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U.S. ECONOMIC IMPACT OF ADVANCED BIOFUELS PRODUCTION:

PERSPECTIVES TO 2030

FEBRUARY 2009

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Executive Summary

The U.S. Renewable Fuel Standard (RFS) for transportation fuels sets minimum levels of renewable fuels that must be blended into gasoline and other transportation fuels from 2006 to 2022. Specific requirements for blending advanced biofuels,** including cellulosic biofuels and biomass-based biodiesel, begin at 0.6 billion gallons per year in 2009 and rise to 21 billion gallons in 2022. The RFS levels for advanced biofuels production will drive the creation of a major new industry, creating a foundation for future technology development and commercial growth.

To estimate the economic implications of the emergence of this new industry, bio-era conducted a meta-analysis of nearly two dozen studies of economic impacts of biofuels production, developed a model to analyze economic output and job creation, and applied this model to analyze the economic impact of increasing U.S. advanced biofuel production to 21 billion gallons per year by 2022.

This analysis yielded the following conclusions:

- Direct job creation from advanced biofuels production could reach 29,000 by 2012, rising to 94,000 by 2016 and 190,000 by 2022. Total job creation, accounting for economic multiplier effects, could reach 123,000 in 2012, 383,000 in 2016, and 807,000 by 2022.
- Investments in advanced biofuels processing plants alone would reach $3.2 billion in 2012, rising to $8.5 billion in 2016, and $12.2 billion by 2022. Cumulative investment in new processing facilities between 2009 and 2022 would total more than $95 billion.
- Direct economic output from the advanced biofuels industry, including capital investment, research and development, technology royalties, processing operations, feedstock production and biofuels distribution, is estimated to rise to $5.5 billion in 2012, reaching $17.4 billion in 2016, and $37 billion by 2022.

** This research was carried out independently by bio-era, with financial support from the Industrial & Environmental section of the Biotechnology Industry Organization (BIO), February 2009.*

***As defined by the Energy Independence and Security Act of 2007, advanced biofuels are renewable fuels, other than ethanol derived from corn starch, that have lifecycle greenhouse gas emissions that achieve at least a 50 percent reduction over baseline lifecycle greenhouse gas emissions. Advanced biofuels may include ethanol derived from cellulose or lignin, sugar or starch (other than corn starch), or waste material, including crop residue, other vegetative waste material, animal waste, and food waste and yard waste; biomass-based diesel; biogas produced through the conversion of organic matter from renewable biomass; butanol or other alcohols produced through the conversion of organic matter from renewable biomass; and other fuel derived from cellulosic biomass.*

- Taking into consideration the indirect and induced economic effects resulting from direct expenditures in advanced biofuels production, the total economic output effect for the U.S. economy is estimated to be $20.2 billion in 2012, $64.2 billion in 2016, and $148.7 billion in 2022.

- Advanced biofuels production under the RFS scenario could reduce U.S. petroleum imports by approximately $5.5 billion in 2012, $23 billion in 2016, and nearly $70 billion by 2022. The cumulative total of avoided petroleum imports over the period 2010–2022 would exceed $350 billion.

The bio-era model was also used to assess the economic implications of a scenario in which total U.S. biofuels production grows to 60 billion gallons by 2030, with 15 billion gallons of conventional biofuels production and 45 billion gallons of advanced biofuels production. This analysis concludes that:

- Approximately 400,000 jobs would be directly created in the advanced biofuels industry, with total employment creation in the U.S. economy totaling 1.9 million jobs.

- Direct economic output from advanced biofuels production would rise to $113 billion by 2030. The total economic output effect would be $300 billion.

- Biomass feedstocks in this scenario could be provided by a mix of agricultural and forest wastes and dedicated energy crops, providing a total of 470 million dry tons of biomass by 2030 using existing crop and forest land.

- The average cost of advanced biofuel production at the plant-gate in 2030 would be $1.88 including all operating costs, overhead, and capital recovery.

Introduction

The emergence of a new advanced biofuels production industry over the next two decades portends significant economic value creation and jobs growth. Although it is early to predict the exact character and dimensions of these impacts, detailed studies of advanced biofuels production processes conducted in recent years provide a foundation for predicting the potential size of economic impacts on the U.S. economy resulting from the growth of this new industry.

In this analysis, we estimate the U.S. economic impact of advanced biofuels production at the levels mandated by the Energy Independence and Security Act of 2007 (EISA). Under EISA, advanced biofuels production will rise from 2.0 billion gallons per year (BGY) in 2012 to 21.0 BGY in 2022 (Figure 1). We compare the economic impact of this trajectory to one in which there is no advanced biofuels production in the United States through 2022.

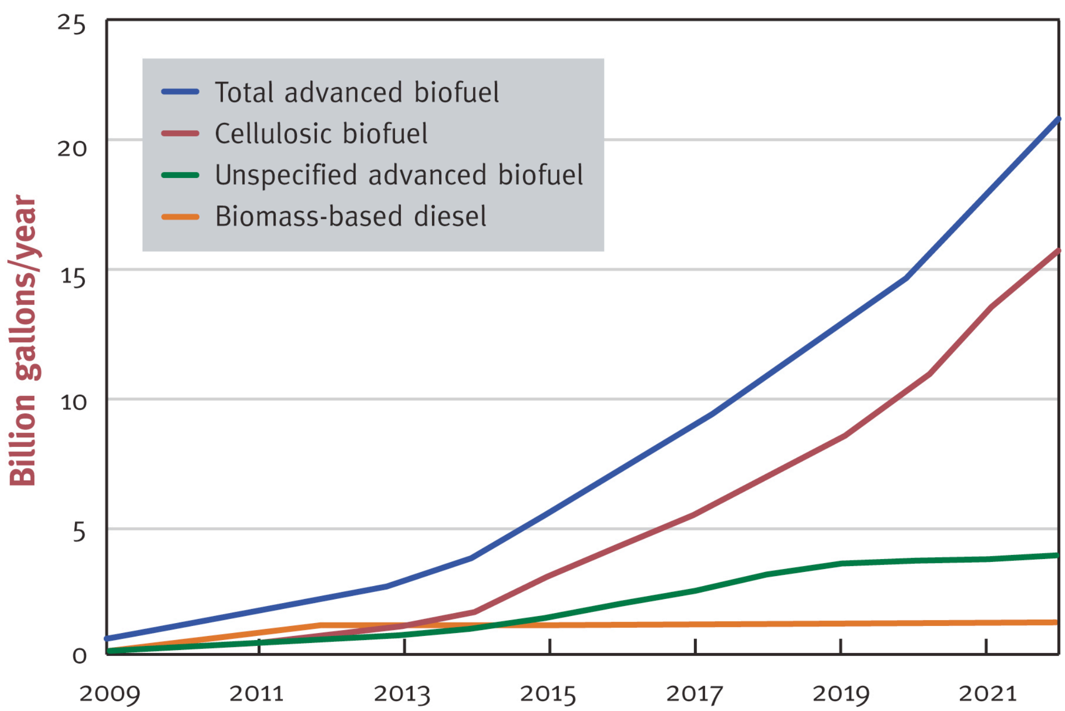


Figure 1: U.S. Production of Advanced Biofuels under the Renewable Fuel Standard

Analysis Approach

Numerous studies have been conducted to measure the economic impacts of biofuels production in terms of economic output and job creation. These studies span a wide range in terms of scope, from individual biofuels processing plants to groups of plants and ancillary operations at the state, regional, or national level.[1] For example, Perez-Verdin (2008), Flanders (2007), Solomon (2007), and Leistritz (2007) have provided thorough and detailed analyses of individual biofuels processing plants for specific state or regional economies. Other studies, including Massachusetts Advanced Biofuels (2008), Leistritz (2008), and Swenson (2007) assess the impacts of multiple plants on a regional or national basis.

Existing studies also consider a wide range of different biofuels processing technologies and feedstock supply options, including various biological and thermochemical conversion processes and feedstocks ranging from crop and forest residues to switchgrass, Miscanthus, and short-rotation woody crops. Finally, several different types of economic models have been used to analyze the total economic impact of biofuels production, including IMPLAN, RIMS II, and Policy Insight.

In this study, we conduct a meta-analysis of nearly two dozen existing studies to provide a foundation for creating key working assumptions about advanced biofuels production operations and the economic multiplier effects related to those operations (see Appendix for further details). We use these assumptions to model the economic impact of the scale-up of advanced biofuels operations, including technology development, plant engineering, procurement, and construction, processing operations, feedstock supply, and biofuels distribution.

Model Assumptions

Advanced biofuels processing capacity and investment. To meet the RFS requirements, we estimate that advanced biofuels production capacity will need to rise to more than 23 billion gallons by 2022, requiring a cumulative capital investment in processing capacity of more than $95 billion. Annual capital investments in advanced biofuels processing plants would rise from $2.0 billion in 2011 to $8.5 billion in 2016 and $12.2 billion in 2022. Figure 2 and Table 1 summarize our assumptions about the capital costs per gallon of installed capacity for cellulosic ethanol plants, the distribution of capacity across various sizes of plants, and the total capital investment in biofuels processing capacity. We assume a capacity utilization factor of 90 percent for advanced biofuels plants. This is comparable to the capacity utilization for petroleum refineries, which averaged 89.5 percent from 1985 to 2007, and that for corn-based ethanol plants, which typically operate at average utilization rates of 90–95 percent.

Processing plants will likely span a wide range of sizes, with most facilities between 20 and 200 million gallons of annual capacity. Smaller plants will have the advantage of shorter haul distances for feedstocks, at least where energy crops are being grown to supply biomass to the plant. On the other hand, economies of scale in engineering, construction, and permitting may make the capital costs per unit of capacity lower for larger plants.

Table 1: Cellulosic Ethanol Processing Plants*

Year	Total installed capacity (BGY) by size of plant				Number of plants operating	Cellulosic ethanol production capacity operating
	20 MGY	50 MGY	100 MGY	200 MGY		
2009	0.0	0.1	0.0	0.0	3	0.1
2010	0.1	0.1	0.1	0.0	7	0.3
2011	0.1	0.2	0.2	0.0	13	0.6
2012	0.2	0.4	0.4	0.0	24	1.1
2013	0.4	0.8	0.8	0.0	43	1.9
2014	0.6	1.2	1.2	0.0	67	3.1
2015	1.0	2.0	2.0	0.0	110	5.0
2016	1.4	2.8	2.8	0.0	153	6.9
2017	1.8	3.6	3.6	0.0	196	8.9
2018	1.7	4.4	4.4	0.6	219	11.1
2019	1.3	5.3	5.3	1.3	233	13.3
2020	1.6	6.2	6.2	1.6	272	15.6
2021	1.9	7.6	7.6	1.9	331	18.9
2022	2.2	8.9	8.9	2.2	389	22.2

** Biomass-based biodiesel plants are treated separately. See Appendix for details.*

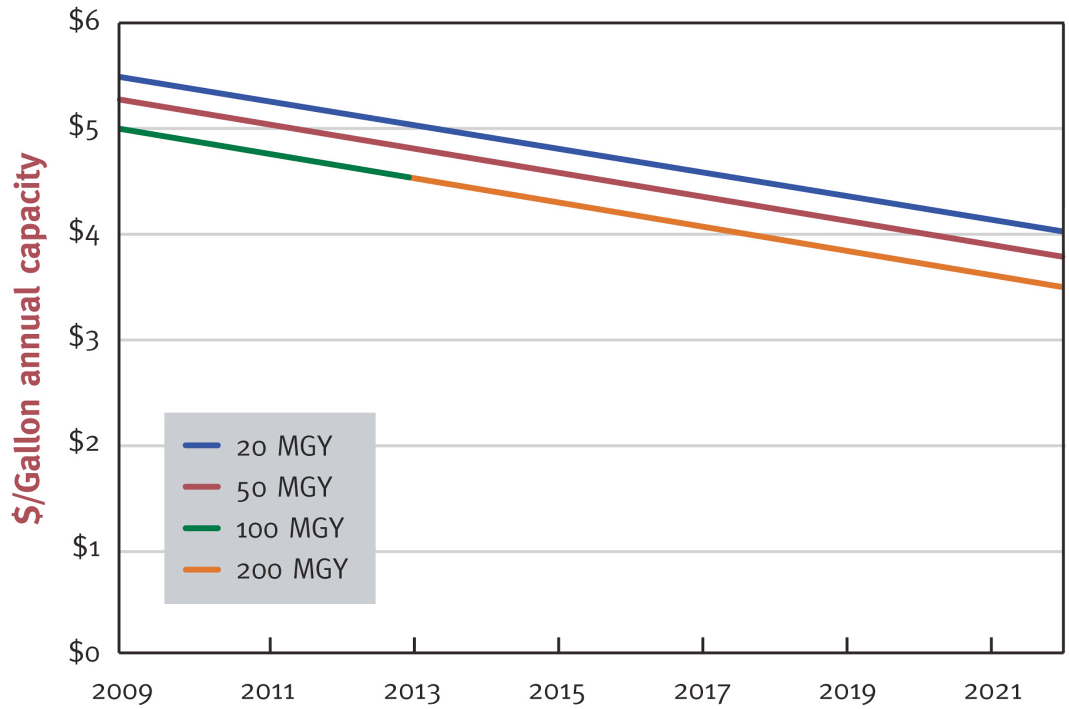


Figure 2: Average Capital Cost of Advanced Biofuels Processing Facilities ($/gallon annual capacity)

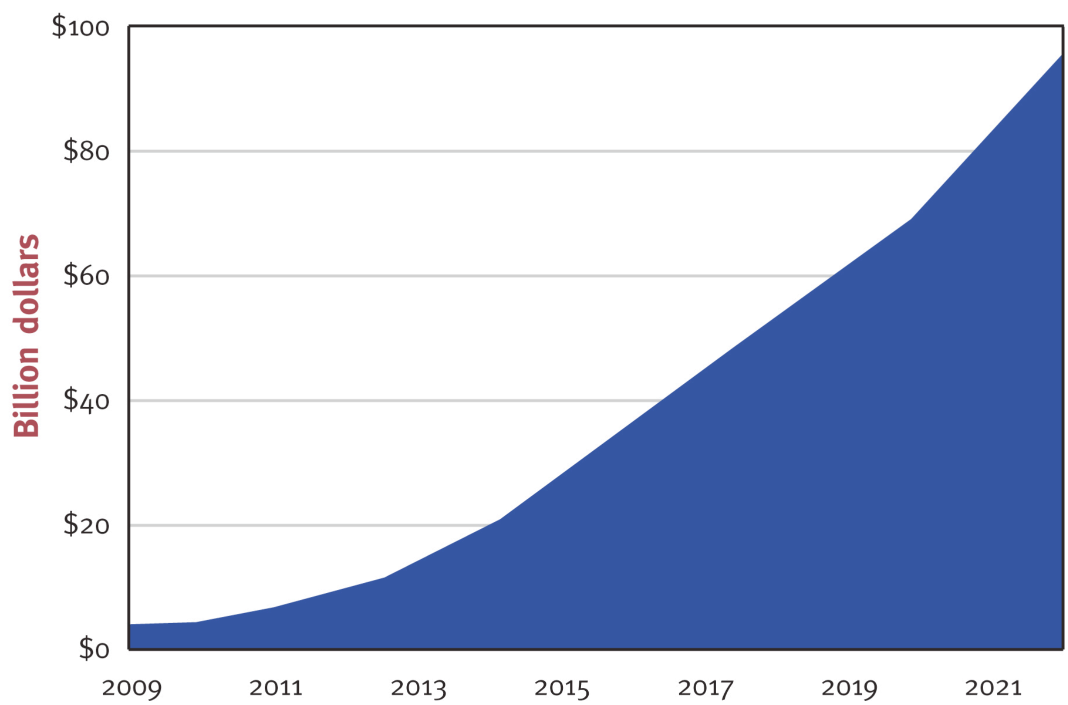
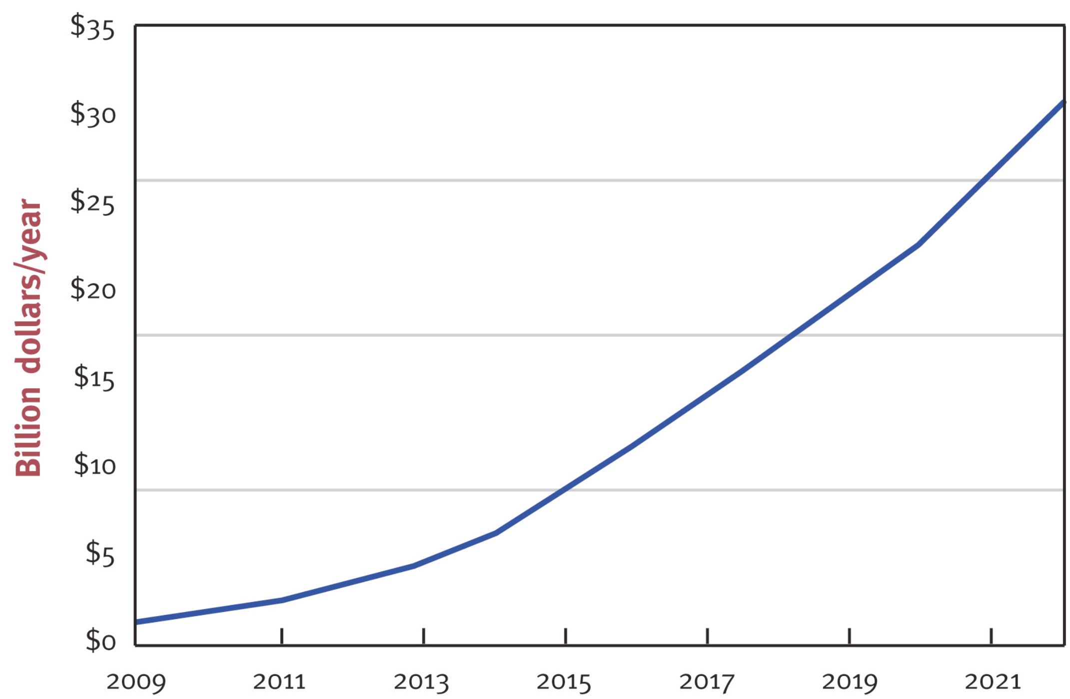


Figure 3: Cumulative Total Capital Investment in Advanced Biofuels Processing Plants

Processing operations. Based on a review of previous studies, we assume an average operating cost for advanced biofuels processing facilities, including feedstock purchases and excluding capital recovery, of $1.65 per gallon of biofuels produced in 2009 falling to $1.45 per gallon in 2022 as processes improve over time. These costs include feedstock procurement and all other operating costs but exclude capital recovery. On this basis, we project total operating expenditures for all advanced biofuels production to rise to $3.2 billion in 2012, $11.2 billion in 2016, and $30.5 billion in 2022.

Figure 4: Direct Expenditures on Advanced Biofuels Processing Operations



Feedstocks. Lignocellulosic feedstocks for advanced biofuels production are likely to come from a wide variety of sources, including crop wastes, forest residues, urban wood waste, and dedicated energy crops. Various analyses have been undertaken to create scenarios for biomass supply to meet U.S. advanced biofuels production requirements.[2] For example, a recent study funded by the U.S. Biomass Research and Development Initiative (BRDI) created detailed scenarios of possible feedstock supplies to 2022 from cropland and forestland biomass, mill residues, and municipal solid waste. The economic, geographic, and environmental implications of these different feedstock supply scenarios could diverge significantly. But it is too early to be able to accurately predict the combination of feedstock supplies that is likely to evolve to support the U.S. biofuels industry in the future.

To estimate economic impacts and job creation, at least to a first order approximation, we adopt a simplifying assumption that all cellulosic feedstock for advanced biofuels production is supplied from dedicated energy crops. We assume an average price of $55 per dry ton for biomass supplied to processing facilities beginning in 2009, falling to $50 per ton after 2013 as agricultural practices, yields, and harvesting processes improve. By comparison, a recent study by the Biomass Research and Development Initiative (2008) estimated total feedstock production costs, including harvest costs, for short-rotation woody crops to be $39–58 per dry ton. We assume 5.6 full-time equivalent (FTE) new jobs created in feedstock seed production, energy crop production, harvesting, transportation and storage for every 1,000 acres of dedicated energy crops cultivated.[3]

Based on these assumptions, farm sector employment related to feedstock production, harvesting, and transportation would increase to 88,000 by 2022, while the total value of feedstock produced would exceed $11 billion in that year (Table 2).

Table 2: Job Creation and Economic Value of Cellulosic Feedstock Production

Year	Tons of biomass per acre* (t/acre)	Gallons biofuels per ton feedstock (gal/ton)	Dollars per ton feedstock ($/bdt)	Total feedstock jobs at RFS levels (thousand)	Value of feedstock produced (billion dollars)
2009	7	77	55	6.2	0.4
2010	8	78	55	9.0	0.7
2011	8	80	55	11.7	0.9
2012	9	81	55	16.0	1.4
2013	9	83	50	20.4	1.7
2014	10	84	50	25.8	2.2
2015	10	85	50	35.3	3.2
2016	11	87	50	43.5	4.2
2017	11	88	50	50.6	5.1
2018	12	89	50	58.1	6.1
2019	12	91	50	64.7	7.2
2020	13	92	50	70.5	8.1
2021	13	94	50	80.0	9.6
2022	14	95	50	88.4	11.1

**Note: Average yields per acre include all land projected to be used for cultivation for energy crops in the U.S. Crops such as switchgrass and Miscanthus may take several years to reach peak production.*

Biofuels distribution. We assume average costs for transportation and distribution of biofuels from production facilities to downstream blending stations within the U.S. liquid fuel infrastructure of $0.23 per gallon. Current transportation costs for ethanol in the United States typically range from $0.18 to $0.30 per gallon.[4] On this basis, the economic value of these operations will increase to $0.5 billion in 2012 and $4.9 billion in 2022.

Research and development. Advanced biofuels producers will need to invest significantly in research and development in order to pioneer new technology applications over the next 10–15 years. Measured as a percentage of total revenues, U.S. industries' investments in R&D range widely, from 13.6 percent for software to 7 percent for consumer electronics to 1 percent for energy and chemicals.[5] We assume that the advanced biofuels sector will spend 5.5 percent of revenues on R&D in the period prior to 2012, declining to 4.5 percent by 2022 as the industry achieves larger-scale operations. On this basis, total R&D spending is estimated to rise to $0.7 billion in 2016, reaching $1.8 billion by 2022. Employment in advanced biofuels R&D is estimated to reach 4,800 by 2016 rising to 12,100 by 2022.

Technology royalties. U.S. companies at the forefront of developing and commercializing advanced biofuels production technologies will likely have opportunities to leverage their intellectual property assets by licensing technology to partners outside the United States or by building and operating advanced biofuels operations in other countries. We estimate the value of potential technology royalties as summarized in Table 3. The International Energy Agency's World Energy Outlook calls for 52 BGY of advanced biofuels globally by 2030 in its Alternative Policy case. Here, we assume that global advanced biofuels production will rise to 33 BGY by 2022, with 12 BGY of advanced biofuels production outside the United States. We assume royalty payments of $0.06 per gallon are paid for one-third of advanced biofuels produced outside the United States. This results in royalties of $240 million to U.S. companies by 2022.

TABLE 3: Value of Advanced Biofuels Technology Royalties from Production Outside the U.S.

Year	US advanced biofuels production	Non-US advanced biofuels production	Share of non-US production under US license	Royalty ($/gallon)	Royalty value (billion $)
2009	0.6				
2010	1.0				
2011	1.4				
2012	2.0	0.2	0.33	$0.06	$0.0
2013	2.8	1.4	0.33	$0.06	$0.0
2014	3.8	2.6	0.33	$0.06	$0.1
2015	5.5	3.7	0.33	$0.06	$0.1
2016	7.3	4.9	0.33	$0.06	$0.1
2017	9.0	6.1	0.33	$0.06	$0.1
2018	11.0	7.3	0.33	$0.06	$0.1
2019	13.0	8.5	0.33	$0.06	$0.2
2020	15.0	9.6	0.33	$0.06	$0.2
2021	18.0	10.8	0.33	$0.06	$0.2
2022	21.0	12.0	0.33	$0.06	$0.2

Measuring Total Economic Impact

The total economic impact of advanced biofuels production will be the combination of direct, indirect, and induced output effects in the economy (Figure 5).

- **Direct output** is a measure of the value of goods and services that can be directly attributed to the sector.
- **Indirect output** accounts for the changes in activity in other sectors as a result of increased demand from the directly affected sector.
- **Induced output** reflects the impact of increased consumer spending resulting from income changes in the directly and indirectly affected sectors.

We estimate indirect and induced economic output and job creation using multipliers derived from a review of detailed economic input-output models of biofuels plants (see Appendix). Table 4 summarizes the multipliers used in this analysis for U.S. economic impacts from various measures of direct economic activity in advanced biofuels production.

Table 4: U.S. Economic Multipliers for Advanced Biofuels

Output multipliers		Jobs multipliers	
Construction	3.2	Construction	2.3
Operations	3.4	Operations	5.3
Feedstocks	3.4	Feedstocks	5.3
Distribution	3.4	Distribution	5.3

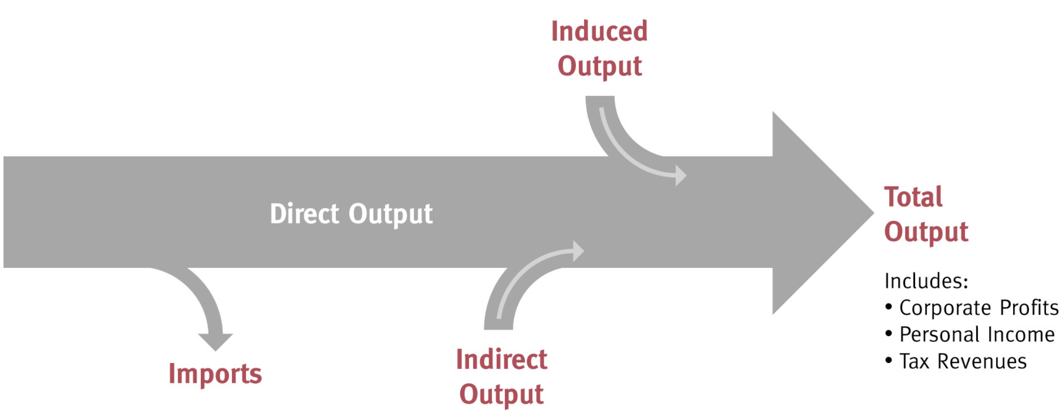


Figure 5: Measuring Economic Output from Advanced Biofuels Production: Direct, Indirect, and Induced Output

Direct Output: Value of goods and services directly attributed to advanced biofuels

Indirect Output: Changes in inter-industry transactions as supplying industries respond to demands from directly affected sectors

Induced Output: increased consumer spending resulting from income changes in directly and indirectly affected sectors

Economic Output from Advanced Biofuels Production

Total direct economic impacts for the RFS scenario are summarized in Figure 6. We estimate a total direct economic impact that rises to $9.3 billion by 2012 and $49.6 billion by 2022. Applying the appropriate economic multipliers to each category of direct output yields a total economic output impact that rises to $20.2 billion in 2012 and approximately $150 billion in 2022 (Figure 7).

Figure 6: Direct Economic Output from U.S. Advanced Biofuels Production

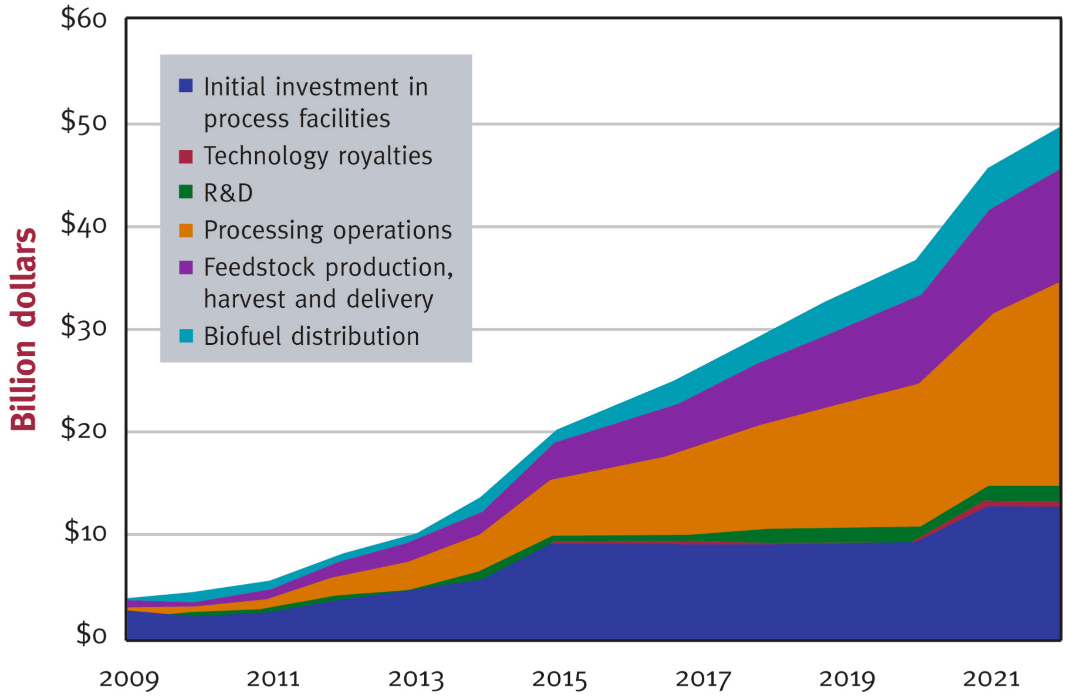
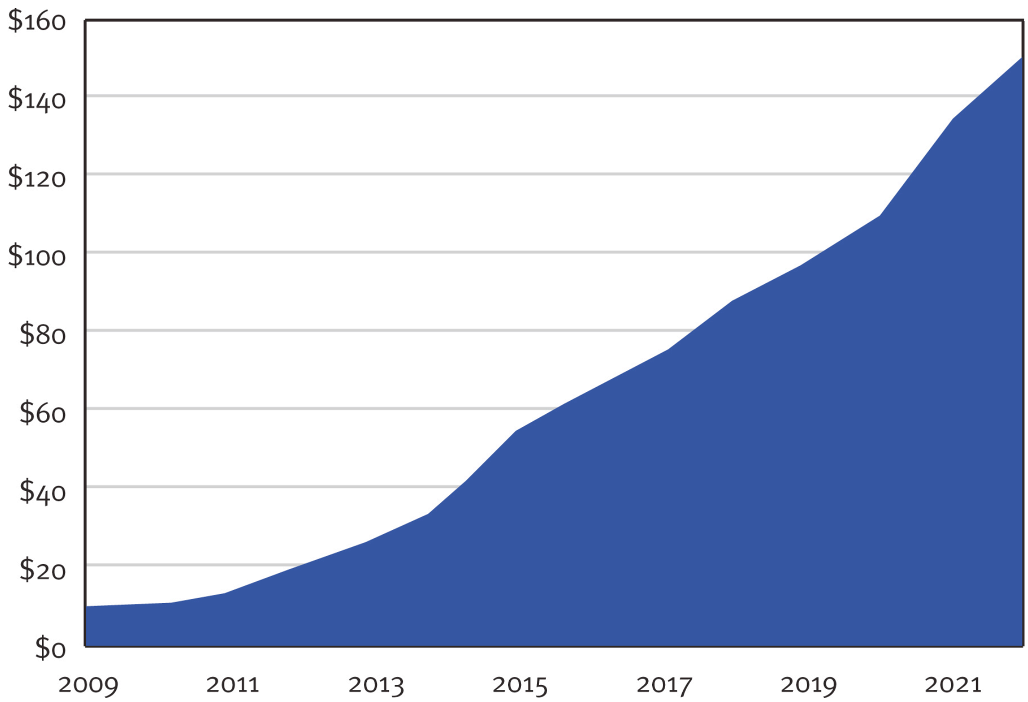


Figure 7: Total Economic Output from U.S. Advanced Biofuels Production



Job Creation

Figure 8 summarizes estimated job creation under the RFS scenario. The total number of jobs directly created reaches 29,000 by 2012 and 190,000 by 2022. Taking into consideration indirect job creation as a result of the economic stimulus created by biofuels development brings total job creation to 123,000 by 2012 and 807,000 by 2022 (Figure 9). These estimates assume that only half of new jobs created in biofuels transportation and distribution represent net job creation in the U.S. economy, since some offsetting jobs losses in the petroleum industry will occur as a result of biofuels' displacement of petroleum product volumes.

Construction jobs will be temporary and are not accumulated as permanent job creation is this analysis. Construction jobs are estimated based on annual construction requirements for each year in the study period. Moreover, the jobs multiplier for construction jobs is less than half that for other permanent jobs created in advanced biofuels operations.

Of the total number of direct jobs created, 46 percent are in the feedstock production (primarily agriculture) and 35 percent are in construction, engineering and procurement, including both on-site and off-site activities.

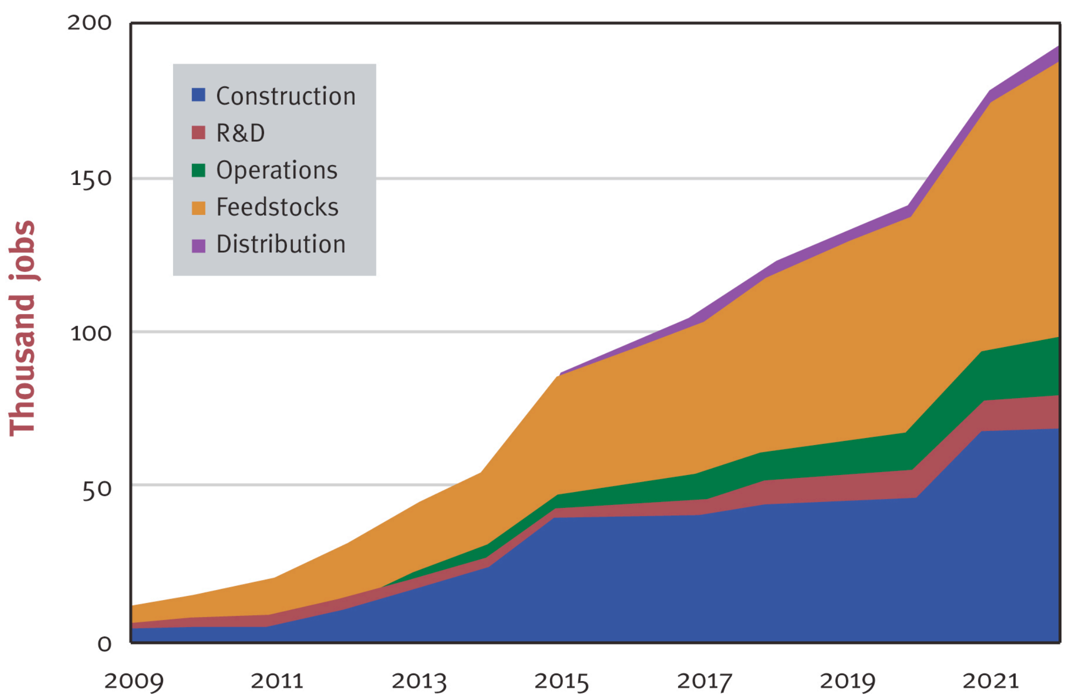
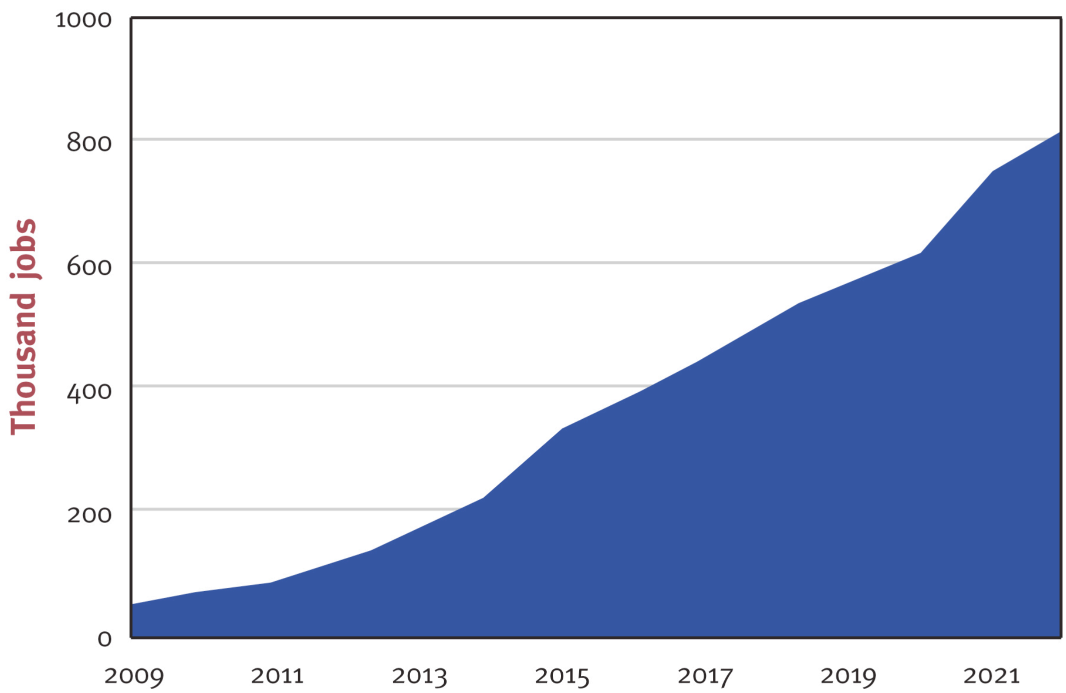


Figure 8: Jobs Directly Created from U.S. Advanced Biofuels Production

Figure 9: Total Jobs Created from U.S. Advanced Biofuels Production: Direct, Indirect, and Induced



The types of jobs likely to be created in advanced biofuels processing facilities are described in Figure 10. These represent middle-skill occupations in the basic chemical manufacturing industry, which includes today's corn-based ethanol and biodiesel production operations. Median annual wages for these jobs range from $27,000 to $71,000, depending on skill levels. As the advanced biofuels industry matures, specialized training and skill certification paths are likely to develop for jobs in biofuels processing operations.

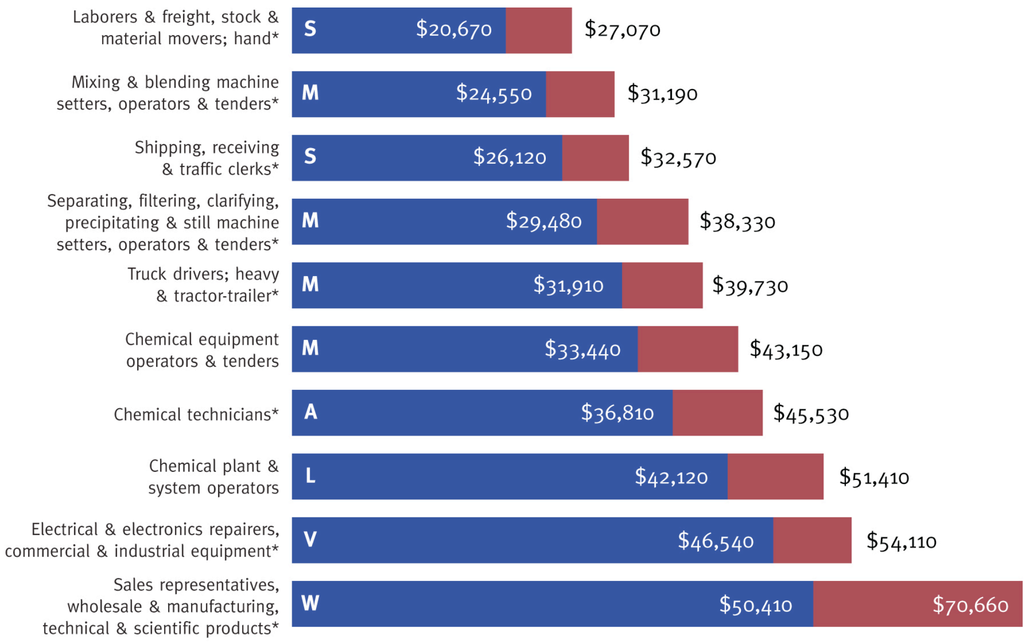


Figure 10: Biofuels Jobs: Wages and Skills

Notes

This chart depicts national wage data for selected middle-skill occupations in the basic chemical manufacturing industry, which includes ethanol and biodiesel production

- The 25th percentile describes wages at the lower end of the labor market.
- Median wage marks the center of the wage distribution in a given occupation.

* In-Demand occupation per DOL, regardless of overall occupational growth levels, because the work is central to a high-growth industry, like energy or construction.

Regional wage ranges and more precise occupational projections by industry can be run on a state-by-state basis.

Typical education and training path:

S Short-term on-the-job training: Requires no more than a month of workplace-based training.

M Moderate-term on-the-job training: Requires from one to twelve months of training, which typically occurs at the workplace.

L Long-term on-the-job training: Requires more than one year of on-the-job training, or combined work experience and classroom instruction, and may include apprenticeships of up to five years.

V Postsecondary vocational award: Requires credentials earned in training programs lasting from a few weeks to more than a year, typically offered at vocational or technical schools.

A Associate degree: Requires two years of full-time academic work beyond high school.

W Work experience in related occupation.

These are general indicators; there may be other pathways into the occupation, as well as additional educational, training, or licensing requirements.

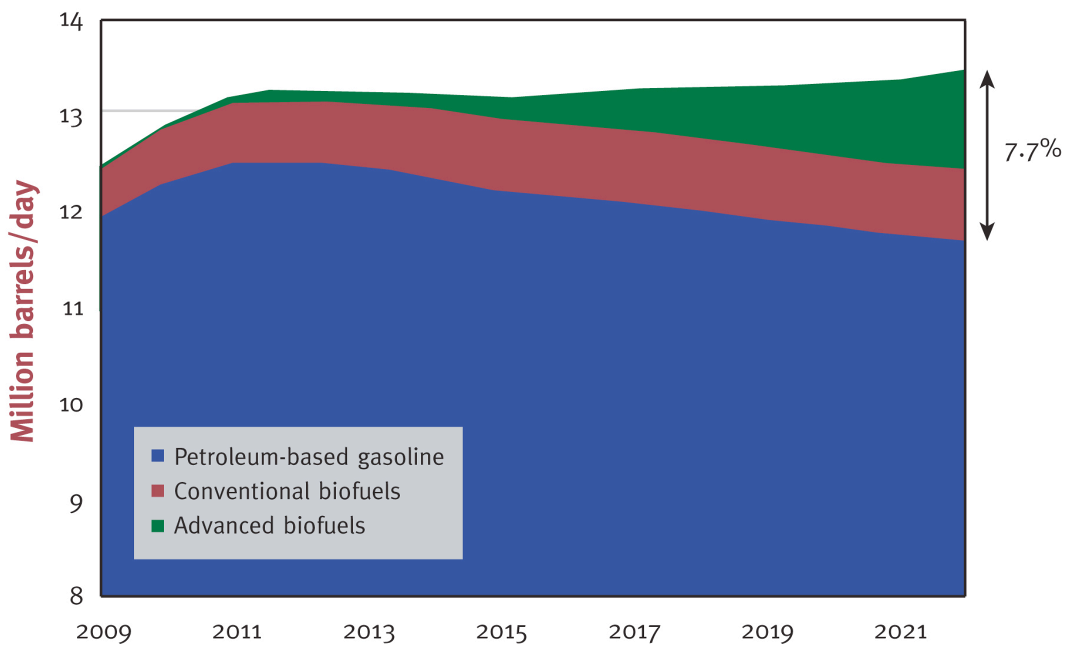
Source: U.S. Bureau of Labor Statistics; Greener Pathways: Jobs and Workforce Development in the Clean Energy Economy (2008)

Balance of Trade and Oil Import Dependence

How will meeting the RFS levels for advanced biofuels production affect the U.S. balance of trade and oil import dependence? Producing 21 billion gallons of advanced biofuels by 2022 would displace at least 15 billion gallons of gasoline and diesel fuel.* This represents 7.7 percent of projected U.S. gasoline and diesel consumption in 2022.

U.S. advanced biofuels production under the RFS scenario will reduce the need for petroleum imports by approximately $5.5 billion in 2012, $23 billion in 2016, and nearly $70 billion by 2022.** The cumulative total of avoided petroleum imports over the period from 2010 to 2022 exceeds $350 billion. These estimates represent a conservative minimum impact, since they do not take into consideration the impact of reduced U.S. oil imports on world oil prices. The increase in production of advanced biofuels under the RFS would actually result in an absolute reduction in U.S. gasoline and diesel consumption between 2011 and 2022.

Figure 11: Biofuels Contribute a Growing Share of U.S. Transportation Fuel Supplies



** The exact amount will depend on the average energy content of the portfolio of biofuels produced. Advances in automotive technology are likely to yield improvements in the performance of ethanol-fueled vehicles. In Sweden, GM/Saab produces a car with a high-compression engine that gets 95% as much mileage from a gallon of ethanol as it does from a gallon of gasoline. We assume that the gasoline displacement ratio for biofuels will rise from 70% in 2009 to 75% by 2022 as a result of a combination of changes in biofuel products and improving engine technologies.*

*** Based on projected petroleum product values in the U.S. Energy Information Administration's Annual Energy Outlook 2009.*

45 BGY of Advanced Biofuels by 2030: Economic and Job Implications

Under the RFS, the U.S. will add 3 BGY of advanced biofuels production each year from 2020 to 2022. If capacity additions were to continue at this same rate through 2030, advanced biofuels production capacity would reach 45 BGY, bringing total U.S. biofuels production to 60 BGY, assuming conventional biofuels production capacity remains flat at 15 BGY. Altogether, this would displace about 22 percent of projected U.S. gasoline consumption in 2030.

Bio-era analyzed the implications of a 45 BGY scenario for advanced biofuels production in terms of economic output and job creation, using the same economic model developed to assess advanced biofuels production under the RFS. Key assumptions through 2030 are as follows:

- Biomass feedstocks come from a portfolio of sources, including energy crops and agricultural and forest residues (see Figure 12). Total biomass utilization reaches 470 million tons in 2030.
- Due to learning curve effects, capital costs for advanced biofuels processing plants fall 5 percent between 2022 and 2030 to an average $3.44 per gallon annual production capacity.
- Biofuels transportation and distribution costs continue to fall as volumes increase, declining to an average of $0.20 per gallon by 2030.
- Streamlining of operations at biofuels processing plants reduces the number of jobs to 85 employees at a typical 100 million gallon advanced biofuels processing plant, including inbound and outbound materials handling, plant operations, and management.
- Operating costs fall to $1.45 per gallon by 2030, bringing total biofuel production costs to approximately $1.88 per gallon.

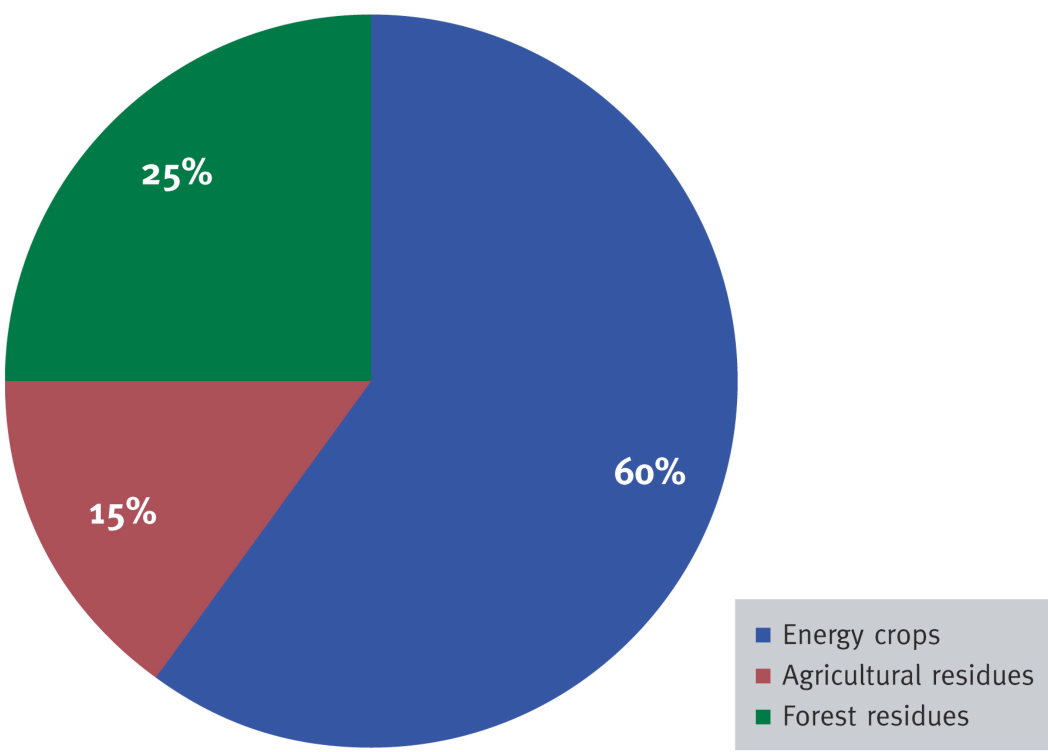


Figure 12: Biomass Feedstocks for 45 BGY Advanced Biofuels Production

Based on these assumptions, producing 45 billion gallons of advanced biofuels in 2030 would result in direct economic output of $113 billion. Taking into consideration multiplier effects in the economy, the total U.S. economic output effect, including indirect and induced economic output, is $300 billion (see Figure 13 and Table 5).

Figure 13: Direct Economic Output from 45 BGY Advanced Biofuels Production (billion dollars)

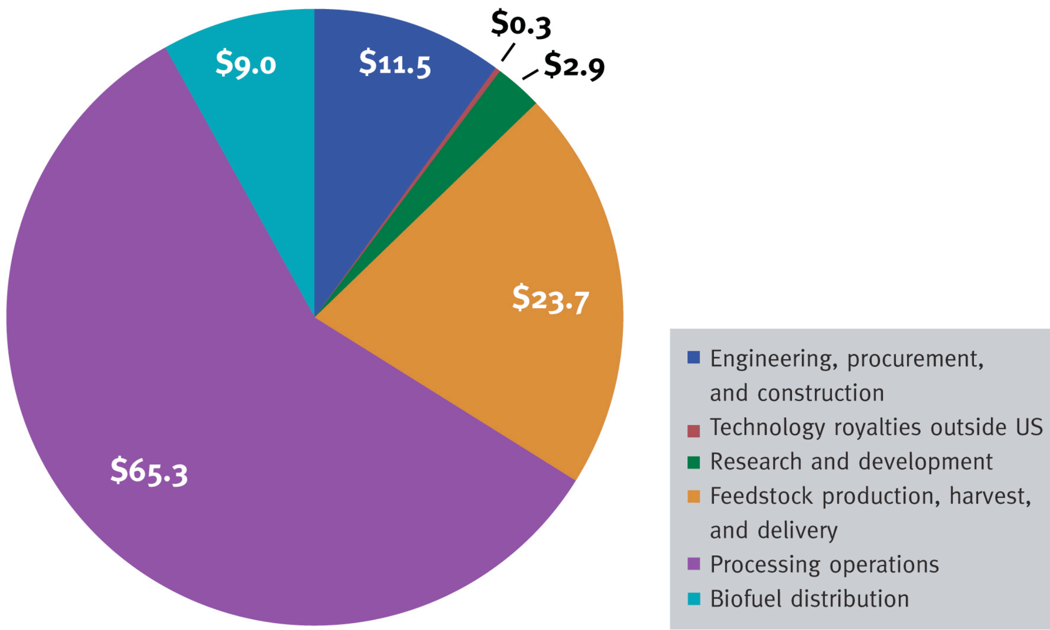


Table 5: Economic Output Effect of 45 BGY Advanced Biofuels Production

Engineering, procurement, and construction	$11.5	10.2%
Technology royalties outside US	$0.3	0.3%
R&D	$2.9	2.6%
Feedstock production, harvest and delivery	$23.7	21.0%
Processing operations	$65.3	57.9%
Biofuel distribution	$9.0	8.0%
Total direct output	**$112.6**	
Total output with multiplier effects	**$299.6**	

Direct job creation is 393,000 jobs, with a total employment impact of 1.9 million jobs created directly or indirectly in the U.S. economy (see Figure 14 and Table 6). Nearly 70 percent of these jobs are in areas related to feedstock production, harvesting, and transport, providing valued jobs and income creation in rural areas. Other high-value jobs are created in areas of research and development, engineering, procurement and construction, and processing operations.

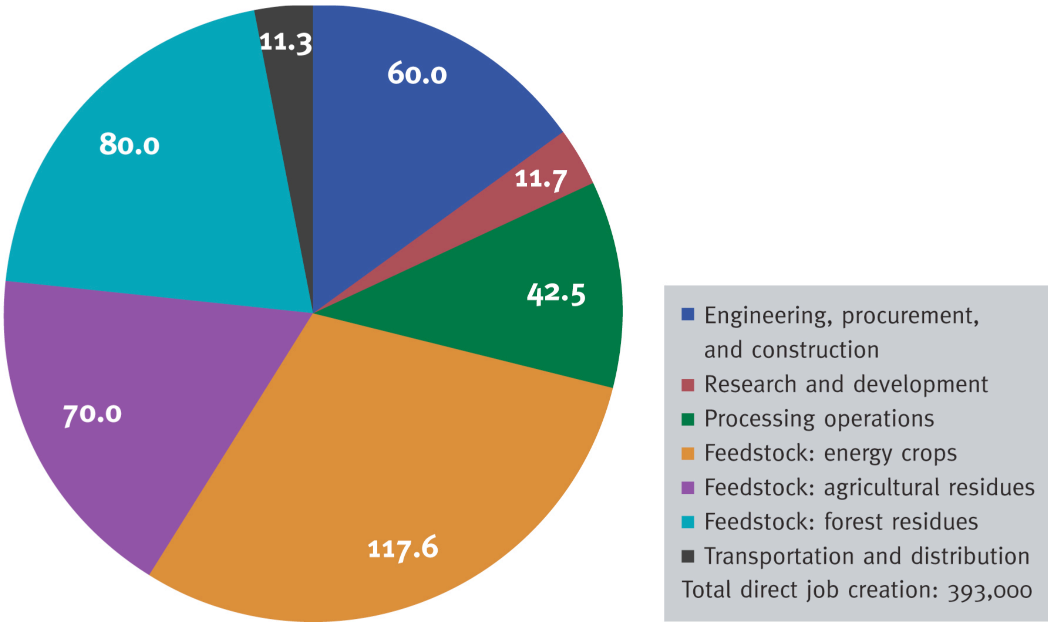


Figure 14: Direct Job Creation from 45 BGY Advanced Biofuels Production

Table 6: Direct Job Creation from 45 BGY Advanced Biofuels Production (new jobs created)

Engineering, procurement, and construction	60.0	15.3%
R&D	11.7	3.0%
Direct processing	42.5	10.8%
Feedstock supply:	267.6	68.0%
Energy crops	117.6	29.9%
Agricultural residues	70.0	17.8%
Forest residues	80.0	20.3%
Transportation and distribution	11.3	2.9%
Direct new jobs created	**393.1**	**100.0%**
Total new jobs (direct, indirect, and induced)	**1,903,400**	

Conclusion

The build-out of a new advanced biofuels industry to meet the requirements of the Renewable Fuel Standard through 2022 will entail the development and commercialization of new technology, the investment of nearly $95 billion in new processing plants, and the direct creation of nearly 200,000 new jobs. In addition, the growth of this new industry will reduce the nation's dependence on imported oil, potentially reducing oil imports by as much as $70 billion per year by 2022. Finally, the growth of the advanced biofuels industry will provide stimulus to the ongoing development of advanced biotechnology tools and platforms for production of energy, chemicals, and materials.

Achieving advanced biofuels production of 45 billion gallons by 2030 would bring even greater economic and employment benefits. Together with the anticipated 15 billion gallons of conventional biofuels production capacity, this would bring total U.S. biofuels production to 60 billion gallons, enough to supply 22 percent of projected U.S. gasoline consumption. Total job creation in this scenario, including indirect and induced jobs, reaches nearly 1.4 million jobs by 2030.

Sources

Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallance, L. Montague, A. Slayton, and J. Lukas. "Lignocellulosic Biomass to Ethanol Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover." National Renewable Energy Laboratory & Harris Group, 2002, (NREL/TP-510-32438).

Biomass Research and Development Initiative, *Increasing Feedstock Production for Biofuels, Economic Drivers, Environmental Implications, and the Role of Research,* 2008, HD9502.5.B543.

BBI International, "State of Maine Ethanol Pre-Feasibility Study," prepared for Finance Authority of Maine, 2002.

Dale, B., "Impacts of Cellulosic Ethanol on the Farm Economy," *A High Growth Strategy for Ethanol,* Aspen Institute, 2006.

DeVos, D., Director of Finance, POET, statement before Energy and Commerce Committee, Subcommittee on Energy and Air Quality, U.S. House of Representatives, April 24, 2007.

Flanders, A. and J. McKissick, "Economic Impact of Cellulosic Ethanol Production in Treutlen County," University of Georgia Center for Agribusiness and Economic Development, April 2007, CR-07-07.

Leistritz, F., N. Hodur, D.M. Senechal, et al., "Biorefineries Using Agricultural Residue Feedstock in the Great Plains," Western Regional Science Association, Jan. 2007, AAE 07001.

Leistritz, F., and N.M. Hodur, "Biofuels: a major rural economic development opportunity," *Biofuels, Bioproducts, and Biorefining,* Sept. 30, 2008, 2:501-504.

Leistritz, F., D. Senechal, et al., "Preliminary Feasibility Analysis for an Integrated Biomaterials and Ethanol Biorefinery Using Wheat Straw Feedstock," 2006 AAE 590, North Dakota State University, Department of Agricultural and Applied Economics.

Massachusetts Advanced Biofuels Task Force (MA ABTF) Final Report, prepared for Massachusetts Executive Office of Energy and Environmental Affairs, Office of Policy, 2008.

Pollin, R., et al., Green Recovery: A Program to Create Good Jobs and Start Building a Low Carbon Economy, Center for American Progress, Sept. 2008.

Perez-Verdin, G., D. Grebner, I. Munn, C. Sun, and S. Grado, "Economic impacts of woody biomass utilization for bioenergy in Mississippi," *Forest Products Journal,* Nov. 2008.

Pierce, V., J. Horner, R. Milhollin, "Employment and Economic Benefits of Ethanol Production in Missouri," Missouri Corn Growers Association, University of Missouri Extension, Feb. 2007.

Schlosser, J.A., J.C. Leatherman and J.M. Peterson, "Are Biofuels Revitalizing Rural Economies: Projected Versus Actual Labor Market Impacts in the Great Plains," presentation to American Agricultural Economics Association, May 2008.

Solomon, B.D., Michigan Tech University, presentation to the Michigan Economic Development Corp., March 16, 2007.

Swenson, D., "Estimating the Future Economic Impact of Corn Ethanol Production in the U.S.," Iowa State University, Dec. 2007.

Ugarte, D. de la Torre, et al., "Economic and Agricultural Impacts of Ethanol and Biodiesel Expansion," University of Tennessee, Dec. 2006.

Urbanchuk, J.M., "Impact of Ethanol on World Oil Demand and Prices," May 27, 2008.

Urbanchuk, J.M., "Contribution of the Ethanol Industry to the Economy of the United States," prepared for the Renewable Fuels Association, Feb. 19, 2007.

U.S. Department of Agriculture, "U.S. Biobased Products: Market Projections and Potential through 2025," Feb. 2008, OCE-2008-1.

U.S. Energy Information Administration, "Annual Energy Outlook 2009," Dec. 2008, DOE/EIA-0383(2009) .

Wright, M.M., and R.C. Brown, "Comparative economics of biorefineries based on the biochemical and thermochemical platforms," *Biofuels, Bioproducts and Biorefining,* 2007, 1:49–56.

Notes

[1] For further information on these studies, see list of Sources provided in this report.

[2] See, for example, Biomass Research and Development Initiative, Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research, 2008.

[3] This figure includes not only farm workers, but labor required for all other feedstock production-related activities. Hence, it is slightly higher than conventional estimates of farm-level employment.

[4] Eidman, Vernon R., "Economic Parameters for Corn Ethanol and Biodiesel Production," Journal of Agricultural and Applied Economics, August 2007,

[5] Jusko, Jill, "R&D Spending: By the Numbers," Industry Week, January 1, 2009.

Appendix: Methodology for Economic Impact Analysis

Base Assumptions

This analysis compares the economic and job impacts of producing advanced biofuels at levels required in the Renewable Fuels Standard (RFS) with an alternative case in which there is no advanced biofuels production.

- **Advanced Biofuels RFS.** In this case, advanced biofuels are produced in the United States in accord with levels specified in the Energy Independence and Security Act (EISA) of 2007 (Table A1). For these purposes, "advanced biofuels" includes cellulosic ethanol, biomass-based biodiesel, and other unspecified types of biofuels other than conventional corn-based ethanol and vegetable oil-based biodiesel. In this scenario, advanced biofuels production reaches 21 billion gallons per year in 2022.

- **No Advanced Biofuels.** In this case, there is no commercial production of advanced biofuels in the U.S.

The EISA offers the following definitions for the biofuels categories described in the Act:

- **Conventional biofuel** means ethanol derived from corn starch. Those facilities that commence construction after the date of enactment must achieve at least a 20 percent reduction in lifecycle greenhouse gas emissions compared to baseline lifecycle greenhouse gas emissions.

- **Advanced biofuel** means renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions that achieve at least a 50 percent reduction over baseline lifecycle greenhouse gas emissions. The types of fuels eligible for consideration as "advanced biofuel" may include: ethanol derived from cellulose or lignin, sugar or starch (other than corn starch), or waste material, including crop residue, other vegetative waste material, animal waste, and food waste and yard waste; biomass-based diesel; biogas produced through the conversion of organic matter from renewable biomass; butanol or other alcohols produced through the conversion of organic matter from renewable biomass; and other fuel derived from cellulosic biomass.

- **Cellulosic biofuel** means renewable fuel derived from any cellulose or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions that achieve at least a 60 percent reduction over baseline lifecycle greenhouse gas emissions.

- **Biomass-based diesel** means renewable fuel that is biodiesel as defined in section 312(f) of the Energy Policy Act of 1992 and that has lifecycle greenhouse gas emissions that achieve at least a 50 percent reduction over baseline lifecycle greenhouse gas emissions. Biomass-based diesel is included as a component of Advanced Biofuels.

Table A1: Renewable Fuel Standard: Energy Independence and Security Act of 2007

Year	Conventional Biofuel	Total Advanced Biofuel	Cellulosic Biofuel	Biomass-based Diesel	Unspecified Advanced Biofuel	Total Renewable Fuel Standard
2008	9.0					9.0
2009	10.5	0.6		0.5	0.1	11.1
2010	12.0	1.0	0.1	0.7	0.2	13.0
2011	12.6	1.4	0.3	0.8	0.3	14.0
2012	13.2	2.0	0.5	1.0*	0.5	15.2
2013	13.8	2.8	1.0	1.0*	0.8	16.6
2014	14.4	3.8	1.8	1.0*	1.0	18.2
2015	15.0	5.5	3.0	1.0*	1.5	20.5
2016	15.0	7.3	4.3	1.0*	2.0	22.3
2017	15.0	9.0	5.5	1.0*	2.5	24.0
2018	15.0	11.0	7.0	1.0*	3.0	26.0
2019	15.0	13.0	8.5	1.0*	3.5	28.0
2020	15.0	15.0	10.5	1.0*	3.5	30.0
2021	15.0	18.0	13.5	1.0*	3.5	33.0
2022	15.0	21.0	16.0	1.0*	4.0	36.0

**Minimum 1 BGY. Specific amount to be determined by the EPA Administrator.*

Economic Impact Analysis

To assess the probable direct economic implications of biofuels production, we reviewed published literature and industry estimates describing the likely size, cost, and labor requirements for advanced biofuels production facilities. These estimates are necessarily speculative, given that the industry is still in a period of rapid technology development. Actual operating experience is confined to pilot or pre-commercial facilities.

Nevertheless, numerous publicly available studies provide detailed estimates of key parameters for advanced biofuels plants based on engineering analyses and assumptions about possible configurations of conversion technologies. Here, we summarize the basis for our assumptions about various parameters for advanced biofuels production facilities.

Processing plant construction costs. Table A2 summarizes published capital cost estimates for cellulosic ethanol plants. Most of these estimates are based on engineering analyses using conventional conversion technologies. Several emerging companies claim to be developing technologies with lower capital costs than those reflected in the academic studies summarized in Table A2. We assume capital costs for advanced biofuels plants will fall in the range of $5.00–5.50 per gallon of annual production capacity in 2009, falling to $3.50–4.00 per gallon in 2022 (Table A3).

Table A2: Capital Cost Estimates for Cellulosic Ethanol Processing Facilities

	Construction cost estimates	Comments
Perez-Verdin (2008)	$4.31	52 MGY cellulosic ethanol plant using woody biomass
DeVos (2007)	$4.00	50 MGY cellulosic ethanol plant
Liestritz (2007)	$3.53	50 MGY cellulosic ethanol plant using wheat straw
Flanders (2007)	$4.59	49 MGY cellulosic ethanol plant (Range Fuels)
Aden (2002)	$2.11	NREL study; cellulosic ethanol plant crop waste or switchgrass
BBI (2002)	$2.11	32.4 MGY cellulosic ethanol plant using wood residues
Wright (2007)	$5.05	50 MGY cellulosic ethanol plant

Table A3: Assumed Capital Cost for New Advanced Biofuels Production Plants (dollars per gallon annual production capacity)

Year	Plant capacity (MGY)			
	20	50	100	200
2009	$5.50	$5.25	$5.00	
2010	$5.38	$5.13	$4.88	
2011	$5.27	$5.02	$4.77	
2012	$5.15	$4.90	$4.65	
2013	$5.04	$4.79	$4.54	$4.50
2014	$4.92	$4.67	$4.42	$4.39
2015	$4.81	$4.56	$4.31	$4.28
2016	$4.69	$4.44	$4.19	$4.17
2017	$4.58	$4.33	$4.08	$4.06
2018	$4.46	$4.21	$3.96	$3.94
2019	$4.35	$4.10	$3.85	$3.83
2020	$4.23	$3.98	$3.73	$3.72
2021	$4.12	$3.87	$3.62	$3.61
2022	$4.00	$3.75	$3.50	$3.50

Biomass-based biodiesel production. Table A4 summarizes key assumptions regarding costs of biomass-based biodiesel production.

TABLE A4: Biomass-based Biodiesel Plants

Year	Initial investment per gallon	Processing costs per gallon
2009	$4.00	$1.60
2010	$3.96	$1.59
2011	$3.92	$1.58
2012	$3.88	$1.58
2013	$3.85	$1.57
2014	$3.81	$1.56
2015	$3.77	$1.55
2016	$3.73	$1.55
2017	$3.69	$1.54
2018	$3.65	$1.53
2019	$3.62	$1.52
2020	$3.58	$1.52
2021	$3.54	$1.51
2022	$3.50	$1.50

Construction jobs. Table A5 summarizes estimates of the number of jobs created to construct advanced biofuels facilities. Because these jobs are temporary, estimates are provided as full-time equivalents (FTE). We assume an industry average of 20 FTE per gallon of annual production capacity. These jobs include not just on-site construction, but all engineering, procurement, permitting, legal, management, and other construction-related employment as well as off-site employment in construction of equipment deployed in the facility.

TABLE A5: Direct Construction Jobs Created in Advanced Biofuels Plant Construction (FTE per million gallons annual production capacity)

Solomon (2007) Scenario B	40.5
Solomon (2007) Scenario C	32.9
MA ABTF (2008)	22.5
Leistritz (2007)	15.9
Flanders (2007)	6.4

Operations costs. Estimates of operating costs for advanced biofuels plants, including feedstock costs are summarized in Table A6. In addition to feedstock supply, operating costs include energy and utilities, maintenance, and operating staff. We assume average operating costs of $1.65 per gallon in 2009, falling to $1.47 in 2022 as industry learning curve effects lead to cost reductions.

Table A6: Estimated Operating Costs for Advanced Biomass Production

Liestritz (2007)	$1.49	Includes feedstock costs of $1.06 for $40/t wheatstraw
MA ABTF (2008)	$2.36	Includes $1.88 in feedstock costs
Wright (2007)	$1.76	Includes $1.03 in feedstock costs

Operations Jobs. The number of full-time jobs required to support operation of advanced biofuels plants is expected to be higher than that required for existing corn ethanol plants. Table A7 summarizes the estimated full-time job requirements of various types of biofuels plants, including corn ethanol plants, according to recent studies. We assume an average of 0.9 jobs per million gallons of annual production capacity or, for example, 90 jobs for a 100 million gallon per year plant. While the number of jobs per gallon of capacity is likely to decline with the size of the plant, we assume 0.9 jobs as an average across all plant sizes.

Table A7: Jobs in Advanced Biofuels Processing Plants (FTE per million gallons annual capacity)

Solomon (2007) Scenario B	17.1	Cellulosic ethanol plant processing wood waste and switchgrass, jobs estimate includes feedstock supply
Solomon (2007) Scenario C	10.5	
Perez-Verdin (2008)	17.5	52 MGY cellulosic ethanol plant using woody biomass; includes feedstock production and delivery jobs
Liestritz (2007)	1.5	50 MGY cellulosic ethanol plant using wheat straw
MA ABTF	1.8	Average for advanced biodiesel plants
Hodur (2006)	0.8	Corn ethanol
Urbanchuk (2007)	4.0	Biodiesel
Petersan (2002)	0.6	Corn ethanol
Schlosser (2008)	1.1	80 MGY corn ethanol plant
Aden (2002)	1.1	NREL study; cellulosic ethanol using plant crop waste or switchgrass
Swenson (2007)	0.46	Corn ethanol

Indirect and Induced Output Effects

The total economic impact of advanced biofuels production will be the combination of direct, indirect, and induced output effects on the economy (see Figure A1).

- **Direct output** is a measure of the value of goods and services that can be directly attributed to the sector
- **Indirect output** accounts for the changes in activity in other sectors as a result of increased demand from the directly affected sector
- **Induced output** reflects the impact of increased consumer spending resulting from income changes in the directly and indirectly affected sectors.

For this study, estimates of the direct effects of advanced biofuels production for the U.S. economy are built up from plant-by-plant figures for expenditures, including construction, operations, and feedstock supply. In addition, revenues earned from licensing advanced biofuels production technologies developed in the United States are estimated. Finally, costs of biofuels transportation and distribution are derived based on overall production volumes.

Indirect and induced effects are estimated based on multiplier effects for the U.S. economy. The multiplier represents the total economic effect, including indirect and induced effects, divided by the direct effect. The multipliers for economic output and jobs used in this study were developed based on a meta-analysis of detailed input-output studies that analyze the impacts of biofuels projects summarized in Table A8. The main economic models used to trace inter-industry transactions and thereby assess indirect and induced economic effects include RIMS II, IMPLAN, and REMI's Policy Insight.

To apply these models, users must categorize various commodity and services input requirements for the construction and operation of a facility. The multiplier values for each category, derived from the input-output (I-O) model, are then applied to yield an overall multiplier value.

Numerous studies have been undertaken using the IMPLAN, RIMS II, and Policy Insight models to assess the total economic impact of biofuels plants, including both conventional and advanced biofuels technologies. For example, Schlosser (2008), Pierce (2007), and Swenson (2007) used I-O models to assess the economic impacts, measured in terms of economic impacts and job creation, of corn-based ethanol production facilities.

Perez-Verdin (2008), Leistritz (2008), and Solomon (2008) used these methods to evaluate the economic impact of lignocellulosic ethanol production facilities and energy crop production at local, state, or regional levels. Similarly, the Massachusetts Advanced Biotechnology Task Force (2008) used multipliers derived from IMPLAN to estimate the economic and employment impacts of a scenario for advanced biofuels production in the state of Massachusetts. In general, the more narrowly limited the scope of impact analysis—for example, county or state impacts versus regional or national—the smaller multipliers will be. This is because part of the economic impact is felt outside the region of study. Input-Output models can be used to estimate the amount of "leakage" from the economic region being studied.

For the purposes of this study, national economic impacts are the point of focus. Nonetheless, the many studies of local and regional economic impacts of biofuels plants provide useful context for estimating the likely multiplier effects of advanced biofuels plants at the national level. For example, the breakdown of expenditures by category for lignocellulosic biofuels facilities is substantially similar to that for other types of biofuels plants. Moreover, the recent studies that have focused specifically on lignocellulosic ethanol production provide a foundation for estimating the probable range of multipliers for advanced biofuels development. Higher-level analyses, for example Dale (2006), have used estimated multiplier effects for the U.S. economy in estimating the aggregate economic impact of various scenarios for biofuels development.

Economic output. Table A8 summarizes the multipliers derived from the application of IMPLAN and other I-O models in evaluating specific biofuels projects. While the majority of these analyses measure state-level impacts, Ugarte (2006) used POLYSIS and IMPLAN models to measure the impacts on the national economy of advanced biofuels production. Ugarte analyzed impacts of cellulosic ethanol production from corn stover, rice straw, wheat straw, and/or switchgrass drawing on technical and economic analysis of emerging biorefinery technologies performed by the National Renewable Energy Laboratories (NREL). Ugarte's research yielded a multiplier of 3.4 for annual output from biofuels production operations. We assume a U.S. economic output multiplier of 3.4, consistent with Ugarte's results.

Table A8: Input-Output Model Results for Economic Output Multipliers based on Annual Output from Biofuels Production Operations

MA ABTF (2008)	1.9	State-level analysis applying IMPLAN multipliers to advanced biofuels production scenarios for Massachusetts
Swenson (2007)	1.7	Adjusted IMPLAN analysis of U.S. impact with downward adjustments to multipliers particular to corn ethanol
Leistritz (2007)	3.5	North Dakota I-O Model cellulosic ethanol production; in-state share of initial plant construction assumed to be 15 percent
Perez-Verdin (2008)	1.6	IMPLAN analysis of woody biomass-based biofuels production for Mississippi
Flanders (2007)	1.6	IMPLAN analysis of cellulosic ethanol production in Georgia
Ugarte (2006)	3.4	POLYSYS/IMPLAN analysis of impacts on national economy of advanced biofuels production
Pierce (2007)	1.9	IMPLAN analysis of corn ethanol production in Missouri

Construction output. The dollars spent on construction of biofuels plants have significantly different sectoral allocations than those flowing from ongoing biofuels production. Moreover, the transitory nature of construction activity yields different economic consequences. Table A9 summarizes multipliers estimated in studies that assessed multipliers for construction expenditures. We assume a U.S. multiplier of 2.4 for construction expenditures.

Table A9: Construction Output Multipliers for Biofuels Plant Construction

MA ABTF (2008)	2.4	Construction multiplier for Massachusetts economy, advanced biofuels construction
Dale (2006)	2.4	Estimate of U.S. multiplier for construction of cellulosic ethanol plants derived from multipliers for construction of corn ethanol plants
Flanders (2007)	1.7	IMPLAN analysis of multiplier for Georgia for cellulosic ethanol plant construction

Permanent jobs. Previous studies have yielded permanent jobs multipliers ranging from 2.3 to 6.4 for biofuels production operations (Table A10). Even higher multipliers (Leistritz, Pierce) result from calculating the total number of direct, indirect, and induced jobs created, including agricultural jobs in feedstock production, divided by the number of direct jobs in biofuels manufacturing. For our analysis, we estimate direct jobs created in biofuels production, agricultural production, and biofuels distribution and apply multipliers to each of these in order to estimate total U.S. job creation impacts.

Table A10: Permanent Jobs Multipliers from Biofuels Production

MA ABTF (2008)	2.3	Massachusetts multiplier based on "high level" analysis of multipliers from IMPLAN models
Swenson (2007)	5.3	U.S. permanent jobs multiplier based on adapted IMPLAN model of organic chemicals sector
Leistritz (2007)	28.8	Total jobs multiplier (including agricultural jobs created) from biofuels production derived from North Dakota Input Output Model
Flanders (2007)	2.8	
Flanders (2007)	6.4	
Schlosser (2008)	3.8	Permanent jobs multiplier for 80 MGY corn ethanol plant
USDA (2008)	6.3	
Ugarte (2006)	3.4	U.S. jobs multiplier for cellulosic ethanol production
Pollin (2008)	2.1	Estimated average multiplier for several categories of "green jobs" including biofuels production
Swenson (2008)	3.7	Permanent jobs multiplier for Iowa based on corn ethanol production
Pierce (2007)	21.6	Jobs multiplier for corm ethanol in Missouri

Construction jobs. Results of previous studies of multipliers from construction jobs related to biofuels plants are summarized in Table A11. Jobs multipliers for construction are typically lower than those for permanent jobs. While neither of the studies cited estimates national jobs multipliers, we conservatively assume a U.S. jobs multiplier for biofuels plant construction of 2.3.

Table A11: Multipliers for Construction Jobs in Biofuels Plant Construction

MA ABTF (2008)	2.3	Massachusetts multiplier based on "high level" analysis of multipliers from IMPLAN models
Flanders (2007)	1.6	Jobs multiplier for Georgia based on IMPLAN model results