ADVANCED BIOFUELS SYSTEM CONFIGURATION IN THE U.S.: COST AND PERFORMANCE TRADEOFFS

Rocío Uría-Martínez

uriamartiner@ornl.gov

Paul Leiby

leibypn@ornl.gov

Energy Analysis Group, Oak Ridge National Laboratory

One Bethel Valley Road, Oak Ridge TN37831

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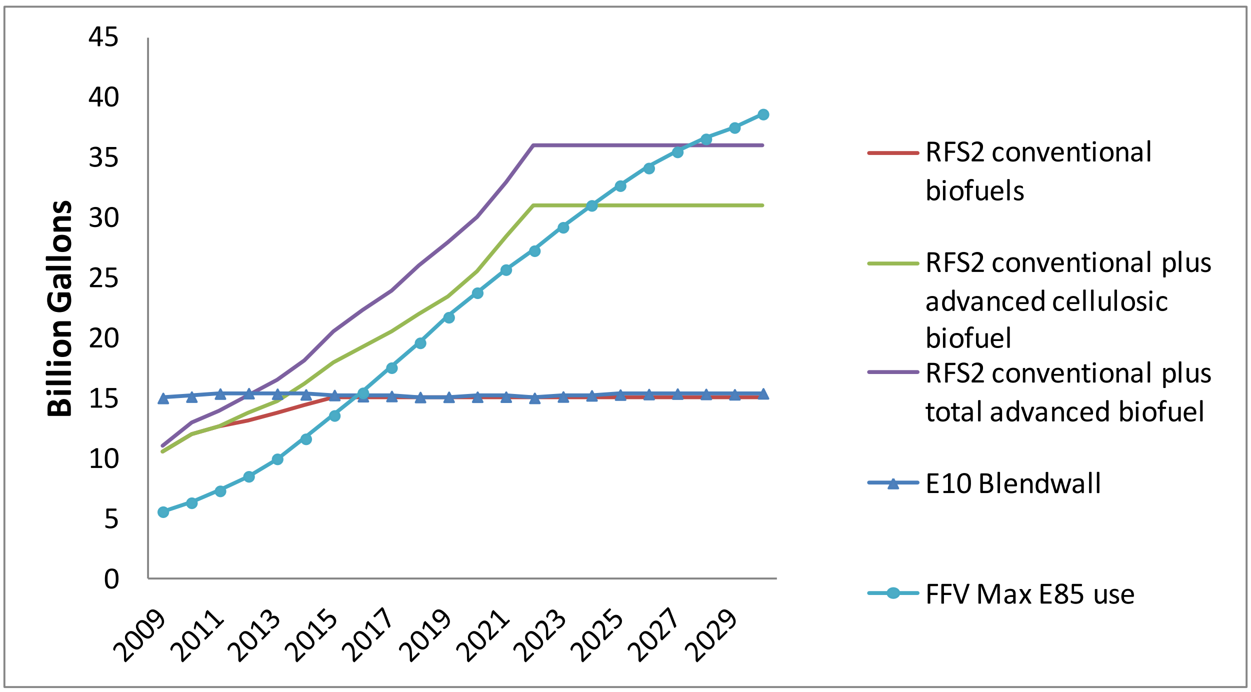
Abstract:

Prospects for the cellulosic biofuel industry are unclear. The EPA has repeatedly lowered production requirements under the Renewable Fuels Standard (RFS-2) to reflect the limited investment in cellulosic biorefineries. The elimination of the VEETC tax credit and of the import tax for Brazilian ethanol at the end of 2011 leave the domestic biofuel industry, particularly advanced biofuels not yet as established as corn ethanol, more exposed to competitive pressures from international commodity markets. The R&D focus seems to be shifting from cellulosic ethanol to drop-in biofuels, which would eliminate the need for infrastructure investments in the downstream segment of the supply chain. However, the challenges associated with handling biomass and configuring a network of biorefineries and biofuel transportation routes remain, regardless of biofuel type. The BioTrans model offers a tool for long-term planning that takes into account strategic interactions among regions and between oil and biofuels while also examining system flexibility and robustness to supply/demand shocks.

1. Introduction/motivation

To meet Energy Independence and Security Act (EISA) goals for renewable fuel in the near future, there is an urgent need for the development and production of advanced biofuels. According to EISA, advanced biofuel is "renewable fuel, other than ethanol derived from corn starch, which has lifecycle GHG emissions that are, at least, 50% less than baseline lifecycle GHG".[1] Advanced biofuel is a subset of renewable fuel. Up till now, the RFS-2 production mandate called for very small amounts of advanced biofuels. That is changing as the system also approaches the blend wall (i.e., the maximum volume of corn ethanol that the current light-duty vehicle fleet could absorb through ethanol blends with up to 10% ethanol content). Figure 1 makes clear the point that meeting RFS-2 objectives will require moving beyond corn ethanol from here on.

Figure 1: RFS-2 Volumetric Requirements and Ethanol Demand Potential



Source: AEO (2010)

In addition, if the advanced biofuels requirement is going to be met using significant volumes of advanced and cellulosic ethanol, the downstream portion of the supply chain will require rapid changes. Adjustments will be needed in both the vehicle and refueling infrastructure. The three US automobile manufacturers have pledged to make 50% of their vehicles in 2012 FFVs.[2] Thus, FFV penetration should

[1] The baseline has been set as the ghg emissions for gasoline or diesel sold as transportation fuel in 2005.

[2] http://growinggeorgia.com/news/2011/10/rfa-automakers-meeting-their-pledge-produce-50-their-vehicles-flexible-fuel/

increase in the next few years. No similar clear commitment can be found from the retail industry to increase the number of blender pumps that could deliver E20-E85 blends to consumers. Tax credit incentives for retail stations incorporating E85 equipment and a USDA program initiative that aims to install 10,000 blender pumps by 2016 are examples of government incentives to try to break the vicious circle of lack of E85 availability inhibiting FFV sales.[3]

Meeting the advanced biofuels requirement with a combination of cellulosic ethanol and drop-in biofuels could partly relieve the need for downstream infrastructure investments. However, technological progress is needed regardless, and other downstream considerations might come to the forefront. For instance, if the drop-in biofuel is a biocrude which needs to be further refined into gasoline or diesel at a petroleum refinery, the location of refineries will become an additional important consideration for where to locate this type of biorefineries.

Regardless of which combination of cellulosic ethanol and drop-in biofuels is chosen, the challenges to configure the system upstream from the biorefinery are the same. A range of analytical and planning issues arise. To what extent will the regional pattern of biofuel production and shipments change as crop residues, energy-dedicated crops and forest residues, among others, start being used in significant volumes? Which biorefinery types and sizes would lead to the most cost-effective and resilient system? How should biomass be efficiently handled from farm to biorefinery? The BioTrans model, whose description and results are discussed in this paper, is a decision framework tool that helps address some of these questions.

2. BioTrans model description

Many technoeconomic analyses focus on a particular conversion technology and/or feedstock (e.g., Kazi et al. 2010, Hamelinck et al. 2005). Others grapple with the questions of sizing and siting biorefineries (e.g. Graham et al. 2011, Parker 2010.). Planning tools that look at the entire supply chain, at the national level, while considering a variety of pathways are less abundant in the literature. UC Davis' GBSM and University of Illinois' BEPAM model are salient examples.

The BioTrans model is a nonlinear programming model that solves for the minimum cost configuration and operation of corn and cellulosic ethanol supply chains to satisfy light-duty vehicle demand for E10 and E85 blends from 2010 to 2030. It models dynamic decisions like investment in biorefinery and retail infrastructure and storage of biomass and biofuel. It is national in scope while offering some regional detail. It disaggregates the nation into the nine Census Divisions shown in Figure 2. Some relevant aspects in which these regions differ (biomass volume availabilities, prevalent feedstock types, E85 retail availability and flexible fuel vehicle penetration) are indicated in Table 1.

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[3] http://www.ethanolrfa.org/news/entry/usda-accepting-reap-fund-apps-for-blender-pump-installation-byo-ethanol-off/

Figure 2: Census Divisions map

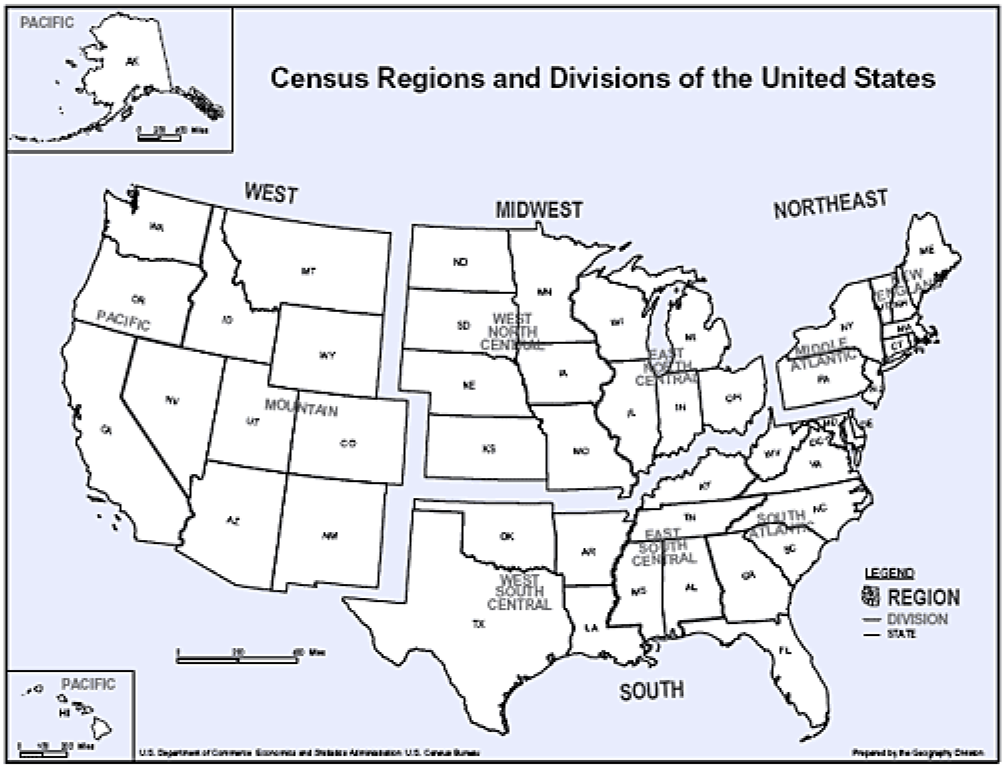


Table 1: Census Division characteristics

Census Divisions	Biomass availability (million dry tons, 2022)	E85 station share (2010)	FFV penetration (2010, cars+light trucks)
D1. New England	2.45	0.1%	2.7%
D2. Middle Atlantic	7.02	0.7%	3.2%
D3. East North Central	39.21	0.5%	4.5%
D4. West North Central	110.33	1.9%	5.0%
D5. South Atlantic	34.27	3.9%	4.2%
D6. East South Central	20.49	0.5%	4.3%
D7. West South Central	40.46	0.2%	5.4%
D8. Mountain	3.73	1.6%	4.0%
D9. Pacific	8.37	0.5%	2.6%

Census Divisions 3 and 4 (East North Central and West North Central) have the largest availability for the set of biomass feedstocks considered in BioTrans (corn, corn stover, switchgrass and forest residues) but do not have neither the largest share of stations offering E85 nor the highest FFV penetration. On the other hand, Census Division 7 (West South Central) with the largest fraction of FFVs had one of the lowest E85 station shares. These geographical mismatches clearly deserve attention as they look like obstacles for maximizing the penetration of biofuels in the market.

BioTrans tracks material balance and costs from the farm to the fuel pump allowing for two different biomass logistic designs (conventional and advanced) and 4 conversion processes (dry milling, single-feedstock biochemical, flexible-feedstock biochemical and flexible-feedstock thermochemical). Biomass is restricted to stay within the Census Division where it grows but biofuel is transported across regions by rail.

Supply chain flexibility is valuable for accommodating short and long-term fluctuations in supply and demand, and is a strategy for addressing the risks in biofuels technologies and markets. However, the minimum cost configuration in an engineering model may sacrifice flexibility at the plant and system level (e.g., no excess capacity, less range of operating modes, mininum working stocks). With limited capability of adjusting, a bad crop year or other supply chain disruption can translate into biofuel price spikes. Our concern is that such a fragile system, even if it is displacing barrels of OPEC oil, could score low in an energy security index. Departing from other national representations of the biofuel supply chain, the BioTrans model is intended to explore some of the tradeoffs between cost and system resilience. It allows evaluating the cost effectiveness of different flexibility elements (e.g., stock-to-use ratio, flexible biorefineries in terms of inputs and/or outputs) or combinations thereof in response to volatility in the corn and petroleum market or other supply/demand shocks. The next subsections provide a little more detail on how each segment of the supply chain is represented in BioTrans.

2.1 Biomass supply

The quantities and prices used to construct supply curves in the BioTrans model come from the Policy Analysis System (POLYSYS) model. Thus, the decision of how much corn or energy crops to plant and where is not endogenous in BioTrans but has been endogenously determined in POLYSYS, which is an agricultural market equilibrium model. POLYSYS solves for county-level harvestable volumes of 15 row crops and five types of crop residues. For corn, the county-level prices correspond to the equilibrium price at a benchmark location, adjusted by an index which reflects distance to that benchmark. For agricultural residues and energy-dedicated crops, POLYSYS assumes an exogenous biomass price in each scenario (POLYSYS scenarios have biomass prices ranging from $20 to $120/dry ton). Since there is only one price for these feedstocks, supply curves are constructed using the county-level production costs. Price/costs from POLYSYS refer to the harvested product (i.e., they already include the costs of collection and, therefore, that activity is not represented in the BioTrans supply chain). The data source for forest biomass is different. Those county-level resource estimates are based on data from the USDA Forest Service for different levels of roadside costs.[4] The available forest residue reported in POLYSYS already has netted out non-biofuel demands. As for corn, non-ethanol demands are based on long-term projections from USDA and are considered as exogenous in BioTrans. Only the residual supply available after satisfying those other demands is considered eligible for ethanol production.

[4] Roadside cost is the price a buyer pays for wood chips at roadside in the forest prior to any transport and secondary processing to the end-use location (DOE, 2011).

The aggregation of county-level estimates into a Census Division supply curve leads to a step supply curve with as many steps as different prices/costs in the region. Such curve is not well suited for the nonlinear programming algorithms used for solving BioTrans. Consequently, the data were fit as a smooth supply curve with the following functional form for each Census Division using a separate GAMS routine.

$$C'(q_{I,R,T}) = \propto_{I,R,T} + \frac{\beta_{I,R,T}}{(\gamma_{I,R,T} - q_{I,R,T})}$$

where *I*, *R* and *T* are the indices for crop types, Census Divisions and time periods respectively.

This marginal cost function corresponds to variable elasticities of supply, with rapidly rising marginal cost once the maximum harvestable volume indicated by POLYSYS is approached.

2.2 Biomass logistics

BioTrans acknowledges two possible biomass logistics designs: conventional and advanced. The conventional design is characterized by handling the biomass in bales while the pioneer design tends towards biomass commoditization by preprocessing the raw harvested product at a depot nearby the farm into a more homogeneous, stable and flowable product which can be transported further and stored longer. Under either design, biomass goes through two transportation segments. The first goes from farm to depot, the second goes from depot to biorefinery. A fixed distance of 10 miles is assumed for the first segment. The second segment has a variable distance and uses truck as mode of transport in the conventional design and rail in the advanced design.

The distance of the second segment depends on the feedstock density which, in turn, determines how many biorefineries would be built and how large they would be. Larger biorefineries can produce at a lower unit cost due to economies of scale but need to draw feedstock from larger areas, which can quickly lead to prohibitive transportation expenses if feedstock density is low. The optimization of the biomass transportation cost/biorefinery capital cost tradeoff was done in a separate GAMS routine, to avoid slowing down the BioTrans model solution time, but based on the same feedstock densities and transportation and capital costs. The resulting biorefinery sizes and biomass distances are entered as exogenous inputs into the BioTrans model. For each year, the separate optimization provides the average distance that surrounding biomass would have to travel to keep a new biorefinery of optimal size working at 100% capacity. However, as years go by, biorefineries of different vintages (and, consequently, different sizes) will have to modify their feedstock drawing area as feedstock density changes. BioTrans takes into account different biorefinery vintages to keep track of these changes, which turn out to be important for those feedstocks whose density increases significantly throughout the planning period. Figures 3 and 4 serve as an example of the evolution of distance and biorefinery sizes over the planning period under the two logistical designs for the case of switchgrass in the South Atlantic division (Census Division 5).

Figure 3: Average distance from farm to biorefinery under advanced logistic design (switchgrass to biochemical plant, South Atlantic region)

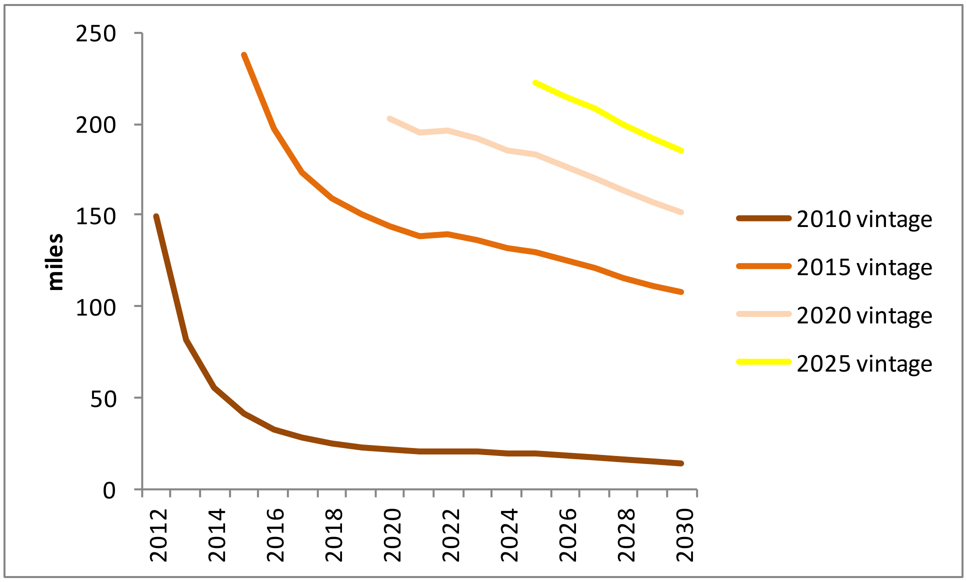
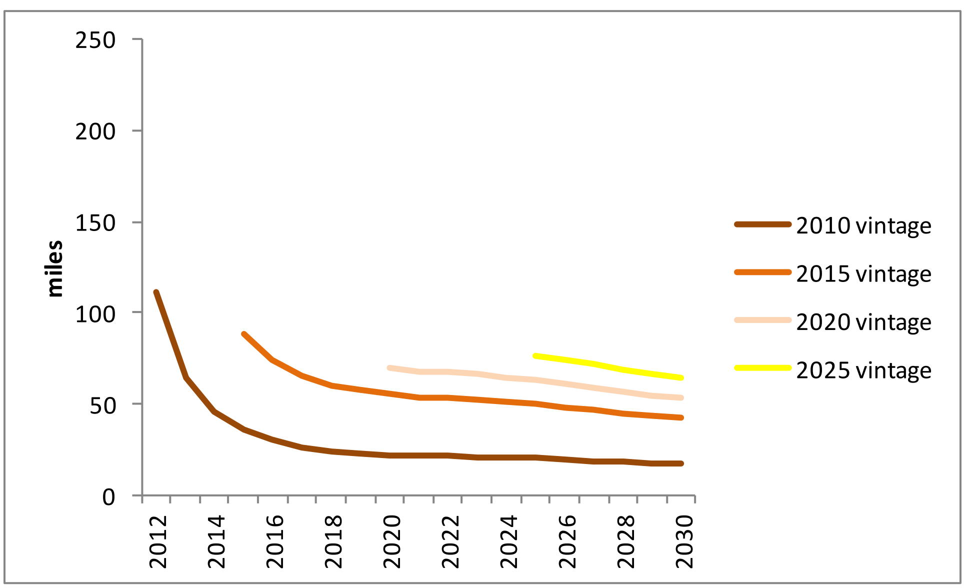


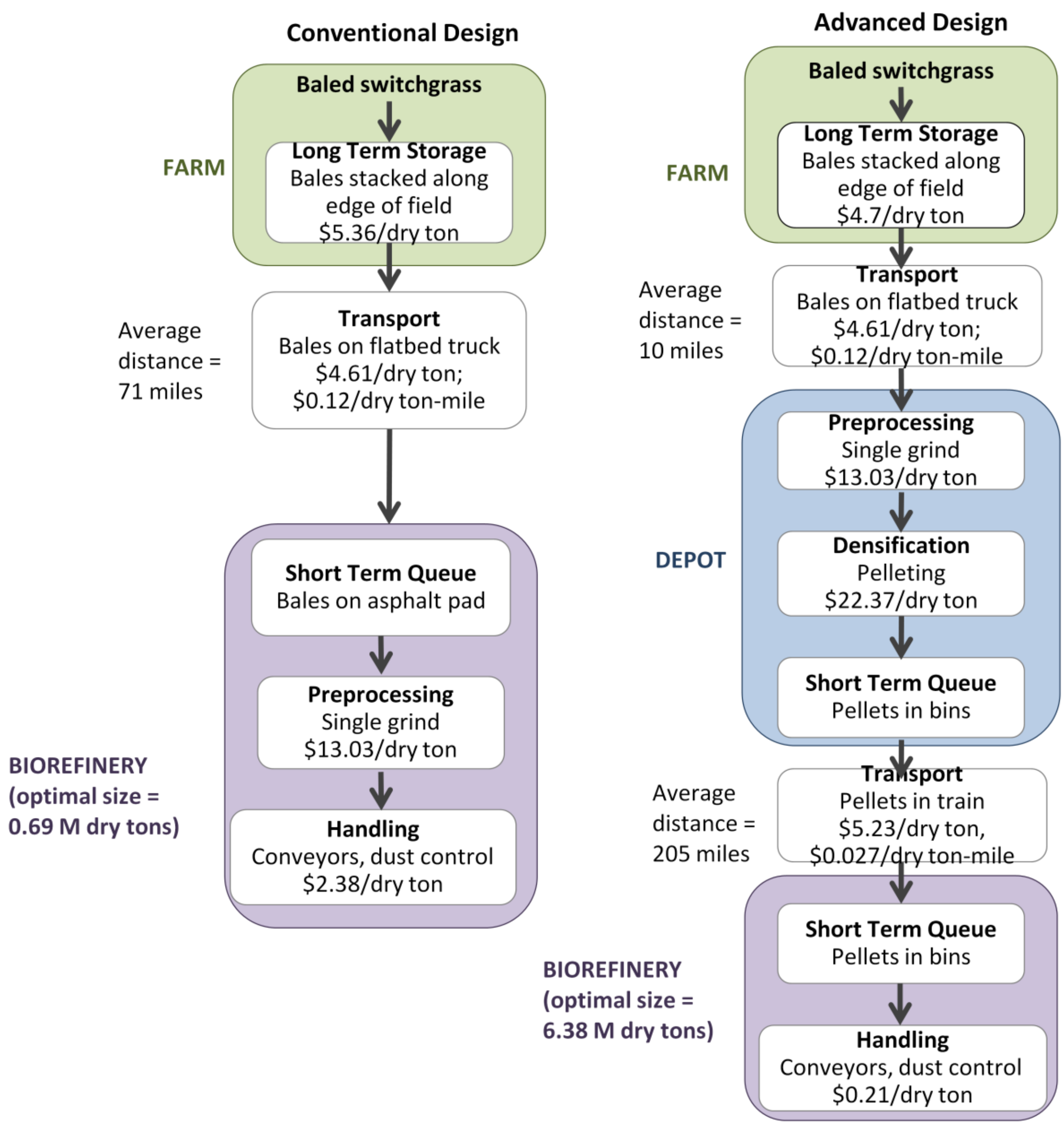
Figure 4: Average distance from farm to biorefinery under conventional logistic design (switchgrass to biochemical plant, South Atlantic region)



For a given vintage, the average distance goes down over time. This results from the increases in switchgrass density in this Census division. On the other hand, for a given year, each later vintage draws from a larger area than the preceding ones. The reason is that optimal biorefinery sizes increase over time. For any given vintage, the optimal size under the conventional design (Figure 4) is larger than under the advanced design (Figure 3). This is consistent with the lower transportation cost (in $/dry-ton mile) of biomass handled according to the advanced logistic design.

Storage is another important component of biomass logistics operations, and historically has been essential for risk management in agricultural commodity and petroleum markets. As the most basic storage methods at the farm do not require any capital investment, BioTrans does not set any storage capacity constraint. A stock-to-use ratio of 15% is imposed for corn and for the cellulosic feedstock category as a whole. This number is in line with what is observed for hay, which has similar properties as the biomass feedstocks considered in this analysis. BioTrans uses annual periods and stocks are interpreted as end-of-year (i.e., carryover) stocks. The diagram in Figure 5 summarizes the differences between the conventional and advanced logistics designs for one particular combination of crop, region and year.

Figure 5: Switchgrass logistics under alternative designs (2020, East South Central region)



2.3 Biorefinery conversion processes

BioTrans treats investment costs in new biorefineries as a lump sum cost. Co-products are represented as outputs that result in fixed proportions with biofuel during the conversion process and their price is exogenous. In the corn dry milling process, the co-products are DDGs. In the biochemical and thermochemical conversion platforms, the co-product is electricity.

Feedstock flexibility is allowed in both biochemical and thermochemical biorefineries but, for the case of biochemical conversion processes, it implies a 20% capital cost premium. Those biorefineries that are flexible in terms of inputs are allowed to consider any mixture of the 3 feedstock considered for the production of cellulosic ethanol (corn stover, switchgrass and forest biomass). In contrast, the technoeconomic studies used to inform biorefinery fixed and variable cost parameters (Tao and Aden (2008), Dutta and Phillips (2009)) typically look at examples in which the process is focused on one feedstock.

2.4 Biofuel logistics

Unlike for biomass, BioTrans allows ethanol to be moved across regions. The assumed transportation mode is rail. In those Census Divisions where unit train terminals for ethanol are available (all except the East South Central and Mountain regions), that most cost-effective option is assumed for selecting transportation rates from USDA's AMS Biofuel Transportation Database. Distance between unit train terminals is taken to calculate this transportation cost. Admittedly, this is a crude approximation. The destination point for interregional rail shipments or intraregional truck shipments of biofuel are wholesale fuel terminals where the ethanol is stored and blended with gasoline. The stock-to-use ratio imposed on ethanol is 5%, in line with what has been observed in the industry in the recent past.

In the current version of BioTrans, the petroleum sector enters the model through a national gasoline supply curve. This supply curve, assumed to be linear, was based on AEO2010 reference quantities and prices and assumes a supply elasticity of 2.5.

2.5 Fuel retail

E10 and E85 blends get to the end-use customers through the retailing activity in the model. Retailing capacity is characterized by the following relationship (used in other studies regarding transition to alternative fuels/vehicles, e.g., Leiby and Rubin 2008)

$$K_{I,R,T}^{RET} = numsta_R * stasize_R * STAFRAC_{I,R,T} * PUMPFRAC_{I,R,T}$$

where $numsta$ is the number of fuel retail stations in region R, $stasize$ is the average size of retail stations in region R, $STAFRAC$ is the fraction of retail stations offering blend fuel I in region R and period T and $PUMPFRAC$ is the share of pumps (in those stations that offer the alternative fuel) which dispense E85. The number and size of retail stations are parameters while the fractions of stations and pumps offering E85 in each region and period are endogenous variables in BioTrans.

The evolution of retail capacity over time is governed by a basic equation of motion

$$K_{I,R,T}^{RET} = (1 - dep) * K_{I,R,T-1}^{RET} + I_{I,R,T}^{RET}$$

where dep is the linear depreciation rate. All retail infrastructure (underground storage tanks as well as aboveground retail dispensing equipment) are assumed to be replaced every 15 years.

3. Satisfying EISA RFS-2 Advanced Biofuel Requirements

In this section, we discuss a scenario where cellulosic ethanol fulfills the fuel RFS-2 cellulosic biofuel requirement. We also assume advanced biomass logistics are adopted by 2017 to provide greater feedstock uniformity and enable lower cost transportation and larger plant scales.[5] The POLYSYS scenario used in this reference case sets the exogenous payment to farmers for cellulosic feedstocks at $50/dry ton.

The simulated harvested volumes dedicated to ethanol production for each biomass type and Census Division are shown in Figure 6 through Figure 9. Census Divisions 3 and 4 (East North Central and West North Central) together remain by far the largest biofuel producers. These two regions do not only dominate production for corn ethanol but also harvest close to 70% of cellulosic feedstocks throughout the planning period. The southern divisions (5.South Atlantic, 6.East South Central and 7.West South Central) contribute 28% of cellulosic feedstock in 2012 and 26% in 2030. By 2030, still over 70% of total feedstock for producing ethanol is corn.

[5] Total system costs are 4.3% higher when the "advanced logistics design" is adopted by 2017 than when biomass is handled in bales from farm to biorefinery throughout the planning period. Despite both biorefinery capital costs and biomass transportation costs being lower in the advanced logistics case, the extra cost from preprocessing the biomass into pellets more than offsets the other savings. Biomass supply-chain models, including BioTrans, do not yet propoerly account for other benefits from biomass commoditization that are anticipated by its industry advocates (e.g., reduced variance in feedstock availability and biorefinery operation costs in the presence of feedstock of more consistent quality) which should be further examined within or outside this model.

Figure 6: Simulated harvested corn volumes dedicated to ethanol production

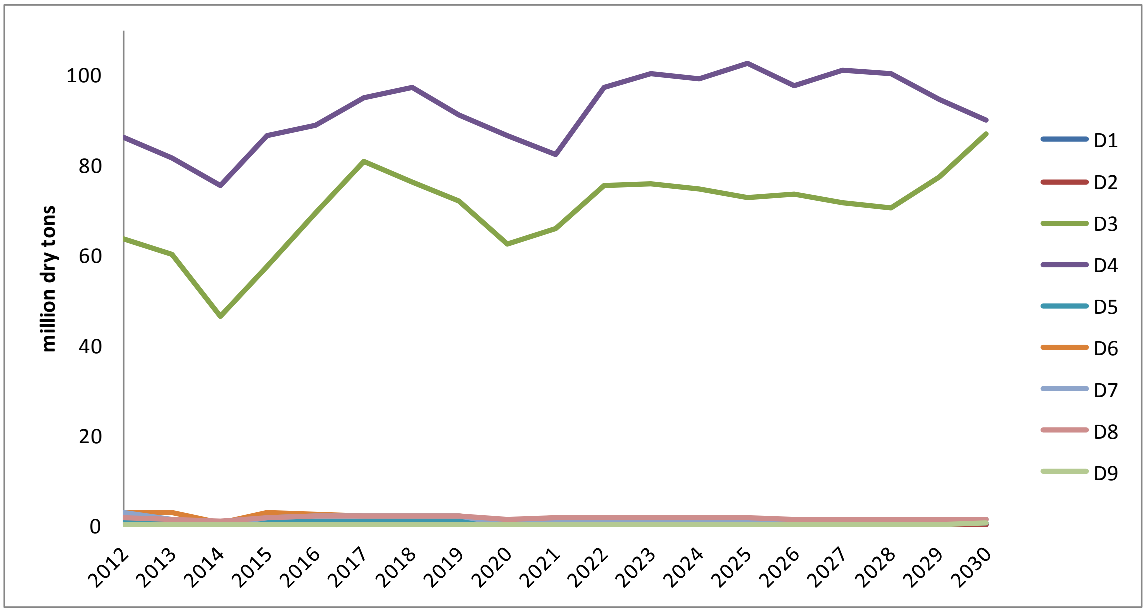


Figure 7: Simulated harvested corn stover volumes dedicated to ethanol production

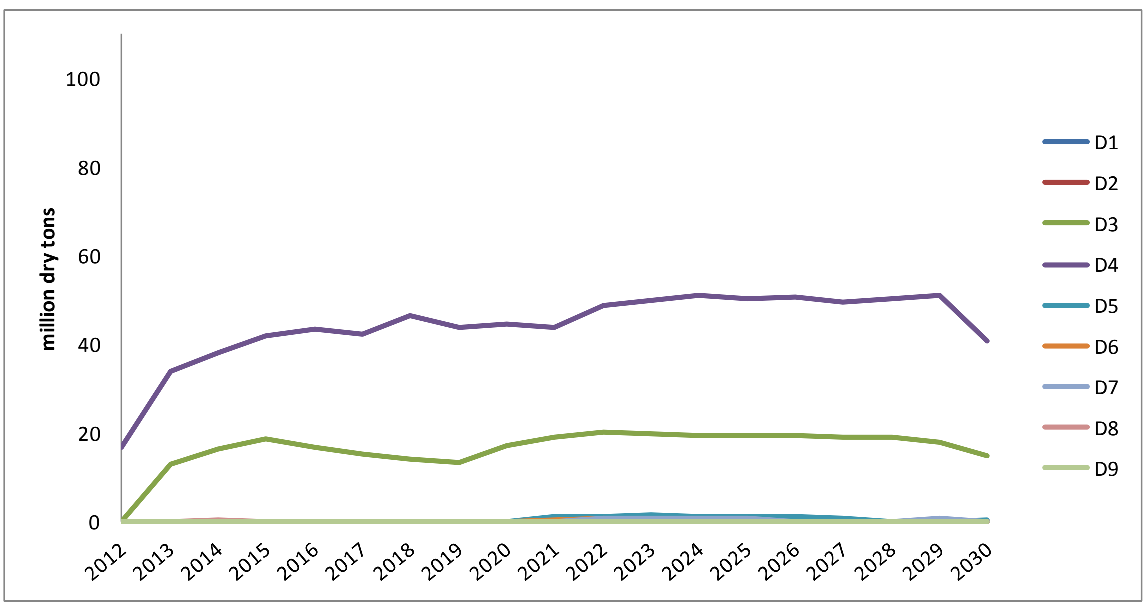


Figure 8: Simulated harvested switchgrass volumes dedicated to ethanol production

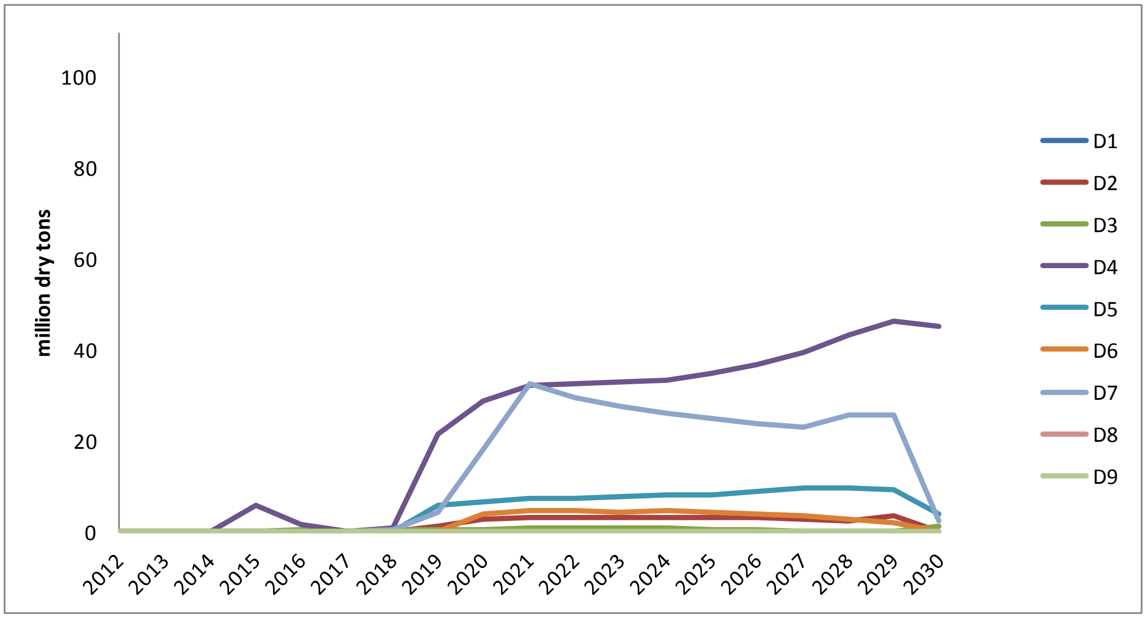
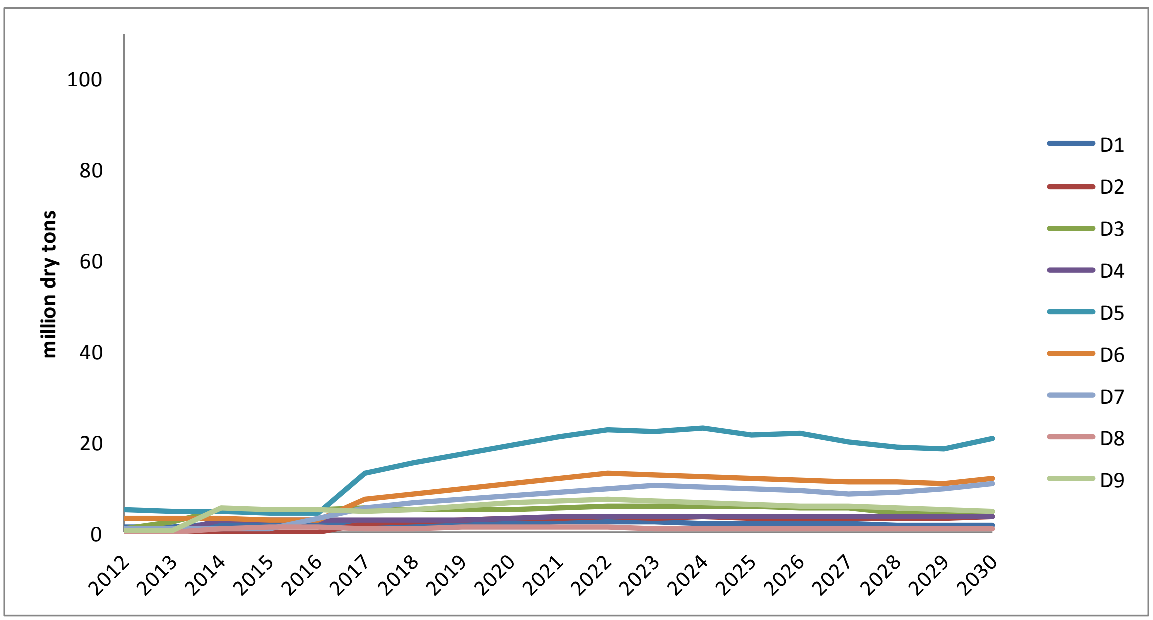


Figure 9: Simulated harvested forest biomass volumes dedicated to ethanol production



Stover is estimated to be the most cost-effective initial cellulosic feedstock. The harvested volumes of stover enter early, helping to meet the 2017 RFS-2 goals, and then oscillate between 50 and 70 million dry tons throughout the planning period. Two forms of biomass feedstock expand significantly in the 2017-2022 period, the time when rapid growth in advanced biofuels production is mandated. Energy-dedicated crops, exemplified by switchgrass, are not available in significant volumes until the end of this decade and the national harvested volume reaches a peak of 86 million dry tons in 2029. Census Division 4 (West North Central) reveals itself as the major producer of switchgrass followed by Census Division 7.

These divisions contain some of the states for which largest switchgrass yields are projected (Wullschleger et al, 2010). As for forest biomass, Census Division 5 (South Atlantic) is the major producer of ethanol from forest biomass, followed by the other two southern divisions. Even though the availability of forest biomass is stable throughout the planning period, its use experiences a significant increase around 2016. From 2020 to 2030, the total volume of forest biomass collected for biofuel production remains stable around 60 million dry tons.

The most cost-effective conversion technology identified given the current data in this model is thermochemical biorefineries. Some capacity of this type is built in every region. The capital costs of thermochemical facilities are higher than for biochemical conversion units but this premium is more than offset by its lower variable costs of operation. On the higher side of the cost spectrum lies a biochemical biorefinery with feedstock flexibility. With both large fixed and capital costs, this is the only biorefinery type for which no investment takes place in the whole planning period. We expect that one reason for this outcome is that the reference scenario does not yet adequately recognize the value of biorefinery flexibility. For clarity, given its low penetration, flexible biochemical technology has not been included in the next set of figures, which depict the evolution of capacity stock for the various biorefinery types.

Figure 10: Simulated capital stock for dry mills

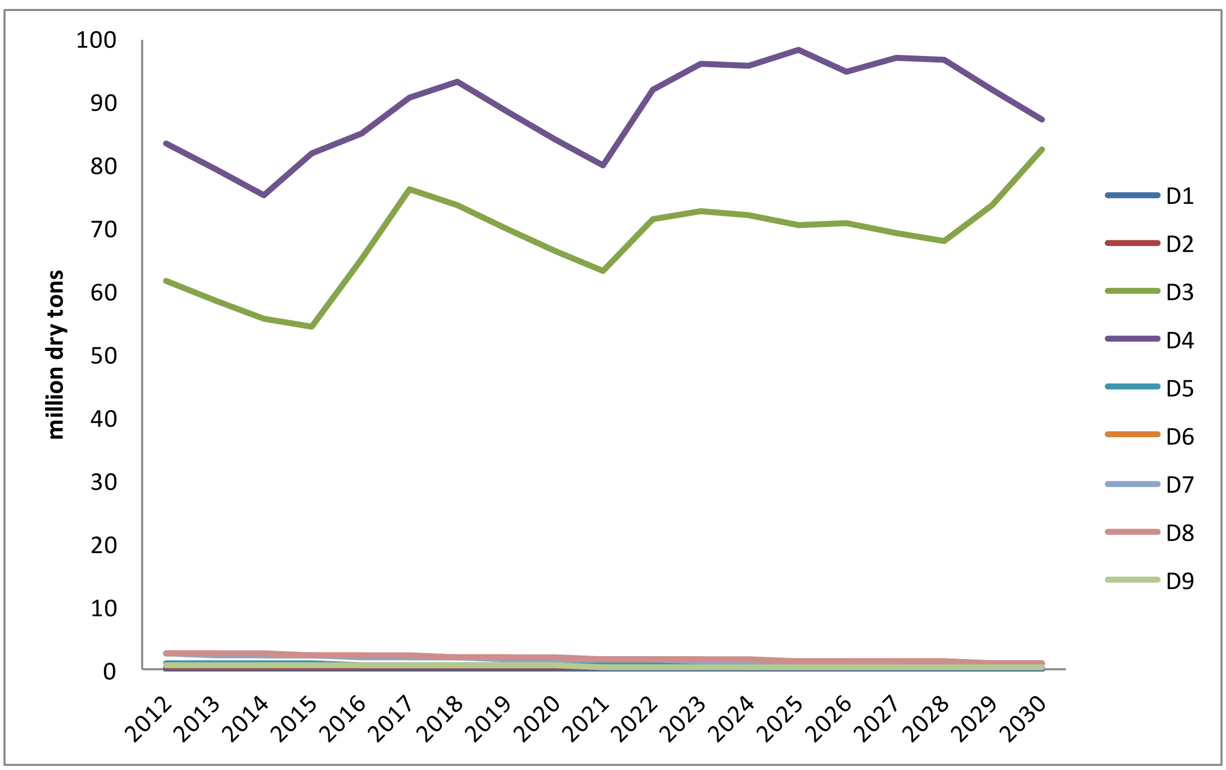


Figure 11: Simulated capital stock for stover-dedicated biochemical biorefineries

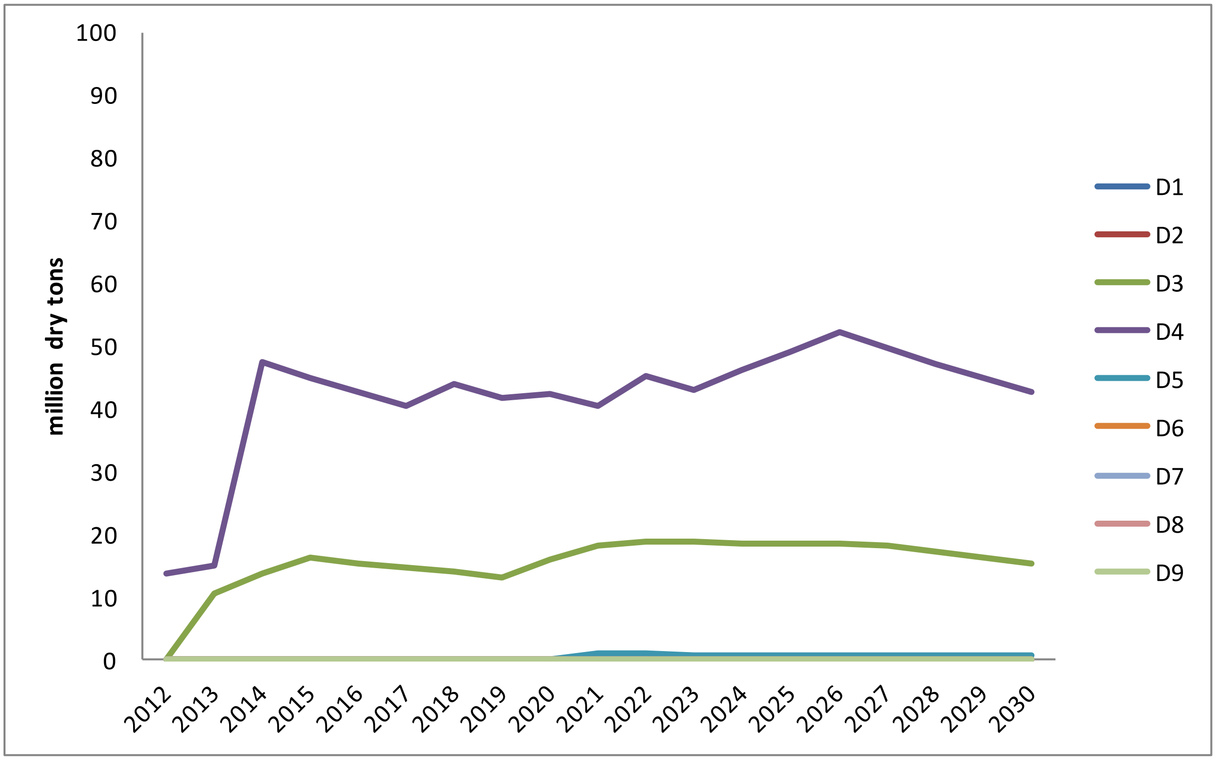


Figure 12: Simulated capital stock for switchgrass-dedicated biochemical biorefineries

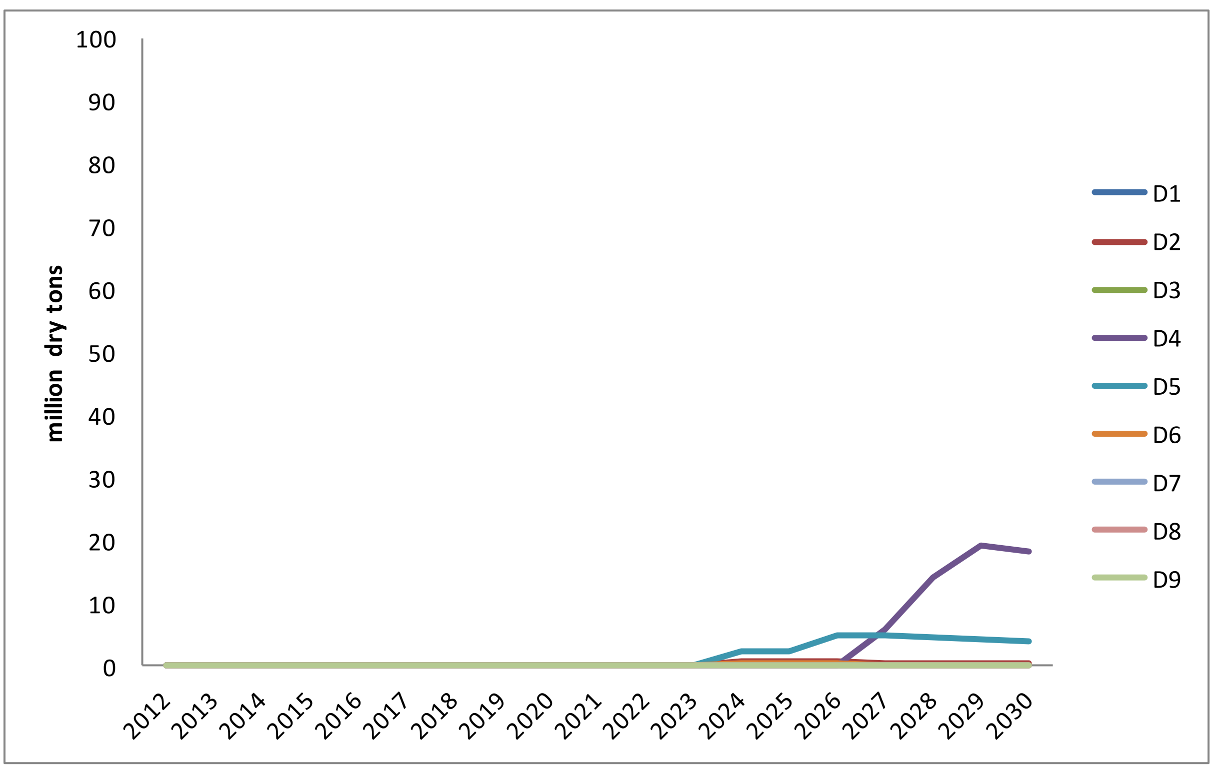
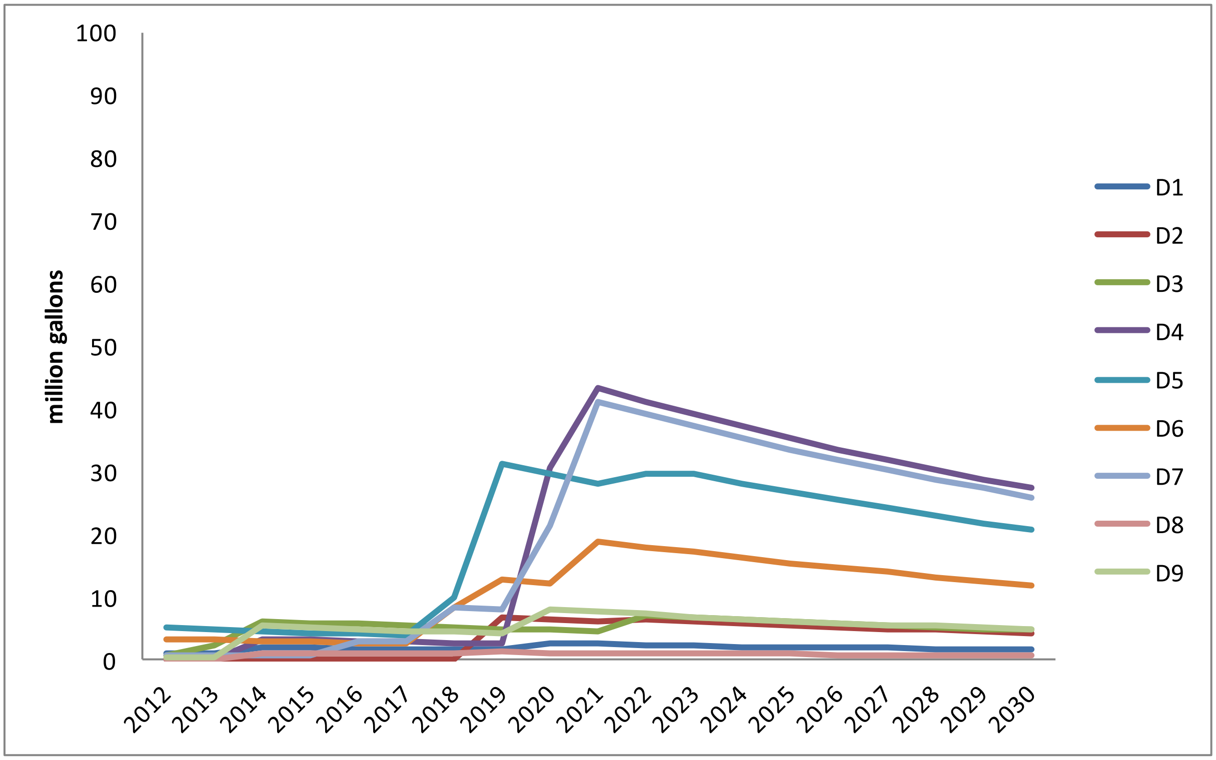


Figure 13: Simulated capital stock for thermochemical biorefineries



For dry mills, no big increase in total capacity takes place, which is consistent with the limit to corn ethanol production being close to what can be produced with the existing fleet of dry mills. Investment in biochemical biorefineries dedicated to stover happens early in the planning period and only in the two corn-belt divisions (3.East South Central and 4.West North Central). On the other hand, biorefineries that use exclusively use switchgrass as feedstock are developed only in the last few years of the period of analysis. Most of the investment in this kind of plant takes place in Census Division 4 (West North Central) which has, by far, the highest switchgrass density (an average of over 300 dry tons per square mile in the year 2030). A first few thermochemical biorefineries are built at the beginning of the planning period throughout the country. But the large jump in investment takes place in 2017. It is at this point that the advanced logistics system is adopted which favors large biorefinery sizes. The optimization of biorefinery sizes given feedstock densities, transportation and capital costs finds that optimal sizes for thermochemical biorefineries are larger than for the other conversion technologies.

Figure 14 and Figure 15 show how thermochemical biorefineries combine the various cellulosic feedstocks for two years: 2015 and 2022.

Figure 14: Simulated feedstock fractions used by thermochemical biorefineries (2015)

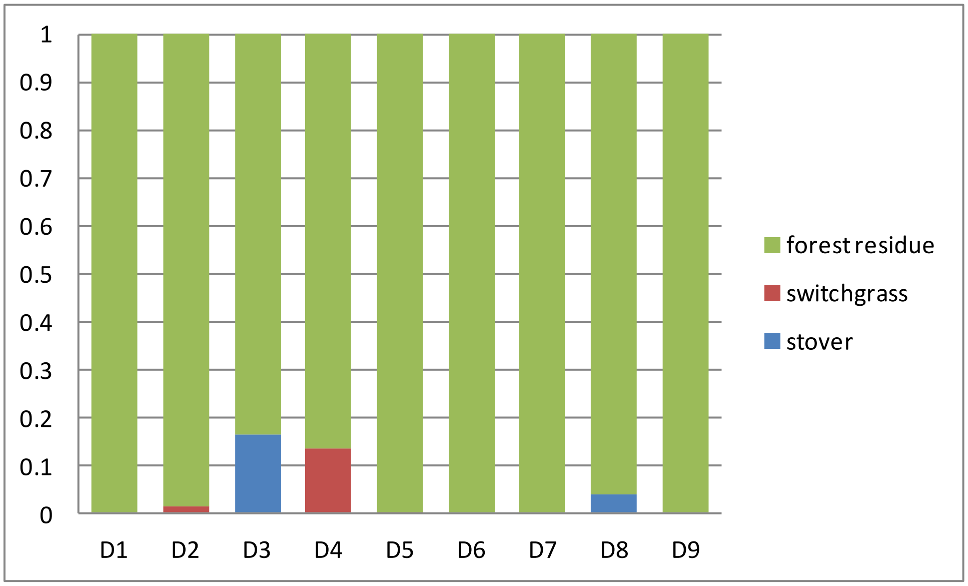
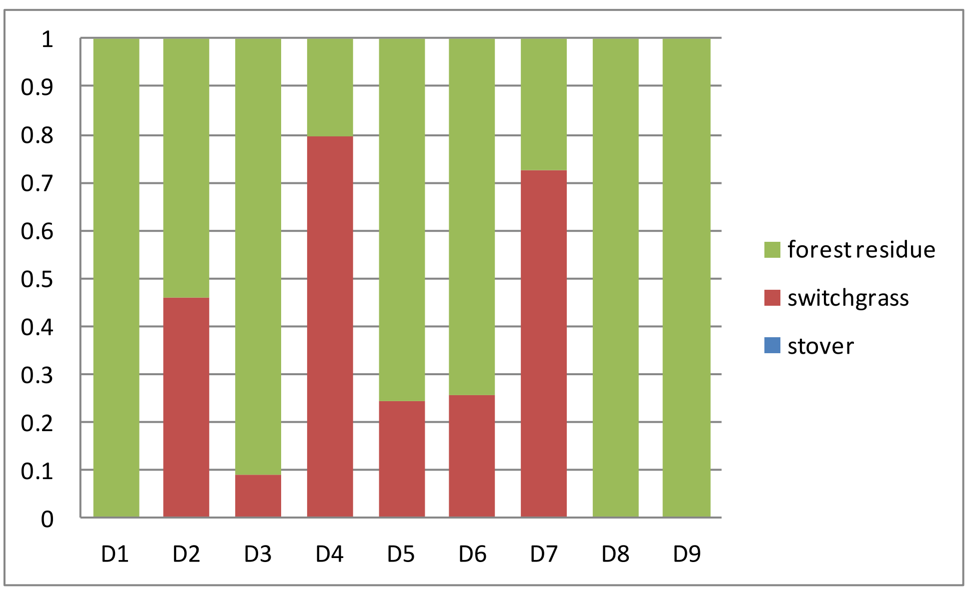


Figure 15: Simulated feedstock fractions used by thermochemical biorefineries (2022)



Among the feedstocks considered here, forest residue produces the highest yield per dry ton in the thermochemical conversion process. On the contrary, corn stover produces the lowest amount of ethanol per dry ton. The relative yield advantage of forest biomass partly explains it being the preferred feedstock, as indicated in Figure 14 and Figure 15. Corn stover is only used in the first few years as a complement to forest residue where no switchgrass is available and stover displays a cost advantage large enough to compensate its lower yield. A cost advantage that offsets the slight yield disadvantage for switchgrass relative to forest residue also explains why switchgrass becomes the primary feedstock for thermochemical biorefineries by 2022 in Census divisions 4 and 7 (West North Central and West

South Central). For Census Divisions 3, 5 and 6 (East North Central, South Atlantic and East South Central), forest residues remain the primary feedstock throughout the entire planning period.

The other infrastructure component whose evolution is tracked by BioTrans is retail capacity. As indicated in the previous section, the two variables that determine E85 retail capacity are the fraction of retail stations that offer them and the fraction of pumps in those stations which are dedicated to this alternative blend. Figure 16 and Figure 17 show the evolution profile for those two variables. Simulated results display large variation across regions in the share of retail stations offering E85 by 2030.

Figure 16: Simulated E85 station share

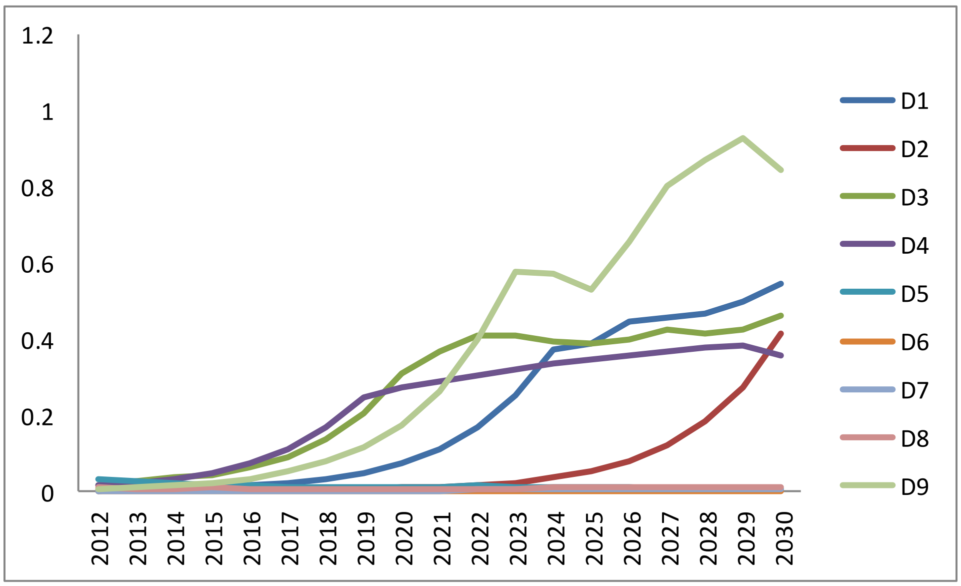
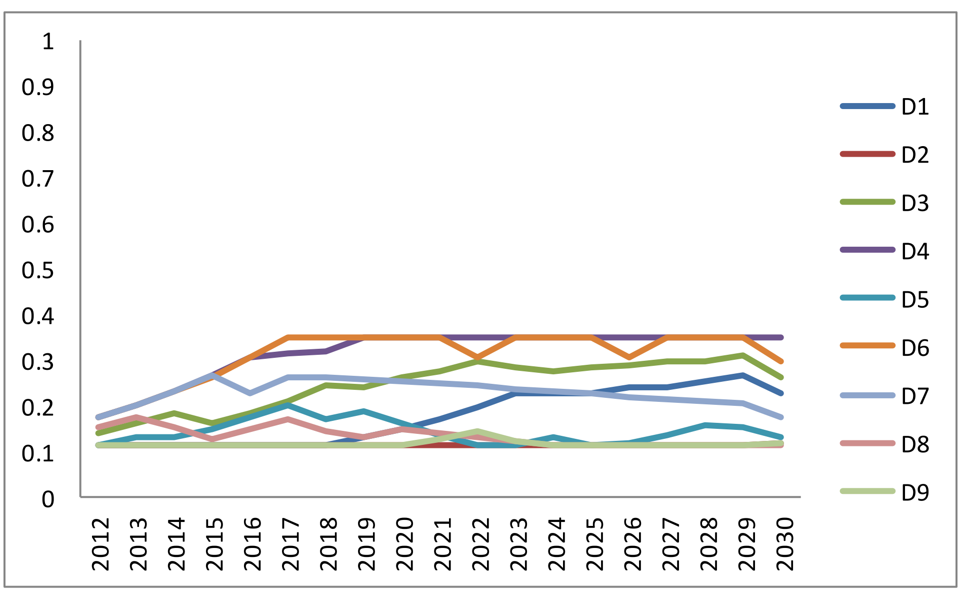


Figure 17: Simulated E85 pump share in multifuel stations



These two figures need to be jointly considered to determine which regions have the largest E85 retail capacity. The average size for retail stations is different in each region and has been estimated based on the maximum average throughput observed in the 2006-2009 period.[6] Thus, the highest shares of stations and pumps do not necessarily lead to the largest retail capacity expressed in millions of gallons of gasoline equivalent (gges). Pump share is restricted not to be higher than 0.35, which is equivalent to assuming that only one underground storage tank would be dedicated to ethanol. Each tank services up to 3 pumps and the average number of pumps, according to a survey by the National Association of Convenience Stores (NACS), is 8.6.

For retail stations, the capital cost modeled in BioTrans depends on load factor. Therefore, the lower that gasoline demand during the forecast horizon is relative to the throughput-based estimate of capacity, the most expensive is to replace retiring capacity with new E85 pumps. Census Division 3 (East North Central) leads the ranking of E85 retail capacity followed by Census Divisions 9 (Pacific) and 4 (West North Central). Overall, E85 retail capacity is heavily concentrated in the northeastern and north central regions (Census Divisions 1 through 4) and in Census Division 9 (Pacific).

4. Simulated unit costs of ethanol and fuel blends

The unit cost of ethanol, at the refinery plant gate, can be decomposed into feedstock costs at the farm field-edge, biomass logistics costs and biorefinery conversion costs. Figures 18 and 19 highlight that the biochemical conversion of corn stover is a potentially low-cost early strategy, despite its comparatively high conversion costs, because of its very low feedstock and logistical cost. The possibly-optimistic technological cost estimates for cellulosic ethanol conversion imply lower plant-gate costs for cellulosic ethanol than (unsubsidized) corn-ethanol. Costs vary slightly from one census division to another, e.g. with early cost-advantages in the corn belt (Division 4, West North Central). From 2015 to 2022 we observe an increase in logistical costs, as feedstock pre-processing enables cheaper shipping, storage, and longer supply chains. This move toward feedstock commoditization allow larger biorefineries to reach to larger feedstock supply markets, and mitigates upward pressure on undelivered feedstock prices.

[6] This average throughput as the ratio of gasoline demand and number of stations in each region. Data on number of retail stations were obtained from the Alternative Fuels and Advanced Vehicles Data Center http://www.afdc.energy.gov/afdc/. Data on gasoline demand are from Annual Energy Outlook 2010.

Figure 18: Simulated unit costs of ethanol at the plant gate (West North Central region)

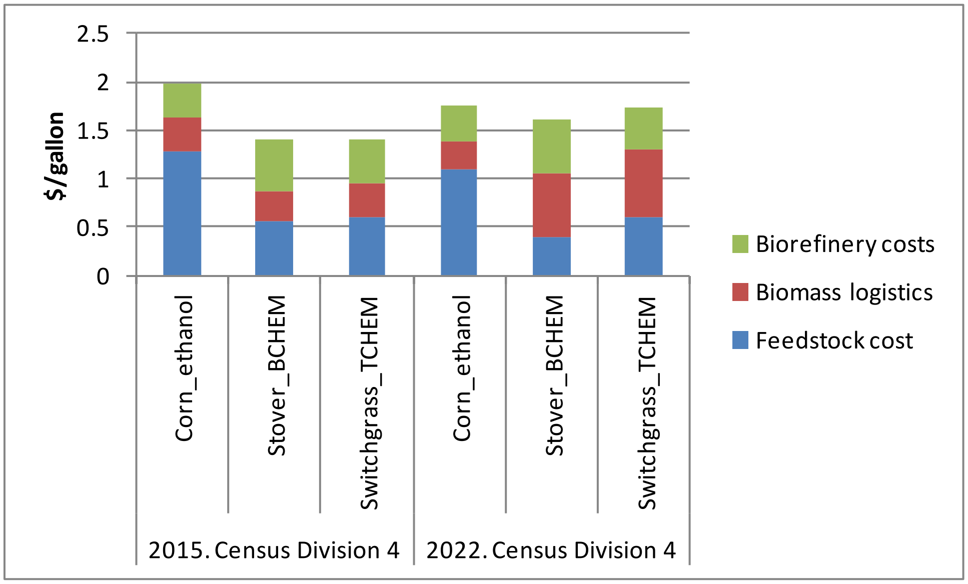
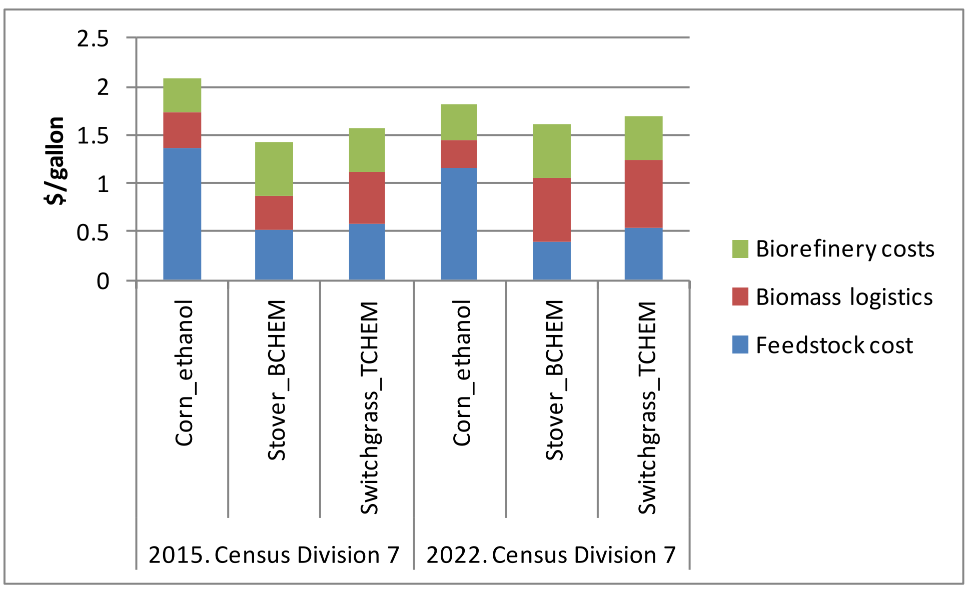


Figure 19: Simulated unit costs of ethanol at the plant gate (West South Central region)



Since cellulosic pathways result in lower cost ethanol at the refinery gate, the model chooses to produce more cellulosic ethanol that is strictly necessary to meet the RFS-2 standard in most periods. However, the final objective is not to produce ethanol but fuel blends. Figures 20 and 21 add the other cost categories needed to get to a price per gallon of gasoline equivalent of E10 or E85 at the retail pump. For E10, not surprisingly, the cost of gasoline overwhelms all other categories. For E85, the cost of gasoline makes up approximately 1/3 of the total.

The fuel retail component accounts for the cost of transporting the blend (E10 or E85) from the wholesale terminal to the retail stations as well as the costs of retail infrastructure and the O&M costs associated to the retailing activity. All together, they about 10% of the unit cost of E85 in 2015 (versus 8% for E10). By 2022, the retail cost fraction is close to 8% for both blends. The slightly higher retail cost of E85 toward the beginning of the planning period has to do with low utilization factors of the new E85 infrastructure in those first years. As soon as the utilization factors for E85 retail stations become comparable to those of conventional gasoline blends, the cost of retail infrastructure is very similar for both.

Figure 20: Simulated unit cost of E85 at the retail pump

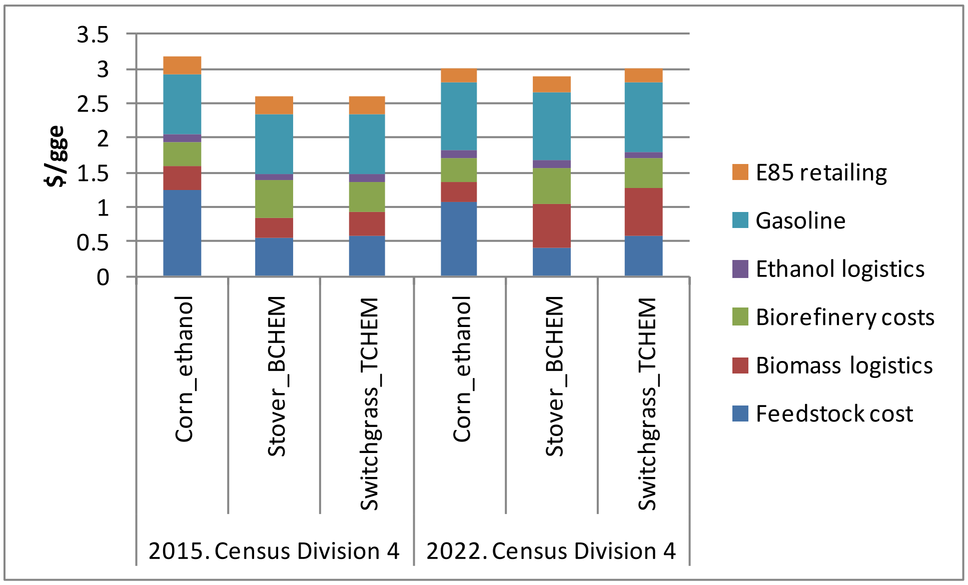
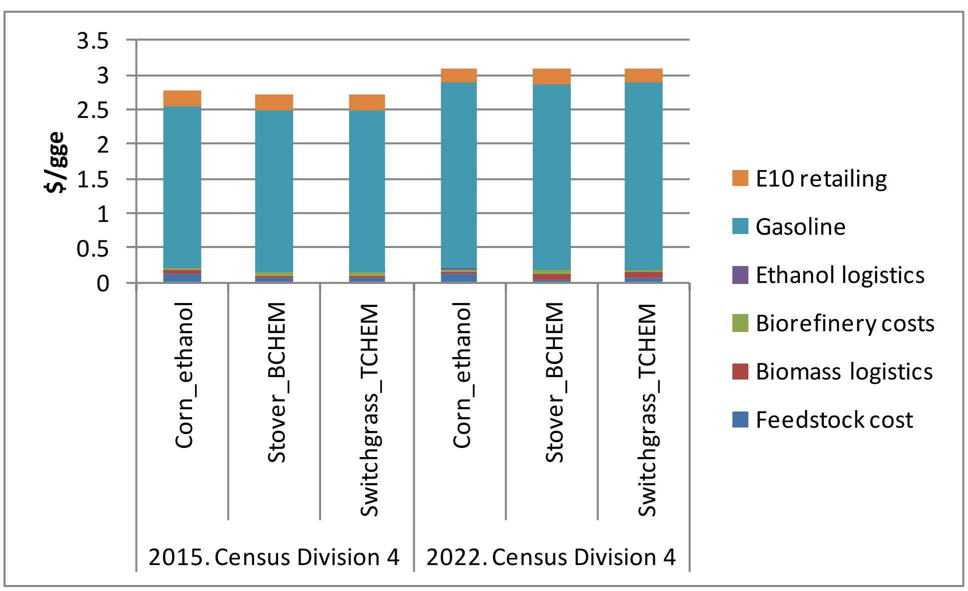


Figure 21: Simulated unit cost of E10 at the retail pump



5. System performance under shocks

Given the strong interest in improving fuel supply stability and energy security, it is important to continue evaluating the effects of biofuels on fuel price volatility and the resilience of the biofuel system to supply shocks (e.g. Hertel and Beckman 2011, Diffenbaugh et al. 2012). We are using the BioTrans model to test the market cost of biomass supply shocks as a function of modeled system flexibility. Annual crop shocks were simulated for two system configurations:

1) System with minimum (unconstrained) inventory levels for biomass and no feedstock flexibility in thermochemical biorefineries

2) System with a maintained (exogenous) stock-to-use ratio of 15% for biomass and flexible feedstock capability in thermochemical biorefineries

Preliminary simulation of an unanticipated 50% increase in costs of corn and corn stover in Census Divisions 3 and 4 (for 2023 and 2024) led to $12.2 billion in national costs without the flexibility elements, and about twenty percent lower costs ($10.0 billion) with them. Other shock types, e.g. to yields of energy crops like switchgrass, suggested significantly higher benefits to stocks and flexibility, but further exploration is needed.

6. Future work

For biofuels to deliver on their full promise to enhance energy security, reduce greenhouse gas emissions and revitalize rural economies, system configuration matters. System configuration includes feedstock choice, farming practices, feedstock logistical design, biorefinery technology mix, feedstock and fuel inventory management, and the delivery of either blends, neat fuels, or drop-in replacement biofuels. The BioTrans model analyzes long-run, strategic developments and interactions at the national system level, to help understand costs and benefits of alternative mixes of feedstocks, processes and fuels that may supply US light-duty vehicle needs in a more sustainable, secure fashion.

Continued work is planned to address some of the limitations of BioTrans and other biofuel supply chain models. Certain feedstocks are omitted (wheat straw, poplar, MSW). The results presented do not model the possible role of new “drop-in” or direct-replacement biofuels. The cost of new E85 (or other specialty biofuel) distribution and retail infrastructure may be underestimated, because excess fuel retail capacity and retail institutional issues may mean that there will be only slow retail capital turnover, and little new capacity investment. The modeling framework, which characterizes market outcomes by minimizing system cost, may be over-concentrating production in some regions, and over-specializing in some feedstock/fuel pathways. Finally, further work is needed to address the role of risk and its influence on firm investments and consumer choices.

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