EPA_S1733_Analysis.pdf.

but it also generates a net gain in social welfare as compared to the RFS alone. Moreover, it attains the same level of GHG emissions as the biofuel subsidies while also leading to a net gain in social welfare.

E. Scenario (5): Biofuel Mandate with Carbon Credits

In this scenario we replace the matching CHST payments of BCAP with payments related to the carbon credits generated by each feedstock relative to gasoline. The carbon credits are valued at $30 per metric ton of CO_2e as in Scenario (4). Unlike the currently proposed matching payments for two years, the carbon credits considered here are paid annually. This policy implies a payment of $0.03 per liter of corn ethanol and about $0.05–$0.06 per liter for cellulosic biofuels depending on their specific GHG emissions. The latter translates into a payment of $16–$18 per metric ton of biomass across the feedstocks considered here. Thus, the payment rate is much lower than the current volumetric tax credits for these biofuels as well as the matching payment under BCAP. As a result, cumulative biofuel consumption over 2007–2022 is at the minimum mandated level as under the RFS alone. Nevertheless, carbon credits do create incentives to produce feedstocks with lower GHG intensity and change the mix of biofuels to meet the RFS in favor of cellulosic biofuels.

As compared to the mandate alone, the acreage of miscanthus is doubled whereas the acreages of all other feedstocks decrease under this scenario because of the greater benefits provided to miscanthus compared to the other feedstocks (due to the higher carbon credit payment per ton and the higher establishment cost-share payments to miscanthus growers). The amount of corn ethanol blended to gasoline decreases by 27% relative to the RFS alone and consequently the GHG emissions decrease slightly by 0.1 billion metric tons (0.5%).

This policy does not create incentives to produce cellulosic biofuels to the same extent as the existing BCAP matching payments (Scenario (2)) and volumetric tax credits (Scenario (3)). The 2022 acreage of perennial grasses, particularly switchgrass, is lower while corn stover is collected from a larger corn area. This is because the carbon credits translate into lower per ton or per liter payments than those under the existing BCAP policy and with volumetric tax credits, even though E&A payments are provided in all three scenarios (Scenarios (2), (3) and (5)). The miscanthus acreage is 1.5 million hectares lower than that under BCAP with matching payments and 4.0 million hectares lower than that under Scenario (3). The acreage of switchgrass is reduced severely due to the relatively smaller carbon credit payments compared to miscanthus.

The reduction in biofuels produced from miscanthus and greater corn ethanol relative to Scenario (2) results in an expansion in the land under corn and larger acreage from which corn stover and wheat straw are collected. GHG emissions are higher than in Scenario (2) (by 0.15

billion metric tons) and Scenario (4) with a carbon tax (by 0.7 billion tons). In part, this is because carbon credits result in slightly lower biofuel prices than in Scenarios (2) and (4); thus, VKT and gasoline consumption are higher than the consumption in those scenarios. An increase in the carbon credit payment induces larger increases in VKT and relatively small increases in the volume of cellulosic biofuels; thus it elevates carbon emissions rather than reducing them. A carbon credit of \$350 per metric ton of CO_2e is needed to achieve the same level of GHG emissions as with a carbon price at \$30 per metric ton of CO_2e. The cost of such a policy to the government would be prohibitive in practice.

This policy leads to lower costs for the government (\$61 billion) than in Scenario (3) with all subsidies (\$331 billion). Of this, \$20 billion is the total cost of E&A payments and the rest is for carbon credit payments. This policy lowers the loss in social welfare compared to the RFS alone and Scenarios (2) and (3); thus it would be preferable on purely economic grounds. The social welfare is \$42 billion lower than under the RFS and is higher by \$24 billion compared to that with BCAP and CHST payments and by \$80 billion compared to Scenario (3) with all subsidies. The external benefits achieved by this policy, however, are small relative to the RFS alone and relative to the other subsidy policies. The resulting net cost of GHG reduction implied by this scenario is \$270 per metric ton of CO_2e. These carbon credits for biofuels result in an increase in gasoline consumption relative to the RFS alone and even compared to the subsidies in Scenarios (2) and (3). It would, therefore, not contribute to additional energy security relative to the RFS. The additional biofuel production induced by this policy is also relatively smaller than that induced by the other subsidy policies. The energy security and GHG reduction benefits of such a policy could be significantly improved with the addition of a carbon tax on gasoline.

F. Sensitivity Analysis

We examine the sensitivity of our results to changes in some key assumptions about technology and cost parameters in the agricultural sector model,[126] such as the rate of yield growth of row crops, the costs of producing bioenergy crops, and land availability for bioenergy crops. We consider the implications of the rate of yield growth for major row crops (corn, soybeans, and wheat) being 50% lower than what was assumed in the benchmark case. Jain et al. describe two scenarios for the costs of production of miscanthus and switchgrass, a low-cost and a high-cost scenario.[127] The benchmark case considered the low cost of miscanthus and switchgrass production described there. We now examine the implications of the costs of production for cellulosic feedstocks being less op-

126. *See id.* at 8.
127. Jain et al., *supra* note 93, at 222–23.

timistic than assumed in the benchmark case.[128] We also investigate the effects of high costs of production for miscanthus while the costs of production for other cellulosic feedstocks are the same as in the benchmark case. Finally, we examine the implications of constraining the amount of land in individual CRDs that can be used for bioenergy crops to 10% instead of 25% as assumed in the benchmark case. In each case, only one parameter is changed at a time while all other parameters remain the same. We report the results for two scenarios only, namely the RFS with a carbon price and the RFS with all subsidies. We present the percentage variations due to the parameter changes relative to the same policy scenarios with the benchmark parameters.

The main effect of a 50% reduction in the rate at which crop productivity increases is on the feedstocks used for biofuel production, particularly under the RFS plus carbon price scenario. Corn ethanol production falls by 24% while cellulosic ethanol production increases by 16% relative to the same scenario with the benchmark parameters. There is a reduction in the production of all row crops and an increase in crop prices (3–7%) whereas acreage from which crop residues are harvested and on which miscanthus is produced increases. The area under miscanthus increases by 1.6 million hectares while the acreage from which corn stover is collected increases by 4.8 million hectares. Under the mandate plus all subsidies scenario, the crop productivity change has small effects on the mix of biofuels because cellulosic biofuels are the primary sources of meeting the RFS. Crop prices are 7% to 8% higher than in the benchmark case, however, due to the reduction in the production of these crops.

Raising the production cost of miscanthus while keeping costs of production of other feedstocks at benchmark levels leads to a significant decrease in the production of miscanthus; thus an increase in the use of crop residues, switchgrass, and forest residues to produce cellulosic biofuels. Under the carbon price scenario, production of corn ethanol increases by 22% while cellulosic ethanol production declines by 15%, resulting in an increase in the price of cellulosic biofuels by 3%. As a result, corn acreage and corn price are 5% and 13% higher than the benchmark results. Under the subsidy scenario, the high cost of miscanthus production raises the price of cellulosic biofuels by 39%. That leads to a reduction in cellulosic ethanol production by 13% and a reduction in total biofuels by 12%. If the costs of all cellulosic feedstocks are higher than in the benchmark case, then the production of cellulosic biofuels would be 38% and 24% lower while that of corn ethanol is 55% and 24% higher in the carbon tax and subsidy scenarios, respectively, compared to their levels in the respective benchmark cases. The increase in corn ethanol is smaller in the subsidy scenario because the high costs of cellu-

128. This scenario considers higher fertilizer application rates, lower yields in the second year, and higher-yield losses during harvest, as well as higher harvesting costs per ton.

losic biofuels induce an increase in ethanol imports by 27%. The demand for corn ethanol raises corn and soybean prices by 16% and 11%, respectively, in the carbon price scenario; effects on crop prices are much smaller in the subsidy case because of the relatively smaller corn ethanol production.

A reduction in available land for bioenergy crops to a maximum of 10% of the land availability in each CRD reduces the acreage under miscanthus and switchgrass to meet the RFS mandate. That significantly raises the land from which corn stover and wheat straw would be harvested under the carbon price and subsidy scenarios. Cumulative cellulosic biofuel production in the carbon price and subsidy scenarios are 11% and 15% lower than in the benchmark case while the price of cellulosic biofuels increases by 2% and 34%, respectively. Corresponding increases in corn ethanol are by 16% and 6%, respectively. Cumulative biofuel production in the subsidy scenario, however, is still 13% lower than in the benchmark case.

In general, we find that changes in technology and cost parameters and land availability for bioenergy crops that limit the potential to expand production of high yielding biofuels reduce the share of cellulosic feedstocks to meet the RFS mandates, increase the production of corn ethanol, and elevate its adverse effects on crop prices. In all of these scenarios, however, the social welfare benefits of the carbon price instrument and the social welfare cost of the subsidy policies relative to the RFS alone do not change significantly. Higher costs of production of cellulosic feedstocks raise GHG emissions under both policy scenarios, but the effects are two-to-three times larger under the subsidy scenario than under the carbon price scenario. This is because the former relies exclusively on substitution toward cellulosic biofuels to reduce GHG emissions. Changes in the parameters considered increase demand for total cropland but the effects are very small.

VII. CONCLUSIONS AND POLICY IMPLICATIONS

This Article examines the effects of supplementing the RFS with BCAP and volumetric tax credits for biofuels on land use, food and fuel prices, GHG emissions, and social welfare. It compares these effects with the effects of supplementing the RFS with two carbon-based policy instruments, one replacing CHST payments of BCAP and the volumetric tax credit with carbon credit–based payments and the other replacing all subsidies with a carbon price.

Our analysis shows that BCAP creates significant incentives for a transition away from corn ethanol to cellulosic ethanol and reduces the adverse impacts of the RFS on crop prices. It also reduces GHG emissions beyond the RFS. It marginally increases gasoline consumption, however, as compared to the RFS. When coupled with the existing volumetric tax credits for biofuels, production of biofuels increases beyond the minimum levels mandated by the RFS. By reducing the demand for corn ethanol, thus increasing the amount of corn available in food and feed markets, these subsidies lower crop prices and benefit agricultural consumers; by subsidizing fuel, these policies benefit fuel consumers also. Although biomass producers benefit from these subsidies, profits for agricultural producers and gasoline producers are reduced because of declined market prices. Together these subsidies impose significant costs on the government ($331 billion). As a result, they lower social welfare below the level with the RFS alone. Though they do reduce GHG emissions by 3% and enhance energy security by reducing gasoline consumption by 100 billion liters over 2007–2022, the overall net effect of these subsidies is a loss in social welfare, by $122 billion, relative to the RFS alone.

We then examine the effects of replacing CHST payments and the volumetric tax credits by carbon credits. The policy leads to higher net social benefits than with BCAP and with all subsidies. Although the policy would require larger government expenditures than BCAP with CHST payments, it costs substantially less than BCAP and volumetric tax credits. With credits valued at $30 per metric ton of CO_2, however, the payments are much smaller than under existing subsidy policies. Moreover, the differential between the payments per liter for corn ethanol as compared to cellulosic ethanol becomes small. Thus, the policy does not lead to a substantial expansion in cellulosic biofuel production or reduction in GHG emissions. This suggests that performance-based subsidies for biofuels would need to be large and/or supplemented with a penalty for gasoline to create significant incentives to reduce gasoline consumption and transition toward biofuels. In contrast to policies that subsidize biofuel production and consumption, we find that supplementing the RFS with a price on all fuels based on their GHG intensity raises social welfare above the level with the RFS alone and lowers GHG intensity and overall fuel consumption. This policy would also raise government revenue instead of lowering it.

The implementation of BCAP simulated here does not consider a budget constraint for the government and assumes that all producers that found producing bioenergy crops profitable are able to enroll in the program. In practice, the program is likely to be subject to a budget constraint and will be selective when enrolling agricultural land in the program. Although the final ruling for BCAP specifies minimum eligibility criteria for receiving payments, it does not include a mechanism to select participants and feedstocks. From a social efficiency perspective, producers who can provide the highest private and social (environmental) benefits at the lowest cost should be selected for enrollment in the program. Our analysis considers one environmental benefit provided by biomass feedstocks, namely GHG emission reduction. Some of these feedstocks (particularly perennial grasses) also have the potential to provide other benefits such as erosion control, reduced nitrogen runoff, and soil carbon sequestration. Other feedstocks, such as crop and forest residues, could worsen soil erosion and soil quality if residue removal rates are high. On the other hand, monocultures of perennial grasses could reduce biodiversity and wildlife habitat in many cases.

With these multiple environmental impacts of biomass production, it is important to develop a mechanism to attach a score or index to each land parcel that seeks to enroll in BCAP. The score should consider not only the environmental impacts, but also the biomass yields per unit of land (which determine its contribution to energy security goals) and the costs of enrollment in the form of E&A payments required. A mechanism such as the Environmental Benefits Index being used by the CRP to select lands enrolled in the program could be developed for selecting participants in BCAP. This would require selecting from a pool of applicants based on some threshold index level and budget constraints instead of accepting participants on a first-come basis using minimum eligibility criteria.

TABLE 1
PRODUCTIVITY OF FEEDSTOCKS AND THEIR GHG EMISSIONS INTENSITY AND CARBON CREDIT

	Productivity (Liters/ha)	GHG Emissions (kg CO_2e/liter)	Carbon Credit at \$30/ton of CO_2e (\$/liter)	Carbon Credit at \$30/ton of CO_2e (\$/MT)
Corn Ethanol	3031.19	0.91	0.03	
Stover Biofuel	949.11	0.46	0.05	15.95
Straw Biofuel	624.48	0.41	0.05	16.44
Miscanthus Biofuel	7845.74	0.22	0.06	18.29
Switchgrass Biofuels	3941.24	0.33	0.05	17.21
Forest Residue Biofuel		0.46	0.05	15.99
Sugarcane Ethanol		0.52	0.05	

TABLE 2
EFFECT OF BIOFUEL POLICIES ON LAND USE IN 2022 (M HA)

	Mandate	Mandate with BCAP	Mandate with All Subsidies	Mandate with $30 Carbon Tax	Mandate with $30 Carbon Credit
Scenarios	(1)	(2)	(3)	(4)	(5)
Total land	127.99	129.26	129.63	127.89	129.16
Corn	33.55	26.38	24.59	30.96	29.06
Soybeans	27.50	29.40	29.59	28.23	28.98
Wheat	22.25	23.19	22.84	22.73	23.56
Stover	3.45	1.11	1.79	3.73	2.11
Straw	1.01	0.07	0.09	1.01	0.10
Miscanthus	4.43	10.75	13.45	5.96	9.29
Switchgrass	3.03	2.02	2.32	2.53	0.50

TABLE 3
EFFECT OF BIOFUEL POLICIES ON COMMODITY PRODUCTION AND PRICES IN 2022

	Mandate	Mandate with BCAP	Mandate with All Subsidies	Mandate with $30 Carbon Tax	Mandate with $30 Carbon Credit
Scenarios	(1)	(2)	(3)	(4)	(5)
Commodity Production (MMT)					
Corn	380.03	298.22	277.92	351.25	325.53
Soybeans	82.87	91.05	91.49	86.67	88.91
Wheat	63.27	67.29	66.67	64.67	66.81
Beef	17.83	18.24	18.24	18.06	18.24
Commodity Prices ($/MT)					
Corn	145.86	113.80	110.53	132.38	121.68
Soybeans	343.62	288.55	287.85	308.66	287.73
Wheat	228.59	217.81	221.95	224.13	216.93
Beef	1230.21	1151.59	1151.25	1185.81	1151.33

TABLE 4
EFFECT OF BIOFUEL POLICIES ON FUEL SECTOR

	Mandate	Mandate with BCAP	Mandate with All Subsidies	Mandate with $30 Carbon Tax	Mandate with $30 Carbon Credit
Scenarios	(1)	(2)	(3)	(4)	(5)
Prices in 2022 ($/KM or $/Liter)					
Kilometers	0.085	0.084	0.078	0.087	0.084
Corn ethanol	0.70	0.65	0.54	0.70	0.62
Cellulosic ethanol	0.70	0.65	0.38	0.70	0.62
Gasoline	0.72	0.73	0.73	0.72	0.73
Cumulative Consumption over 2007–2022 (B Liters and B KMs)					
Kilometers	83,235.64	83,283.73	84,017.29	82,114.66	83,379.86
Gasoline	8333.78	8338.94	8234.33	8211.29	8349.44
Ethanol	1220.98	1220.98	1536.29	1220.98	1220.98
Corn	613.22	248.91	130.20	476.10	448.20
Advanced Biofuels	607.77	972.07	1406.09	744.88	772.78
Stover	24.75	3.29	31.55	35.00	16.19
Straw	2.14	0.22	1.43	2.23	0.59
Miscanthus	299.76	742.12	1032.78	450.00	583.15
Switchgrass	107.87	121.39	169.04	81.48	1.63
Ethanol Imports	38.22	34.57	22.55	37.71	36.85
Forest Residues	135.03	70.48	148.73	138.46	134.37

TABLE 5
EFFECT OF BIOFUEL AND CLIMATE POLICIES ON SOCIAL WELFARE ($B)

	Mandate	Mandate with BCAP	Mandate with All Subsidies	Mandate with $30 Carbon Price	Mandate with $30 Carbon Credit
Scenarios	(1)	(2)	(3)	(4)	(5)
Total Government Exp.	2.40	-45.79	-330.20	621.44	-60.81
Tax Revenue	2.40[1]	2.16	1.39	621.44[2]	2.32
E&A Payments		-24.10	-31.62	0.00	-19.63
CHST/Carbon Credit Payments		-23.85	-33.67		
Volumetric Tax Credits		0.00	-266.29		
Changes in Social Welfare Relative to Mandate ($B)		-66.04	-121.42	207.86	-41.75
Changes in GHG Emissions (B Tons)		-0.31	-0.84	-0.84	-0.15
Cost per ton of CO_2e reduction ($ per ton of CO_2e)		215.74	143.88	-[3]	269.50

[1]Estimate of fuel tax revenue
[2]Revenue if carbon tax is imposed
[3]This scenario increases net social welfare relative to the RFS alone and reduces GHG emissions implying a negative cost of reducing GHG emissions

TABLE 6
SENSITIVITY ANALYSIS[1]

	Rate of growth of annual crop yields reduced by 50%		High cost of production of cellulosic feedstocks		Low cost of production of switchgrass and high cost for miscanthus		Upper limit on energy crop acres reduced from 25% to 10%	
	RFS+ Carbon Price	RFS+ Subsidies	RFS+ Carbon Price	RFS+ Subsidies	RFS+ Carbon Price	RFS+ Subsidies	RFS+ Carbon Price	RFS+ Subsidies
Changes in Land Uses in 2022 (%)								
Total Land	0.1	0.1	1.7	0.1	0.5	-0.2	0.3	0.0
Corn	-5.3	1.7	9.7	3.9	5.4	-0.2	3.3	0.5
Soybeans	3.9	0.3	-2.3	-0.6	-2.1	-1.2	-1.2	0.6
Wheat	0.6	0.2	1.0	2.2	-1.6	-0.1	-0.3	2.6

Continued on next page

1. Percentage changes are calculated relative to the same policy in the benchmark scenario.

TABLE 6—*continued*

Cellulosic Feedstock in 2022 (Changes in ha)								
Stover	4.8	0.0	15.5	11.8	13.7	17.3	8.9	13.4
Straw	0.0	0.0	12.8	14.7	4.5	15.4	0.1	9.3
Miscanthus	1.6	-0.2	-4.3	-2.4	-6.0	-12.2	-1.0	-3.9
Switchgrass	-0.1	0.0	-1.1	0.7	6.1	13.7	-1.4	-0.9
Changes in Crop Prices in 2022 (%)								
Corn	2.6	8.0	15.5	3.7	13.0	-2.6	7.8	0.4
Soybeans	5.4	6.7	11.4	0.0	7.3	2.5	5.4	2.2
Wheat	7.2	6.8	-0.1	-2.8	1.6	0.3	0.0	-1.4
Changes in Fuel Prices in 2022 and Cumulative Fuel and Kilometers Consumption (%)								
Gasoline Price	0.0	0.1	0.0	0.2	0.0	0.2	0.0	0.3
Corn Ethanol price	1.3	3.5	2.9	1.2	3.8	-1.0	2.0	-0.1
Cellulosic Ethanol Price	0.6	0.0	12.1	40.7	2.8	39.3	1.7	33.5
Gasoline	0.0	0.0	0.0	1.6	0.0	1.0	0.0	1.1
Corn Ethanol	-24.1	-0.3	54.7	22.5	22.4	-13.9	16.1	6.3
Cellulosic Ethanol	16.1	-0.3	-37.5	-23.5	-15.3	-12.7	-11.0	-15.1
Total Biofuels	0	-0.3	0	-18.8	0	-12.4	0	-12.9
Kilometer Consumption	0.0	0.0	0.0	-0.4	0.0	-0.2	0.0	-0.2
GHG Emissions and Social Welfare (%)								
GHG	-0.4	-0.2	1.0	2.1	0.5	1.4	0.3	1.1
Social Welfare	0.0	-0.1	0.4	0.1	0.1	0.3	0.1	0.2

FIGURE 1(A)
LAND UNDER ENERGY CROPS UNDER SCENARIOS (1)–(3)

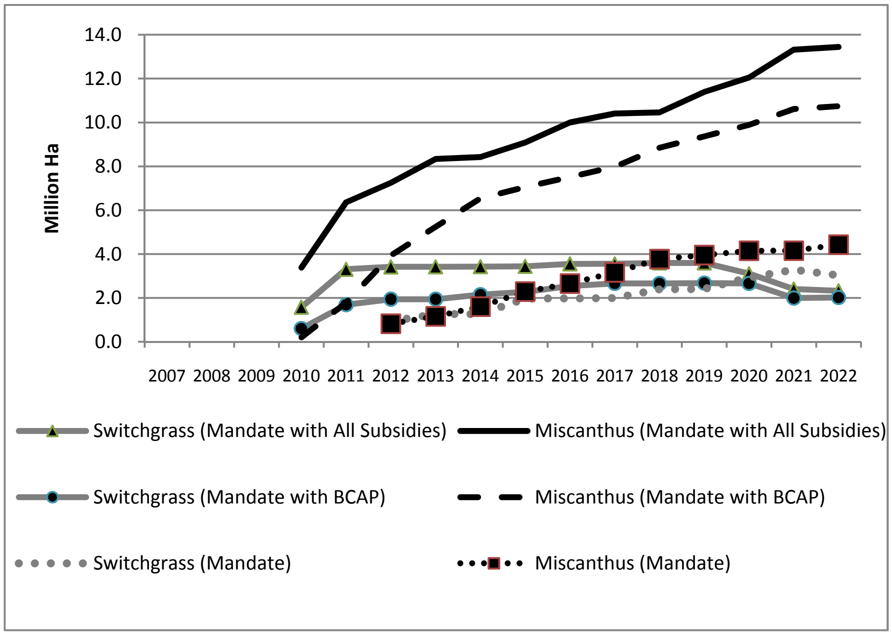


FIGURE 1(B)
LAND UNDER ENERGY CROPS UNDER SCENARIOS (4)–(5)

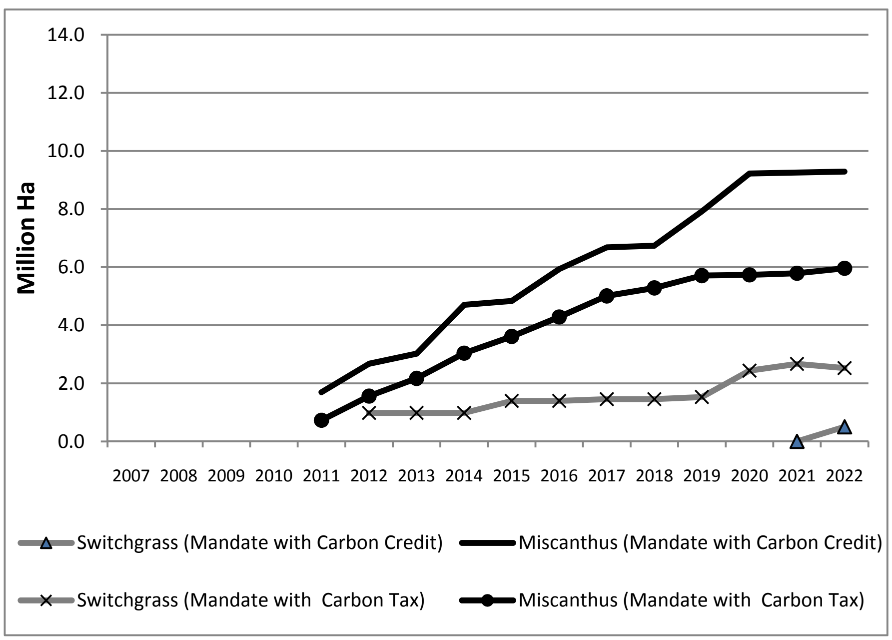
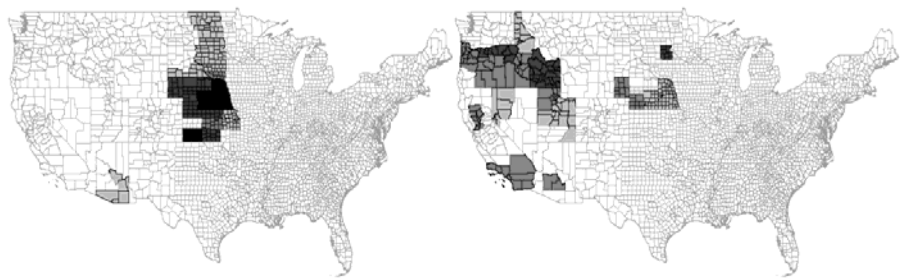


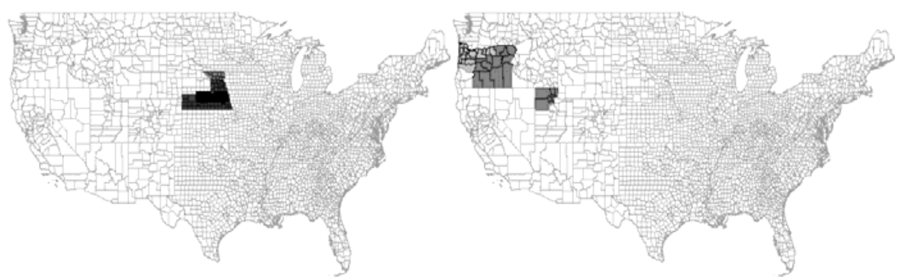
FIGURE 2
SPATIAL DISTRIBUTION OF CROP RESIDUES IN 2022

Corn Stover Wheat Stover

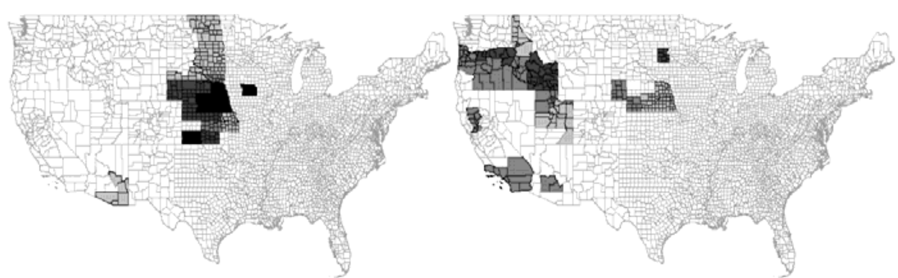
(a) Mandate alone



(b) Mandate with BCAP and Volumetric Tax Credits



(c) Mandate with a Carbon Price of $30 per ton



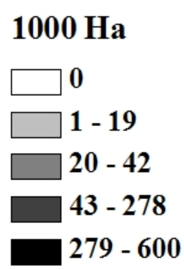
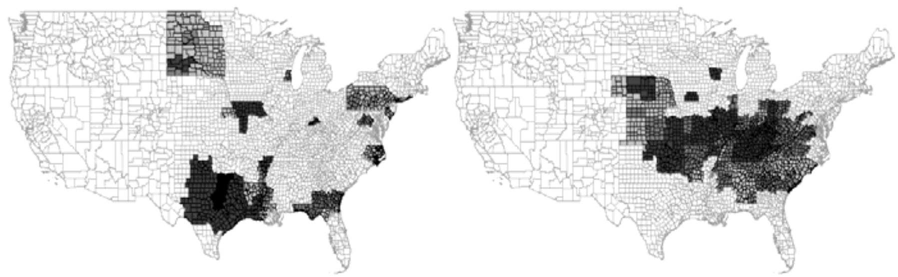


FIGURE 3
SPATIAL DISTRIBUTION OF BIOENERGY CROPS IN 2022

Switchgrass Miscanthus

(a) Mandate alone



(b) Mandate with BCAP and Volumetric Tax Credits

(c) Mandate with Carbon Price of $30 per Ton