An Overview of the Biomass Scenario Model

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Contents

Figures and Tables

Introduction

This report describes the structure of the current (2011-07) version of the Biomass Scenario Model (BSM). BSM aims to provide a framework for exploring the potential contribution of biofuel technologies to the transportation energy supply for the United States over the next several decades. The model has evolved significantly from the prototype that was developed as part of the Role of Biomass in America's Energy Future (RBAEF) project. In its current state, BSM represents the supply chain surrounding conversion pathways for multiple fuel products, including ethanol, butanol, and so-called refinery-ready fuels (diesel, jet fuel, gasoline).

Purpose and strategy

Throughout the BSM effort, the BSM team –key team members include staff from the National Renewable Energy Laboratory (NREL), United States Department of Energy (DOE) sponsors, other contractors, and Peterson—has worked to develop a framework for understanding the evolution of the supply chain for biofuels. We seek to understand the circumstances that govern the rapid introduction of biofuels into the United States transportation fuel system. Figure 1 depicts our strategy and approach:

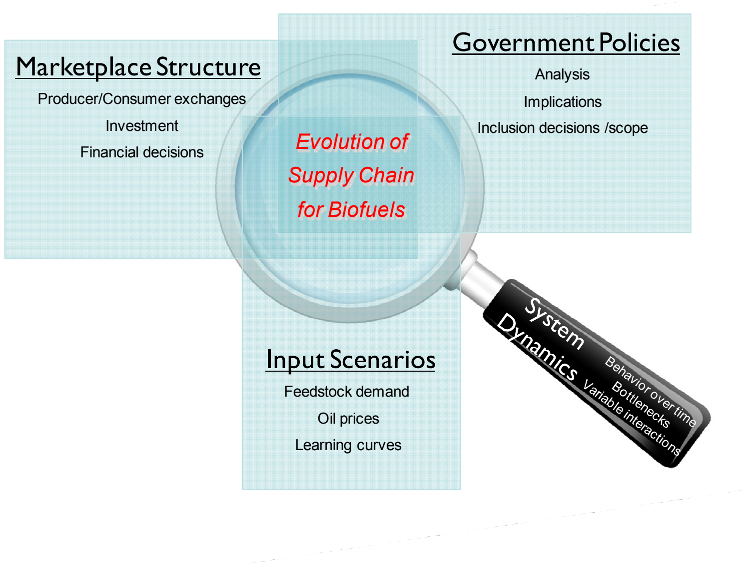

Figure 1. BSM strategy and approach

In order to gain a clear view into the evolution of the supply chain for biofuels, BSM focuses on the interplay between marketplace structures, various input scenarios, and government policy sets. In order to represent this rich interplay, we have employed system dynamics. System dynamics has a rich history of application to a broad array of application areas (Sterman, 2000). Its strengths in representing and simulating the behavior feedback-rich social systems make it well-suited to the task of helping us to emphasize and understand system interconnections from feedstock production to fuel end use.

What's in this document[1]

This report provides a description of the structure of BSM. It begins with an overview of the model architecture. Second, it takes a deep dive into the sectors and modules that comprise the model. Moving across the supply chain, this second section provides a view into a) feedstock supply and logistics; b) multiple conversion pathways; c) "downstream" ethanol and butanol dynamics; d) the BSM representation of the oil industry; and e)ethanol import. Third, the report identifies key connections *between* model sectors. Fourth, the report briefly describes our approach to data inputs for the model. Fifth, a brief section describes directions for analysis with the current version of the model. An appendix to the report provides detail on the form of the pricing structure at multiple places within the model.

An Overview of the BSM Architecture

BSM has been designed in a top-down, modular fashion. In developing the model, we have taken care to create a structure that is transparent, modular, and extensible. This modular approach enables standalone analysis of individual model components as well as testing of different module combinations. As shown below in Figure 2, the model is framed as a set of interconnected sectors and modules.

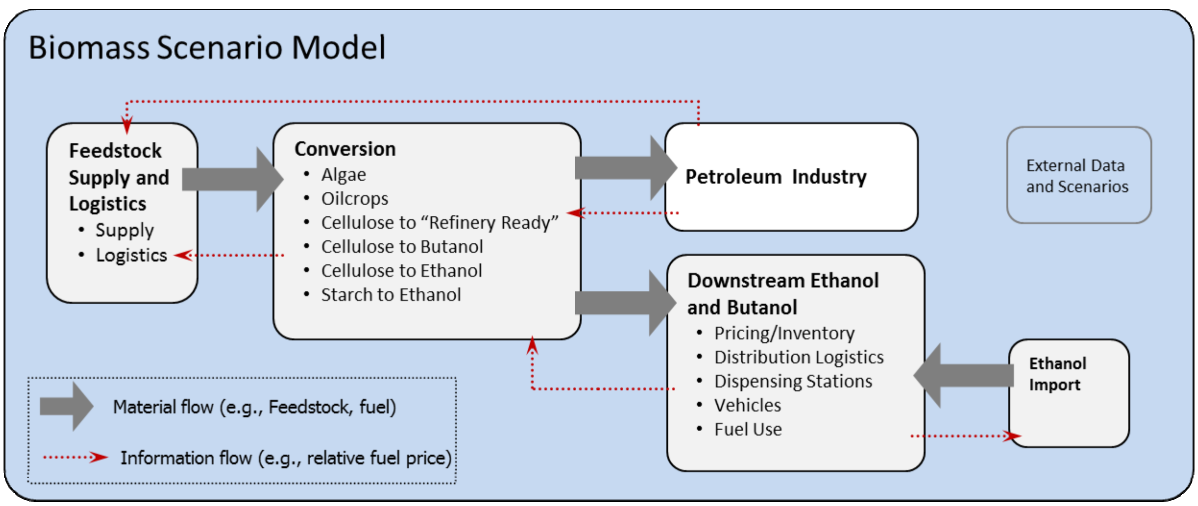

Figure 2. Overview of BSM structure

Feedstock supply and logistics

The feedstock supply and logistics sector captures the dynamics of cellulosic, oil crop, and starch feedstock supply from agricultural lands. It captures harvesting and transportation logistics associated

[1]Over the course of this project, the project team has developed numerous internal reports and briefing documents. These are housed on the project repository at (bsm.nrel.gov). This report draws liberally from these reports and briefing documents—particularly for the figures used within. Adaptations of many of these graphics and a parallel description of much of the model appears in a forthcoming book chapter (Newes, Inman, & Bush, (forthcoming)) written by members of the BSM team.

with cellulosic feedstock. It also captures feedstock supply and logistics associated with both forest, urban, and agricultural residues.

Feedstock production from agricultural land occurs against the backdrop of other uses of the agricultural land base. These include commodity crop production (corn, wheat, soybean, small grains, cotton), hay, pasture, and Conservation Reserve Program (CRP) land. The agricultural production system disaggregated regionally into 10 production regions taken from the United States Department of Agriculture (USDA). These production regions are shown below, in Figure 3:

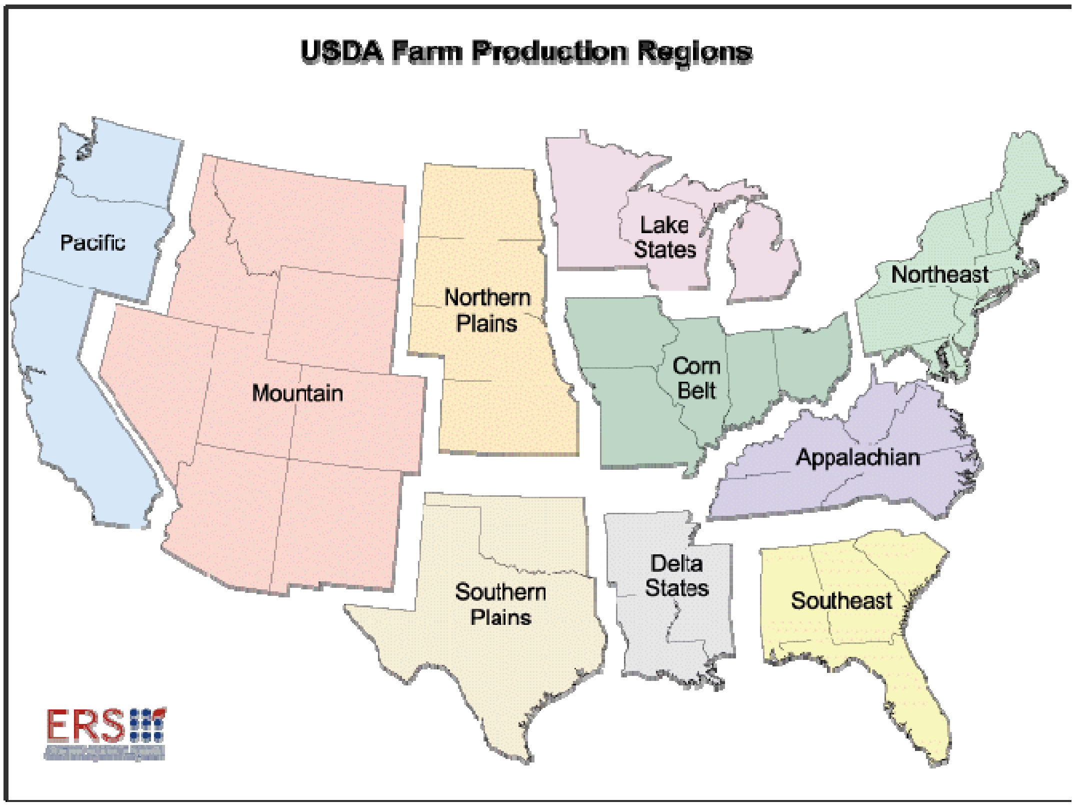

Figure 3. USDA farm production regions

Conversion

The conversion sector is composed of six different conversion modules, each corresponding to a different set of pathways for production of biofuels.

- Starch to Ethanol: This module represents the conversion capacity associated with the existing starch (corn) ethanol industry. This industry is considered to be mature; hence, the module represents simply the financial logic associated with acquisition and utilization of commercial scale corn ethanol facilities. This module is disaggregated by USDA production regions.

- Cellulose to Ethanol: This module captures the development of the cellulose-to-ethanol conversion industry. Biochemical and thermochemical conversion options are considered on a USDA-regionalized basis. The module represents pilot, demonstration, pioneer-commercial and full-commercial scale facilities. It includes learning curve dynamics, investment decision logic, and utilization logic for both pioneer and full commercial scale facilities.
- Cellulose to Butanol: This module captures the development of the cellulose-to-butanol conversion industry. In BSM, butanol serves as an industrial solvent and as a substitute for ethanol in the oxygenate market. A single, regionally-disaggregated cellulose-to-butanol conversion option is captured in the model. The module represents pilot, demonstration, pioneer-commercial and full-commercial scale facilities. It includes learning curve dynamics, investment decision logic, and utilization logic for both pioneer and full commercial scale facilities.
- Cellulose to “Refinery Ready:” This module captures the development of the cellulose-to-refinery-ready “fungible fuels” conversion industry. Multiple conversion options are considered, including:
    - Fast Pyrolysis
    - Fischer-Tropsch
    - Methanol to Gasoline
    - Fermentation
    - Aqueous Phase Reforming

  As with other cellulosic modules, this module is disaggregated by USDA regions. It represents pilot, demonstration, pioneer-commercial and full-commercial scale facilities. It includes learning curve dynamics, investment decision logic, and utilization logic for both pioneer and full commercial scale facilities. Multiple products or product substrates can be produced, including gasoline, diesel, and jet fuel. The “drop-in point” for various products is determined as a scenario variable.

- Oil crops: The Oil crop module captures development of conversion capacity for soy-to-refinery and “other” oilseed to refinery processes. Oil crops are not geographically disaggregated. The module represents pilot, demonstration, pioneer-commercial and full-commercial scale facilities. It includes learning curve dynamics, investment decision logic, and utilization logic for both pioneer and full commercial scale facilities.
- Algae: The Algae model represents open pond, photobioreactor, and heterotrophic conversion options. It is not geographically disaggregated. Algae production is presumed to be vertically integrated in the algae to refinery-ready system. The module represents pilot, demonstration, pioneer-commercial and full-commercial scale facilities. It includes learning curve dynamics, investment decision logic, and utilization logic for both pioneer and full commercial scale facilities.

In addition to the six conversion modules, the conversion sector includes a simple module that knits together the attractiveness of the various investments in conversion options, allocating facility construction capacity among these options based on their relative economic value.

Petroleum industry

The petroleum industry sector comprises scenario inputs around crude oil prices, It provides logic that translates these prices into price inputs for the various refinery ready conversion modules and the pricing/inventory module of the downstream ethanol/butanol sector. Additionally, the petroleum industry model provides accounting logic that captures displacement of crude by biofuel-derived gasoline, diesel, and jet fuel.

Downstream ethanol and butanol

The downstream ethanol and butanol sector is composed of a set of five modules. These modules capture activities “downstream” of conversion of ethanol and butanol.

- Pricing/Inventory: Module captures pricing structure and the inventory dynamics for both ethanol and bio-based-butanol. Ethanol flows into two distinct but coupled markets: the “low-blend” oxygenate market and the “high-blend” market associated with flexible fuel vehicles. Bio-butanol can serve as a substitute for ethanol in the oxygenate market, and also can supplant butanol produced by other processes in the industrial market.
- Distribution logistics: This module provides a very simple representation of the regional build-out of the distribution network for fuel ethanol.
- Dispensing stations: The dispensing station module addresses the regional acquisition of tankage and equipment capable of dispensing high ethanol blends into flex-fuel capable vehicles. Build-out of E85-capable stations is driven by economic considerations, and is constrained by regional availability of ethanol from the distribution network.
- Regional potential fuel demands for ethanol and for gasoline are treated as a set of scenario inputs in the Vehicle module. A separate model handles the accounting associated with the acquisition, vintaging, and retirement of vehicles, as well as the translation of vehicles into potential demand for fuel.
- Fuel use: The mix of low-ethanol-blend vs. high-ethanol-blend consumption is determined by the relative economics of the two products as constrained by the regional availability of ethanol for high-blend consumption through dispensing stations.

Ethanol Import

The ethanol import module provides a simple representation of the evolution of non-domestic ethanol production capacity. It generates imports of ethanol into the US based on a price differential as perceived from outside the US. This structure enables the model to capture historical patterns of growth and decline in imports of fuel ethanol.

A More Detailed view of BSM

Feedstock supply and logistics

The feedstock supply and logistics sector is responsible for generating cellulosic, starch, and oil crop feedstocks for the conversion sector in BSM. The US agricultural system forms the context for the production of a significant portion of these feedstocks. Accordingly, in developing the feedstock supply and logistics sector we have taken care to respect both the physical (land use) and economic aspects of US agriculture. The sector is divided into two modules: Feedstock Supply and Feedstock Logistics.

Feedstock supply

Feedstock supply refers to the production of different feedstocks required as substrate for conversion. Feedstocks generated by the Feedstock supply module are summarized in Table 1.

Feedstock	Source	Use	Notes
Corn	Crop Land	Ethanol	
Soy	Crop Land	“Refinery Ready” fuels	
Other Oil seed	Crop Land (small grains)	“Refinery Ready” fuels	Model does not explicitly represent land allocation to other oil seed (e.g., rapeseed)
Crop Residue	Crop Land	Ethanol | Butanol | “Refinery Ready” fuels	Model allows residue collection from corn, wheat, other grains, cotton
Herbaceous Cellulosic energy crop	Crop land Pasture land	Ethanol | Butanol “Refinery Ready” fuels	
Woody cellulosic energy crop	Crop land Pasture land	Ethanol | Butanol “Refinery Ready” fuels	
Pasture	Pasture land	Ethanol | Butanol “Refinery Ready” fuels	
Urban residue	Urban areas	Ethanol | Butanol “Refinery Ready” fuels	Represented as simple price-response supply curve
Forest residue	Forest lands	Ethanol | Butanol “Refinery Ready” fuels	Represented as simple price-response supply curve

Table 1. Summary of feedstocks produced by Feedstock Supply Module

As indicated in Table 1, urban and forest residue feedstocks are generated using simple price-supply relationships. All other feedstocks are produced by the agricultural land base. Figure 4 identifies the different land categories represented within the feedstock supply module.

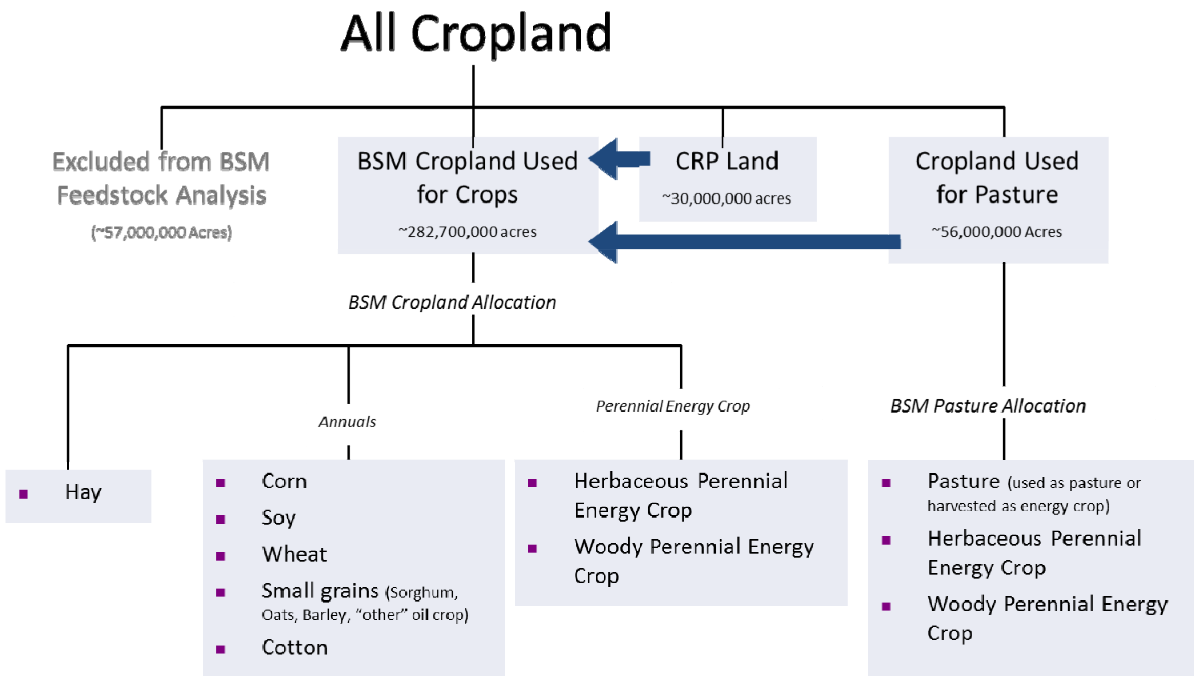

Figure 4. Land categories represented within Feedstock Supply Module

Within each of the ten USDA regions represented in the model, land is divided among three high-level categories: cropland used for crops, CRP land, and cropland used for pasture. These land bases are typically treated as static quantities over the course of a simulation run. However, as indicated in Figure 3, it is possible via scenario input to "leak" land from CRP or pasture into cropland used for crops. Within each land base, land is allocated among different uses based on expected relative per-acre grower payment accruing to producers from the various products. Land allocation occurs within regions. Only those producers who have adopted the practice of producing cellulosic products (either residue or perennials) consider cellulosic grower payments in their decision making. "New practice" producers can grow over time based on the potential profitability of cellulosics, as constrained by the requirements of the existing and prospective conversion facilities.

Detail around the land allocation decision process is shown in Figure 5.

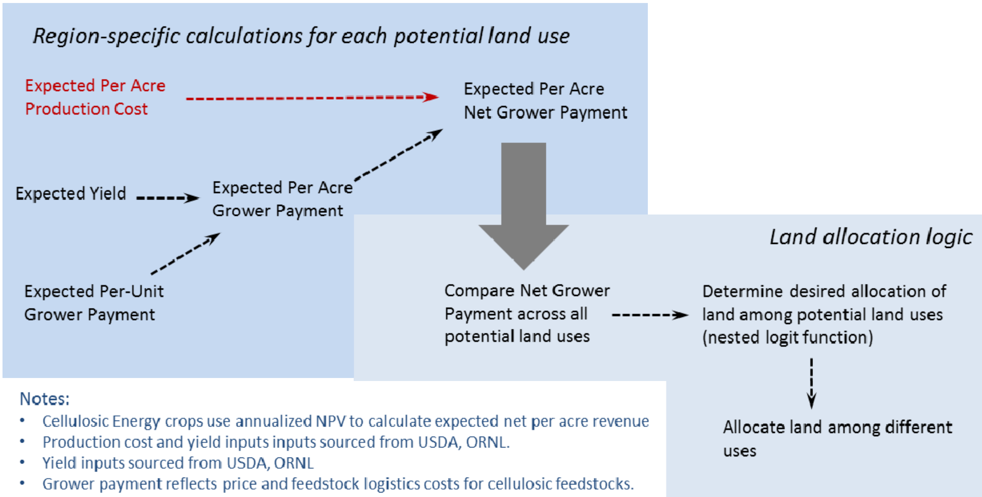

Figure 5. The agricultural land allocation algorithm

Not shown in Figure 5, but essential to the dynamics of BSM, is the logic surrounding pricing for the various commodity crops, cellulosic products, and hay. This logic is central to a feedback mechanism that uses land allocation to equilibrate production and consumption across all product categories in the model. A more detailed treatment of the pricing structure used in BSM is provided in the appendix. Figure 6 shows in simple terms the feedbacks around price in the feedstock supply module.

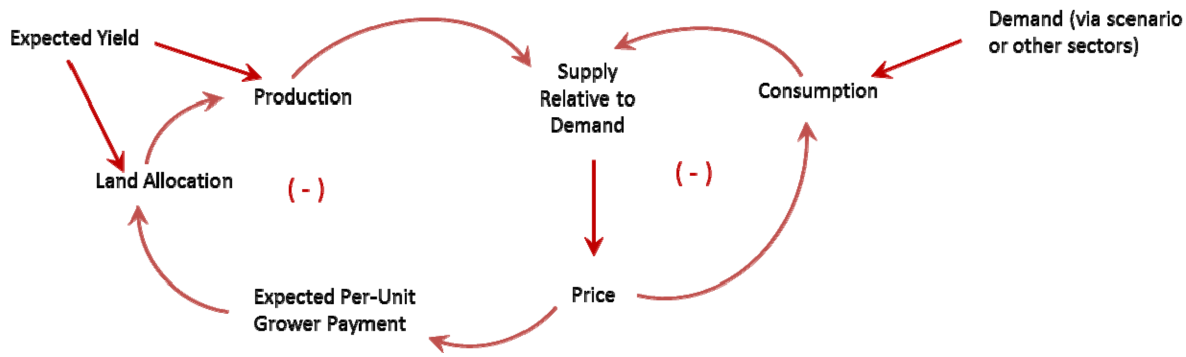

Figure 6. Price feedbacks in feedstock supply module

Feedstock Logistics

The feedstock logistics module provides a simple accounting structure that captures the following costs:

- Harvesting and collection
- Transport from "farmgate" to "plantgate"
- Storage, queuing, handling, and pre-processing between farmgate and plantgate

These costs are used to translate the per-ton price of feedstock at the plantgate into a per-ton grower payment at the farmgate. In developing the feedstock logistics module, we have drawn from analyses of the IBSAL model at the Idaho National Laboratory (INL). In its current form, the feedstock logistics module supports cost accounting for both pioneer and advanced storage, pre-processing, and queuing/handling processes.

One interesting aspect of the feedstock logistics module is the interplay among different cost components. For example, truck transport is viewed as a primary mechanism for moving feedstock from farmgate to plantgate. Depending upon the feedstock involved, the mass transported on the truck varies, with residue resulting significantly lighter loads than woody cellulosic crops. Other things equal, this implies a higher logistics cost per ton for residues than for woody cellulosic crops.

A second interesting aspect of the feedstock logistics module is the calculation of the travel distance from farm to conversion facility. The model estimates farm-plant distances regionally, by considering the following components:

- The total number of cellulosic plants requiring agriculturally-produced feedstock
- The total volume of agricultural land allocated to producing cellulosic feedstock
- The aggregate average yield of those producing acres
- An estimate of the fraction of land within the "plant-shed" that is available for cellulosic harvesting
- Geometric factors that relate the resultant plant-shed area to average travel distance from farm to plant.

Conversion Sector

The conversion sector is responsible for transforming feedstock into liquid fuels, including ethanol, butanol, and refinery-ready fuels (gasoline, diesel, jet fuel) suitable for insertion into the existing fuel infrastructure as refinery feedstocks, blendstocks, or finished products. In BSM, the conversion module comprises a significant fraction of the overall model structure. It consists of seven modules. Six of these modules look at the dynamics of industry development for sets of conversion pathway. These dynamics include operations at different scale factors, learning along multiple dimensions, logic surrounding the attractiveness of investment in new facilities, and utilization of existing facilities. A seventh module compares investment attractiveness across all conversion options, allocating scarce investment capacity among these options based on their net present value.

Table 2, provides an overview of the scope of the conversion sector. As indicated in Table 2, there is significant overlap among the different industry development modules. In particular, most modules share the following characteristics:

- Multiple conversion options, represented using an arrayed variable structure
- Regional disaggregation, following the feedstock supply module's use of ten USDA production regions
- Incorporation of pre-commercial pilot and demo-scale operations

- Representation of pioneer-commercial-scale operations
- Representation of Full-scale operations
- Learning curve dynamics

	Conversion Options	Regional?	Feedstock	Products	Pilot & Demo Ops?	Pioneer-scale Ops?	Full-scale Ops	Learning Curve Dynamics?
Starch to Ethanol	Single pathway	Yes	Corn	Ethanol	No	No	Yes	No (assume mature industry)
Cellulose to Ethanol	Biochemical Thermochemical	Yes	Cellulosic Feedstock	Ethanol	Yes	Yes	Yes	Yes
Cellulose to Butanol	Single Pathway	Yes	Cellulosic Feedstock	Butanol	Yes	Yes	Yes	Yes
Cellulose to Refinery	Fast Pyrolysis Fischer-Tropsch Methanol to Gasoline Fermentation APR	Yes	Cellulosic Feedstock	Gasoline Diesel Jet fuel (3 drop-in points)	Yes	Yes	Yes	Yes
Oil Crop to Refinery	Soy Other	No	Oil crop	Diesel Jet fuel (3 drop-in points)	Yes	Yes	Yes	Yes
Algae to Refinery	Pond Photobioreactor Heterotrophic	No	Algae—treated as part of conversion process	Diesel Jet fuel (3 drop-in points)	Yes	Yes	Yes	Yes (feedstock supply considered endogenous to module and subject to learning curve)

Table 2. "Dimensionality" of Conversion Sector

For some modules (oil crop, algae) it is not necessary to disaggregate by region. The starch to ethanol industry, for example, is assumed to have reached maturity. Because the industry is mature in the model, there is no need to represent the dynamics of pilot, demo, or pioneer scale operations. Nor is there a requirement to represent learning curve dynamics. In the algal module, feedstock production is considered as endogenous to the algae system rather than produced by the feedstock supply sector. Algal feedstock production costs are subject to learning curves in the algae module.

Within the typical conversion module, there are multiple processes that govern the development of the conversion options under consideration and their production of fuel. These processes are centered on:

- Pilot and Demo Scale Operations
- Pioneer-commercial scale operations
- Full-commercial scale operations
- Expected economic value of the “next” investment

- Allocation of scarce capital in the investment decision
- Learning along multiple dimensions
- Industry aggregate average utilization rates for existing facilities

Figure 7 provides a schematic representation of key interconnections among these processes.

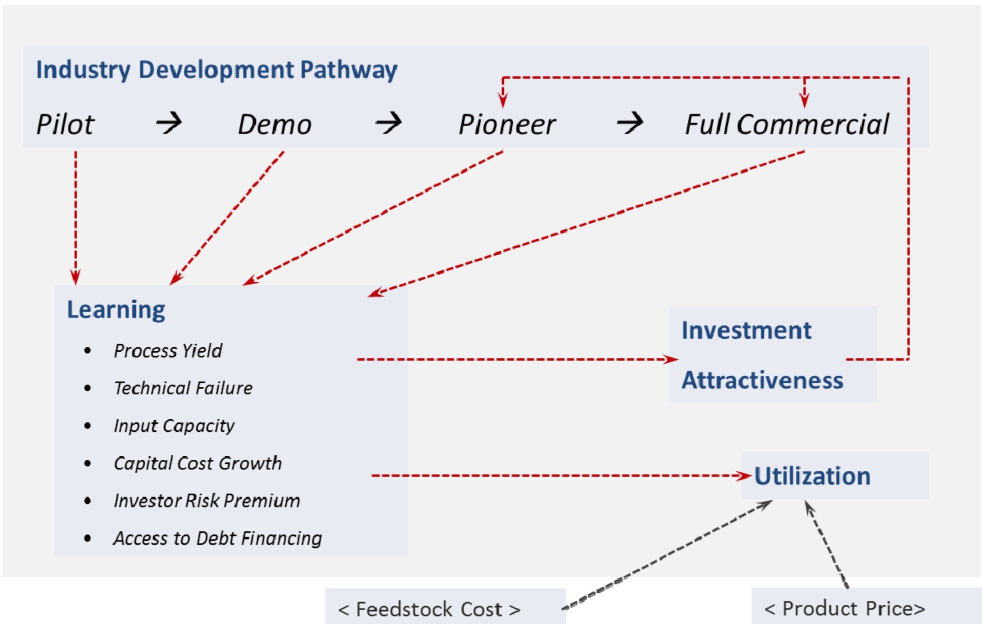

Figure 7. Key interactions within the typical conversion module

Pilot- and Demonstration-Scale Operations

Pilot and demonstration-scale operations are represented simply in the model. Figure 8 shows the stock/flow structure of these operations.

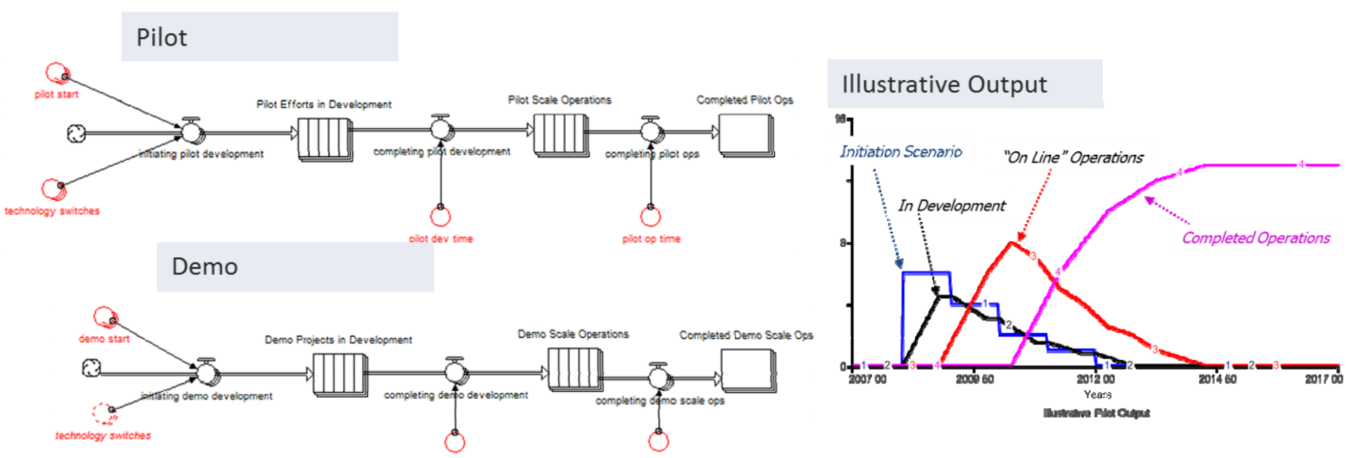

Figure 8. Pre-commercial structure and illustrative output

There are several important features to note in Figure 8. First, note that the structure for each pre-commercial scale operation is arrayed, based on the number of conversion options at play within the module. Technology switches, set by the user, enable the activation/deactivation of each conversion option. Second, note that both pilot and demo operations are specified as exogenous scenario inputs. These scenario inputs enable an arbitrary pattern of initiation to be specified by the end user. Third, note that the model explicitly represents the dwell time between initiation and completion of development using conveyors. Fourth, note that the time for which operations are active—used in the model to generate learning—is limited in duration. Finally, note that cumulative completed operations are tracked by the structure. Figure 8 provides illustrative output that translates an arbitrary initiation scenario into development, “on line,” and completed operations.

Pioneer-commercial-scale operations

In the model, Pioneer-commercial-scale facilities are typically the first commercial scale plants to come on line. These facilities have a smaller (about 1/3) capacity than full-commercial-scale facilities. They do not take full advantage of economies of scale. Hence, in typical simulations of BSM subsidies are required to stimulate investment in pioneer plants. Note that the starch to ethanol module excludes pioneer facilities from analysis.

As shown in Figure 9, two stock/flow chains are used to account for pioneer scale plants. Depending on the module in question, these chains are arrayed by conversion option and/or by region (Refer to Table 2, above, for details on the “dimensionality” of each conversion modules). The top chain represents the *number* of plants in design and construction, in startup, and in use. The bottom chain is a co-flow structure that is used to account for the *process yield* (gallons of output per ton of feedstock input). These two concepts—facilities and process yield—jointly determine the output capacity for pioneer facilities. Output capacity is a reflection of the total ability to produce fuel, for the conversion option in question.

The co-flow structure here is essential for the accurate accounting of facilities and their associated process yields. Whenever a new facility enters the system through the initiating flow, the model samples the current state of the industry process yield for the associated conversion option. This process yield then moves along with the facility through the development process, eventually being used as an input for the average process yield of on-line facilities. This structure enables the model to dynamically track the industry implications of growth in process yields for “new” plants, as the industry moves from “blue sky” to “nth plant maturity.”

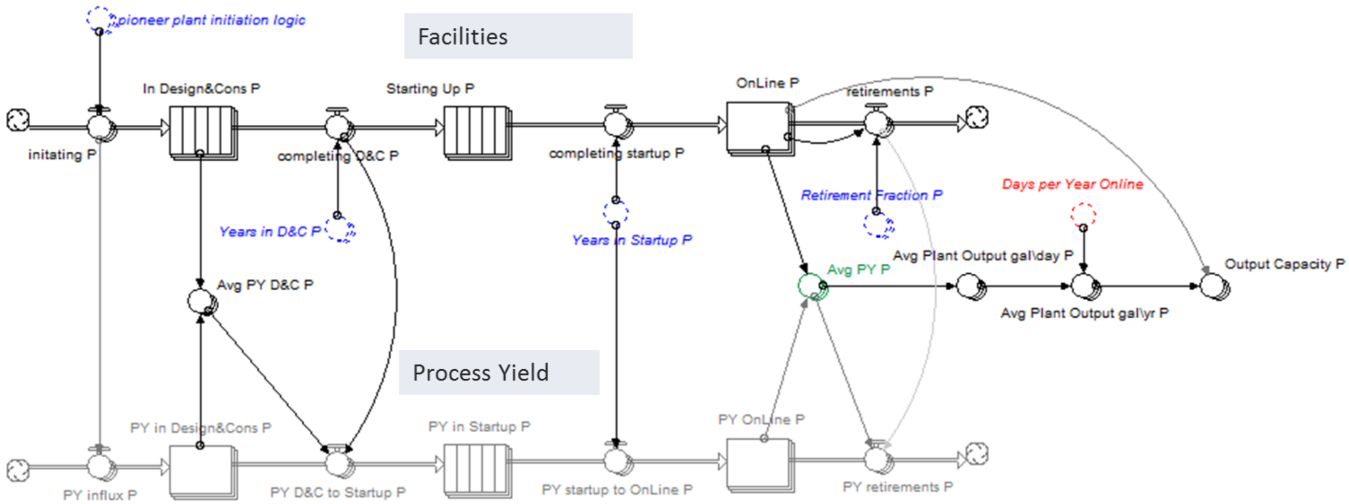

Figure 9. Accounting for pioneer facilities, process yield, and output capacity

Note that structure has been provided to account for retirement of plants. In the current version of the model, we assume a retirement fraction of zero, which implies that no plants are taken permanently off line over the course of a simulation. The logic that controls utilization factors, discussed below, accounts for the dynamics of short-term plant idling in response to market forces.

Full-commercial-scale operations

Figure 10 shows the structure that accounts for full-commercial-scale operations in the model. As with pioneer plants, commercial plants use two stock/flow chains to represent the design and construction, the start-up, and the on line phases of the facility life cycle. As with pioneer plants, the structure for commercial operations is arrayed by conversion option and/or by region within each module.

A casual observation of Figure 10 will reveal two notable differences between the pioneer and commercial accounting structures. First, note that in contrast to pioneer facilities, commercial facilities in the start-up phase are assumed to contribute to the overall output capacity. A utilization rate (less than 1) is assumed for plants during the period that they are in startup.

Second, note that a new flow has made its way into the process yield chain for commercial scale facilities. This flow enables the model to capture the effect of process yield improvements to be incorporated into the *existing* capital stock. The specific rate at which a yield gap—measured as the discrepancy between the state of the industry process yield for a particular conversion option and the existing industry average process yield for that conversion option—is eliminated can be set by the model user.

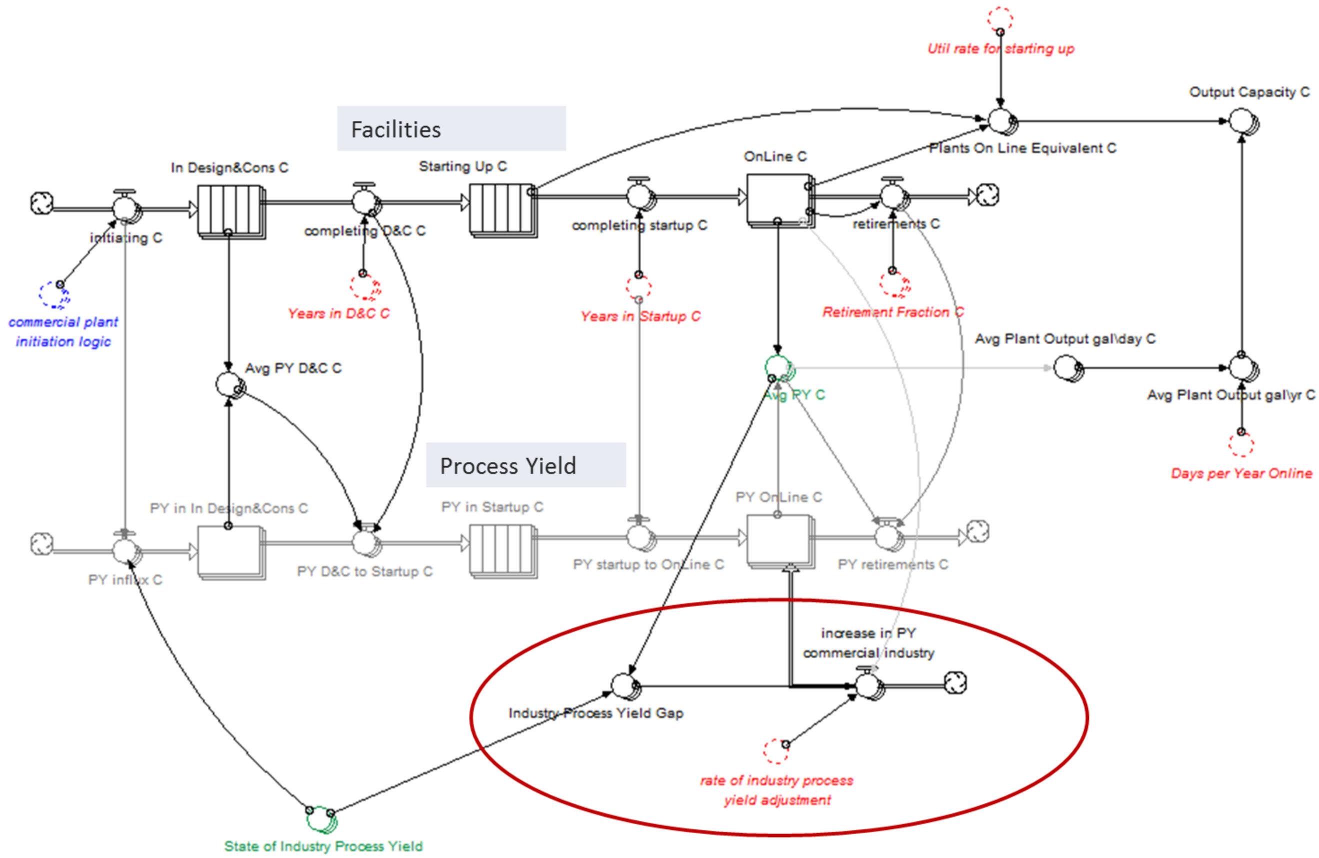

Figure 10. Accounting for commercial operations, process yield, and output capacity

Expected Economic Value of the "Next" Investment

In developing BSM, an important challenge arose around the need for a simple, defensible mechanism for determining the viability of investment in the "next" plant at either pioneer or commercial scale for the various conversion options within the regions under consideration. Rather than a static calculation, we needed a dynamic economic mechanism to drive industry growth. Our approach in meeting this challenge was to develop a net present value calculation that captures important streams of costs and revenues associated with a prospective project investment. By discounting these streams to the present, we capture the dynamics of an evolving industry with a simple metric that enables us to compare prospective investments across multiple conversion options, regions, and scales. This metric enables the model to allocate scarce capital toward its highest valued uses.

A parallel algorithm is used for Net Present Value (NPV) calculations within each conversion module. As appropriate to each module, the algorithm reflects conversion options, regional considerations, and scale. Given this degree of disaggregation, the approach operates at the highest possible degree of aggregation, rolling up wherever possible sub-categories into high-level summaries. For example, for purposes of the NPV calculation, factor inputs and expected per-gallon revenues are held constant over the plant lifetime. Figure 11 provides a simple influence diagram showing the logic flow leading to the NPV calculation.

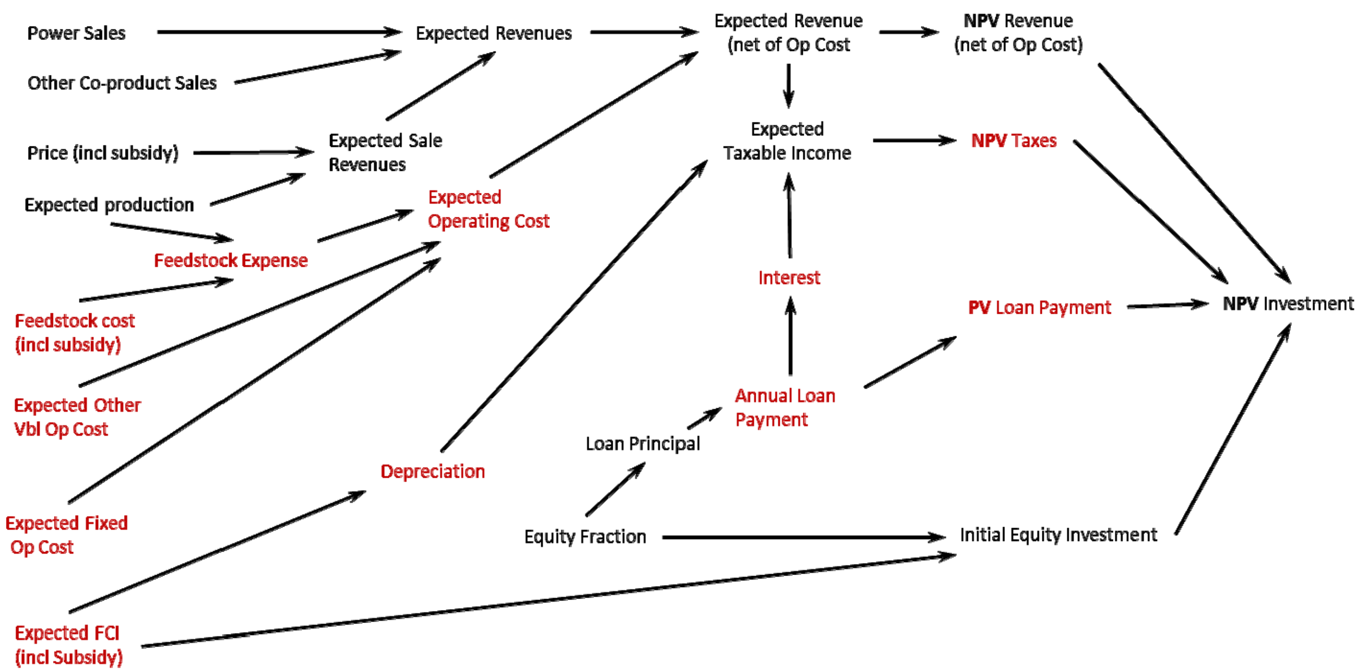

Figure 11. Logic of NPV calculation

In developing the NPV logic, we have adopted some important simplifications. First, we assume straight-line depreciation. This significantly reduces detail complexity in the model. Second, we divide the overall project life cycle into distinct phases, as shown in Figure 12. In the model, NPV calculations are made for each phase of the project life cycle, and then rolled up to create an overall NPV for the plant.

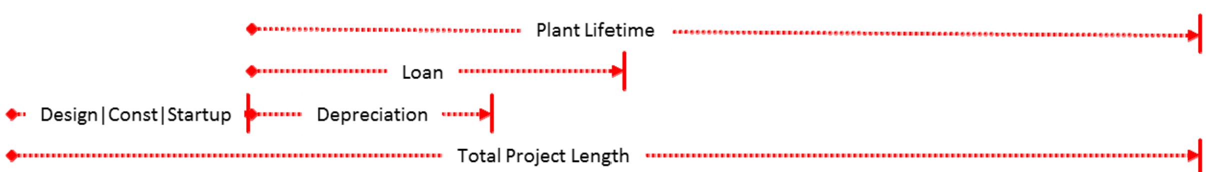

Figure 12. Phases of project life cycle

Allocation of scarce capital

Within the BSM conversion sector, then, multiple opportunities present themselves to potential investors at any point in time. At the extreme, thirteen conversion options can be active. Nine options compete across ten regions. Twelve conversion options exist at both pioneer and commercial scale. That's a lot of options for investors to consider. Within the model, each conversion module uses NPV as a basis for determining the attractiveness of the various investment options under consideration. This is done using a logit function. The resultant attractiveness metrics are then compared within the Relative

Attractiveness (RAT) module, which also includes a default “other” investment category. The relative attractiveness for each alternative is then applied to a scenario-driven maximum construction capacity, which generates a platform and scale-specific yearly start rate. This “desired” start flux is communicated back into the conversion modules, where it is allocated regionally if required and “batchified” so as to send a discrete signal to begin plant development. Figure 13 provides a view into the logic surrounding allocation of capital.

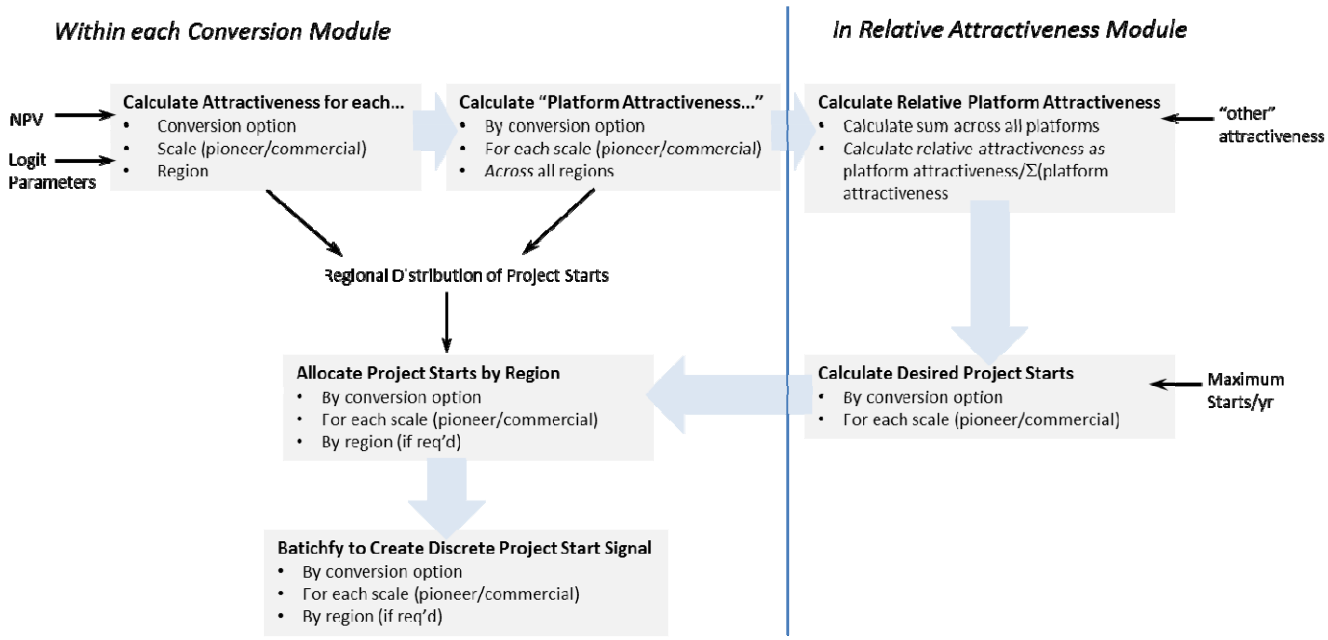

Figure 13. Translating NPV into project start signal

Learning Along Multiple Dimensions

For most conversion options under consideration in BSM, the initial performance on multiple dimensions would fall far short of expected “Nth plant” performance, as reflected NREL and other design studies. Industry evolution is in no small measure the story of performance improvement that results from learning by doing. Merrow’s research on cost growth in capital-intensive industries (Merrow, 1983), for example, underscores the importance role of experience at prior scale in reducing the risk of capital cost growth at commercial scale. Henderson’s work with the Boston Consulting Group in the 1970s (Hax & Majluf, 1982) demonstrates the role of learning as a cost-reduction strategy at commercial scales.

Given the important connections between learning and industry evolution, we needed to develop a simple, consistent, and defensible mechanism to translate the accumulation of experience into a set of performance parameters to represent the current “state of the industry” for each conversion option. Our approach, which we call “cascading learning curves” draws upon simple learning curve principles in order to address learning for multiple conversion options at multiple development stages, addressing multiple performance attributes. There are four fundamental attributes to the cascading learning curve approach:

- Develop separate cascading curves for each conversion option. By providing separate structure for each conversion option, we have created the possibility to separately characterize different initial conditions, mature industry conditions, and learning rates on a conversion option-specific basis.
- Capture learning for each conversion option at three distinct development stages. In BSM, we look at learning for pilot scale operations, for demonstration scale operations, and for commercial scale operations (including pilot and full commercial scale). A staged approach to learning enables us to capture prior scale effects (important for capital cost growth). It also enables us to explore the implications of stage-specific progress rates as well as the analysis of timing and placement of policy initiatives.
- Use learning to create indices of maturity. These indices of maturity, in turn, drive essential technology attributes that are used within BSM. Key attributes of performance for each conversion option are:
    - Process yield
    - Likelihood of "technical failure"
    - Feedstock throughput capacity—the degree to which facilities are able to perform at nameplate capacity
    - Capital cost growth—the premium in capital cost, beyond Nth plant estimate, which would be observed if development of a facility was begun today.
    - Investor risk premium—the additional premium, beyond normal hurdle rate, that investors would require for investment in the facility.
    - Access to debt financing—the portion of the expected facility capital cost that would be financed via borrowing (vs. equity investment)

The generic stock/flow learning curve structure is shown below in Figure 14. Annotations describe key aspects of the structure.

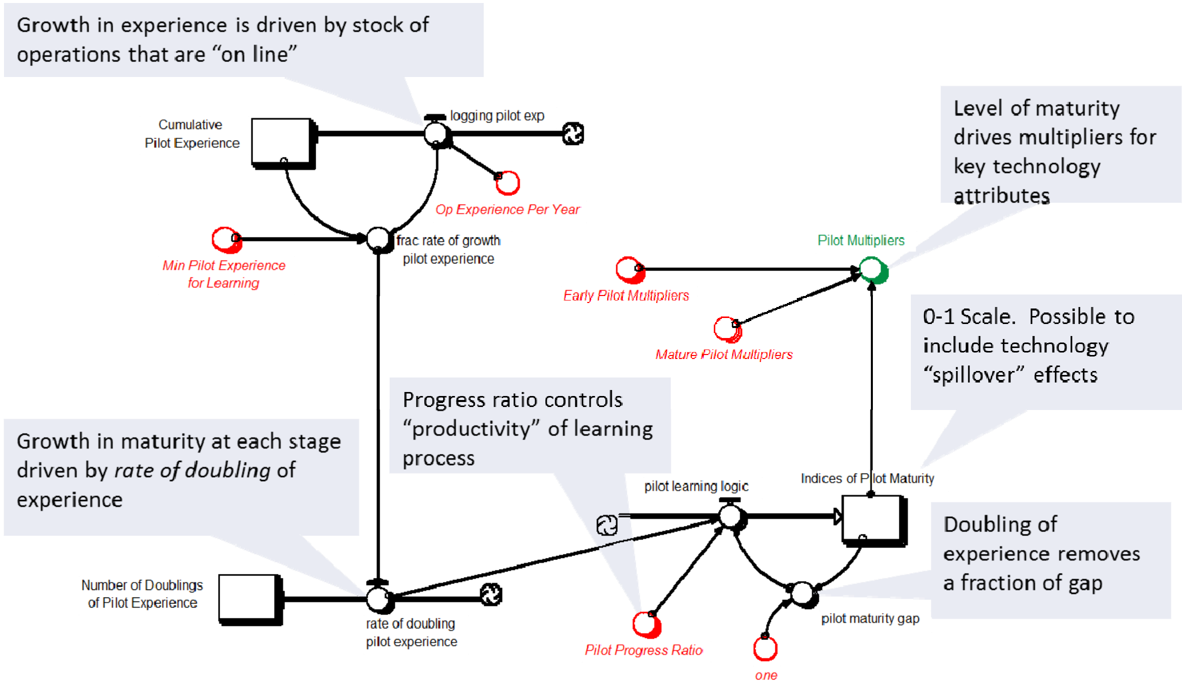

Figure 14. Industry learning curve structure

There are some differences between the representation of the learning curve structure in BSM and other, perhaps more common, formulations of learning curves. In the classic formulation of a learning curve, for example, a power law is used to relate cumulative experience to a single attribute such as cost. The asymptote of cost is often set implicitly to zero. By contrast, in BSM, cumulative learning at each stage of development is reflected along a 0-1 scale in pilot, demo, or commercial maturity. As experience accrues, the model calculates explicitly the rate at which experience is doubling. This rate of doubling is applied to a maturity gap (simply the difference between current maturity and full maturity) to generate learning. Maturity, in turn, drives movement along a vector of attributes.

A second set of differences involves the development stages over which learning is applied. While a typical learning curve analysis might consider cost reductions for relatively stable industries, in BSM we consider multiple attributes over multiple development stages. Figure 15 shows how the learning curves cascade over multiple development stages.

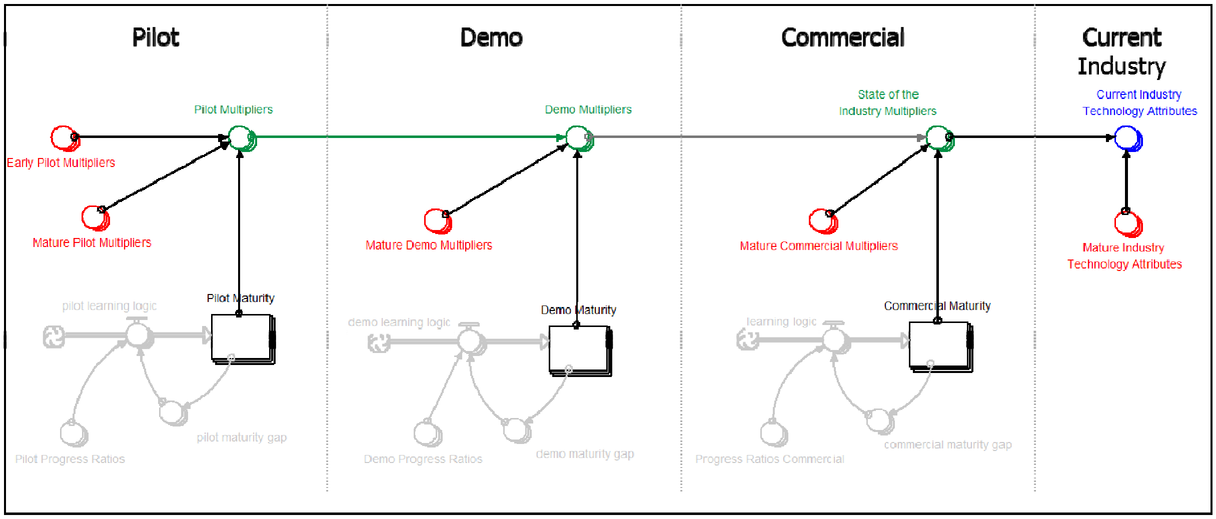

Figure 15. Cascading learning curves

At any point in simulated time, the current industry technology attributes reflect the performance and cost characteristics associated with an investment in a pioneer or full-commercial scale facility for a given conversion option. At each stage, multipliers that are passed on to the next stage are calculated as a weighted average, with the maturity level used as the weighting factor.

Dynamically, this structure enables BSM to jump from one performance trajectory to another based on the behavior of pilot, demo and commercial operations. Figure 16 illustrates. In the figure, simple exogenously-defined scenarios for pilot, demo, and commercial scale operations drive learning at each stage. Cost and yield parameters follow three distinct pathways as the industry evolves.

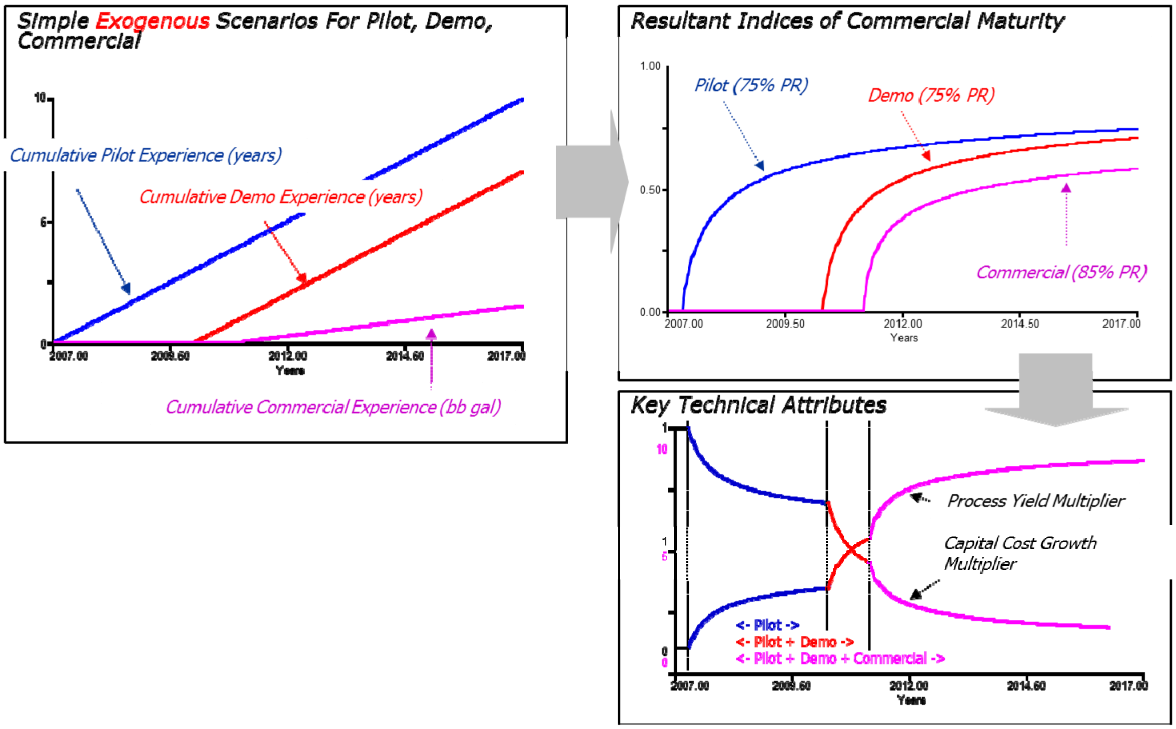

Figure 16. Illustrative learning curve dynamics

Learning curve dynamics, of course, do not occur in isolation from the overall dynamics of the industry. For a given conversion option, learning curves are at the heart of feedbacks that surround the investment process, and which can underwrite industry “take-off.” These feedbacks are shown in a simple loop diagram in Figure 17. Each feedback is a positive feedback, in the sense that it tends to reinforce development of the conversion option in question.

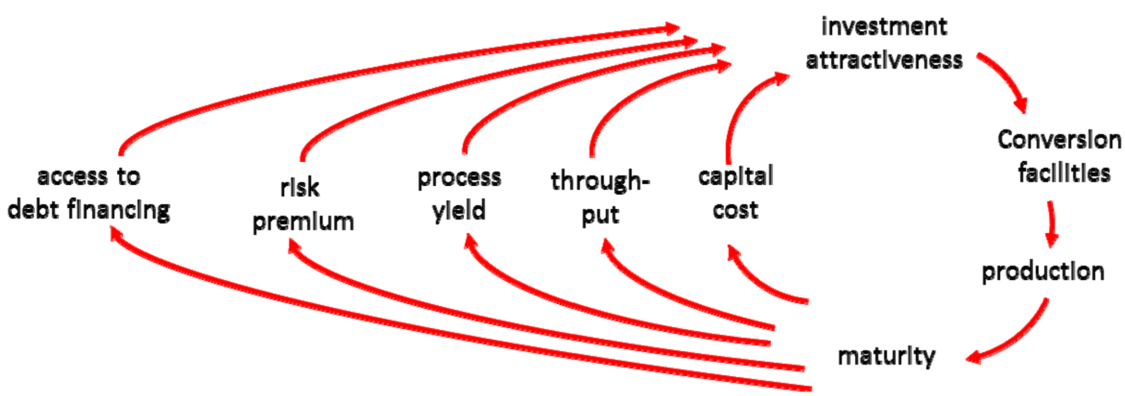

Figure 17. Key feedbacks emerging from learning curve structure

Utilization of existing facilities

Multiple processes are at work in the conversion sector to generate the production of biofuels. A final set of processes concerns the utilization of existing facilities. A fundamental premise of basic economics is that "sunk costs" don't matter. In BSM, conversion facilities are assumed to follow this premise; the capacity utilization rate for each conversion option (within each region, as appropriate) at either pioneer or full commercial scale is developed as a response to the "cost-price ratio" for its products. As the price received for its product (including any subsidies) grows relative to the per-gallon cost of producing that product (after factoring net per-gallon co-product revenues into the mix), utilization increases to its maximum. On the other hand, as the price-cost ratio declines below unity, utilization rates decline. The logic determining cost-price ratios and utilization is shown below, in Figure 18.

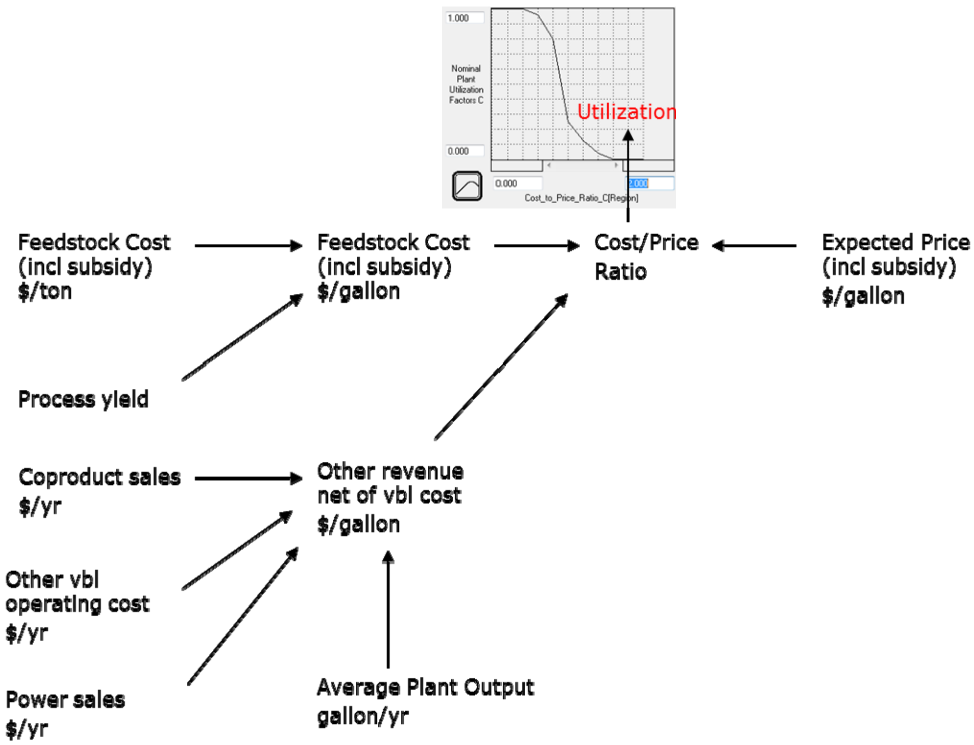

Figure 18. Determining utilization from cost-price ratios

Utilization, by controlling both production of products and consumption of feedstock, is central to the feedback that occurs across the supply chain in BSM.

Conversion Sector in Summary

Each conversion module within the conversion sector is built up from multiple simpler structures that represent pre-commercial demonstration and pilot scale operations, pioneer and full commercial scale operations, the expected economic value of investment, learning and utilization. These structures are connected within each module in order to generate products (diesel, jet fuel, gasoline, butanol, ethanol). They are connected across modules via the logic within the relative attractiveness module that allocates scarce investment capital. The conversion sector is connected upstream in the supply chain to the agricultural system through feedstock supply dynamics, and to both the oil industry (algae, oil crop and cellulose to refinery-ready modules) and the downstream ethanol sector. These downstream sectors determine price (and in the case of ethanol, demand) signals which are sent to the conversion sector modules.

Downstream EtOH sector

The downstream ethanol sector comprises a set of interconnected modules that take fuel ethanol from conversion facilities to end users, both in low-blend (E10) and high blend (E85) form. Additionally, the downstream sector contains logic that controls the use of bio-butanol as a substitute for ethanol in the low-blend market. The model assumes that physical characteristics of ethanol require separate infrastructure for distribution and dispensing than for petroleum-based fuels. A significant portion of the downstream sector, therefore, is focused on distribution and dispensing station dynamics.

Figure 19 provides a picture of the content of the downstream sector. As suggested by the diagram, downstream dynamics focus on the build-out of distribution infrastructure, the development of dispensing infrastructure, and decision making around fuel usage.

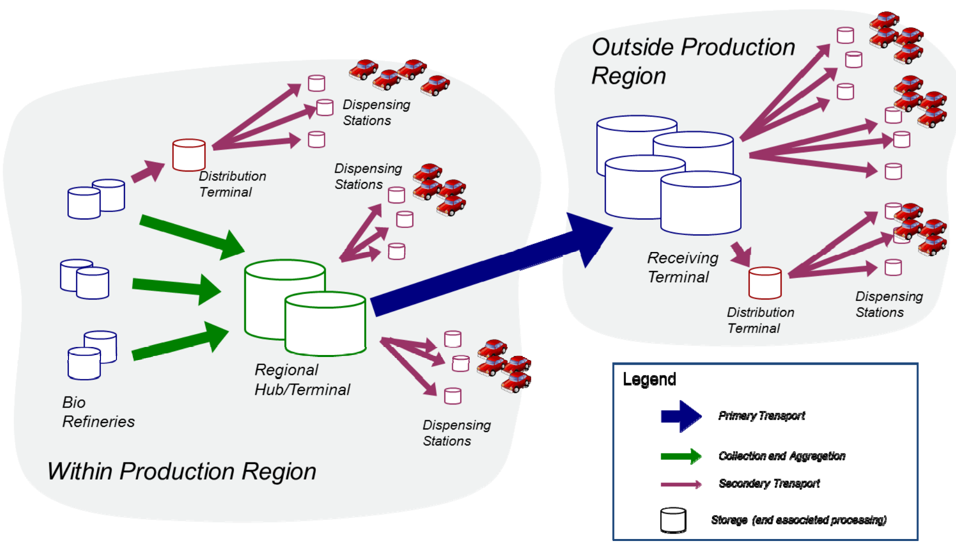

Figure 19. An overview of downstream dynamics

To support these dynamics, multiple modules comprise the downstream sector of BSM. These include:

- Distribution logistics
- Dispensing station
- Fuel use
- Vehicle module inputs
- Pricing and inventory

This report will provide a brief view into each module. Detailed analysis of downstream ethanol dynamics can be found in (Vimmerstedt, Peterson, & Bush, forthcoming).

Distribution Logistics Module

One of the fundamental challenges associated with ethanol as a transportation fuel, is its apparent incompatibility with existing infrastructure. The distribution logistics module provides a very simple representation of the build-out of ethanol-friendly distribution infrastructure. The structure focuses on the acquisition of ethanol infrastructure for terminals within each region. The module is silent on the specific details of infrastructure, instead focusing on the drivers and time delays associated regional build-out.

Figure 20 provides a simplified view of the structure within the distribution logistics module.

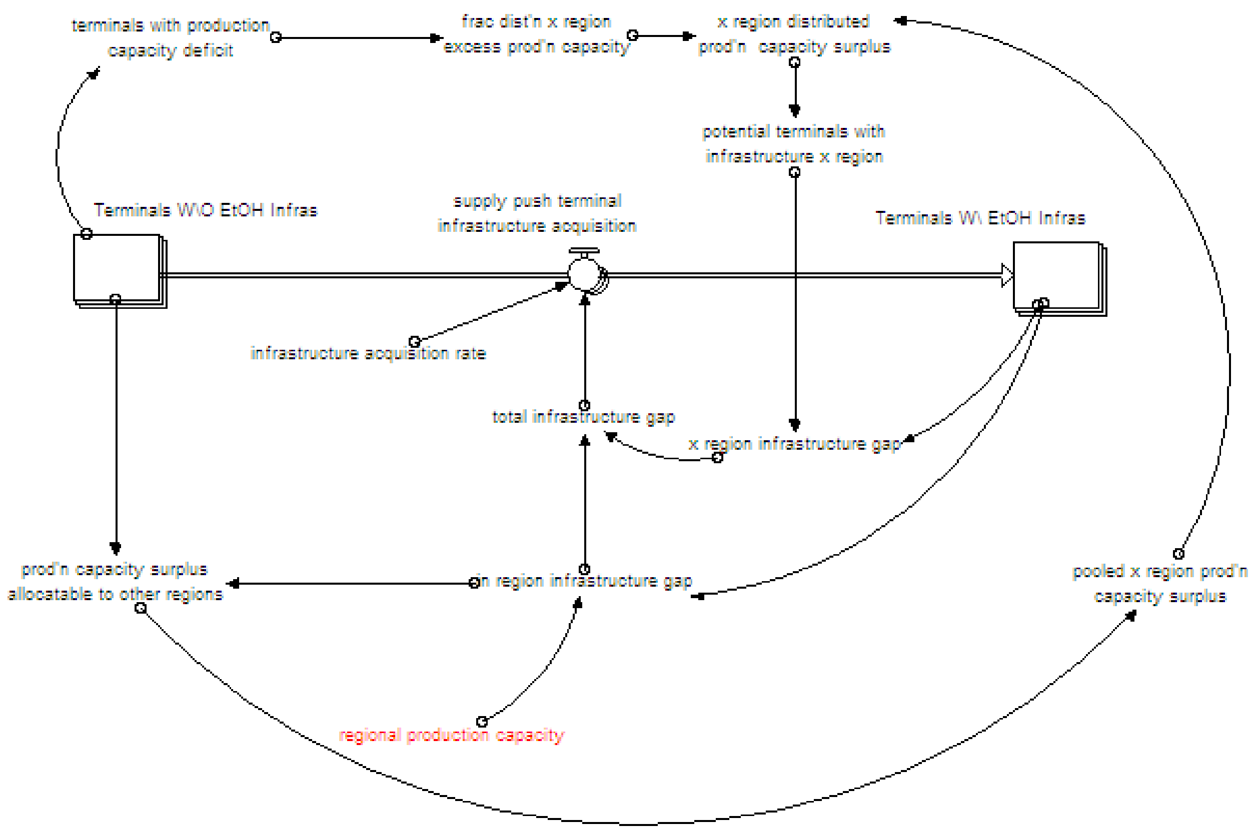

Figure 20. Distribution logistics

A two-stage supply-push approach is embedded within the module. This supply push works both within and across regions. First, the model seeks to balance ethanol production capacity within each region against terminal capacity to distribute that ethanol. As production capacity within a region grows, there is pressure within the region for terminals to acquire ethanol infrastructure.

Second, as build-out occurs within each region, any excess regional production capacity is pooled across regions. This capacity surplus drives acquisition of infrastructure in other regions, in proportion to the terminal density within each region.

The result of this two-stage supply-push algorithm is an initial build-out of distribution infrastructure in ethanol producing regions, followed by a slower build-out in non-producing regions. Infrastructure coverage, in turn, constrains regional investment in ethanol dispensing tankage and equipment, thus setting a limit on the uptake of ethanol in high-blend form.

Dispensing Station Module

The dispensing station module focuses the decision making associated with the acquisition and use of high-blend tankage and equipment by retail dispensing stations. The module considers roughly 120,000 stations, distributed both regionally and by ownership among oil-owned, branded independents, unbranded independents, and hypermart. The fundamental decision for each station is the acquisition of tankage and dispensing equipment required to dispense high-ethanol blends into flex-fuel vehicles. The module assumes that ten percent of stations have repurposable mid-grade tanks. The capital cost of repurposing is assumed to be significantly lower than investment in new tankage and equipment for hi-blends ($20k vs. $60k).

The basic logic within the dispensing station module reflects both the physics of high blend availability and the economics of the investment decision. Stations will not consider investment unless distribution infrastructure is sufficient within the region. They will not invest unless the investment makes economic sense, as reflected in a net present value calculation that captures the discounted stream of expected costs and benefits from the investment.

Thus, two fundamental structures are at play within the dispensing station module. The first is an accounting structure that considers the movement of stations as they adopt high-blend tankage and equipment. The second provides a detailed view into the net present value calculation that undergirds the decision to invest in high blend tankage and equipment. Station movement structure is shown in Figure 21; NPV logic is shown in Figure 22.

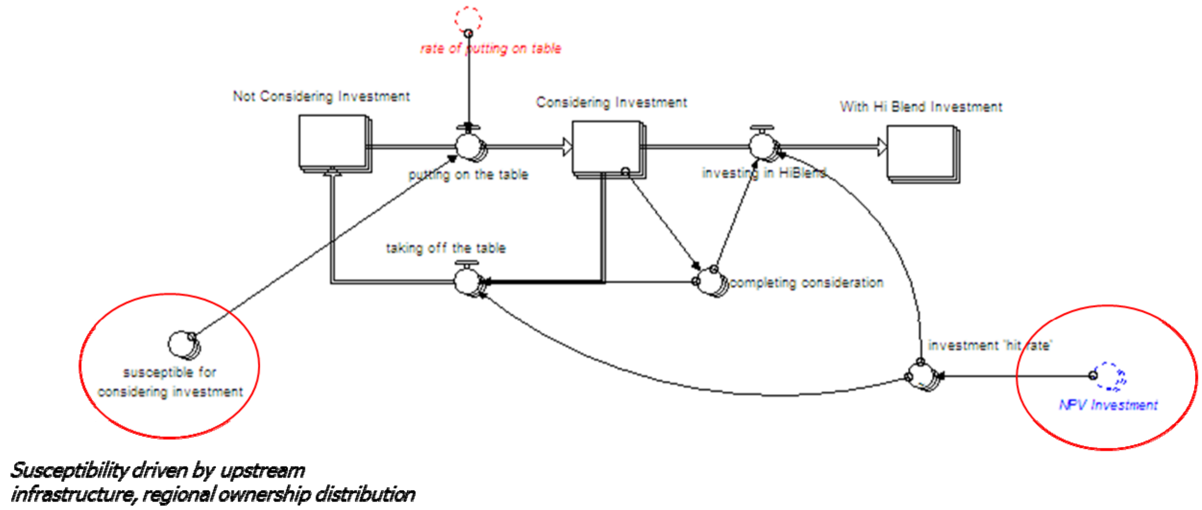

Figure 21. Dispensing station accounting structure

As shown in Figure 21, stations exist in one of three states with respect to investment in high blend tankage and equipment. Depending on the dynamics of regional distribution infrastructure availability, a portion of those stations not considering investment put the investment decision on the table each year. Based on the economic viability of the investment, as reflected in the NPV of the decision, the consideration of investment culminates in a decision to invest or to stop considering the decision. This investment process is disaggregated by region (so as to account for differential degrees of distribution infrastructure within each region), by ownership (to enable different potential affinities for high-blend ethanol sales among different ownership types, and to account for different business details for different ownership types), and by repurpose vs. new investment (to account for different capital costs associated with repurposing vs. new investment in tankage and equipment).

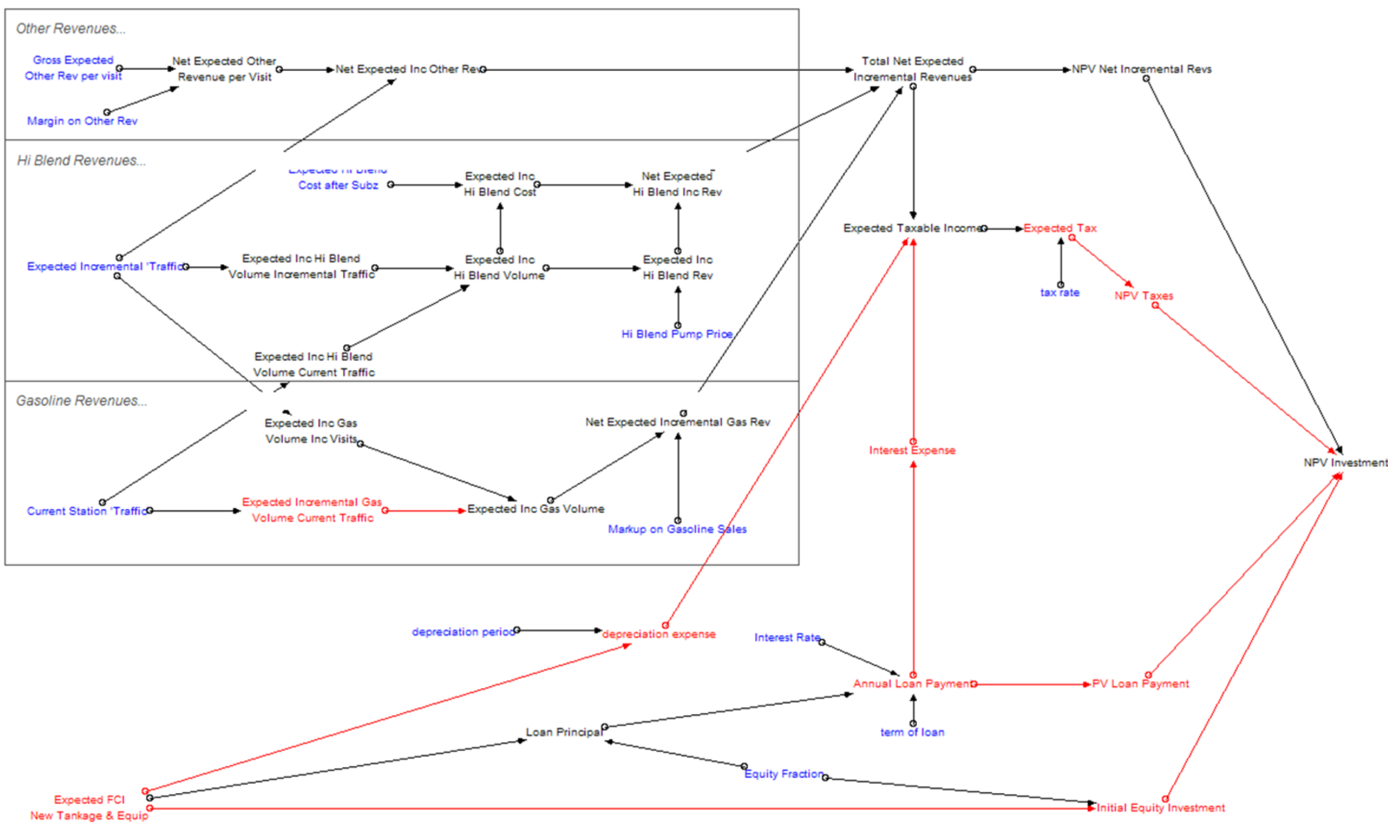

Figure 22. Detail of NPV calculation for stations

As shown in Figure 22, the NPV calculation considers major categories of revenue and expense associated with station investment. In addition to the capital cost of the investment, the NPV calculation considers marginal cost and revenue streams associated with changes in the mix of high-blend vs. “straight” gasoline sales, changes to station traffic (to account for first-mover advantage) and other revenues from c-store operations.

Just as the distribution logistics module provides a context that constrains the acquisition of tankage and equipment for stations, the dispensing station module provides a context for fuel use. Accessibility of high blend stations within a region will constrain the potential for flex-fuel vehicles to access high blend fuels. Regional dispensing station coverage thus sets a physical limit on ethanol uptake in the system.

Fuel Use Module

The fuel use module captures the both the effects of regional high-blend fuel availability and the effects of relative gasoline/high-blend pricing on the decision making for flex fuel vehicle (FFV) owners, with respect to the use of high-ethanol fuel blends. The module contains two major interconnected components. The first component accounts for the affinity of FFV owners toward high-blend fuels. The second uses a logit function to allocate fuel use between for FFV owners who are “occasional” and “regular” users of high-blend fuels.

Figure 23 shows the accounting structure for FFV owners within a region.

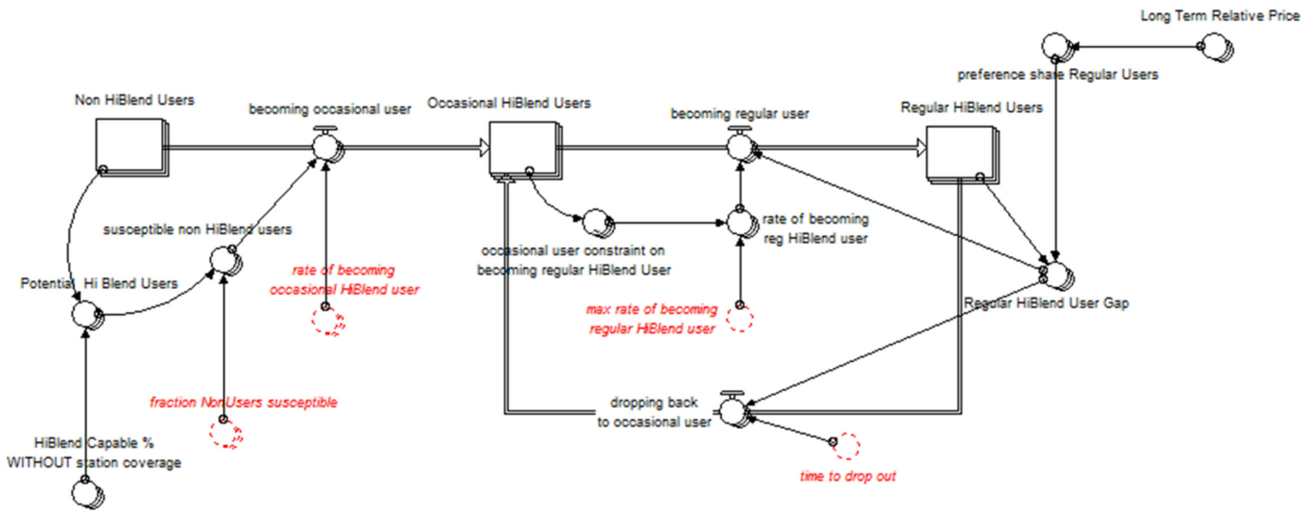

Figure 23. FFV accounting structure

As shown in Figure 23, FFV users (expressed as a % of regional FFV vehicles) are divided into three distinct categories: *non* high-blend users, *occasional* high-blend users, and *regular* high-blend users. Non high-blend users do not use high blend because a) they do not have access to stations that dispense high blend; b) they do not know they have an FFV; or c) they do not desire to use high blend, for non-economic reasons. Based on regional dispensing station coverage and a fraction of non-users who are assumed to be amenable to using high blends, FFV owners leak over time from the non-user to occasional user category. Under conditions of price parity between high blend and regular gasoline, occasional users are assumed to fill 20% of their fuel requirements using high blend. Regular users, on the other hand, are assumed to fill 80% of their fuel requirements using high blend under conditions of price parity. Movement between occasional and regular users is driven by a long-term retail price differential between the two products.

The distribution of high blend users provides a physical basis for ethanol usage among FFVs. Logit functions are used to translate relative high-blend/gasoline retail prices into instantaneous usage shares for both occasional and regular high blend users. The distribution of occasional and regular users is then applied to these usage shares. The resultant user-weighted usage shares are multiplied against potential high blend fuel consumption in order to generate actual high blend consumption within each region. Figure 24, below, provides a view into the logic involved.

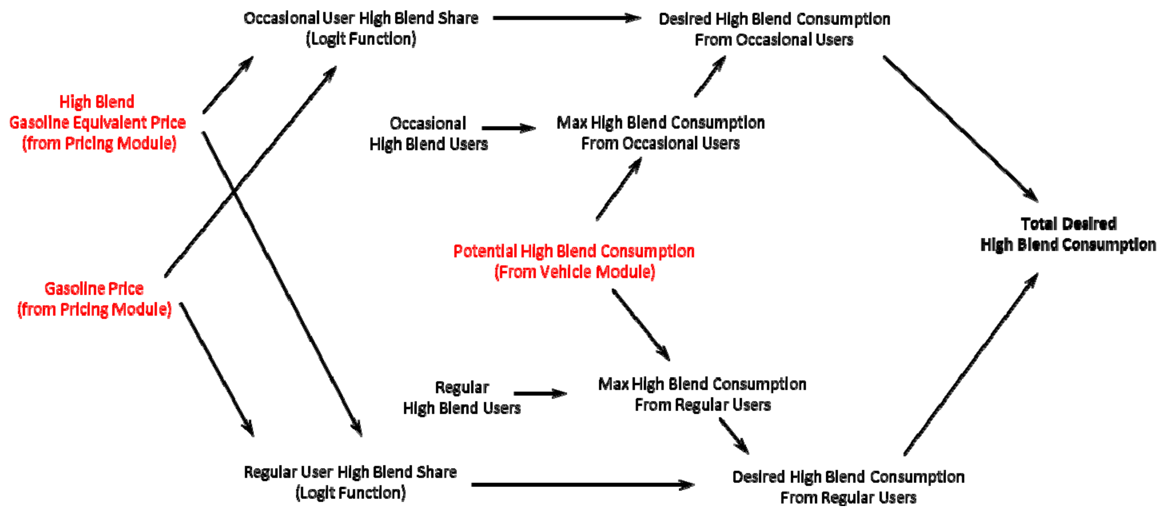

Figure 24. Logic behind high blend consumption

Inputs from DSM VM

The inputs from DSM VM module serves as a repository for containing scenario inputs around potential fuel demands from “regular” vehicles and from FFVs. These inputs, listed below, were developed using the separately-simulated vehicle model.

- Regional potential low blend consumption from FFVs
- Regional potential low blend consumption from non-FFVs
- Regional potential high blend consumption from FFVs

The source for these inputs is a detailed vehicle vintaging chain for each region. The model applies age-specific survivorship estimates to vehicles as they vintage through the chain. It differentiates among seven different fuel types:

- Gasoline
- Diesel
- Flex Fuel
- Gasoline Hybrid Electric
- Gasoline Plug Hybrid Electric
- Diesel Hybrid Electric
- Other

It also differentiates between four different vehicle classes:

- More Efficient Automobile
- Less Efficient Automobile
- More Efficient Light Truck

- Less Efficient Light Truck

For each of these 28 combinations, a scenario over time for new vehicle sales is accompanied by a scenario for new vehicle efficiency. The model tracks over time the implications of these new vehicle scenarios for overall vehicle efficiency and resultant fuel demand. A portion of the vintaging chain for one region is shown below, in Figure 25.

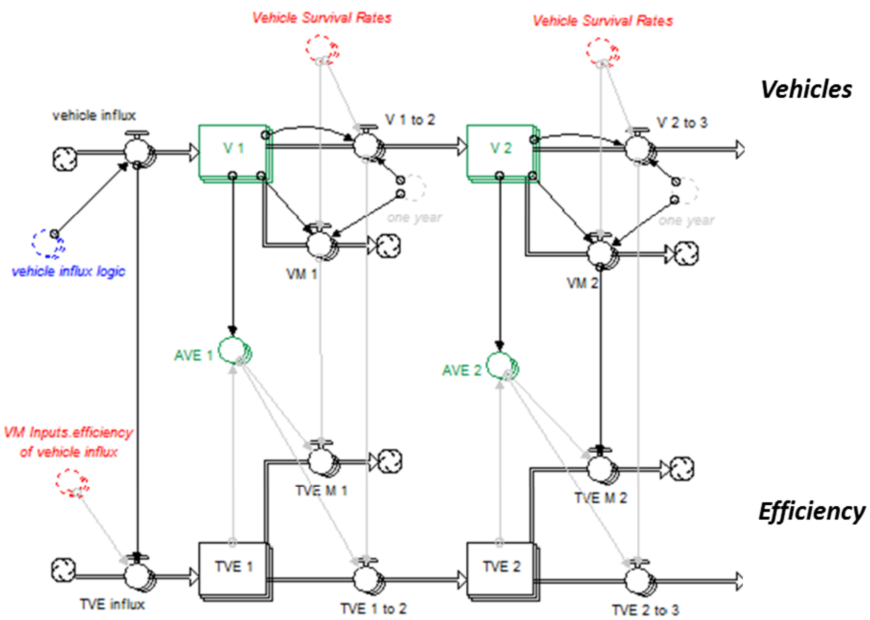

Figure 25: Tracking Vehicles and Efficiency

Pricing and Inventory Module

The final module within the downstream sector accounts for ethanol pricing and inventory dynamics. Pricing and inventory for butanol, which in the model forms a substitute for ethanol in the low-blend market, are also captured within the pricing and inventory module.

For ethanol, the ethanol inventory is aggregated across the entire supply chain within each region. The model allows for cross-regional movement of ethanol based upon regional surpluses or shortfalls within each region. The logic of inventory dynamics is shown in Figure 26.

There are several important features to note in Figure 26. First, note the three sources of regional ethanol production: the starch to ethanol module, the cellulose to ethanol module, and the import module. Second, note the regional import/export structure that facilitates cross-regional movement of ethanol. Third, note the single driver of ethanol consumption. This total reflects ethanol demand from both low-blend (i.e. E10) and high-blend (i.e. E85) uses. Finally, note the rich feedback that drives cross-regional movement of ethanol.

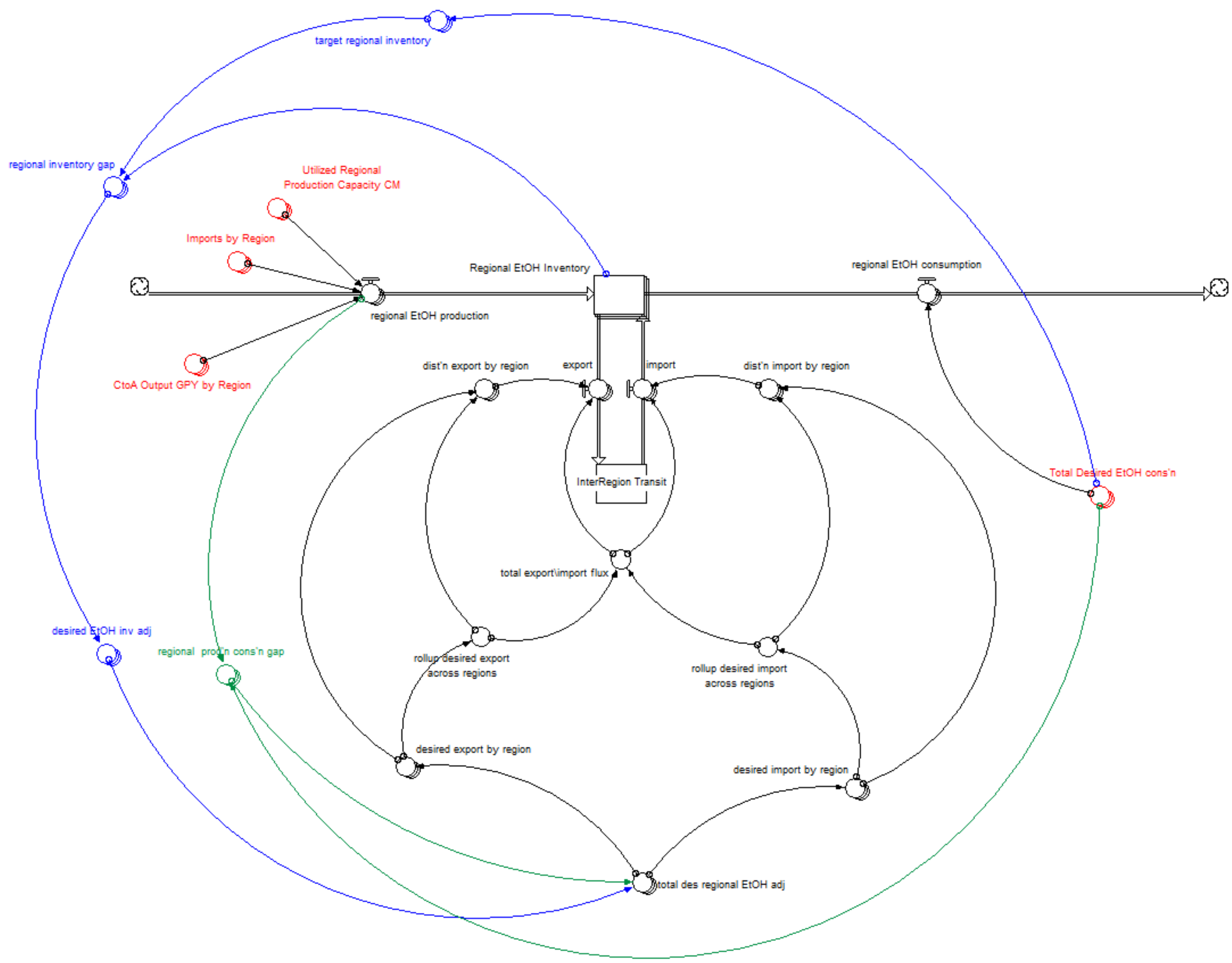

Figure 26: Downstream ethanol inventory dynamics

This cross-regional movement algorithm is relatively straightforward, and is outlined below:

- Calculate desired inventory adjustment in each region required to bring inventories to desired levels (blue connections in Figure 26)
- Calculate the regional production/consumption gap as the difference between regional production and consumption (green connections in Figure 26)
- Sum the inventory adjustment and production/consumption gap to arrive at overall desired movement in ethanol by region
- Roll up total desired imports and exports across all regions.
- Limit total inter-regional movement to minimum of total desired imports, exports
- Allocate exports, imports in proportion to relative desired imports, exports

Pricing for ethanol is considered at multiple downstream points along the supply chain. Figure 27 provides an overview of the approach. Ethanol price is considered at point of production, at point of distribution, and at the pump. Supply/demand imbalances in the downstream supply chain drive changes in price at point of distribution (note that details around the pricing algorithm used within BSM are provided in the Appendix). Transport and storage costs, which vary based on distribution infrastructure within a region, are applied to the point of production price in order to generate an ethanol point of distribution price. The price for high-blend ethanol at the pump is determined as a weighted average of point of distribution price and gasoline prices, based on a regression analysis of the two. Not shown in Figure 27, but relevant to policy analysis, are multiple points along the supply chain where initiatives can work to reduce costs and/or change price as perceived by producers, distributors, retailers, or end users of ethanol or high blend.

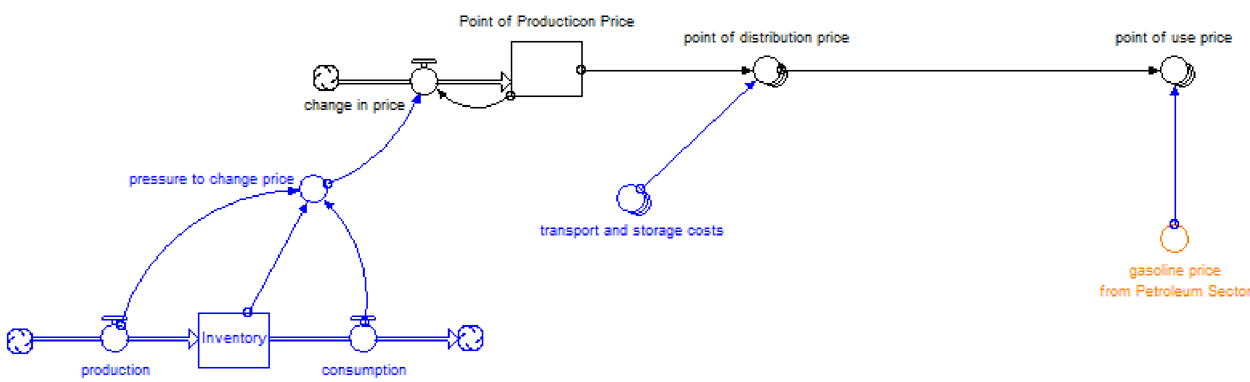

Figure 27. Simplified ethanol pricing structure

The pricing and inventory for butanol follows similar logic to that of ethanol, with some notable exceptions:

- A single, national inventory is considered.
- In addition to its use in the low-blend oxygenate market, butanol can be consumed for industrial uses.
- Pricing for butanol is captured at point of production only. There is neither a point of distribution nor a point of use price for butanol.

The dynamics of butanol use and pricing center on the substitution of bio-butanol (produced within the BSM cellulose to butanol module) for butanol produced by other means, and on the substitution of butanol for ethanol in low-blend uses. These substitution dynamics are determined by relative price considerations. To capture these two dynamics, logit formulations are employed that translate relative prices into market shares. For industrial uses, the price of bio-butanol competes against an assumed alternative price of $4.00/gal (this value can be varied as a scenario). For completion against ethanol, the endogenously-generated bio-butanol price is compared against the price of ethanol.

Oil Industry Sector

The oil industry sector is relatively simple, containing a single module that houses:

- A set of scenarios used to determine crude oil prices
- Refinery product prices for diesel, jet fuel, and gasoline
- Algebraic relationships that translate crude oil prices, refinery product prices, and an assumed refinery "drop in point" for each fungible fuel pathway into price inputs for the different conversion modules and for the downstream pricing and inventory module.
- Accounting structure that captures petroleum displaced by diesel, jet fuel, and gasoline produced by the different fungible fuel pathways.

Import Module

The import module is an exceedingly simple structure focused on the import of fuel ethanol from outside US borders based on relative price considerations. Figure 28, below, shows the essential structure of the module.

This structure compares the ethanol point of production price generated within the downstream pricing and inventory module against a threshold (including tariffs) that reflects the cost of bringing fuel ethanol into the US. As the price within the US exceeds the threshold, and increasing fraction of offshore production capacity is utilized. This simple structure enables analysis of scenarios around tariff policies, cost reduction, and capacity growth for offshore ethanol production facilities.

Interconnections among sectors

Figure 2 provided a high level overview of the sectors that comprise BSM, and the previous discussion has given a detailed view into the modules that are found within each sector. Another perspective on the system is given by the nature of the interconnections among the different sectors. As shown in Table 3, the connections between sectors are relatively few in number, typically consisting of price signals and supply/demand quantities.

From/To	**Feedstock Supply & Logistics**	**Conversion**	**Import**	**Oil Industry**	**Downstream**
Feedstock Supply & Logistics		Feedstock consumption Feedstock price (plantgate)			
Conversion	Feedstock demand Cost to price ratios Output capacity			Fungible fuel production	Ethanol Production Butanol Production
Import					Ethanol import
Oil Industry	Gasoline point of distribution price	Module-specific price input			Gasoline point of distribution price
Downstream		Ethanol point of production price Butanol point of production Price input	Ethanol price input		

Table 3. Inter-sector connections

Data Inputs

Multiple data inputs are required to run BSM. These inputs range from agricultural cost and yield parameters, to performance and learning parameters for the various conversion modules, to logit coefficients, to petroleum prices, to adoption rates for new farm practices and for dispensing station owners. Given the forward-looking nature of BSM, it is not surprising that the availability and quality of input data is highly variable. In many instances, assumptions or informed opinion were used to populate the parameter space. Table 4 provides a summary of the data inputs used in developing BSM.

	Input data area	Source(s)	Comments
Feedstock Supply & Logistics	Crop production costs	ORNL/POLYSYS	Assumed constant over simulation time frame Ongoing interaction with ORNL analysts
	Energy price/crop production price coupling	Pacey study (McNulty, 2010)	Price coupling factors derived from Pacey report
	Yields	ORNL/POLYSYS	yield growth treated as assumption/scenario
	Calibration data for production, prices	USDA baseline (United States Department of Agriculture)	Calibration done ~annually based on annual updates to baseline and updates to input data from ORNL
	Logit parameters	Assumption	Assumptions modified as needed as part of calibration process
	Harvest, transportation, Q&H, preprocessing logistics	INL/IBSAL	Structure and input data updated periodically to reflect ongoing interaction with INL analysts
Conversion	Performance and cost data for different conversion options	NREL design reports PNL design reports Analysis papers Expert opinion Internal secondary analysis/interpolation	NREL staff are assembling and vetting these data. For some conversion options, formal analysis reports do not exist. We are in process of vetting available data, developing assumptions, and facilitating an expert review
	Learning curve parameters	Assumption informed by Beck study (RW Beck, 2010)	Sensitivity analysis planned
	Logit parameters	Assumption	Plan sensitivity and robustness analysis around current logit parameters
	Construction capacity	Assumption	
	NPV of “other” option	Assumption	
Oil Industry	Oil price	EIA (United States Energy Information Agency), arbitrary scenarios	Data taken from “official” scenarios. Oil price shocks, other scenarios available to the system
	Fuel mix	Assumption	Treated as assumption but informed by design reports
	Drop in points	Assumption	
Downstream EtOH	Distribution Terminals by region	EIA	Developed from EIA data in 2008
	Initial mix of terminals with/without infrastructure	Assumption	
	Infrastructure acquisition rate	Assumption	
	Number, distribution of dispensing stations by ownership, dispensing station economics	NREL (Johnson & Melendez, 2007 draft) NACS (National Association of Convenience Stores, 2007)	NACS provides a rich perspective on “other” sales associated with dispensing stations in the spreadsheets that accompany the text of their annual report
	Initial repurposable stations	Assumption	
	Station adoption rates as f(NPV)	Assumption	
	Logit parameters for fuel use	assumption	
	Vehicle influx, miles traveled, miles per gallon	EIA/NEMS	
	Ethanol price at point of distribution	Assumed	Assumed values for storage and transport applied to endogenous point of production price
	High blend point of use price	NREL/Lexidyne regression	Regression of available data provides weighting factors for point of use price
Import	Capacity, price threshold for import, learning curve parameter	Assumed	Values used to calibrate against observed data for fuel ethanol imports

Table 4. Summary of data inputs to BSM

Analysis

Analysis efforts with BSM have been ongoing since early in 2010. These efforts have used the earlier version 2.0 of BSM, a model of the biofuels supply chain that focuses on ethanol from cellulose and starch crops. Analysis with this earlier version of the model suggests an analysis pattern for the current version, which focuses on both ethanol and fungible fuels. One potential approach to an analysis effort, which is based on the 2.0 analysis path, is outlined below.

- Team vetting of model structure and parameters
    - Equation-by-equation review of model structure
    - Automated factorial sensitivity and robustness analysis
- Revision of model structure and parameters as required to address issues uncovered in team vetting process
- Calibration of model using current input and calibration data sets
    - Agricultural system input data
    - Feedstock logistics data
    - Cost and performance data for conversion options
    - Fuel price scenario inputs
- Sensitivity studies around
    - Nth plant capital cost
    - Learning parameters—initial conditions and progress ratios for different conversion options/development stages
    - Initial vs. Nth plant multipliers for capital cost and yield
    - Pilot and demo scale scenarios for different conversion options
- "Generic" policy studies
    - Impact of capital cost reduction policies
    - Impact of subsidies aimed at various stages of the supply chain
- Targeted policy studies—aimed at providing a perspective on different initiatives under consideration by DOE and other organizations.

Concluding remarks

The Biomass Scenario Model provides a rich representation of the supply chain associated with the production of biofuels. By integrating feedstock production and logistics, multiple conversion options, and market dynamics for butanol, fuel ethanol, and fungible fuels (gasoline, diesel, jet fuel), the model serves as a vehicle for exploring the mechanisms by which the biofuels industry might develop beyond its current state. By providing a representation that reflects both the physics and economics of the system, BSM can serve as a tool for building understanding around initiatives that seek to stimulate sustainable development of the industry. By representing the system of interactions simply and transparently, the model can shed light on gaps in the data as well as areas where understanding of system structure is in need of enrichment.

Analyses of earlier versions of the model—both as standalone modules and in integrated form—have underwritten powerful insights about the nature of the supply chain and of the nature of policy initiatives required to stimulate industry take off. We anticipate that in the coming months the current version of the model will facilitate the development of additional insight and understanding around the evolution of the biofuels industry.

Appendix: Pricing within BSM

In BSM, an endogenous pricing mechanism is an essential component of the structure that underwrites industry development. The model incorporates endogenous pricing structures for

- Each of the commodity crops (corn, wheat, cotton, small grains, soy)
- Hay (regional markets)
- Cellulosic feedstocks (regional markets)
- Ethanol
- Butanol

It can be helpful to view price mechanisms within BSM as central components of an economic control system. Each price signal evolves in response to the interplay of the forces of supply and demand. As production, consumption, and inventories change over time, price responds imbalances. Prices, in turn, play a critical role in the investment, allocation and utilization decisions of producers of agricultural products and of biofuels. They also play a critical role in the fuel use decisions for butanol and for high-ethanol-blend fuels.

In developing the pricing structure used in BSM, we were mindful of multiple design constraints. First, pricing mechanism needed to be simple so as to be understandable to a broad audience of model users. Second, the structure needed to be sophisticated, in order to *not* generate spurious dynamics. Many simple pricing formulations can lead to steady-state error in controlled quantities or can become trapped in unrealistic states in response to extreme condition tests. Finally, the pricing mechanism needed to be flexible enough to support real world circumstances such as market initiation and scale-up.

The basic feedback relationships of the BSM pricing mechanism are shown in Figure 28.

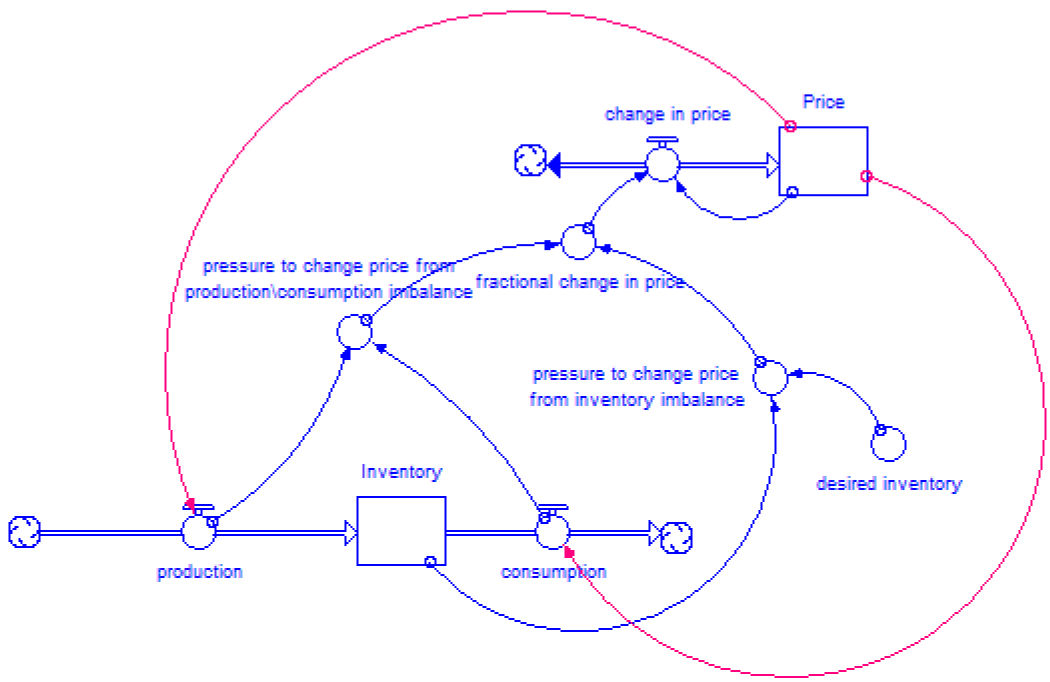

Figure 28. Stylized view of feedbacks in BSM pricing mechanism

In this highly stylized map, price works to balance production and consumption *and* to balance inventory against desired or target levels. Production/consumption imbalances create pressure to change price, as do imbalances between inventory and desired inventory. Because price is represented as a stock, it accumulates or integrates these pressures over time. The representation of price as a stock, in conjunction with pressure from inventory, results in oscillatory tendencies in the system; oscillations are dampened by the presence of feedback connections around production and consumption.

In BSM pricing, the mechanisms that connect production, consumption, and inventory to fractional change in price are significantly more detailed, as illustrated in Figure 29. The figure shows the structure used to develop ethanol point of production pricing. Pricing structures for commodity crops, for hay, for cellulosic feedstocks, and for butanol use this generic structure.

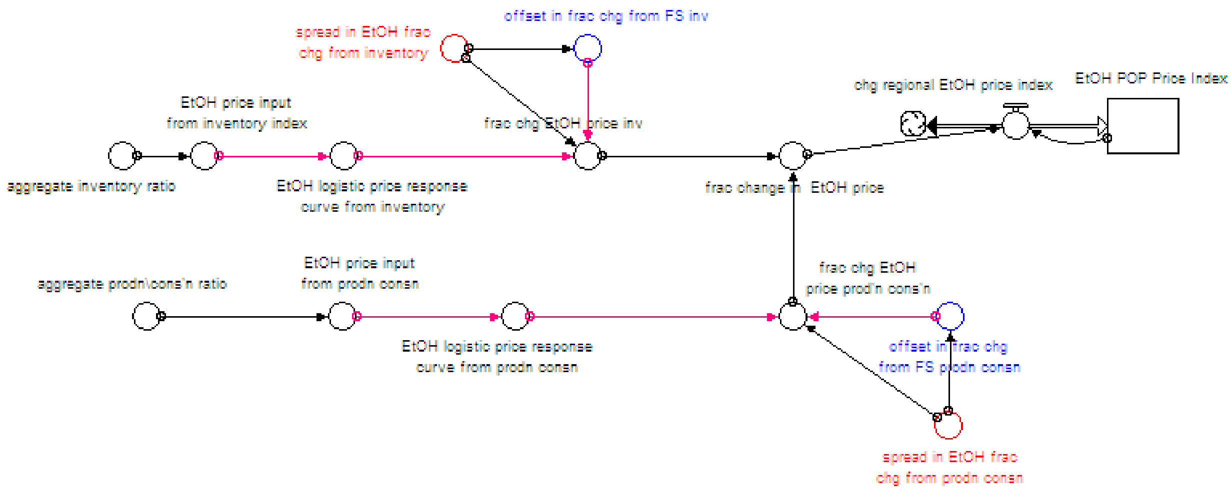

Figure 29. Detail of ethanol pricing structure

The algorithm associated with this structure uses a bit of sophisticated math, but is relatively straightforward. It begins by calculating the price input—either from inventory or from production relative to consumption—as a distance from equilibrium in doublings or doublings. When the ratio is 1, the input is at its equilibrium value. When it is 2, it is one doubling away from equilibrium. When it is 0.5, it is one halving away from equilibrium. To capture this distance simply, the model uses logarithm functions as illustrated in Figure 30.

Second, the price input processed through a logistics function to generate a well-behaved response curve. Price input and logistics calculations are shown in Figure 30.

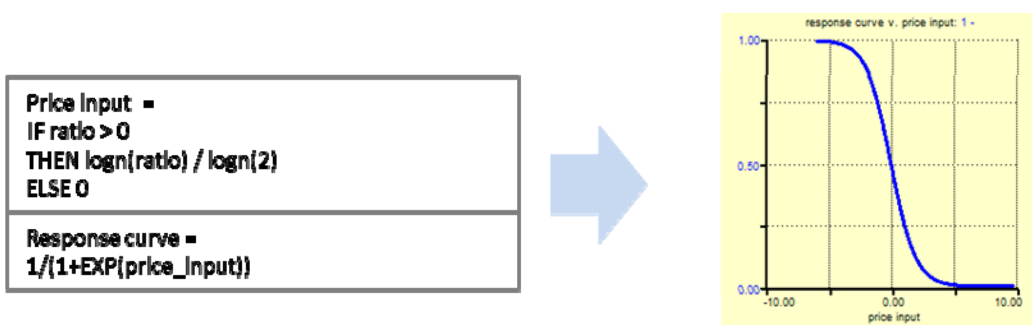

Figure 30. Illustrative price input and response curve calculations

The third step in this algorithm is to scale the response curve by shifting its intercept to (0,0) and setting its asymptotes to desired maximum and minimum fractional changes in price. Finally, the total fractional change in price is calculated as the sum of fractional changes from inventory and production/consumption, and the result is applied to the price to generate a total fractional change in price.

In BSM, this generic pricing structure is applied to multiple market situations. Context-specific details, outlined below, are important to note.

Ethanol Pricing:

- Price index is applied to baseline price to generate point of production price
- Inventory target is calculated as a multiple of desired ethanol consumption—enabling inventory to grow as demand for ethanol grows
- Price feedback affects consumption of ethanol through
  - Buildout of dispensing station high-blend tankage and equipment
  - Relative price dynamics with gasoline in high-blend market for occasional and regular users
  - Relative price dynamics with butanol in low-blend market
- Price feedback affects production of ethanol through
  - Investment attractiveness
  - Utilization of existing conversion facilities
  - Ethanol import dynamics

Butanol Pricing:

- Price index is applied to baseline price to generate point of production price
- Inventory target is calculated as a multiple of desired butanol consumption—enabling inventory to grow as demand for butanol grows
- Price feedback affects consumption of ethanol through
  - Relative price dynamics with non-bio-butanol in the industrial market
  - Relative price dynamics with ethanol in low-blend market
- Price feedback affects production of butanol through
  - Investment attractiveness
  - Utilization of existing conversion facilities

Cellulosic Feedstocks:

- A single aggregate average feedstock price is considered at the plantgate in each of 10 regions
- Inventory targets are determined as a multiple of desired feedstock consumption, enabling inventory to grow as demand grows
- Grower payment considers plantgate price net of harvest and logistics costs
- Feedstock price is set to zero until a conversion facility enters the development pipeline. Assumed “seed” values for feedstock prices are used to set the initial nonzero price.
- A price ceiling for cellulosic prices is set by downstream conversion facility dynamics. This ceiling constrains prices from growing in excess of their value in producing end products.
- Price feedback affects consumption of feedstocks through
  - Investment attractiveness for conversion facility investment
  - Utilization of existing conversion facilities

- Price feedback affects production of feedstocks through
  - Movement along supply curve for forest, urban residues
  - Relative grower payment for producers of feedstocks, which in turn changes land allocation
  - Changing the rate at which producers become producers of cellulose

Commodity crops:

- A single national aggregate average price is used for each commodity crop
- An adjustment factor is used to couple small grain prices to corn. These product classes are substitutes for one another in the animal feed market, and their prices tend to move in concert.
- Inventory feedback is developed using stock:use ratios. These ratios are allowed to float over time, enabling the model to capture observed history around prices and stock:use ratios.
- Price feedback affects consumption of commodity crops through small changes to baseline USDA projections
- Price feedback affects production of commodity crops through relative grower payments to producers, which in turn changes land allocation

Hay:

- Regional price indices are used to represent hay
- Inventory dynamics are not included as an input to hay prices, reflecting the assumption of "use it or lose it" for hay
- Demand and supply for pasture are considered in hay price dynamics
- Price feedback affects consumption of hay through small changes to baseline model values
- Price feedback affects production of hay and pasture through relative grower payments to producers, which in turn changes land allocation

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