

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Understanding the Developing Cellulosic Biofuels Industry through Dynamic Modeling

Emily Newes, Daniel Inman and Brian Bush
*National Renewable Energy Laboratory
 United States of America*

1. Introduction

Biofuels are promoted in the United States through aggressive legislation, as one part of an overall strategy to lessen dependence on imported energy as well as to reduce the emissions of greenhouse gases (Office of the Biomass Program and Energy Efficiency and Renewable Energy, 2008). For example, the Energy Independence and Security Act of 2007 (EISA) mandates 36 billion gallons of renewable liquid transportation fuel in the U.S. marketplace by the year 2022 (U.S. Government, 2007). Meeting such large volumetric targets has prompted an unprecedented increase in funding for biofuels research. Language in the EISA legislation limits the amount of renewable fuel derived from starch-based feedstocks (which are already established and feed the commercially viable ethanol industry in the United States); therefore, much of the current research is focused on producing ethanol—but from cellulosic feedstocks. These feedstocks, such as agricultural and forestry residues, perennial grasses, woody crops, and municipal solid wastes, are advantageous because they do not necessarily compete directly with food, feed, and fiber production and are envisaged to require fewer inputs (e.g., water, nutrients, and land) as compared to corn and other commodity crops. In order to help propel the biofuels industry in general and the cellulosic ethanol industry in particular, the U.S. government has enacted subsidies, fixed capital investment grants, loan guarantees, vehicle choice credits, and aggressive corporate average fuel economy standards as incentives. However, the effect of these policies on the cellulosic ethanol industry over time is not well understood. Policies such as those enacted in the United States, that are intended to incentivize the industry and promote industrial expansion, can have profound long-term effects on growth and industry takeoff as well as interact with other policies in unforeseen ways (both negative and positive). Qualifying the relative efficacies of incentive strategies could potentially lead to faster industry growth as well as optimize the government's investment in policies to promote renewable fuels.

The purpose of this chapter is to discuss a system dynamics model called the Biomass Scenario Model (BSM), which is being developed by the U.S. Department of Energy as a tool to better understand the interaction of complex policies and their potential effects on the burgeoning cellulosic biofuels industry in the United States. The model has also recently been expanded to include advanced conversion technologies and biofuels (i.e., conversion pathways that yield biomass-based gasoline, diesel, jet fuel, and butanol), but we focus on cellulosic ethanol conversion pathways here. The BSM uses a system dynamics modeling approach (Bush et al., 2008) built on the STELLA software platform (isee systems, 2010) to

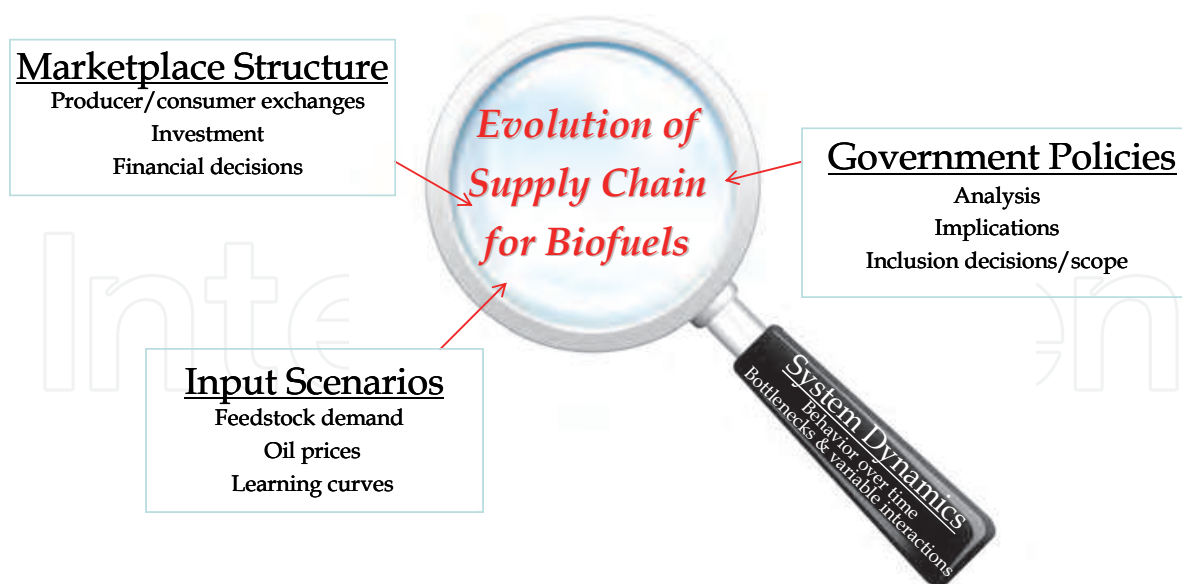


Fig. 1. Key components of the Biomass Scenario Model

model the entire biomass-to-biofuels supply chain. Key components of the BSM are shown in Figure 1. In addition to describing the underpinnings of this model, we will share insights that have been gleaned from a myriad of scenario- and policy-driven model runs. These insights will focus on how roadblocks, bottlenecks, and incentives all work in concert to have profound effects on the future of the industry.

2. Model background

The major sectors of the ethanol supply chain are shown in Figure 2. Each sector (feedstock production, feedstock logistics, biofuels production, biofuels distribution, and biofuels end use) has been modeled as a standalone module but is linked to the others to receive and provide feedback. The feedstock production module simulates the production of biomass as well as other crops (corn, wheat, soybeans, cotton, and other grains) through farmer decision logic, land allocation dynamics, new agricultural practices, markets, and prices. The feedstock logistics system models the harvesting, collection, storage, preprocessing, and transportation of biomass feedstocks from the field (or forest) to the biorefinery. The conversion module has three conversion technologies [corn dry mill, biochemical (dilute acid enzymatic hydrolysis), and thermochemical (indirect gasification and mixed alcohol synthesis)] at four scales (pilot, demonstration, pioneer, and full-scale commercial). The ethanol produced during conversion is then distributed throughout the region(s). The model is solved numerically at a sub-monthly level and reports output for the timeframe of 2005 to 2050. Although the description herein implies a linear flow of information between the modules, in reality the modules receive and react to information in a complex, non-linear fashion that depends on, among other things, industrial learning, project economics, installed infrastructure, consumer choices, and investment dynamics. The model is geographically stratified, using the 10 U.S. Department of Agriculture (USDA) farm production regions as a basis, which facilitates analysis of regional differences in key variables. The BSM is particularly facile at addressing the following types of inquiries:

- Which sources of feedstock might plausibly contribute substantially to production in different regions of the United States?
- Under what combination of policies does the biofuels industry observe gradual, sustained growth?
- What gasoline price scenarios have the potential to increase biofuels adoption?

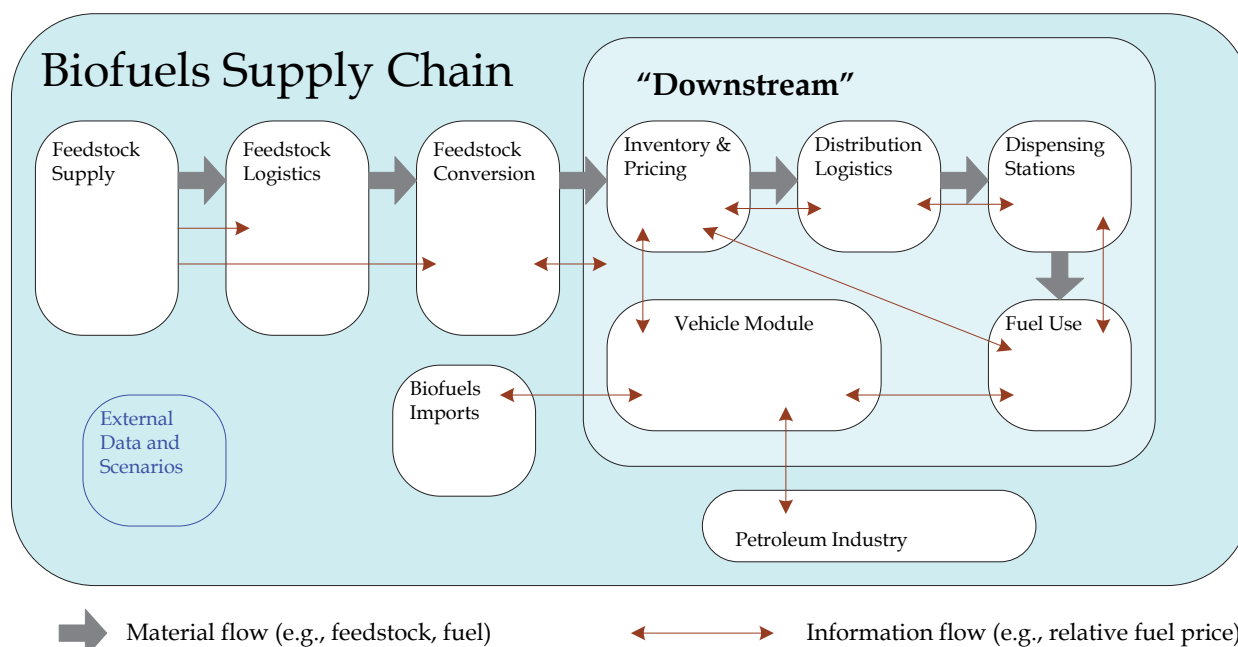


Fig. 2. Architecture of the BSM

3. System dynamics structure

Transitioning from the United States' current petroleum-based transportation fuel economy to one that incorporates significant amounts of alternative and renewable transportation fuels is characterized and addressed in the BSM as a "system of systems" problem. System dynamics, as a modeling discipline, focuses on the relationships and feedback among parts of a system and helps identify possible unintended consequences of certain inputs along with synergistic effects, bottlenecks, and leverage points for intervention; it is an established methodology for analyzing the behavior of complex, real-world feedback systems over time. Figure 3 shows a causal loop diagram, which is a visual way to explain key connections in a dynamic system for a simplified conception of the cellulosic ethanol supply chain. It also shows the direction of the main feedbacks in the system. Its broad, high-level approach captures the entire supply chain.

Within each module, the BSM contains several key decision-making variable interactions with complicated, yet understandable, logic. The major dynamic components that make up the model are described in this section.

3.1 Feedstock production dynamics

In the BSM, the production of both commodity and energy crops is governed by the dynamics of farmers' decision making, land allocations, crop markets, and farmers' transition to new agricultural practices (i.e., switching from growing traditional crops to

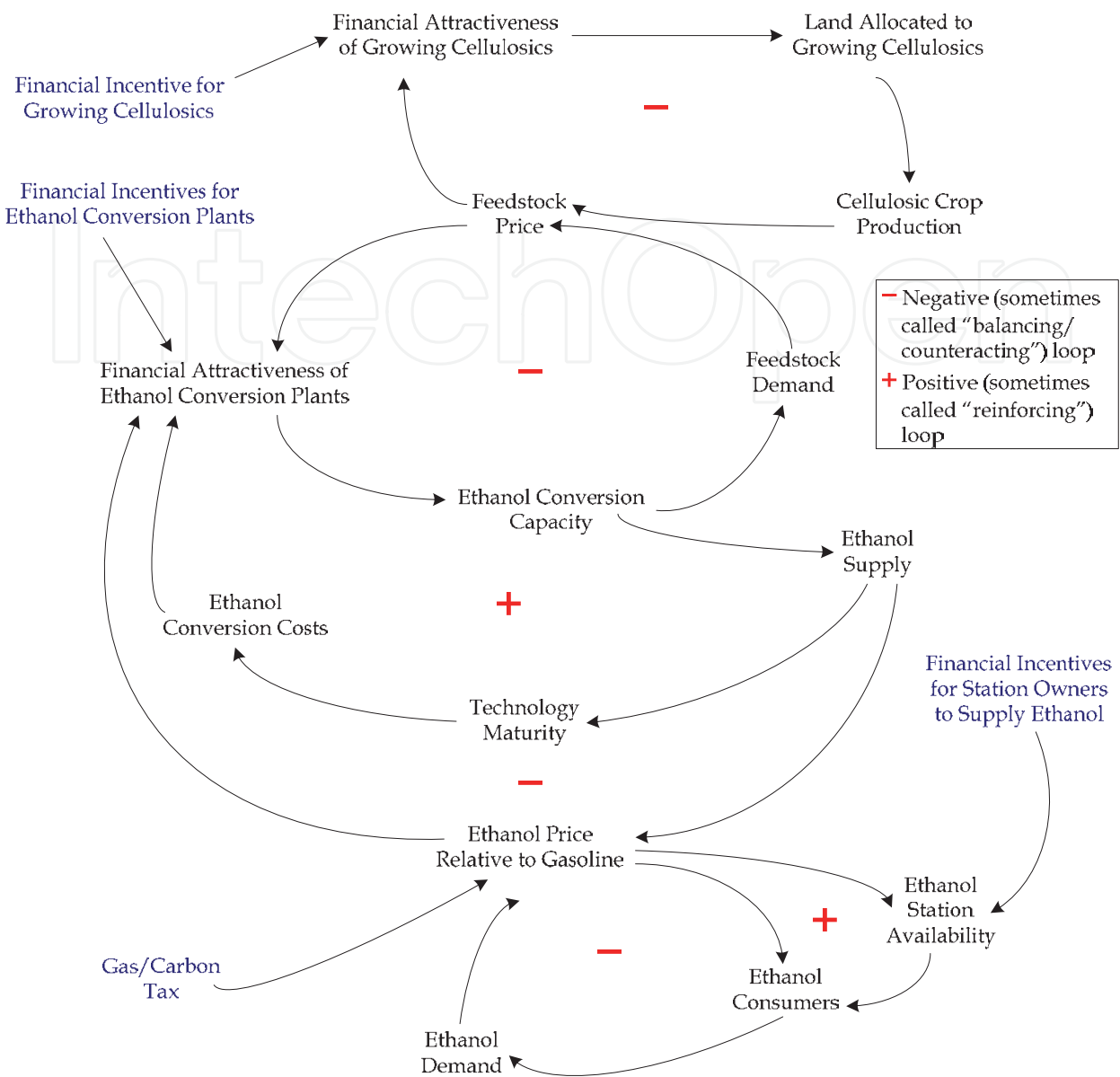


Fig. 3. Causal loop diagram representing key variable interactions in the BSM

either harvesting residues or explicitly growing energy crops). At a high level, there is a balancing loop (also known as a negative feedback loop) that controls feedstock production; this loop is shown in the upper right hand portion of the causal loop diagram in Figure 3. In this balancing loop, feedstock prices (as received by the farmers) directly affect the attractiveness of growing cellulosic crops; the higher the feedstock price being paid, the more attractive it is for farmers to reallocate land from commodity or hay crops to growing energy crops or harvesting agricultural residues. When land is allocated to growing energy crops, at the expense of producing commodity crops, the supply of the former is reduced, which can, in some situations, result in higher regional prices for the commodity crops. Conversely, as more farmers switch to new practices and allocate land to producing cellulosic crops, the availability of cellulosic material increases, which will cause the price paid for cellulosic feedstocks to be reduced, thereby diminishing the attractiveness of producing cellulosic crops; thus, the loop is balanced. Implicit in the very simple causal loop

diagram depicted in Figure 3 and described above are numerous complex feedback loops, both balancing and reinforcing (also known as positive feedback loop), that interact across all modules of the BSM. Both types of feedbacks play important roles: balancing loops often encourage stability (in feedstock prices, for instance), and reinforcing loops encourage development (in growth of overall production capacity). The descriptions in Section 3.2–Section 3.5 provide more detail on the dynamics that underpin farmer decision making, land allocation, crop markets, and transitions to new practices. Key insights that pertain to these specific areas as well as to feedstock production, in general, will also be highlighted and discussed.

3.2 Farmers' decision making

Farmers make decisions each season that affect the supply side of agricultural markets. For example, each year individual farmers have to choose what crop(s) to plant and what portion(s) of their land they will utilize for these crops. At the farm level, these decisions are based on a myriad of factors including local climate, available equipment, land base, capital, past experience, tolerance to risk, and market cues such as future pricing and anticipated payments (e.g., farm subsidies). In the BSM, farmer decisions are nested in the Feedstock Supply Module (FSM). Farmers' decisions that are explicitly captured in the BSM include the type of crop grown during a particular year (commodity crop, no crop, hay crop, or bioenergy crop) and amount (area) of land dedicated to the production of the crop(s). Decisions on whether to cultivate bioenergy crops or to collect crop residues are based on endogenous net revenue calculations that are applied to a nested logit-based land-allocation model (Figure 4). Within the FSM, potential net payments to growers are calculated for each of the 10 USDA farm production regions. Net per-acre grower payments reflect the profitability of land, including subsidies, across its various uses less the costs of production, harvesting, storage, and transportation. Subsidies contained in the FSM include the Biomass Crop Assistance Program, which is administered by the U.S. Department of Agriculture and which provides a per-ton payment to farmers producing energy crops, an establishment payment for the establishment of woody and herbaceous crops, and a per-acre annual payment for those in designated project areas. The BSM contains different subsidy inputs based on current government programs and policies that could be potentially implemented. They can be altered depending on the user-defined scenario and are updated as regulations change. Two separate grower payments are considered for commodity crop (corn, wheat, soybeans, other grains, and cotton) production: (1) grower payments for production of primary and secondary crops and (2) grower payments for production of a primary crop with a crop residue potentially available for collection and processing for ethanol conversion. Production costs taken from the Policy Analysis System (POLYSYS) model (The University of Tennessee n.d.) for commodity crops, primary and secondary crops, and crop residues include collection and plant nutrient replacement (e.g., fertilization). POLYSYS is an agricultural economics simulation model that computes the volume of agricultural commodity production for a given farm gate price for each of the USDA farm production regions. The gross value of the primary crop is the crop price multiplied by the yield (tons per acre) plus any government subsidy; the gross value of the secondary crop is specified as a fraction of that for the primary crop. The net grower payment is calculated as the difference between the gross value and the production costs. Similarly, the value of residue from annual crops is the residue price minus the production costs.

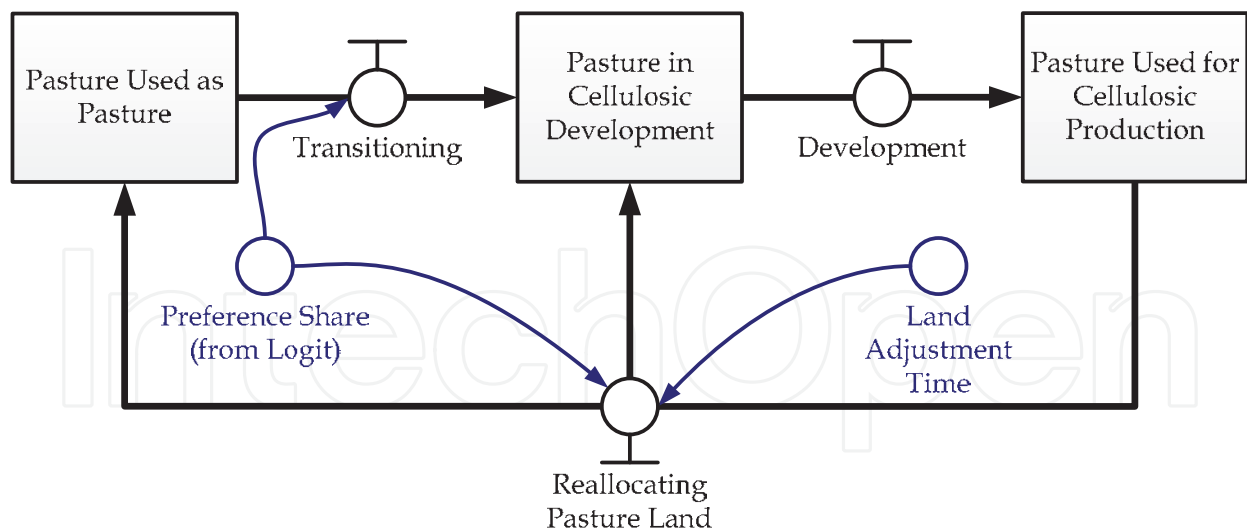


Fig. 4. Land allocation structure for pasture land allocation decisions

3.3 Land allocation

Land allocation in the BSM is driven by the farmers' decisions and is nested in the FSM, where land is allocated by a modified nested logit model that tracks correlations among decisions to allocate land to commodity crops (with or without the collection of crop residues), hay, and perennial energy crops. The logit model accounts for economic contributions (e.g., expected net revenue per acre) and non-economic contributions to the utility of land-allocation choices. For each production region, the model treats separately the distribution of land among pastureland and active cropland; within each of these categories, the "desired" allocation of land among specific crops was calculated from the nested logit, which was calibrated by comparison to long-term agricultural forecasts annually published by the USDA and where the nesting involves broad crop categories at the higher level and individual crops at the lower level. By determining distribution of land, we accounted for the fraction of land associated with growers who have adopted the new practice of producing cellulosic feedstocks (crop residue and/or perennial energy crops). Over time, the land allocations gradually adjust themselves toward the distribution indicated by the farmers' planting decisions. This logic works to reflect results of micro-level decision making by farmers and accounts for land area. The resolution with which land is tracked in the FSM is based on the USDA agricultural production regions and accounts for regional differences in production costs, yields, and potential feedstock supply. Available cropland is divided into three categories: active cropland, pastureland, and Conservation Reserve Program (CRP) (U.S. Department of Agriculture, 2011) land (shown in Table 1). Active land can be used to produce annual crops, perennial energy crops (herbaceous and woody), and hay. Five major types of cellulosic feedstocks are modeled: herbaceous energy crops, woody energy crops, crop residues, forest residues, and urban residues. Allocation of land within the FSM is based on net revenue calculations for the different crops, which are input to the logit function. Expected crop yield, price (i.e., grower payment), and production costs are all considered and integral to the net revenue calculations. The supply of commodity crops (wheat, corn, soybeans, cotton, and small grains) is similarly computed from the land base. The actual production from each source is calculated dynamically by regional price signals and competition among land uses. The model respects the fact that land-use change does not occur suddenly and that perennial

energy crops pass through a development period where yields are lower than their mature production value. For each region, the desired separation of land among CRP, pastureland, and active cropland uses is determined after the distribution of land among specific crops is calculated. Determining the distribution of land accounts for the fraction of land that is associated with new practices (producing cellulosic feedstocks). Over time, the land allocations are adjusted toward the distribution “desired” by the farmers via a diffusion model with a single rate constant. This logic works to reflect results of micro-level decision making by farmers and accounts for the potential alternative uses of land area.

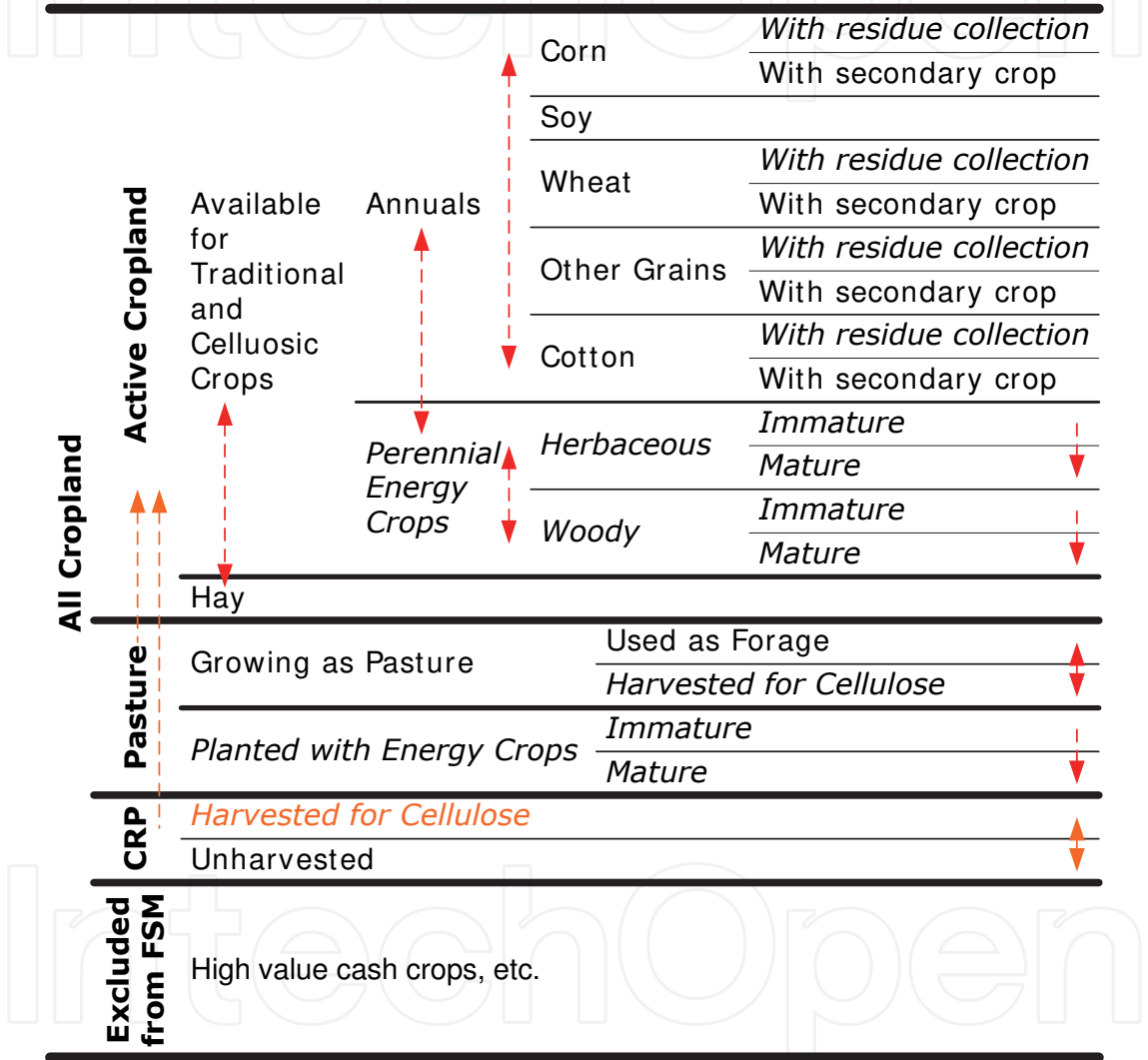


Table 1. Land categories and corresponding production combinations that are tracked in the FSM

3.4 Crop markets

The market for commodity crops, hay, and energy crops is captured in the FSM; it provides a physical basis for generating a supply of biomass feedstocks for cellulosic ethanol production, while representing the economics of and physical constraints within the U.S. agricultural system. The FSM includes a market mechanism that provides feedback in the FSM, connecting production and demand for agricultural products. The basic feedbacks that

drive changes in price for annuals are (1) the total inflow (roll-up of regional production and imports) relative to total consumption (domestic, export, shrinkage) and (2) the stock-to-use ratios relative to long-term ratios (allowing “target” stock-to-use ratios to float over time). For annuals, the regional production is rolled into aggregate inventory, and a single aggregate price index is generated for each annual; multipliers (derived from regional price variation in the incoming data set) are then used to provide regional price variations. The structures of the cellulosic feedstock and hay markets are similar to the annuals markets, but these are region-specific rather than national. Because transporting bulky feedstock over long inter-regional distances is costly, it was necessary to model separate markets for feedstock in each USDA region. The production levels of annuals and their prices were calibrated to USDA baseline projections. A simple diffusion structure within the module captures the adoption of new practices (crop residues and dedicated perennial energy crops) (Figure 5). The crop market is captured on a regional basis, based on the feedstock production capacities of the 10 USDA farm production regions and regional ethanol demands. In the BSM, the regional feedstock demands emerge endogenously from the simulation via the feedbacks between supply, demand, and logistics and associated capacity constraints. For perennial energy crops, the production costs vary annually over the life cycle of the project, which is generally 10 years, but can vary regionally. The supply/demand structure provides key feedbacks to the crop markets, connecting production and demand for agricultural products. The basic feedbacks that drive changes in price for commodity crops are (1) the total inflow (aggregate of regional production and imports) relative to total consumption (domestic, export, and shrinkage) and (2) the stock-to-use ratios relative to long-term ratios (allowing target stock-to-use ratios to float over time). For commodity crops, the regional production is represented as a single price index and is generated for each crop; multipliers are then used to provide regional price variation. The structures of the cellulosic feedstock and hay markets are similar to the commodities markets, but they are regional as opposed to national. The production volume of commodity crops and their prices are calibrated to USDA annual baseline projections (Interagency Agricultural Projections Committee, 2007). Within the crop market, cellulosic crops compete equally with commodity crops.

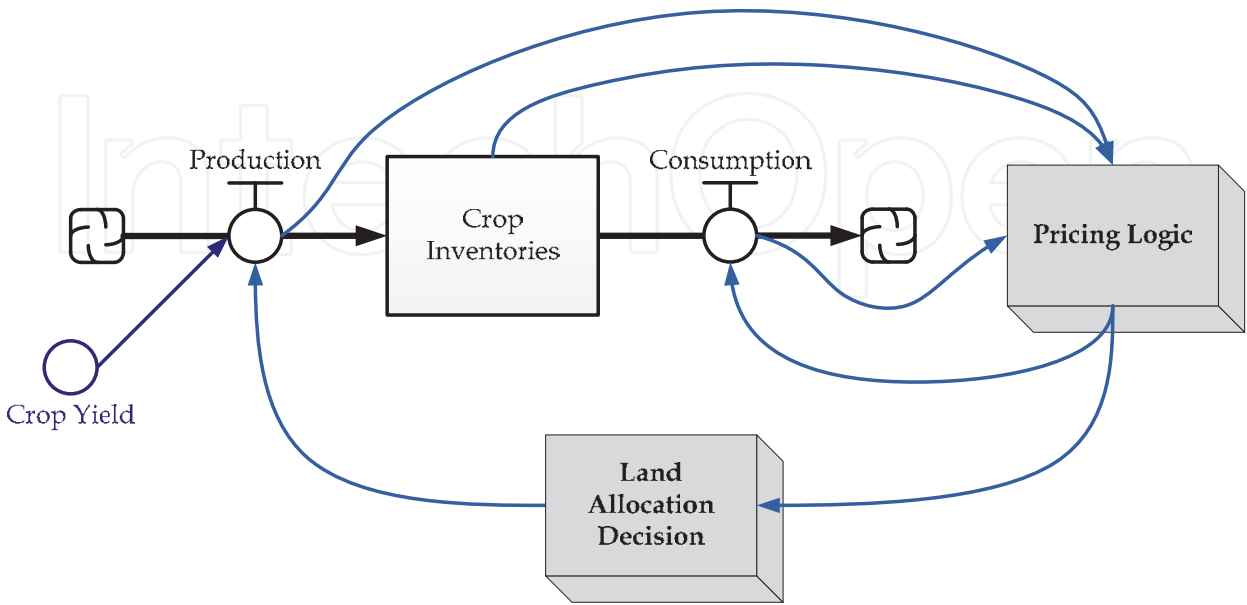


Fig. 5. Stock and flow structure showing the crop market, as modeled in the BSM

3.5 Transition to new practices

In the BSM old and new practices are defined as producing traditional commodity crops and producing biomass for conversion to fuel, respectively. Figure 6 shows the stock and flow structure that governs the transition to and from new practices. The fraction of old and new practice producers, within each region, is calculated endogenously by considering a combination of factors including expected net revenue and proximity to a biorefinery; only land that is within a biorefinery’s collection radius (discussed in section 3.6) can shift to “new practices.” As with other aspects of the FSM, much of the driving force behind transitioning to new practices is economic incentives in the form of grower payments received by the producers. The key drivers impacting the movement of producers to new practices are profitability per acre (for crop residues or cellulosic energy crops) as well as proximity to a biorefinery. New practices include both growing energy crops (herbaceous and woody) and collecting agricultural residues. The BSM accounts for potential presence of extremely risk-averse producers by tracking a subset of producers that will not shift to producing cellulosic material under any circumstances. The influences integral to the diffusion and uptake of new practices are represented by a simple modeling structure (Figure 6) that categorizes producers as employing “old” or “new” practice. The rate at which producers move from old to new practice is constrained by a scenario-dependent, exogenously-specified function of expected revenue. In the model, only the new practice farmers consider planting perennial energy crops, collecting crop residues, or harvesting cellulose from pasture or CRP land. The way in which the transition is modeled in the BSM allows for the analyses to explore questions around producers’ conservatism. The amount of land in new practices is a key factor in cellulosic feedstock price stability in some regions; see Figure 7 for an example of the relationship between new practices and cellulosic ethanol production.

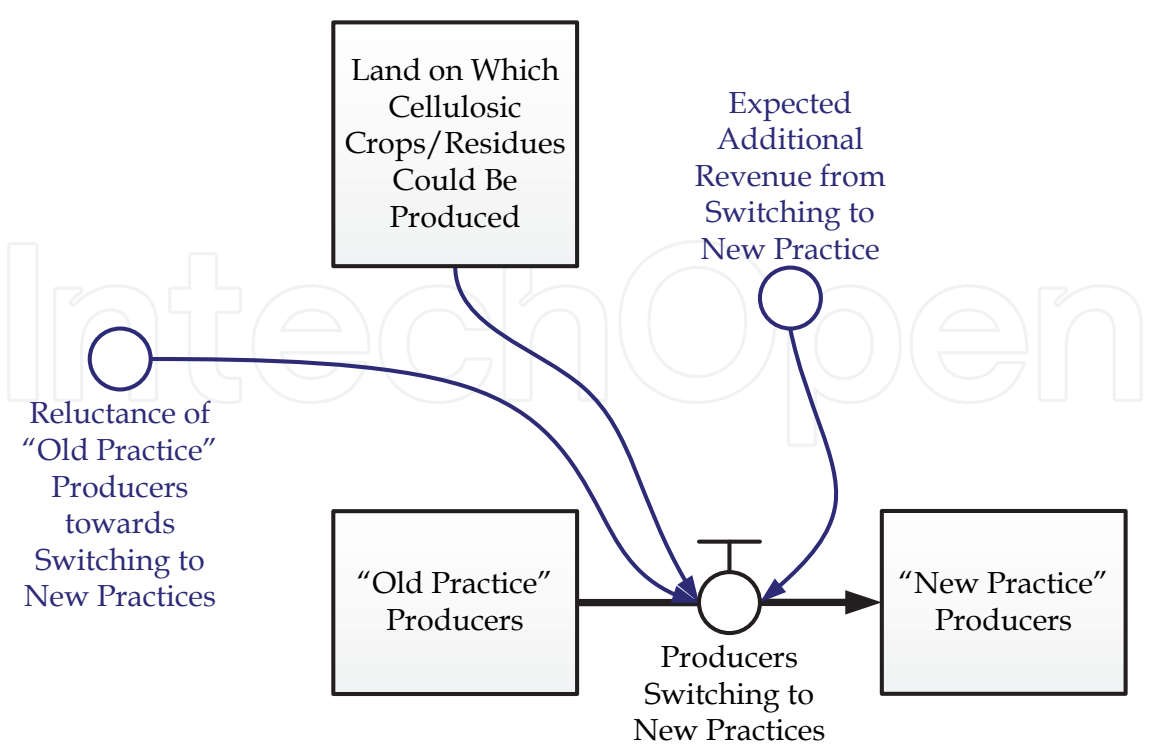


Fig. 6. Stock and flow structure showing the transition to new practices

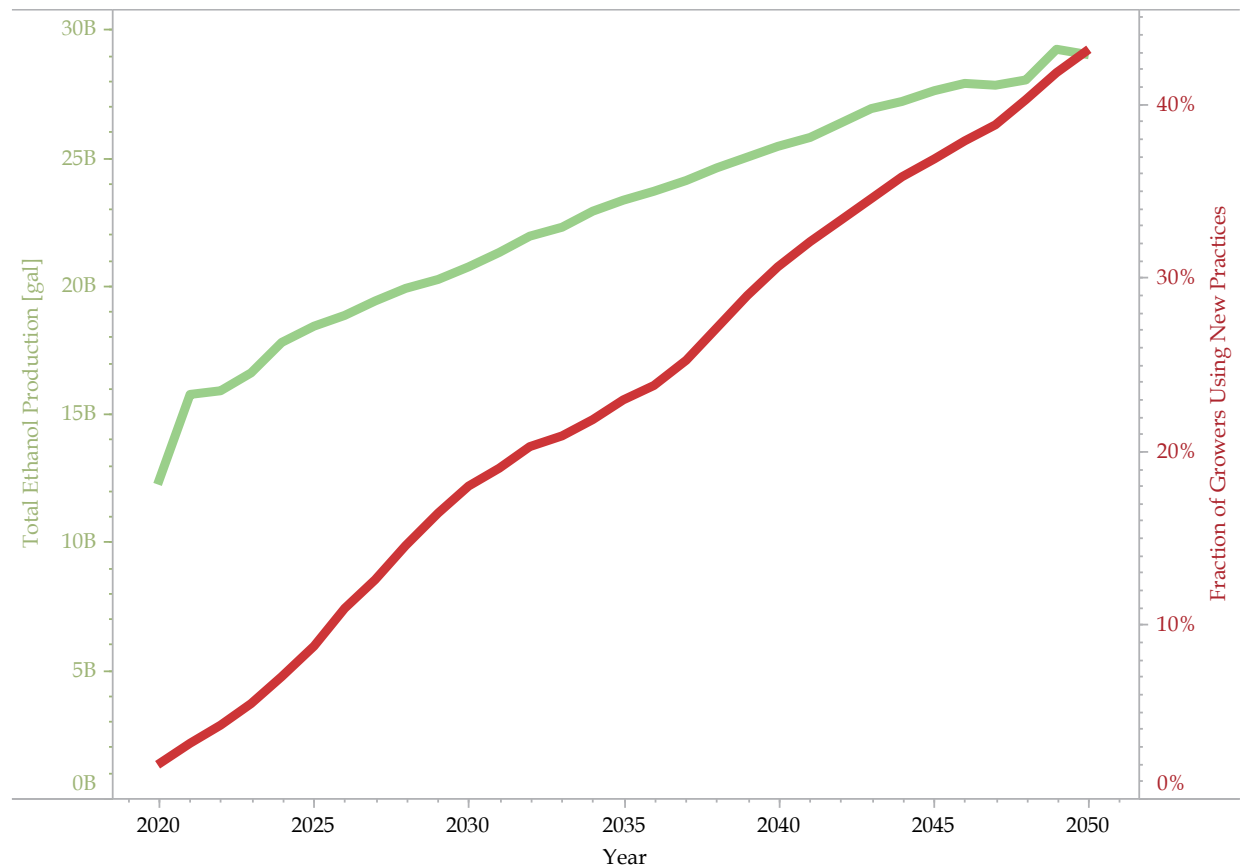


Fig. 7. Relationship between adoption of new practices and cumulative ethanol production; figure is based on results from the reference case (discussed in Section 4)

Multiple scenarios have been run using the BSM to provide insights into the biomass to biofuels supply chain; some important feedstock market insights include:

- **Feedstock Price Floor/Subsidy:** Subsidies and policies focused on the feedstock production side of the ethanol supply chain alone do little towards pushing the system to meet the annual volumetric production goals outlined in the Renewable Fuel Standard II (RFS), which mandates 36 billion gallons by 2022 (U.S. Environmental Protection Agency, 2010). Establishing a price floor on cellulosic crops, where producers are guaranteed a minimum price, has little effect on transitioning to new practices and stimulating cellulosic feedstock production during the early years of industry development. However, a price floor does have a small but positive system-wide effect in the mid- and long-term if it is sustained. The greatest benefit is realized at a price floor above \$70 per dry ton. At the \$100-level, crop market instability is observed because the investment climate (e.g., willingness to invest in new biorefineries) causes the demand for cellulosic biomass to oscillate; market signals cause producers to over- and under-produce biomass. This oscillation is accentuated by the fact that perennial energy crops take between three to eight years to mature.
- **Initial Feedstock Prices:** As with a price floor and subsidy, high initial feedstock prices alone are not sufficient for meeting RFS volumetric goals. That said, in terms of total cellulosic feedstock production, an initial feedstock price \$80 to \$90 per ton does promote the production of cellulosic feedstocks throughout most of the USDA farm production regions. Lower initial feedstock prices (less than \$80 per ton) cause growers

to not allocate land to producing cellulosic feedstocks, and the industry does not take off. At the other end of the spectrum, feedstock prices greater than \$90 per dry ton cause downstream bottlenecks that feed back to the farmers causing them to not produce cellulosic feedstocks. At a regional level, cellulosic feedstock prices show considerable fluctuation when the cellulosic feedstock market is beginning to develop (because the market is not large enough to support stable prices over time); prices typically stabilize as regional demand becomes substantial and its trend of increase becomes more gradual.

- **Feedstock Supply:** In general, feedstock production resources are available to contribute significantly towards producing renewable fuels (both cellulosic and starch-based) as long as the payments received are high enough to alter the farmers' decisions with regard to land allocation. Under high-demand scenarios, feedstock production is nearly stretched to its maximum. The dominant sources of feedstock are herbaceous energy crops and forest residues. Neither crop residues nor urban residues contribute significantly to the overall feedstock supply. In general, competition between energy crops and commodity crops does not substantially increase annual crop prices unless feedstock demand is high.

3.6 Collection radius

Whether a feedstock producer can participate in the market for cellulosic materials depends greatly on the location of conversion facilities. Transport distances for cellulosic feedstock are estimated regionally from combining (1) the endogenously computed weighted average feedstock yields for cellulosic energy crops and agricultural residues with (2) biorefinery size, (3) an assessment of the fraction of arable land available for cellulosic harvesting, and (4) geometric factors accounting for the layout of the road network. The final three drivers of transportation distance are specified exogenously. Collection radii and transportation distances are typically observed in most scenarios at around 30–50 miles and often decrease as industry maturity and harvest yields increase, although the opposite behavior might be seen in some alternative feedstock logistics scenarios.

3.7 Experience at different stages

The BSM explicitly represents learning-by-doing in the refining of cellulosic feedstocks into ethanol via a modeling technique known as “cascading learning curves.” This technique is an elaboration of common power-law representation of industrial learning that is typically expressed in the form $y = ax^b$, where y is the cumulative average cost per unit, x is the cumulative number of units produced, a is the cost of the first unit, and b is a constant characterizing the cost reduction that occurs with increasing experience. Learning occurs separately for each biofuels pathway (starch-ethanol, biochemically converted cellulosic ethanol, and thermochemically converted cellulosic ethanol), and the BSM actually tracks four scales of operation and maturity: (1) pilot, (2) demonstration, (3) pioneer commercial, and (4) full-scale commercial. Experience accumulates at each of these four scales, and each scale has a unique techno-economic characterization. In the cases of pilot and demonstration scale refineries, maturity is measured as the cumulative number of years of operation of plants at that scale; for pioneer and full-scale commercial plants, maturity is measured as cumulative industry output. Pilot- and demonstration-scale plants are specified

exogenously to the BSM as scenario inputs, while pioneer and full-scale commercial plants are generated endogenously, although additional plants in these stages can also be added exogenously. The maturity, M , is related to a set of techno-economic multipliers, m , by the following equations:

$$M = \begin{cases} 1 - (1 - M_0) \left(\frac{E^*}{C} \right)^{\left(\frac{1-R}{\ln 2} \right)} & \text{for } C \geq E^* \\ M_0 & \text{otherwise} \end{cases} \quad (1)$$

$$E^* = \max\{E, C_0\} \quad (2)$$

$$m = m_{\text{early}} (1 - M) + m_{\text{mature}} M \quad (3)$$

Where M_0 indicates initial maturity, E is the minimum experience for learning, E^* is the effective minimum experience for learning, C is the cumulative experience, C_0 is the initial cumulative experience, R is the progress ratio, m_{early} is the “early” multiplier and m_{mature} is the “mature multiplier”.

Maturity is the ratio of current experience compared to the experience of the “ n^{th} plant,” or the infinitely mature biorefinery at that scale. With each doubling of experience, the gap remaining between current maturity and full maturity is decreased by a percentage derived from the progress ratio¹. The progress ratio defines how much of the maturity gap remains after each doubling, meaning that maturity increases more slowly at higher progress ratio values. The multipliers are used to adjust the key techno-economic characteristics for the scale/stage as that stage matures. These learning curves “cascade” in the sense that the early multiplier for each stage equals the actual multiplier achieved at the previous scale; essentially, each subsequent stage builds upon the techno-economic learning that resulted from the previous stage. The key techno-economic biorefinery attributes affected by maturity at each stage are: (1) the conversion process yield, (2) the probability for technical yield, (3) input capacity, (4) capital cost for a new refinery, (5) technical risk in financial calculations, and (6) the portion of debt that can be financed through a loan to build a new plant. Within the model, the current attribute values are captured in the “state of the industry” variable and are the result of the maturity level across all stages; input data are taken from a variety of industry assessments, design reports, and research results. Figure 8 illustrates the interconnections between industrial development, learning, and investment in the BSM.

The structure of the BSM does not presuppose any particular evolution of the industry in terms of how pilot, demonstration, pioneer, and full-scale commercial operations are staged or scheduled. It is possible to “ride” the learning curve at any stage (scale of operation) of development if the introduction of new plants starting operation is carefully timed; investment at subsequent stages can compensate or substitute for a lack of investment in

¹Technically, the progress ratio is defined as the ratio of the gap between the state of the industry after a doubling of experience (typically cumulative years in operation or production) and the current state of the industry.

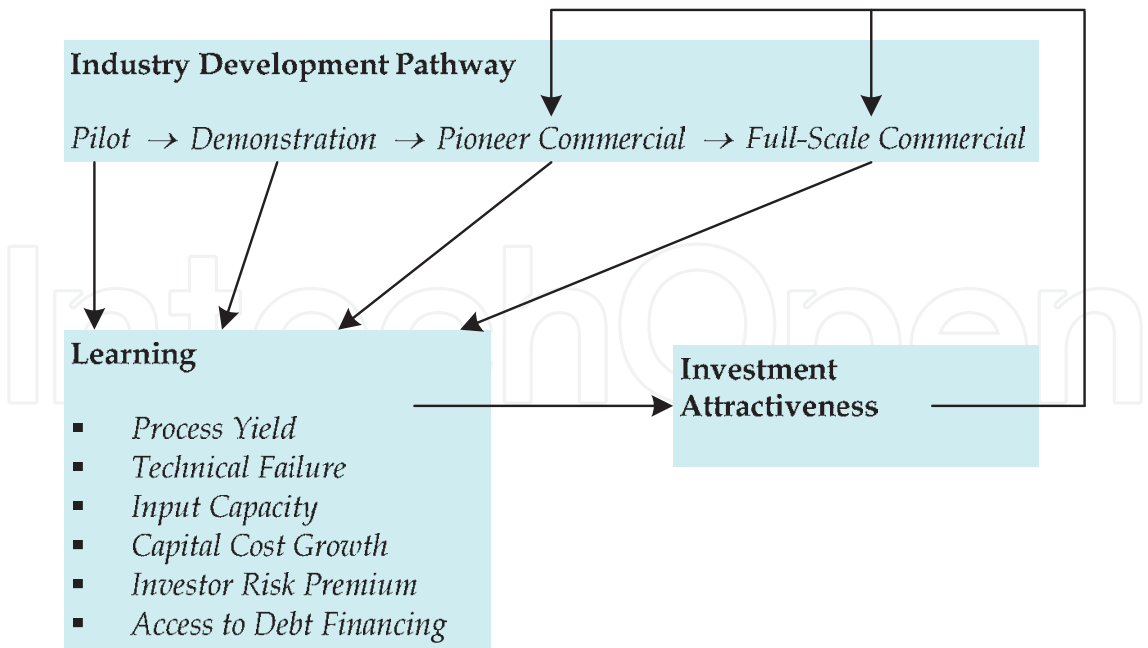


Fig. 8. Interaction in the BSM among learning, development, and investment

prior stages since an investment in a prior stage can affect the “starting point” for learning in subsequent stages. It is possible to construct development paths that are optimal in terms of cost or time by tracking learning curves and shifting investment to subsequent stages as the learning asymptote in a prior stage is approached. Figure 9 illustrates how process yield (quantity of ethanol produced per biomass input) and capital cost growth (ratio of the actual

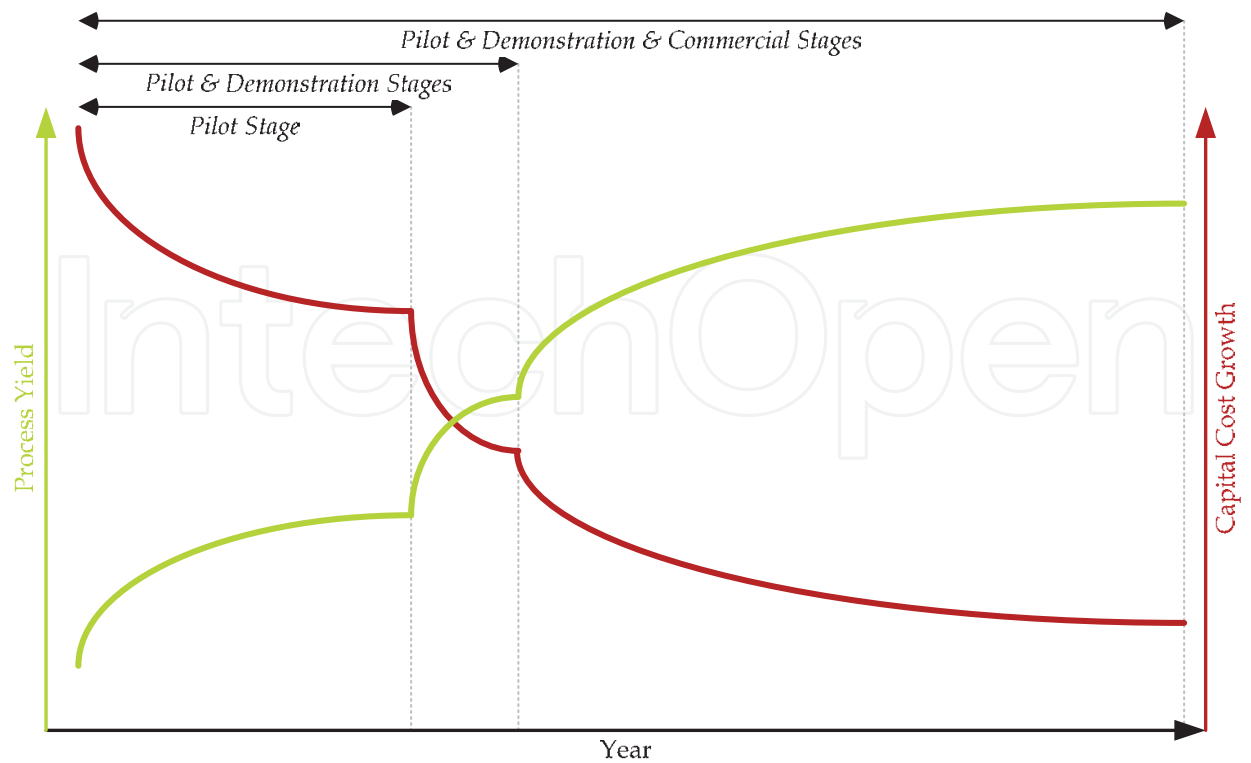


Fig. 9. Process yield and capital cost growth with different scales of operation

capital cost for a new plant to that cost when the industry is fully mature) rise or drop, respectively, as pilot, demonstration, and commercial experience accumulates. Analysis of realistic scenarios using the BSM has demonstrated the critical importance of industrial learning in the growth of the biofuels industry; policies that incentivize the early construction of even small numbers of pilot, demonstration, and pioneer plants typically have long-term positive impacts on ethanol production that are out of proportion with the cost of the policies.

3.8 Investment in biorefineries

The BSM uses a standard set of financial computations that mimic those that might be used by a potential investor to initiate the construction of a new pioneer or full-scale commercial biorefinery. These calculations compute the expected rate of return for the investment using major categories of revenue and expenses, assuming that ethanol price and other factors are constant over the plant lifetime. We assume straight-line depreciation, which significantly reduces detail complexity, constant tax and interest rates, and maturity-based capital costs and access to credit. The algorithm divides the biorefinery project into multiple periods (see Figure 10) whose present value is summed to arrive at an overall net present value for the prospective project. Figure 11 sketches the key elements of the algorithm. As the state-of-the-industry attributes improve through maturation, the estimated net present value increases and investment in new refineries becomes more attractive.

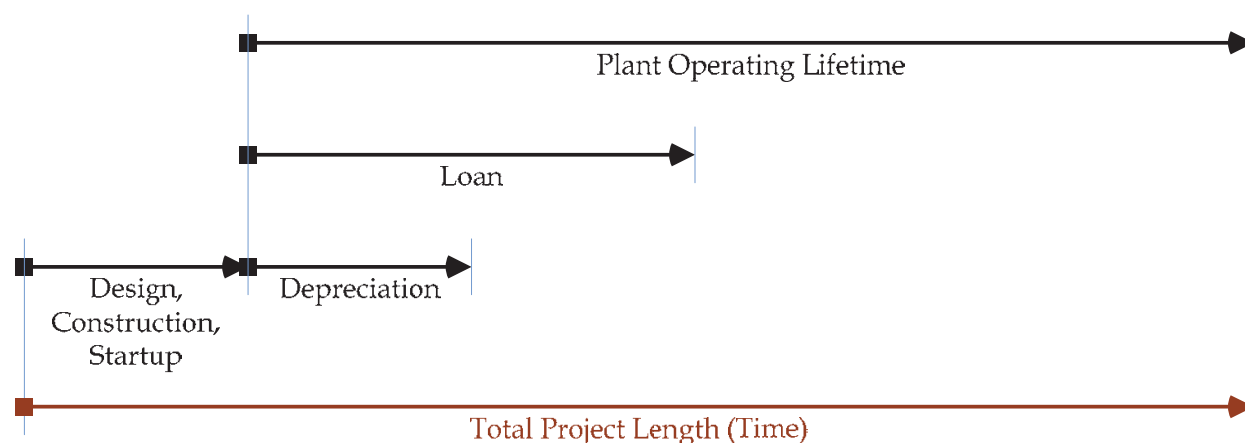


Fig. 10. Phases in the plant life cycle represented in the BSM

The conversion module in the BSM is responsive to a number of potential policies that improve the financial prospects of new biorefineries:

- **Product Subsidy:** Pays a fixed pre-tax amount to the ethanol producer at the plant gate for each gallon of cellulosic ethanol produced, improves the revenue stream in financial calculations, and enables regulators to indirectly manage the selling price of ethanol.
- **Feedstock Subsidy:** Pays a fixed amount to the non-corn feedstock suppliers (farmers) to lower the price paid by the cellulosic ethanol producer, which affects the expenses stream in the financial calculations and is not a direct subsidy of the ethanol production industry.
- **Capital Cost Reduction Subsidy:** Pays a percentage of the initial "cash" payment that is needed to start construction of a cellulosic ethanol pioneer-scale plant. The subsidy improves the construction cost of the pioneer-scale plants only and is a direct payment to the cellulosic ethanol producer.

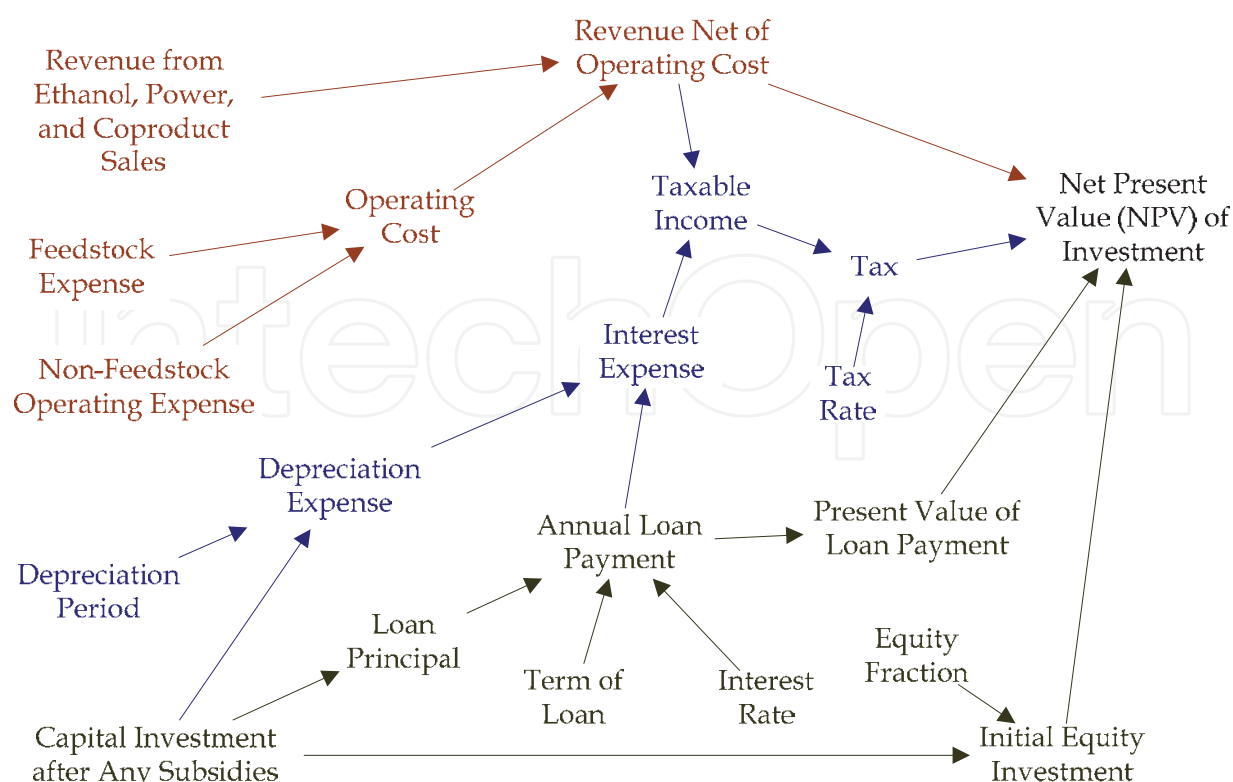


Fig. 11. Simplified representation of project economics computations in the BSM

- **Loan Guarantee:** Covers a fraction of loan given to a cellulosic ethanol producer to construct a pioneer-scale plant. The guarantee improves the ability of cellulosic ethanol producers to obtain financing for pioneer-scale facilities from banks and does not necessarily equate to a cost for the government if the ethanol plant is successful.

Typically one finds in scenario analysis that capital cost reduction and loan guarantee policies are somewhat substitutable and equally effective at addressing the cost barrier of the large amount of capital needed to build a biorefinery. Also, feedstock and product subsidies are mostly interchangeable and redundant. Rapid industry growth can be fostered by an early, but perhaps brief, implementation of policies, such as capital cost reduction and loan guarantees, followed by longer-term volumetric subsidies on feedstock or ethanol production that are gradually phased out.

3.9 Choice of plant type and location

Even if building a plant of a particular type is economical due to its net present value being favorable, it does not follow that such a plant would necessarily be built. Other biorefinery plant types might be more attractive or the general plant construction capacity (not just for biorefineries but for chemical plants and other large industrial facilities) in the nation might be constrained. In order to translate economic viability of the potential “next” plant into aggregate growth of the cellulosic ethanol industry by conversion option and region and to constrain the growth of industry in a “natural” way as overall industry runs into constraints imposed by capacity to produce new plants, we model the allocation of constrained production capacity among potential uses via a logit function that was calibrated to the historical experience of the starch-ethanol industry. This calculation determines the characteristics involved in the decision of whether to build a conversion facility including

(1) the several biomass-to-ethanol conversion pathways, (2) the pioneer and full commercial scales, (3) the 10 geographic regions represented in the BSM, and (4) other uses of plant-construction capacity. Key drivers of allocation include the net present value, the overall capacity to produce new plants (shared across technologies and regions), the maximum economically sustainable number of plants in the region, the regional feedstock availability, the potential market demand for products, and the extensiveness of the downstream logistics infrastructure. Once the decision to construct a particular type of plant in a particular region is made, additional model structure transforms this continuous signal into discrete plant additions. The BSM then tracks the progression of biorefineries from initiation, design and construction, start-up, and production while concurrently tracking the process yield. The logic assumes that as the industry develops, the yield for all of the plants improves in synchrony. Technical failures occur during the start-up phase of the plant and are captured within the model but do not feed back into any decision making in the industry. Once a biorefinery is built, it is not taken off-line, but it is assumed that the investor will continue to upgrade and maintain the biorefinery (see Figure 12). Figure 13 illustrates how maturity improves plant profitability, which in turn advances maturity.

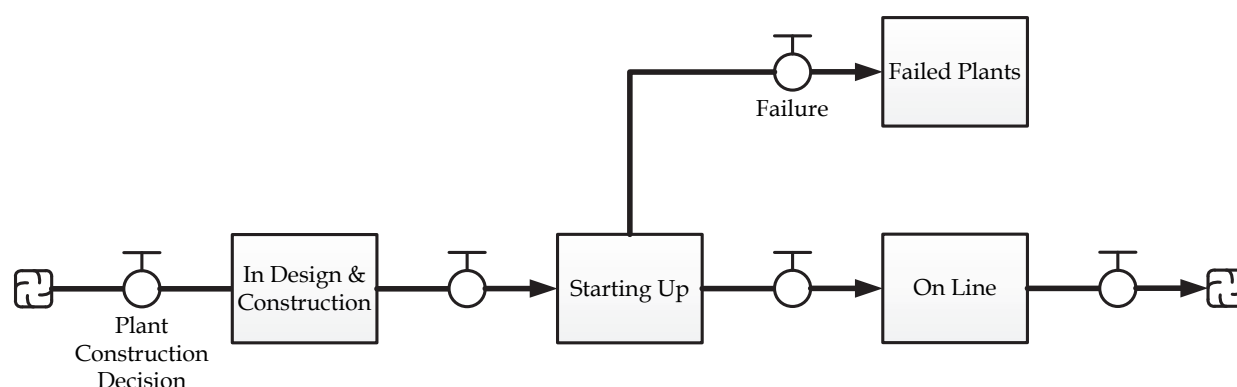


Fig. 12. Stock and flow diagram of biorefinery life cycle in the BSM

3.10 Building ethanol capability at terminals

From the conversion facilities, ethanol travels to terminal facilities. Regrettably, ethanol cannot be transported in the same pipelines as gasoline due to their differing chemical properties. Therefore, ethanol is generally transported via truck or rail. Once it arrives at the terminal, it is blended with gasoline and transferred to its final distribution location (see Figure 14). Not all terminals are suited to store or blend ethanol, so the BSM includes logic for terminals that do not yet have ethanol infrastructure and a means by which they can acquire that structure.

Contained in the Distribution Logistics Module, the ethanol terminal logic aims to provide a simple, high-level, physical, defensible representation of an evolving distribution network for biofuels, while respecting both economic and public policy considerations (see Figure 15). It takes regional ethanol production from the Feedstock Conversion Module and determines whether existing terminal capacity is sufficient or if a gap exists between desired and existing capacity. Given current model input settings, the dynamic interaction shows potential evolution from the current “as is” world. Some of the key variables from Figure 15 include:

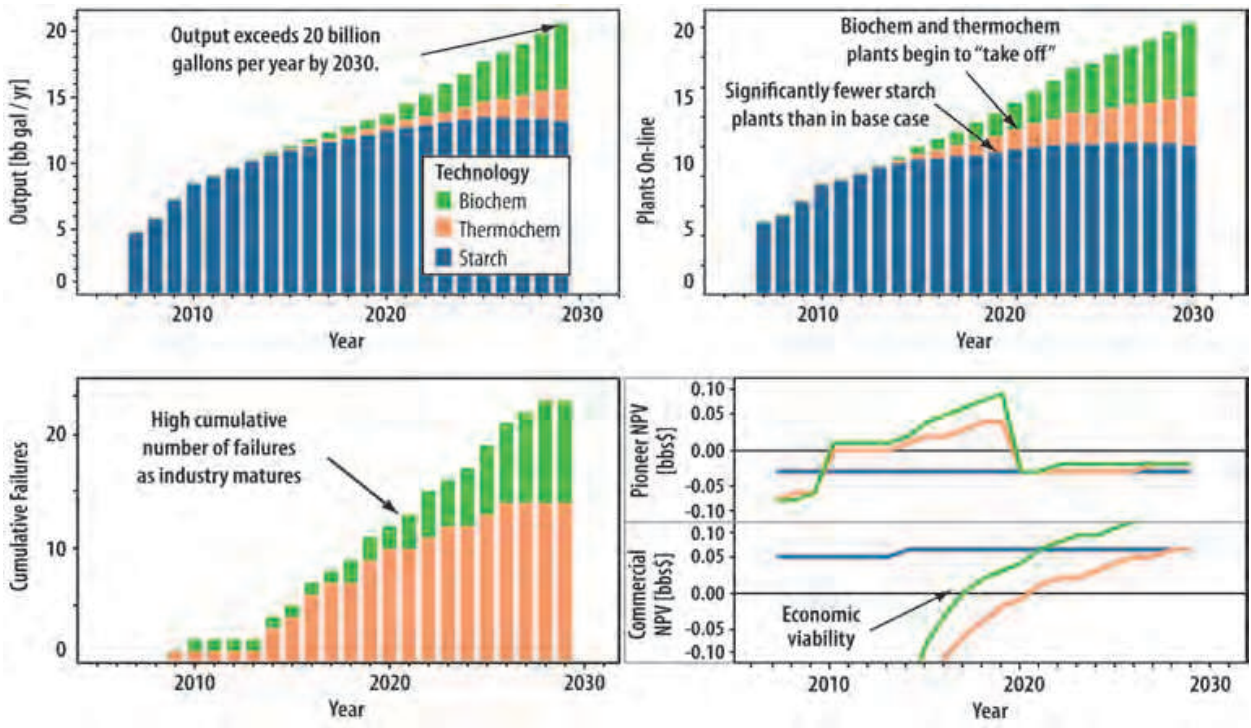


Fig. 13. Plant maturity logic in the BSM

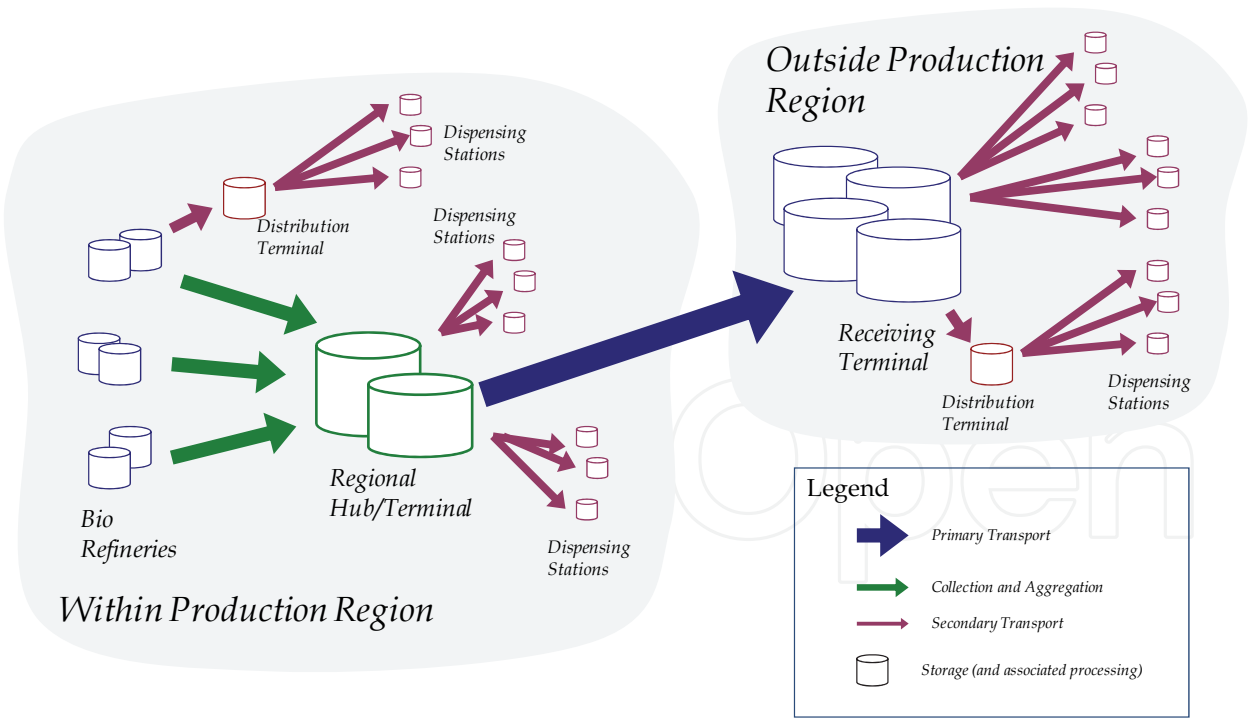


Fig. 14. Ethanol distribution system

- **Infrastructure Gap by Region:** For regions where there is ethanol production, shows the potential number of terminals that could have infrastructure, given current production capacity and potential gasoline consumption relative to the number of terminals with infrastructure.

- **Infrastructure Acquisition Rate:** Represents the effective rate at which the infrastructure gap is eliminated per year, given an increasing rate of adoption among terminals without ethanol infrastructure and external information on how quickly terminals are being upgraded.
- **Terminal Infrastructure Acquisition:** Shows the acquisition of ethanol infrastructure by terminals within a region, given the infrastructure gap and the rate at which infrastructure can be acquired.
- **Regional Ethanol Production without Terminal:** Addresses the situation when there is more ethanol capacity in a certain region than ethanol-capable terminals can store and transports that capacity to a different region.

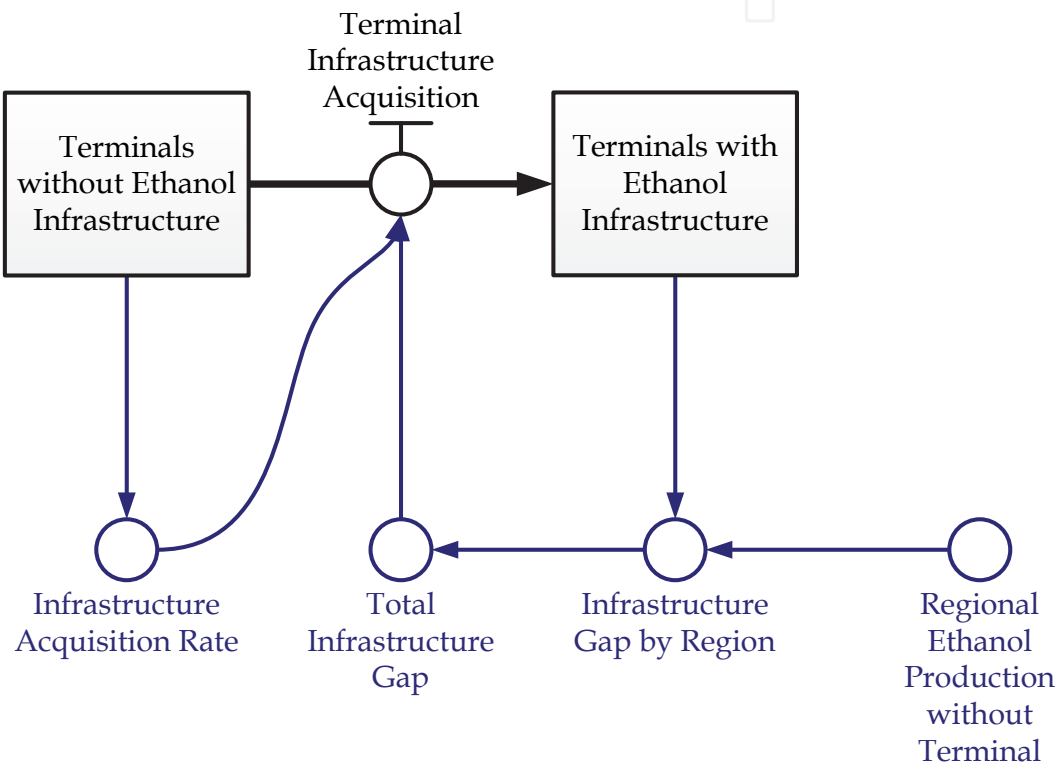


Fig. 15. Terminals acquiring ethanol infrastructure logic

Some powerful insights can be gained just by reviewing the dynamics of building ethanol-capable terminals in conjunction with the rest of the supply chain. In the absence of subsidies, the lack of distribution infrastructure seriously hinders downstream availability and adoption of high-blend fuel. The presence of ethanol distribution infrastructure supports consumption growth once demand has developed. Finally, overall penetration of high-blend fuel is constrained by infrastructure coverage and supply/demand/price considerations. In this idealized system, there is insufficient production capacity to cover potential demand so prices increase to stave off demand.

3.11 Gasoline stations having, considering, or not having high-blend fuel capabilities

In order for ethanol to be blended at the terminals, there must be sufficient distribution storage to accept the end product and dispensers to get the product to the consumers. Although many states do require a boutique blend of ethanol with gasoline due to emissions

regulations, this alone will not cause the ethanol industry to expand; it will require a proliferation of fuels with a higher blend of ethanol to occur. But many gasoline station owners are hesitant to invest in high-blend tankage or repurpose existing tankage since they generally operate in a low-profit-margin environment.

There are three categories of gas station owners: those who have high-blend tankage, those who are considering it, and those who do not have it and are not considering it. Whether station owners actually invest depends upon the value proposition, which includes the current status of the regional distribution network, the potential demand for the high-blend fuel, and the opportunity cost of not investing. Figure 16 shows how this decision making is handled in the Dispensing Stations Module of the BSM.

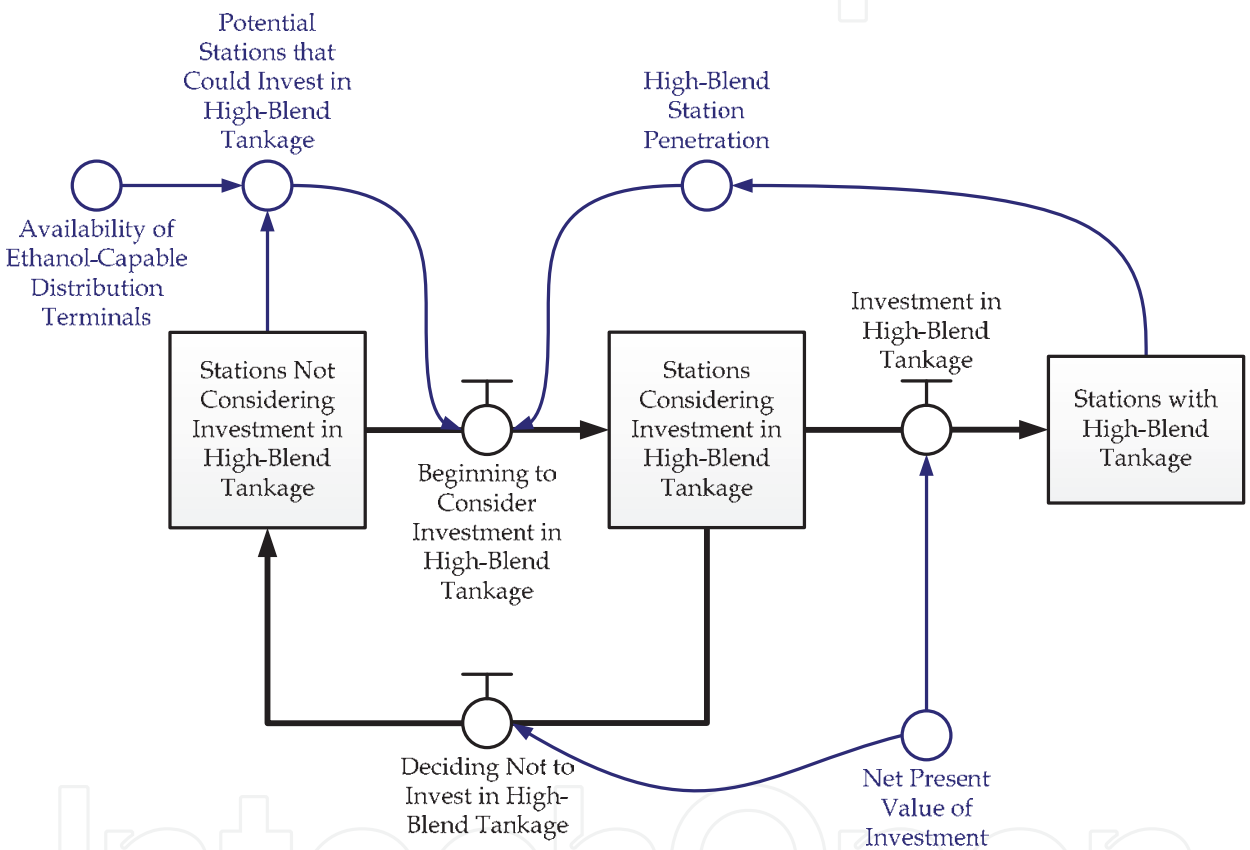


Fig. 16. BSM logic of investment in high-blend tankage

A similar logic is used for the repurposing of existing tankage. An important variable in Figure 16 that could be overlooked is “Net Present Value of Investment.” The NPV calculation looks at the station owners’ expected financials. The computation takes into account the expected incremental sales of conventional gasoline and high-blend fuel, sales of other items from the convenience store, expected taxes, financing from investing in high-blend tankage, and incentives for the investment.

There are many valuable takeaways that can be gained by evaluating how this decision logic fits into the system of the biofuels industry. Due to the small operating margins of refueling stations, comprehensive subsidies are essential in fostering the installation of high-blend refueling capacity. Even with significant external intervention, adjustment can take multiple years. The presence of ethanol-dispensing tankage supports consumption growth in the

early years as long as the point-of-use prices remain low. In contrast, the lack of available tankage, dispensing equipment, and refueling stations hampers high-blend fuel adoption. Finally, the system appears to be delicately-situated (especially in the case of unbranded independent gas stations because of relatively low margins and small sales volumes); small changes in incentives or input assumptions can lead to big changes in output behavior.

3.12 Ethanol and gasoline price—consumer decision making

Even if dispensing stations provide high-blend fuel as an option, there is no guarantee that flex-fuel vehicle owners will buy it. The choice to fill up using high-blend fuel depends mainly on price and availability. If there are no high-blend pumps in close proximity when the vehicle owner needs to fill his tank, he is unlikely to drive out of his way to find a facility that offers high-blend fuel. In addition, flex-fuel vehicle owners are unlikely to pay a premium on high-blend fuel. The relative price could confuse consumers, though, due to the different volumetric energy content of high-blend fuel in comparison with conventional gasoline.

In the BSM, the fuel choice logic is contained in the Fuel Use Module. Figure 17 gives a visual representation of how consumers choose what fuel to use. There are three types of fuel consumers: regular high-blend users, occasional high-blend users, and non-high-blend users. These stocks are all represented as a percent of total fuel consumers. One of the main constraints is a variable “Stations that Offer High-Blend Fuel,” which excludes all consumers who do not have a station offering high-blend fuel in their areas. Since high-blend fuel’s relative price compared with gasoline plays a major role in consumers’ fuel selection, it is included in the decisions to either move to being a regular high-blend user from being an occasional user or to drop back to being an occasional user from being a regular user. Whether fuel purchasers are occasional or regular users is determined by the price advantage of ethanol over gasoline. The larger the price gap between high-blend fuel and gasoline, the more quickly the occasional users will become regular users (or the smaller the gap, the more quickly the regular users will drop back to occasional users).

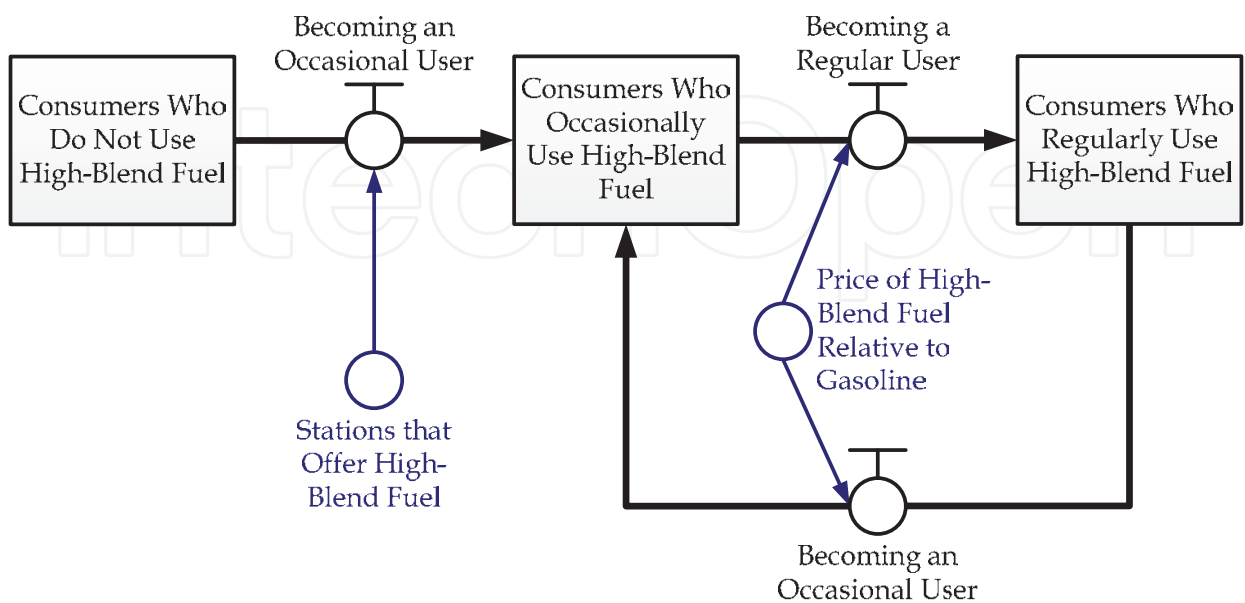


Fig. 17. High-blend fuel choice logic

As a base scenario, the model uses gasoline price projections from the 2010 Annual Energy Outlook (Energy Information Administration 2010), but it also provides the option of choosing from a variety of other gasoline price scenarios, some with price shocks, or for entering user-provided pricing data. The high-blend fuel price is estimated using a blend of two pricing strategies used by fuel station owners, as revealed through surveying owners in Minnesota (Anderson, 2009). The first strategy says that the price of E85 is a multiple of retail gasoline price. The second strategy determines E85 price by adding some constant markup factor from ethanol rack price. Therefore, the price of E85 can be expressed as a weighted average of the two strategies, shown as a mathematical relationship below, where P_{E85} is the retail price of E85, P_{gas} is the retail price of gasoline, P_{etoh} is the rack price of ethanol, f is the weight given to strategy 1 (a fraction between 0 and 1), b is the coefficient for strategy 1 (a discount on retail gasoline price), c is the coefficient for strategy 2 (a constant markup on ethanol rack price), and ε is the error term of the regression.

$$P_{E85} = f(b * P_{gas}) + (1-f)(c * P_{etoh}) + \varepsilon \quad (4)$$

Policymakers can gain a different perspective on high-blend fuel consumption from the following system insights gained from evaluating different scenarios in the BSM. Even under the best conditions, adjustment can take multiple years, and 100% penetration is never reached. Both accessibility and price differential are needed to drive market penetration. Accessibility gives people the option to choose high-blend fuel, whereas price differential transforms occasional users into regular users and boosts high-blend share for each sub-group. The market for high-blend fuel does not persist in cases where high-blend price advantage or parity is lost; consumption quickly reverts mostly to gasoline when the price gap with high-blend fuel closes. In addition, select BSM runs show that short-term (less than one year) gasoline price shocks do not cause a large shift of users from gasoline to high-blend fuel, but long-term or repeating shocks do cause more consumers to switch to using high-blend fuel.

3.13 Maturation of fleet

In addition to the consumer's decision on which fuel to use, the number of flex fuel vehicles in commission has a large impact on the demand for biofuels. In order to address this element, the vehicle module aims to provide a physical basis for generating potential demand for transportation fuel arising from automobiles and light trucks. It has a simple structure to track influx, vintaging, and retirements from stock of vehicles. It does not integrate consumer vehicle purchasing decisions; rather, it provides an accounting framework to inspect potential policy pressures on vehicle stocks and related maximum potential ethanol consumption. Its purpose is to produce policy scenarios that can then be used in the downstream BSM. The maximum ethanol utilization potential under each scenario over time becomes an input to the integrated downstream model. The evolution of the system is driven by scenarios around volume, mix, and efficiency of new vehicles over time. The model contains vehicle tracking by fuel type (gasoline, diesel, flex fuel vehicle, gasoline hybrid electric vehicle, gasoline plug-in hybrid electric vehicle, diesel hybrid electric vehicle, and other) and by efficiency class (more/less efficient automobile and more/less efficient truck).

Figure 18 shows a simplification of the logic contained in the model. Although it only displays three vehicle cohorts (A, B, and C), there are 20 time periods represented in the

actual model. After each year, a vehicle can either be removed from service or continue on to the subsequent year. In addition, the average vehicle efficiency can be altered on an annual basis depending on the characteristics of the cars and trucks that are retired. Whether a vehicle is taken out of service is dependent upon the vehicle survival rates, which are computed from historical data for the technology and efficiency classes. The baseline vehicle fleet is taken from the U.S. Energy Information Administration’s *Annual Energy Outlook* (Energy Information Administration, 2010), but the parameters can be altered to meet the needs of any given scenario.

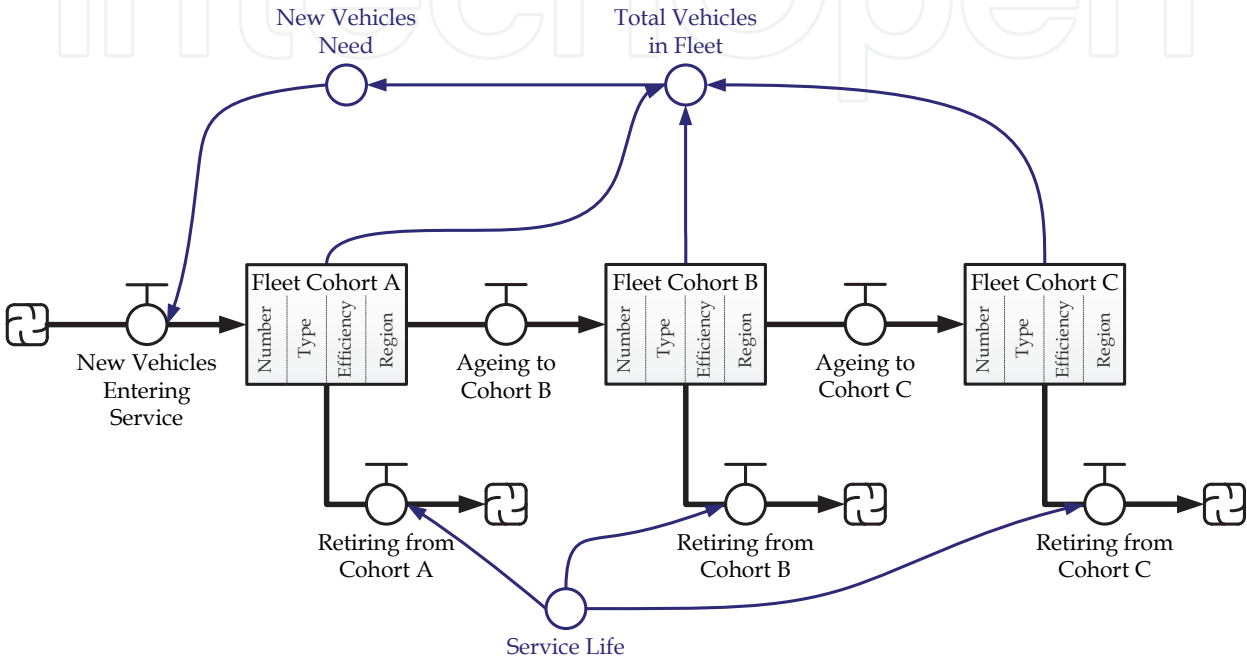


Fig. 18. Vehicle Module logic

Even though the Vehicle Module does not currently include a robust consumer choice component, insights can still be developed. In order for high-blend fuel to have a high amount of penetration, flex fuel vehicle adoption must be substantially higher than Annual Energy Outlook forecasts. For example, a policy that could increase the amount of flex fuel vehicles on the road is the Car Allowance Rebate System (also known as “cash for clunkers”): through this program, older vehicles are replaced by newer ones that have a high probability of having flex fuel capability. See recent analyses by Vimmerstedt et al. (2011) for further discussion on insights gained from the downstream portion of the BSM.

4. Analysis approach

Specific policy-relevant scenarios or past scenarios can be used to drive the BSM simulations, though the BSM is not limited to scenario analysis. Under a specified scenario, the BSM can be used to track the hypothetical development of the biofuels industry given the deployment of new technologies within various elements of the supply chain and the reaction of the investment community to those technologies and given the competing oil market, vehicle demand for biofuels, and various government policies over an extended timeframe. Note, however, that high-level models such as the BSM are not typically used to

generate precise estimates but rather to (1) analyze and evaluate alternate policies, (2) generate highly effective scenarios, (3) identify high-impact levers and bottlenecks, and (4) focus discussion among policymakers, analysts, and stakeholders. When the model output includes unexpected system behaviors, modeling assumptions—particularly the behavioral aspects of decision making and the adequacy of the representation of feedback—need careful reexamination to distinguish potential insights from model limitations. The model itself often indicates what assumptions need the most scrutiny; hence, it helps define the research and learning agenda.

Although the BSM inputs can be altered to include any combination of policies, establishing a “reference policy case” to which subsequent scenarios are compared can be useful for determining what policies will have the greatest potential for producing substantial industry growth. The BSM reference policy case includes moderate incentives for ethanol production and a 50 cent per gallon gasoline tax (which could be interpreted as a “carbon” or GHG tax of approximately 51 dollars per ton of carbon dioxide). Policies are phased out in a staged manner, with the policies involving grants for capital equipment or loan guarantees ending earlier and the policies involving volumetric subsidies phasing out anywhere from 2020 to 2050. Each of the policies included in the reference case is based on historical precedence or future plausibility. Sensitivity, bottleneck, tipping-point, and other analyses are typically carried out with respect to a baseline scenario of existing policies and the reference policy case.

5. Scenario exploration and insight

Current experience with the biofuels industry and analysis of the supply chain components suggest that the cellulosic biofuels industry is unlikely to develop without substantial help from external sources. The BSM provides a valuable platform through which the possible effects of policy can be explored. Figure 19 shows many of the insights that have been

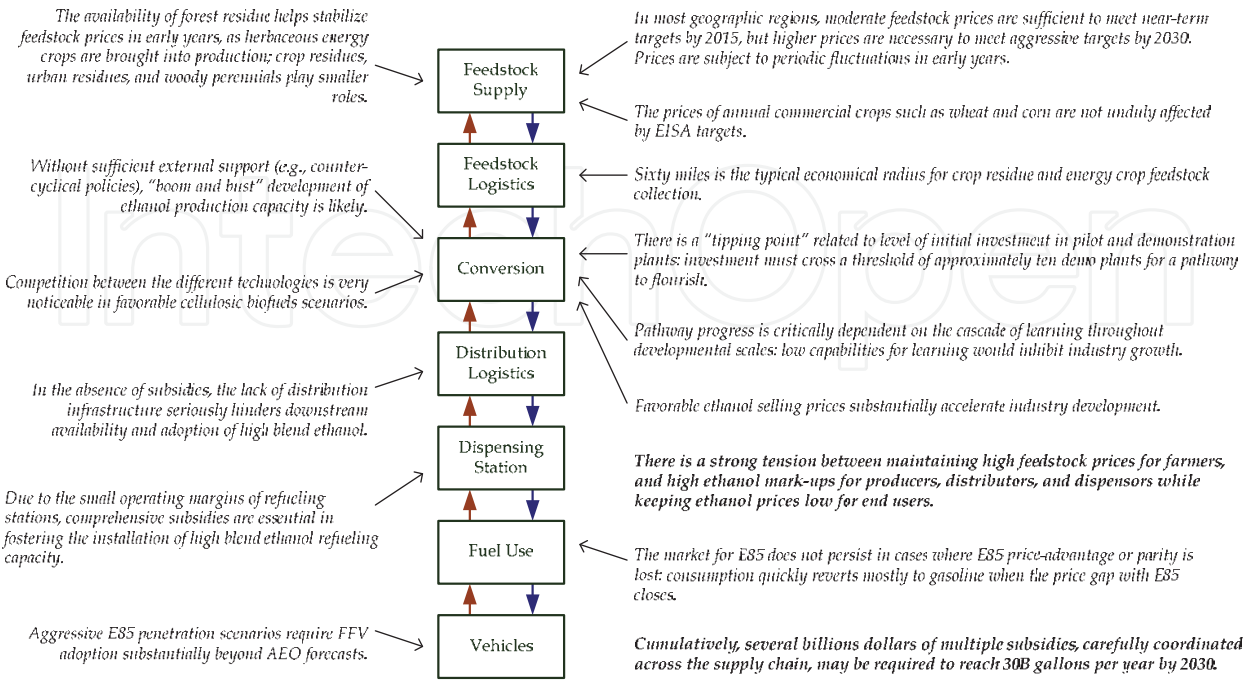


Fig. 19. Insights gained throughout the biofuels supply chain

gained from countless analyses and studies performed using the model. Each component of the supply chain has its own unique needs in terms of policy implementation, bottlenecks, and favorable points of intervention. Many of the insights were already discussed in the sections above dealing with dynamic components of the BSM.

Given the insights discovered in different areas of the supply chain, a picture begins to emerge dealing with a portfolio of policies that could lead to cellulosic ethanol industry takeoff. Based on a scenario without policy initiatives, the model results indicate a complete failure of the cellulosic ethanol industry to take off (left side of Figure 20) given the currently observed investments in demonstration and pioneer conversion plants. Furthermore, our analysis shows that overly aggressive or poorly targeted subsidies cause industry instability and only lead to a paltry increase in cellulosic biofuels production.

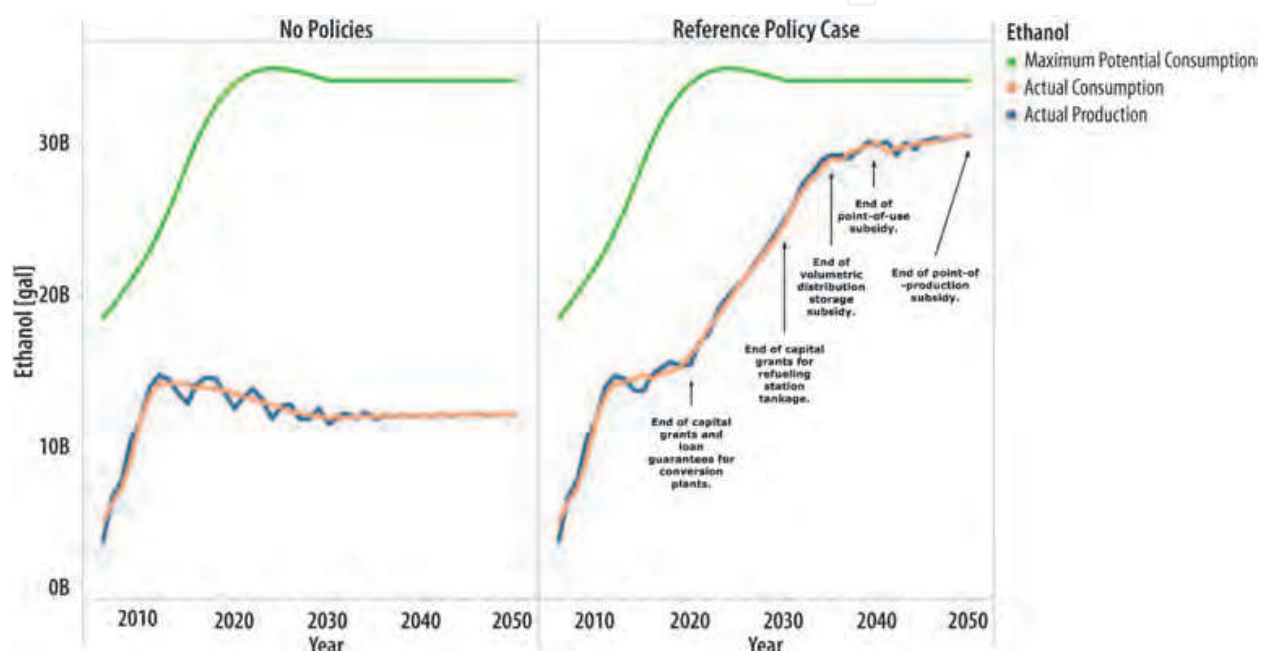


Fig. 20. Set of “reference policy” inputs produce a moderate, sustained industry takeoff (“B” = billion)

In general, policies are sequenced such that the more expensive or least cost-effective ones are phased out earlier; policies are phased out as early as possible so as to still achieve substantial industry growth. This policy configuration and these results are not intended to be prescriptive or to represent the minimal effective policy; instead, they simply form a basis against which the impact of potentially sensitive data inputs can be studied and against which an “on the margin” policy analysis can be conducted. Nevertheless, there is general historical precedence or future plausibility for each of the policies included in the reference and for the rough order of magnitude of the policies.

Figure 20 illustrates the resulting ethanol consumption and production in the BSM with and without the reference policy. Without the policies in place, the cellulosic ethanol industry does not take off; on the contrary, ethanol consumption actually falls with time due to the increased efficiency of the vehicle fleet. [Note that vehicle fleet and gasoline price forecasts from the Energy Information Administration’s *Annual Energy Outlook* (Energy Information Administration, 2010) reference case are being used.] The leveling off of ethanol production around 2012 results from the saturation of ethanol demand for the blending of E10 and the

EISA-imposed 15B gallon limit on the production of starch-based ethanol. For scenarios with a higher level of ethanol production, resource constraints, such as availability of flex fuel vehicles and biomass supply, play a role in the leveling out of production in later years. This result is not fundamental to the model but rather an artifact of the given model setting of a certain scenario. Figure 21 provides a rough, preliminary estimate of the magnitude of the costs associated with the policies in the reference case. It is important to note that the revenue from the gasoline tax far exceeds the cost of these policies.

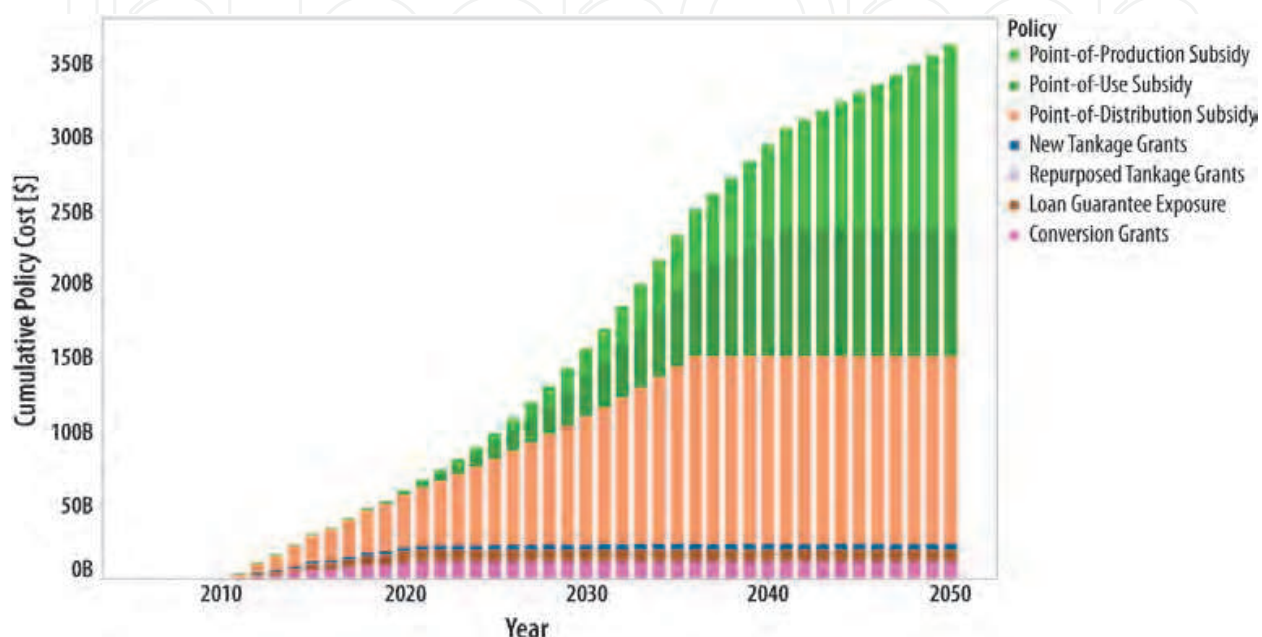


Fig. 21. Preliminary, rough estimate of the costs associated with the reference policy ("B" = billion)

In constructing the reference policy, we examined the effects of eliminating various grants or subsidies. Figure 22 shows the effect of removing each separately, suggesting that the availability of grants for new high-blend tankage at refueling stations is an essential component of this policy case. Other policies, particularly the gas/carbon tax are highly influential. In contrast to where single policies are "turned off," nearly every case where two policies are turned off results in ethanol consumption that is substantially lower than in the reference case.

Looking at the reference case and other runs of the BSM, insights can be gained in terms of what needs to be in place in order for the cellulosic ethanol industry to take off. In particular, the combination of initiatives is likely to require:

- Mechanisms to ensure a favorable-to-high-blend price spread as perceived by end users
- A high level of external investment in dispensing station infrastructure (tankage and related equipment)
- Aggressive initial external investment in pilot, demonstration, and pioneer-scale conversion facilities
- High rates of industry learning.

We have performed multiple analyses in the BSM dealing with different mechanisms for pricing high-blend fuel at the pump along with ethanol and gasoline price coupling. In general, high-blend fuel appears to be highly coupled with gasoline price. When short-term

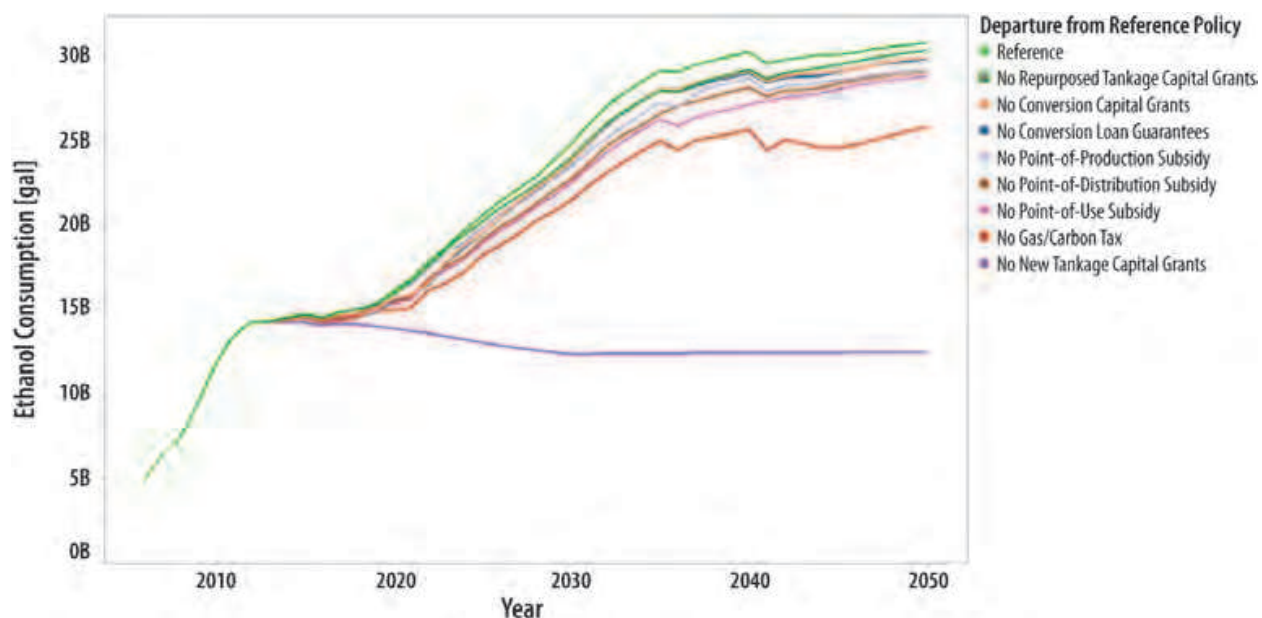


Fig. 22. Variations of the reference policy case, where one of the policies is “turned off” (“B” = billion)

gasoline price shocks are applied to the model, there is very little reaction by consumers to substitute high-blend fuel. Long-term, sustained gasoline price shocks do show some fuel switching but increases are less than 10% of the total ethanol consumption. As was discussed in Section 3.12 in recent research (Anderson, 2009), investigators found that there are two main methods by which gasoline station owners price high-blend fuel: as a discount on the gasoline price or as a mark-up on the rack ethanol price. The two-strategy pricing scheme was incorporated in the BSM and comparative tests were performed with and without the relationship in place. The link suggests tradeoffs. Price coupling implies a higher degree of profitability per gallon from high-blend fuel, which implies greater incentive for stations to invest in high-blend tankage and equipment. On the other hand, price coupling implies a smaller spread between gasoline and high-blend fuel, which suggests lower market penetration than in the previous formulation. Further exploration of price coupling effects between high-blend fuel and gasoline is warranted.

Bottlenecks in downstream distribution and dispensing infrastructure may significantly impede the growth of the cellulosic biofuels industry. Managing the biomass-to-biofuels supply chain involves a carefully-orchestrated arrangement of flow-through capacities at various stages in the chain. Bottlenecks result when those capacities are out of synch. For example, bottlenecks in downstream distribution and dispensing infrastructure may significantly impede the growth of the cellulosic biofuels industry. In the reference policy case, the critical importance of the capital grant subsidy for new high-blend tankage indicates the potential for bottlenecks in the downstream portion of the supply chain. To test this hypothesis, the fraction of the distribution system (terminals and transport) with ethanol infrastructure was set arbitrarily to 100% and the fraction of refueling stations with ethanol-capable tankage to 100%. This mimics the situation where ethanol would be a fungible or infrastructure-compatible fuel. Figure 23 indicates that removing these downstream constraints results in substantially more ethanol consumption, either with or without supportive policies. In general, a lack of appropriate downstream policies could limit the effectiveness of otherwise successful upstream ones, and vice versa. In addition, a

carbon policy could potentially aid in elevating demand for high-blend ethanol. Although carbon policy has been discussed extensively in U.S. national policy considerations, the BSM does not currently implement it explicitly. Rather, carbon taxes and carbon caps can be simulated through a gasoline tax. It would be relatively simple to add a feedback controller, but the policy would have to be more well-defined. Currently it is not clear where the policy would affect the industry across the supply chain.

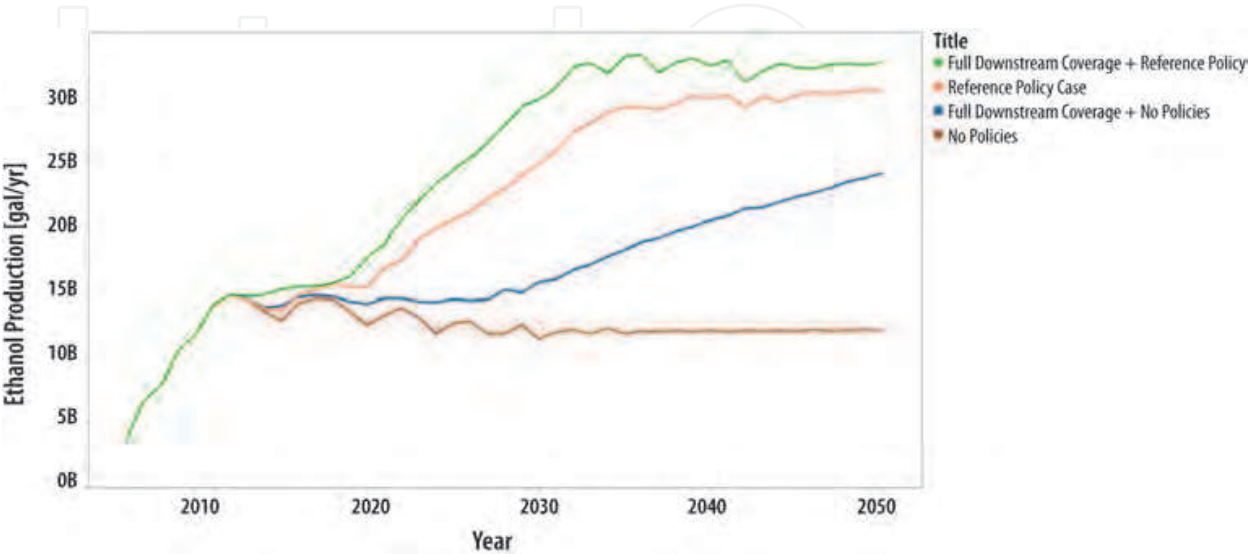


Fig. 23. Effect of removing downstream infrastructure constraints (“B” = billion)

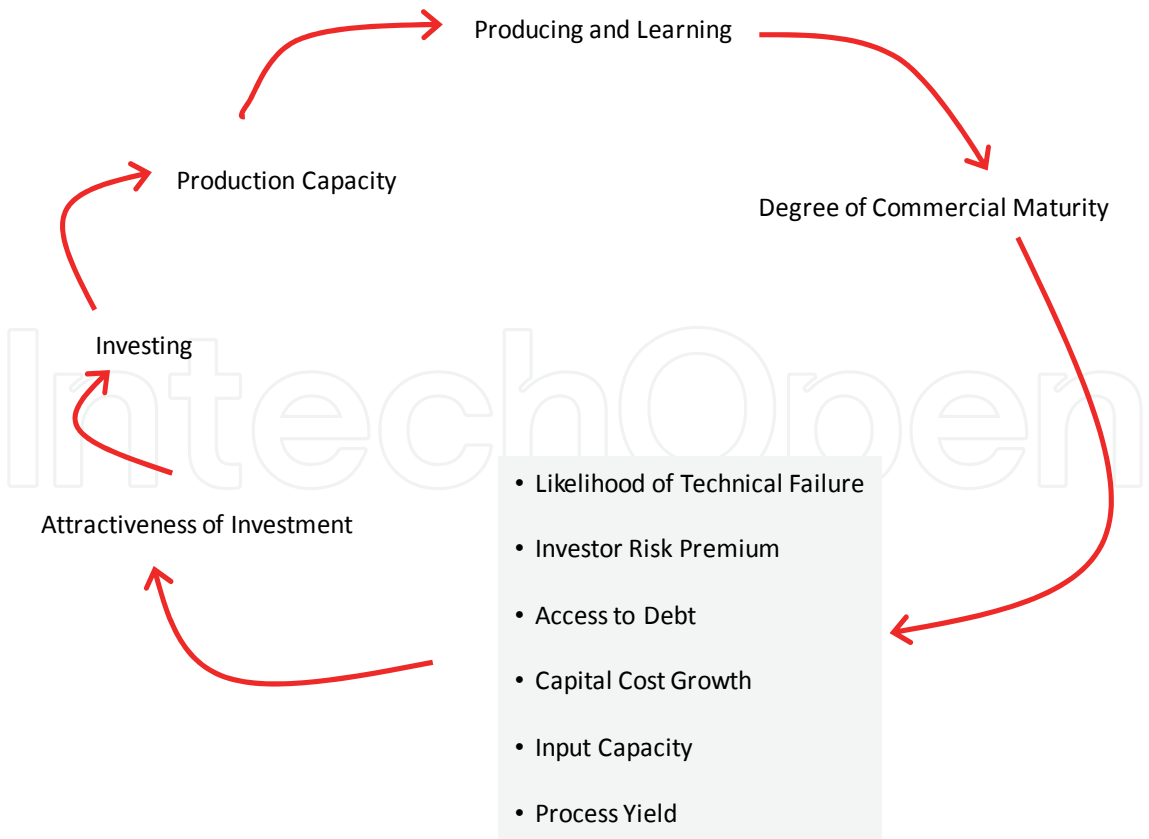


Fig. 24. Key feedback driving investment attractiveness

Although policies are important for industry takeoff, aggressive investment in conversion facilities and accelerated industry learning are also essential. In general, rapid learning in conversion technologies/plants “tips” the ethanol market. A focal point in the Conversion Module portion of the BSM is the concept of “cascading learning curves,” which was already discussed in Section 3.7. The logic depicted in Figure 24 enables the model to capture the evolution of a conversion platform from an arbitrary initial state to “*n*th plant” maturity. As shown in Figure 24, embedded within the learning curve logic is a rich set of positive/reinforcing feedbacks, all of which can drive a conversion technology toward a high degree of investment attractiveness and low production costs.

One critical component of the learning curve dynamics in the model is the concept of a progress ratio. Essentially, a progress ratio translates the activity basis of producing into learning and thereby into increases in commercial maturity. Figure 25 shows model simulations of total cellulosic ethanol production for five values of the progress ratio ranging from 75% to 95%. Smaller values for the progress ratio mean that cost falls faster with increases in cumulative production. Progress ratios in the range of 75% to 90% show similar levels of ethanol production, while a value of 95% causes production to stagnate. The response of production to different progress ratios is highly nonlinear. Moving from 95% to 90% causes a big response, while additional 5% percent decreases cause much smaller responses. Note that it is conceivable that certain types of government policies could alter industry progress ratios towards lower, more favorable values.

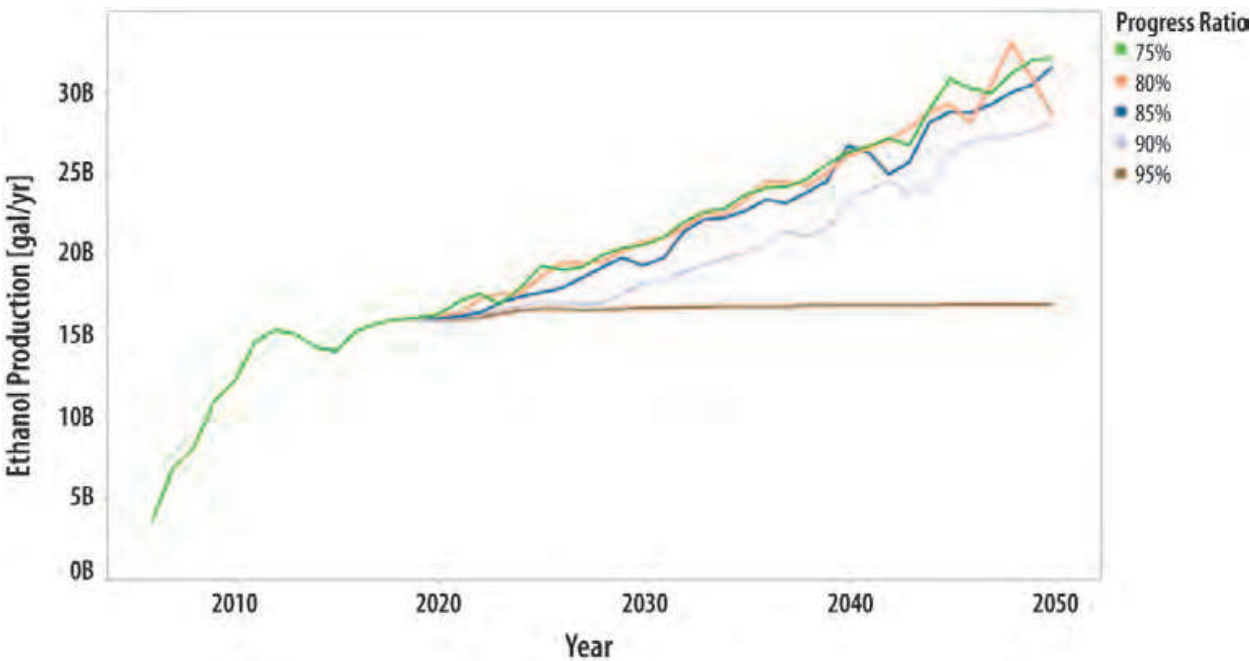


Fig. 25. Total ethanol production, given progress ratios of 75% to 95% (“B” = billion)

The nonlinear response to changes in the progress ratio in these simulations is the result of layered constraints in the production system. When the progress ratio is 95%, cumulative experience has a small impact on production cost and the high cost of cellulosic ethanol remains the main constraint on market growth. A progress ratio of 90% generates much lower production costs, which causes production to nearly double. Progress ratios below about 80% cause the system to encounter new constraints that limit market growth; ethanol production is no longer the binding constraint at lower progress ratio levels. One of the

newly emerging constraints is the number of filling stations that have high-blend ethanol pumps. A second constraint is the supply and price of feedstock. The large increase in ethanol production causes feedstock prices to rise, which reduces the profitability of investments in new plants.

Figure 26 shows an ethanol price index over the period of interest. With faster rates of learning (as indicated by lower progress ratios), the system settles into a much lower price regime. With very slow rates of learning, prices remain very high (double the initial value) over the course of the simulation. The results for intermediate learning rates hint at increased price volatility. The oscillations observed at the start of the simulations are a result of the lag in the production response to demand signals in the early years of the cellulosic ethanol industry; the prices are not a forecast but rather an indication of dynamic interactions in the model.

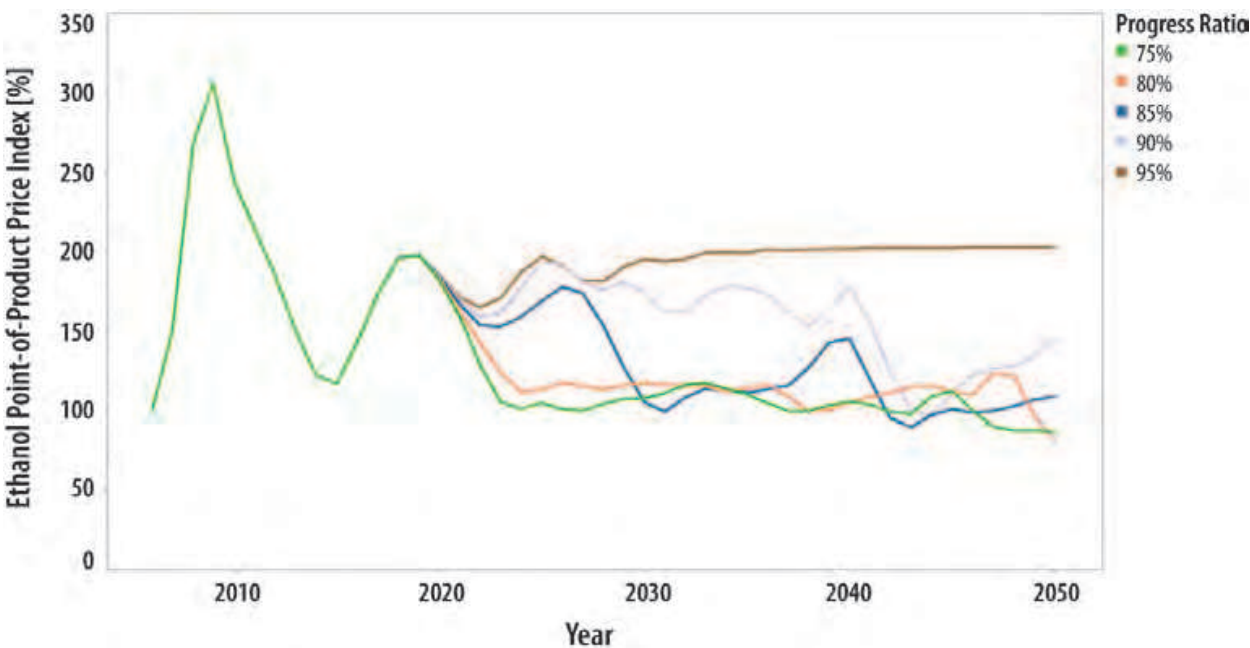


Fig. 26. Ethanol point-of-production price indices, given progress ratios of 75% to 95%

We have already discussed how certain policies must be in place in order to have significant cellulosic ethanol industry growth. There is also a dynamic element that policies alone are less effective than policies that are implemented in coordination with one another. The sum of benefits from each policy implemented in solitude is much less than the benefits attained when the policies are combined. In Figure 27, a policy focused on growers is combined with one targeting conversion facilities. When they are implemented in isolation, the policies are concretely less effective than when they are placed into service together.

This result highlights a significant advantage of a systems-focused simulation; rather than displaying just the summation of separate, static, disconnected analyses, systems modeling shows how the different sections of the supply chain work together to enhance policy outcomes. As installed capacity grows, it is easier to self-sustain growth in the industry. Because of multiple feedbacks, policy initiatives can potentially create interdependent benefits (see Figure 28).

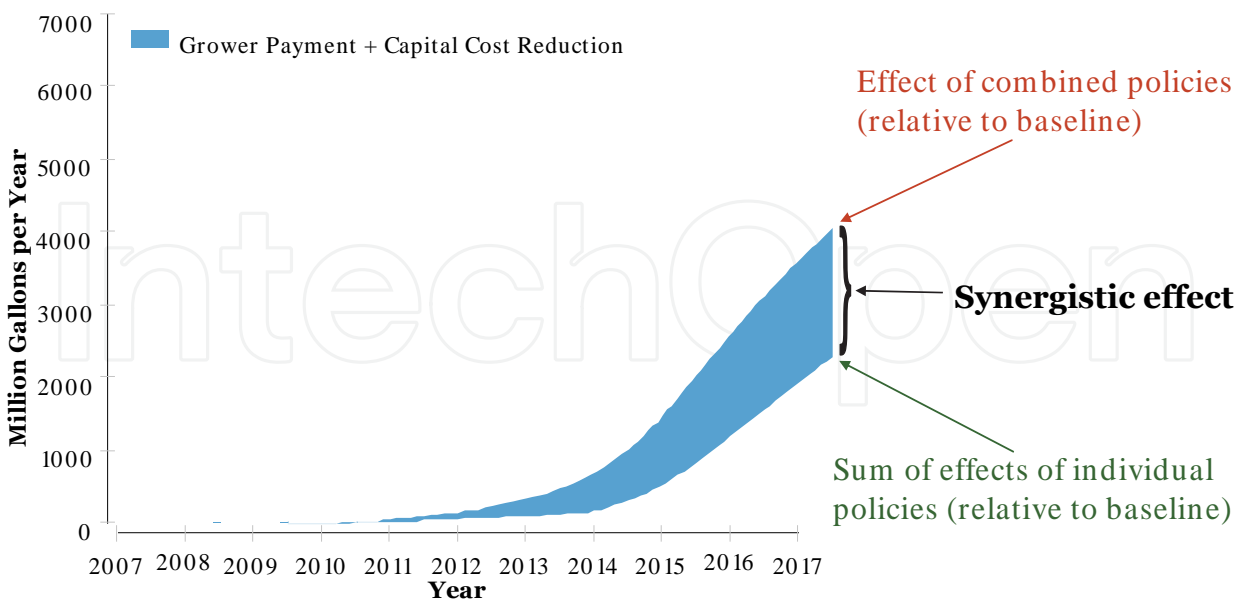


Fig. 27. Synergistic effect of coordinating policy implementation

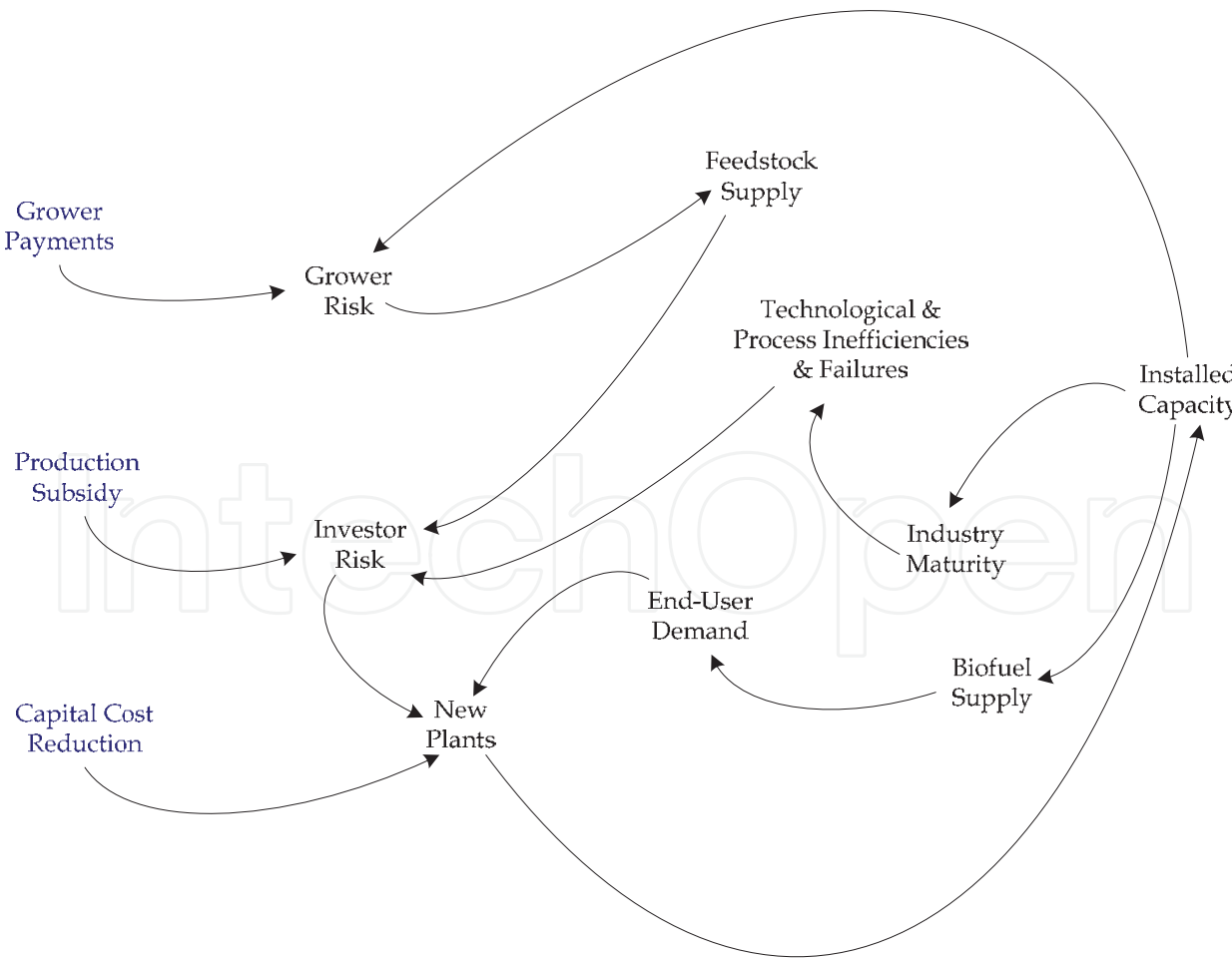


Fig. 28. Dynamic effects of synergistic policy interaction

6. Conclusion

The BSM is a powerful tool for gaining insights on the whole biomass-to-biofuels supply chain. It has unique mathematical formulations that comprise its variables with dynamic interconnections among them. A look at some of the specific influence diagrams representing complicated logic in the BSM shows how the interactions are modeled and gives a glimpse at how the BSM arrives at results after iteration. Each component of the supply chain is modeled so that it can either be run as a standalone model or with connection to the other components. Powerful insights have been gained from both the standalone modules and the entire system model. Overall, in the BSM simulations the cellulosic ethanol industry tends not to rapidly thrive without significant outside actions in early years of its evolution. An initial focus for jumpstarting the industry typically has strongest effects in the BSM in areas where effects of intervention have been identified to be multiplicative. Due to industrial learning dynamics, support for the construction of cellulosic ethanol conversion facilities in the near future encourages the industry to flourish. By accelerating the pace of development, industrial learning can grow substantially. In addition, without the alleviation of bottlenecks of high-blend fuel distribution and high-blend fuel pumps, the increased amount of ethanol produced may not have a viable market to serve. Future work includes additional analyses using the BSM and expanding the model to include infrastructure-compatible (“fungible”) fuels such as biomass-based gasoline, diesel, and aviation fuel.

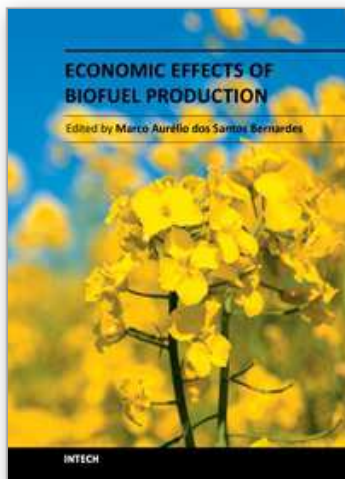
7. Acknowledgment

The authors would like to mention the people without whom the Biomass Scenario Model would not exist and the included analyses would not have been performed. Robert Wallace (Booz Allen Hamilton) and John Sheehan (The University of Minnesota) were instrumental in getting the initial model off the ground. Steve Peterson (Peterson Group) has been with the effort since its inception and has continued to be the main contributor to the modeling effort. Zia Haq and Sheila Moynihan of the U.S. Department of Energy have been tireless advocates for continuing analyses to shed light on the biofuels system. In addition, the other BSM team members have been invaluable: Corey Peck and Mark Paich of Lexidyne LLC and Laura Vimmerstedt, David Hsu, Dana Stright, Andrew Argo, and Amy Schwab, all of NREL.

8. References

- Anderson, S. T. 2009. *The Demand for Ethanol as a Gasoline Substitute*. East Lansing, MI: Michigan State University, August.
- Bush, B., M. Duffy, D. Sandor, and S. Peterson. 2008. *Using System Dynamics to Model the Transition to Biofuels in the United States: Preprint*. Preprint. Golden, CO: National Renewable Energy Laboratory.
- Energy Information Administration. 2010. *Annual Energy Outlook 2010. Forecasts & Analyses*. May. <http://www.eia.doe.gov/oiaf/archive/aeo10/index.html>.
- Interagency Agricultural Projections Committee. 2007. *USDA Agricultural Projections to 2016*. U.S. Department of Agriculture.

- isee systems. 2010. STELLA: Systems Thinking for Education and Research Software. <http://www.iseesystems.com/software/Education/StellaSoftware.aspx>.
- Office of the Biomass Program, and Energy Efficiency and Renewable Energy. 2008. *Multi-Year Program Plan March 2008*. Multi-Year Program Plan. U.S. Department of Energy, March.
- The University of Tennessee. n.d. Agricultural Policy Analysis Center Research Tools - POLYSYS. *Agricultural Policy Analysis Center - The University of Tennessee*. <http://www.agpolicy.org/polysys.html>.
- U.S. Department of Agriculture. 2011. Conservation Reserve Program. *Conservation Programs*. February. <http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp>.
- U.S. Environmental Protection Agency. 2010. Renewable Fuels: Regulations & Standards. *Fuels and Fuel Additives*. December. <http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm>.
- United States Government. 2007. *Energy Independence and Security Act of 2007*.
- Vimmerstedt, L, B Bush, and S Peterson. 2011. Ethanol Distribution, Dispensing, and Use: Analysis of a Portion of the Biomass-to-Biofuels Supply Chain Using System Dynamics. Manuscript submitted for publication.



Economic Effects of Biofuel Production

Edited by Dr. Marco Aurelio Dos Santos Bernardes

ISBN 978-953-307-178-7

Hard cover, 452 pages

Publisher InTech

Published online 29, August, 2011

Published in print edition August, 2011

This book aspires to be a comprehensive summary of current biofuels issues and thereby contribute to the understanding of this important topic. Readers will find themes including biofuels development efforts, their implications for the food industry, current and future biofuels crops, the successful Brazilian ethanol program, insights of the first, second, third and fourth biofuel generations, advanced biofuel production techniques, related waste treatment, emissions and environmental impacts, water consumption, produced allergens and toxins. Additionally, the biofuel policy discussion is expected to be continuing in the foreseeable future and the reading of the biofuels features dealt with in this book, are recommended for anyone interested in understanding this diverse and developing theme.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Emily Newes, Daniel Inman and Brian Bush (2011). Understanding the Developing Cellulosic Biofuels Industry through Dynamic Modeling, Economic Effects of Biofuel Production, Dr. Marco Aurelio Dos Santos Bernardes (Ed.), ISBN: 978-953-307-178-7, InTech, Available from: <http://www.intechopen.com/books/economic-effects-of-biofuel-production/understanding-the-developing-cellulosic-biofuels-industry-through-dynamic-modeling>

INTech
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2011 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](https://creativecommons.org/licenses/by-nc-sa/3.0/), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen