Effects of Deployment Investment on the Growth of the Biofuels Industry

Laura J. Vimmerstedt and Brian W. Bush

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National Renewable Energy Laboratory
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Executive Summary

In support of the national goals for biofuel use in the United States, numerous technologies have been developed that convert biomass to biofuels. Some of these biomass to biofuel conversion technology pathways are operating at commercial scales, while others are in earlier stages of development. The advancement of a new pathway toward commercialization involves various types of progress, including yield improvements, process engineering, and financial performance. Actions of private investors and public programs can accelerate the demonstration and deployment of new conversion technology pathways. These investors (both private and public) will pursue a range of pilot, demonstration, and pioneer scale biorefinery investments; the most cost-effective set of investments for advancing the maturity of any given biomass to biofuel conversion technology pathway is unknown. In some cases, whether or not the pathway itself will ultimately be technically and financially successful is also unknown. This report presents results from the Biomass Scenario Model—a system dynamics model of the biomass to biofuels system—that estimate effects of investments in biorefineries at different maturity levels and operational scales. The report discusses challenges in estimating effects of such investments and explores the interaction between this deployment investment and a volumetric production incentive. Model results show that investments in demonstration and deployment have a substantial growth impact on the development of the biofuels industry. Results also show that other conditions, such as accompanying incentives, have major impacts on the effectiveness of such investments. This report does not advocate for or against investments, incentives, or policies, but analyzes simulations of their effects.

Table of Contents

List of Figures

List of Tables

1 Introduction

The Energy Independence and Security Act of 2007 (EISA) established a national goal of 36 billion gallons/year of renewable liquid transportation fuel in the United States by 2022 [1]. A variety of biomass resources can be converted to biofuels [2][3][4][5][6][7][8][9], including conversion of corn starch, sugar cane, or other biomass to ethanol; biological oils to biodiesel; and cellulose or other biomass to hydrocarbons. Some biomass to biofuel conversion technology pathways are financially viable at commercial scales, while others face more uncertainty because they are in earlier stages of development. For example, ethanol from corn starch is a large-scale, fully commercial industry with 13.8 billion gallons annual production capacity [10] and biodiesel production capacity is 2.1 billion gallons per year [11]. Other conversion pathways started commercial production in 2013 [12]. KiOR's Columbus, Mississippi, pioneer facility with an 11-million-gallon-per-year capacity started production in March 2013 using a biomass to hydrocarbon conversion pathway [12], and INEOS Bio's Vero Beach, Florida, 8-million-gallon-per-year capacity pioneer facility started production using a cellulose to ethanol pathway in July 2013 [12][13].

Commercialization of new biomass to biofuels conversion technology pathways may require improvements that include yield improvements, process engineering improvements, and financial performance developments that together drive down costs and reduce risks [14]. Actions of both private investors and public programs contribute to the demonstration and deployment of new pathways. For example, the U.S. Department of Energy, Bioenergy Technologies Office, invests in research, development, demonstration, and deployment activities that aim to advance the commercialization of biofuels [15] among other goals. The set of investments (both private and public) that will most cost-effectively advance the maturity of a new pathway is not known and is inherently uncertain. Deployment investments may take place at a variety of operational scales and levels of maturity ranging from investment in pilot, to demonstration, to pioneer scale biorefineries. This report estimates effects of investment in selected sets of biorefineries and discusses challenges in making such estimates. The estimates are based on results from the Biomass Scenario Model (BSM)—a system dynamics model of the biomass to biofuels system that can be used to understand system behavior and policy effects but is not intended for making precise predictions. Based on the results presented in this report, investments in demonstration and deployment of biomass to biofuels conversion technologies have a positive effect on the development of the biofuels industry, and supportive policies, among other conditions, have major impacts on the effectiveness of such investments. This report does not advocate for or against investments, incentives, or policies.

Steps toward deployment are made by proving various aspects of performance at different scales. Smaller-scale, less-costly, shorter-duration activities are completed first, on the theory that successful completion of these smaller-scale activities improves the chances of success of larger-scale facilities that follow, reducing financial risk. For purposes of this report, we discuss four biorefinery scales that are distinguished by throughput capacity and maturity of operations: pilot, demonstration, pioneer, and commercial. At the pilot scale (typically greater than one dry tonne of feedstock processed per day and less than one-fiftieth of commercial scale), process yield improvement is a major emphasis. This may involve optimizing inputs, catalysts, micro-organisms, temperatures, pressures, residence times, and other process engineering parameters. Successful pilot operations identify problems to be addressed before scale-up and provide essential data for demonstration scale design. At the demonstration scale (typically on the order of 50 tons of feedstock processed per day, or one-tenth to one-fiftieth of full commercial scale), proving total system operation is a key challenge, especially maintaining process yield at this larger scale while proving the efficacy of process and material handling systems. Successful demonstration provides critical industrial-scale design information for the pioneer scale. At the pioneer scale (typically hundreds of tons of feedstock processed per day), maintaining performance at a larger scale is again a focus, and the successful pioneer scale biorefinery will result in proof of all aspects of commercial scale system operations, reducing risk and enabling future biorefineries to secure financing on better terms.[1] Pioneer scale is not always defined separately from commercial scale in the literature or in general usage, and is sometimes called first-of-a-kind. Distinguishing a pioneer scale from commercial scale is useful here because it highlights the higher costs and risks that are still present for biorefineries at early stages of commercialization. While pioneer facilities are too risky to receive regular project financing, successful pioneer operations could enable future full-scale commercial facilities to receive project financing at more favorable interest rates. Pioneer is also distinguished from commercial scale in modeling so that higher costs and risks of these early commercial plants are included in calculations.

This report addresses the question, "What might be the effect of concerted investment in a set of biorefineries on advancing biomass to biofuels conversion technology pathways toward commercialization?" Answering this question could help either public or private investment portfolios by informing their design and potentially improving their cost-effectiveness.

Section 2 of the report describes how the BSM simulates the commercialization process, especially the effects of demonstration and deployment investment at different scales. Section 3 presents results under two investment and two incentive conditions: baseline or additional demonstration and deployment investment conditions, with or without a production incentive. This section also discusses limitations of the results. Section 4 summarizes conclusions and possible next steps to further understand the role of investment in biorefineries (at all scales of operation) in advancing commercialization of conversion pathways.

[1] Although the BSM uses a definition of pioneer and commercial scale based on size, commercial scale could be defined as any biorefinery that can make a profit. Biorefineries that produce high-value products could be commercial at smaller scales than the BSM commercial sizes.

2 Modeling Commercialization of Biofuels in the Biomass Scenario Model

The U.S. Department of Energy-Bioenergy Technologies Office and the National Renewable Energy Laboratory (NREL) developed the BSM to explore the development of a U.S. biofuels industry [16][17][18][19]. Using a system dynamics modeling approach, the BSM is built on the STELLA software platform [20]. The model represents the dynamic interactions of the major sectors of the biofuels industry—feedstock production and logistics, feedstock conversion, and downstream elements (inventory, dispensing, distribution, fuel use, and vehicle fleet). The BSM represents contextual aspects of the developing biofuels industry, including investment in new biomass to biofuel conversion technologies, competition from petroleum fuels, vehicle demand for biofuels, and various government policies, using all of these to simulate the development of the industry. The purpose of the BSM is to generate and explore plausible scenarios for the evolution of a biofuels industry in the United States, and as a high-level system model it is not designed for precise, quantitative forecasting. Instead, it is best used to (1) analyze and evaluate alternate policies; (2) generate scenarios; (3) identify high-impact levers and bottlenecks to system evolution; and (4) seed focused discussion among policymakers, analysts, and stakeholders. In this report, the BSM will be used to explore how public or private investment at pilot, demonstration, and pioneer biorefineries might affect biofuels industry development under different incentive conditions.

2.1 Biomass Scenario Model Overview

The major sectors of the biofuel industry and the associated BSM modules are shown in Figure 1. Previous publications [16][17][18][19] offer a more detailed discussion of the BSM, including its geographic stratification, module logic and structure, and data sources. The part of the model most relevant to this report is the conversion module of the BSM, which simulates the conversion of biomass to biofuels, including the demonstration and deployment of new pathways.

Figure 2 shows the feedstocks, fuels or blendstocks, and biomass to biofuel conversion pathways in the BSM.

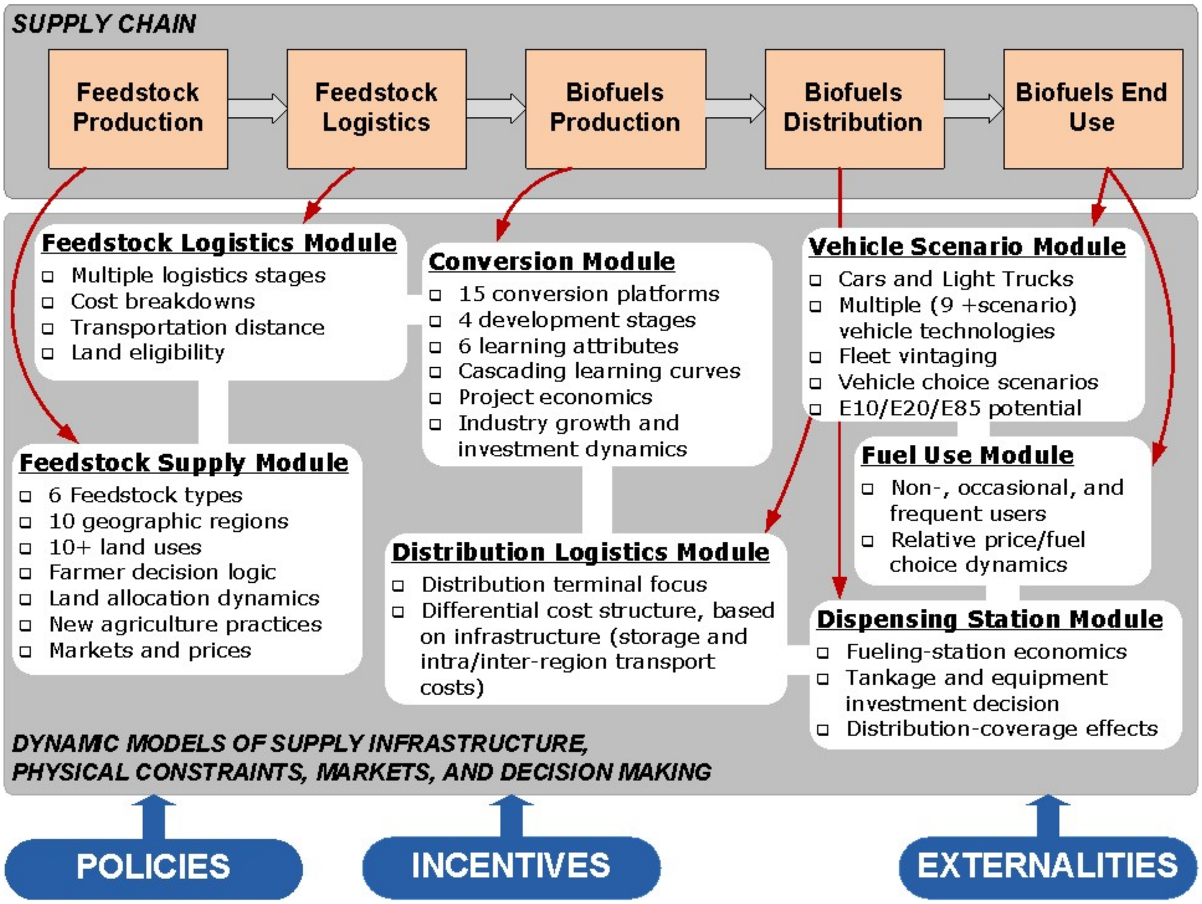

Figure 1. Major modules in the Biomass Scenario Model represent major sectors of the biofuels industry

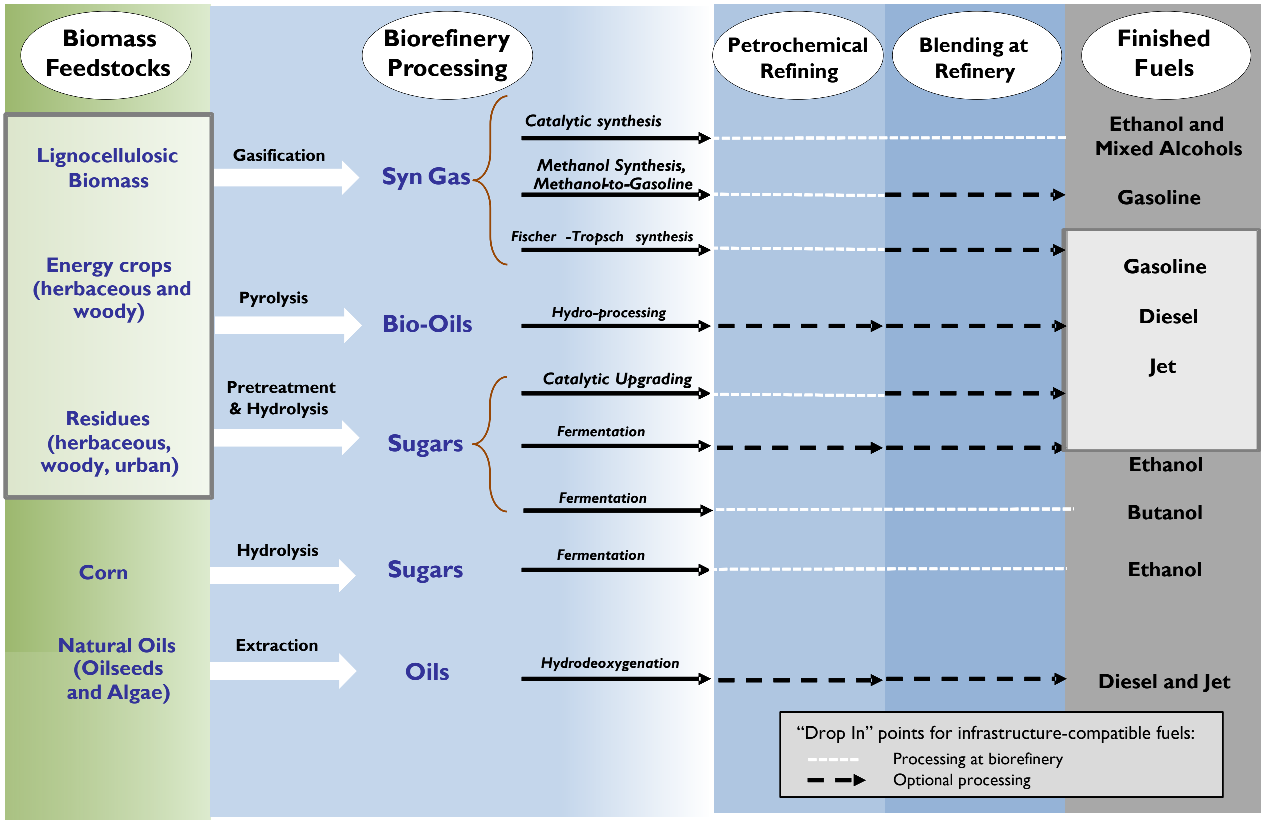

Figure 2. The Biomass Scenario Model considers multiple conversion pathways; line formats show that there are multiple possibilities for integrating biomass-derived products

Industrial learning [14] is central to the modeling of technology deployment. The BSM simulates the benefits of learning through experience,[2] separate from economies of scale. Learning through experience primarily addresses improvements to cost and performance metrics; while improvements in safety or environmental compliance may also occur through experience, adherence to safety and environmental standards is assumed at all scales, even in their immature states, because construction of biorefineries would rely on the established capability of the chemical industry to meet such standards. Learning through experience is also distinct from improvements that are made through research and development. In the BSM, research and development could improve expected performance of the mature commercial biorefinery and improve the initial state of a conversion technology pathway. It could also reduce the risk that commercial biorefineries using the targeted conversion pathway would fail to perform at expected levels; this risk is not explicit in the BSM.

[2] Learning through experience is also called learning-by-doing or experiential learning.

Learning drives the major dynamic feature of the BSM conversion module through reinforcing feedback as shown in Figure 3. The model estimates the growth of the industry on the basis of four scales of operation[3] (pilot, demonstration, pioneer, and commercial) for five performance metrics (yield of conversion process, input capacity for feedstocks, capital cost, risk premium that investors require to compensate for additional risk, and eligibility for debt financing). In the BSM, commercial facilities are assumed to be both larger and less expensive then pioneer facilities because of the additional learning that occurs at the pioneer scale.

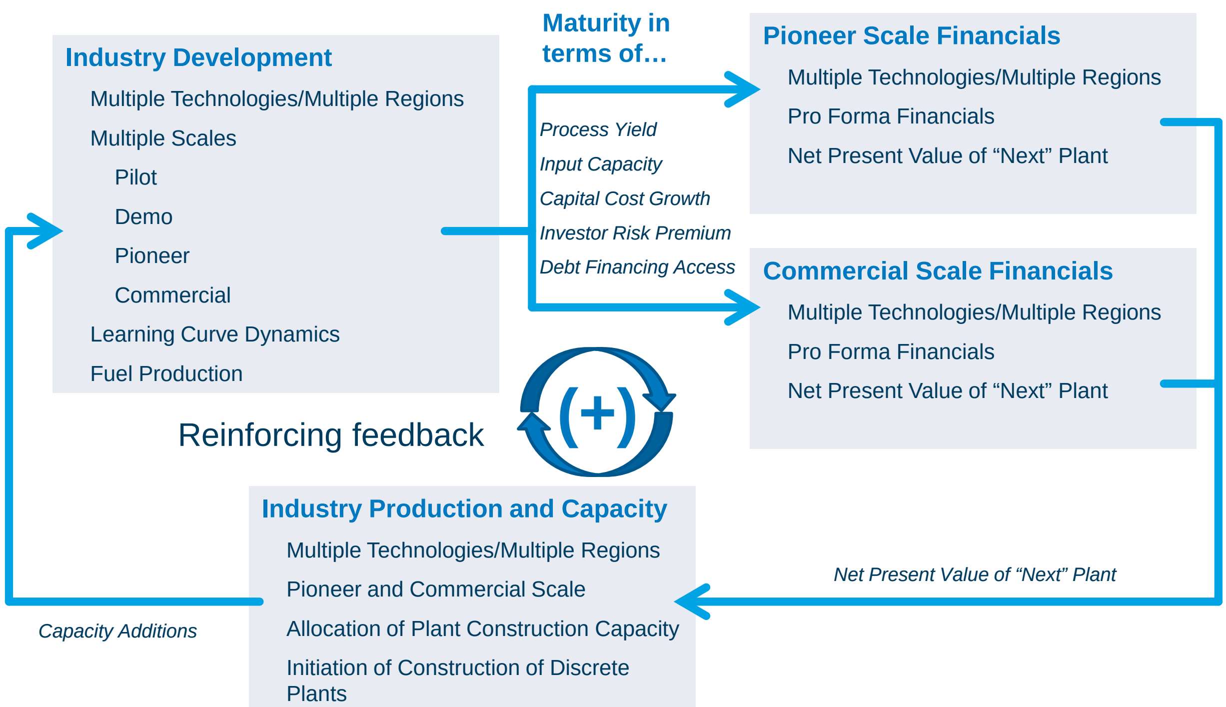

Figure 3. The Biomass Scenario Model includes a reinforcing feedback around industrial development, financial performance, and industrial production and capacity

In this study, assumptions about the rate of experiential learning impact results. The effectiveness of pilot, demonstration, pioneer, and commercial scale activities in advancing the maturity level of a pathway is an uncertain but highly influential assumption. This relationship determines the effect of deployment investment in the simulations, as described further below.

The attractiveness of an investment in a biorefinery is a key metric of the commercial maturity of a pathway and a critical driver of further deployment. The model approximates investors' considerations through calculation of the expected net present value of an investment in a new pioneer or full-scale commercial biorefinery. A simplified schematic of these calculations is

[3] In the BSM, a single throughput is assumed for commercial scale biorefineries within a given conversion technology pathway. For example, commercial biorefineries in cellulose to ethanol and cellulose to hydrocarbons pathways are assumed to have a 2,000 Mg/day feedstock throughput. Pioneer biorefineries are assumed to have 30% of commercial throughput.

shown in Figure 4. As shown in Figure 3, the estimated net present value of a new biorefinery increases with industry maturity, improving the financial attractiveness of investing.

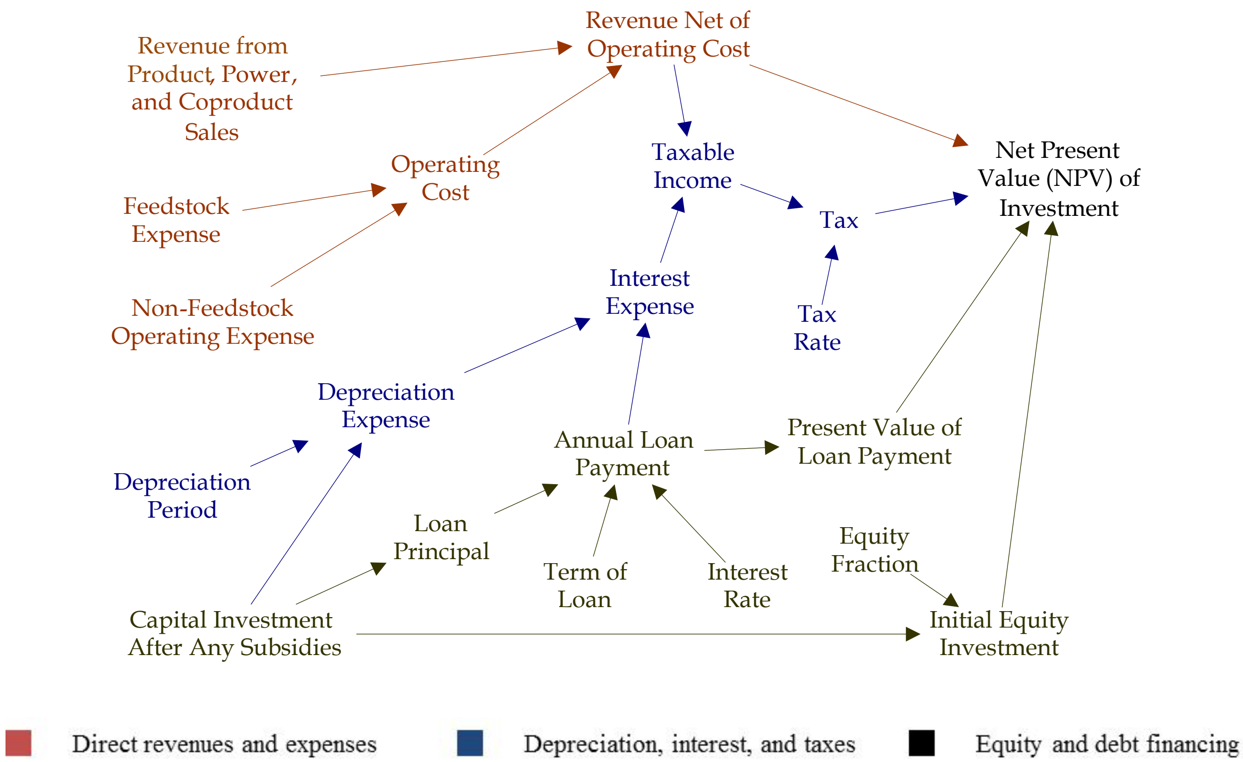

Figure 4. Computations of the financial characteristics of prospective new biorefineries in the Biomass Scenario Model are used to estimate net present value; the figure shows stages, types, and interrelationships among the financial computations

Policy conditions can affect the attractiveness of investment, and incentive policies are important to biofuels industry development. The BSM can represent a wide variety of policies that provide incentives during conversion pathway start up or throughout its development, including point-of-production incentives; construction incentives (fixed capital investment, government loan guarantee); feedstock incentives; and downstream incentives (downstream point of use, distribution and storage, dispensing station fixed capital investment or capital expenditures, dispensing station repurposing, high-blend point of use). A library of incentive scenarios is available for BSM simulations, as described in Inman et al. [18]. For this study, two incentive conditions were considered: a case with a production incentive and a case without a production incentive.

The model represents biorefinery construction based on two different methods. First, biorefinery construction starts can be generated from within the model: if investment conditions are favorable and demand for biofuels is sufficient, the algorithm will initiate construction of a biorefinery. However, resources to build additional production capacity are constrained. The allocation choice distributes these resources among biorefinery construction projects by considering their characteristics: conversion pathway, pioneer or full commercial scales, and geographic region. Biorefineries also must compete for these construction resources with similar investments outside of the biofuels industry. Not all financially attractive biorefineries are assumed to be built because other investments might be more attractive (other biorefinery types or investments outside of biorefining) or there might not be available capacity for construction of large industrial facilities.

Second, biorefinery starts can be scheduled: Inputs to the model can specify the year, pathway, location, and size of new biorefineries. In this study, this method is used to insert into the model two different schedules for planned biorefinery construction starts: one based on an assumed baseline industry and public investment and another based on an assumed additional deployment investment.

2.2 Study Design

A set of BSM simulations were developed to explore the effects on industry growth of investment in biorefineries under a variety of conditions. This report focuses on deployment investment and production incentives, a key subset of a much larger set of simulations that involved the consideration of other policies, variations in ethanol demand, assumptions about industrial learning, uncertainties in techno-economic assessments, and other factors. The scenarios examined here were based on two dimensions or thematic categories that consisted of groups of related input parameters. These two dimensions were incentives and cellulose to hydrocarbon deployment investment. These dimensions are described in Sections 2.2.1 and 2.2.2, and Table 1 shows how two incentive conditions and two deployment investment conditions were combined in the four distinct cases for this study.

Table 1. Four Combinations of Incentive Conditions and Deployment Investment Conditions Used in the Simulations

Baseline Deployment Investment With Production Incentive	Additional Deployment Investment With Production Incentive
Baseline Deployment Investment Without Production Incentive	Additional Deployment Investment Without Production Incentive

2.2.1 Incentives

This study selects two incentive scenarios from the BSM scenario library. Here, these are labeled With Production Incentive and Without Production Incentive; in Inman et al., they are called the Point-of-Production-Focused Incentives Scenario and the Minimal Incentives Scenario. Features of these scenarios are shown in Table 2.

The production incentive was a point-of-production payment of $0.45/gallon (by volume, not energy content) for production of cellulose to hydrocarbons, cellulosic ethanol, and butanol. This amount of incentive is within the range of historical renewable identification number Renewable

Identification Number (RIN) market values, and this point-of-production payment scenario condition could be considered a very rough approximation of RIN market effects.

Table 2. Two Incentive Scenarios Used

Scenario Name	Incentives	Rationale
With Production Incentive	Point-of-production payment of $0.45/gal for cellulose to hydrocarbons, cellulosic ethanol, and butanol for all simulation years.	EISA has established RIN markets to provide production incentives, and a production incentive could continue to the end of the simulation period in 2030. The $0.45/gal value is within the range of historic RIN values.
Without Production Incentive	Does not include point-of-production payment of $0.45/gal	Production incentive could change, so the production incentive was removed to estimate these effects.

Note: Two other incentives apply in both point-of-production payment scenarios. A point-of-production payment for ethanol, for one simulation year only (2011–2012), mimics the last year of the Volumetric Ethanol Excise Tax Credit [26 U.S. Code 6426]. The Biomass Crop Assistance Program [7 U.S. Code 8111] is represented in the model throughout the simulation period.

2.2.2 Baseline and Additional Deployment Investment

Investment in new biorefineries may prompt advancement of the biomass to biofuels industry toward commercial maturity. One possible multi-stage strategy is to invest in a relatively large number of pilots, followed by a smaller number of demonstrations, and then by an even smaller number of pioneer scale facilities. Such an investment strategy could minimize the amount of capital at risk due to uncertainties in the techno-economics of particular processes and pathways. In particular, it allows for important and necessary technology advances to be made at lower scales and lower cost. This approach allows for the possibility that lack of progress in an earlier (pilot or demonstration) stage would cause a pathway not to receive investment in the next larger scale. Overall, this approach could allow potential commercial pathways to be identified and developed at much lower cost because subsequent, larger investments are conditional on the successful results of initial, smaller investments.

For this study, we performed simulations in the BSM with a baseline level of scheduled advanced biorefinery development and with an additional deployment investment, as shown in Table 3. Additional details on assumptions about pathways and timing of scheduled advanced biorefinery development are shown in the appendix. Each scale of biorefinery, and several different conversion technologies, is included among the scheduled developments. In addition to this scheduled biorefinery development, the BSM will generate biorefinery construction if conditions for industry growth are favorable, as described above.

The baseline level of scheduled advanced biorefinery development is based on professional judgment and informed by industry data [21][22][23]. The baseline deployment scenario also includes scheduled advanced biorefineries that received public incentives from the U.S. Department of Energy. In addition to the baseline scheduled biorefinery construction, this study tests the effects of additional investment in the set of biorefineries as summarized in Table 3 and the appendix. The baseline scheduled advanced biorefinery investment includes both cellulose to ethanol and cellulose to hydrocarbon pathways, and includes commercial scale biorefineries. The additional scheduled advanced biorefinery investment includes only select cellulose to hydrocarbon pathways, and does not include commercial scale biorefineries, as it is intended to represent a higher-risk public or private investment. These baseline and additional deployment investment schedules are only two of many possible scenarios for planned construction and are used for analysis and discussion but are not forecasts, nor are they representative of any detailed market analysis. Further market analysis is planned.

Table 3. Scenarios for Scheduled Advanced Biorefinery Construction with Baseline and with Additional Deployment Investment[a]

Scale of Biorefinery	Baseline Advanced Biorefineries	Additional Advanced Biorefineries	Baseline + Additional Advanced Biorefineries	Additional Advanced Biorefinery Construction Start Date Range
Pilot	11	7	18	2016–2022
Demonstration	18	5	23	2014–2021
Pioneer	7	4	11	2017–2021
Commercial	6		6	
Total	**42**	**16**	**58**	

[a] See appendix for details.

3 Results and Discussion

The BSM was used to perform simulations to explore the effects of demonstration and deployment investment under different incentive and investment scenarios. The resulting estimated numbers of biorefineries is shown in Figure 5, including starch to ethanol facilities. Numbers of plants are normalized to BSM plant sizes and do not correspond to actual plant counts.

Figure 6 presents the corresponding results on the basis of total annual volumetric biofuels production rates. The long-term decline in ethanol use is based on the expected declining use of gasoline, as light-duty vehicle efficiency continues to improve.

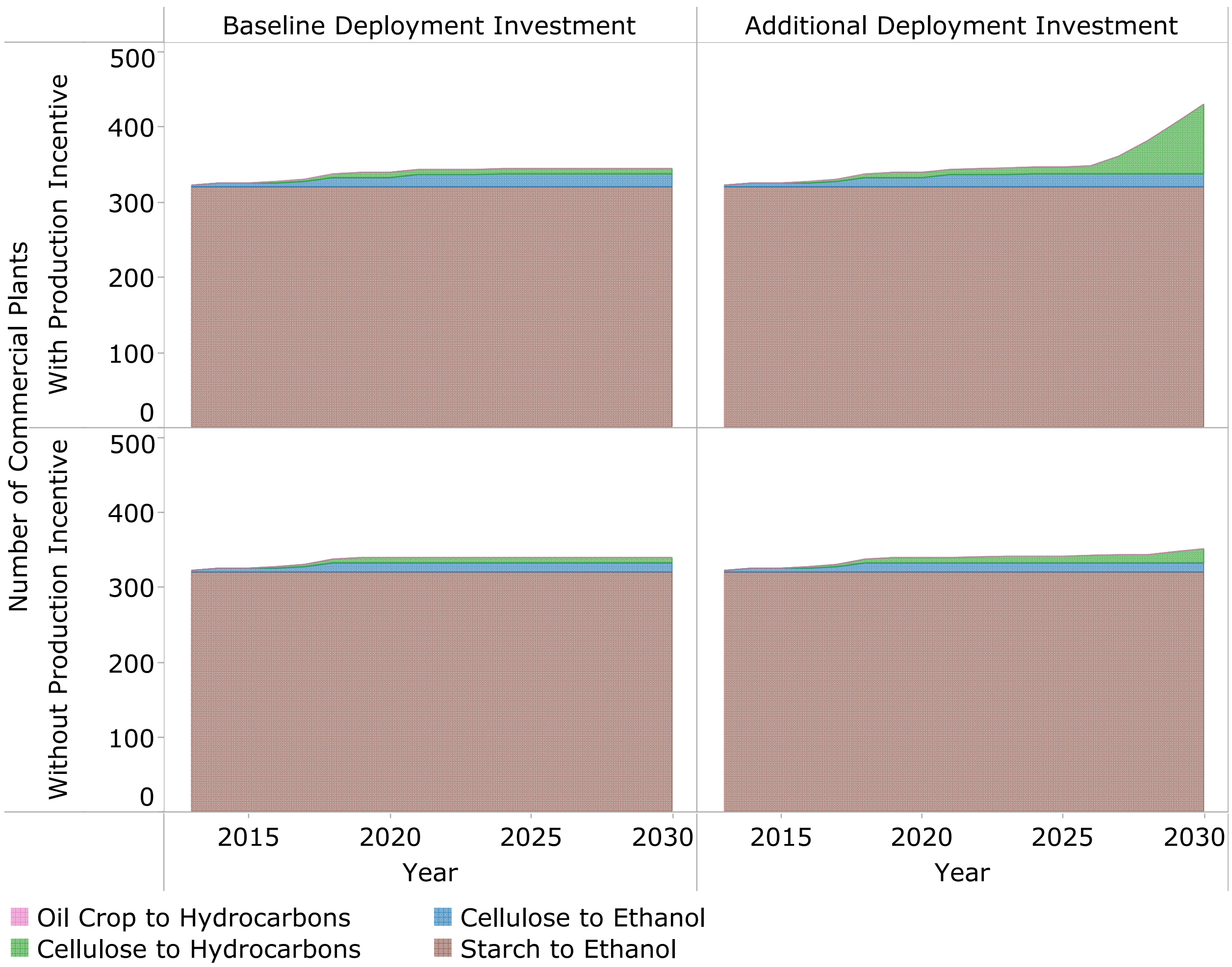

Figure 5. Number of pioneer and commercial biofuels production facilities with baseline and additional deployment investment and incentives, showing starch to ethanol facilities[4]

[4] Numbers of plants are normalized to BSM plant sizes and do not correspond to actual plant counts.

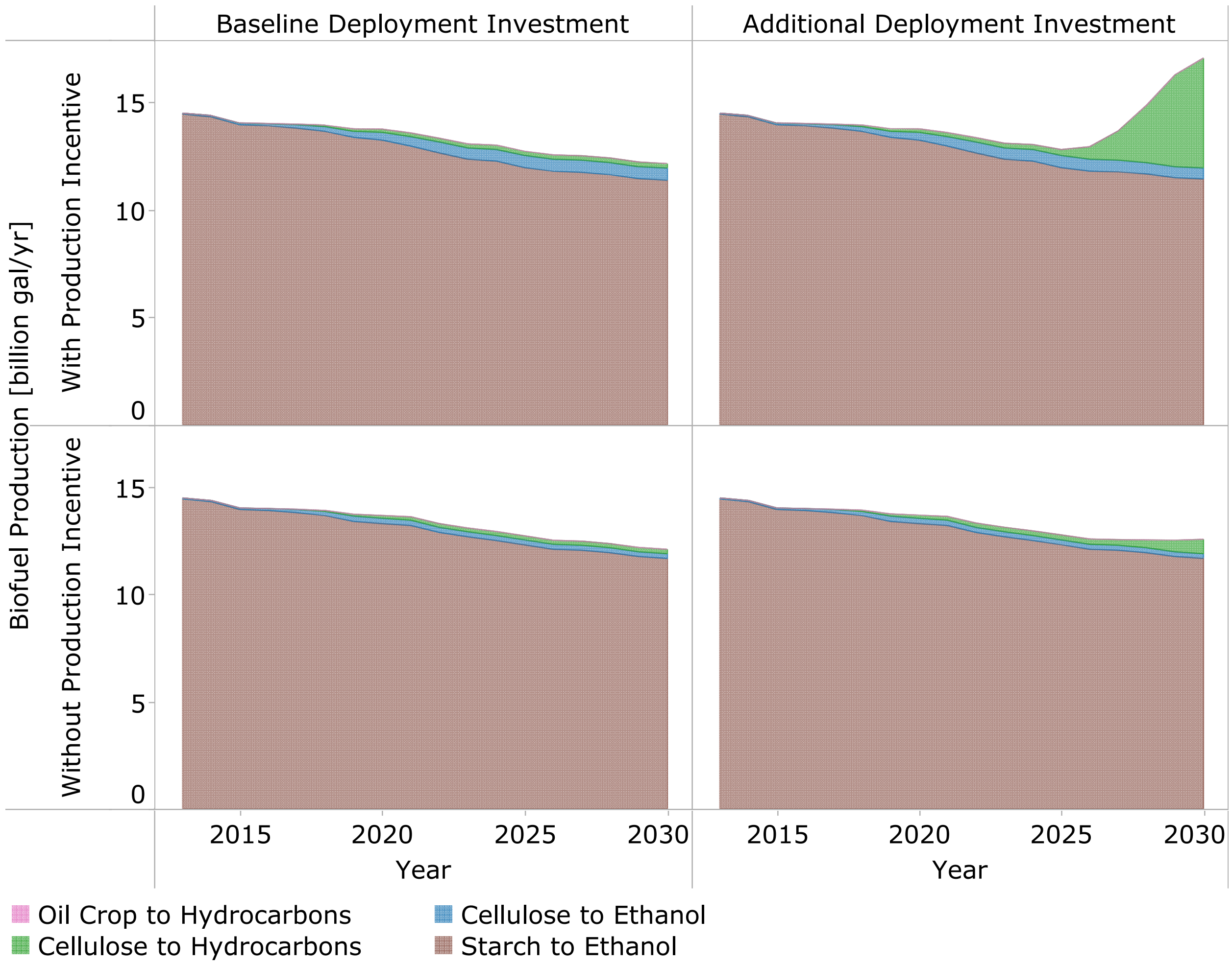

Figure 6. Biofuels production with baseline and additional deployment investment and incentives, showing starch to ethanol production[5]

[5] Figure displays moving average over 3 years (preceding, current, and following year).

In Figure 7 and Figure 8, starch facilities and starch production are not shown so that it is easier to see the growth in the advanced biomass to biofuels conversion technology pathways.

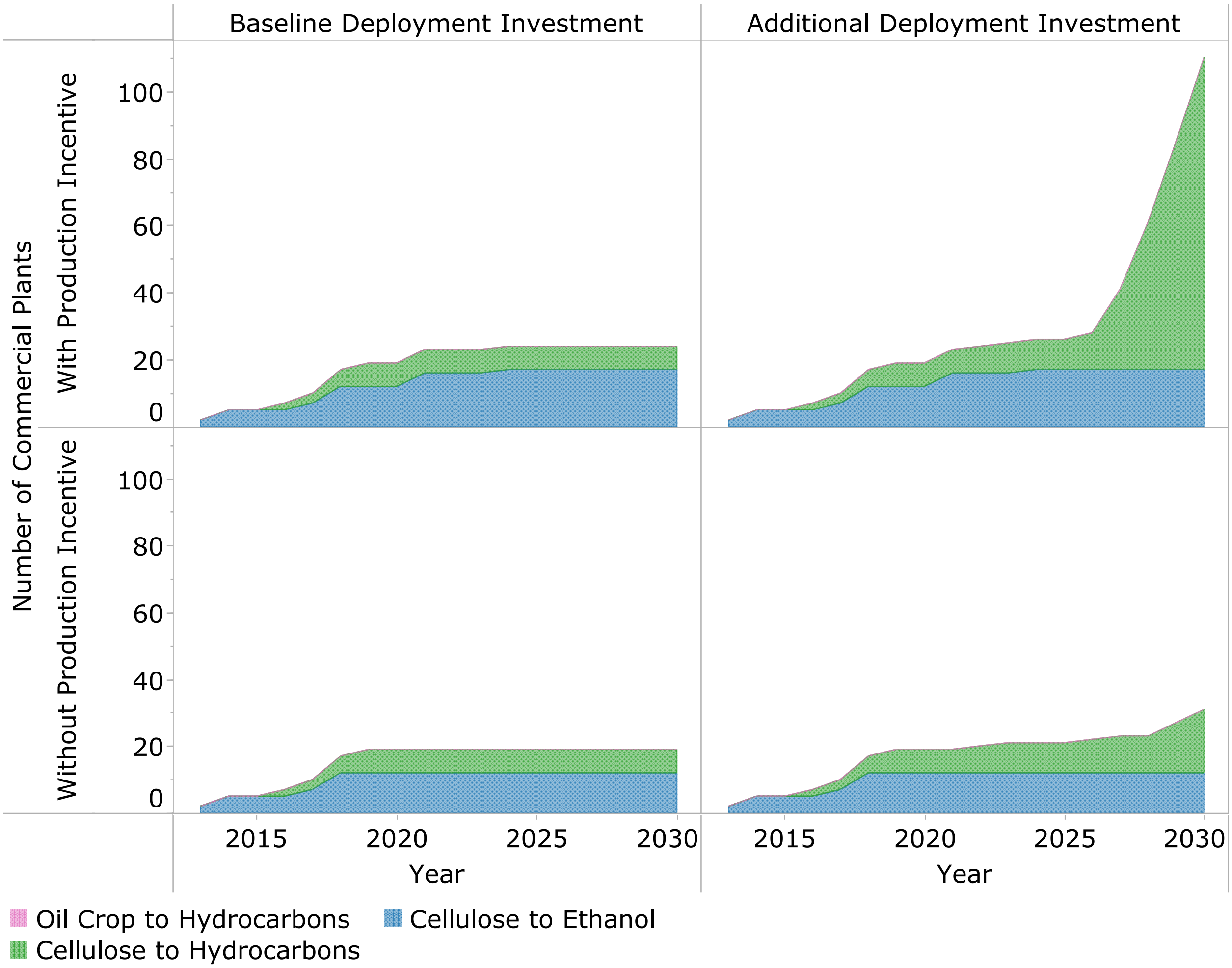

Figure 7. Number of pioneer and commercial advanced biofuels production facilities with baseline and additional deployment investment and incentives[6]

[6] Numbers of plants are normalized to BSM plant sizes and do not correspond to actual plant counts.

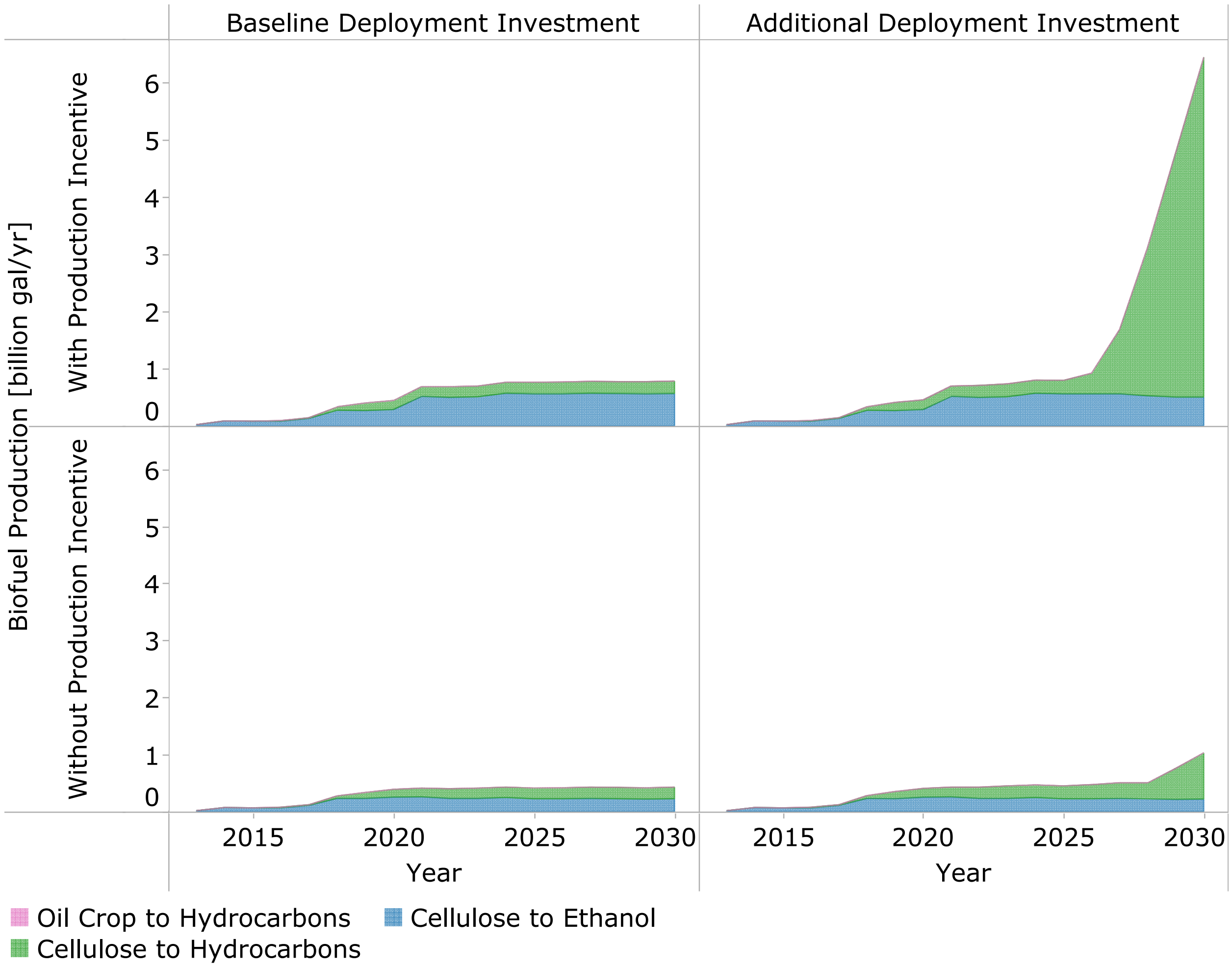

Figure 8. Advanced biofuels production with baseline and additional deployment investment and incentives

Figures 5 through 8 show that modeled deployment investment can have a significant effect on the development of conversion pathways. Under conditions with the production incentive, the additional deployment investment was sufficient to catalyze growth in biorefinery construction in the targeted pathways. The additional deployment investment, represented by seeding pilot, demonstration, and pioneer scale biorefinery construction starts, improved the maturity of the targeted pathways enough that they became sufficiently attractive investments that the model began generating plant starts internally. This effect is illustrated in upper right quadrant of the figures, where numbers of plants and biofuel production increase sharply. However, the cases without the production incentive offered insufficiently favorable conditions for the model to generate plant starts in the targeted pathways, even with the additional deployment investment.

The improvements to pathway maturity are shown in Figure 9, for cases that correspond to the preceding figures. These maturity improvements and the industry growth shown in Figures 5–8 reinforce each other. This is an example of the reinforcing feedback that is shown in Figure 3: Biorefineries seeded due to the additional deployment investment produce additional biofuel, and that experience increases maturity relative to the baseline.

Fast Pyrolysis and Fischer Tropsch pathways receive less pilot scale investment than others because of the extensive piloting that has already been completed. Both of these pathways receive pioneer scale investment during the simulation period because they are assumed to have experienced sufficient pilot and demonstration scale, and associated maturation, to warrant the next scale of investment during this time period. Catalytic upgrading of sugars to hydrocarbons and fermentation of sugars to hydrocarbons pathways receive pilot and demonstration scale investments during the simulation period. If successful at those stages, a longer-term simulation could show subsequent pioneer scale investment in those pathways. Figure 9 also illustrates that conditions are insufficiently favorable for the fermentation to hydrocarbons pathway to generate commercial maturity improvement, but this analysis depends on the techno-economic assumptions and is not designed to predict the relative commercial prospects of particular pathways.

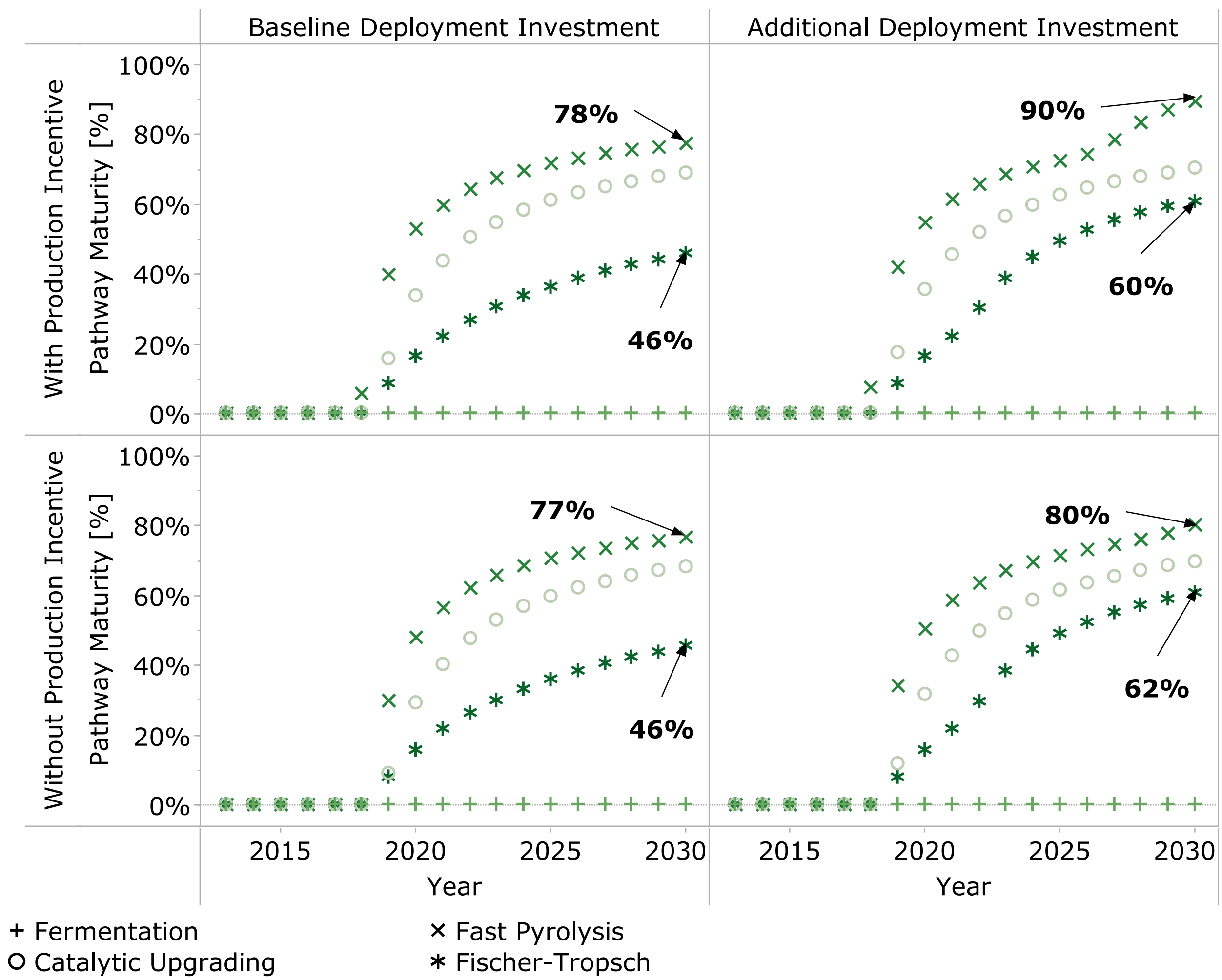

Figure 9. Effect of deployment investment and incentives on maturity of targeted pathways

Model results are limited and must be interpreted with caution. In addition, a specific limitation of these results relates to the uncertainty surrounding the effectiveness of a given deployment investment in improving the maturity of the targeted pathway. The size of the effect of the deployment investment depends on experiential learning assumptions about effects of different types of investment on maturation. These assumptions are calibrated to historical experience, but considerable uncertainty remains, and simulation results are highly sensitive to this assumption. This limits the application of the results because it is impossible to predict, with any certainty, the ultimate effectiveness of any given deployment investment strategy. Figure 10 shows sensitivity to assumptions about the progress ratio[7] [16]—a measure of the effect of deployment investment on maturity. The middle row of Figure 10 (75% progress ratio) is comparable to the "With Production Incentive" row of Figure 9, except that the simulation associated with results in Figure 10 has different baseline industry conditions.

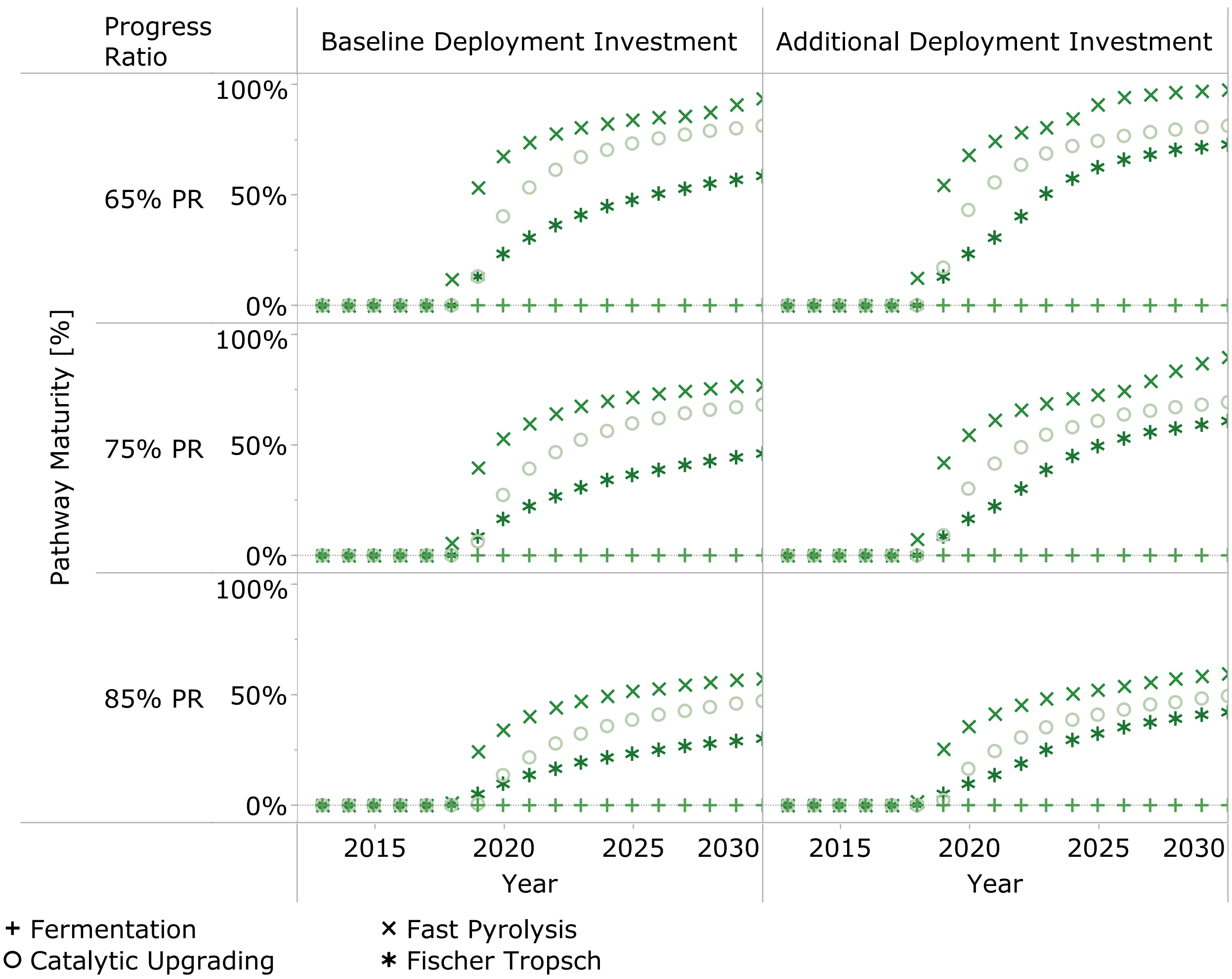

Figure 10. Effect of progress ratio assumption on maturity improvement—a 75% progress ratio is used in other simulations

[7] The BSM formulates industrial learning as the rate at which the gap between current maturity and full-scale commercial maturity closes. The progress ratio defines how much of the gap remains with each doubling of experience, such that more gap remains if the progress ratio is higher, so maturity increases more slowly at higher progress ratio values.

Another limitation is the uncertainty about biofuels industry development with baseline investment. The considered data about industry growth from a variety of sources when developing baseline assumptions [21][22][23]. Construction of biorefineries is often slower than initial plans propose. Planned scheduled biorefinery construction growth assumptions used for this study could be either an under- or an over-estimate of future biofuels industry development. In turn, the significance of the additional deployment investment studied here could be under- or over-estimated because of this uncertain baseline. A more detailed market analysis, which is planned, may serve as a future baseline.

4 Conclusions and Possible Next Steps

Deployment investments substantially accelerate industrial development under certain conditions, as modeled in the BSM. The BSM can detect effects of the different amounts of demonstration and deployment investment in pilot, demonstration, and pioneer scale biorefineries. The size of the effect of this type of deployment investment in simulation results depends heavily on other conditions, such as incentives, baseline scheduled biorefinery investments, and techno-economics. The deployment investment effects that were detected in the BSM include accelerated industrial learning, biorefinery construction, and biofuel production in the targeted pathways. The results of this study showed sharply increasing biorefinery construction and biofuels production when additional deployment investment was combined with a production incentive. While simulation results cannot precisely predict real-world events, these results suggest that deployment investments can accelerate industrial development if conditions are sufficiently favorable.

Next steps could include incorporating further market analysis, refining techno-economic estimates, and exploring additional interactions between deployment investment and other conditions that constrain or enable the growth of the biofuels industry. More detailed market analysis is planned, and when it becomes available, it will be incorporated into industry growth scenarios. Techno-economic performance estimates are being developed for an updated set of biomass to biofuels conversion technology pathways, and these will be used to update techno-economic data in the BSM. In addition, analysis of interactions between deployment investment and progress due to experiential learning can help quantify the effects of more biorefinery construction in one conversion pathway.

Other conditions that are important to biofuels industry growth and can interact with deployment investment include overall economic growth, petroleum price, growth of other non-petroleum transportation fuels, capacity for construction of biorefineries and other chemical industry facilities, ease of industrial learning within and among biomass to biofuels conversion technology pathways, ethanol blending policy, and incentive policies that target various parts of the biofuels industry with production, point of use, capital, or other incentives. Exploration of how these many other conditions interact with deployment investment could reveal bottlenecks and synergies that could help target incremental investment where it is most effective. A key next step within this exploration would be to understand in greater detail the synergies between production incentives and deployment investment in biorefineries and to evaluate the impact of investment levels in each category.

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Appendix

This appendix documents the pathway, scale, and timing of facilities that comprise the deployment investment. This report uses two scenarios for scheduled biorefinery construction: with baseline or with additional deployment investment. Scenarios are shown in two formats: Table A-1 and Figure A-1. This is not a forecast.

Table A-1. Scheduled Advanced Biorefinery Construction with Baseline or Additional Deployment Investment, by Pathway, Year, and Scale

	Scale	Pathway	Construction Start Year	Baseline Deployment Investment	Additional Deployment Investment
Cellulose to Hydrocarbons	Pilot	Catalytic Upgrading	2016		1.00
			2019		1.00
			2022		1.00
		Fermentation	2011	1.00	1.00
			2019		1.00
			2022		1.00
		Fast Pyrolysis	2011	2.00	2.00
			2013	2.00	2.00
			2014	1.00	1.00
			2016		1.00
		Fischer Tropsch	2011	3.00	3.00
			2012	1.00	1.00
			2014	1.00	1.00
			2019		1.00
	Demonstration	Catalytic Upgrading	2018		1.00
		Fermentation	2012	1.00	1.00
			2021		1.00
		Fast Pyrolysis	2015		1.00
			2018		1.00
		Fischer Tropsch	2011	1.00	1.00
			2013	2.00	2.00
			2014		1.00
		Methanol to Gasoline	2013	1.00	1.00
	Pioneer	Fast Pyrolysis	2011	1.00	1.00
			2012	1.00	1.00
			2021		1.00
			2022		1.00
		Fischer Tropsch	2017		1.00
			2018		1.00

	Commercial	Catalytic Upgrading	2013	1.00	1.00
			2014	1.00	1.00
		Fast Pyrolysis	2013	1.00	1.00
			2014	1.00	1.00
Cellulose to Ethanol	Pilot	Biochemical	2011	Pilot scale assumed fully mature at start of simulation	
		Thermochemical	2011	Pilot scale assumed fully mature at start of simulation	
	Demonstration	Biochemical	2011	7.00	7.00
			2013	1.00	1.00
		Thermochemical	2011	3.00	3.00
			2012	1.00	1.00
			2014	1.00	1.00
	Pioneer	Biochemical	2013	2.00	2.00
		Thermochemical	2012	2.00	2.00
			2013	1.00	1.00
	Commercial	Biochemical	2013	2.00	2.00

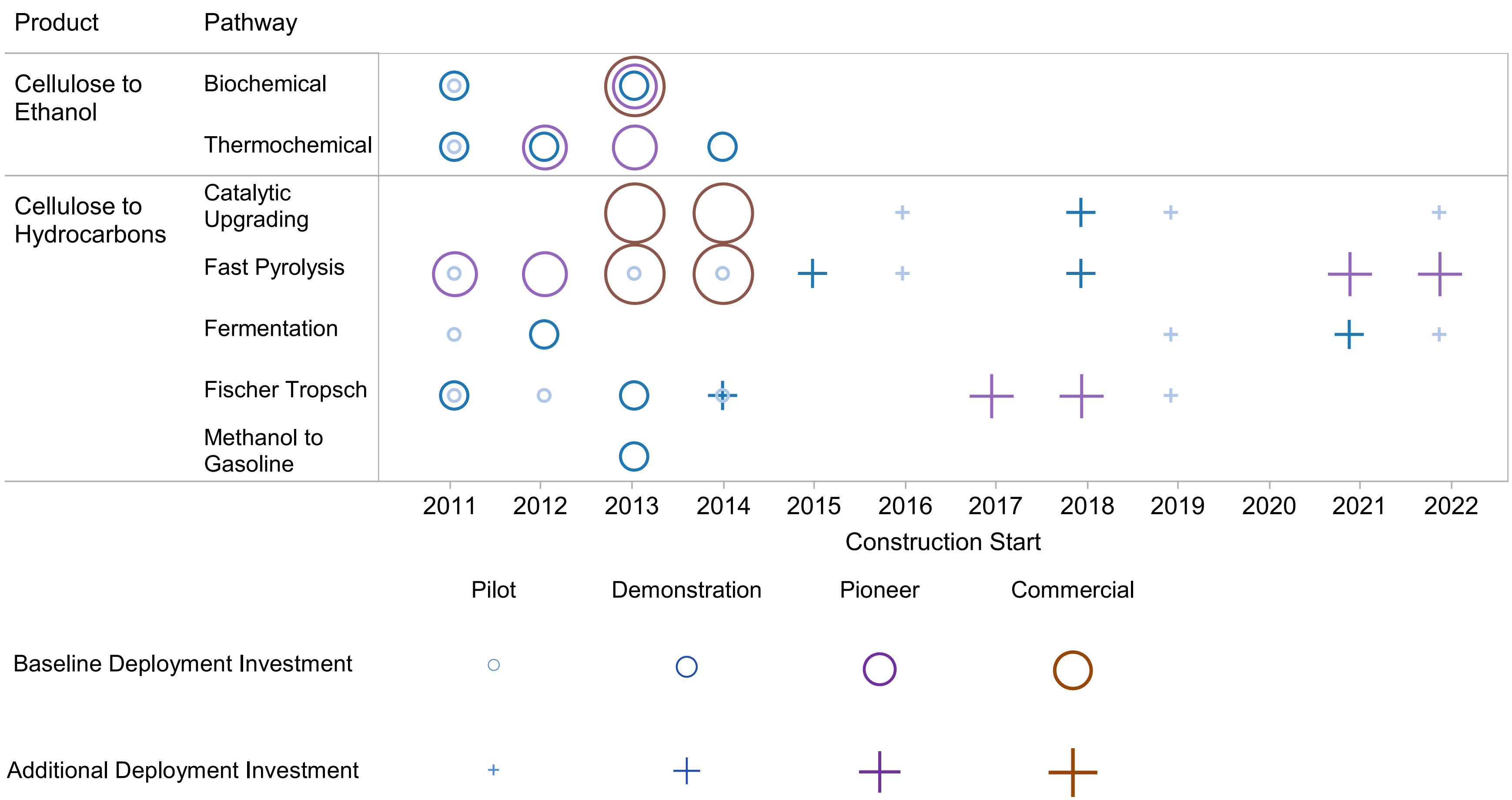

Figure A-1. Scheduled advanced biorefinery construction with baseline and additional deployment investment, by pathway, year, and scale