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Technical Report
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April 2014

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Abstract

Understanding the development of the biofuels industry in the United States is important to policymakers and industry. The Biomass Scenario Model (BSM) is a system dynamics model of the biomass-to-biofuels system that can be used to explore many aspects of the industry. Because of the complexity of the model, as well as the wide range of possible future conditions that affect biofuels industry development, we have not developed a single reference case but instead have designed a set of six incentive-focused scenarios. The purpose of this report is to describe the scenarios that comprise the BSM scenario library. At present, we have the following six incentive-focused scenarios in our library: minimal incentives scenario; ethanol-focused incentives scenario; equal access to incentives scenario; output-focused incentives scenario; pathway-diversity-focused incentives scenario; and the point-of-production-focused incentives scenario. This report describes the model settings and rationale for each scenario.

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1 Introduction

Understanding the development of the biofuels industry in the United States is important to energy policymakers and many industrial sectors. Development of the biofuels industry responds to incentives, market disruptions, and technological changes, among other influences. Numerous research, development, and deployment strategies are currently being considered to advance the industry; decisions made at what is still an early stage of development will shape the future of biofuels in the United States. The biofuels industry can be considered a dynamically complex system of systems (Bush et al. 2008). Exploring the multifaceted and at times counterintuitive dynamics of large systems can elucidate unforeseen interactions and inform strategy. System dynamics models have a long history of being used to explore questions of public policy (Ghaffarzadegan et al. 2011). The U.S. Department of Energy has funded the development of the Biomass Scenario Model (BSM), which is a system dynamics model that is designed to explore the expansion of the biofuels industry in the United States (Figure 1). The BSM is used to investigate a wide range of scenarios (e.g. policy, climate, demand, and deployment) across the entire biofuels industry as well as individual parts of the industry (e.g., feedstock supply and logistics). Below is a brief description of the BSM, please refer to Newes et al. (2011) and Peterson et al. (2013) for a more complete description of the BSM.

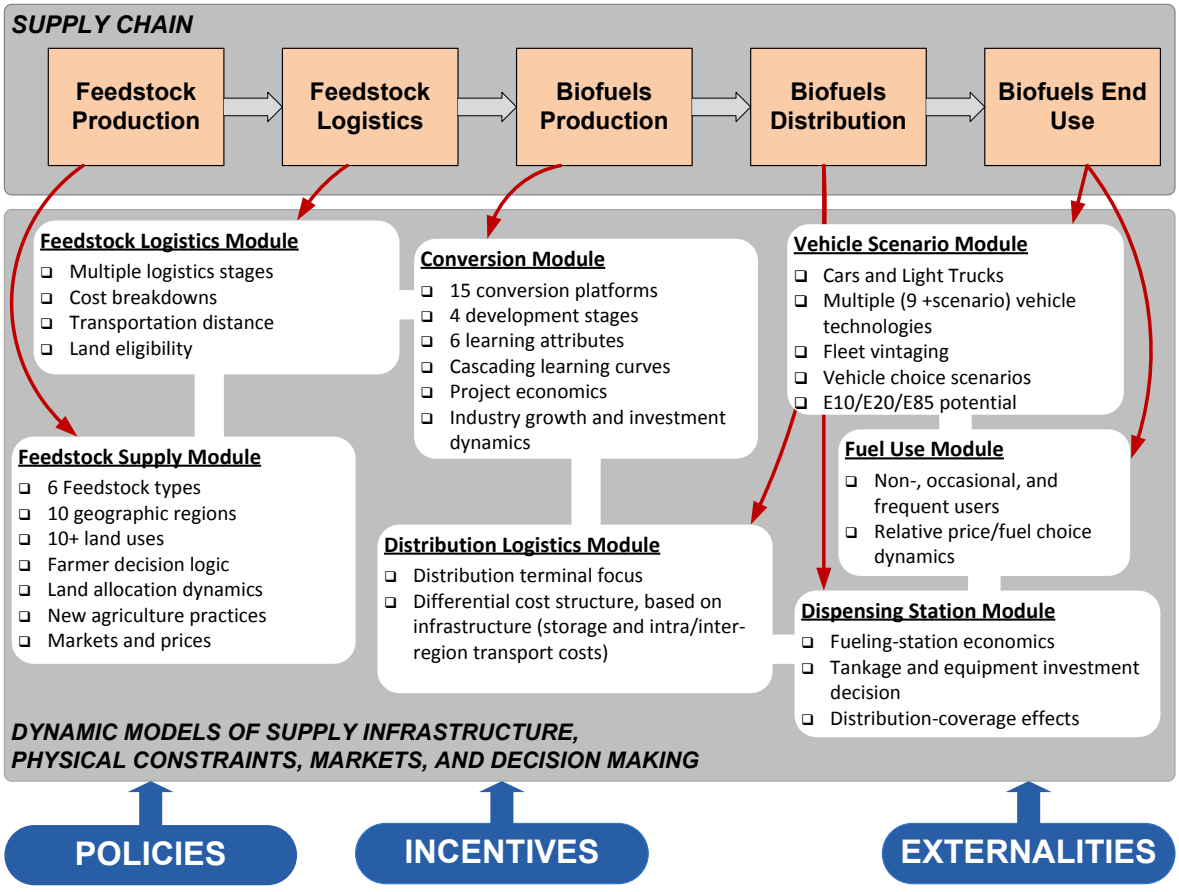

Figure 1. High-level schematic showing the elements of the biofuel supply chain modeled in the Biomass Scenario Model

1.1 Model Overview

The BSM is designed in a top-down, modular fashion that allows material (feedstocks) to flow down the supply chain and be converted into various types of biofuels, with feedback mechanisms among and between the various modules. The BSM's structure is transparent, modular, and extensible, enabling standalone analysis of individual model components as well as testing of different module combinations. Below is a brief description of the primary sectors that are modeled in the BSM. Each sector described below is comprised of a "module" or set of "modules" which are self-contained models of specific parts of the supply chain. It is the use of "modules" that allows for singular aspects of the supply chain to be analyzed in isolation. The BSM is disaggregated into ten agricultural production regions (USDA-ERS, 2010).

Feedstock supply and logistics

The feedstock supply and logistics sector models the dynamics associated with producing and delivering biofuel feedstocks and includes harvesting and transport of starch, herbaceous (energy crops and residues), woody (crops and residues), and urban residues. Feedstock production competes with other uses of the agricultural land base such as commodity crop production (corn, wheat, soybean, small grains, and cotton), hay, pasture, and Conservation Reserve Program land.

Conversion

The conversion sector is composed of six different modules, each corresponding to a different set of biofuel conversion pathways. Each conversion module represents pilot, demonstration, and pioneer-commercial and full-commercial scale biorefineries and includes learning curve dynamics, investment decision logic, and utilization logic. The *starch to ethanol* module represents dynamics associated with the existing starch (corn) ethanol industry. The industry is considered to be mature; hence, the module provides a simple representation of the financial logic that controls acquisition and utilization of commercial scale corn ethanol facilities. The *cellulose to ethanol* module captures the development of the cellulose-to-ethanol conversion industry. Biochemical and thermochemical conversion modeled based on published design reports (Humbird et al., 2011; Dutta et al., 2012). The *cellulose to butanol* module captures the development of the cellulose-to-butanol conversion industry. In the BSM, butanol serves as an industrial solvent and as a substitute for ethanol in the oxygenate market. The *biomass to hydrocarbon* module captures the industry development of biomass to hydrocarbon conversion processes. Currently the following conversion options are modeled: fast pyrolysis; Fischer-Tropsch; methanol to gasoline; catalytic pyrolysis; fermentation of sugars to hydrocarbons; and aqueous phase reforming. Multiple products can be produced, including gasoline, diesel, and jet fuel. The oil crops module captures development of conversion capacity for soy-to-refinery and "other" oilseed-to-refinery processes. The algae module represents open pond, photo-bioreactor, and heterotrophic conversion options. Algae feedstock production is presumed to be vertically integrated in the algae to refinery-ready system. In addition to the six conversion modules, the conversion sector includes a module that models the attractiveness of investing in the various conversion options, allocating limited facility construction capacity among these options based on their perceived relative economic value.

Petroleum industry

The petroleum industry sector is comprised of inputs around crude oil prices, providing logic that translates these prices into price inputs for the various refinery ready conversion modules as well as 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 infrastructure compatible fuels.

Downstream ethanol and butanol

The downstream ethanol and butanol sector is composed of a set of four modules. These modules capture the dynamics of the activities that occur after fuel production. The pricing and inventory module captures pricing and inventory dynamics for both ethanol and bio-based butanol. Ethanol flows into two distinct but coupled markets: the oxygenate market and the high-blend ethanol fuel market. 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. The distribution logistics module provides a very simple representation of the regional expansion of the distribution network for fuel ethanol. The dispensing station module addresses the regional acquisition of tankage and equipment capable of dispensing ethanol. Expansion of E85-capable stations is driven by economic considerations, and is constrained by regional availability of ethanol from the distribution network. The fuel use module represents 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.

Vehicles

The vehicle module is used in BSM to keep track of the cumulative effect of volume, vehicle mix, vehicle efficiency, and vehicle miles traveled for the car and light duty truck sectors. Its structure captures acquisition, aging, and retirement of vehicles, as well as the translation of vehicles into potential demand for fuel.

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 United States based on a price differential as perceived from abroad. This structure enables the model to capture historical patterns of growth and decline in imports of fuel ethanol. It is structured to facilitate exploration of multiple scenarios around production cost.

1.2 Purpose

The scenarios described in this report are focused on biofuel incentives. The term “scenario: is used to represent a collection of model settings that are intended to represent a hypothetical future. Although this report describes incentive-focused scenarios, scenarios can also represent other areas of the model such as the feedstock supply system and fuel use, for example. Development of a “baseline” or “reference” case is a common practice for users of a given model because such cases provide a stable reference point for comparative analyses and for modifications to the model. Because the future is uncertain with regard to biofuel policies and because the BSM has so many biofuel pathways modeled, developing a single reference case is

challenging. Instead, we designed a series of scenarios that are comprised of biofuel incentives. Each scenario represents a potential means to achieve a certain goal for the biofuels industry. These scenarios may be used as analyses by themselves or as the initial model conditions for other directed analysis. For example, analysts could use one or more scenarios as the base conditions to explore an analysis of oil price volatility.

The purpose of this report is to describe the model settings used construct the scenarios in the BSM scenario library, as of October 2013. This report is intended as the first in a series of reports that describe the library scenarios used in BSM analyses. Subsequent reports will describe scenarios that are either added to the set described in this report, or describe changes to scenarios included in this report when such changes are significant. This report also serves as a singular reference document that will be used to provide a unified set of definitions and descriptions of our scenarios and the input parameters used to construct them.

This report first describes the types of economic incentives that are included in the BSM and how these incentives are combined to form scenarios. The scenarios described in this report represent incentives (both real and hypothetical) that are intended to achieve a specific outcome for the biofuels industry. In this report, the magnitude of each incentive and the ways in which they are activated and/or structured do not necessarily represent existing or proposed incentives. The types of incentives modeled in the BSM provide flexibility to model a wide range of incentive strategies (across different parts of the industry and characteristics of biomass-to-biofuels conversion pathways) as well as proxy existing and/or proposed incentive programs.

The types of incentives modeled and where they affect the supply chain are shown in Figure 2. In the BSM, incentives that are applied to the portion of the industry that is "upstream" of the conversion facility include the Biomass Crop Assistance Program's (BCAP) matching, establishment, and annual payments (USDA, 2010). Incentives that are focused on expanding the industry through defraying the cost of installed capital include fixed capital investment (FCI) and government loan guarantees incentives. Incentives that are applied to the portion of the supply chain that is "downstream" of the conversion facility are aimed at lowering the risk of installing specialized equipment for the distribution and dispensing of ethanol-based fuels (e.g., distribution and storage incentives and FCI and dispensing equipment repurposing incentives and lowering the cost of purchasing qualified biofuels (point-of-use incentives).

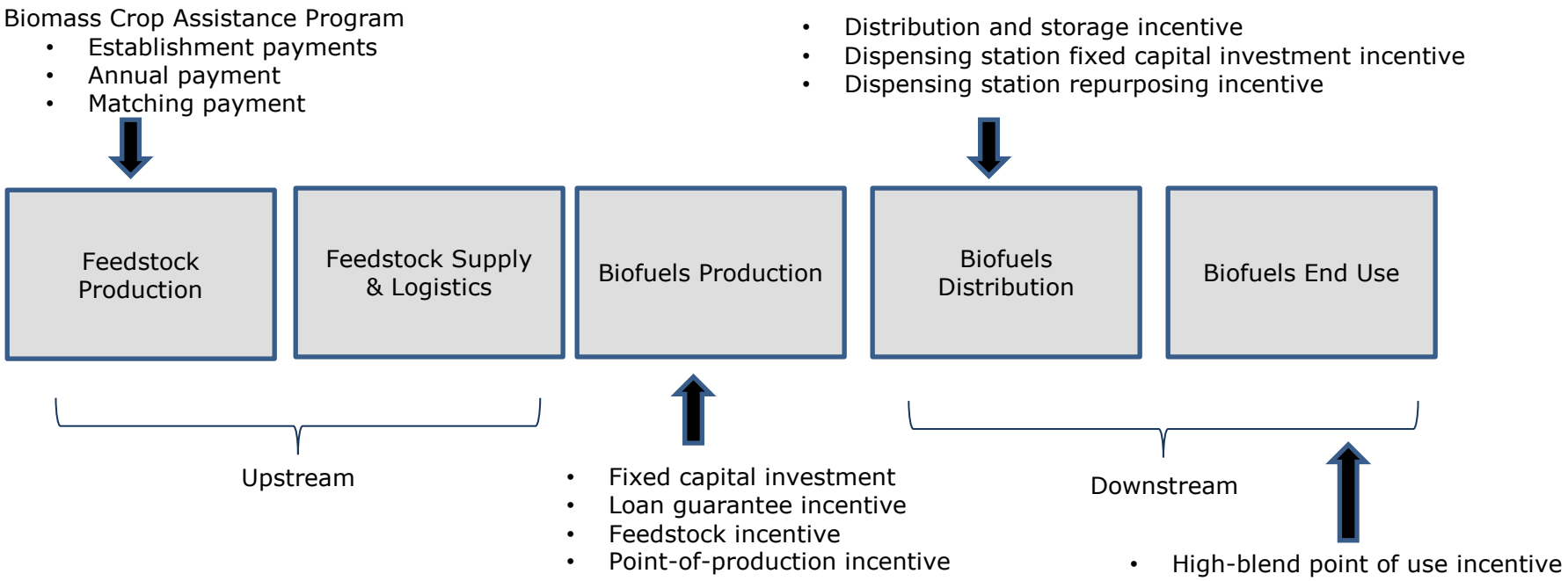

Figure 2. Generalized diagram of the biofuel supply chain modeled in the Biomass Scenario Model; incentives are indicated at the part of the supply chain upon which they are applied.

2 Definitions

Fixed Capital Investment (FCI) incentive (*Unitless)* is the fraction of the total capital costs, including a portion of capital cost growth, which is provided by the government. The portion of capital cost growth can range from 0 to 1 and is set to 1 in the BSM. This incentive can be applied to both pioneer- and commercial-scale biorefineries in the BSM. It lowers the construction cost associated with building new biorefineries. This incentive results in a direct payment to biofuel producers.

Government loan guarantee incentive (*Unitless*) is the equity portion of the FCI investment and reflects the amount that the government agrees to assume if the borrower defaults. The guarantee improves the ability of producers to obtain financing from private lenders and does not cost the government if the plant is successful. In the BSM, this incentive can be applied to both pioneer- and commercial-scale biorefineries.

Feedstock incentive (*Units = USD ton^{-1})* is provided to the biofuel producer for the purchase of qualifying feedstocks. This incentive lowers the costs associated with acquiring feedstocks and may be applied to both pioneer- and commercial-scale biorefineries in the BSM.

Point-of-production incentive (*Units = USD gallon^{-1})* is an incentive provided to fuel producers of qualifying biofuels based on the volume of biofuel produced. As used in the BSM, this incentive mimics some aspects of the Renewable Identification Number (RIN) program and provides a fixed, pre-tax amount to the biofuel producer for each gallon of biofuel produced.

Ethanol distribution and storage incentive (*Units = USD gallon^{-1})* is only applied to ethanol fuels and is provided to offset the costs associated with investing in additional capital equipment needed to store and distribute ethanol compared to other fuels.

Ethanol dispensing station FCI Incentive *(Unitless)* is an incentive that is applied only to ethanol fuels. This incentive is provided to owners of retail dispensing stations to a fraction of the costs associated with purchasing the specialized tankage and dispensing equipment needed to handle ethanol fuels that are more expensive than equipment handling hydrocarbon fuels.

Ethanol dispensing station repurposing incentive *(Unitless)* is applied only to ethanol fuels. This incentive is provided to owners of retail dispensing stations to offset the costs associated with repurposing existing tankage and dispensing equipment to accommodate ethanol fuels.

High-blend ethanol point-of-use incentive (*Units = USD gallon^{-1})* affects high-blend ethanol fuels (i.e., E85 and higher) and accrues to retailers of ethanol fuels.

Biomass Crop Assitance Program (BCAP) Incentives is composed of three incentives: matching payments, establishment payments, and annual payments, each defined further below. In the BSM, the BCAP is initiated in 2009 with only matching payments. In 2013, the program transitions to establishment payments for one simulation year, followed by annual payments which eventually cease in 2026. In the BSM we assume that all cellulosic feedstocks are eligible for BCAP payments. Please refer to the proposed rulemaking document for more information on the BCAP (United States Department of Agriculture 2010).

BCAP matching payment Incentive (a.k.a. collection, harvest, storage, and transport payments) (*Units = USD ton^{-1})* are provided for the collection, harvest, storage and transportation of cellulosic biofuel feedstocks as a 50% match of costs to the grower up to \$45 ton^{-1} for a contract term of 2 years.

BCAP establishment payment Incentive (*Units = USD acre^{-1} year^{-}1)* is given to offset 75% of the cost associated with preparing fields to produce herbaceous and woody energy crops.

BCAP annual payment Incentive *(Units = USD year^{-1})* uses agricultural land cash rental rates for land in the given project area as a basis for payment. This incentive is given to cellulosic biofuel feedstock producers in eligible project areas for a contract term of 5 or 15 years.

Startup levels are applied to a subset of conversion-focused incentives (FCI, government loan guarantee, feedstock incentive, and point-of-production incentive). Startup levels for incentives are typically set to high amounts and for short periods of time. The idea behind applying a startup level for a given incentive is to essentially give a portion of the supply chain an early boost. Startup levels are constrained by a biofuel production level, once this level is met the level is either set to a lower level for a longer period of time (background level) or the incentive is turned off completely.

Background levels are applied to a subset of conversion-focused incentives (FCI, government loan guarantee, feedstock incentive, and point-of-production incentive). Background levels for incentives are typically set to low levels for long periods of time. The rationale behind applying a background level for a given incentive is to allow for protracted support at a low to modest level. Background levels are constrained by time, once a given year is reached the incentive is turned off.

3 Scenario Library

The scenarios discussed below are focused on incentivizing the biofuels industry. However, scenarios can be crafted that focus on any aspect of the supply chain (e.g., oil prices, feedstock production/disruption, technological assumptions, vehicle/end-use assumption) (see Figure 2). Incentive settings for each scenario are presented in Figure 3. In all of the scenarios described, there were no additional gasoline taxes applied (beyond state and federal taxes) and feedstocks were incentivized through BCAP.

Minimal Incentives Scenario

The minimal incentives scenario presents a case in which there are no substantive production incentives for biofuels. This scenario applies a point-of-production incentive of 0.45 USD gallon^{-1} of ethanol produced, for one year (2011) which is consistent with the implementation of the Volumetric Ethanol Excise Tax Credit (VEETC), as it was applied to starch-based ethanol; the cellulosic portion of the VEETC is not represented in this scenario (Congressional Budget Office, 2010).

Ethanol-Focused Incentives Scenario

The ethanol-focused incentives scenario is structured to provide moderate support to the starch and cellulosic ethanol industries. Much of this scenario is focused on accelerating industrial learning at an early stage through FCI and government loan guarantees for pioneer-scale cellulosic ethanol biorefineries. Support is also provided to cellulosic ethanol refineries through a point-of-production incentive. The starch industry receives a 0.45 USD gallon^{-1} point-of-production incentive that ends in 2012. The cellulosic ethanol industry receives a point-of-production incentive of 2.65 USD gallon^{-1} for the first one billion gallons of ethanol production, after which the level drops to 0.15 USD gallon^{-1}. Additionally the point-of-use incentive and the

distribution and storage incentive are applied equally to both the starch and cellulosic ethanol industries.

Equal Access to Incentives Scenario

The equal-access-to-incentives scenario is constructed such that all cellulosic biofuel production technologies (i.e., cellulose-to-ethanol, -to-butanol, and -to-hydrocarbons) have access to the same incentives at the same levels. In other words, qualifying biofuel technologies have access to incentives regardless of their economic viability and attractiveness to investors. In this scenario, incentives are set to very high levels for the first decade. After which all but the point-of-production incentive is turned off.

Output-Focused Incentives Scenario

The overall goal of the output-focused incentives scenario is to maximize biofuel production (ethanol and biomass-derived hydrocarbons) without exceeding 10 billion USD in annual costs. The annual spending cap of 10 billion USD is loosely based on the spending observed for the VEETC program, which was reported to be over 6 billion USD in 2010 (Congressional Budget O 2010). Much of this support is directed toward the construction of pioneer- and commercial-scale refineries by providing high levels of FCI and loan guarantee support. This scenario incentivizes one biomass-to-hydrocarbon biofuel production technology in an effort to maximize its fuel production targeting the most technologically attractive biofuel pathway

Pathway-Diversity-Focused Incentives Scenario

The pathway-diversity-focused incentives scenario utilizes a series of incentives that lead to multiple biomass-to-hydrocarbon fuel pathways gaining market share in addition to the ethanol industry retaining some market share without exceeding 10 billion USD in annual spending . The incentives are triggered to promote as many pathways as reasonably possible. For example, pathways that are immature receive early and substantial support for the construction of biorefineries (FCI and loan guarantee). Once these pathways have enough industrial momentum (accumulated learning), the incentives are reduced or terminated. In contrast, more mature pathways are incentivized at either lower levels or for shorter periods of time, or both. In this scenario, four pathways can be incentivized to achieve at least modest success. Avoiding technological lockout is difficult and requires incentives to have staggered start times and variable duration. Some pathways have a combination of technoeconomic attributes (based on published data) such that they require only minimal incentives, while others need continued support to remain viable in the context of multiple competing pathways.

Point-of-Production-Focused Policies Scenario

The point-of-production-focused incentives scenario is a case where a low level of production incentives is available. This scenario applies a point-of-production incentive of 0.45 USD gallon^{-1} across all biofuels. In this scenario, starch-based ethanol is subsidized for one simulation year (2011), which is consistent with the implementation of VEETC. All other renewable fuels are subsidized for the duration of the simulation, which is within the range of historical RIN values and could be considered a very rough approximation of RIN market effects.

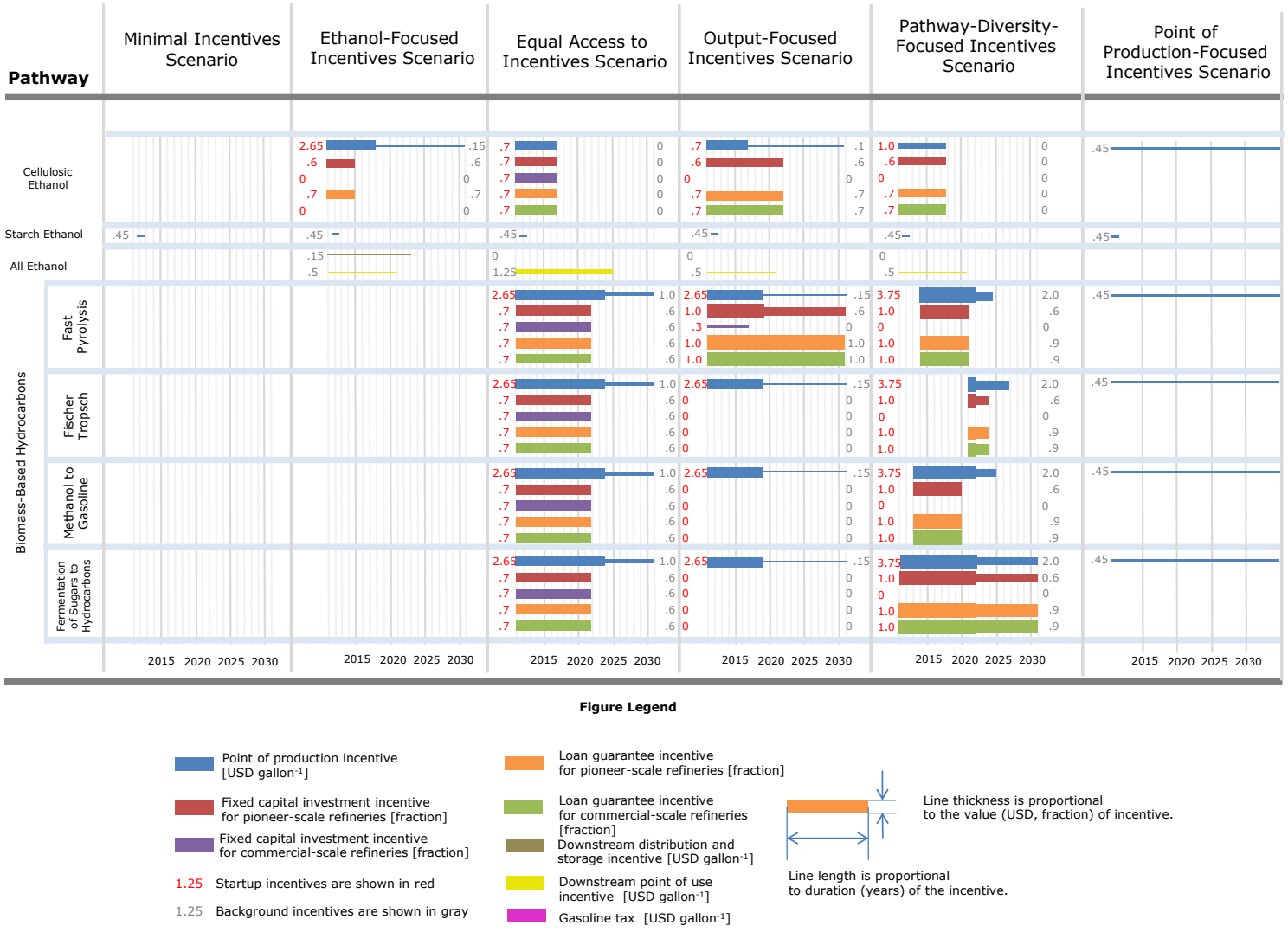

Figure 3. Scenario library incentive type, level, and duration by scenario

Notes: Only biofuel technologies that are active in the listed scenarios are shown. BCAP incentives are active in all scenarios and are not shown because BCAP is held constant across scenarios.

4 Summary

We have developed six incentive-focused scenarios to provide background settings and context to analyses performed using the BSM. In this report, scenarios represent a set of hypothetical incentives. Scenarios will continue to be developed and added to the BSM scenario library as the model and analyses continue to mature. Future scenarios are not limited to incentive-focused scenarios and may include scenarios such as climate, oil prices, feedstock supply, and vehicle/end use assumptions, to name a few.

Because the BSM is so complex and its results so impacted by initial model settings, having a singular reference case does not make sense. As with other models that provide a glimpse at a potential future, the BSM has a range of scenarios that provide alternative futures that may be compared and used to gain insights into the system and how certain analysis settings interact with a range of scenario settings.

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