United States Government Accountability Office

Report to the Chairman, Subcommittee on Regulatory Affairs and Federal Management, Committee on Homeland Security and Governmental Affairs, U.S. Senate

November 2016

RENEWABLE FUEL STANDARD

Low Expected Production Volumes Make It Unlikely That Advanced Biofuels Can Meet Increasing Targets

GAO-17-108

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GAO Highlights

Highlights of GAO-17-108, a report to the Chairman, Subcommittee on Regulatory Affairs and Federal Management, Committee on Homeland Security and Governmental Affairs, U.S. Senate.

Why GAO Did This Study

The RFS generally mandates that domestic transportation fuels be blended with increasing volumes of biofuels through 2022, with the goals of reducing greenhouse gas emissions and expanding the nation's renewable fuels sector while reducing reliance on imported oil. Blending of conventional renewable fuels, primarily ethanol derived from corn starch which is required to reduce greenhouse gas emissions by 20 percent compared with petroleum-based fuels, has nearly reached the maximum called for under the RFS. Further growth in renewable fuels is to come from advanced biofuels, which must reduce life-cycle greenhouse gas emissions by at least 50 percent compared with petroleum-based fuels to qualify under the RFS. However, production of advanced biofuels has not kept pace with statutory targets. To promote the development and commercialization of advanced biofuels, the federal government has supported R&D efforts for biofuels since the 1970s.

GAO was asked to review issues related to advanced biofuels R&D. This report describes (1) how the federal government has supported advanced biofuels R&D in recent years and where its efforts have been targeted and (2) expert views on the extent to which advanced biofuels are technologically understood and the factors that will affect the speed and volume of production. GAO interviewed DOD, DOE, EPA, NSF, and USDA officials and worked with the National Academy of Sciences to convene a meeting of experts from industry, academia, and research organizations.

EPA generally agreed with the report.

View GAO-17-108. For more information, contact Frank Rusco at (202) 512-3841 or ruscof@gao.gov.

What GAO Found

The federal government has supported research and development (R&D) related to advanced biofuels through direct research or grants, and the focus is shifting away from cellulosic ethanol and toward drop-in biofuels. Unlike corn starch-based or cellulosic ethanol, drop-in fuels such as renewable gasoline are fully compatible with existing infrastructure, such as vehicle engines and distribution pipelines. In fiscal years 2013 through 2015, the federal government obligated more than $1.1 billion for advanced biofuels R&D. Of this amount, the Department of Energy (DOE) obligated over $890 million. For example, DOE's Office of Science funds three bioenergy research centers affiliated with universities and national labs that conduct basic research for all stages of biofuel production. The Department of Agriculture (USDA) obligated over $168 million in fiscal years 2013 through 2015 to support advanced biofuels. For example, USDA scientists developed a novel process to increase production of butanol, a drop-in fuel that lowered production costs by over 20 percent. The remaining federal obligations during these years were through the Environmental Protection Agency (EPA), the Department of Defense (DOD), and the National Science Foundation (NSF), which obligated relatively less for such R&D. According to agency officials, agencies are shifting their focus to drop-in fuels in part because they are compatible with existing infrastructure. Officials from one federal funding agency said this compatibility makes drop-in fuels more desirable than cellulosic ethanol.

Experts said that several advanced biofuels are technologically well understood and some are being commercially produced, but they noted there is limited potential for increased production in the near term and cited several factors that will make significant increases challenging. Given that current advanced biofuel production is far below Renewable Fuel Standard (RFS) targets and those targets are increasing every year, it does not appear possible to meet statutory target volumes for advanced biofuels in the RFS under current market and regulatory conditions. Biofuels that are technologically well understood include biodiesel, renewable diesel, renewable natural gas, cellulosic ethanol, and some drop-in fuels. A few of these fuels, such as biodiesel and renewable diesel, are being produced in significant volumes, but it is unlikely that production of these fuels can expand much in the next few years because of feedstock limitations. Current production of cellulosic biofuels is far below the statutory volumes and, according to experts, there is limited potential for expanded production to meet future higher targets, in part because production costs are currently too high. Experts told GAO that technologies for producing other fuels, such as some drop-in fuels, are technologically well understood but that these fuels are not being produced because production is too costly. Among the factors that will affect the speed and volume of production, experts cited the low price of fossil fuels relative to advanced biofuels. This disparity in costs is a disincentive for consumers to adopt greater use of biofuels and also a deterrent for private investors entering the advanced biofuels market. Experts also cited uncertainty about government policy, including whether the RFS and federal tax credits that support advanced biofuels will remain in effect. While such policies should encourage investment, investors do not see them as reliable and thus discount their potential benefits when considering whether to invest.

Contents

Abbreviations

ARPA-E	Advanced Research Projects Agency-Energy
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
NSF	National Science Foundation
PETRO	Plants Engineered to Replace Oil
R&D	research and development
RFS	Renewable Fuel Standard
TERRA	Transportation Energy Resources from Renewable Agriculture
USDA	Department of Agriculture

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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November 28, 2016

The Honorable James Lankford
Chairman
Subcommittee on Regulatory Affairs and Federal Management
Committee on Homeland Security and Governmental Affairs
United States Senate

Dear Mr. Chairman:

The Renewable Fuel Standard (RFS) calls for increasing volumes of renewable fuels to be blended into domestic transportation fuels through 2022, with the goals, as outlined by the Environmental Protection Agency (EPA), of reducing greenhouse gas emissions and expanding the nation's renewable fuels sector while reducing reliance on imported oil.[1] Blending of conventional renewable fuels, primarily ethanol derived from corn starch, has nearly reached the maximum called for under the RFS. Such fuel is required to reduce greenhouse gas emissions by 20 percent compared with petroleum-based fuels.[2] The RFS calls for further growth in renewable fuels to come from advanced biofuels—that is, transportation fuels, other than corn-starch ethanol, that are made from biological materials and that reduce life-cycle greenhouse gas emissions by at least 50 percent compared with petroleum-based fuels. However, production of advanced biofuels has not kept pace with targets in the RFS. In part because of insufficient production, EPA, which is responsible for implementing the RFS, has used its authority to set annual volume requirements for advanced biofuels that are below the targets in the statute starting in 2014. For example, for 2016, EPA set a volume requirement of 3.61 billion gallons for total advanced biofuel, although the statutory target is 7.25 billion gallons. This lower volume requirement

[1]42 U.S.C. § 7545 (o)(2)(B). The Renewable Fuel Standard was established by the Energy Policy Act of 2005 and expanded by the Energy Independence and Security Act of 2007.

[2]Life-cycle greenhouse gas emissions reduction comparisons are based on a 2005 petroleum baseline. Biofuel facilities that were producing fuel prior to the enactment of the Energy Independence and Security Act of 2007 are grandfathered under the statute, meaning these facilities are not required to meet the greenhouse gas reductions. As a consequence, the emissions reductions from these facilities are unknown.

reflected in part, EPA's expectation of how much advanced biofuel could be produced.[3]

To reach large-scale production, advanced biofuels must go through a scale-up process from laboratory-proven technology to production on a commercial scale—a process that can be time-consuming and expensive. To promote this process, the federal government has supported research and development (R&D) efforts for biofuels since the 1970s.

You asked us to review issues related to advanced biofuels R&D. This report describes (1) how the federal government has supported advanced biofuels R&D in recent years and where its efforts have been targeted and (2) expert views on the extent to which advanced biofuels are technologically understood and the factors that will affect the speed and volume of production.

To describe how the federal government has supported advanced biofuels R&D in recent years and where its efforts have been targeted, we reviewed documents and obligations data and interviewed officials from the Department of Agriculture's (USDA) Agricultural Research Service and National Institute of Food and Agriculture; the Department of Defense's (DOD) Defense Advanced Research Projects Agency; the Department of Energy's (DOE) Advanced Research Projects Agency–Energy, Bioenergy Technologies Office, Office of Science, and Vehicle Technologies Office; EPA's Office of Transportation and Air Quality; and the National Science Foundation (NSF). We reviewed obligations data for advanced biofuels R&D for fiscal years 2013 through 2015. In some cases, agencies or offices estimated these obligations because they did not track obligations data for advanced biofuels R&D separately from other biofuels or bioenergy R&D. To assess the reliability of the obligations data, we requested information from officials who maintain the relevant databases about steps they take to maintain them. We determined that the data we used were sufficiently reliable for the purposes of our reporting objectives.

To describe expert views on the extent to which advanced biofuels are technologically understood and on the factors that will affect the speed and volume of production, we worked with the National Academy of

[3]Units for all statutory target and annual requirement fuel volumes are in ethanol-equivalent gallons, except for biomass-based diesel volumes, which are expressed as physical gallons in line with EPA reporting methods.

Sciences to convene a group of 19 experts for a 2-day meeting in May 2016. One additional expert was unable to attend the meeting, and we interviewed him separately. (See app. II for a list of the experts we consulted.) We analyzed summary statements agreed upon by experts at the meeting as well as meeting transcripts to inform this report. To better understand the extent to which advanced biofuels are technologically understood and the factors that will affect the speed and volume of production, we also interviewed representatives from 11 companies that produce, or aim to produce, advanced biofuels. We selected these producers on the basis of technology used and scale of production. Specifically, we selected companies using well-established technologies and producing at commercial scale, companies using first-of-their-kind technologies and producing at commercial scale, and companies using first-of-their-kind technologies and not yet producing at commercial scale. Our interviews with producers provided key insights on and real-world examples of the factors that influence the speed and scale of advanced biofuel production; however, the results of our interviews cannot be generalized to all producers. (See app. III for a list of the producers we interviewed.) A more detailed description of our objectives and the scope and methodology of our review is presented in appendix I.

We conducted this performance audit from June 2015 to November 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

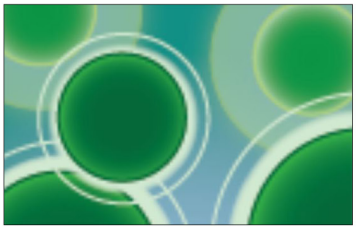
Background

Advanced biofuels are produced through a variety of combinations of (1) a feedstock, which is the type of renewable biomass that is converted into a renewable fuel, and (2) a conversion technology, which is used to convert renewable biomass into fuel. The result is a final fuel product.[4] Advanced biofuels may be made from an assortment of feedstocks, ranging from waste fats and oils to crops grown expressly for biofuels production, such as grasses like miscanthus and switchgrass. (See fig. 1.)

[4]EPA calls this combination of a feedstock, a conversion technology, and a final fuel product a “pathway.”

Figure 1: Examples of Advanced Biofuels Feedstocks

Algal feedstocks



A large, aquatic group of simple plant-like photosynthetic organisms—from microscopic cyanobacteria to giant seaweed.

Source: *National Algal Biofuels Technology Review*, Bioenergy Technologies Office, Department of Energy, June 2016.

Corn kernel cellulose

Fibrous cellulose remaining after corn grain ethanol production in a dry mill.

Source: Agricultural Research Service, Department of Agriculture.

Crop residues

Materials left on the field after crop harvesting, such as corn stover, and materials that remain after the crop has been processed into a primary product.

Source: GAO.

Dedicated energy crops

Crops specifically grown for bioenergy production, including grasses such as switchgrass and miscanthus.

Source: Great Lakes Bioenergy Research Center.

Municipal solid waste

Waste from residential and business sources, such as yard trimmings.

Source: PhotoDisc.

Oils, fats, and greases

Lipid-based feedstocks, such as vegetable oils and animal fats or recycled grease.

Source: Agricultural Research Service, Department of Agriculture.

Woody biomass

Forest logging residues, mill residues, and other woody waste sources.

Source: Great Lakes Bioenergy Research Center.

Source: GAO analysis of Department of Energy information (text). | GAO-17-108

These feedstocks are converted into fuel using a variety of conversion technologies that generally rely on chemicals, catalysts, enzymes, heat, or pressure. Depending on the feedstock and conversion technology used, the fuel may fit into one or more of three advanced biofuels categories established in the RFS.

- **Advanced:** renewable fuel, other than ethanol derived from corn starch, that has life-cycle greenhouse gas emissions at least 50 percent lower than traditional petroleum-based fuels. This is a catch-all category that may include a number of fuels, including fuels made from algae or ethanol made from sugar cane. This category includes the following subcategories:
  - **Biomass-based diesel:** biodiesel or renewable diesel that has life-cycle greenhouse gas emissions at least 50 percent lower than traditional petroleum-based diesel fuels.
  - **Cellulosic:** renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and has lifecycle greenhouse gas emissions at least 60 percent lower than traditional petroleum-based fuels.[5] This category of fuel may include cellulosic ethanol, renewable gasoline, cellulosic diesel, and renewable natural gas from landfills that can be upgraded and used in vehicles designed to run on liquefied or compressed natural gas.

Some advanced biofuels are compatible with existing engines and the fuel distribution infrastructure. Such fuels, known as "drop-in" fuels, include renewable diesel, renewable jet fuel, and renewable gasoline. Other advanced biofuels are not fully compatible. For example, cellulosic ethanol, like corn-starch ethanol, faces limits on the amount that can be blended into gasoline, in part because it is more corrosive.[6] Drop-in fuels do not face this limitation because they are compatible with current infrastructure.

EPA is responsible for implementing the RFS through several mechanisms. [7] Specifically, EPA approves new combinations of feedstocks, conversion processes, and fuels that can be counted toward

[5]Plant biomass is made up primarily of cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are made up of potentially fermentable sugars. Lignin provides the structural integrity of plants by enclosing the tightly linked cellulose and hemicellulose molecules, which makes these molecules harder to reach.

[6]See GAO, *Biofuels: Challenges to the Transportation, Sale, and Use of Intermediate Ethanol Blends,* GAO-11-513 (Washington, D.C.: June 3, 2011).

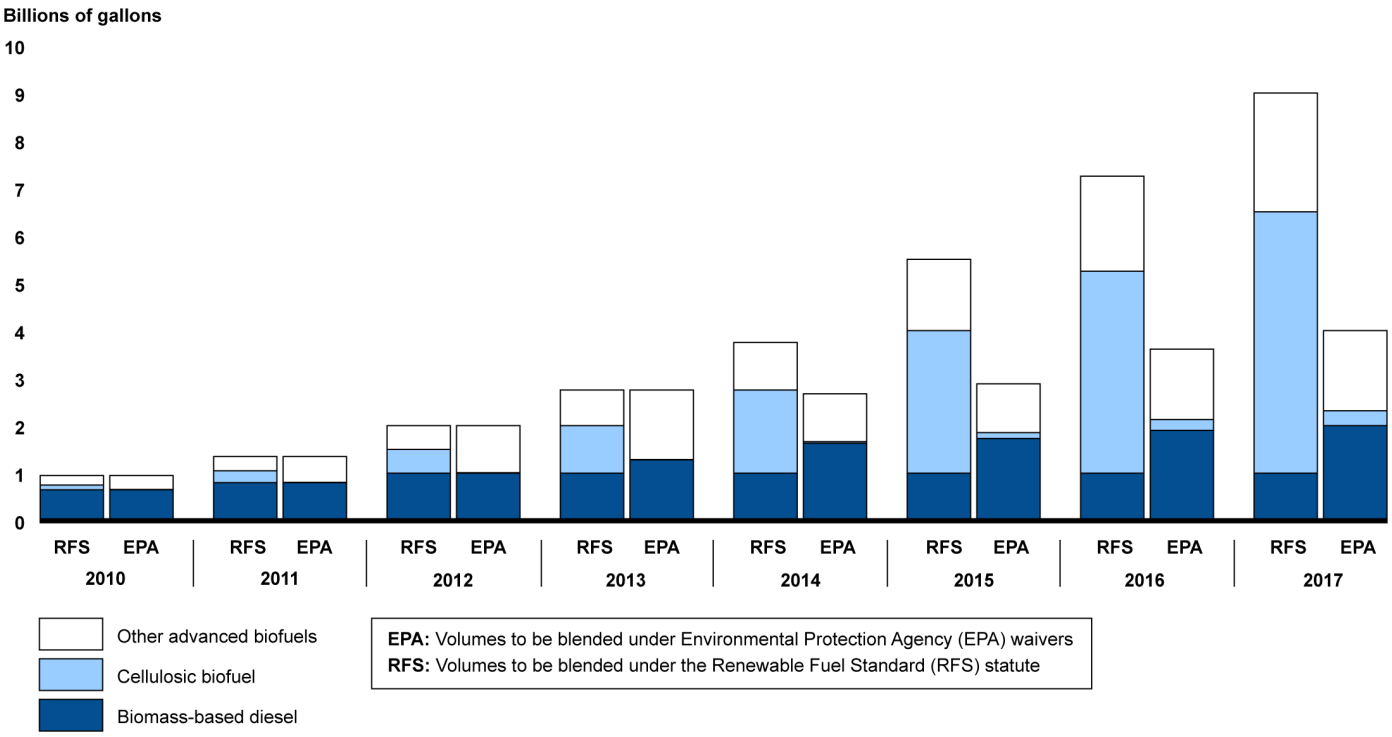
[7]For more information on the implementation of the RFS, see GAO, *Renewable Fuel Standard: Program Unlikely to Meet Its Targets for Reducing Greenhouse Gas Emissions,* GAO-17-94 (Washington, D.C.: Nov. 28, 2016). This report provides information on (1) whether the RFS is expected to meet its goals, (2) expert views on federal actions, if any, that could improve the RFS framework, and (3) policy alternatives experts suggested to better meet the goals of the RFS in the future.

the statutory targets. EPA also has the authority to waive statutory targets and set annual volume requirements for categories of renewable fuels, including advanced biofuels. These volumes may deviate from the statutory targets because of inadequate domestic supply, among other reasons. For 2010 through 2013, EPA set annual volume requirements for the cellulosic biofuels category that were below statutory targets, but kept the overall volume for all advanced biofuels in line with the statute. For 2014 through 2017, in addition to setting lower annual volume requirements for the cellulosic biofuels category, EPA also set lower overall volume requirements for all advanced biofuels.[8] For 2013 through 2017 EPA also set volume requirements for biomass-based diesel that were higher than the minimums set in the statute, which somewhat offset the lower requirements for cellulosic biofuels.[9] (See fig. 2 for a comparison of statutory targets and volume requirements set by EPA.)

[8]80 Fed. Reg. 77419 (Dec. 14, 2015) and 81 Fed. Reg. 34778 (May 31, 2016). As of September 2016, EPA volumes for 2017 are proposed, except for the biomass-based diesel volume for 2017, which is final.

[9]The RFS statute provides, in what is commonly referred to as the "reset provision," that the EPA Administrator is to modify the applicable volumes of the RFS for subsequent years if the Administrator waives the statutory levels of renewable fuel, advanced biofuel, cellulosic biofuel, or biomass-based diesel by at least 20 percent for 2 consecutive years or by at least 50 percent for a single year. The final rule issued by EPA for 2014, 2015, and 2016 triggered this reset provision. The Administrator has not yet announced steps to implement this provision.

Figure 2: Volumes of Advanced Biofuels to Be Blended into Domestic Transportation Fuel, as Set by the Renewable Fuel Standard Statute and by the Environmental Protection Agency, 2010 through 2017



Source: GAO analysis of legal requirements and EPA data. | GAO-17-108

Note: As of September 2016, EPA volumes for 2017 are proposed, except for the biomass-based diesel volume for 2017, which is final. Units for all volumes are ethanol-equivalent, except for biomass-based diesel volumes, which are expressed as physical gallons in line with EPA reporting methods.

In addition to the RFS, there are federal tax incentives to promote the production and use of advanced biofuels. These include the Biodiesel Income Tax Credit, which provides a $1 per-gallon tax credit for producers of certain biodiesel or renewable diesel.[10] Separately, the Second Generation Biofuel Producer Tax Credit provides advanced

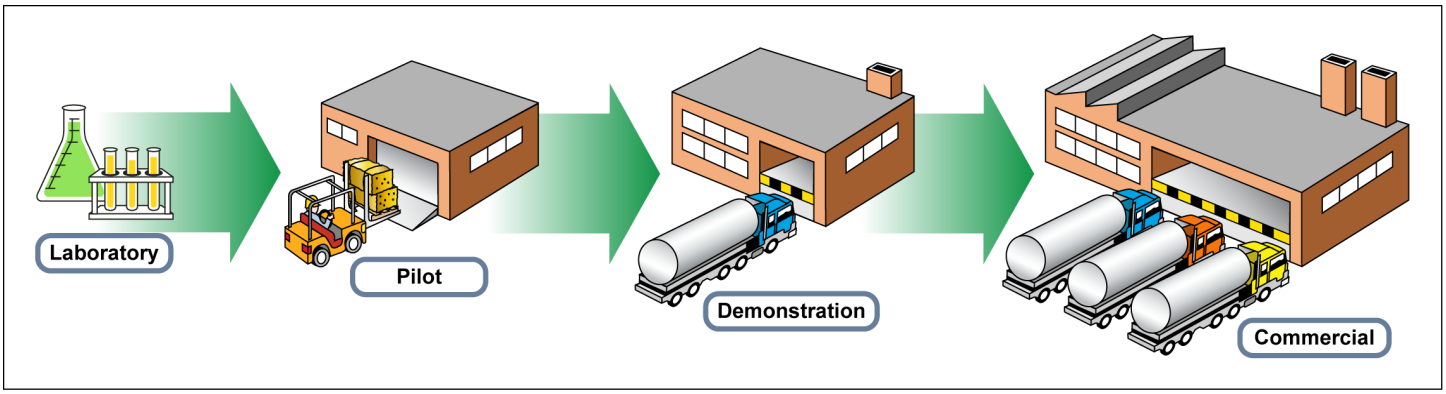
[10]26 U.S.C. § 40A The biodiesel credit of any taxpayer for any taxable year is $1.00 for each gallon of biodiesel which is not in a mixture with diesel fuel and which during the taxable year— (i) is used by the taxpayer as a fuel in a business, or (ii) is sold by the taxpayer at retail to a person and placed in the fuel tank of such person's vehicle.

biofuel producers a tax credit of up to $1.01 per gallon of advanced biofuel produced and used domestically.[11]

R&D related to advanced biofuels includes both basic and applied research. In general, basic research focuses on gaining a fundamental understanding of a material or process. Applied research explores the potential of a material or process to satisfy a technology need. Components of an advanced biofuels applied research portfolio may include developing technologies to provide a reliable, affordable, and sustainable biomass supply. To reach commercial-scale production, advanced biofuels must go through a process of increasing the scale of production, beginning with a research and development phase that culminates in proving a given technology in a laboratory setting. Once a conversion technology has been proven at laboratory scale, it can be scaled up and tested in a pilot facility. Pilot-scale facilities are small-scale facilities that verify the integrated performance of a given suite of technologies from feedstock through final product. Once a technology has been proven at this scale, it can be scaled up to a demonstration facility, which verifies the performance of integrated technologies at a scale that can be used to determine design specifications for a still larger facility. Commercial-scale facilities, including both “first-of-its-kind” and subsequent facilities, aim to produce commercial volumes economically on a continuous basis, with a reliable feedstock supply and production distribution system. Figure 3 illustrates the stages in the advanced biofuels scale-up process.

[11]To qualify for the Second Generation Biofuel Producer Tax Credit, a second generation biofuel must be produced by the taxpayer and, during the taxable year, sold to another person for use in the production of a qualified second generation biofuel mixture in trade or business, for use as a fuel in trade or business, or to be sold at retail and placed in the fuel tank of the buyer. Second generation biofuel is defined as liquid fuel produced from any lignocellulosic or hemicellulosic matter that is available on a renewable basis or any cultivated algae, cyanobacteria, or lemna.

Figure 3: Stages in the Advanced Biofuels Scale-Up Process

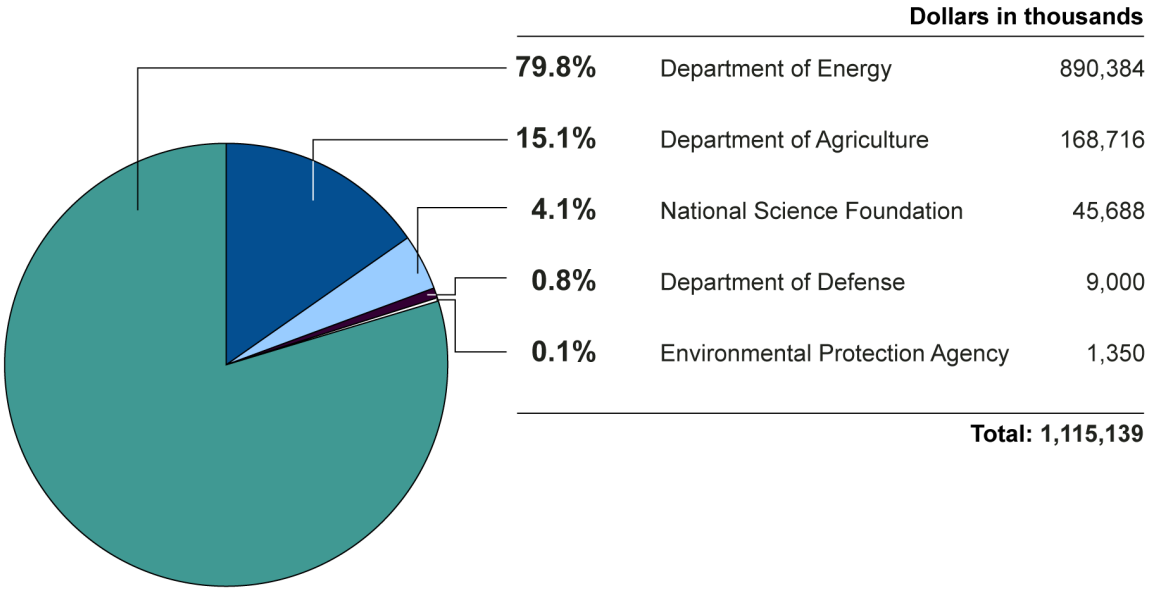


Source: GAO. | GAO-17-108

Recent Federal Support for R&D Related to Advanced Biofuels Has Been Through Direct Research and Grants, and the Focus Is Shifting toward Drop-In Fuels

The federal government has supported R&D related to advanced biofuels through direct research and grants in recent years, with the focus of this R&D shifting away from cellulosic ethanol, an advanced biofuel that is not fully compatible with current vehicle engines and fuel distribution infrastructure, and toward drop-in biofuels, which are compatible with this infrastructure. Agency officials said that they are focusing on drop-in fuels in part because of this compatibility. As figure 4 shows, the federal government obligated about $1.1 billion for R&D related to advanced biofuels in fiscal years 2013 through 2015, of which DOE obligated over $890 million, or about 80 percent of the total. USDA obligated over $168 million for such R&D in this time frame, or about 15 percent of the total. Of these obligations, $3 million of DOE's total and about $5.29 million of USDA's total were obligated for projects through the Biomass Research and Development Initiative—an annual joint funding opportunity announcement focused on biofuels and bioproducts. NSF, DOD, and EPA spent relatively small amounts on R&D related to advanced biofuels in fiscal years 2013 through 2015, compared with DOE and USDA.

Figure 4: Federal Agencies' Obligations for Research and Development Related to Advanced Biofuels, Fiscal Years 2013 through 2015



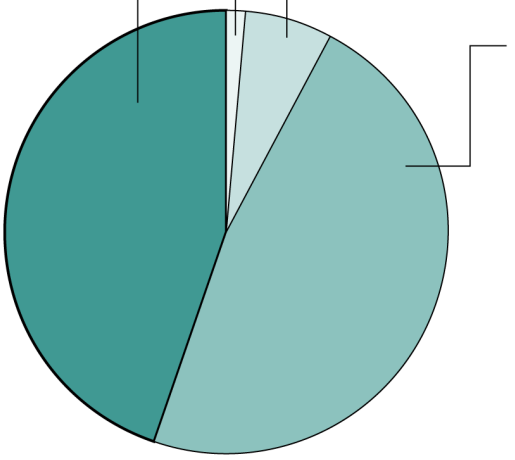
Source: GAO analysis of obligations data provided by the Department of Energy, Department of Agriculture, National Science Foundation, Department of Defense, and Environmental Protection Agency. GAO-17-108

Note: Values do not add to total and percentages do not add to 100 because of rounding. Data from the Department of Agriculture's Agricultural Research Service represents allocations for advanced biofuels research and development, rather than obligations, because the agency allocates funding by research project and does not track research by obligations. In addition, Environmental Protection Agency obligations are an estimate because the agency does not track obligations for advanced biofuels research and development separately.

DOE Funds the Majority of Federal R&D Related to Advanced Biofuels and Has Shifted Its Focus Away from Cellulosic Ethanol

In fiscal years 2013 through 2015, DOE obligated $890.4 million—the majority of all federal funding for R&D related to advanced biofuels—through four offices: the Office of Science, the Bioenergy Technologies Office, the Advanced Research Projects Agency-Energy (ARPA-E), and the Vehicle Technologies Office. (see fig. 5.)

Figure 5: The Department of Energy's Obligations for Research and Development Related to Advanced Biofuels, Fiscal Years 2013 through 2015



		Dollars in thousands
44.6%	Bioenergy Technologies Office	397,461
1.2%	Vehicle Technologies Office	10,853
6.5%	Advanced Research Projects Agency-Energy	57,943
47.6%	Office of Science	424,127
		Total: 890,384

Source: GAO analysis of obligations data provided by the Department of Energy. | GAO-17-108

Note: Percentages do not add to 100 because of rounding.

The following DOE offices obligated funds for basic and applied R&D on all stages of advanced biofuel production, and overall have shifted away from R&D on cellulosic ethanol:

- **Office of Science.** In fiscal years 2013 through 2015, DOE's Office of Science obligated approximately $424.1 million for external R&D related to advanced biofuels. According to an agency official, the office supports basic R&D in this field primarily by funding three bioenergy research centers.[12] The Office of Science also awards grants to fund projects at national laboratories and academic institutions. Research covers all areas of biofuels R&D, including sustainability, feedstock development and logistics, and conversion

[12]DOE established three bioenergy research centers in 2007 to conduct basic scientific research to develop a cost-effective cellulosic advanced biofuels industry. The three bioenergy research centers are: (1) the Joint BioEnergy Institute, led by Lawrence Berkeley National Laboratory; (2) the BioEnergy Science Center, led by Oak Ridge National Laboratory; and (3) the Great Lakes Bioenergy Research Center, led by the University of Wisconsin-Madison, in partnership with Michigan State University.

technologies. DOE officials told us that, although they continue to investigate cellulosic ethanol, drop-in fuels are more desirable because they are compatible with current engine designs and fueling infrastructure. According to an agency official, the office supports basic research and focuses efforts on demonstrating proof of concept—showing that laboratory results can be replicated in real-world conditions. For example, staff at one of the bioenergy research centers supported by the Office of Science recently transplanted poplar trees that had been cultivated for biofuel production under laboratory conditions to the field to observe their growth. Once proof of concept has been demonstrated in this way, research often transitions to other federal offices and/or industry to conduct additional applied research.

- **Bioenergy Technologies Office.** In fiscal years 2013 through 2015, this office obligated approximately $397.5 million for in-house and external R&D related to advanced biofuels. The office conducts its own basic and applied R&D at federal laboratories including the National Renewable Energy Laboratory in Golden, Colorado, and partners with industry and universities. The office focuses on developing and transforming renewable biomass into commercially viable high-performance biofuels, bioproducts, and biopower. The office spent much of the past decade focusing R&D on cellulosic ethanol, but after meeting key goals to reduce production costs, the office shifted its focus to drop-in fuels in 2012. For example, the Bioenergy Technologies Office funded a project by the nonprofit Gas Technology Institute to develop a process for converting a broad range of feedstocks—residue from wood harvesting and manufacturing, algae, and corn stover—into drop-in fuels. According to DOE officials, the process resulted in fuels that meet technical specifications for gasoline and diesel while achieving a 90-percent reduction in greenhouse gas emissions relative to fossil fuels. Officials told us the technology was licensed in June 2015 to a company that plans to build a demonstration plant.
- **ARPA-E.** In fiscal years 2013 through 2015, DOE's Advanced Research Projects Agency-Energy obligated approximately $57.9 million for external R&D related to advanced biofuels.[13] ARPA-E awards funds for applied research to outside organizations, such as private companies and academic institutions. The agency seeks to

[13]According to ARPA-E officials, approximately 10 percent of ARPA-E's cumulative projects obligations since the agency's inception in 2009 have been for advanced biofuels projects.

fund high-impact energy technologies that are too early for private-sector investment. More than 87 percent of ARPA-E's advanced biofuel R&D projects are funded as part of the Plants Engineered to Replace Oil (PETRO) program and the Transportation Energy Resources from Renewable Agriculture (TERRA) program.[14] Neither of these programs directly supported cellulosic ethanol research. During fiscal years 2013 through 2015, the agency obligated more than $18 million for advanced biofuels projects through the PETRO program, which seeks to fund technologies that optimize production and conversion of plants for use as advanced biofuels, aiming to significantly reduce production costs. In fiscal year 2015, the agency obligated more than $32 million through the TERRA program, which began that year and focuses on improving production of sorghum as an advanced biofuel feedstock.

- **Vehicle Technologies Office.** In fiscal years 2013 through 2015, DOE's Vehicle Technologies Office obligated approximately $10.9 million for in-house and external R&D related to advanced biofuels, focusing on end-user considerations. The Vehicle Technologies Office supports applied research to increase knowledge of the effects of conventional and advanced biofuels on engines and improve the efficiency of alternative fuel vehicles, among other things. It supports this research primarily through collaboration with national laboratories, universities, and industry. For example, the office is collaborating with Cummins engine company to develop a compression ignition engine capable of running on ethanol, which is usually a spark-ignition fuel, and diesel, which is a compression ignition fuel. An agency official told us that because compression ignition is more efficient than spark ignition, such an engine allows ethanol to be used more efficiently, thus decreasing petroleum consumption.

USDA Is the Second Largest Funder of Federal R&D Related to Advanced Biofuels and Targets Drop-In Fuels

In fiscal years 2013 through 2015, USDA obligated approximately $168.7 million for R&D related to advanced biofuels—making it the second largest funder of federal R&D related to advanced biofuels. It obligated these funds through two agencies: the Agricultural Research Service and the National Institute of Food and Agriculture. Each agency accounts for approximately half of USDA's obligations related to R&D for advanced biofuels.

[14]The funding opportunity announcement for the PETRO program was issued in April 2011 with initial awards distributed in fiscal year 2012.The funding opportunity announcement for the TERRA program was issued at the start of fiscal year 2015 with initial awards distributed that same fiscal year.

Similarly to DOE, these agencies funded basic and applied research on all stages of advanced biofuel production, focusing on drop-in biofuels, biodiesel, and coproducts.

- **Agricultural Research Service.** In fiscal years 2013 through 2015, USDA's Agricultural Research Service obligated approximately $85.5 million for in-house R&D related to advanced biofuels. According to its officials, the Agricultural Research Service conducts both basic and applied advanced biofuels R&D in four national research centers.[15] The Agricultural Research Service is USDA's chief in-house research arm, and its biofuels research is aimed at the production of advanced biofuels, focusing on drop-in fuels, biodiesel, and bioproducts. For example, scientists in Peoria, Illinois, developed a novel process that increased production of butanol—a drop-in fuel—from corn stover and lowered estimated production costs from $4.39 per gallon to $3.42 per gallon. The key to this cost reduction is to recover the butanol continuously as it is generated, which is done using a special pretreatment and distillation process. Scientists at the same laboratory also developed a new method of converting plant oils into skin care and food ingredients with antioxidant properties that extend shelf life. Agency officials told us that such high-value bioproducts may pave the way for commercial production of advanced biofuels. Such products may help offset the up-front cost and minimize the risk of constructing large, commercial-scale biorefineries that produce advanced biofuels.
- **National Institute of Food and Agriculture.** In fiscal years 2013 through 2015, USDA's National Institute of Food and Agriculture obligated approximately $83 million for external R&D related to advanced biofuels. The agency funds basic and applied research through grants to academic institutions, non-governmental organizations, government laboratories, and industry. According to agency officials, the National Institute of Food and Agriculture's current advanced biofuels research focuses on drop-in fuels. For example, the agency is investing in seven regional public/private consortia developing supply chains for biofuels and biobased products. One consortium, led by Washington State University, successfully developed a series of processes to take logging residues from Weyerhaeuser—a forest products company—and convert them to alternative jet fuel.

[15]The four national research centers conducting advanced biofuel R&D are located in Peoria, IL; Philadelphia, PA; Albany, CA; and New Orleans, LA.

DOE and USDA Obligated Funds to the Biomass Research and Development Initiative for R&D Projects

DOE's and USDA's obligations to support advanced biofuels R&D included funds they contributed to the Biomass Research and Development Initiative, which funds R&D projects through funding opportunity announcements.[16] Specifically, in fiscal years 2013 through 2015, USDA obligated $5.29 million to Biomass Research and Development Initiative projects through its National Institute of Food and Agriculture, and DOE obligated $3 million to these projects through its Bioenergy Technologies Office. The Initiative's 2015 funding opportunity announcement called for applicants in the technical topic areas of feedstock development, including harvest and storage; biofuels and bioproducts development, including for chemicals that can potentially increase the economic viability of large-scale fuel production in a biorefinery; and biofuels and bioproducts development analysis, focusing on analytical tools to better evaluate bioproducts. One of the selected projects proposes to convert poplar trees to ethanol and polyurethane—a material that is used in a variety of applications, including insulation and foam cushioning.

NSF, DOD, and EPA Obligated Smaller Amounts for R&D Related to Advanced Biofuels

NSF, DOD, and EPA obligated less for R&D related to advanced biofuels than DOE and USDA; combined, these three agencies accounted for about 5 percent of the federal funds obligated for such R&D in fiscal years 2013 through 2015. In these years, NSF awarded approximately $45 million, mostly to academic research institutions, to fund external R&D related to advanced biofuels that could include cellulosic ethanol or drop-in fuels. These funds supported mostly basic and some applied research. One NSF-funded project at the University of Kentucky aims to develop an improved process for the conversion of vegetable oils and animal fats into a drop-in substitute for diesel. The process uses nickel, which is abundant and inexpensive, as a catalyst for conversion, as opposed to the expensive precious metals commonly used. DOD, through the Defense Advanced Research Projects Agency, funded one R&D project related to advanced biofuels during this period for a total of $9 million. This project sought to develop more efficient methods of growing and harvesting

[16]The Biomass Research and Development Act of 2000 directed the Secretaries of Agriculture and Energy to coordinate policies and procedures that promote R&D leading to the production of biofuels and bioproducts. In addition, the act directed the Secretaries of Agriculture and Energy to establish a Biomass Research and Development Initiative to award grants, contracts, and financial assistance to develop and conduct research on biofuels and bioproducts. The act also created the Biomass Research and Development Technical Advisory Committee, composed of about 30 representatives from industry, academia, and state government.

algae. According to EPA officials, the agency did not conduct any R&D on new ways to produce advanced biofuels; rather, in its role of administering the RFS program, it primarily conducted analyses to determine the life-cycle greenhouse gas emissions of combinations of feedstocks, conversion technologies, and the advanced biofuels produced to determine if they meet the requirements to be counted toward the statutory targets under the RFS.

Experts Agreed Several Advanced Biofuels Are Technologically Well Understood, but They Cited Several Factors That Make It Challenging to Significantly Increase Production

Experts said that several advanced biofuels are technologically well understood but noted that among those currently being produced there is limited potential for increased production in the near term. They further cited multiple factors that will make it challenging to significantly increase the speed and volume of production. In addition, current advanced biofuel production is far below overall RFS target volumes, and those volumes are increasing every year. Given expert views on the limited potential for increased production and current production volumes, it does not appear possible to meet the targets in the RFS for advanced biofuels under current market and regulatory conditions.

Several Advanced Biofuels Are Technologically Well Understood, but They Are Not Being Produced at the Overall Volumes Called for in the RFS

Several advanced biofuels are technologically well understood, according to experts, and some are being commercially produced in significant quantities, but the overall volume being produced falls short of the volume target in the RFS. For example, in 2015, about 3.1 billion ethanol-equivalent gallons of advanced biofuels were produced, falling short of the statutory target of 5.5 billion gallons in the RFS for that year.[17] By 2022, the advanced biofuels target increases to 21 billion gallons, so production would have to rapidly increase to meet this target.

Biodiesel and renewable diesel—which typically fall under the category of biomass-based diesel in the RFS—are among the types of advanced biofuels that are technologically well understood, according to experts, and they are being produced in the largest volumes. Biomass-based

[17]All values are ethanol-equivalent on an energy content basis, except values for biomass-based diesel, which are given in actual gallons.

diesel, which has its own minimum statutory volume target set in the RFS, is the exception among the categories in that it exceeded its minimum of at least 1 billion gallons for 2015. In 2015, about 1.5 billion gallons of biodiesel were produced, according to EPA. In addition, about 300 million gallons of renewable diesel were produced in 2015.[18] Experts agreed that expansion potential for these fuels is limited by the availability of feedstocks (fats and oils), for which there are competing uses. For example, soybean oil is also used as a cooking oil.

Cellulosic biofuels—specifically cellulosic ethanol and renewable natural gas from landfills—are also technologically well understood, according to experts, but current production is far below the volume needed to meet the target for these fuels. Specifically, in 2015, about 142 million gallons of cellulosic biofuel overall—including about 2 million gallons of cellulosic ethanol and about 140 million gallons of renewable natural gas—were produced. This cellulosic biofuel volume was less than 5 percent of the statutory target of 3 billion gallons. According to experts, there is limited potential for expanded production of cellulosic ethanol in the next 5 years to meet the higher volumes called for in the statute. Experts said that the most economical way to quickly expand production of cellulosic ethanol is through “bolt-on” facilities, which use the cellulosic corn fiber remaining after corn-starch ethanol production as a feedstock; however, the experts said that such facilities would not boost overall cellulosic ethanol volumes by more than about 750 million gallons even if added to every existing corn-starch ethanol refinery. This is far short of the 2015 target of 3 billion gallons. Several corn-starch ethanol producers are already using such bolt-on facilities, and other corn-starch ethanol producers are expected to follow suit, according to experts and producers we interviewed, because these technologies require relatively low expenditures of capital and these costs can be recovered relatively quickly. Experts said that significant expansion of cellulosic ethanol production beyond current levels would require construction of large stand-alone facilities and that even though several such facilities have been built, attracting the investments necessary to build more is unlikely until conversion yields and operability improve and costs come down. Concerning renewable natural gas, which is produced mainly from landfills, an expert noted that to be usable as a transportation fuel, the gas must be purified and adjusted to specifications. A renewable natural gas producer we spoke with said the

[18] Total biomass-based diesel production in 2015 in ethanol-equivalent gallons is about 2.8 billion gallons.

cost to upgrade landfill gas to meet such specifications is significant and that landfill gas can be used for other purposes, including making electricity, without this costly upgrading. The producer told us that despite the additional cost, the incremental revenue from credits under the RFS makes it worthwhile to upgrade landfill gas.

According to the experts, some other technologies for producing advanced biofuels are also well understood, but these technologies have produced relatively small volumes of fuel because they cannot compete with petroleum-based fuels given current oil prices and despite federal biofuels tax credits and other incentives. These technologies include pyrolysis, which involves the thermal and chemical decomposition of a feedstock without the introduction of oxygen. About 44,000 gallons of cellulosic renewable gasoline blendstock and about 9,000 gallons of cellulosic diesel were produced in 2014 and none in 2015 or 2016 because the producer went out of business. Both of these fuels are considered drop-ins.

Experts agreed that algal biofuels are technologically well understood and have significant future potential, but are still several years away from being economical to produce because of the high cost of growing algae. Experts estimated it may cost $1200 to $4000 per ton to produce algae currently, and costs need to fall to $400 to $500 per ton to make the process economical for fuel production. For example, one producer we interviewed can reliably produce biofuel from algae but is focusing on higher-value nutritional and pharmaceutical products.

According to Experts, Several Factors That Affect the Speed and Volume of Production Will Make Significant Increases Challenging

Experts identified several factors, many related to cost, that will affect the speed and volume of production of advanced biofuels and make it challenging to significantly increase production in the next 5 to 10 years. These factors include the following:

- **Low price of fossil fuels relative to advanced biofuels.** According to experts, low fossil fuel prices affect advanced biofuels in two ways. First, experts said getting consumers to accept higher blends of advanced biofuels at the pump will require those biofuels to be priced competitively with equivalent fossil fuels. While the average retail gasoline price was over $4 per gallon in May 2011, it dropped to under $2 per gallon in early 2016, making it harder to compete on

price at the pump.[19] Similarly, retail diesel prices were over $4 per gallon as recently as March 2014, but briefly fell below $2 in early 2016.[20] Second, experts said low fossil fuel prices are a significant impediment to biofuels investment. One expert noted that investment in advanced biofuels technology has dropped since oil prices have dropped, making it difficult to fund the R&D needed to reduce the cost of biofuels. Experts agreed that one option to overcome this fossil fuels price advantage would be to put a price on greenhouse gas emissions—for example, through a carbon tax or similar mechanism.

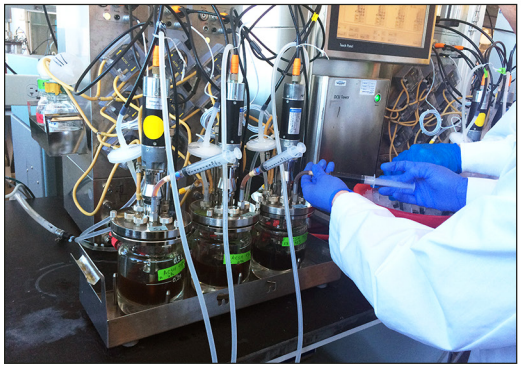
- **High cost of converting cellulosic feedstocks.** Experts told us that conversion costs are a function of (1) the number of processing steps it takes to convert a raw feedstock to a fuel; (2) the difficulty of transporting and handling solid feedstocks as compared with liquid or gaseous feedstocks; (3) the difficulty of handling and disposing of waste products from the conversion process; and (4) infrastructure challenges associated with a plant's location, such as access to a steady feedstock supply and rail lines to transport fuel. For example, one expert noted that handling solid feedstocks on the front end of conversion, as opposed to liquids or gases, is more time consuming and complex, resulting in additional costs. These feedstocks, such as corn stover or forest logging residues, may need to be ground or chipped to a uniform size so they will more easily flow through equipment, and debris such as rocks and dirt may need to be removed to prevent damage to equipment. In addition, experts noted that it can be costly to dispose of waste products from the conversion process. Ideally, producers will find ways to monetize waste products by creating coproducts, but more work is needed in this area to make that a reality. For example, lignin—a part of plant matter that is left over after conversion to cellulosic ethanol—can be burned to produce energy. One producer told us using lignin in carbon fiber may be a future possibility.
- **Time and cost to bring a new technology to commercial-scale production.** Experts told us that developing a biofuel technology and bringing it from laboratory scale to commercial scale may take 12 years if every step works out well, and could take considerably longer; one representative we interviewed from a company that produces

[19]These are weekly data from DOE's Energy Information Administration on retail gasoline prices in all of the United States, for all grades and all formulations.

[20]These are weekly data from DOE's Energy Information Administration on retail diesel prices in all of the United States.

biofuel said this process may take 15 to 25 years. (See fig. 6 for examples of laboratory-scale and commercial-scale advanced biofuels production.) Once a biofuel technology is technologically ready, the design, engineering, and construction of the first plant normally take 3 to 4 years, according to experts. Such first-of-their-kind facilities often face challenges because the companies are still optimizing the technology and may encounter problems that only occur when building at commercial scale. One producer told us they overbuilt their first commercial facility out of caution. Therefore these facilities take longer and are more expensive to construct than subsequent facilities. A representative of a company that produces advanced biofuel told us that, compared to the cost of its first plant, it has identified opportunities that could save about 25 percent on its next plant.

Figure 6: Examples of Laboratory-Scale and Commercial-Scale Advanced Biofuels Production



Laboratory-scale microbial fermentation of pretreated corn stover to produce cellulosic ethanol at the Great Lakes Bioenergy Research Center in Madison, Wisconsin.

POET-DSM's Project Liberty commercial-scale cellulosic ethanol facility in Emmetsburg, Iowa.

Source: GAO. | GAO-17-108

Expiration and Extension of Tax Credits

The Biodiesel Income Tax Credit provides a $1 per gallon tax credit for producers of certain biodiesel or renewable diesel. Since its enactment in 2004, the credit had been extended six times, in four cases retroactively after it expired. The current extension lasts through December 31, 2016.

The Second Generation Biofuel Producer Tax Credit provides advanced biofuel producers a tax credit of up to $1.01 per gallon of advanced biofuel produced domestically that is sold for use in the United States as motor vehicle fuel or to be blended into a biofuel mixture. This credit has been retroactively extended twice since 2014. The current extension lasts through January 1, 2017.

Source: 26 U.S.C. §§ 40 and 40A. | GAO-17-108

- **Time and cost to secure fuel certification and acceptance.** Experts told us that once a fuel can be produced several steps remain before it can be brought to market, including regulatory registration, certification by ASTM International, as well as oil company and vehicle acceptance.[21] These steps can occur concurrently, but they have different time frames. In addition, these steps are costly for companies. For example, one expert said that passing the EPA registration for a new fuel costs millions of dollars, while another noted that ASTM certification of a new fuel is a longer and more expensive process. Oil companies and vehicle manufacturers must also approve a new fuel before they will be willing to blend it for use in transportation fuels. New advanced biofuels must also have their combination of a feedstock, a conversion process, and a final product approved by EPA in order to be counted toward the annual volume requirements under the RFS. A representative from one company we spoke to told us EPA's reviews are taking longer than expected. One expert told us that two different advanced biofuels projects have been recently cancelled specifically because of the time it has taken for EPA to complete these approvals.
- **Uncertainty about government policy.** Experts agreed that uncertainty about government policy is a major barrier for the commercialization of advanced biofuels because it sends mixed signals to the market, which can limit investment. The future of the RFS, the Biodiesel Income Tax Credit, and the Second Generation Biofuel Producer Tax Credit may all be sources of uncertainty. Regarding the RFS, there is uncertainty about whether it will remain in place, and uncertainty about where EPA will set annual volume requirements. As described in the sidebar on this page, the tax credits have been allowed to expire and then have been retroactively extended in the past. This uncertainty affects all stages of biofuel production. For example, one expert stated that producers of farm equipment will not invest in new harvesting technology to maximize biomass feedstock yields if they see too much uncertainty in the market for advanced biofuels over the next 10 years, while other experts noted the difficulty in obtaining capital to build commercial-scale plants. Every advanced biofuels producer we interviewed also cited uncertainty about government policy as a major barrier to

[21]Regulatory registration takes place with EPA's Office of Transportation and Air Quality, which requires submission of information about a fuel's potential impact on public health and other information. ASTM International is an international organization that defines and sets standards for various industries and specifications for products, including biofuels.

commercial-scale production. One producer said policy uncertainty has increased since 2013 when EPA used its waiver authority to reduce the RFS statutory volumes, causing investors to lose confidence and interest in commercial-scale plants. Another producer we interviewed told us that producers cannot rely on the Second Generation Biofuel Producer Tax Credit in their investment decisions.

- **Underdeveloped feedstock supply chain.** Experts agreed that the lack of logistics for the entire feedstock supply chain—from securing a contract to delivering and storing a feedstock—is an economic barrier to the production of advanced biofuels. One expert noted that it may take longer to set up contracts with farmers for feedstock delivery, such as corn stover, than it takes to build an advanced biofuels plant. Without a developed commodity market for advanced biofuel feedstocks, producers must negotiate contracts with individual farmers, which is costly and time consuming. One cellulosic biofuel producer told us it faced challenges with feedstock transport and storage in trying to minimize burdens on farmers. Specifically, the producer noted that it was working with farmers to offer two different contract models: to store bales of stover at the farm, or to store them at the plant. Experts also noted that large amounts of dry cellulosic feedstock in storage may be susceptible to fire, such as from lightning strikes—something that has happened at one cellulosic ethanol facility.

Agency Comments

We provided a draft of this report to EPA, USDA, NSF, DOE, and DOD for review and comment. In its written comments, reproduced in appendix IV, EPA generally agreed with the report and its findings. USDA and NSF provided technical comments, which we incorporated as appropriate. DOE and DOD did not have any comments on the draft.

As agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the appropriate congressional committees, the Secretary of Agriculture, the Secretary of Defense, the Secretary of Energy, the Administrator of the Environmental

Protection Agency, the Director of the National Science Foundation, and other interested parties. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

If you or your staff members have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix V.

Sincerely yours,

Frank Rusco
Director, Natural Resources and Environment

Appendix I: Objectives, Scope and Methodology

This report provides information related to advanced biofuels research and development (R&D). Specifically, it describes (1) how the federal government has supported advanced biofuels R&D in recent years and where its efforts have been targeted and (2) expert views on the extent to which advanced biofuels are technologically understood and the factors that will affect the speed and volume of production.

To describe how the federal government has supported advanced biofuels R&D in recent years and where its efforts have been targeted, we reviewed documents and obligations data and interviewed officials from the following agencies: the Department of Agriculture's (USDA) Agricultural Research Service and National Institute of Food and Agriculture; the Department of Defense's (DOD) Defense Advanced Research Projects Agency; the Department of Energy's (DOE) Advanced Research Projects Agency–Energy, Bioenergy Technologies Office, Office of Science, and Vehicle Technologies Office; the Environmental Protection Agency's (EPA) Office of Transportation and Air Quality; and the National Science Foundation (NSF). We reviewed obligations data for advanced biofuels research and development for fiscal years 2013 through 2015. In some cases, agencies or offices estimated these obligations because they did not track obligations data for advanced biofuels R&D separately from other biofuels or bioenergy R&D. In addition, USDA's Agricultural Research Service was not able to provide obligations data for advanced biofuels R&D, but provided allocations data instead. These data differ in that allocations are a delegation of authority to obligate funds, while obligations are legally binding agreements to outlay funds. According to officials from the Agricultural Research Service, it does not track funding for its research projects by obligations but rather by the allocation of funding by research project. Agency officials told us that they have reasonable certainty that the allocations they provided to us would align one-to-one with the obligations for agency research projects. To assess the reliability of the obligations data, we asked officials who maintain the relevant databases for information about steps they take to maintain the data. We determined that the data we used were sufficiently reliable for purposes of describing the scale of advanced biofuels R&D by the federal government. In addition, to further develop an understanding of the type of R&D done with federal funding, we visited the USDA Agricultural Research Service's National Center for Agricultural Utilization Research in Peoria, Illinois and National Laboratory for Agriculture and the Environment in Ames, Iowa. We also visited a DOE Office of Science Bioenergy Research Center in Madison, Wisconsin.

To describe expert views on the extent to which advanced biofuels are technologically understood and on the factors that will affect the speed and volume of production, we contracted with the National Academy of Sciences to convene a group of 20 experts for a 2-day meeting in May 2016. One expert was unable to attend the meeting, and we interviewed him separately. (See app. II for a list of the experts who participated.) Participants, who were identified and recommended by the National Academy of Sciences and approved by us, included experts in advanced biofuels feedstocks, conversion technologies, and the use of biofuels from industry, academia, and research organizations.

We asked these experts to discuss the technological readiness of a variety of biofuels and the economic and other factors that may affect the speed and volume of their commercial-scale production. Specifically, we asked the experts to discuss the short-, medium-, and long-term technical potential of a variety of advanced biofuels and the conversion processes and feedstocks that can be used to make them, as well as any opportunities and challenges associated with these fuels, conversion processes, and feedstocks. We also asked them to discuss the most important economic and scale-up factors that will affect the speed and volume of commercial-scale production of advanced biofuels once they are technologically ready, and any particular areas on which the federal government should focus its R&D efforts to advance the technological readiness of advanced biofuels. We analyzed summary statements agreed upon by experts at the meeting as well as meeting transcripts to inform this report.

To better understand the extent to which advanced biofuels are technologically understood and the factors that will affect the speed and volume of production, we also interviewed representatives, either in person or over the phone, from 11 companies that produce, or aim to produce, advanced biofuels. We visited POET-DSM's cellulosic ethanol plant in Emmetsburg, Iowa; Quad County Corn Processor's' cellulosic ethanol plant in Galva, Iowa; and Solazyme's demonstration plant in Peoria, Illinois. Producers were selected on the basis of technology used and scale of production to ensure a variety of perspectives. Specifically, we selected companies that are using well-established technologies and producing at commercial scale, companies using first-of-their-kind technologies and producing at commercial scale, and companies using first-of-their-kind technologies and not yet producing at commercial scale. These selection criteria allowed us to obtain broader perspectives on the logistical challenges of scaling up a technology, the factors involved in processing different fuel types, and the factors involved in EPA

registration. These producer interviews provided key insights on and real-world examples of the factors that influence the speed and scale of advanced biofuel production; however, the results of our interviews cannot be generalized to all producers. (See app. III for a list of producers interviewed.)

We conducted this performance audit from June 2015 to November 2016 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Expert Meeting Participants

The experts who participated in our meeting on advanced biofuels research and development at the National Academy of Sciences on May 26 and 27, 2016, are listed below.

John Benemann
CEO, MicroBio Engineering, Inc.

Dan Cummings
CEO, Guidewire Strategies

Brian H. Davison
Chief Scientist for Systems Biology and Biotechnology, Oak Ridge National Laboratory

Zia Haq
Senior Analyst and Defense Production Act Coordinator, Bioenergy Technology Office, U.S. Department of Energy

George Huber
Harvey Spangler Professor of Chemical Engineering, University of Wisconsin-Madison

Stephen R. Kaffka
Extension Specialist, Department of Plant Sciences and Director, California Biomass Collaborative, University of California, Davis

Douglas Karlen
Research Soil Scientist, U.S. Department of Agriculture – Agricultural Research Service, National Laboratory for Agriculture and the Environment

Lee Rybeck Lynd
Paul and Joan Queneau Distinguished Professor of Engineering and Adjunct Professor of Biology, Thayer School of Engineering, Dartmouth

Stephen Mayfield
Co-Director, Food & Fuel for the 21st Century and Director, California Center for Algae Biotechnology, University of California, San Diego

Maureen Caroline McCann
Director, Energy Center and Professor of Biological Sciences, Purdue University

Stephen J. McGovern
Principal, PetroTech Consultants

John A. Miranowski
Professor of Economics, Iowa State University

Michael Sanford
Technical Lead, DuPont Industrial Biosciences

Stephanie Y. Searle
Senior Researcher, International Council on Clean Transportation

David Shonnard
Robbins Chair, Department of Chemical Engineering, and Director, Sustainable Futures Institute, Michigan Technological University

Daniel Strope
President, Refining Sciences, LLC

Wallace A. Tyner
James and Lois Ackerman Professor, Department of Agricultural Economics, Purdue University

Paul Willems[1]
Technology Vice-President for Energy Biosciences, BP

Charles Wyman
Distinguished Professor, Department of Chemical and Environmental Engineering, and Ford Motor Company Chair in Environmental Engineering, Bourns College of Engineering Center for Environmental Research and Technology, University of California, Riverside

Sonia Yeh
Adlerbertska Visiting Professor at Chalmers University of Technology, Sweden, 2015-2016 and Research Scientist, Institute of Transportation Studies, University of California, Davis

[1]Dr. Willems was not able to attend the expert meeting. We interviewed him separately.

Appendix III: Advanced Biofuels Producers Interviewed

The companies listed below are advanced biofuels producers we interviewed between January and June of 2016 to inform this report.

- Aemetis
- Cool Planet
- Dupont
- Ensyn
- Lanzatech
- POET-DSM
- Quad-County Corn Processors
- Renewable Energy Group (REG)
- Solazyme[1]
- Virent
- Waste Management Renewable Energy (WMRE)

[1]In March 2016, Solazyme announced it was focusing the company exclusively on food, nutrition, and specialty ingredients, and changing its name to TerraVia to reflect this focus.

Appendix IV: Comments from the Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 16 2016

OFFICE OF
AIR AND RADIATION

Mr. Frank Rusco
Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, N.W.
Washington, D.C. 20548

Dear Mr. Rusco:

Thank you for the opportunity to review and comment on the U.S. General Accountability Office's draft report, "Low Expected Production Volumes Make It Unlikely That Advanced Biofuels Can Meet Increasing Targets" (GAO-17-108). As stated in the report, GAO's objectives were to examine: (1) how the federal government has supported advanced biofuels research and development (R&D) in recent years and where its efforts have been targeted, and (2) expert views on the extent to which advanced biofuels are technologically understood, and the factors that will affect the speed and volume of production.

I am responding on behalf of the U.S. Environmental Protection Agency, as one of the primary offices that participated in this review is the EPA's Office of Air and Radiation. As the report acknowledges, the vast majority of federal biofuel R&D funding is allocated through the Departments of Energy and Agriculture; the EPA is not primarily an R&D agency, and our funding for biofuels R&D is negligible relative to that of other federal efforts. As the agency charged with implementing the Renewable Fuel Standard Program (RFS), however, the EPA is directly involved in the advanced biofuel sector, and we monitor multiple facets of advanced biofuel development on an ongoing basis. The EPA believes that GAO's draft report provides a helpful overview of some of the technological and economic challenges associated with increasing production of advanced biofuels. This report does not contain any recommendations. Below I provide a handful of observations on the draft report.

The EPA agrees with the report's findings that it is unlikely the Congressional volume targets established for advanced biofuels under the RFS will be met. As part of our work establishing the annual volume requirements under the RFS program, the EPA invests significant time and resources in assessing the state of the advanced biofuel industry and the ability of the marketplace to absorb any such advanced biofuels. As the report notes, some advanced biofuels are technologically well understood and commercially viable today, including biodiesel and renewable diesel. Others, particularly cellulosic and drop-in biofuels, still face significant technological and economic challenges before wide-scale commercial production and use can be achieved. Through our annual rulemaking

efforts we have concluded that the Congressionally-established targets for advanced biofuels in certain years can not be met, and we have exercised our waiver authorities under the Clean Air Act to adjust the volumes appropriately.[1] Those rulemakings provide in-depth information on the volumes of advanced biofuels we estimate to be available, and provide a complementary source of information to this GAO report on the topic. The challenges associated with expanding production of some advanced biofuels, which we detail in those rulemakings, also helps clarify why federal research is shifting towards "drop-in" fuels, as GAO documents in the draft report.

The EPA generally agrees with factors in the draft report identified as affecting the speed and volume of future advanced biofuel production, and which will make achieving future significant increases challenging. These factors include the low price of fossil fuels relative to advanced biofuels; the high cost of converting cellulosic feedstocks; the time and cost to bring a new technology to commercial scale production; and an underdeveloped feedstock supply chain. The draft report also identifies in this list "uncertainty about government policy," including uncertainty about whether the RFS will "remain in place," and the levels at which the EPA will set annual volume requirements. The EPA acknowledges that sources of policy uncertainty exist, and in recent years we have endeavored to reduce any uncertainty that might arise through the EPA actions. For example, we have successfully returned to issuing annual volume rules on the Congressionally-required timetable, and our volume rules have set targets for advanced biofuel growth that increase steadily but at a realistically achievable pace. Other sources of policy uncertainty are not within our control. For example, some stakeholders have communicated to the EPA that the statute's requirement to establish the volume requirements for the program on an annual basis itself contributes to uncertainty in the marketplace, but any change to this approach would require Congressional amendments to the law. As to whether the RFS will "remain in place," we note that while Congress set out volumetric targets only through 2022, it gave the EPA, in coordination with the Departments of Agriculture and Energy, responsibility for setting targets in 2023 and beyond.[2]

It is important to note that the shortfall in meeting the Congressional advanced biofuel targets is largely due to the gap between current cellulosic biofuel production and the statutory targets. Other non-cellulosic advanced biofuels, like biodiesel and renewable diesel, are being produced and used successfully. The EPA's recent biodiesel targets, for example, are double the statutory minimum.

With respect to another challenge citied in the report – the time and cost to secure fuel certification and acceptance – we note that the EPA has made strides in streamlining some of our processes (the report accurately notes that some of the certification/acceptance issues do not relate to the EPA's responsibilities). For example, we have improved the quality, transparency, and efficiency of our petition review process for new biofuel pathways that can count under the RFS program. These improvements to our pathways review process are already making a difference. Since putting our streamlining initiative into place, we have approved several new pathways for second-generation biofuels.

[1] See, for example, Renewable Fuel Standard Program: Standards for 2014, 2015, and 2016 and Biomass-based Diesel Volume for 2017; Final Rule, 80 Fed. Reg. 77420 (2015) and Renewable Fuel Standard Program: Standards for 2017 and Biomass-Based Diesel Volume for 2018; Proposed Rule, 80 Fed. Reg. 34778 (2016).
[2] See Clean Air Act Section 211(o)(2)(B)(ii).

Finally, we note that the Agency continues to take actions that will support growth in advanced biofuel volumes over time. This work complements federal R&D efforts on advanced biofuels, and includes actions such as establishing annual volume standards that require increasing volumes of advanced biofuels over time.[3] It also includes other regulatory work, such as our recently proposed *Regulatory Enhancement and Growth Support* rulemaking, a collection of regulatory changes intended to support market growth of advanced and other biofuels in the U.S.[4] That proposal, for example, would establish an updated regulatory structure that would allow biofuel producers to partially process renewable feedstocks at one facility and further process them into renewable fuels at another facility under existing pathways. This would increase the economics and efficiency for the production of biofuels, particularly advanced and cellulosic fuels that have the lower carbon footprints.

Thank you again for the opportunity to review and respond to the draft report. If you have any questions or require further information, please contact Julia Burch at (202) 564-0961.

Sincerely,

Janet G. McCabe
Acting Assistant Administrator

Enclosure: EPA edits to draft GAO report

[3] https://www.epa.gov/renewable-fuel-standard-program/proposed-renewable-fuel-standards-2017-and-biomass-based-diesel
[4] https://www.epa.gov/renewable-fuel-standard-program/proposed-renewables-enhancement-and-growth-support-regs-rule

3

Appendix V: GAO Contact and Staff Acknowledgments

GAO Contact:

Frank Rusco, (202) 512-3841 or ruscof@gao.gov

Staff Acknowledgments:

In addition to the contact named above, Karla Springer (Assistant Director), Tim Bober, Philip Farah, Cindy Gilbert, Connor Kincaid, Jesse Lamarre-Vincent, Janice Latimer, Cynthia Norris, Madhav Panwar, Marietta Mayfield Revesz, Dan Royer, Angela Smith, and Barbara Timmerman made key contributions to this report.