Energy Policy 41 (2012) 484–493

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Price projections of feedstocks for biofuels and biopower in the U.S.

Matthew Langholtz [a,*], Robin Graham [a], Laurence Eaton [a], Robert Perlack [a], Chad Hellwinkel [b], Daniel G. De La Torre Ugarte [b]

[a] Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6335, USA
[b] Agricultural Policy Analysis Center, Department of Agricultural Economics and Rural Sociology, The University of Tennessee, 310 Morgan Hall, Knoxville, TN 37901-1071, USA

ARTICLE INFO

Article history:
Received 11 February 2011
Accepted 3 November 2011
Available online 17 November 2011

Keywords:
Agricultural policy analysis
Bioenergy
U.S. Energy independence and security act

ABSTRACT

The economic availability of biomass resources is a critical component in evaluating the commercial viability of biofuels. To evaluate projected farmgate prices and grower payments needed to procure 295 million dry Mg (325 million dry tons) of biomass in the U.S. by 2022, this research employs POLYSYS, an economic model of the U.S. agriculture sector. A price-run simulation suggests that a farmgate price of \$58.42 Mg^{-1} (\$53.00 dry ton^{-1}) is needed to procure this supply, while a demand-run simulation suggests that prices of \$34.56 and \$71.61 Mg^{-1} (\$30.00 and \$62.00 dry ton^{-1}) in are needed in 2012 and 2022, respectively, to procure the same supply, under baseline yield assumptions. Grower payments are reported as farmgate price minus resource-specific harvest costs.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Second-generation biofuels are expected to be an important contribution to renewable energy options in the U.S. and internationally. Advanced biofuels can displace non-renewable liquid transportation fuels and provide environmental and economic benefits. Research and development currently aims to produce advanced biofuels that are cost-competitive with conventional fossil fuels. This research evaluates feedstock price as a component of total delivered cost of cellulosic biofuels.

The Office of Biomass Programs (OBP) in the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) administers research and development efforts across industry, academic institutions, and national laboratories. OBP aims to foster commercialization of the bioenergy industry in the U.S. that will enhance U.S. energy security, reduce dependence on oil, provide environmental benefits, and create economic opportunities. The OBP publishes a Multi-Year Program Plan (MYPP) (2010), which is a dynamic document outlining the DOE's strategy for research, development, and deployment of various biomass technologies. The program aims to support the Energy Independence and Security Act of 2007 (EISA), with the goal of producing and using 136 billion liters (36 billion gallons) of renewable fuels by 2022. This ramp-up of biofuels use includes second-generation cellulosic biofuels and biomass-based diesel, and must accommodate additional projected demand for biopower (i.e. electricity generation from biomass).

The MYPP includes projected price targets for liquid fuels. Embedded in fuel price targets are costs associated with feedstock conversion (biochemical and thermochemical) processes, transportation, storage, and preprocessing and handling. Also included are production and procurement costs, here referred to as "grower payments". Grower payment, the equivalent of stumpage price for forestry resources, is the price required for rights to harvest material from the field, and includes cost of production, profit, and, in the case of crop residues, compensation for soil nutrient removal. Succinctly, grower payment is farmgate price minus harvest cost. Similarly, for forest resources, stumpage price is the price of roadside chips, minus harvest and chipping costs.

Previous MYPP grower payments were estimated based on an analysis of production costs for energy crops and nutrient values for crop residues to meet initial, low-volume demands for biofuel feedstocks. Under 2009 MYPP projections to 2012, grower payments for herbaceous crops and residues were reported as \$17.53 Mg^{-1} (\$15.90 dry ton^{-1}) (2007\$) comprising 45% of total feedstock cost, while woody feedstock grower payments were \$19.32 Mg^{-1} (\$15.70 dry ton^{-1}) comprising up to 31% of total feedstock cost (U.S. Department of Energy, 2010). However, a range of factors are likely to influence actual grower payment prices in the future, including feedstock supply and demand, competing market alternatives, biomass yield and productivity, and costs of production. This analysis aims to improve MYPP grower payment price projections by accounting for these factors.

The objective of this paper is to calculate grower payments needed to supply projected feedstock demand to meet both EISA targets beyond 2012 and additional demand for biopower in the U.S. To calculate grower payments of agricultural residues and energy crops, this research employs POLYSYS, a national

* Corresponding author. Tel.: +1 865 574 6520.
E-mail address: langholtzmh@ornl.gov (M. Langholtz).

0301-4215/\$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.11.009

simulation model of the U.S. agriculture sector that has been previously used in bioenergy and carbon policy analysis (De la Torre Ugarte et al., 2009, 2006; Dicks et al., 2009; Hellwinckel et al., 2010; Larson et al., 2010; U.S. Department of Energy, 2011; Walsh et al., 2007). This analysis combines exogenously calculated stumpage prices for forest resources and wood wastes with the agricultural resources modeled in POLYSYS to meet the combined demand estimated for both the EISA mandate and projected biopower increase.

2. POLYSYS

2.1. Agricultural land-use modeling

The POLYSYS modeling framework can be conceptualized as a variant of an equilibrium displacement model (EDM). EDMs establish simultaneous systems of generalized functions where endogenous variables are measured as proportionate changes and are a function of proportionate changes in exogenous, or curve-shifting, variables. The equilibrium market is shocked exogenously and the impacts of this disturbance are approximated by linear combinations of the products of the exogenous variables and their elasticities.

The wide appeal of EDMs in analytical work results in part from their flexibility in modeling a wide variety of market structures. The simplicity of an EDM also contributes to its usefulness and popularity (Aliston et al., 1995; Piggot, 1992). Given the elasticities associated with prices and curve-shifter variables, estimates of the impacts associated with a percentage change in an exogenous variable (or multiple variables) may be easily and quickly obtained.

An EDM assumes that the structural parameters are known with certainty. Thus, one caveat of EDMs is that errors in estimating structural parameters are transferred to the EDM, biasing the central tendencies of the estimates. Additionally, unless the true functional forms are linear, the results are only a first-order approximation of the true impacts. While such criticisms may warrant further consideration for application of an EDM for some research purposes, the conceptual framework is useful for presenting the theoretical underpinnings of the POLYSYS model of U.S. agriculture.

Piggot (1992) suggests that use of equilibrium displacement modeling is particularly relevant (i.e., preferable to econometric estimation of a simultaneous system of market equations) in cases where (1) sufficient data for econometric modeling may be unavailable, (2) where data are unreliable (which is often the case in developing countries), or (3) where "good" data and extensive prior research results and experience are available to develop large-scale models of complex relationships. The latter describes the objective and setting of POLYSYS; a national model of U.S. agriculture is understandably large and complex, and a large volume of data and research exist to establish and corroborate response parameter estimates required by an EDM.

POLYSYS was developed to simulate changes in economic policy, agricultural management, and natural resource conditions, and to estimate the resulting impacts from these changes on the U.S. agricultural sector (De la Torre Ugarte and Ray, 2000; Lin et al., 2000; Ray et al., 1998). At its core, POLYSYS is structured as a system of interdependent modules simulating (a) crop supply for the continental U.S., which is disaggregated into 3110 production regions; (b) national crop demands and prices; (c) national livestock supply and demand; and (e) agricultural income. Variables that drive the modules include planted and harvested area, production inputs, yield, exports, costs of production, demand by use, commodity price, government program outlays, and net realized income. Conventional crops currently considered in POLYSYS include corn, grain sorghum, oats, barley, wheat, soybeans, cotton, rice, and hay. POLYSYS also considers annual and perennial herbaceous energy crops and coppice and non-coppice woody crops for bioenergy, and the collection of crop and woody residues as additional cellulosic feedstocks. The taxonomy of these modeled feedstocks is illustrated in Fig. 1. For this study, switchgrass and sorghum are summarized as herbaceous energy crops, and poplars and willows are summarized as woody energy crops, consistent with the MYPP.

All cellulosic feedstocks from cropland are estimated in the form of bales or clean chips at the farmgate or roadside. Feedstock transportation is limited to logistical operations within the representative farm boundaries (i.e. no on-road transportation or storage costs are assumed). Transportation and logistics requirements beyond the farmgate represent an additional cost beyond the scope of this paper. Research about the spatial distribution of biomass resources and possible logistical advantages of dense feedstocks (e.g., woody resources over herbaceous) is ongoing.

2.2. Crop supply module

The regional crop supply module consists of 3110 independent linear programming regional models that correspond to county boundaries. Each county is characterized by relatively homogeneous production for all cropland area by crop type and tillage. The purpose of the crop supply module is to allocate land at the county level to the model crops given baseline information on county land area of the model crops, regional enterprise budgets of each crop, prices from the previous year and a set of allocation rules.

Regional baseline cropland area is anchored to a national baseline, which is disaggregated to a regional level based on historical crop production and supply patterns. Once the total area available for crop production in each county is determined using a three year average of planted area, cropland in production is held fixed across crop type and management from the baseline year. The supply module allocates cropland to competing crops using a linear programming model that maximizes expected returns using the previous year's estimated prices.

Production from each of the 3110 counties is determined independently and aggregated to obtain national production. Allocation rules are utilized to limit the cropland area that can switch from production of one crop to another or be removed from production in each county. These allocation rules simulate the inelastic nature of agricultural supply. In regions where dedicated biomass crops are determined to be profitable, some pasture can be converted to bioenergy production. For pastureland to come into production, any loss of regional forage production associated with livestock must be replaced through intensification of an equal amount of regional pastureland. We assume that forage production can double through management-intensive grazing, therefore total forage production is held constant at the county level. In sum, it is assumed that pasture can be converted to biomass or forage production, but can't be converted to traditional cropland.

The 2007 Census of Agriculture has determined that 164 million hectares (406 million acres) can be classified as cropland, while 166 million hectares (409 million acres) are classified as pastureland or rangeland. POLYSYS model crops encompass 126 million hectares (311 million acres) of national cropland. Pastureland capable of transitioning to dedicated biomass is restricted within POLYSYS to the 57 million hectares (140 million acres) of non-irrigated pastureland east of the 100th meridian. Pastureland west of the 100th meridian was excluded from consideration due

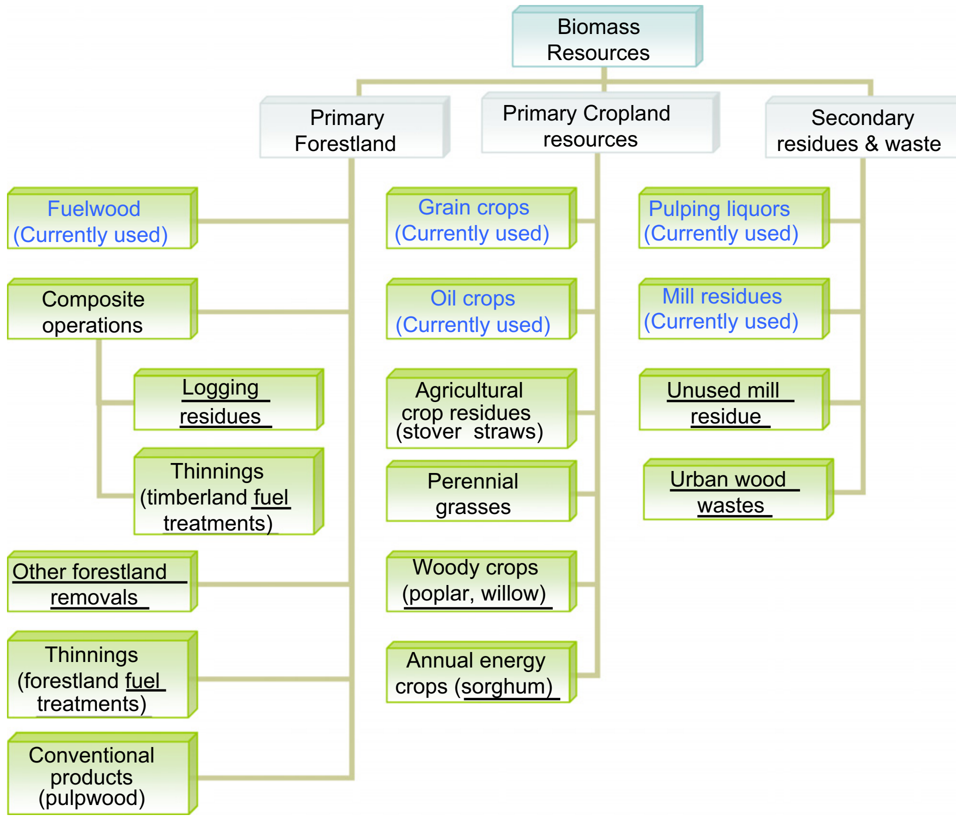

Fig. 1. Taxonomy of biomass feedstocks. Underlined feedstocks are categories reported in this study. Sorghum and switchgrass are combined and reported as "herbaceous energy crops"; Poplars and willows are combined and reported as "woody energy crops". Only unused resources are included in this analysis.

to insufficient evidence that pastureland can be intensified in arid regions without irrigation. Additionally, irrigated pastureland cannot convert. These two conditions lower the total pastureland available for conversion to 30.4 million hectares (75.2 million acres).

2.3. Crop demand module

The crop demand module estimates national-level demand quantities and prices using elasticities and changes in baseline prices. Crop utilization is estimated for domestic demand (food, feed, and industrial uses), exports, and stock carryovers. Derivative products such as soybean oil and meal are also included. Demand quantities are estimated as a function of own- and cross-price elasticities and selected non-price variables such as livestock production. The crop prices are estimated using price flexibilities and stock carryovers are estimated as the residual element. The income module uses information from the crop supply, crop demand, and livestock modules to estimate cash receipts, production expenses, government outlays, net returns, and net realized farm income.

2.4. Livestock module

The livestock module is an integrated version of the Economic Research Service (ERS) econometric livestock model (Weimar and Stillman, 1990) that interacts with the crop supply and demand modules to estimate livestock production, feed use, and market prices. Livestock production levels are a function of lagged livestock and feed own and cross prices, as well as the baseline levels and exogenously determined variables such as livestock exports. The livestock sector is linked to the supply and demand modules principally through the feed grain component. Livestock quantities affect feed grain demand and price, and feed grain prices and supply affect livestock production decisions. Exports and imports of livestock products are exogenous to the model.

2.5. Feedstock simulation

Biomass crops are allocated to agricultural land based on relative profitability to conventional major crops. Residues are collected when there is positive profit. The model can be used to estimate feedstock availability in two ways. Either a specific biomass price or a specific biofuel demand level can be exogenously introduced to the model. If biomass price is exogenously introduced, all feedstocks in all regions are offered the same price per dry tonne, land is allocated to the most profitable regional feedstocks, and the model determines the national supply level associated with the exogenous price. If an exogenous demand for biofuels is introduced, then the model iterates by incrementally increasing the biomass price until the national demand level is reached. By introducing an exogenous demand level, the model determines the equilibrium feedstock price that is necessary to meet this demand. Further documentation regarding the application of POLYSYS to biomass crops is available in the appendix of English et al. (2010).

2.6. Baseline scenario

POLYSYS anchors its analyses to U.S. Department of Agriculture (USDA) published baseline projection for the agriculture sector, which are endogenously extended to 2030 for this analysis (USDA-OCE, 2009). Changes in agricultural land use, based on cropland allocation decisions made by individual farmers, are primarily driven by the expected productivity of land, the cost of crop production, the expected economic return on the crop, and the domestic and world market conditions.

County-level cropland area (2007–2009) and tillage mixes were used as an initial point of departure for projections. Low-till and no-till agriculture, which minimizes or eliminates soil disturbance and leaves some portion of crop residues as soil cover, is widely viewed as an opportunity to reduce soil erosion, maintain soil carbon and organic matter, and improve water quality. The amount of residue that might be removed from a field is a function of crop yield, tillage practices, and need to leave residue for purposes of reducing erosion and maintaining soil carbon (U.S. Department of Energy, 2011). Data from the National Agricultural Statistics Service (NASS) provided annual estimates of crop area per county for each major crop type. Data from the Conservation Technology Information Center (CTIC) provided information on the area of major crop types using different tillage practices including conventional-tillage, reduced-tillage, and conservation tillage. These three tillage practices are defined, respectively, as leaving less than 15% of the ground covered by crop residue, between 15% and 30% ground cover, and greater than 30% ground cover (CTIC, 2005). Increases in no-tillage adoption were extended through 2030 by projecting CTIC state-level tillage trends at a conservative 50% rate.

Baseline simulation uses USDA forecasted demand through 2018 to project crop demand for current land area and prices, after which the model endogenously projects trends outward to 2030. The model forecasts beyond the final year of USDA baseline by extending the USDA trend assumptions for three variables: population, exports and crop yields. All other variables are solved endogenously through the year 2030. More information about POLYSYS assumptions and operations are available from De la Torre Ugarte and Ray (2000).

3. Methods

Steps for the workflow for this analysis are enumerated in Fig. 2. These include: (1.a.) quantifying projected feedstock demand for biorefineries, (1.b.) quantifying projected feedstock demand for biopower, (2) calculating combined farmgate demand, (3) modeling projected farmgate prices in POLYSYS, and (4) deriving feedstock-specific grower payments. Following is a description of these steps.

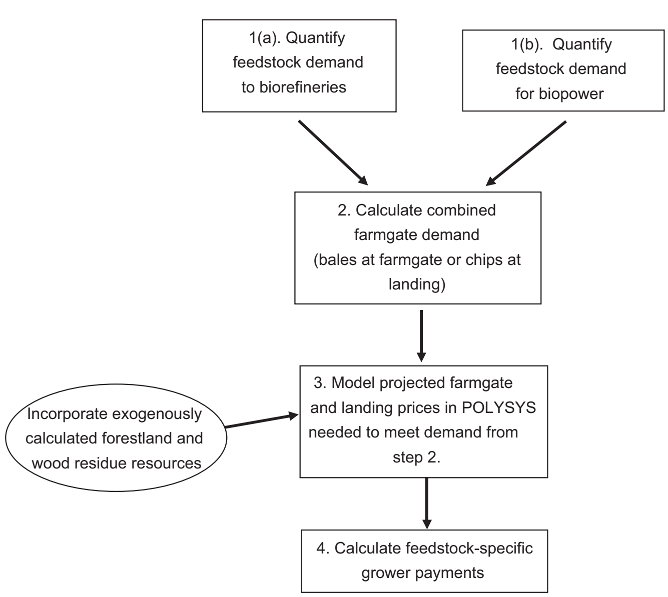

Fig. 2. Workflow diagram to calculate grower payments needed to procure feedstock to supply both EISA mandates and projected biopower demand.

Step (1.a.): *Quantify projected feedstock demand for biofuels.* EISA mandates for advanced biofuels from 2012 to 2017 and 2022[1] are shown in Table 1 row (a). These mandates represent a ramp-up of 1–9% of projected liquid transportation fuels during these years (Energy Information Administration, 2010, Figure 79 source data). Assuming a generalized conversion yield of 355 l dry Mg^{-1} (85 gallons dry ton^{-1}) (U.S. Department of Energy, 2010), biofuels facility throat demand (i.e., feedstock required as feed-in to the plant conversion process accounting for losses throughout the supply chain) is shown in Table 1 row (b).

Step (1.b.): *Quantify projected feedstock demand for biopower.* Grower payment prices are generally assumed to be positively correlated with feedstock demand. Thus, in addition to demand for biofuels production to meet EISA mandates, this research accounts for additional demand for projected biopower production in determining grower payments. Table 1 row (i) shows projected energy generation from wood and other biomass (Energy Information Administration, 2010, Table 16, reference case). Row (i) includes generation from both (1) projected biofuels facilities, and (2) generation from the pulp and paper industry. These uses do not represent additional competing demand, but rather are byproducts of existing or projected industries. Therefore, electricity generation from biofuels[2] (Table 1 row (ii)) and electricity generation from the pulp and paper industry[3] (Table 1 row (iii)) were removed from biopower generation in Table 1 row (i) to provide net additional projected biopower generation (Table 1 row (iv)). Resulting values were converted to dry tons assuming 13.7 million J (13,000 Btu) kWh^{-1} (Energy Information Administration, 2010) and 1.86×10^{10} J Mg^{-1} (16 million Btu dry ton^{-1}) (Boundy et al., 2010). Resulting net additional feedstock demand from biopower is then shown in Table 1 row (c). Projected generation from biorefinery byproducts, pulp and paper byproducts, and net additional demand is shown in Fig. 3. Facility throat demand for biopower comprises 38% of combined feedstock demand in 2011, and is reduced to 24% in 2022 as feedstock demand to meet EISA mandates increases (Fig. 4).

Step (2): *Calculate combined farmgate demand.* Biofuels feedstock demand (Table 1 row (b)) is added to additional biopower demand (row (c)) to yield combined national feedstock demand at the farmgate (row (d)). This demand ranges from 40 million dry Mg (44 million dry tons) in 2012 to 295 million dry Mg (325 million dry tons) in 2022 (row (d)). For comparison, these quantities are less than the total supply shown available by U.S. Department of Energy (2011) in rows (e) and (f).

Step (3): *Model projected farmgate prices for agricultural resources in POLYSYS.* After determining national feedstock demand shown in Table 1 row (d), POLYSYS is used to determine what farmgate prices are needed to procure these quantities. As described above, this can be done in two ways: (1) price-run scenario, i.e. iteratively fix prices in POLYSYS to determine what farmgate price is needed to procure 318 million dry Mg in 2022, or, (2) demand-run scenario, i.e. input in POLSYSY the supplies required in 2012 through 2022 from Table 1 row (d) and run the model to determine what farmgate prices are necessary to procure the national feedstock demand. The price-run scenario has a price fixed for all years, reflecting potential long-term contracting conditions, where biomass consumers lock land into production for specific facilities. The price established in the

[1] These years were chosen to be consistent with the DOE 2011 MYPP update.
[2] *Source*: AEO 2010, Table 26, reference case.
[3] *Source*: AEO 2010, Table 36, reference case.

Table 1
Calculation of feedstock demand needed to meet combined EISA mandates and biopower projections, and comparisons with projected feedstock availability.

	2012	2013	2014	2015	2016	2017	2022
(a) EISA advanced biofuels mandate (billion liters year^{-1})	7.57	10.41	14.20	20.82	27.44	34.07	79.49
(b) Throat demand at 355 l/dry Mg (million Mg year^{-1})	21	29	40	59	77	96	224
Biopower calculation:							
(i) Generation from wood and other biomass (billion kWh)[a]	57.7	68.3	75.5	84.5	94.2	103.0	172.1
(ii) Generation from biorefineries (billion kWh)[b]	1.2	1.8	3.0	4.0	5.6	7.9	38.7
(iii) Generation from pulp and paper (billion kWh)[c]	31.5	32.7	33.6	34.0	34.5	35.2	36.9
(iv) Net additional demand for biopower (i)−[(ii)+(iii)] (billion kWh)	25.0	33.8	38.9	46.5	54.1	59.9	96.5
(c) Power demand (million Mg year^{-1})[d]	18	25	29	34	40	44	71
(d) National feedstock demand (million Mg year^{-1})	40	54	69	93	117	140	295
(e) Potential supply, baseline assumptions (million Mg year^{-1})[e]	227	250	274	297	320	343	503
(f) Potential supply, high-yield assumptions (million Mg year^{-1})[f]	307	348	389	431	472	513	876

[a] 2010 AEO Reference Case Table 16: Generation: Wood and biomass.
[b] Generation from biorefineries, *source*: AEO Table 26 reference case.
[c] Generation from the pulp and paper industry, *source*: AEO Table 36 reference case.
[d] From (iv) assuming 13.7 million J (13,000 Btu) kWh^{-1} (Energy Information Administration, 2010) and 1.86×10^{10} J Mg^{-1} (16 million Btu dry ton^{-1}) (Boundy et al., 2010).
[e] U.S. Department of Energy (2011) baseline assumptions, under farmgate price of \$66 dry Mg^{-1}.
[f] U.S. Department of Energy (2011) High-yield assumptions (4% rate of annual energy crop growth), under farmgate price of \$66 dry Mg^{-1}.

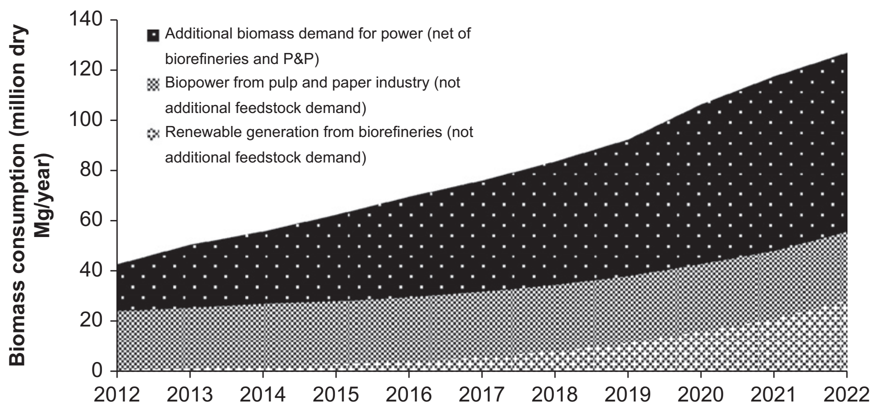

Fig. 3. Gross projected biopower demand, including generation from biorefinery byproducts, pulp and paper byproducts, and net additional demand (*data source*: Energy Information Agency Annual Energy Outlook, 2010).

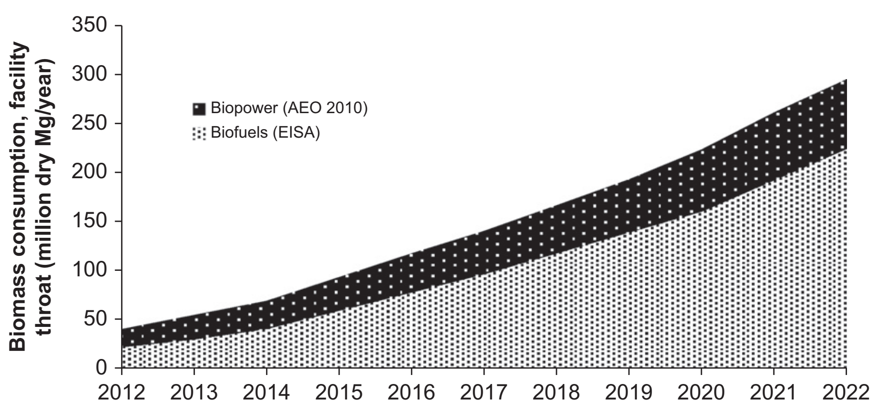

Fig. 4. Projected biomass demand for biofuels (EISA mandate) and additional biopower (AEO 2010 projections).

contract is simulated as a nominal average price (\$/Mg) that is received throughout the life of the contract (in the case of energy crops, the lifetime of the stand) until expiration. The demand-run scenario simulates a gradual increase in demand each year. These two scenarios highlight complimentary approaches to projecting feedstock prices using POLYSYS.

Several assumptions are made in the model execution. Harvest losses are yield dependent and crop specific, and losses from field to farmgate as well has farmgate to the facility are both assumed to be 7% (Idaho National Laboratory, unpublished data). Sustainability retention coefficients for residues are derived from Revised Universal Soil Loss Equation (RUSLE2) and the Wind Erosion Prediction System (WEPS), and fertilizer is applied as need to replace nutrients removed in crop residues (U.S. Department of Energy, 2011). Dedicated energy crop yields were assumed as non-irrigated establishment and maintenance, with nutrients applied according to BMP by Farm Production Region (Jager et al., 2010). Demands for food, feed, fiber and exports established in the USDA baseline are met before energy crops are established (USDA-OCE, 2009). Food-fuel tradeoffs can be

Table 2
Price elasticities of supply for corn and soybeans in 2017 and 2022.

Biomass price range ($/dry Mg)	Cross price elasticity			
	Corn, 2017	Corn, 2022	Soybeans, 2017	Soybeans, 2022
55–61	0.11	0.08	0.16	0.17
61–66	0.05	0.11	0.17	0.16

evaluated by calculating cross-price elasticities of supply. Cross-price elasticities in Table 2 indicate that supply is inelastic with biomass prices up to $66.00 dry Mg^{-1}, and there is no clear pattern for the direction of these prices at the biomass prices evaluated here. These results are consistent with the conventional theory of inelastic nature of agricultural land.

Forest lands are assumed not to be converted to agricultural lands, and thus the availability of forest resources is calculated exogenously. Forest lands include both timberlands[4] and other forest lands[5] (Smith et al., 2009). Forest resources included in this study and shown in Fig. 1 include logging residues, fuel treatments (on both timberland and other forest lands), other forest-land removals,[6] and pulpwood. Further, unused mill residues and urban wood wastes are included as secondary residues and waste resources. Forest resources are calculated at the FIA stand level, and supplies are estimated according to the cost to harvest, skid to the forest landing, and chip both logging residues (tops and branches) and small-stemmed thinning treatments. Sustainability constraints include steepness and wetness restrictions for resource removal according to the individual plot conditions (U.S. Department of Energy, 2011). These feedstocks are currently not collected, but may be available for a bioenergy and bioproducts industry. The estimates of this supply are in addition to current uses for lumber and pulp. Therefore, price interruptions to current uses are minimized. POLYSYS combines endogenously modeled agricultural resources with the exogenously calculated forestland and waste wood resources in calculating total resource quantities and costs.

Step (4): *Calculate feedstock-specific grower payments*. Grower payments for agricultural resources are calculated as farmgate price minus feedstock-specific harvest cost. Stumpage prices for forest resources are calculated as landing price minus resource-specific harvest cost. Crop-specific harvest costs are calculated as a function of yield, with higher per-hectare yields decreasing per-ton harvest costs. Average national yields for each feedstock were calculated (Table 3), and the corresponding feedstock-specific average harvest cost was used to calculate grower payments and stumpage prices. All prices are expressed as 2011 dollars.

4. Results and discussion

To supply the combined national feedstock demand shown in row (d) of Table 1, farmgate prices of $58.42 dry Mg^{-1} ($53.00 dry ton^{-1}) and $34.56–71.60 dry Mg^{-1} ($30.00–62.00 dry ton^{-1}) are needed under the price-run and demand-run scenarios, respectively (Table 4). Under the price-run scenario, a farmgate price of $58.42 dry Mg^{-1} procures five times the needed supply in 2013, but close to the 318 million dry Mg required in 2022. As expected, this high initial contract price encourages quicker adoption of perennial crops with slower maturity (e.g. woody crops). Conversely, under the demand-run scenario, a contract price of $34.56 dry Mg^{-1} is needed in 2012, which procures twice the forecasted demand in 2012, but $65.04 dry Mg^{-1} is required in 2022 to make up for the slow adoption of cellulosic crops in early target years. In short, $58.42 dry Mg^{-1} across the total mandated period procures more supply than required in 2012–2017, and allows for cheaper supply in later years due to the model's ability to account for the long-term nature of contracts of perennial crops for bioenergy.

Subtracting resource-specific harvest costs from farmgate costs yields grower payments. Supplies and grower payments for eight model resources are shown in Table 5, Figs. 5 and 6 for the price-run simulation, and Table 6, Figs. 7 and 8 for the demand-run simulation. POLYSYS outputs of switchgrass and sorghum are summarized as herbaceous energy crops, and poplar and willow outputs are summarized as woody energy crops. Wood residues are distributed across other forestland removals, logging residues and fuel treatments, pulpwood, and urban and mill wood wastes, proportionally according to each category's contribution to total forestland removals (U.S. Department of Energy, 2011).

The variation in outcome between the two modeling runs elucidates the economic implications of meeting biomass targets established by national policy in the face of competing uses of feedstocks. The projections presented above indicated variability in prices and feedstock supply composition. First, crop residue production is relatively stable across the two scenarios. This is because the technical availability of these feedstocks is contingent upon grain markets. Due to the sensitivity of the harvesting methods to collection costs, most supply is achieved at lower prices, indicating increasing average cost to collect additional units of residues. A similar situation is confronted with forest resources, namely logging residues and fuel treatments. Logging residues are collected in an integrated fashion with sawlogs

Table 3
Average biomass feedstock national yields (dry Mg ha^{-1}) at harvest. Yields are expressed as average annual yields for all crops, herbaceous, and woody.

Scenario	2012	2013	2014	2015	2016	2017	2022
Price-run							
Stover	4.1	4.3	4.4	4.6	4.7	4.8	5.3
Straw	2.5	2.6	2.7	2.7	2.8	2.8	3.0
Herbaceous energy crop	3.4	5.2	6.5	7.6	8.3	8.7	10.1
Woody energy crop	n/a	n/a	n/a	11.2	11.4	11.4	12.3
Demand-run							
Stover	4.3	4.5	4.6	4.7	4.7	4.9	5.3
Straw	3.2	3.2	3.2	3.3	3.1	3.1	3.1
Herbaceous energy crop	4.9	6.5	7.4	8.1	7.8	8.3	9.0
Woody energy crop	n/a	n/a	n/a	n/a	n/a	n/a	13.5

Table 4
Farmgate prices ($ dry Mg^{-1}) needed to meet combined biofuels and biopower feedstock demands under POLYSYS price-run and demand-run scenarios.

	2012	2013	2014	2015	2016	2017	2022
Price-run	$61.23	$61.23	$61.23	$61.23	$61.23	$61.23	$61.23
Demand-run	$34.65	$34.65	$46.20	$49.66	$49.66	$55.44	$71.61

[4] Timberland is defined as forestland that is producing, or is capable of producing, in excess of 20 ft^3 per acre per year of industrial wood and not withdrawn from timber utilization by statute or administrative regulation (Smith et al., 2008).

[5] Other forestland is defined as forestland other than timberland and productive reserved forestland (Smith et al., 2008).

[6] Unutilized wood volume from cut, or otherwise killed, growing stock from cultural operations such as precommercial thinnings or from timberland clearing. Does not include volume removed from inventory through reclassification of timberland to productive reserved forest land (Smith et al., 2008).

Table 5
Price-run simulation grower payment ($ dry Mg^{-1}) and supplies (million Mg).

Supply and grower payments	2012	2013	2014	2015	2016	2017	2022
Stover							
Supply	68	75	76	83	84	88	102
Grower payment	$40.20	$40.78	$41.24	$41.59	$41.82	$42.17	$43.21
Straw							
Supply	15	17	18	19	20	21	26
Grower payment	$32.69	$33.16	$33.73	$34.08	$34.31	$34.66	$35.35
Herbaceous energy crop							
Supply	5	11	22	34	46	60	127
Grower payment	$29.81	$33.85	$35.70	$36.97	$37.66	$38.01	$39.05
Woody energy crop							
Supply				0.1	0.1	0.3	18.3
Grower payment				$43.90	$43.90	$43.90	$43.90
Other forestland removals							
Supply	15	15	15	15	11	11	8
Grower payment	$43.90	$43.90	$43.90	$43.90	$43.90	$43.90	$43.90
Logging residues and fuel treatments							
Supply	48	48	48	48	35	35	26
Grower payment	$27.96	$27.96	$27.96	$27.96	$32.81	$32.81	$36.51
Pulpwood							
Supply	1.7	1.7	1.7	1.7	1.3	1.3	0.9
Grower payment	$35.47	$35.47	$35.47	$35.47	$35.47	$35.47	$35.47
Urban and mill wood wastes							
Supply	47	47	47	47	35	35	26
Grower payment	$43.90	$43.90	$43.90	$43.90	$43.90	$43.90	$43.90
Total weighted average price	$37.56	$37.84	$37.98	$38.27	$39.36	$39.52	$40.59
Total supply	**200**	**215**	**228**	**247**	**234**	**252**	**334**

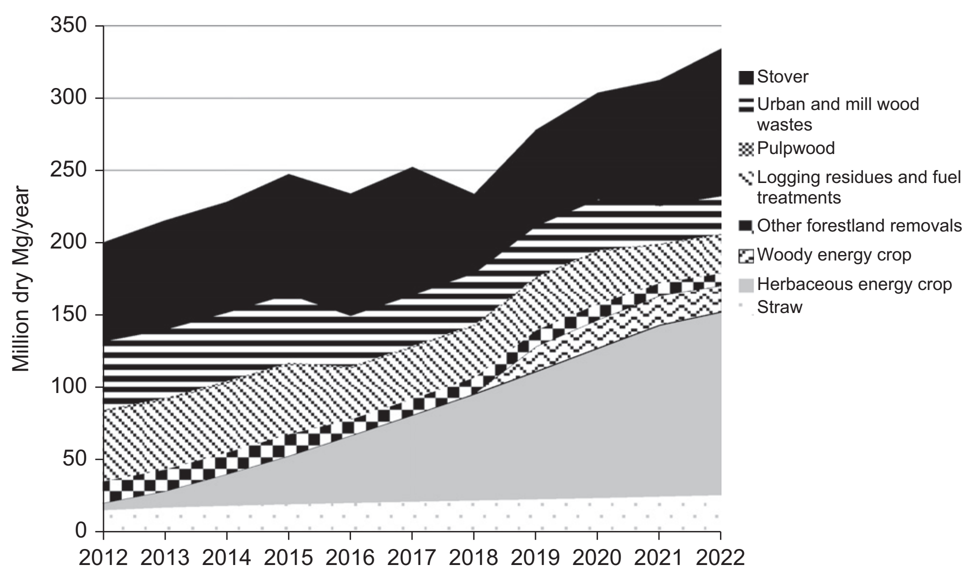

Fig. 5. Supply profile meeting EISA and biopower demand, price-run simulation.

for pulp and timber. The costs to procure these feedstocks are realized through the collection and processing of tops and branches secondary to established markets for forest resources. Fuel treatment thinnings involve harvesting and gathering of small diameter trees, in a cost situation similar to crop residues in that their availability is sensitive to the cost to extract. Both forest resources production and crop residues involve grower payments targeted at collection of existing resources, and their collection involves a secondary activity to producing forest and grain products.

Economic theory suggests high initial contract prices encourage earlier adoption of alternative crops. This is supported by the price-run scenario where perennial herbaceous crops rapidly increase in production, first surpassing small grain residues in 2014 then corn stover in later years. Forest residues were allocated to meet the projected demand in early years, and in later years the supply of these resources to meet demand drops, but their availability still exists at a stable supply level. Perennial herbaceous crops become the largest source of biomass feedstock in 2022 at 127 million Mg (140 million dry tons) annually.

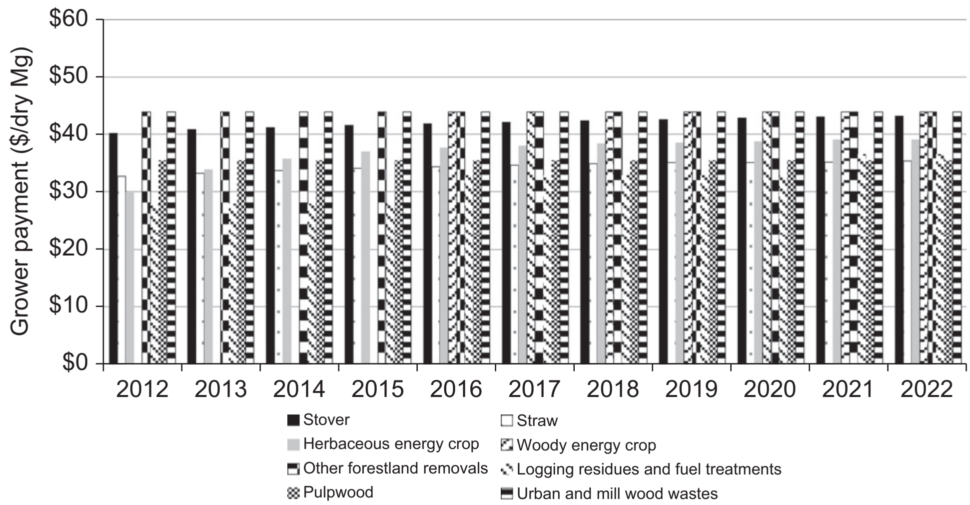

Fig. 6. Grower payments, price-run simulation.

Table 6
Demand-run simulation grower payment ($ dry Mg^{-1}) and supplies (million Mg).

Supply and grower payments	2012	2013	2014	2015	2016	2017	2022
Stover							
Supply			47	73	76	86	105
Grower payment			$28.09	$30.08	$30.33	$36.42	$53.69
Straw							
Supply			5	9	10	15	27
Grower payment			$27.25	$27.25	$30.33	$36.42	$45.78
Herbaceous energy crop							
Supply				0.1	0.4	3	59
Grower payment				$26.36	$32.15	$33.81	$49.49
Woody energy crop							
Supply							2
Grower payment							$54.39
Other forestland removals							
Supply	6	6	7	7	7	9	16
Grower payment	$16.38	$17.35	$28.92	$32.39	$32.39	$38.17	$54.39
Logging residues and fuel treatments							
Supply	20	20	21	23	23	30	52
Grower payment	$16.38	$16.38	$16.38	$16.41	$21.29	$27.07	$46.98
Pulpwood							
Supply	1	1	1	1	1	1	2
Grower payment	$18.17	$18.17	$18.17	$16.41	$21.29	$29.73	$46.98
Urban and mill wood wastes							
Supply	20	20	21	22	23	29	51
Grower payment	$16.38	$17.35	$28.92	$32.39	$32.39	$38.17	$54.39
Total weighted average price	**$16.40**	**$15.33**	**$24.45**	**$28.01**	**$29.23**	**$35.12**	**$51.23**
Total supply	**48**	**53**	**102**	**134**	**140**	**174**	**313**

Woody crops lag in production due to slower maturity and reach a production level of 14% and planting area of 21% relative to herbaceous energy crops in the final year of our analysis. At lower initial prices simulated in the demand-run scenario, mandate levels are achieved primarily through low-cost feedstocks, like crop and forest residues.

Weighted average grower payments increase throughout the mandate period in both the demand-run and price-run scenarios. Average grower payment is inversely related to harvest cost, and directly related to yield, *ceteris paribus*. Therefore, with the fixed contract price of $58.42 dry Mg^{-1} in the price run, grower payments increase 7.4% from 2012–2022 due to the general trend that increased yields tend to reduce harvest costs. However, the magnitude of change is larger in the demand-run scenario, where the weighted average grower payment more than doubles after the farmgate doubles over the period of analysis (from $34.56 to $71.61 dry Mg^{-1}). This variation in farmgate price and grower payment highlights the difference between aggressive production contracting efforts and a more free-market approach to solve equilibrium price for biomass feedstock production for energy. In sum, both achieve the target levels, but farmgate price stability and grower payment growth contrast between the two scenarios for the period of interest.

Results of sensitivity for stover and herbaceous energy crops are displayed in Table 7. The chosen parameters are production

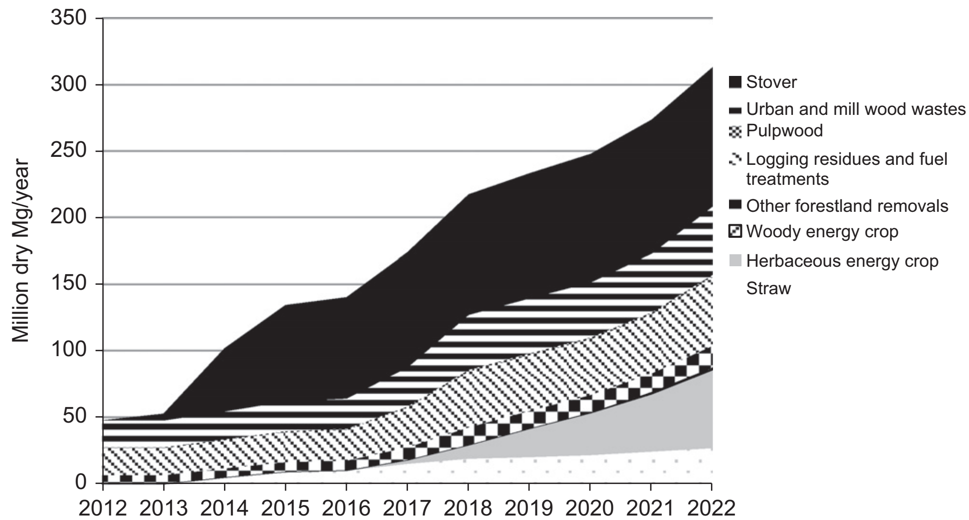

Fig. 7. Supply profile meeting EISA and biopower demand, demand-run simulation.

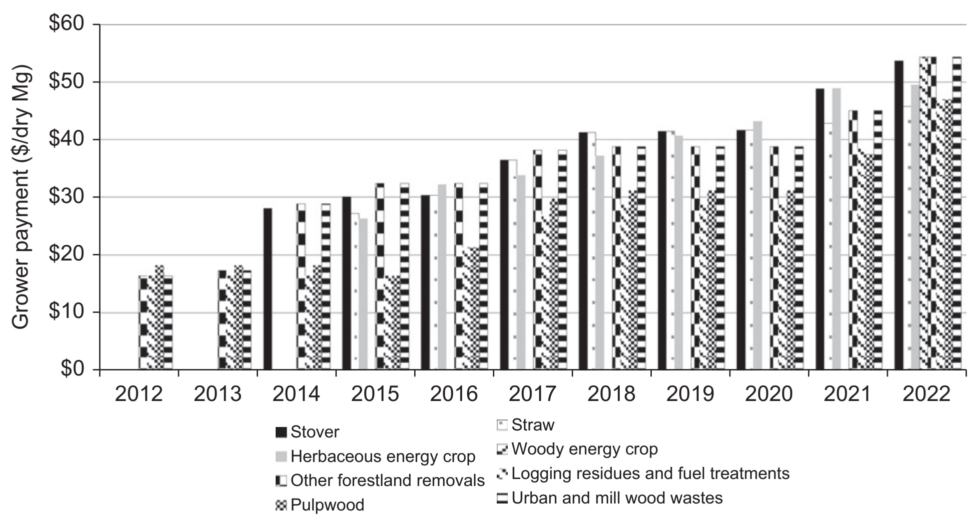

Fig. 8. Grower payments, demand-run simulation.

Table 7
Price and supply response to high no-till adoption and high energy crop yield for corn stover and herbaceous energy crops in 2017 and 2022.

	2017			2022		
	Baseline	High no-till	High energy crop	Baseline	High no-till	High energy crop
Corn stover						
Grower payment ($/Mg)	$42.16	$42.42	$32.64	$42.39	$43.75	$36.13
Supply (MMg)	88	152	92	102	166	104
Herbaceous energy crop						
Grower payment ($/Mg)	$38.01	$35.36	$36.78	$39.05	$39.03	$40.94
Supply (MMg)	60	64	97	127	137	230

and grower payment sensitivity to tillage adoption paths of traditional crops and yield growth of energy crops.

The results follow a sequence of impacts. When no-till adoption increases (shifting from conventional tillage, maintaining most land in reduced till where necessary), corn stover, and grain to a lesser extent, experiences a per-acre yield increase. At $60.60 Mg^{-1}, higher no-till adoption increases stover production 72% over the baseline in 2017 and 63% in 2022. The small grain yield increase allows for less land to be required to meet food, feed, fiber, and export demands and herbaceous energy crop production gains are small between these two sets of results (only 4 million dry tons difference in 2017, 10 million dry tons in 2022).

The second parameter tested was assumed energy crop yield increases, which was assumed 1% in the baseline and 3% in the sensitivity. The impact of this change on energy crop production is large, with over 60% increase in energy crop production in 2017 and over 80% increase in 2022. Woody crop production experiences similar gains in planted acres as herbaceous energy crops, and, due to the slow maturity of those crops, production begin to enter the market in 2020. Stover production increases when energy crop yields increase because corn production is intensified when energy crops enter on marginal croplands.

The direction of grower payments across these sensitivity results is ambiguous. This is a consequence of the fact that grower payments are tied to average per acre yield. These particular drivers of yield change, relaxing of behavior constraints (e.g. tillage adoption) and exogenous technology factors (e.g. yield growth), result in a shifting of the stover and herbaceous energy crop supply curve which may or may not increase the corresponding grower payment.

5. Conclusions

Biomass feedstocks to meet EISA advanced biofuels mandates are estimated to increase from 21 to 224 million dry Mg from 2012 to 2022. Additional demand for projected biopower is likely to increase from 18 to 71 million dry Mg from 2012 to 2022. Combined farmgate demand to serve both biofuels and biopower demand, including losses, is estimated to increase from 40 to 295 million dry Mg between 2012 and 2022.

Feedstock price, influenced by competition from other crop alternatives and competing demands, is a factor in the cost of production in biofuels. Our land use optimization modeling results suggest that mandate levels can be achieved through varying trajectories and final levels of prices for cellulosic feedstocks. Simulations suggest a minimum farmgate price of \$58.42 dry Mg^{-1} (\$53.00 dry ton^{-1}) for all years would incentivize farmers to increase production to meet or surpass combined farmgate demand. Establishing this grower payment in 2013–2017 may be needed to incentivize adoption of significant hectares of perennial herbaceous and woody feedstocks in 2022. Alternatively, in a demand-run scenario, demand could be met with farmgate prices increasing from \$34.56 dry Mg^{-1} (\$30.00 dry ton^{-1}) in 2012 to \$71.61 dry Mg^{-1} (\$62.00 dry ton^{-1}) in 2022 (in 2011 dollars), with higher prices in later years needed to meet increasing mandated and forecasted demand. The results suggests an inherit tradeoff between short-term and long-term costs that merit additional consideration in the socially optimal level of intervention to achieve bioenergy production targets. These grower payments and stumpage prices contribute to understanding of the total delivered cost of biomass feedstocks and associated bioenergy costs at projected demand levels.

Limitations to this modeling approach should be considered. For example, forest resources are modeled on a 5-yr time step; actual and projected prices diverge (as noted earlier); yield estimations rely on little data; transport and handling losses are modeled as uniform but in reality vary by crop type and logistics approach; supplies may be stranded at lower feedstock prices; and feedstock price may be underestimated when there are multiple buyers, as this modeling doesn't account for feedstock price bidding. More research is needed regarding spatial distribution of resources, associated access, and logistical strategies for optimizing delivery from farmgate to plant throat. Annual supply projection updates planned at Oak Ridge National Lab will provide opportunities to refine these results and explore different scenarios and issues, e.g. food vs. fuel, pasture intensification, competition for conventional forest products, and others.

References

Aliston, J.M., Norton, G., Pardey, P.G., 1995. Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press, Ithinca, NY.

Boundy, B., Davis, S., Wright, L.L., Badger, P., Perlack, R., 2010. Biomass Energy Data Book: Edition 3. Oak Ridge National Laboratory, Oak Ridge, TN.

CTIC, 2005. National crop residue management survey, 1989–2004. Conservation Technology Information Ctr, West Lafayette, IN.

De la Torre Ugarte, D., English, B., Hellwinckel, C., West, C., Jensen, C.W., Clark, C., Menand, R., 2009. Analysis of the Implications of Climate Change and Energy Legislation to the Agricultural Sector, Publication of the $25 \times$'25 Working Group, Washington, DC.

De la Torre Ugarte, D., English, B., Jensen, K., Hellwinckel, C., Menard, J., Wilson, B., 2006. Opportunities and Challenges of Expanding the Production and Utilization of Ethanol and Biodiesel, Final Report. Study funded by the National Commission on Energy Policy and the Governors' Ethanol Coalition.

De la Torre Ugarte, D., Ray, D.E., 2000. Biomass and bioenergy applications of the POLYSYS modeling framework. Biomass & Bioenergy 18, 291–308.

Dicks, M., Campiche, J., De la Torre Ugarte, D., Hellwinckel, C., Bryant, H., Richardson, J., 2009. Land use implications of expanding biofuel demand. Journal of Agricultural and Applied Economics 41, 435–453.

Energy Information Administration, 2010. Annual Energy Outlook 2010. Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC, p. 231.

English, B., De la Torre Ugarte, D., Hellwinckel, C., Jensen, K., Menard, R.J., West, T.O., Clark, C., 2010. Implications of Energy and Carbon Policies for the Agriculture and Forestry Sectors. Department of Agricultural & Resource Economics, Institute of Agriculture, The University of Tennessee, Knoxville, TN.

Hellwinckel, C., West, T.O., De la Torre Ugarte, D., Perlack, R., 2010. Evaluating possible cap and trade legislation on cellulosic feedstock availability. Global Change Biology Bioenergy 2, 278–287.

Jager, H.I., Baskaran, L.M., Brandt, C.C., Davis, E.B., Gunderson, C.A., Wullschleger, S.D., 2010. Empirical geographic modeling of switchgrass yields in the United States. Global Change Biology Bioenergy 2, 248–257.

Larson, J., Hellwinckel, C., English, B., De la Torre Ugarte, D., West, T.O., Menard, R., 2010. Economic and environmental impacts of the corn grain ethanol industry on the United States agricultural sector. Journal of Soil and Water Conservation 65, 12.

Lin, W., Westcott, P., Skinner, R., Sanford, S., De la Torre Ugarte, D., 2000. Supply Response under the 1996 Farm Act and Implications for the U.S. Field Crops Sector. Market and Trade Economics Division, Economic Research Service, United States Department of Agriculture, Washington, DC.

Piggot, R.R., 1992. Some old truths revisited. Australian Journal of Agricultural Economics 26, 117–140.

Ray, D., De la Torre Ugarte, D., Dicks, M., Tiller, K., 1998. The POLYSYS Modeling Framework: A Documentation. Agricultural Policy Analysis Center, University of Tennessee, Knoxville, TN.

Smith, W., Miles, P., Perry, C.H., Pugh, S., 2009. Forest Resources of the United States, 2007, In: U.S. Department of Agriculture Forest Service (Ed.), Washington, DC, p. 336.

U.S. Department of Energy, 2010. Biomass Multi-Year Program Plan, March 2010. U.S. Department of Energy, Washington DC, pp. 1–206.

U.S. Department of Energy, 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN 227p.

USDA-OCE, 2009. USDA Agricultural Baseline Projections to 2020. Office of the Chief Economist, U.S.D.o.A., Washington, DC.

Walsh, M., English, B., De la Torre Ugarte, D., Jensen, K., Hellwinckel, C., Menard, R., Nelson, R., 2007. Agricultural impacts of biofuels produciton. Journal of Agricultural and Applied Economics 39, 365–372.

Weimar, M.R., Stillman, R.P. 1990. A long term forecasting model of the livestock and poultry sectors. In: Proceedings of the NCR134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. Chicago, IL.