EPA/600/R-24/343F| January 2025| www.epa.gov/research

EPA
United States
Environmental Protection
Agency

Biofuels and the Environment:

Third Triennial Report to Congress

EPA/600/R-24/343F
January 2025

Biofuels and the Environment
Third Triennial Report to Congress

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC

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Acronyms and Abbreviations

ABS	Anti-backsliding study
ACEP	Agricultural Conservation Easement Program
ACP	Acidification potential
ADAGE	Applied Dynamic Analysis of the Global Economy
AEO	Annual Energy Outlook
AEPE	Agricultural Energy Partial Equilibrium
AFDC	Alternative Fuels Data Center
AI	Active ingredient
AKI	Anti-knock index
Al	Aluminum
AMPA	Aminomethylphosphonic acid
ANL	Argonne National Laboratory
ANPRM	Advance notice of proposed rulemaking
APEX	Agricultural policy extender
APHIS	Animal and Plant Health Inspection Service, part of the U.S. Department of Agriculture (USDA)
ARMS	Agricultural Resource Management Survey
ARPA-E	Advanced Research Projects Agency-Energy
ARS	Agricultural Research Service, part of the U.S. Department of Agriculture (USDA)
ATTAINS	Assessment, Total Maximum Daily Load Tracking and Implementation System
B5, B10, B20, B100	Types of biodiesels (blended with 5%, 10%, 20% and 100% of biodiesel relative to diesel)
BAP	Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Program
BAT	Base acres treated
BAU	Business as usual
BBD	Biomass-based diesel
BBS	Breeding Bird Survey
BC	Black carbon
BEA	Bureau of Economic Analysis, part of the U.S. Department of Commerce
BEAD	Biological and Economic Analysis Division, part of the U.S. Environmental Protection Agency (EPA)
BEIOM	Bioeconomy Economic Input Output Model

Bgal	Billion gallons
BIP	Biofuel Infrastructure Partnership
BMP	Best management practice
BOB	Blendstock for oxygenate blending
BRS	Biotechnology Regulatory Services
BSM	Biomass Scenario Model
BT16	2016 Billion Ton Study
BTC	Biodiesel Tax Credit
BTU	British thermal unit
BWF	Blue water footprint
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAC	Central America and the Caribbean
Ca	Calcium
$CaCO_3$	Calcium carbonate
CAFE	Corporate average fuel economy
CAG	Crop acres grown
CARB	California Air Resources Board
CARD	Center of Agricultural and Rural Development
$CaSO_4$	Calcium sulfate
CBI	Caribbean Basin Initiative
CCS	Carbon capture and storage
CDL	Cropland data layer
CDPF	Catalyzed diesel particulate filter
CDS	Condensed distillers' solubles
CEAP	Conservation Effects Assessment Project
CEC	California Energy Commission
CFR	Code of Federal Regulations
CGE	Computable general equilibrium
CGF	Corn gluten feed
CGM	Corn gluten meal
CH_4	Methane
CI	Confidence interval
CL	Confidence limit

CLCA	Consequential lifecycle analysis
CMAQ	Community Multiscale Air Quality
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CONUS	Contiguous United States
COP23	23rd Conference of the Parties
CPI	Consumer Price Index
CRC	Coordinating Research Council
CRD	Cropland Reporting Districts
CRLF	California red legged frog
CRP	Conservation Reserve Program
CS	Corn-soybean
CSP	Conservation Stewardship Program
D3	D-code for generating RINs with cellulosic biofuel
D4	D-code for generating RINs with biomass-based diesel
D5	D-code for generating RINs with advanced biofuel
D6	D-code for generating RINs with renewable biofuel
D7	D-code for generating RINs with cellulosic biofuel or biomass based diesel
DBP	Disinfection by-products
DCO	Distillers’ corn oil
DDG	Distillers’ dried grains
DDGS	Distillers’ dried grains with solubles
DEER	Diesel Engine-Efficiency and Emissions Research
DEM	Digital Elevation Model
DG	Distillers’ grains
DisN	Dissolved nitrogen
DisP	Dissolved phosphorus
DOC	Dissolved organic carbon
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOM	Dissolved organic matter
DON	Dissolved organic nitrogen
DPPR	Dakota Prairie Pothole Region

DRIA	Draft Regulatory Impact Analysis
DWG	Distillers' wet grains
DWGS	Distillers' wet grains with solubles
E0, E10, E15, E85	Types of gasoline (blended with 0%, 10%, 15% and 85% of ethanol relative to gasoline)
E&P	Extraction and production
EAEP	Enzyme-assisted aqueous extraction process
EAS	Exhaust aftertreatment systems
EC	Elemental carbon
EC50	Median effective aqueous concentrations
EDDMapS	Early Detection and Distribution Mapping System
EEF	Enhanced efficiency fertilizer
EEIO	Environmentally-extended input-output
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act
EJ	Exajoule
EMTS	EPA Moderated Transaction System
EOR	Enhanced oil recovery
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 1992
EPIC	Environmental Policy Integrated Climate
EQIP	Environmental Quality Incentives Program
ERD	External review draft
ERS	Economic Research Service, part of the U.S. Department of Agriculture (USDA)
ESA	Endangered Species Act
ET	Evapotranspiration
ETBE	Ethyl-tertiary-butyl-ether
EU	European Union
FAA	Federal Aviation Administration
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
FAS	Foreign Agricultural Service, part of the U.S. Department of Agriculture (USDA)
FASOM	Forest and Agricultural Sector Model
FCA	Food, Conservation and Energy Act of 2008

FD	Final demand
FDA	U.S. Food and Drug Administration
Fe	Iron
FFV	Flex-fuel vehicles
FIA	Forest Inventory and Analysis
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FOB	Freight on board
FOD	First order draft
FOGs	Fats, oils, and greases
FQAPA	Food Quality Protection Act
FR	Federal Register
FRIS	Farm and Ranch Irrigation Survey
FSA	Farm Service Agency, part of the U.S. Department of Agriculture (USDA)
GAIN	Global Agricultural Information Network
GCAM	Global Change Analysis Model
GCAU	Grain consuming animal units
GCRP	Grassland subprogram of the Conservation Reserve Program
GDI	Gasoline direct injection
GDP	Gross domestic product
GE	General equilibrium (Chapter 4 and 6)
GE	Genetically engineered (Chapter 3)
GHG	Greenhouse gas
GIS	Geographic information system
GLOBIOM	Global Partial Equilibrium Model
GRCAU	Grain and roughage consuming animal units
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies
GRSW	Grassed waterways
GTAP	Global Trade Analysis Project
GTW	Grease trap waste
GWP	Global warming potential
H_2O	Water
HAA	Haloacetic acids
HAB	Harmful algal blooms
HACCP	Hazard analysis and critical control points

HBIIP	Higher Blends Infrastructure Incentive Program
HERO	Health and Environmental Research Online database
HP	Horsepower
HPA	High Plains Aquifer
HPCAU	High-protein consuming animal units
HS	Harmonized System
HSMU	Homogenous spatial mapping units
HT	Herbicide-tolerant
HTP	Human toxicity potential
HUC	Hydrologic Unit Code
IAM	Integrated assessment model
ICCS	Industrial Carbon Capture and Storage
ICTSD	International Centre for Trade and Sustainable Development
ILUC	Indirect land use change
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated pest management
IPPC	International Plant Protection Convention
IR	Insect resistant
JCA	Jobs Creation Act
K	Potassium
K_2O	Potassium oxide
KOH	Potassium hydroxide
LAMPS	Land-use and Agricultural Management Practice web-Service
LANID	Landsat-based Irrigation Dataset
LC	Land cover
LCA	Life cycle assessment
LCC	Land capability class
LCFS	Low Carbon Fuel Standard
LCI	Lifecycle inventory
LCIA	Life cycle impact assessment
LCLM	Land-cover-land-management
LEMA	Local enhancement management area
LFG	Landfill gas

LM	Land management
LMOP	Landfill Methane Outreach Program
LMRB	Lower Mississippi River Basin
LNG	Liquified natural gas
LTAP	Long term agricultural projections
LUC	Land use change
LULUC	Land use and land use change
Mac	Million acres
MCE	Model Comparison Exercise
MCL	Maximum contaminant level
Mg	Magnesium
MGY	Million gallons per year
MJ	Megajoules
MLU	Major land use
MMI	Multi-metric index
Mn	Manganese
MORB	Missouri River Basin
MOVES	MOtor Vehicle Emission Simulator
MSAT	Mobile source air toxics
MSQA	Midwest Stream Quality Assessment
MSW	Municipal solid waste
MT	Metric tonnes
MTBE	Methyl tert-butyl ether
MU	University of Missouri
MY	Market year
N	Nitrogen
N_2O	Nitrous oxide
Na	Sodium
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NAIP	National Agricultural Imagery Program
NaOH	Sodium hydroxide
NARS	National Aquatic Resource Surveys
NASA	U.S. National Aeronautics and Space Administration

NASEM	National Academies of Science, Engineering, and Medicine
NASS	National Agricultural Statistics Service, part of the U.S. Department of Agriculture (USDA)
NAWCA	North American Wetlands Conservation Act
NAWMP	North American Waterfowl Management Plan
NAWQA	National water-quality assessment
NCCA	National Coastal Condition Assessment
NCDC	National Climatic Data Center
NCEI	National Centers for Environmental Information
NEI	National Emissions Inventory
NH_3	Ammonia
NLA	National Lakes Assessment
NLCD	National Land Cover Dataset
NMFS	National Marine Fisheries Service
NMHC	Non-methane hydrocarbon
NMOG	Non-methane organic gases
NOAA	U.S. National Oceanic and Atmospheric Administration
NO_X, NO, NO_2, NO_3	Nitrogen oxides
NPL	Northern Plains
NRCS	National Resources Conservation Service, part of the U.S. Department of Agriculture (USDA)
NREL	National Renewable Energy Laboratory
NRI	Natural Resources Inventory
NRSA	National Rivers and Streams Assessment
NSE	Nash-Sutcliffe efficiency
NUE	Nitrogen use efficiency
NWALT	National Wall-to-Wall Anthropogenic Land Use Trends
NWS	National Weather Service
O_2	Oxygen
O_3	Ozone
OCSPP	Office of Chemical Safety and Pollution Prevention, part of the U.S. Environmental Protection Agency (EPA)
ODP	Ozone depletion potential
OPEC	Organization of the Petroleum Exporting Countries

OPIS	Oil Price Information Service
OPP	Office of Pesticide Programs, part of the U.S. Environmental Protection Agency (EPA)
ORAU	Oak Ridge Associated Universities
ORB	Ohio River Basin
OrgN	Organic nitrogen
OrgP	Organic phosphorus
OTAQ	Office of Transportation and Air Quality, part of the U.S. Environmental Protection Agency (EPA)
P	Phosphorus
P2O5	Phosphorus pentoxide
P&E	Palustrine and estuarine
PADD	Petroleum Administration for Defense District
PAN	Peroxyacetyl nitrate
PBIAS	Percent bias
PCT	Percent crop treated
PE	Partial equilibrium
PEP	PM exposure potential
PFI	Port fuel injection
pH	Expression of the hydrogen ion in water
PHEV	Plug-in hybrid vehicles
PM	Particulate matter
$PM_{2.5}$, PM_{10}	Particulate matter with a nominal mean aerodynamic diameter less than or equal to 2.5 or 10 µm
PMI	Particulate matter index
PMP	Particle measurement programme
PN	Particle number
POC	Precursor organic compounds
POLYSYS	Policy Analysis System Model
POTW	Publicly owned treatment works
PPQ	Plant protection and quarantine
PPR	Prairie Pothole Region
PRELIM	Petroleum Refinery Life Cycle Inventory Model
PRIA	Pesticide Registration Improvement Extension Act
PWS	Public water systems
QBTU	Quadrillion British thermal units

RB	Riparian buffer
RBSB	Riparian buffer/saturated buffers
RCAU	Rough consuming animal units
RFA	Renewable Fuels Association
RFG	Reformulated gasoline
RFS	Renewable Fuel Standard
RIA	Regulatory Impact Analysis
RIN	Renewable Identification Number
RMP	Risk mitigation plan
RNG	Renewable natural gas
ROA	Real options analysis
RRB	Republican River Basin
RRR	Registration, reporting, and recordkeeping
RSPO	Roundtable on Sustainable Palm Oil
RtC1	First Triennial Report to Congress
RtC2	Second Triennial Report to Congress
RtC3	Third Triennial Report to Congress
RVO	Renewable volume obligations
RVP	Reid vapor pressure
SB	Saturated buffer
SCOPE	Scientific Committee on Problems of the Environment
SCR	Selective catalytic reduction
SDWA	Safe Drinking Water Act
SEDS	State Energy Data System
SFP	Smog formation potential
SHP	Southern High Plains
SO_2	Sulfur dioxide
SOC	Soil organic carbon
SOM	Soil organic matter
SPA	Structural path analysis
SPN	Solid particle number
SRE	Small refinery exemption
SRWC	Short-rotation woody crop
SS	Suspended sediments

STATSGO	State Soil Geographic Database
STEO	Short Term Energy Outlook
STIR	Soil Tillage Intensity Ratings
SWAT	Soil and Water Assessment Tool
T&E	Threatened and endangered
TAME	Tertiary-amyl-methyl-ether
TBA	Tertiary-butyl-alcohol
THC	Total hydrocarbons
THM	Trihalomethanes
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TPL	Temperate Plains
TRACI	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts
TRF	Total renewable fuel
TSS	Total suspended sediment
TVA	Tennessee Valley Authority
UCO	Used cooking oil
UL	Underwriters Laboratories
ULSD	Ultra-low sulfur diesel
UMRB	Upper Mississippi River Basin
UMW	Upper Midwest
UN	United Nations
UPGM	Unified Plant Growth Model
USDA	U.S. Department of Agriculture
USEEIO	United States Environmentally-Extended Input-Output
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USMCA	U.S., Mexico, Canada
UST	Underground storage tank
VEETC	Volumetric Ethanol Excise Tax Credit
VOC	Volatile organic compounds
VRT	Variable rate technology
WATER	Water Analysis Tool for Energy Resources

WF	Water footprint
WRA	Weed risk assessment
WRE	Wetland Reserve Easement
WSA	Wadeable Streams Assessment
WTI	West Texas Intermediate
WTP	Willingness-to-pay
WTW	Well-to-wheel
ZLD	Zero liquid discharge

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Unit Abbreviations and Conversions

Volume

1 gallon (gal) (U.S. gallon)	=	3.8 liters (L)
1 bushel (bu)	=	35 liters (L)
1 barrel (bbl)	=	42 gallons (gal)
1 acre-foot (acre-ft)	=	325,851 gallons (gal)

Area

1 acre (ac)	=	0.4 hectares (ha)
1 hectare (ha)	=	2.5 acres (ac)
1 square kilometer (km^2)	=	247 acres (ac)

Weight

1 pound (lb)	=	0.45 kilograms (kg)
1 ton (U.S. ton)	=	907 kilograms (kg)
1 gram (g)	=	0.035 ounces (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 metric ton or tonne (MT)	=	2,200 pounds (lb)
1 teragram (Tg)	=	1,102,000 tons (t)

Length

1 mile (mi)	=	1.6 kilometers (km)
1 inch (in)	=	2.5 centimeters (cm)
1 kilometer (km)	=	0.6 miles (mi)

SI Prefixes

peta = 10^{15}	centi = 10^{-2}
tera = 10^{12}	milli = 10^{-3}
giga = 10^{9}	micro = 10^{-6}
mega = 10^{6}	nano = 10^{-9}
kilo = 10^{3}	
hecto = 10^{2}	

Executive Summary

This is the Third Triennial Report to Congress on Biofuels (RtC3) as required under Section 204 of the Energy Independence and Security Act of 2007 (EISA). The purpose of the report is to examine the effects of the Renewable Fuel Standard (RFS) Program on the environment, including the impacts to date and likely future impacts to the nation's air, land, and water resources. The statute requires a focus on environmental and resource conservation issues, including effects on air quality, soil quality and conservation, water quality and availability, terrestrial ecosystems, aquatic ecosystems, and wetlands, and consideration of invasive or noxious species. This report emphasizes domestic effects, but also examines effects overseas. The RtC3 considers all 17 types of biofuels produced in or imported to the U.S. from 2005-2020 and focuses on the four biofuels that dominated U.S. production and consumption over this period: (1) ethanol from U.S. corn, (2) biodiesel from U.S. soybean, (3) biodiesel from U.S. fats, oils, and greases (FOGs), and (4) imported ethanol from Brazilian sugarcane. Although these four biofuels are the focus of the RtC3, other biofuels (cellulosic biofuels, algae, palm oil, and others) are also discussed where appropriate. While EPA acknowledges the importance of greenhouse gases (GHGs) in assessing the environmental impacts of biofuels and the RFS, consistent with earlier reports, the RtC3 does not assess them here; EPA evaluates GHGs while administering the RFS Program (Sections 201 and 202 of EISA[1]).

In the First and Second Triennial Reports to Congress on Biofuels (RtC1 and RtC2, respectively), the Agency could not separate the effects of the RFS Program from the effects of other factors (e.g., market or other policy effects). Many studies assessed the impacts from biofuels on the environment, but very few separated the effects of the RFS Program from other factors that also affect biofuel production and consumption in the United States. As attribution was identified as a major knowledge gap in previous reports, this report includes a new emphasis on attribution, referred to in this report as an "attribution analysis."

This report examines the many factors that simultaneously influenced the production and use of domestic corn ethanol in the United States to assess attribution. These factors include the need for fuel oxygenates in gasoline during the phaseout of methyl-tert-butyl-ether (MTBE) from 2003–2006, the Volumetric Ethanol Excise Tax Credit (VEETC) from 2004–2010, high oil prices from 2005–2015, and dozens of individual state biofuel programs and MTBE bans over this period. The RFS Program has

[1] Energy Independence and Security Act of 2007, Pub. L. No. 110-140, § 202, 121 Stat. 1492, 1521-28 (2007) (codified as amended at 42. U.S.C. § 7545(o)). Detailed assessment of the GHG balance of corn ethanol and other biofuels are not in scope of this report series. See Chapter 2 (Box 2.2) for an overview and see Federal Registry (FR) FRL–9307–01–OAR (https://www.epa.gov/renewable-fuel-standard-program/workshop-biofuel-greenhouse-gas-modeling) and EPA's 2023 lifecycle analysis Model Comparison Technical Document (https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1017P9B.pdf).

changed as well over this period, from the first version (RFS1) created under the Energy Policy Act of 2005, to a more robust version (RFS2) created under EISA in 2007. Because of these complexities, assessing the effect from the RFS Program as required under EISA, as opposed to the biofuels industry more generally, is challenging. Furthermore, the policy and the market are dynamic, so that the effect of the policy changes over time. Despite these challenges, by assembling multiple lines of evidence from empirical records and simulation modeling from the peer-reviewed literature, this report finds that corn ethanol production and consumption in the United States attributable to the RFS Program varies through time and may include no attributable effect. This finding is expressed throughout the report as a range in billions of gallons per year and includes zero in the range. This report estimates that from 2006 to 2011 the RFS Program—in isolation—accounted for 0–1.0 billion gallons per year of ethanol, mostly by establishing market certainty and encouraging capital investment from the RFS2, and to a lesser extent by stabilizing demand during the Great Recession of 2008–2009. From 2012 to 2018, the RFS Program accounted for an estimated 0–2.1 billion gallons per year, a wider range than from the previous period. This suggests the RFS Program is responsible for 0–9% of cumulative corn ethanol production and consumption in the United States over the historical period assessed (2005–2018).

Many uncertainties are associated with this estimate of the volume of ethanol attributable to the RFS Program. The growth of corn ethanol production in the United States over the years coincided with the MTBE phaseout by 2006, expiration of VEETC at the end of 2010, and lower oil prices after 2015. Disentangling the effect of the RFS Program, as required under EISA Section 204, is difficult given the many cooccurring factors that affect biofuels in the United States. As a mandate, the RFS Program *could have* driven most of the increase in ethanol production and consumption in the United States if it were the only factor affecting ethanol. However, as events played out, non-RFS factors that are known to also influence the market were favorable and appear to explain much of the increase in ethanol production and consumption in the United States. There are many unquantified factors not included in the attribution analysis contained in this report, including the effect of the existence of the RFS Program in influencing state biofuel programs to be enacted and the costs or willingness of refiners to switch back to producing finished gasoline if ethanol were no longer economical, to name a few. Notwithstanding various uncertainties, these ranges are estimated based on currently available information for the historical effect of the RFS Program on corn ethanol production and consumption in the United States.

For biodiesel and renewable diesel, the attributional effect of the RFS Program is estimated to be different. Using similar lines of evidence as for corn ethanol, where available, this report concludes that the RFS Program has driven a significant portion of the use of these biofuels from 2010–2020. However, there is insufficient information available at present to confidently quantify the attributional effect annually of the RFS Program for these years. This is mostly due to a lack of data and peer-reviewed studies that focus on biodiesel that control for key factors important in the biodiesel market such as the Biodiesel Tax Credit (BTC) and state incentive programs. Together, the RFS Program and the BTC are likely responsible for roughly 70–100% of soybean biodiesel and renewable diesel production and consumption in the United States.

Using the estimated range in the volume of corn ethanol attributable to the RFS Program, this report estimates the RFS Program's effect on corn ethanol production and consumption resulted in 0–1.9 million acres of cropland expansion from direct and indirect effects domestically between 2005 and 2016, and 0–3.5 million acres of corn expansion, with many years of no effect. The 1.9 million acres of cropland corresponds with less than 1% of all cropland in 2017, but also represents approximately 19% of the estimated cropland *expansion* between 2008 and 2016. The maximum of 3.5 million acres of corn corresponds with less than 5% of all planted corn in 2017 but represents an almost 35% *increase* in corn acreage between 2008 and 2016. Thus, though these upper range estimates are still small relative to the total acreage of cropland or corn, potential effects from the RFS Program may be locally significant where any land use changes may have occurred. Cropland expansion often leads to increases in soil erosion, pesticide and fertilizer applications, and losses of seminatural habitat. These upper range estimates of the effects on total cropland due to the RFS Program would have had modest negative impacts on many of the environmental effects reviewed in this report, as concluded but not quantified in the RtC1 and RtC2. However, specific areas where environmental effects may have occurred cannot be quantified with confidence due to the vast quantity of potential cropland in the United States and the multitude of factors that contribute to an individual farmer's decision whether to bring additional land into crop production. The ranges analyzed represent an updated estimate based on the currently available science and literature and may be revised as further research is conducted.

Despite the finding of potentially modest annual effects of the RFS Program nationally for the environmental impacts assessed, these may have important cumulative impacts on the environment. For example, by 2004–the year before enactment of the Energy Policy Act–over half of the historical wetlands in the lower 48 states had already been lost (>100 million acres lost), with several Midwestern states losing more than 80% of their historical wetlands. Additional losses of up to 275,000 acres of wetlands are estimated to have occurred between 2008 and 2016 from all causes, only a portion of which are attributable to the RFS Program. This acreage is small compared with historical losses but could have cumulative environmental effects or landscape level effects in some areas. Similarly, according to national surveys conducted by the EPA, 67% of the wadeable streams in the United States were already in poor or fair biological condition as of 2004. Thus, even though the RFS Program may not result in *new exceedances* of numerical nutrient thresholds, it does represent additional strain on already strained ecosystems. Moreover, the effects of the RFS Program likely fall disproportionally in certain areas of the

United States, such as in rural areas with greater amounts of grassland habitat lost to corn or soybeans. Some of these areas may contain locally endemic species and other important local environmental resources, which may appear underrepresented in a large national-scale assessment. Thus, even modest national effects do not preclude potentially larger effects at the local level. At this time, however, EPA cannot identify with any specificity and certainty which parcels of land at the local level may have been affected by the RFS Program.

International effects associated with imported biofuels, and market mediated effects on crop and biofuel production in other countries, are even more uncertain than national effects. These effects are highly uncertain due to the large range of estimates among studies, poorly evaluated differences among models, and a lack of adequate representation in these models of biofuel policies in countries other than the United States. However, effects from imported biofuel are likely modest given the relatively small quantity of imports relative to domestic biofuel production since the RFS Program went into effect. It does not necessarily follow that overall international effects of the RFS Program have been small, as research has shown the indirect effects of increased biofuel production on feedstock commodity trade flows could be substantial.

Domestically, some of the agricultural practices that can mitigate environmental impacts are becoming widely adopted (e.g., conservation tillage), while others are not (e.g., cover crops). While some of these adoptions may explain regional improvements in some environmental conditions, they do not yet appear to be large enough to improve many of the environmental effects reviewed in this report. Greater adoption of these conservation practices could help offset potential effects from the RFS Program or broader effects from agriculture.

This report reinforces the broad conclusions from the RtC1 and RtC2 on biofuels in general and further evaluates attribution of those effects to the RFS Program more specifically. Although the overall environmental effects attributable to the RFS Program to date are likely modest but negative, biofuels continue to have the potential for both positive and negative environmental effects, depending on the many factors discussed in this report.

For the future period, EPA included the estimated effects of the RFS Program for 2023–2025 as a part of the Final Set Rule 88 Federal Register 44468 (July 12, 2023). EPA projected an increase of approximately 3.9 billion ethanol equivalent gallons of renewable fuel use in the United States by 2025 due to the RFS Program. This overall increase is estimated to be primarily from compressed/liquified natural gas (CNG/LNG) derived from biogas (+932 million gallons), biodiesel and renewable diesel from soybean oil (+1,484 million gallons) and canola oil (+614 million gallons), and ethanol from corn (+787 million gallons). EPA expects smaller effects from the RFS Program on other biofuels (e.g., +110 million gallons of renewable diesel from FOGs). For the crop-based biofuels with potential effects on cropland, EPA estimated the RFS Program could potentially lead to an increase of as much as 2.65 million acres of cropland by 2025. These estimated increases in the future are on top of historical effects. As with the historical land use changes, EPA cannot at present identify with any specificity and certainty which parcels of land at the local level may be affected by the RFS Program. Several factors contribute to uncertainty in these estimates of the likely future, including ongoing recovery from the global COVID-19 pandemic, uncertainty in the penetration of E15 in the marketplace, competition with other technologies such as electric vehicles, and continued but slow growth of cellulosic ethanol production from agricultural or marginal lands. As policy and market conditions change, so may the factors to consider and the estimate of the likely future effects of the RFS Program. Further details can be found in the associated docket (EPA-HQ-OAR-2021-0427).

Detailed recommendations are discussed in this report and primarily include research recommendations to fill key knowledge gaps to support policy decision making. These include, but are not limited to, research to improve estimates of the attributional effect from the RFS Program on all types of biofuels that include realistic industry and economic detail, methods to link these attributional effects to specific land areas domestically and internationally, improved remote sensing and local data to enable verification of these estimated changes on the land, and more research overall on the environmental effects from newly emerging biofuels. Furthermore, conservation practices exist to offset many of the environmental effects from the cultivation of conventional biofuel feedstocks (e.g., corn, soybean) and agricultural effects more generally; and, while some of these have been widely adopted (e.g., conservation tillage), some have not (e.g., cover crops). A sustained effort to deploy these practices across a wider area, especially in areas of recent cropland expansion may be needed to offset the potential negative effects from the RFS Program specifically and biofuels more generally.

Integrated Synthesis

This is the Third Triennial Report to Congress on Biofuels (RtC3) as required under Section 204 of the Energy Independence and Security Act of 2007 (EISA[1]). The purpose of this report and its predecessor reports (i.e., the First and Second Triennial Reports to Congress on Biofuels, RtC1 and RtC2, respectively) is to assess the "impacts to date and likely future impacts" of the Renewable Fuel Standard (RFS) Program on a range of environmental and resource conservation issues. Section 204 states:

"(a) In General. Not later than 3 years after the enactment of this section and every 3 years thereafter, the Administrator of the Environmental Protection Agency, in consultation with the Secretary of Agriculture and the Secretary of Energy, shall assess and report to Congress on the impacts to date and likely future impacts of the requirements of Section 211(o) of the Clean Air Act on the following:

1. *Environmental issues, including air quality, effects on hypoxia, pesticides, sediment, nutrient and pathogen levels in waters, acreage and function of waters, and soil environmental quality.*
2. *Resource conservation issues, including soil conservation, water availability, and ecosystem health and biodiversity, including impacts on forests, grasslands, and wetlands.*
3. *The growth and use of cultivated invasive or noxious plants and their impacts on the environment and agriculture.*

In advance of preparing the report required by this subsection, the Administrator may seek the views of the National Academy of Sciences or another appropriate independent research institute. The report shall include the annual volume of imported renewable fuels and feedstocks for renewable fuels, and the environmental impacts outside the United States of producing such fuels and feedstocks. The report required by this subsection shall include recommendations for actions to address any adverse impacts found."

What follows is the "Report at-a-Glance," which provides a high-level bulleted overview of the entire RtC3. The Integrated Synthesis then describes the background on the scope and content of the RtC3 and compares the overall conclusions from the RtC3 with the RtC2. Subsequently, the Integrated Synthesis presents the specific conclusions from individual chapters on the impacts to date and likely future impacts from the RFS Program.[2] The Integrated Synthesis then closes with discussion of uncertainties and limitations, and future recommendations.

[1] Energy Independence and Security Act of 2007, Pub. L. No. 110-140, 121 Stat. 1492, preamble (2007).
[2] In the RtC3, the term "impacts" is used to generally mean negative effects, while "effects" are more general and may be positive or negative.

Report At-a-Glance

Main Conclusions

- The impacts to date from the RFS Program are separate from, but overlap with, the effects of biofuels as an industry more generally. The estimated impacts to date from the RFS Program varied through time and for different biofuels as conditions in the market and co-occurring policies at the state and federal levels changed. The estimated impacts are expressed throughout the report as a range in billions of gallons per year and may include zero in the range.
- The impacts the RFS Program may have had in the past do not dictate the potential future effects of the Program, which can change as feedstocks, production, and conversion processes change.

Background

- The RtC3 assesses all 17 types of biofuels that were produced in or imported to the United States from 2005 through 2020. Emphasis is placed on the environmental and resource conservation issues specified in Section 204 from the production and use of biofuels that dominated U.S. production and consumption over this interval. These include: (1) domestic corn ethanol, (2) domestic soybean biodiesel, (3) domestic biodiesel from fats, oils, and greases (FOGs), and (4) imported ethanol from Brazilian sugarcane [Chapter 2, sections 2.3 and 2.5, Table 2.1, 2.2]. Although the focus of the RtC3 is on these four biofuels, other biofuels and their effects are discussed where appropriate [Chapters 8–15, sections 8.6, 9.6, etc., and Chapter 16].
- The period of rapid growth in the domestic corn ethanol industry was from 2002 to 2012. The RFS Program has changed over this period. The two versions of the RFS Program are commonly called the “RFS1” (in effect 2006–2008) and “RFS2” (in full effect since 2010). Nearly 40% of the increase in ethanol consumption had already occurred by the first full year of the RFS1 in 2006, and over 90% of the increase in consumption had already occurred by the first full year of the RFS2 in 2010 [Chapter 6, section 6.2].
- After decades of decline in cultivated cropland since at least the 1980s, increases in cultivated cropland by roughly 6–10 million acres have been recorded in multiple federal datasets, using a variety of methodologies, following the 2007 to 2012 period. This increase in cultivated cropland was largely driven by a net 26.5 million-acre increase in corn and soy with small grains and hay in rotation decreasing by 16.5 million acres. More than half of the corn and soybean acreage increase has come from other cultivated cropland (56%), while the rest has come from smaller proportions of pasture (13%), noncultivated cropland (20%), and the Conservation Reserve Program (CRP, 11%). Many of these changes are taking place throughout the Midwest, with

hotspots in northern Missouri, eastern Nebraska, North and South Dakota, Kansas, and parts of Wisconsin [Chapter 5, section 5.3].

- While EPA acknowledges the importance of greenhouse gases (GHGs) in assessing the environmental impacts of biofuels and the RFS, consistent with earlier reports, the RtC3 does not assess them here; EPA evaluates GHGs while administering the RFS Program (Sections 201 and 202 of EISA[3]).

Attribution

- Data allows for quantitative attribution of the potential impacts of the RFS Program on corn ethanol production and consumption. Information from economic models, observed prices for compliance credits (i.e., Renewable Identification Numbers [RINs]), and other sources suggest that from 2006 to 2011 the RFS Program—in isolation—accounted for 0–1 billion gallons per year of the U.S. corn ethanol produced and consumed. The estimated effect in these early years may have been primarily driven by encouraging market growth and capital investment and to a lesser extent by stabilizing demand during the Great Recession of 2008–2009. Other factors together likely played a more significant role in these earlier years (e.g., replacement of methyl tert-butyl ether [MTBE], volumetric excise tax credit [VEETC], and changes in refining operations). In more recent years other factors impacted the corn ethanol marketplace as well, such that the effect of the RFS Program is estimated to be 0–2.1 billion gallons per year [Chapter 6, sections 6.2, 6.3]. Based on these data, it is estimated that 0–9% of the corn ethanol production and consumption in the United States from 2005–2018 is attributable to the RFS Program.
- Uncertainties in the estimated effect of the RFS Program on domestic corn ethanol production and consumption remain, including the effect of the RFS Program in establishing market certainty and infrastructure buildout before the mandates were in full effect, future crude oil prices, the costs or willingness of refiners to switch back to producing finished gasoline without ethanol if blending ethanol were no longer economical, and many others. These factors are difficult to quantify. Thus, notwithstanding the many uncertainties, the ranges above represent the most current estimates based on current information for the effect of the RFS Program on domestic corn ethanol production and consumption in the United States [Chapter 6, sections 6.3.7, 6.4.4, 6.6].

[3] Energy Independence and Security Act of 2007, Pub. L. No. 110-140, § 202, 121 Stat. 1492, 1521-28 (2007) (codified as amended at 42. U.S.C. § 7545(o)). Detailed assessment of the GHG balance of corn ethanol and other biofuels are not in scope of this report series. See Chapter 2 (Box 2.2) for an overview and see Federal Registry (FR) FRL–9307–01–OAR (https://www.epa.gov/renewable-fuel-standard-program/workshop-biofuel-greenhouse-gas-modeling) and EPA's 2023 lifecycle analysis Model Comparison Technical Document (https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1017P9B.pdf).

- The RFS Program likely had a larger effect on biodiesel and renewable diesel (and other biofuels) throughout the years of the RFS2. However, there is insufficient information available at present to confidently quantify the attributional effect annually of the RFS Program alone on biodiesel and renewable diesel. This is mostly due to a lack of data and peer-reviewed studies that focus on biodiesel and control for key factors important in the biodiesel market, such as the Biodiesel Tax Credit (BTC) and state incentive programs. Initial estimates suggest that taken together, the RFS Program and the BTC are likely responsible for 70–100% of historical biodiesel and renewable diesel use in the United States [Chapter 7].
- The development of the dry mill ethanol industry in the United States was largely underway and mostly completed by the time that the RFS2 was passed and took effect. These legislative and regulatory actions, or the prospects of them, likely provided policy certainty for investors, including farmer cooperatives. The use of corn and soybean surpluses for transportation—driven by a variety of factors—was in effect a market clearing mechanism that reduced surplus stocks, sustained crop prices above the costs of production, and partially shifted the support of agricultural surpluses from the Farm Bill to the transportation sector.
- This report only quantifies the volumes of corn ethanol attributable to the RFS Program alone and therefore the effects on land and other environmental and resource conservation issues are only quantified for the RFS-effect on corn ethanol, and not for the RFS-effect on soybean biodiesel or other biofuels.
- As the effect of the RFS Program on corn ethanol varies through time and includes zero, so do estimates on cropland expansion from the RFS Program [Chapter 6, section 6.4]. Between zero and 1.9 million acres of new cropland (0–20% of the observed *increase* in cropland, 0–0.5% of all cropland) and between zero and 3.5 million acres of additional corn (0–35% of the observed *increase* in corn, 0-3.7% of all corn), mostly in the Midwest, are estimated to be attributable to the RFS Program. Data limitations prevent the isolation of the exact areas of cropland expansion that were estimated attributable to the RFS Program. For the high end of these ranges, there is a greater estimated increase in corn acreage than overall cropland acreage because some new corn may come from switching of crops on existing cropland (commonly from soy, wheat, or cotton).

Environmental Effects

- Applying the estimated ranges of cropland expansion potentially attributable to the RFS Program suggests that the RFS Program may have been responsible for a range of effects, from no effect to small negative effects on soil quality [Chapter 9, section 9.3.3], water quality [Chapter 10, section 10.3.3], and other environmental effects covered in this report, as concluded but not quantified in the RtC1 and RtC2. More precise descriptions or quantifications of effects on various environmental end points are not possible because data identifying specific areas of RFS-induced land use change are unavailable.

- The RtC3 reiterates the conclusions from the RtC1 and RtC2 that emissions of nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), volatile organic compounds (VOCs), ammonia (NH_3), and particulate matter ($PM_{2.5}$) can occur at each stage of biofuel production, distribution, and usage and impact air quality [Chapter 8]. In addition, impacts on ambient concentrations vary depending on the geographic location and local conditions. The EPA's anti-backsliding study, which focused on changes in air quality associated with vehicle and engine emissions (rather than the full lifecycle) using "pre-RFS" fuel and "with-RFS" fuel, found ozone and $PM_{2.5}$ can increase or decrease depending on location, and in general, NO_2 and acetaldehyde increase, while CO and benzene decrease [Chapter 8, section 8.3.2.2].
- Lifecycle assessments of criteria air pollutants and precursors using GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies) suggest that lifecycle emissions per unit energy from corn ethanol are generally higher than from gasoline for VOCs, SO_x, $PM_{2.5}$, PM_{10}, and NO_x, and that lifecycle emissions per unit energy from soybean biodiesel are generally higher than from diesel for VOCs, SO_x, and NO_x. However, the location of emissions from biofuel production tends to be in more rural areas where there are fewer people. How this translates to health effects on communities is complex, as it depends not only on the number of people, but on their demographics and vulnerability, as well as the dose-response relationship, which is pollutant-specific, among other factors. Trends suggest that the potential lifecycle effects per unit energy from biofuels are decreasing over time as industries mature and practices improve. These lifecycle inventories from GREET estimate emissions rather than estimate actual effects to biological receptors (e.g., humans, ecosystems) and may underestimate effects from fossil fuels due to the omission of factors such as oil spills [Chapters 8, 10, 11; sections 8.5, 10.5, 11.5].
- Although this report estimates that nationally 0 to 1.9 million acres of additional cropland and 0 to 3.5 million acres of additional corn may be attributable to the RFS Program for the historical period assessed, there are insufficient data to determine potential land, water, and species impacts in specific areas below the county scale. If a portion of the observed cropland expansion was due to the RFS Program, it may have had some effect on critical habitat and threatened and endangered species; however, whether that effect would have constituted an adverse effect in the context of the Endangered Species Act (ESA) is unknown [Chapter 12, sections 12.3.2 and 12.3.3; Chapter 13, sections 13.3.2.2 and 13.3.3]. EPA has separately evaluated the potential effects on threatened and endangered species for 2023–2025 in the Set Rule (docket #EPA-HQ-

OAR-2021-0427) and determined that the rule is not likely to adversely affect listed species and their designated critical habitats.[4]

- Overall, even though the estimated environmental impacts from the RFS Program may be small, any impacts may represent additional strain to already strained environments and could be significant locally. Some conservation practices are becoming widely adopted in the United States with positive effects on the environment, while others are not. Many of the potential impacts from the RFS Program specifically and biofuels more generally could be offset with greater adoption of conservation practices [Chapter 3, section 3.2.1].

Likely Future Effects

- The likely future effects from the RFS Program were published in the Final Set Rule for 2023–2025 and projected an increase of 3.9 billion gallons in 2025 due to the RFS Program over the baseline (with no RFS Program) [Chapter 6, Table 6.12]. This increase in 2025 from the RFS Program is primarily from increases in biodiesel and renewable diesel from soybean oil (+1.5 billion gallons), increases in cellulosic biofuel from compressed natural gas (CNG)-liquified natural gas (LNG) biogas (+932 million gallons), and increases in corn ethanol (+787 million gallons). Domestic production and consumption of other biofuels are expected to change little by comparison. These estimated impacts in 2025 from the RFS Program are different from the trends through time from 2022 to 2025. Though highly uncertain, EPA determined in its ESA biological evaluation for the Set Rule that the RFS-attributable volumes could potentially lead to an additional increase of up to 2.65 million acres of cropland by 2025.
- While the projected cropland expansion for 2023–2025 is slightly larger than the estimated historical cropland expansion from the RFS Program, it cannot be said with reasonable certainty that any particular environmental and resource conservation effect will be impacted, due to the numerous layers of uncertainty between the finalized RFS annual volumes and on-the-ground, localized land use changes. These projected future effects remain uncertain due to many other factors, including ongoing recovery from the global COVID-19 pandemic, uncertainty in the penetration of E15 in the marketplace, uncertain growth of cellulosic ethanol production from

[4] On August 3, 2023, EPA completed its Endangered Species Act informal consultation on the Renewable Fuel Standard (RFS) Program: Standards for 2023-2025 and Other Changes rulemaking (also known as the RFS "Set Rule"). With the Biological Evaluation that EPA submitted to the National Marine Fisheries Service (NMFS) and Fish and Wildlife Service (FWS) on May 19, 2023, EPA determined that the RFS Set Rule is not likely to adversely affect listed species and their designated critical habitats. EPA received letters of concurrence with this determination from NMFS on July 27, 2023, and from FWS on August 3, 2023, thereby concluding the consultation. The Biological Evaluation and Letters of concurrence are available at https://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuels-standards-rule-2023-2024-and-2025.

agricultural or marginal lands, and complex transportation market dynamics, among other factors [Chapter 2, section 2.3.2; Chapter 6, section 6.5].

Background

In August 2005, the Energy Policy Act of 2005 (EPAct)[5] was enacted, which included the creation of the RFS Program to be administered by the EPA. In December 2007, EISA was enacted with the stated goals of "mov[ing] the United States toward greater energy independence and security [and] to increase the production of clean renewable fuels." In accordance with these goals, Section 202 of EISA revised the RFS Program to nearly double the volume of renewable fuel required to be blended into transportation fuel from 5.4 to 9 billion gallons in 2008 and to 36 billion gallons per year by 2022. EISA also included Section 204 which required this report every three years. The two versions of the RFS Program under the EPAct and EISA are commonly called the "RFS1" (in effect 2006–2008) and "RFS2" (in full effect since 2010).[6]

More than a decade after the full implementation of the RFS2, there is sufficient data and scientific literature to assess partially the historical effects of the RFS Program. These data and information were not available for the 2011 RtC1, which was primarily forward looking; and, much of it was not available for the 2018 RtC2. Many important analyses have been published since 2018. The detail and sophistication of the literature has evolved over time, with earlier studies often presuming the RFS Program was the only factor affecting biofuels in the United States and assuming higher levels of biofuel production than later occurred (e.g., cellulosic biofuels). More recent studies include more market and industry detail, with more realistic assumptions of biofuel production levels informed by observations. Thus, more than a decade after implementation of RFS2, there exist data to more fully assess the potential impacts of the RFS Program since its inception.

One of the emphases in the RtC3 is on attribution of effects to the RFS Program as opposed to biofuels in general. Impacts from the RFS Program may overlap partly or entirely with the impacts from biofuels more generally. Many studies have assumed either implicitly or explicitly that U.S. biofuel production was driven solely by the RFS Program, which has limited the ability of previous assessments to attribute effects to the Program. There are many policies—federal and state—and economic and agronomic factors that affect biofuel production, not just the RFS Program. It is not the purpose of the RtC3 to assess the effect of all these other drivers on biofuels, nor to assess the environmental effects of

[5] Energy Policy Act, Pub. L. No. 109-58, 119 Stat. 594 (2005).

[6] 2009 was a transition year between programs, where the total biofuel volume standards were based on the RFS2-level volumes, but there was only a single total renewable fuel standard as with the RFS1. The RFS2 with its four nested renewable fuel standards [Chapter 1, section 1.1] was not fully implemented until 2010.

all of agriculture or even all agricultural feedstocks that may be used for biofuels. However, many of these contexts are discussed for comparison. Rather, the purpose of this report, as stated clearly in EISA, is to assess the impacts to date and likely future impacts of the RFS Program to inform Congress and EPA in the administration of the Program.

The RtC3 evaluated all biofuel-feedstock-region combinations that produced RINs (e.g., biodiesel-soybean-Argentina, ethanol-corn-U.S.) since the inception of the RFS Program (2005) to 2020, and focused on those that dominated the U.S. biofuel marketplace. Thus, while 17 combinations were evaluated for this report (Figure IS.1, Chapter 2, section 2.3), four were identified as potentially having substantive impacts on the environmental effects covered in this report: (1) domestic corn ethanol, (2) domestic soybean biodiesel, (3) domestic fats, oils, and greases (FOGs), and (4) imported ethanol from Brazilian sugarcane. Although the emphasis of the RtC3 is on these four biofuels, other biofuels and effects are also discussed in the chapters where they may be particularly relevant (e.g., cellulosic biofuels in Chapter 9 [section 9.6], palm biodiesel from Southeast Asia in Chapter 16 [section 16.4 and 16.5]).

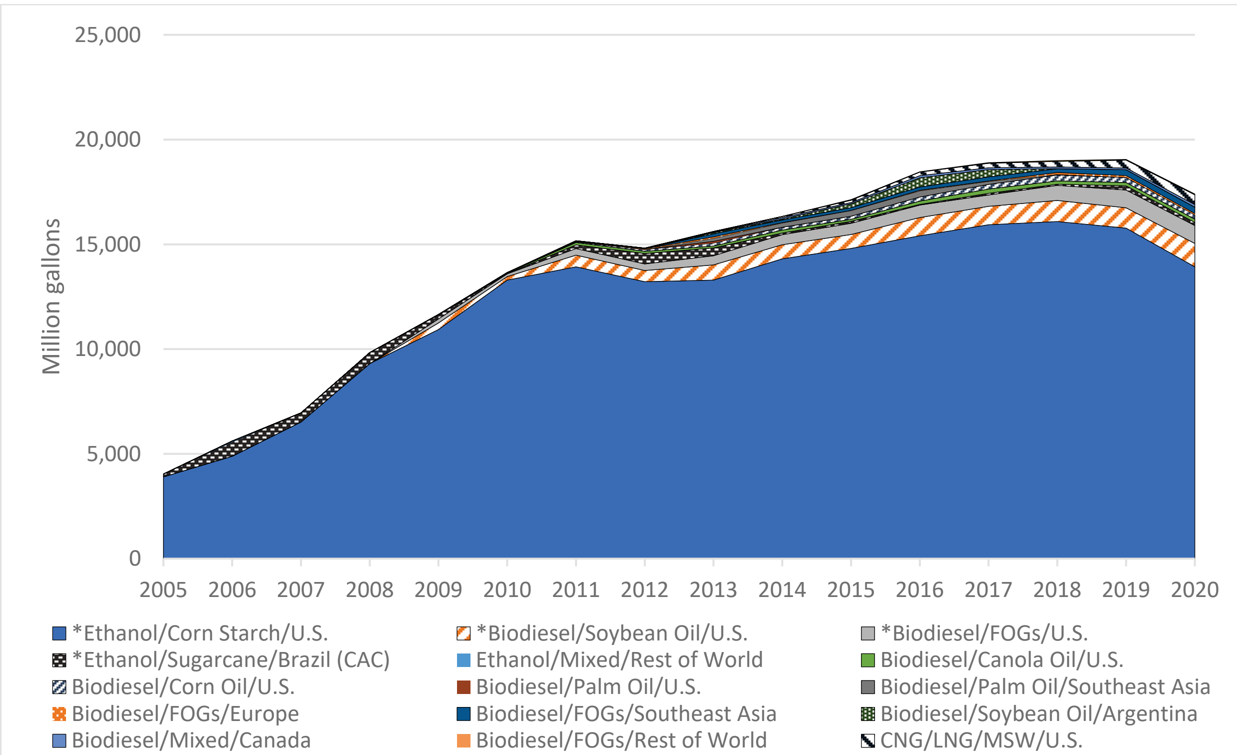

Figure IS.1. The estimated volumes of biofuel (million gallons) imported or domestically produced from individual biofuel/feedstock/region combinations from 2005 to 2020 (same information as Chapter 2, Table 2.1[7]). All combinations are mentioned in the RtC3 but the four dominant biofuels (*) are emphasized. Note that biodiesel also includes renewable diesel.[8]

[7] For Figure IS.1, sugarcane ethanol from Central America and the Caribbean (CAC) was combined with Brazil because, as explained in Chapter 2, most of the ethanol imported from the CAC actually originated in Brazil.

[8] Details on the sources of information for Table IS.1 are in Chapter 2 and Appendix B. CNG/LNG-MSW stands for compressed natural gas (CNG) or liquified natural gas (LNG) from municipal solid waste (MSW).

The statutory language in Section 204 of EISA establishes the general environmental and resource conservation issues to be addressed in the reports. The authors interpret and define terms in the statutory language based on technical knowledge of the subject matter. From this, the categories listed in the statutory language were reorganized into groups that are more consistent with the scientific literature (Table IS.1).

In addition to what is included in the statutory language of EISA Section 204, what is not included in Section 204 helps to limit the scope. GHGs and climate change are not mentioned in EISA Section 204, and thus are not explicitly addressed in this report (but see Chapter 2, Box 2.2 for a brief overview). GHGs are explicitly addressed in EISA Section 202 which modified the RFS Program, and are evaluated during the biofuel pathway analysis conducted by EPA as part of the ongoing implementation of the RFS Program. EPA maintains a summary of lifecycle GHG intensities estimated for the RFS Program, which are available in spreadsheet form in a document titled "Summary Lifecycle Analysis Greenhouse Gas Results for the U.S. Renewable Fuels Standard Program."[9] EPA's

Table IS.1. Mapping of statutory language in EISA Section 204 and the RtC3

EISA Section 204(a) statutory language	RtC3 chapter number (and title)
Environmental [. . .] and Resource [C]onservation [I]ssues	Chapters contained in Part 3
[A]ir quality	Chapter 8 (Air quality)
[E]ffects on hypoxia	Chapter 13 (Aquatic ecosystems)
[P]esticides, sediment, nutrient, and pathogen levels in waters	Chapter 10 (Water quality)
[A]creage and function of waters	Chapter 11 (Water availability)
[S]oil environmental quality	Chapter 9 (Soil quality and conservation)
[S]oil conservation	Chapter 9 (Soil quality and conservation)
[W]ater availability	Chapter 11 (Water availability)
[E]cosystem health and biodiversity	Chapter 12–14 (separated by ecosystem type for terrestrial [12], aquatic [13], and wetlands [14])
[I]mpacts on forests	Chapter 12 (Terrestrial ecosystems)
[I]mpacts on [. . .] grasslands	Chapter 12 (Terrestrial ecosystems)
[I]mpacts on [. . .] wetlands	Chapter 14 (Wetlands)
The growth and use of cultivated invasive or noxious plants and their impacts on the environment and agriculture.	Chapter 15 (Invasive species)
[T]he annual volume of imported renewable fuels and feedstocks for renewable fuels, and the environmental impacts outside the United States of producing such fuels and feedstocks.	Chapter 16 (International effects)

[9] This document is available on EPA's website at https://www.epa.gov/fuels-registration-reporting-and-compliance-help/lifecycle-greenhouse-gas-results. This summary is also available in docket EPA-HQ-OAR-2021-0324.

analyses of the lifecycle assessment (LCA) of various pathways are also published online.[10] A list of pathways that have been approved by regulation can also be found at 40 CFR 80.1426(f)(1). This approach of omitting GHGs in the RtC3 is consistent with the RtC1 and RtC2.

Comparison of Overall Conclusions Between the RtC2 and RtC3

This section presents the overall conclusions from the RtC2 (literature review cutoff date of April 2017) and discusses any different or new conclusions in RtC3 versus the earlier report. Overall conclusions from the RtC2 were:

- Disregarding any effects that biofuels have on displacing other sources of transportation energy, evidence since 2011 indicates the specific environmental impacts listed in EISA Section 204 are negative. The environmental and resource conservation impacts, whether positive or negative, related to displacement of other transportation energy sources by biofuels were not assessed.
- Literature published since 2011 supports the conclusion of the potential for positive and negative effects. Available information suggests, without accounting for the environmental effects of displacing other sources of transportation energy, the specific environmental impacts listed in EISA Section 204 are negative in comparison to the period prior to enactment of EISA.
- Evidence continues to support the conclusion that biofuel production and use could be achieved with reduced environmental impacts. The majority of biofuels continue to be produced from corn grain and soybeans, with associated impacts that are well understood. Cellulosic and other feedstocks remain a minimal contributor to total biofuel production.

The RtC3 reaffirms the conclusions in the RtC2. The RtC2 reported that there were land use change trends observed that were consistent with a potential effect from the RFS Program (e.g., increases in corn acreage and total cropland). However, there was not enough information available at the time to separate the effects of biofuels generally from the effects of the RFS Program specifically (see RtC2 page ix). The RtC3 advances the knowledge in this important area. The RtC3 reaffirms the conclusion that biofuels have the potential for positive and negative effects, and that the majority of impacts to date come from lifecycle effects from corn ethanol and soybean biodiesel. The RtC3 does not focus on comparing the impacts from biofuels to those of conventional fossil fuels, as Section 204 does not address fossil fuels' impacts. Part 3 of this report (Chapters 8–16) includes limited comparisons where the scientific literature is available. Additionally, related material comparing biofuels to their fossil fuel counterparts on

[10] See https://www.epa.gov/renewable-fuel-standard-program/approved-pathways-renewable-fuel and https://www.epa.gov/renewable-fuel-standard-program/other-actions-renewable-fuel-standard-program

a per-megajoule basis is presented from established lifecycle models (i.e., Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies [GREET]), and from other approaches and models. The RtC3 focuses on estimating the impacts from the RFS Program, though impacts from biofuels more broadly are also discussed as important context. Overall conclusions from the RtC3 are:

- The overall effect of the RFS Program on biofuels depends on the biofuel being discussed and is dynamic through time because of several co-occurring market and non-market factors. The RFS Program itself played a relatively minor role in the increase in corn ethanol in the United States, but has played a more significant role for other biofuels.
- The volume of domestic corn ethanol consumption estimated to be attributable to the RFS Program historically suggests that a maximum of 0–1.9 million acres of cropland expansion (roughly 0–20% of the estimated *increase* in cropland, and 0–0.5% of all cropland) and 0–3.5 million acres of corn expansion (roughly 0–35% of the observed *increase* in corn acreage, and 0–3.7% of all corn acreage) are estimated to be attributable to the RFS Program.
- As the historical effect of the RFS Program on domestic corn ethanol production and consumption and associated land use changes varies through time and includes zero in the range of estimates each year, estimates of environmental impacts also vary through time and include zero each year. This holds for most end points examined, with small but negative potential impacts nationally on soil quality, water quality, biodiversity, and other effects. Local impacts may be larger in some areas for some effects, but this could not be quantified for the RtC3.
- Though adoption of conservation practices is improving, additional conservation measures—such as further adoption of conservation tillage and cover crops—would help reduce the impacts of biofuels generally and the potential RFS Program specifically on the environment.
- Consistent with the RtC1 and RtC2, the RtC3 does not estimate or assess the impact of increased renewable fuel consumption on conventional fossil fuel consumption, nor does it assess the environmental impacts of changes in of fossil fuel production or consumption.

The following sections discuss specific conclusions from chapters in the RtC3 on the impacts to date, the likely future effects, uncertainties and limitations, and recommendations.[11]

[11] Specific conclusions from Chapters 1–4 are not presented in the Integrated Synthesis as these are more background material for the RtC3.

Specific Conclusions: Impacts to Date

Domestic Land Cover and Land Management [Chapter 5]

Land use change from all causes shows a steady increase in total cultivated cropland and corn/soy acreage since 2007. Based on the 2012, 2015, and 2017 U.S. Department of Agriculture (USDA) National Resource Inventory (NRI), from 2007 to 2017 there has been a 10 million-acre increase in cultivated cropland coinciding with a 15 million-acre decline in perennially managed land (i.e., sum of lands in the Conservation Reserve Program [CRP],[12] pasture, and noncultivated cropland). This increase in cultivated cropland was largely driven by a 26.5 million-acre increase in corn and soybeans with small grains and hay in rotation decreasing by 16.5 million acres. Results from other federal datasets such as the Cropland Data Layer (CDL) and the Census of Agriculture are consistent with the NRI when harmonized appropriately. Thus, after decades of decline in cultivated cropland since at least the 1980s, increases have been recorded in multiple federal datasets using a variety of methodologies following the 2007 to 2012 period. More than half of the corn and soybean increase has come from other cultivated cropland (56%), while the rest has come from approximately equal proportions of pasture (13%), noncultivated cropland (20%), and CRP (11%). Many of these changes are taking place throughout the Midwest, with hotspots in northern Missouri, eastern Nebraska, North and South Dakota, Kansas, and parts of Wisconsin. Lands enrolled in the CRP have steadily decreased since 2007; and, although these decreases are likely due to Farm Bill policies and not directly to biofuels, how these lands are managed after leaving the CRP are likely influenced by biofuels and the RFS Program. More recently, the Agriculture Improvement Act of 2018 increased maximum allowable CRP land to 27 million acres in 2023 and enrolled acreage has increased significantly. Data to assess the effect of the RFS on CRP enrollment under this new allotment is not currently available.

Attribution: Corn Ethanol and Corn [Chapter 6]

Multiple lines of evidence suggest the RFS Program itself played a relatively minor role in the growth of corn ethanol in the United States (0–1.0 billion gallons per year from 2002–2011) and may have played a more important role more recently since reaching the E10 blend wall (0–2.1 billion gallons per year from 2012–2018).[13] Many factors overlap with and predate the RFS Program. Principal among these was the need of a replacement for methyl-tert-butyl-ether (MTBE) as an

[12] https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/

[13] The E10 blend wall commonly describes the amount of ethanol that can be blended into the gasoline pool at 10% by volume. Above this limit, higher amounts of ethanol consumption domestically would have to come from higher blends where it faces greater economic challenges. E15 is approved for use in vehicles manufactured after 2000 but remains limited in availability nationally [see Chapters 2 and 3].

oxygenate[14] in gasoline for areas with smog concerns administered under the Reformulated Gasoline Program (RFG). From 2003 to 2006, largely before the RFS Program, roughly a third of the national gasoline pool needed a substitute for MTBE because of growing concerns, ongoing litigation, and individual states addressing the environmental issues associated with MTBE. At the time, that substitute was ethanol from corn grain. Ethanol is an oxygenate, and ethanol from corn grain was estimated at the time to be the only substitute available in the quantities needed that did not require expensive refinery retrofitting that other petroleum-based alternatives may have needed. Furthermore, ethanol did not have the same potential water quality concerns as other petroleum-based substitutes for MTBE (e.g., ethyl tertiary butyl ether, or ETBE). The logistical barriers that had previously limited ethanol consumption to the Midwest had to be overcome to provide ethanol to the largely coastal and urban areas that were administered under the RFG.

Gasoline used to be produced as “finished gasoline” (E0) ready for sales at gas stations. This gasoline met all the necessary standards under the Clean Air Act (CAA) for transportation fuels. To make E10 in these early years, E0 was “splash blended” with ethanol often at the gas station or terminal. Splash blending refers to mixing ethanol with finished gasoline to reach 10% ethanol by volume. Between 2005 and 2010, refineries invested in switching to “match blending,” whereby refineries utilized the higher octane in ethanol in their processes to target a specific octane rating in the finished product. To carry out match blending, refineries switched to producing Blendstocks for Oxygenate Blending (BOBs), which are "unfinished gasoline" that can only be legally sold at the pump (i.e., meeting all applicable CAA standards) after an oxygenate is added. These BOBs were then mixed with ethanol at the refinery or terminal to produce E10. BOBs are cheaper to produce because they require less refining and take advantage of the higher octane value of the oxygenate. They rely on changes to refinery operations and the downstream distribution and blending network. As a result of these changes, it would be difficult and costly to revert back to the production of finished gasoline.

Once the supply chains were in place, and with the construction boom in ethanol biorefineries in 2006 and 2007, ethanol in the United States was poised to quickly reach market saturation at 10% of the gasoline pool. By 2006 (the first year of the RFS Program), ethanol consumption far outpaced the RFS1 mandates and had already increased to 40% of the E10 blend wall. By 2010—the first year of the RFS2—ethanol consumption was nearing 93% of the E10 blend wall, and the volume of ethanol production either operating or under construction was already 13.4 billion gallons. Record high oil prices in this period,

[14] Octane enhancers are added to transportation gasoline to avoid engine knock. Octane enhancers may be oxygenates (i.e., contain oxygen, such as MTBE and ethanol) or not (e.g., tetra-ethyl lead, or “lead”), and may be petroleum-based (e.g., MTBE) or renewable (e.g., corn ethanol). Octane enhancers used in U.S. gasoline has changed through time, from lead in the 1920s–1980s, to MTBE in the 1980s–2000s, to ethanol from the 2000s to the current day.

beginning in 2005, also made gasoline with 10% ethanol cheaper to produce than gasoline without ethanol, and so the market responded with increased ethanol consumption also in non-RFG areas. If these factors had not been in place, the RFS Program likely would have had a stronger and more direct effect in encouraging the growth of corn ethanol in the United States.

More recently, the RFS Program may be playing a more significant role in the continued production and consumption of corn ethanol. Market and policy conditions have changed with the expiration of the Volumetric Ethanol Excise Tax Credit (VEETC, 2004–2011), the drop in oil prices after 2015, and the decrease in consumption from the global COVID-19 pandemic starting in 2020. Therefore, the effect of the RFS Program in sustaining production may be more important in recent years compared with historically. However, there remains uncertainty surrounding the recent influence of the RFS Program because refineries have already made costly investments to switch to match blending, and retrofitting refineries to produce gasoline without ethanol could be cost prohibitive.

The RFS Program is a policy applied to a dynamic market, and therefore the effect of the policy is also dynamic through time. RIN prices for renewable (D6) fuels provide evidence that the RFS Program increased U.S. consumption of renewable biofuels in 2009 (and late 2008) and from 2013 to 2019. Higher D6 RIN prices after reaching the E10 blend wall in 2013 are likely not indicative of an effect on corn ethanol, because of the nested nature of the RFS standards. They are indicative of an effect on total renewable fuel. Nonetheless, estimates from simulation models, the observed overproduction of ethanol domestically compared to the RFS standards, and other sources suggest that from 2006 to 2011 the RFS Program—in isolation—accounted for 0–1 billion gallons of ethanol. This effect in the earlier years appears to be due to contributions to market certainty and encouragement of capital investment from EISA, and to a lesser extent by stabilization of demand during the Great Recession of 2008–2009. In other years of this period, the RFS Program is estimated to have had no effect on ethanol production, with other factors having more influence (Figure IS.2). From 2012 to 2018, there is a wider range of estimates of the effect of the RFS Program than in the 2006–2011 period, as other contributing factors diminished (e.g., oil prices declined after 2015, VEETC expired at the end of 2011, MTBE transition had already occurred). From 2012 to 2018, annual estimates of the range of impacts of the RFS Program vary from year to year. The minimum estimated effect is zero for every year examined, and the maximum varied from year to year and was highest in 2016 at 2.1 billion gallons. (Figure IS.2). The low end of this range is driven by a thorough state-by-state analysis of the relative economics for refiners for match blending 10% ethanol into gasoline, taking into consideration its considerable octane value. In addition, even where the economics for blending ethanol may not have been favorable for some gasoline grades in some states, a strong "lock-in effect" from the transition to match blending was presumed to prevent reversion. The high end of this range is from economic modeling of the biofuels industry that includes key factors such as the price of oil, MTBE, and the potential octane value of ethanol. This report focuses on this historical period when the growth in domestic ethanol production occurred.

Combining these estimated volumes attributable to the RFS Program with literature reviews and a recent statistical analysis suggests that additional corn and new cropland areas, with estimates ranging from zero to as high as 3.5 ± 1.0 million acres of corn, and from zero to as high as 1.9 ± 0.9 million acres of cropland expansion may be attributable overall to the RFS Program from direct and indirect effects.[15] Though small relative to total cropland (0–0.5%) and total corn acreage (0–3.7%), this corresponds to 0–20% of the *increase* in cropland and 0–35% of the *increase* in corn acreage from 2008 to 2016.

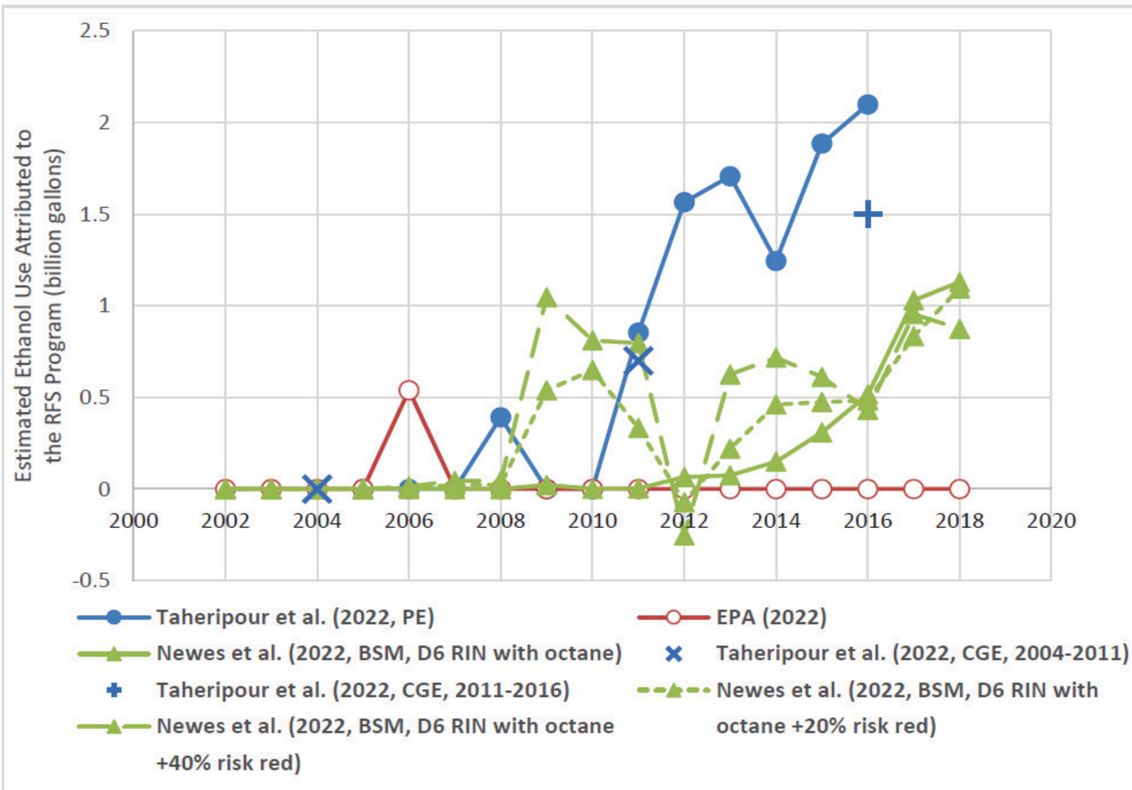

Figure IS.2. Comparison of estimates of ethanol use attributed to the Renewable Fuel Standard (RFS) Program from key studies in Chapter 6. Shown are estimates from recent models that separate estimated RFS effects from other key factors (e.g., oil price, MTBE, transition to match blending). These include: the annual partial-equilibrium (PE) model in Taheripour et al. 2022 (AEPE, blue line, circles); the two general equilibrium (GE) periods in Taheripour et al. 2022 (GTAP-BIO; 2004–2011, blue "x"; and 2011–2016, blue "+"); Newes et al. 2022 using the Biomass Scenario Model (BSM, green line, triangles); and an economic analysis from EPA 2022 (red line, circles). Note the estimate in 2006 from EPA 2022 is driven more by the MTBE phaseout than the RFS Program (see section 6.3.5). The estimates from Newes et al. (2022) show those that include the estimated effect the RFS Program had on increasing market certainty (dashed green lines, two levels of 20% and 40% risk reduction), and those that do not include this effect (solid green line).

[15] Note that the additional corn could have come all from existing cropland, or up to 1.9 million acres of it could come from new cropland. This result simply means that it is estimated that there are 0–3.5 million more acres of corn and 0–1.9 million more acres of total cropland than would have occurred absent the RFS Program.

There are many uncertainties associated with this estimate of the volume of ethanol attributable to the RFS Program. There is no single study that used robust methodologies across all steps of the analysis; thus, this estimate represents a synthesis from the best available studies to date. Disentangling the effect of the RFS Program, as required under EISA Section 204, is difficult given the many co-occurring factors that affect biofuels in the United States. As a mandate, the RFS Program created a guaranteed market demand for biofuels in the United States that certainly *could have* driven the increase in ethanol production and consumption. However, this potential market demand from the RFS Program also existed for cellulosic biofuels that have not seen a similar increase; thus, clearly other factors must also align. There are many factors not included or not investigated in depth in this analysis, including a more detailed examination on the effect the RFS Program had in influencing investor confidence and infrastructure buildout before the mandates were in full effect, the costs or willingness of refiners to switch back to producing finished gasoline if the RFS Program were no longer in effect, and others. These factors are difficult to quantify. Furthermore, as events played out, non-RFS factors that are quantified and known to influence the market were favorable and appear to sufficiently explain much or all of the increase in corn ethanol production and consumption in the United States. Thus, though notwithstanding several uncertainties, these represent the best estimate based on currently available information for the effect of the RFS Program on corn ethanol and the associated effects on cropland in the United States.

These RFS effects, though smaller than anticipated by many studies discussed in Chapters 4 and 6, may still have implications on the nation's air, land, and water, and have more significant effects locally. However, specific areas where environmental effects may have occurred cannot be quantified with confidence due to the vast quantity of potential cropland in the United States and the multitude of factors that contribute to an individual farmer's decision whether to bring additional land into crop production. The more likely hotspots of increased cropland and corn/soy acreage have been identified throughout the country (Chapter 5, section 5.3.1).

Attribution: Biodiesel and Renewable Diesel [Chapter 7]

The RFS Program, especially after the expansions in the RFS2, likely always played an important role in supporting the production and consumption of biodiesel and renewable diesel, in contrast to corn ethanol. However, separating the effect of the RFS Program quantitatively from other factors remains difficult. Before 2010 and the RFS2, the RFS Program had little effect on biodiesel because there was no separate biodiesel or advanced mandates, and domestic corn ethanol and imported Brazilian sugarcane ethanol[16] were the most cost-effective way to meet the total renewable fuel

[16] Imports from Brazil were largely temporary, limited to a few early years before U.S. production had grown, and to a few later years when drought occurred that lowered U.S. production.

standards under the RFS1. Other factors such as the Biodiesel Tax Credit (BTC) and state incentives were especially influential in these earlier years for biodiesel. Once there existed a biodiesel mandate with the RFS2, the RFS Program and other policies played an important role in the increased production and consumption of biodiesel and renewable diesel. Biodiesel and renewable diesel demand is fundamentally different from ethanol—biodiesel and renewable diesel were not incentivized by the need for a substitute for MTBE in gasoline, and oil prices were not ever high enough to make biodiesel competitive with diesel on the basis of price alone. Thus, the RFS Program created an important added incentive beginning with the RFS2 in 2010. Advanced (D5), biomass-based diesel (D4), and cellulosic (D3) RIN prices provide evidence that the RFS2 increased U.S. consumption of advanced, biomass-based diesel, and cellulosic biofuels. Aside from observed RIN prices and a handful of studies, there is much less quantitative information in the peer-reviewed literature on the effects of the RFS Program on biodiesel compared with effects on corn ethanol, and none of the studies assessed included other factors such as FOGs, the BTC, or state biofuels mandates. The handful of economic models suggest a strong effect from the RFS Program—with a 1 billion gallon increase in the RFS biodiesel standard inducing an increase in biodiesel consumption by 0.6–1.1 billion gallons. Comparison of state and federal mandates suggest that while roughly 0–30% of biodiesel consumption may be due to state programs (e.g., mandates and low carbon programs like the California Low Carbon Fuel Standard, LCFS), the remaining 70–100% may be attributable to a combination of other factors, primarily the RFS Program and the BTC. The effects of the RFS Program on the historical period cannot be isolated at this time because most studies do not separate the RFS from other important factors that occurred at the same time such as the BTC and state programs. Although multiple lines of information suggest a sustained effect of the RFS Program since 2010 on supporting biodiesel production and consumption, the effects from other factors such as the BTC and state incentives cannot be quantitatively separated from the effects of the RFS Program at this time. Thus, instead of a volumetric and acreage-based estimate of attribution in the RtC3, a more general synthesis is provided.

Air Quality [Chapter 8]

The RtC3 reiterates the conclusions from the RtC1 and RtC2 on air quality, concluding that emissions of nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), volatile organic compounds (VOCs), ammonia (NH_3), and fine particulate matter ($PM_{2.5}$) can be impacted at each stage of biofuel production, distribution, and usage. EPA's "anti-backsliding" study (see section 8.3.2.2) examined the impacts on vehicle and engine emissions and air quality from two different fuel scenarios for calendar year 2016. Specifically, the study compared air quality impacts of actual renewable fuel volumes in 2016 to a scenario with renewable fuel use approximating the 2005 levels before the RFS was enacted. The anti-backsliding study, which is not a full lifecycle assessment but focused on vehicle and engine emissions, found atmospheric concentrations of ozone and $PM_{2.5}$ can increase or decrease depending on location, and in general, NO_2 and acetaldehyde concentrations increase, while CO and benzene concentrations decrease. Lifecycle analyses conducted by the Argonne National Lab using GREET indicate that on a per unit energy basis many non-GHG emissions, including of several criteria air pollutants, are higher for biofuels per unit energy than their petroleum counterparts. However, the location of emissions from biofuel production tends to be in more rural areas where there are fewer people. How this translates to health effects on communities is complex, as it depends not only on the number of people, but on the dose-response relationship (e.g., possibly fewer people in rural areas but receiving higher or lower doses), their demographics and vulnerability (e.g., elderly or other at-risk populations), as well as other factors. Other modeling approaches support these findings, but also show that biofuels are improving as industries mature and practices improve. These analyses, though state-of-the-art, may not reflect some recent improvements in biorefining, are not spatially resolved enough to be directly linked with exposure, and do not account for many large-scale events associated with oil and gas exploration that may affect the overall results (e.g., oil spills).

Soil Quality [Chapter 9]

Effects on soil quality to date, as with effects detailed in other chapters, continue to be primarily from the cultivation of corn and soybean feedstocks. The soil quality effects of these crops are well established in the scientific literature, yet the amount attributable to biofuels and the RFS Program specifically remains less understood. Soil quality impacts are highest when land in perennial cover is converted to annual crop production. Simulations using the EPIC (Environmental Policy Integrated Climate) model estimate that satellite-derived conversions of 4.2 million acres of grassland to various assumed agricultural scenarios negatively affected soil quality across a 12-state U.S. Midwestern region, increasing erosion by -0.9–7.9%, nitrogen loss by 1.2–3.7%, and soil organic carbon loss by 0.8–5.6%. The range in losses depended upon the assumed tillage practices, with no-till at the low end and conventional tillage at the high end of the range of effects. As noted above from Chapter 6, an estimated 0 to 20% of cropland expansion is estimated to be associated with corn ethanol production from the RFS Program historically, with larger attributable effects if other biofuels (e.g., soybean biodiesel) were included quantitatively and smaller effects in years with smaller effects from the Program. Nevertheless, applying these percentages to the modeling results yields estimates from zero to relatively small negative soil quality effects. Thus, the effects of the RFS Program on soil quality are likely comparatively small in magnitude relative to that of cropland over a large, multistate region or the contiguous United States, yet may be more important at local scales. Additional conservation measures—such as further adoption of conservation tillage and cover crops—would help reduce the impacts on soil quality of biofuels generally and the potential impacts of the RFS Program specifically.

Water Quality [Chapter 10]

As with soil quality, effects on water quality continue to be from cultivation of corn and soybean, with well established relationships between water quality and these crops generally, and less established relationships with biofuels and the RFS Program specifically. Trends in total nitrogen (TN) and total phosphorus (TP) from the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) from 2002 to 2012 show that both are likely decreasing in the central Midwest where conservation tillage practices have increased, and both are likely increasing in the areas of cropland expansion in western and northern Midwest where such practices are less common. Although TN and TP concentrations may be improving in some locations, trends in nutrient condition[17] from the EPA's comprehensive National Aquatic Resource Surveys (NARS) are less conclusive, with little change in stream TN condition and many areas worsening in stream TP condition. Simulations using the Soil & Water Assessment Tool (SWAT) in the Missouri River Basin estimated that for TN and TP loads and concentrations, satellite-derived grassland conversion to continuous corn would result in the greatest increase in TN and TP loads (6.4% and 8.7% increase, respectively); followed by conversion to corn/soybean rotation (TN increased 6.0% and TP increased 6.5%); and then conversion to corn/wheat rotation (TN increased 2.5% and TP increased 3.9%). As with soil quality, the effects from cropland expansion potentially attributable to the RFS are estimated to be roughly 0–20% of these. These estimated increases are relatively small on an absolute basis considering this basin is already intensively cultivated but aggravate impacts in watersheds already affected by nutrients. Lifecycle potential eutrophication effects for both corn ethanol and soybean biodiesel are higher than their fossil fuel counterparts (gasoline and diesel, respectively) per unit energy and in total in most cases, although these analyses do not include many factors and may underestimate the effects from petroleum.

Water quality considerations are not just from farming activities, but also from potential leakages from underground storage tank (UST) systems, which may be affected by increased concentrations of biofuels. Most older, and even some newer, existing UST systems are not fully compatible with higher blends of ethanol (e.g., E15, E85) and may require modification before storing them. For example, the actual tank is often compatible with E15, but some of the other system components may not be.

[17] While nutrient concentration is the estimated concentration of nutrients in the water, nutrient condition refers to the concentration relative to region-specific reference water bodies that are relatively unpolluted. Nutrient condition in the NARS is often categorized as "good", "fair", and "poor." Thus, nutrient concentration may improve, but not enough to change nutrient condition classes.

Water Use and Availability [Chapter 11]

National-level impacts to date on water use and availability may be relatively limited as only 10–14% of soybean and corn acreage is irrigated, but those impacts may be important regionally and are an additional pressure on already stressed water resources such as the High Plains Aquifer (HPA). Most water withdrawals in the United States are for thermoelectric power (41%) followed by irrigation (37%). And, while most corn and soybean acreages are rainfed (86% and 90%, respectively), nearly 40% of water withdrawals for irrigation are for these two crops. Almost all of the irrigated corn is in the western corn belt where much of the observed cropland expansion has occurred. Water use and water availability impacts related to biofuels are primarily due to irrigation of feedstocks (88–99% across the lifecycle), while water use in biorefineries represents a small (1–9%) and declining percentage of lifecycle water use as biorefinery production efficiencies improve. Nevertheless, lifecycle estimates suggest that corn ethanol requires an average of 13 times more water per gallon of fuel produced compared to gasoline, ranging from roughly break-even with gasoline (at 8.7 gallons per gallon fuel) under rainfed conditions and efficient conversion facilities, to greater than 100 times more water requirements under irrigated and less efficient conversion facilities.

Terrestrial Ecosystem Health and Biodiversity [Chapter 12]

Effects on terrestrial ecosystems, particularly terrestrial biodiversity and possibly threatened and endangered species, continue to be primarily from corn and soybean feedstock production, with the two main drivers of effects being shifts in perennial cover to corn and soybeans and associated agronomic practices. The USDA NRI estimates that almost half of the lands shifting to corn and soybeans from 2002 to 2017 were previously under perennial cover (e.g., grasses on CRP land, pasture). Satellite-derived data suggest grasslands account for 88% of land in perennial cover that were converted to annual crops between 2008 and 2016, while 3% and 2% were from wetlands and forests, respectively. These shifts in perennial cover may negatively impact grassland birds, bats, pollinators and other beneficial insects, and plants, including threatened and endangered species. Across the contiguous United States, 27 terrestrial threatened and endangered species had an estimated 10 acres or more of non-cropland conversion to corn or soybeans within 1-mile of its critical habitat between 2008 and 2016. Of those, six threatened and endangered species had estimated conversion of 10 acres or more within their designated critical habitat. Ancillary datasets such as from the USDA National Agriculture Imagery Program (NAIP) are needed to verify these estimates. These impacts are from land conversion to agriculture and cannot be attributed to the RFS Program specifically because the range of the impact of the RFS Program on corn ethanol consumption includes zero and because methods to explicitly link the RFS Program with individual parcels of land do not currently exist. Overall, the range of possible impacts from the RFS Program likely spanned from no effect to a negative effect on terrestrial biodiversity historically (2008 to 2016). The magnitude of any impacts is uncertain and may be relatively small compared to that of total U.S. cropland, but may still be important for locally endemic species and other important local environmental resources. It is unknown whether these relatively small changes in land cover and land management may or may not cross ecological thresholds for various habitats and species. Whether these effects historically were adverse or not in the context of the ESA is unknown. Notably, these findings do not necessarily apply for years beyond 2016, when the effects of the RFS Program on corn ethanol and soy biodiesel production may have changed.

Aquatic Ecosystem Health and Biodiversity [Chapter 13]

As with other environmental effects, the primary impacts to date on aquatic ecosystems are from the conversion of grasslands to corn and soy production, which often lead to increased sediment, pesticide, and nutrient loads to aquatic ecosystems. Although the estimated effects from the RFS Program are not likely to shift current biological conditions, they are estimated to be an additional stress on already stressed ecosystems. As reported in the water quality chapter [Chapter 10], although nutrient concentrations and loads in certain areas of the Upper Midwest are estimated to be improving from the USGS NAWQA, these improvements do not appear to be sufficient to lead to improvements in stream biological conditions (e.g., fish, macroinvertebrates). For pesticides, potential harm to aquatic life was indicated by exceedances of benchmarks for several pesticides used in row crop production, especially neonicotinoid insecticides widely used as coatings on corn seeds. Based on data from nationally representative surveys of the nation's wadeable stream miles in 2004 and about 10 years later in 2013–2014, biological condition generally worsened between the two surveys, although there was wide regional variation in the response. In the SWAT study in the Missouri River Basin (MORB) introduced in Chapter 10, the flow-weighted nutrient concentrations increased by less than 5% on average across the MORB from estimated agricultural expansion from 2008 through 2016. Thus, increases in nutrient concentrations that may be attributable to the RFS Program are unlikely to result in *new exceedances* of current state numeric nutrient criteria (where available) in agricultural regions of the United States. However, most watersheds already experience exceedances of multiple stressors; thus, additional nutrients aggravate stream condition even if only by a small amount. For example, according to national surveys conducted by the EPA, 67% of the wadeable streams in the United States were already in poor or fair biological condition as of 2004. Many states have no numerical criteria with which to compare these concentrations. This SWAT analysis did not assess pesticides which are difficult to accurately characterize due to the large variety of pesticides to potentially model. Total effects may be larger or smaller because this study only included effects from agricultural expansion (expected to be the largest source) and not agricultural intensification or recent improvements in tillage practices. Nonetheless, the potential effects from the RFS Program may be contributing to additional strain to aquatic ecosystems, potentially exacerbating harmful algal blooms and hypoxia events. There were 78 aquatic threatened and endangered species that had an estimated 10 acres or more of non-cropland conversion to corn or soybeans within 1 mile of their critical habitat between 2008 and 2016. As discussed in Chapter 12, these cannot be attributed to the RFS Program specifically; thus, the range of possible impacts from the RFS Program likely spanned from no effect to a negative effect on aquatic biodiversity historically (2008 to 2016).thus, the range of possible impacts from the RFS Program likely spanned from no effect to a negative effect on aquatic biodiversity historically (2008 to 2016).

Wetland Ecosystem Health and Biodiversity [Chapter 14]

Although cropland expansion from 2008 through 2016 is estimated to be mostly of grasslands and not of wetlands, some additional losses of wetland acreages are estimated in ecologically sensitive areas which had already experienced significant losses before the inception of the RFS Program. Since 2007, the nation has lost 120.3 thousand acres of palustrine (marsh-like) wetlands and gained 205.9 thousand acres of lacustrine (lake-like) wetlands in the conterminous United States. The diverse wetlands within these broad classes support different species and perform different ecosystem functions. Lacustrine habitats are generally deeper, less vegetated, and more permanently ponded, providing ecological functions similar to lake ecosystems. Palustrine habitats, on the other hand, are shallower, have dense emergent vegetation, generally greater biodiversity, and undergo periodic drying that enhances biogeochemical processes such as denitrification. In the palustrine class, small, seasonal wetlands are being lost at a faster rate, though the direct effect from biofuels generally or the RFS Program specifically cannot be determined from available surveys. Although cropland expansion from 2008–2016 was mostly from conversion of grassland (88%), 3% was estimated from reclamation of wetlands, totaling nearly 275,000 acres of wetlands concentrated in the Prairie Pothole Region. A percentage of this (0–20%) may be attributable to the RFS Program. This acreage is small compared with historical losses of wetlands but could have cumulative environmental effects or landscape level effects in some areas. For example, by 2004—the year before enactment of the Energy Policy Act—over half of the historical wetlands in the lower 48 states had already been lost (>100 million acres lost), with several Midwestern states losing more than 80% of their historical wetlands. Given currently available datasets, which wetlands specifically may have been converted as a result of the RFS Program cannot be accurately estimated. Unlike other waterbird species, commercially valued waterfowl (ducks, geese, swans) as a group have not experienced national declines over the past decade, possibly due to a positive response to availability of food (grains) and habitat from interspersed lake-like wetlands and agricultural fields along migration routes. While national trends in status of wetland resources document large-scale transitions from palustrine wetlands toward more lake-like, lacustrine conditions, federal and state programs are having a positive influence on wetland conservation. The USDA has multiple programs focused on conserving and enhancing wetlands on agricultural lands, including the USDA Natural Resources Conservation Service's (USDA-NRCS) Agricultural Conservation Easement Program and the North American Wetlands Conservation Act (NAWCA) grant program, which has contributed to the protection, restoration, and enhancement of approximately 30.7 million acres total of wetlands and associated upland habitats since 1991.

Invasive or Noxious Plant Species [Chapter 15]

Impacts to date on the environment from the cultivation of invasive or noxious plant species as biofuel feedstocks have not been observed, but cultivation practices of corn and soybean feedstocks have likely contributed to the increasing incidence of herbicide-resistant weeds. Currently, most biofuel is produced from a small number of non-invasive feedstock species (i.e., corn, soybean) and therefore do not pose risk of invasion directly. However, impacts from the cultivation practices of corn and soybeans on the evolution of herbicide-resistant weeds do exist, although it is unclear to what extent impacts can be attributed to corn and soybeans grown to meet either biofuel demand generally or the specific requirements of the RFS Program. While potential impacts have been identified using weed risk assessment for some newer feedstocks being considered, none are currently used to produce biofuels and there are practices available for their mitigation (e.g., registration, reporting, and record keeping requirements).

International Effects [Chapter 16]

Direct international effects from the RFS Program attributable to biofuel imports from other countries could not be quantified in the RtC3. Although the United States imported biofuels from several regions that are biologically diverse, these amounts of imported biofuel were small and relatively short-lived, with the United States transitioning to being a net exporter of biofuels that may actually reduce environmental effects overseas. It does not necessarily follow that overall international effects of the RFS Program have been small, as research has shown the indirect effects of increased biofuel production on feedstock commodity trade flows could be substantial. Combining published simulation modeling estimates of the non-U.S. land use change effects of biofuels and estimates for the effect of the RFS Program on corn ethanol (Chapter 6) yields an illustrative range of the effect of the RFS Program on non-U.S. cropland area of 0 to 1.6 million acres. The estimated effect of the RFS Program does not yet include effects on soy biodiesel. As more data become available and are analyzed, historical relationships among U.S. biofuel policies, production, trade, environmental indicators, and other variables may be clarified and uncertainties reduced. Estimating indirect land use change (ILUC) overseas remains one of the most challenging areas of biofuels research. Most simulation models may capture U.S. policies adequately, but offer only a simplified view of the dozens of biofuel policies in other countries, and are based on many parameters that have not been thoroughly and transparently evaluated. The Model Comparison Exercise (MCE) conducted by OTAQ may help improve these models and their estimates of ILUC by identifying priority areas for research.[18] The United States was a net importer of ethanol from 2004 to 2007, mostly but not entirely originating from Brazil. The United States transitioned to a net ethanol exporter as the domestic biofuel industry matured. For biodiesel the trends were different. After a period of little biodiesel trade from 2002 to 2006, the United States was a net exporter of biodiesel from 2007 to 2012, and since has transitioned to be a net importer after ethanol reached the E10 blend wall in roughly 2013 and the advanced biofuel mandate continued to increase. Biodiesel imports from 2013 to 2017 were primarily of soybean biodiesel from Argentina, and to a lesser extent from FOGs and palm oil from Southeast Asia, and biodiesel from Canada. After 2017, total biomass-based imports of biodiesel have declined significantly and stopped from Argentina, and since then are predominantly biodiesel and renewable diesel from Southeast Asia and Canada. There are important uncertainties that remain, for example surrounding the potential for low-cost palm oil from ecologically sensitive areas in Southeast Asia to "backfill" diverted soybean oil from international vegetable oil markets, and especially if RFS Program total biofuel mandates increase in the future. These effects from the RFS Program, however, may be small, as palm oil is affected by many regions and markets, predominantly developing Asian markets, only a fraction of which directly intersect with the U.S. biofuels industry.

Specific Conclusions: Likely Future Effects

EISA requires the EPA to also examine the "likely future" effects of the RFS Program, which for this report is interpreted out to roughly 2025, presuming current likely future technologies, rates of market penetration, current policy, and market dynamics. The likely future effects from the RFS Program were published in the Final Set Rule for 2023–2025 (docket # EPA-HQ-OAR-2021-0427) and projected an increase in 2025 due to the RFS Program over the baseline (with no RFS Program) of 3.9 billion gallons (Chapter 6, Table 6.12). This increase in 2025 from the RFS Program is primarily from increases in biodiesel and renewable diesel from soybean oil (+1.5 billion gallons), increases in cellulosic biofuel from CNG-LNG biogas (+932 million gallons), and increases in corn ethanol (+787 million gallons).

[18] See the docket #EPA-HQ-OAR-2021-0427 and the EPA workshop on GHG modeling (https://www.epa.gov/renewable-fuel-standard-program/workshop-biofuel-greenhouse-gas-modeling) for additional information.

Domestic production and consumption of other biofuels are expected to change fairly little by comparison. These estimated effects in 2025 from the RFS Program are different from the trends through time from 2022 to 2025. Though highly uncertain, EPA determined in its ESA biological evaluation for the Set Rule that the RFS-attributable volumes could potentially lead to an increase of up to 2.65 million acres of cropland by 2025. While the projected cropland expansion for 2023–2025 is slightly larger than the estimated historical cropland expansion from the RFS Program (2.65 versus 1.9 million acres), there is uncertainty whether any particular area will be impacted, due to the numerous layers of uncertainty between the finalized RFS annual volumes and on-the-ground, localized land use changes. Other sources of uncertainty also remain, including ongoing recovery from the global COVID-19 pandemic, uncertainty in the penetration of E15 in the marketplace, uncertain growth of cellulosic ethanol production from agricultural or marginal lands, and complex transportation market dynamics, among other factors [Chapter 2, section 2.3.2; Chapter 6, section 6.5]. As policy and market conditions change, so may the factors to consider and the estimate of the likely future effects of the RFS Program.

Uncertainties and Limitations

Although much information is presented in this report on the impacts to date and likely future impacts from the RFS Program, there are many uncertainties and limitations that remain. These come in many forms, including data limitations, modeling limitations, and other sources of uncertainty. Data and modeling limitations are numerous and include a current inability to link RFS-attributable biofuels to specific areas, as well as a lack of detailed data through time (e.g., annually) and space (e.g., county-level or smaller) on many practices such as conservation tillage, cover crops, pesticide application rates, and others. Other data limitations include a lack of data to track crops from the farm to the biorefinery, which often travel through an intermediary (e.g., a grain elevator or crusher). Another central limitation is the inherent difficulty of using remote sensing data to correctly assign grass-covered land to the correct land use (e.g., pasture, CRP, grassland, idle), as well as the various and often inconsistent definitions of different land covers among available datasets and publications. The models available also have important limitations, including a lack of industry detail both domestically and abroad, a lack of contributing biofuel and agricultural policies in other countries in driving biofuel production around the world, and a lack of examination of many biofuels that are actually emerging as opposed to the biofuels that were anticipated to emerge following EISA (e.g., cellulosic biofuels on marginal lands). There are other limitations as well, including the inherent challenges of projecting into the future. Notwithstanding these significant uncertainties and limitations, this report makes significant progress towards a better understanding of the impacts to date and likely future impacts of the RFS Program to a broad range of environmental and resource conservation issues.

Recommendations

- Additional research is needed to link the quantities of biofuels estimated attributable to the RFS Program in this report to specific local changes in land cover and land management. This linkage would enable more explicit quantification of the impacts to date of the RFS Program and facilitate informed assessments of the likely future effects of the RFS Program.
- Conservation practices exist to offset many of the environmental effects from the cultivation of conventional biofuel feedstocks (e.g., corn, soybean) and agricultural effects more generally; and, while some of these have been widely adopted (e.g., conservation tillage), some have not (e.g., cover crops). A sustained effort to deploy these practices across a wider area, especially in areas of recent cropland expansion may be needed to offset the potential negative effects from the RFS Program specifically and biofuels more generally.
- Additional research is needed to better understand the several other complex uncertainties that remain, including the effects from the RFS Program on biofuels other than corn ethanol, the potential for palm oil and other low-cost oils to "backfill" soybean oil diverted toward biofuels, improvements in the skill of many remote-sensing datasets in quantifying grassland conversion, better data on where and which conservation practices are in place across the landscape, and others discussed above and in more detail throughout this report.
- More research overall on the environmental effects from the emerging biofuels is needed given that the mix of emerging biofuels may not have the same effects as the biofuels that were historically dominant.