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Biofuels and the Environment: First Triennial Report to Congress

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National Center for Environmental Assessment Office of Research and Development U.S. Environmental Protection Agency Washington, DC

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1		EXECUTIVE SUMMARY
2 3 4 5 6 7 8 9	This re Congress require EPA to revise fuel blended in per year by 20 volume require renewable fue	eport is the first of the U.S. Environmental Agency's (EPA's) triennial reports to irred under the 2007 Energy Independence and Security Act (EISA). EISA requires the Renewable Fuel Standard (RFS) program to increase the volume of renewable nto transportation fuel from 9 billion gallons per year in 2008 to 36 billion gallons 22. The revised standards (RFS2), finalized in 2010, establish new specific annual ements for cellulosic biofuel, biomass-based diesel, advanced biofuel, and total 1 in transportation fuel.
10 11 12 13 14 15	EISA s conservation i soil quality an species, and ir entire biofuel distribution, a	Section 204 calls for EPA to report to Congress on the environmental and resource mpacts of increased biofuel production and use, including air and water quality, d conservation, water availability, ecosystem health and biodiversity, invasive international impacts. This report reviews impacts and mitigation tools across the supply chain, including feedstock production and logistics, and biofuel production, nd use. The report focuses on:
16 17 18 19 20 21 22	•	Six feedstocks: The two most predominantly used (<i>corn starch</i> and <i>soybeans</i>), and four others (<i>corn stover, perennial grasses, woody biomass</i> , and <i>algae</i>) that represent a range of feedstocks currently under development. Because the RFS2 limits the amount of corn starch-derived biofuel that counts toward the volume requirement in 2022 to 15 million gallons, an increased reliance on other feedstocks is predicted.
23 24 25 26	•	Two biofuels: <i>Ethanol</i> (both conventional and cellulosic) and <i>biomass-based diesel</i> , because they are the most commercially viable in 2010 and/or projected to be the most commercially available by 2022.
20 27 28 29 30 31	This fi reflects the cu presented, who to uncertaintie which do not a	rst report represents peer-reviewed information available through July 2010 and rrent uncertainty about biofuel production and use. Quantitative assessments are ere possible, however, in most cases only qualitative assessments were feasible due as and the lack of data and analyses in the peer-reviewed literature. Conclusions, account for existing or potential future mitigation measures or regulations, include:
32 33 34 35 36 37	•	Life Cycle Assessment. Some segments of the biofuel life cycle result in greenhouse gas (GHG) emissions; however, as noted in EPA's RFS2 Regulatory Impact Analysis, when the entire biofuel life cycle is considered, the EISA-mandated revisions to the RFS2 program are expected to achieve a 138-million metric ton reduction in carbon dioxide-equivalent emissions by 2022 compared to continued reliance on petroleum-based fuels.
38 39 40 41 42 43	•	Water Quality. Ground and surface water quality can be impacted by erosion and runoff of fertilizers and pesticides when feedstocks, particularly row crops such as corn, are cultivated for biofuel; through pollutants in the wastewater discharged from biofuel production facilities; and from leaks and spills during fuel transport.

44 Water Ouantity. Effects of feedstock production on water availability vary • 45 greatly by feedstock, processes used to produce the feedstock, and location. Depending on location, the amount of water required to grow corn and soybean 46 47 for biofuel can be far greater than that required to grow perennial grasses, woody biomass, and algae. Water used by biofuel production facilities is modest 48 49 compared to that required to produce biofuel feedstocks, and impacts depend on 50 the location of the facility in relation to water resources. 51 52 **Soil Quality.** Increased cultivation of biofuel feedstocks is likely to affect soil • 53 quality in various ways, depending on the feedstock. Some feedstocks may contribute to detrimental effects, including increased soil erosion, decreased soil 54 55 organic matter content, increased soil GHG emissions, and increased nitrogen and phosphorus losses to ground and surface waters. Other feedstocks may contribute 56 57 to advantageous effects such as increased soil carbon and reduced erosion. 58 59 Air Quality. Air quality may be impacted by pollutants from feedstock • production, such as farm equipment emissions and soil/dust particles made 60 airborne during field tillage and fertilizer application; by emissions from 61 62 combustion equipment used for energy production at biofuel production facilities; 63 and by evaporative and tailpipe emissions from combustion in vehicles. 64 Ecosystem. Increased cultivation of feedstocks for biofuel could significantly 65 • affect biodiversity through habitat alteration when uncultivated land is put into 66 production; from exposure of flora and fauna to pesticides; or through 67 68 sedimentation and eutrophication in water bodies resulting from soil erosion and 69 nutrient runoff, respectively. Invasiveness potential of cultivated feedstocks is also a concern, but varies by feedstock. 70 71 72 **International.** Increases in U.S. biofuel production and consumption volumes • 73 will affect many different countries as trade patterns and prices adjust in response 74 to global supply and demand. This will result in land use change and effects on air 75 quality, water quality, and biodiversity. Direct and indirect land use changes will likely occur across the globe as the U.S. and other biofuel feedstock-producing 76 77 countries alter their agricultural sectors to allow for greater biofuel production. 78 Many locations where biofuel production is growing, such as Indonesia, 79 Malaysia, and Brazil, are also areas of high biodiversity value. Depending where 80 biofuel feedstock production occurs, and to what extent the level of production increases with time, impacts to biodiversity could be significant. 81 82 83 Most activities, processes, and products associated with the biofuel supply chain are 84 already regulated, subject to limitations, or mitigated through various approaches. To further 85 address adverse impacts, EPA recommends: 86 Developing and evaluating Environmental Life Cycle Assessments for biofuels. • 87 88 Ensuring the success of current and future environmental biofuel research through 89 improved cooperation and sustained support. 90

91 92 93 94	•	Improving the ability of federal agencies (within their existing authorities) to develop and implement best management and conservation practices and policies that will avoid or mitigate negative environmental effects from biofuel production and use
95 96 97	•	Engaging the international scientific community in cooperative efforts to identify and implement sustainable biofuel practices that minimize environmental impact.
98 99 100	Becau address these agencies and	se biofuel impacts cross many topics and Agency responsibilities, EPA likely will recommendations through continued and strengthened cooperation with federal international partners, including the U.S. Departments of Agriculture and Energy.

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1 **1. INTRODUCTION**

In December 2007, Congress enacted the Energy Independence and Security Act (Public Law 110-140) (EISA) to reduce U.S. energy consumption and dependence on foreign oil, and to address climate change through research and implementation of strategies to reduce greenhouse gases. Accordingly, EISA requires the U.S. Environmental Protection Agency (EPA) to revise the Renewable Fuel Standard (RFS) program, created under the 2005 Energy Policy Act,^a to increase the volume of renewable fuel^b required to be blended into transportation fuel from 9 billion gallons per year in 2008 to 36 billion gallons per year by 2022.

EPA finalized revisions to the RFS program in February 2010. The revised statutory
requirements (commonly known as the RFS2) establish new specific annual volume standards
for cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel that must
be used in transportation fuel (see Chapter 2). Meeting RFS2 in 2022 will result in biofuels
making up an estimated 7 percent of fuels (by volume) used for transportation (U.S. EPA,
2010a). The purpose of this report is to examine the environmental and resource conservation
impacts of this change, as required under EISA Section 204.

EISA Section 204 calls for EPA to report to Congress every three years on the
 environmental and resource conservation impacts of increased biofuel production and use as
 follows:

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(0) of the Clean Air Act^c on the following:

24	1.	Environmental issues, including air quality, effects on hypoxia, pesticides,d
25		sediment, nutrient and pathogen levels in waters, acreage and function of waters,
26		and soil environmental quality.
27	2.	Resource conservation issues, including soil conservation, water availability, and
28		ecosystem health and biodiversity, including impacts on forests, grasslands, and
29		wetlands.
30	3.	The growth and use of cultivated invasive or noxious plants and their impacts on
31		the environment and agriculture.
32	4.	The report shall include the annual volume of imported renewable fuels and
33		feedstocks for renewable fuels, and the environmental impacts outside the United

^a The 2005 Energy Policy Act amended the Clean Air Act and established the first national renewable fuel standards. The statute specifies the total volume of renewable fuel that is to be used based on the volume of gasoline sold in the U.S. each year, with the total volume of renewable fuel increasing over time to 7.5 billion gallons in 2012.

^c EISA 2007 amended Section 211(o) of the Clean Air Act to include the definitions and requirements of RFS2.

^d Pesticides include antimicrobials, fungicides, herbicides, insecticides, and rodenticides.

^b To be considered "renewable," fuels produced by biorefineries constructed after EISA's enactment on December 19, 2007, must generally achieve at least a 20 percent reduction in life cycle greenhouse gas emissions compared to petroleum fuels.

- States of producing such fuels and feedstocks. The report required by this subsection shall include recommendations for actions to address any adverse impacts found.
- 38 This is the first of EPA's triennial reports on the current and potential future 39 environmental impacts associated with the requirements of Section 211(o) of the Clean Air Act. 40 This report reviews environmental and resource conservation impacts, as well as mitigation tools 41 to reduce these impacts, across major components of the biofuel supply chain: feedstock
- 42 production, feedstock logistics, biofuel production, biofuel distribution, and biofuel use.
- This report emphasizes domestic impacts; however, the substantial market created for biofuels by the U.S, Brazil, and other countries has important global implications. For example, countries that produce feedstocks, now or in the future, which are converted to biofuels that qualify for use in the U.S. will experience direct impacts; other countries will have to adapt to changing agricultural commodity distributions that result from diversion of food exports to biofuel production. As required under EISA Section 204, this report describes the impacts of increased feedstock and biofuel production in other countries as a result of U.S. policy.
- 50 This first triennial Report to Congress represents the best available information through 51 July 2010 and reflects the current understanding about biofuel production and use, including input from the U.S Departments of Agriculture and Energy, with whom EPA consulted during 52 53 development of this report. Quantitative assessments are presented, where possible, using 2010 54 or the most recently available data; however, in most cases only qualitative assessments were 55 feasible due to uncertainties and lack of data and analyses in the peer-reviewed literature. Future reports will reflect the evolving understanding of biofuel impacts in light of new research results 56 57 and data as they become available. This initial report to Congress serves as a starting point for 58 future assessments and for taking action to achieve the goals of EISA.

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1 2. BACKGROUND AND APPROACH

2 2.1 EISA and RFS2 Requirements for Biofuel Production and Use

3 RFS2 (the Renewable Fuel Standard as amended by the Energy Independence and 4 Security Act [EISA]) establishes new specific annual volume standards for four categories of renewable fuels that must be used in transportation fuel⁵: cellulosic biofuel, biomass-based 5 diesel, advanced biofuel, and total renewable fuel (see *Glossary* in Appendix A for fuel 6 definitions). Under RFS2, conventional biofuel (i.e., ethanol derived from corn starch) with a 7 maximum volume target and "additional renewable fuels"⁶ are included as eligible fuels to meet 8 the total renewable fuel standard. The revised statutory requirements also include new definitions 9 and criteria for both renewable fuels and the feedstocks used to produce them.⁷ including new 10 greenhouse gas emission (GHG) reduction thresholds (as determined by the life cycle assessment 11 12 that EPA conducted as part of its Regulatory Impact Analysis [RIA] during the final RFS2 rulemaking). 13

Table 2-1 shows the RFS2 annual renewable fuel standards through 2022. Total
renewable fuel under the standard will increase to 36 billion gallons per year (bgy) by 2022 (of
which corn starch ethanol is not to exceed 15 bgy).

17 While EISA establishes the renewable fuel volumes shown in Table 2-1, it also requires 18 the EPA Administrator each November to set the volume standards for the following year based in part on information provided by the Energy Information Administration (EIA) and other data 19 20 indicating the commercial capacity for producing cellulosic biofuels. EISA therefore requires the EPA Administrator to adjust the cellulosic standard, and potentially the total advanced biofuel 21 22 and total renewable fuel standards, each year based on this assessment. For 2010, the 23 Administrator adjusted the cellulosic standard from 0.1 bgy (100 million gallons per year) in RFS2 to 5.0 million gallons, but did not adjust the total advanced or total renewable fuel 24 standard.⁸ Therefore, the final 2010 standard for total renewable fuel is set at 12.95 bgy, with 25 26 specific targets for cellulosic biofuel (5.0 million gallons per year), biomass-based diesel (1.15 bgy [combining the 2009 and 2010 standards as proscribed in RFS2]), and total advanced biofuel 27

28 (0.95 bgy).

⁵ Transportation fuel includes fuels used in motor vehicles, motor vehicle engines, non-road vehicles, or non-road engines (except for ocean-going vessels).

⁶ EISA defines "additional renewable fuel" as "fuel produced from renewable biomass that is used to replace or reduce fossil fuels used in heating oil or jet fuel." Though RFS2 does not specify a volume standard for this fuel category, it does allow renewable fuel blended into heating oil or jet fuel to count toward achieving the standard for total renewable fuel. (This contrasts with the original RFS [RFS1], which did not provide credit for renewable fuel blended into non-road fuel.) More information about "additional renewable fuel" can be found in Section II.b.e of the final RFS2 rule available at http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm.

⁷ EISA requires that all renewable fuel be made from feedstocks that meet the new definition of renewable biomass, which includes certain land use restrictions. For full details, see Section 3.1.

⁸ Although EISA specified a 2010 cellulosic biofuel requirement of 100 million gallons/year, as shown in Table 2-1, EPA determined that this level was not achievable for 2010. EIA projected 5 million gallons/year of cellulosic production for 2010 (6.5 million gallons ethanol equivalent), and EPA accepted this as the 2010 standard. While this is lower than the level specified in EISA, no change to the advanced biofuel and total renewable fuel standards was warranted due to the inclusion of an energy-based equivalence value for biodiesel and renewable diesel.

	Renewable Fuel				
		Advanced Biofuel			
Year	Conventional Biofuel	Cellulosic Biofuel	Biomass-Based Diesel	Advanced Biofuel [°]	Total Renewable Fuel
2008	9.0	n/a	n/a	n/a	9.0
2009	10.5	n/a	0.5	0.6	11.1
2010	12.0	0.1 ^d	0.65	0.95	12.95
2011	12.6	0.25	0.80	1.35	13.95
2012	13.2	0.5	1.0	2.0	15.2
2013	13.8	1.0	TBD ^e	2.75	16.55
2014	14.4	1.75	TBD ^e	3.75	18.15
2015	15.0	3.0	TBD ^e	5.5	20.5
2016	15.0	4.25	TBD ^e	7.25	22.25
2017	15.0	5.5	TBD ^e	9.0	24.0
2018	15.0	7.0	TBD ^e	11.0	26.0
2019	15.0	8.5	TBD ^e	13.0	28.0
2020	15.0	10.5	TBD ^e	15.0	30.0
2021	15.0	13.5	TBD ^e	18.0	33.0
2022	15.0	16.0	TBD ^e	21.0	36.0

Table 2-1: RFS2	Renewable Fuel	Requirements	(billion	gallons pe	er year) ^{a, j}
		1	`	0 I	

29 a – The requirements for cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel are 30 minimum required volumes that must be achieved and may be exceeded. The conventional biofuel requirement is a

31 cap that cannot be exceeded.

32 b – Note that the RFS2 volume requirements are nested: cellulosic biofuel and biomass-based diesel are forms of 33 advanced biofuel; and advanced biofuel and conventional biofuel are forms of total renewable fuel.

34 c – Note that the sum of the required amounts of cellulosic biofuel and biomass-based diesel is *less* than the required

35 volume of advanced biofuel. The additional volume to meet the advanced fuel requirement may be achieved by the 36 additional cellulosic biofuel and biomass-based diesel (i.e., beyond the required minimum) and/or by other fuels that 37 meet the definition of advanced biofuel (e.g., sugarcane ethanol).

38 d – As described above, and as allowed under EISA, the EPA Administrator determined that original RFS2 standard

39 of 0.1 bgy for cellulosic biofuel was not achievable for 2010 and therefore decreased this standard to 5 million 40 gallons for 2010.

41 e – To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons. This requirement was

42 designated under EISA as "to be determined" with a minimum requirement because of the uncertainty about future 43

capacity to produce fuel that meets the biomass-based diesel definition.

44 Source: U.S. EPA, 2010b. 45

46 2.2 Projected Fuel and Feedstock Use to Meet Required RFS2 Targets through 2022

47 Figure 2-1 summarizes the fuel types and volumes *projected* to meet the required targets

through 2022, as estimated in the RFS2 Regulatory Impact Analysis. Although actual volumes 48

49 and feedstocks will likely be different, EPA believes the projections are within the range of

expected outcomes when the standards are met (U.S. EPA, 2010b). 50



52 Source: U.S. EPA, 2010b.



Figure 2-1: Projected Renewable Fuel Volumes to Meet RFS2 Targets

54 In 2009, corn ethanol constituted 95 percent of total U.S.-produced renewable fuel, with biodiesel made from soybean oil, other virgin vegetable oils, rendered fats, greases, and corn oil 55 56 from ethanol production accounting for almost all the remaining biofuel consumed (FAPRI, 57 2010a; EIA, 2010). However, as technologies improve, EPA expects more advanced cellulosic feedstocks, such as agricultural residues (e.g., corn stover, sugarcane bagasse, wheat residue, 58 59 sweet sorghum pulp), forestry biomass, urban biomass waste, and dedicated energy crops (e.g., switchgrass) to produce biofuels (Figure 2-2) (U.S. EPA, 2010b). Present research is focused on 60 61 improving technologies to convert different feedstocks to biofuels in an economically viable 62 manner, and determining sustainable biofuel production methods.



64

Figure 2-2: Examples of Feedstocks Available for Biofuel Production

65 With respect to biodiesel, EPA expects continued use of soybean oil, which made up 54

66 percent of feedstock used for biodiesel in 2009 (EIA, 2010), as well as a varying percentage of

67 other vegetable oils, rendered fats, greases, and corn oil from ethanol production through 2022

68 (see Table 4-1 for a more detailed breakdown) (U.S. EPA, 2010b). Algae could potentially 69 provide large volumes of oil for the production of biomass-based diesel. However, several

69 provide large volumes of oil for the production of biomass-based diesel. However, several 70 hurdles, including technical issues, will likely limit production volumes within the 2022

71 timeframe (U.S. EPA, 2010b).

Imported sugarcane ethanol, also represents a significant potential supply of biofuel by
2022 (U.S. EPA, 2010b). In 2009, the United States imported 198 million gallons of ethanol
(EIA, n.d. [d]). Import volumes are expected to grow as U.S. demand increases to meet the
biofuel targets.

76 2.3 Assessment of the Environmental and Resource Conservation Impacts of Biofuels

77 2.3.1 Approach

This report presents a comprehensive survey of environmental evaluations across the biofuel supply chain (see below), including current and anticipated future feedstock production and logistics and biofuel production, distribution, and use. It summarizes much of the available information and identifies research needed to evaluate potential environmental impacts from a life cycle perspective and quantify them using more substantive and systematic assessment tools. This report therefore is the first step towards conducting a biofuels environmental life cycle assessment (LCA), which EPA will conduct for its future Reports to Congress (see Chapter 7).

Life cycle assessment evaluates environmental impacts resulting from all stages of a product's development—from extraction of fuel for power to production, marketing, use, and

- disposal. EPA has begun to collaborate with partners and stakeholders to formulate specific
- questions, establish boundaries, and identify critical assessment endpoints to be used in modeling
- the input and output data for comprehensively assessing potential impacts across the biofuel
- 90 supply chain and integrating environmental risk assessment (ERA) tools. Although this report
- 91 does not attempt a comprehensive biofuels environmental LCA, as part of the EISA-mandated 92 revisions to the RFS program, EPA conducted a life cycle assessment of GHG emissions from
- 92 revisions to the KFS program, EFA conducted a fire cycle assessment of OHO emissions from
 93 increased renewable fuels use, which projected a 138-million metric ton reduction in CO₂-
- 94 equivalent emissions by 2022 (U.S. EPA, 2010b). Section 4.3.2.3 provides more details about the
- 95 LCA methodology and results. This work, which will provide the foundation for future versions
- 96 of this Report to Congress, will draw from the considerable work that has already been done to
- 97 develop LCA and other methodologies, including ecological and human health risk assessment,
- 98 to assess impacts of specific biofuel products and processes.

99 2.3.2 Biofuel Supply Chain

- 100 There are five main stages in the biofuel supply chain: feedstock production, feedstock
- logistics, fuel production, fuel distribution, and fuel use (Figure 2-3). The specific impacts
 associated with a particular feedstock or biofuel will vary depending on many factors, including
- 102 associated with a particular reedstock or biofuel will vary depending on many factors, including 103 the type, source, and method of feedstock production; the technology used to convert the
- feedstock to fuel; methods used and distances traveled to transport biofuels; the types and
- 104 recusiock to rule, memous used and distances traveled to transport bioruels; the types 105 quantities of biofuels used; and controls in place to avoid or mitigate any impacts
- 105 quantities of biofuels used; and controls in place to avoid or mitigate any impacts.



- 106
- 107

Figure 2-3: Five Stages of the Biofuel Supply Chain

108 2.3.3 Feedstocks and Fuels Discussed in This Report

109 There is uncertainty regarding which feedstocks will be used to meet the RFS2 targets in the mid- to long-term time horizon. A few feedstocks are already in use, including primarily corn 110 111 and soybean, as well as others in smaller quantities. Other feedstocks are in the early stages of 112 research and development or their potential future commercial viability is still unknown. This report focuses on six feedstocks: the most predominantly used (corn and soybeans) and four 113 others (corn stover, perennial grasses, woody biomass, and algae) that represent a range of 114 115 feedstocks currently under development. The biofuels highlighted in this report are ethanol (both conventional and cellulosic) and biomass-based diesel. Ethanol and biomass-based diesel are the 116 focus because they are currently the most commercially viable and/or are projected to be the 117 118 most commercially available by 2022, and they are the primary fuels currently projected to meet 119 RFS2. Future reports will analyze other feedstocks and fuels.

139 140

120 2.3.4 Impacts Discussed in This Report

121 This report focuses on specific environmental and resource conservation impacts specified in EISA Section 204, as shown in Figure 2-4 and described in Tables 2-2 and 2-3. This 122 123 report does not include extensive discussion of carbon dioxide or other greenhouse gas emissions; interested readers are referred to the EPA's RFS2 Regulatory Impact Analysis (U.S. 124 EPA, 2010b). A short discussion is provided in Section 4.3.2.3 of this report. The environmental 125 and resource conservation impacts discussed in this report reflect a complex set of interactions 126 and feedbacks between land, soil, air, and water; future versions of this report will explore 127 128 analysis of these important complexities as enhanced data and analysis tools become available. 129 This report does not attempt to conduct a quantitative analysis of the range of impacts associated 130 with increased production of biofuel. Instead, it represents a compilation of available information and analyses that can inform the nature and extent of impacts that might be expected to occur. 131 Thus, this report does not use a baseline year, per se, against which future impacts can be 132 measured. Different impacts have been assessed using applicable baselines cited in the literature 133 or, as appropriate, in the RFS2 RIA. Generally, however, the primary reference point used in this 134 document is consistent with the primary reference case used in the RFS2 RIA. This reference 135 136 case is a projection made by the U.S. Energy Information Administration prior to EISA in their

137 2007 Annual Energy Outlook of renewable fuel volumes expected in 2022.



141 Figure 2-4: Environmental and Resource Conservation Issues Addressed in This Report

142 Chapter 3 focuses on feedstock production, including cultivation and harvest. Chapter 4 143 covers impacts of feedstock logistics and biofuel production, distribution, and use. Many 144 activities, processes, and products associated with the biofuel supply chain are already regulated, 145 are subject to limitations, or are mitigated through various approaches, as discussed in these 146 chapters. The potential impacts associated with imported biofuels are discussed in Chapter 5. 147 Currently, imported ethanol and biodiesel supply a relatively small percentage of U.S. biofuel 148 consumption—approximately 9 percent in 2008 (EIA, 2009, n.d.[a]; U.S. ITC, 2010; ERS, 149 2010a). If these percentages increase, future versions of this report may provide expanded

150 analysis of international impacts associated with imported biofuels.

151 EPA's ability to assess environmental and resource conservation impacts is limited by 152 uncertainties associated with even a qualitative assessment of the direct impacts. Many feedstock 153 technologies are in the early stages of research and development, therefore empirical and 154 monitoring data relevant to environmental impacts are limited and projections of their potential 155 future use are highly speculative. Recommendations in Chapter 6 and the approach to future 156 assessments described in Chapter 7 address how the EPA intends to bolster data availability and 157 analysis to improve understanding of environmental impacts in future reports.

	Feedstock Production and Transportation	Fuel Production, Distribution, and Use
Water Quality	 Pollution of ground, surface, and drinking water due to runoff containing sediments, nutrients, pesticides, and metals Loss of aquatic habitat due to pollution and sedimentation. Water quality impacts of converting pasture or marginal or non-cultivated land to feedstock production 	• Contamination of surface, ground, and drinking water by wastewater from biofuel production facilities and from leaks and spills during fuel transportation and storage
Water Availability	 Reduced availability of local or regional water due to withdrawals of water needed to irrigate feedstocks Loss of aquatic habitat due to lowered stream flow 	 Lowered stream flow and aquifer levels due to water withdrawals for biofuel conversion. Reduced availability of water due to contamination (see above)
Soil Quality and Soil Conservation	 Degradation in soil quality due to (1) changes in land use; (2) increased use of nutrients, pesticides, and tillage and (3) harvesting of agricultural and forest residue Soil contamination from use of pesticides 	 Soil contamination from leaks and spills during fuel transportation and storage Addition of methane to soil gas resulting from biodegradation of spilled biofuel
Air Quality	 Emissions of criteria pollutants, air toxics, and greenhouse gases by farm and transportation vehicles Fugitive dust from feedstock production operations 	• Emissions of criteria pollutants, air toxics, and greenhouse gases during conversion and by transportation vehicles and off-road equipment

Table 2-2: Overview of Environmental and Resource Conservation ImpactsAddressed in This Report ^a

Table 2-2: Overview of Environmental and Resource Conservation Impacts
Addressed in This Report ^a

	Feedstock Production and Transportation	Fuel Production, Distribution, and Use
Ecosystem Health/Biodiversity (including invasive and noxious plants)	 Impacts on flora and fauna and loss of ecosystem services due to pollution and habitat changes Establishment and spread of invasive or noxious plants 	• Establishment and spread of invasive or noxious plants

a – The impacts in this table are generalized and do not take into account location or effectiveness of mitigation
 practices.

160

Table 2-3: Overview of Environmental and Resource Conservation Impacts on SpecificEcosystems Addressed in This Report ^a

	Feedstock Production
Forests	 Short rotation woody crop (SRWC) plantations may deplete soil nutrients over the long run, but appropriate management techniques may increase soil nutrients. SRWC plantations can sustain high species diversity, although bird and mammal species tend to be habitat generalists. Some tree species under consideration as feedstocks may invade forests in certain locations. Forest thinning can reduce the threat of catastrophic wildfires. Forest thinning can increase nutrient availability in soils over the short term. Harvesting forest residues decreases nutrient availability, soil organic matter, and habitat for some forest species.
Grasslands	 Conversion of grasslands to row crops impacts grassland-obligate species, potentially leading to declines in wildlife habitat. Higher proportions of corn within grassland ecosystems leads to fewer grassland bird species. Growing more switchgrass may improve grassland habitat for some species depending on management regimes. Conversion of Conservation Reserve Program lands to perennial grasses or harvesting of existing grasslands is likely to have low impacts on grassland species, particularly if harvesting occurs after the breeding season. Use of native mixtures of perennial grasses can restore some native biodiversity. Cultivation of switchgrass outside of its native range may lead to invasions of native grasslands. Cultivation of <i>Miscanthus</i> may lead to invasions of pasture and other grasslands.

Table 2-3: Overview of Environmental and Resource Conservation Impacts on SpecificEcosystems Addressed in This Report ^a

	Feedstock Production
Wetlands	 Increased sediments, nutrients, pesticides, and pathogens from runoff can flow into downstream wetlands. Increased nutrient loadings can lead to changes in wetlands community structure. Reduced sediment and nutrient loadings can lead to improved water quality, depending on the specific management practice used. Some grass species under consideration may invade wetlands, including giant reed (<i>Arundo donax</i>) and reed canary grass (<i>Phalaris arundinacea</i>).
	 Harvesting forest residues and forest thinning may increase nutrient loads, depending on slopes, soils, presence of buffer zones, and use of best management practices to reduce runoff. Algal strains created may escape from cultivation and invade wetlands.

a – The impacts in this table are generalized and do not take into account location or effectiveness of mitigation
 practices.

163164 2.4 Regulatory Authority Relevant to Biofuel Environmental Impacts

EPA, as well as states, tribes, and local environmental agencies, has statutory responsibility to assess and control air emissions, water discharges, use of toxic substances, microbial and pesticide use, and waste disposal. Many existing environmental regulations and programs are applicable to the biofuel supply chain, including feedstock production and logistics; biofuel production and distribution, and biofuel use.

170 EPA's primary federal regulatory authority is derived from the Clean Air Act (CAA); the Clean Water Act (CWA), the Federal Insecticide Fungicide and Rodenticide Act (FIFRA); 171 172 Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act 173 (TSCA). Under the CAA, EPA has broad direct statutory authority to regulate fuel quality and emissions from refining and production facilities for all fuels, including biofuels. The CAA also 174 establishes limits for mobile source (vehicular) emissions. The Clean Water Act requires permits 175 for point source discharges to waters of the U.S, and development of water quality standards, and 176 177 Total Maximum Daily Loads (TMDLs) for water bodies where water quality standards have not been met. FIFRA establishes standards for storage and use of pesticides in a manner that does 178 179 not harm human health or the environment. RCRA governs the generation, storage, treatment, 180 transport, and disposal of hazardous waste. TSCA requires manufacturers and importers of new chemicals to submit "pre-manufacture" notices for EPA review prior to manufacture and 181 182 commercial use of new chemicals, including new fuels, new biological materials, and new 183 genetically engineered microorganisms used to produce biofuels or co-products. Through the 184 CWA's Spill Prevention, Control and Countermeasure rule, EPA has enforceable regulations to 185 control water quality impacts from spills or leaks of biofuel products and by-products. In 186 addition, the Safe Drinking Water Act establishes maximum contaminant levels (MCLs) for 187 more than 90 drinking water contaminants to ensure public health. These statutes provide opportunities within the existing regulatory framework to regulate and mitigate some of the 188 189 potential adverse health and environmental effects of biofuels. Selected environmental laws 190 relevant to the production and use of biofuels are summarized in Appendix B.

191 Generally, EPA headquarters offices develop policies and regulations for these federal 192 statutes, while regional EPA offices, in partnership with the states and tribes, implement these 193 programs, ensure compliance, and enforce regulations. EPA and its regional offices work closely 194 with states and tribes to review permit applications for new facilities and to monitor 195 environmental impacts to ensure compliance with all permit conditions. EPA has prepared two 196 documents to help biofuel facilities understand the full range of regulatory requirements (U.S. 197 EPA, 2007a, 2008a). While EPA has oversight authority for federal environmental regulatory 198 programs and regulations, state agencies and tribes are often "delegated" the responsibility for 199 issuing permits, conducting inspections, ensuring compliance, and taking enforcement action. 200 EPA regulations establish minimum requirements. States can enact more stringent standards, 201 although several states have enacted legislation that prohibits adopting requirements stronger 202 than those set by EPA.

1 3. ENVIRONMENTAL IMPACTS OF SPECIFIC FEEDSTOCKS

2 3.1 Introduction

3 The Energy Independence and Security Act (EISA) requires that all renewable fuel be 4 made from feedstocks that meet the definition of renewable biomass (see textbox). Many 5 different feedstocks meet these requirements and can be used to produce ethanol, other biofuels 6 or biofuel components.

7 In 2009, 95 percent—or 10.9 billion gallons—of total renewable fuel produced in the 8 U.S. was produced from corn and refined almost entirely in the form of conventional corn starch 9 ethanol (FAPRI, 2010a). Soybean oil-based biodiesel accounted for most of the remainder—505 10 million gallons. EPA expects that corn and soybean feedstocks will continue to account for a large share of biofuel production in the U.S. (U.S. EPA, 2010b) in the near future. As of July 11 12 2010, there was no significant commercial-scale production of ethanol from cellulosic or 13 hemicellulosic feedstocks, nor was there significant biodiesel production from oil seed

- 14 feedstocks other than soybean in the U.S.
- 15 As science and technology improves,
- 16 EPA expects an increase in the use of
- 17 cellulosic feedstocks to produce advanced
- 18 biofuel. Such feedstocks include agricultural
- 19 residues (e.g., corn stover, sugarcane
- 20 bagasse, sweet sorghum pulp), forestry
- 21 biomass, urban waste, and dedicated energy
- 22 crops (e.g., switchgrass) (U.S. EPA, 2010b).
- 23 Technologies for producing biodiesel from
- 24 vegetable oils, recycled oils, rendered fats, 25
- greases, and algal oils have been developed
- 26 and tested at various scales from the 27
- laboratory to demonstration plants and semi-
- 28 commercial facilities. EPA expects biodiesel 29 from these feedstocks to gain a wider market
- 30 share as their production becomes more
- 31 economically and technologically feasible
- 32 (U.S. EPA, 2010b).
- 33 The feedstocks discussed in this
- 34 chapter include corn and soybeans, as well
- 35 as four others currently under development:
- 36 corn stover, perennial grasses, woody
- biomass, and algae (see Table 3-1). These 37
- 38 feedstocks represent different cultivation
- 39 and production practices.

Requirements for Renewable Fuels

Under the Energy Independence and Security Act, all renewable fuel must be made from feedstocks that meet the EISA definition of renewable biomass, which includes:

- Planted crops and crop residue from agricultural lands that were cleared prior to December 19, 2007, and were actively managed or fallow on that date.
- Planted trees and tree residue from tree plantations that were cleared prior to December 19, 2007 and were actively managed on that date.
- Animal waste material and by-products.
- Slash and pre-commercial thinnings from nonfederal forestlands that are neither old-growth nor listed as critically imperiled or rare by a State Natural Heritage program.
- Biomass cleared from the vicinity of buildings and other areas at risk of wildfire.
- Algae.
- Separated vard waste and food waste.

Currently, as described in the final RFS2 rule, EPA deems renewable fuel producers using domestically grown crops and crop residue as feedstock to be in compliance with the renewable biomass requirements. However, EPA will annually review U.S. Department of Agriculture (USDA) data on lands in agricultural production to determine if these conclusions remain valid.

40 This chapter reviews the actual (where known) and potential environmental impacts of producing these six feedstocks, including impacts on water quality and quantity, soil and air 41

- 42 quality, and ecosystem health/biodiversity. Feedstock production impacts are considered during
- 43 the cultivation and harvest processes (see Figure 2-3). Impacts associated with the subsequent
- four stages of the biofuel supply chain are presented in Chapter 4. Row crop feedstocks (corn,
- 45 corn stover, and soybean), which share many commonalities, are discussed in Section 3.2.
- 46 Sections 3.3 to 3.5 present potential effects associated with switchgrass, woody biomass, and
- 47 algae.

Table 3-1: Primary Fuels a	and	Feedstocks	Discussed	in	this
ŀ	Rep	ort			

EISA Biofuel Type	Biofuel	Feedstock
Conventional Biofuel	Ethanol	Corn Starch
Cellulosic Biofuel	Ethanol	Corn Stover
		Perennial Grasses
		Woody Biomass
Biomass-Based Diesel	Biomass-Based	Soybeans
	Diesel	Algae

In addition to the six primary feedstocks examined in this report, Section 3.6 briefly discusses waste materials as potential emerging feedstocks for biofuels. In addition to general ecosystem impacts, Section 3.7 reviews impacts on specialized habitats (forests, grasslands, and wetlands), as required under EISA Section 204. Section 3.8 reviews environmental concerns associated with genetic engineering of feedstocks, commonly referred to as genetically modified organisms (GMOs).

55 3.2 <u>Row Crops (Corn, Corn Stover, Soybeans)</u>

56 3.2.1 Introduction

- 57 U.S. corn and soybean production
 58 have increased steadily over the past
 59 several decades. Increased demand for
- 60 biofuel provides additional incentive to
- 61 continue research and development for
- 62 increasing crop yields. As shown in Figure
- 63 3-1, U.S. corn production increased by
- 64 more than a factor of four between 1950
- and 2010. These increases were largely
- 66 due to gains in efficiency and crop yield.
- 67 Soybean yields have also increased. For
- 68 example, soybean yields increased from
- 69 21.7 bushels per acre in 1950 to 43.9
- 70 bushels per acre in 2010 (NASS, 2010a).



Source: NASS, 2010a.

Figure 3-1: U.S. Corn Production

Actual environmental impacts will vary, depending on the number of acres in production,
 cropping techniques, implementation of conservation practices, and the location of the crop
 acreage including hydrology, soils, and other geographic factors.

74 **3.2.1.1** Current and Projected Cultivation

In 2009⁹, U.S. farmers planted 86 million acres of corn, harvesting 13.1 billion bushels 75 (NASS, 2010a). Approximately 4.6 billion bushels of corn from the 2009 harvest were used to 76 produce corn ethanol. In 2010, U.S. farmers planted 88 million acres of corn, harvesting 12.5 77 78 billion bushels (NASS, 2010a). Approximately 4.8 billion bushels (or 38.4 percent) of corn are 79 projected to be used to produce corn starch ethanol biofuel between September 2010 and August 2011 (ERS, 2010c), up from 11.2 percent in the 2004-2005 harvest year (ERS, 2010b, 2010c). 80 Corn is grown throughout the U.S., but the vast majority of the crop is grown in 12 states: 81 82 Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin. Figure 3-2 shows a map of planted acres by county (for selected 83

84 states) in 2009.







Figure 3-2: Planted Corn Acres by County, for Selected States (2009)

88

⁹ As of January 2011, 2009 was the last year for which USDA NASS and EIA had complete datasets.

89 EISA establishes 15 billion gallons as the maximum amount of corn starch ethanol that 90 can contribute to meeting the 36 billion gallon per year renewable fuel target in 2022. Domestic 91 production, which totaled 10.9 billion gallons in 2009 (EIA, n.d.[c]), is expected to meet this 92 target through a combination of increased corn yield, increased acreage, and, potentially, 93 improved efficiency in converting corn starch to ethanol. U.S. Department of Agriculture 94 (USDA) estimates that planted corn acreage will remain at 88 million acres through 2021(USDA 95 does not project acreage beyond 10 years), as U.S. demand for biofuel increases (USDA, 2010a). 96 In the RFS2 analysis, EPA estimates that in order to produce 15 billion gallons of corn starch 97 ethanol per year by 2022, the percentage of corn acreage dedicated to ethanol could rise from the 98 current 38 percent to as high as 41 percent in 2022 (U.S. EPA, 2010b).

99 Concern has been raised that the demand for corn ethanol may put pressure on the USDA's Conservation Reserve Program (CRP) (Secchi and Babcock, 2007). This program 100 provides farmers with financial incentives to set aside a certain portion of their cropland for 101 102 buffer zones in order to conserve wildlife habitat, reduce erosion, protect water quality, and 103 support other environmental goals. CRP lands are not precluded by the feedstock requirements 104 for renewable fuels (see text box on page 3-1) from being used to grow biofuel feedstocks. 105 Therefore their conversion to biofuel feedstocks could reduce the effectiveness of the CRP 106 program in protecting the environment, and could result in increased environmental impacts, 107 depending on the nature (i.e., crop) and extent of the conversion. One estimate, which examined 108 the state of Iowa, predicted that high corn prices could lead to the recultivation of up to 70 percent of the expiring acreage enrolled in the CRP (Secchi and Babcock, 2007). Other states 109 110 may not have such high rates of recultivation given that much of the land in the CRP is marginal 111 and would be expensive to cultivate.

The Food, Conservation, and Energy Act of 2008 (Farm Bill) capped CRP acreage at 32 million, reducing enrollment by 7.2 million acres from the 2002 Farm Bill and potentially making more acreage available for corn production (ERS, 2008). In 2007, approximately 28.5 million acres or 78 percent of all CRP lands consisted of some type of grassland (FSA, 2008).

116 A USDA study estimates that, to meet the renewable fuel standard, total cropland will 117 increase 1.6 percent over 2008 baseline conditions by 2015, with corn acreage expanding 3.5 percent, accounting for most of the cropland increase (Malcolm et al., 2009). While corn acreage 118 119 is expected to expand in every region, this USDA study estimates that traditional corn-growing 120 areas would likely see the largest increases—up 8.6 percent in the Northern Plains, 1.7 percent in 121 the Corn Belt, and 2.8 percent in Great Lakes States (Malcolm et al., 2009). Historically, corn 122 has been grown in rotation with other crops such as wheat, hay, oats, and especially soybeans. 123 However, high corn prices have created incentives for continuous cultivation of corn (NASS, 124 2007a), and in some cases conversion of non-cropland to corn.

125 Corn stover—the stalks, leaves, husks, and cobs that are not removed from the fields 126 when the corn grain is harvested—provides another potential feedstock for meeting EISA 127 requirements. In the RFS2 RIA, EPA estimated that 7.8 billion gallons of ethanol could be 128 produced from corn stover by 2022. Most corn stover harvesting for biofuel is expected to be 129 from the major corn producing states. As of July 2010, there is no commercial production of 130 cellulosic ethanol from corn stover. Because corn stover protects underlying soil from wind and water erosion, the use of corn
 stover as a feedstock could increase soil erosion and environmental impacts compared to existing

- 133 practices (Sheehan et al., 2004; Williams et al., 2009). The USDA's Natural Resource
- 134 Conservation Service (NRCS) has established soil loss tolerance levels, and farmers harvesting
- 135 corn stover are encouraged to maintain a minimum level of groundcover or using other practices
- 136 to minimize soil loss. Under current rotation and tillage practices, approximately 30 to 40 percent 137 of stover could be collected cost effectively, taking into consideration erosion reduction, soil
- moisture needs and nutrient replacement (Graham et al., 2007; Perlack et al., 2005).

Maintaining soil carbon levels is another concern that should be taken into account when determining the extent of stover harvesting. To maintain soil carbon levels, a significant portion of the corn stover would need to be left on fields, reducing the amount of the biomass that could be collected for feedstock. Sustainable residue removal rates depend on tillage practices, with notill allowing for the greatest level of sustainable removal. Developing a single national estimate of the amount of residue that must remain on the ground to meet conservation goals is difficult because much depends on site-specific conditions.

146 After corn, soybean is the second largest agricultural crop (in terms of acreage) in the U.S. In 2009, American farmers planted 77.4 million acres and harvested 3.4 billion bushels. In 147 2010, American farmers planted 77.7 million acres of soybeans and again harvested 3.4 billion 148 149 bushels (NASS, 2010a). Soybean oil is the principal oil used for commercial production of 150 biodiesel in the U.S., responsible for about half of total biodiesel production, with the rest 151 coming from various other vegetable oils such as canola oil as well as waste fats, tallow and 152 greases (see Table 4-1 for more detailed breakdown) (EIA, 2010). In harvest year 2008/2009, 153 approximately 5.6 percent of the soybean harvest, or about 1.9 billion pounds of soybean oil 154 (USDA, 2010b), went to biodiesel production and yielded 505 million gallons in calendar year 155 2009 (EIA, n.d. [d]). This was a significant decline from the production total in 2008 of 676 156 million gallons (EIA, n.d. [d]). Nonetheless, USDA expects the percentage of soybean harvest going to biodiesel to increase to 7.8 percent by 2012 and holding steady through 2019. USDA 157 also projects that soybean oil used for biodiesel will represent 13-15 percent of total use of 158 soybean oil-approximately 400 million gallons of biodiesel (USDA, 2010b).¹⁰ USDA estimates 159 160 that soybean acreage will level off at approximately 76 million acres through 2019 (USDA, 161 2010b).

- In terms of cultivation, soybeans are typically grown in the same locations as corn. Figure
 3-3 shows that soybean production is centered in the Upper Midwest and along the Mississippi
- River Valley, with Iowa, Illinois, Indiana, Minnesota, and Nebraska representing the top
- 165 soybean-producing states.

¹⁰ Percentages were calculated by multiplying together the percentage of soybean crop converted to soybean oil, percentage of soybean oil converted to biodiesel, and total bushels produced, then dividing by total bushels produced.



Source: NASS, 2010b.

168

Figure 3-3: Planted Soybean Acres by County (2009)

169 Much of the recent expansion in corn acreage for ethanol production has come at the expense of land previously used for other crops, especially soybeans (Fargione et al., 2009; 170 Keeney and Hertel, 2009). In 2007, corn acreage expanded 23 percent in response to high prices 171 172 and the demand for corn ethanol production (Mitchell, 2008). This expansion resulted in a 16 173 percent decline in soybean acreage, which reduced soybean production and contributed to a 75 percent rise in soybean prices between April 2007 and April 2008 (Mitchell, 2008). Much of the 174 soybean acreage decrease occurred as a result of changing agricultural rotation, for example 175 some corn-soybean-corn rotations were replaced by continuous corn (Fargione et al., 2009). In 176 2008, corn acreage declined by 7.5 million acres, to 86 million acres, while soybean acreage 177 increased by almost 11 million acres. A large proportion of the soybean acreage increase came 178 179 from the reduction in corn acreage as well as switching crops other than corn to soybeans, loss of CRP land, and an increase in soybean double cropping (Babcock and McPhail, 2009). Such 180 tradeoffs between food crops, energy crops, and CRP lands may become more critical in the 181 182 future, especially as climate change affects global cropland area and water availability for 183 irrigation. One study predicted that climate change will reduce global cropland area by 9 percent 184 by the year 2050, although noting that this could be buffered by the increased use of water management strategies (Rost et al., 2009). 185

186**3.2.1.2Overview of Environmental Impacts**

Corn and soybean production entails the use of pesticides, fertilizer, water, and
 fuel/energy, in addition to drainage systems, each of which can affect water quality, water

- availability, soil quality, air quality, and ecosystem health. Changes in land cover, vegetation,
- and habitat have additional impacts on the environment. Table 3-2 summarizes these impacts and
- 191 the factors that influence them. (Note: Because corn stover is essentially a by-product of corn
- 192 production, only direct environmental impacts from stover harvest are considered for discussion
- 193 of this feedstock's impacts.)

Impact/Resource Use Category	Corn Starch ^a	Harvest of Corn Stover	Soybean
Water Quality	Corn production can lead to erosion of sediment and the runoff and leaching of fertilizers such as nitrogen and, phosphorus, and pesticides such as atrazine. Artificial drainage like tile drains increases loss of nitrogen to surface waters. Actual water quality impacts depend on a number of geographic and management factors: for instance, the rate, timing, and method of application of fertilizers, manure, and pesticides; and the use of erosion control practices such as edge of field controls like vegetative buffers, controlled drainage, or constructed wetlands.	Removal of corn stover will require increases in fertilizer application rates, which can result in the pollution of surface and ground waters. Erosion can also increase as more stover is removed, providing less ground cover. Actual water quality impacts will depend on a variety of geographic and management factors.	The majority of soybean acreage is managed with conservation tillage, minimizing erosion. Though soybean production requires smaller amounts of many nutrients— especially nitrogen—than does corn production, it often still requires potassium and phosphorus, which may impact water quality. Actual water quality impacts depend on a variety of geographic and management factors.
Water Quantity	In areas where corn production requires irrigation, surface and ground water quantities may be affected. Irrigation requirements depend on rainfall, relative humidity, soil properties, and crop yield.	Additional water use for stover production is likely to be minimal.	In areas where soybean production necessitates irrigation, surface and ground water quantities may be affected. Irrigation requirements depend on rainfall, relative humidity, soil properties, and crop yield.

Table 3-2: Impacts Associated with Biofuel Feedstock Production (Corn Starch, Corn Stover, and Soybean)

Impact/Resource Use Category	Corn Starch ^a	Harvest of Corn Stover	Soybean
Soil Quality	The conversion of uncultivated land or marginal cropland to corn production may lead to higher soil erosion and lower quantities of soil organic matter. Soil quality is maintained through management practices that include reduced use of tillage, use of crop rotations, and the return of organic matter to the soil through cover crops, manure, or crop residues.	Excess removal of corn stover can increase erosion, decrease soil organic matter and degrade water quality. These impacts depend on management practices and local conditions, including slope, soil type, and prior land use.	The majority of soybean acreage is managed with conservation tillage practices, mitigating erosion and impacts on soil organic matter.
Air Quality	Emissions of criteria and air toxic pollutants are associated with several sources, including combustion of fossil fuels by farm equipment; airborne particles (dust) generated during tillage and harvesting; and the production and application of fertilizers and pesticides.	Corn stover harvesting may affect air quality if it requires the combustion of additional diesel or gasoline beyond that used to harvest corn, if it leads to additional fertilization of fields, or if additional dust is released into the air during harvest operations.	Emissions of criteria and air toxic pollutants are associated with several sources, including combustion of fossil fuels by farm equipment; airborne particles (dust) generated during tillage and harvesting; and the production and application of fertilizers and pesticides.
	Actual impacts depend on use rates and formulations of fertilizers, and pesticides; tillage methods; the type of fuel and agricultural equipment; and conditions at time of tillage and harvest.		Actual impacts depend on use rates and formulations of fertilizers and pesticides; tillage methods; the type of fuel and agricultural equipment; and conditions at time of tillage and harvest.
Ecosystem Impacts	The type and extent of ecosystem impacts depend on local conditions and management. Nutrients, sediment, and pesticides can contaminate surface waters and wetlands, leading to changes in biodiversity.	Corn stover harvest may decrease soil biodiversity. The water quality impacts described above may affect wetland biodiversity. The ecosystem impacts of stover removal depend on a variety of geographic and management factors, including the amount of stover removed.	The type and extent of ecosystem impacts depend on local conditions and management. Nutrients, sediment, and pesticides can contaminate surface waters and wetlands, leading to changes in biodiversity.

Table 3-2: Impacts Associated with Biofuel Feedstock Production (Corn Starch, Corn Stover, and Soybean)

Impact/Resource Use Category	Corn Starch ^a	Harvest of Corn Stover	Soybean		
Invasiveness Potential	Corn is non-invasive.	See "Corn"	Soybean is non-invasive.		
a – Impacts associated with corn production are described in the "Corn Starch" column.					

Table 3-2: Impacts Associated with Biofuel Feedstock Production (Corn Starch, Corn Stover, and Soybean)

194 195

Cultivation of row crops such as corn and soybeans may lead to high levels of soil erosion, nutrient loss, and pesticide and water use if not managed adequately (Groom et al., 2008, Table 1). Agricultural conservation systems may be used to reduce or minimize the impact of row crop agriculture on the environment. The systems support 1) controlled application of nutrients and pesticides through proper rate, timing, and method of application, 2) controlling erosion in the field (i.e., reduced tillage, terraces, or grassed waterways), and 3) trapping losses of soil at the edge of fields or in fields through practices such as cover crops, riparian buffers,

203 controlled drainage for tile drains, and constructed/restored wetlands (Blanco-Canqui et al.,
204; Dinnes et al., 2002; NRCS, 2010).

The effectiveness of conservation practices, however, depends upon their adoption. The USDA Conservation Effects Assessment Project (CEAP) recently released a major study quantifying the effects of conservation practices commonly used on cultivated cropland in the Upper Mississippi River Basin. It found that, while erosion control practices are commonly used, there is considerably less adoption of proper nutrient management techniques to mitigate nitrogen loss to water bodies (NRCS, 2010).

Further, even when erosion practices are reliably implemented, conservation practices and best management practices (BMPs) are not a panacea. A case study in the Chesapeake Bay (CENR, 2010) found that, although the implementation of BMPs since 2000 has significantly lowered loadings of nitrogen (72 percent of sites showed downward trends), total phosphorus (81 percent of sites), and sediment (43 percent of sites), lower nutrient input has not improved dissolved oxygen levels overall in the Chesapeake Bay, with the exception of small-scale reversals in hypoxia.

218 3.2.2 Water Quality

Water quality impacts from increased corn and soybean production for biofuel may be significant, and are caused by pollution from nutrients, sediment, and pesticides, as well as biological contaminants such as pathogens that are released when animal manure is applied as fertilizer. Multiple studies predict that increased production of crops for biofuels will exacerbate water quality problems in the Gulf of Mexico and other U.S. coastal waters if the crops are not grown under improved agricultural conservation practices and expanded nutrient BMPs (Greene et al., 2009, and Rabalais et al., 2009, cited in CENR, 2010).

226 **3.2.2.1** Nutrient Loading

227 Nutrients—Surface Water Impacts

228 Increased production of row crops for biofuel, especially corn, will increase nitrogen and 229 phosphorus loading to surface waters if not managed appropriately. Excessive levels of nutrients 230 in a body of water can cause accelerated algal growth, reducing light penetration and oxygen levels. Low dissolved oxygen (i.e., hypoxia) can kill fish, reducing their populations and the 231 232 species diversity in the affected area. This nutrient enrichment process (eutrophication) can cause 233 serious deterioration of both coastal and inland water resources. According to a 2008 report by 234 the National Research Council, excess nutrients and sediment from the high corn-producing 235 Midwest are the primary sources of water quality degradation in the Mississippi River Basin and 236 the Gulf of Mexico (NRC, 2008, p. 88). Further, the National Summary of Impaired Waters (U.S. EPA, 2010c)¹¹ documented that in 2008, nationwide, approximately 50 percent of the 3.5 237 million miles of stream and rivers and 66 percent of the over 41 million acres of lakes and 238 239 reservoirs in the U.S. were impaired due to nutrient enrichment. The 2007 National Estuarine Eutrophication Assessment found that the Mid-Atlantic is the region most impacted by hypoxia, 240 241 with almost 60 percent of the waters affected by anthropogenic land-based sources of nutrient pollution, agriculture being the largest contributor (CENR, 2010). The National Summary of 242 243 Impaired Waters also reported that in 2008 over 68,000 miles of streams and rivers and over 1.3 244 million acres of lakes and reservoirs in the Mississippi River Basin states were impaired because 245 of nutrients. Increased corn and soybean production for biofuels could exacerbate this situation 246 due to the nutrients from additional fertilizer or increases in the acreage or extent and density of 247 subsurface tile drainage. The Committee on Environment and Natural Resources cites a 2008 report that predicts the average annual flux of dissolved inorganic nitrogen to the Gulf of Mexico 248 249 could increase by 10 to 34 percent, based on a "pessimistic" scenario in which corn production 250 acreage increases by up to 9 percent (Donner and Kucharik, 2008, cited in CENR, 2010).

In evaluating the potential for water quality impacts due to increased nutrient loads to surface waters, there is some debate about which nitrogen compounds to consider. Not all nitrogen compounds can be easily used by algae (i.e., are bioavailable) and thus some forms of nitrogen impact eutrophication more than others. Ammonia is the inorganic nitrogen compound that is easiest for most algae to use, followed by nitrate and nitrite (Cole, 1983). Total nitrogen is a measure of the sum of the nitrogen present in both inorganic and organic compounds in water.

257 Although many studies track total nitrogen, some researchers argue that it is more 258 appropriate to consider inorganic nitrogen compounds only, as those are most likely to impact 259 water quality through eutrophication. When tracking the fate and transport of nitrogen in surface 260 waters within large watersheds (e.g., in the Mississippi River Basin), it is important to remember 261 that inorganic nitrogen compounds are readily converted to organic nitrogen compounds and back to inorganic compounds by organisms present in surface waters and sediments. At the basin 262 263 scale, measuring total nitrogen provides insight into the potential maximum impact of nitrogen 264 inputs into surface waters.

¹¹ Numbers in text were calculated by summing miles/acres reported by each state in their 305(b) assessments as impaired by "nutrients"; "ammonia, un-ionized"; "nitrogen, total"; "nutrient/eutrophication"; "phosphorus, total"; "ammonia, total"; "nitrogen, nitrate"; and "ammonia."

265 Corn has the highest fertilizer use per acre of any of the biofuel feedstocks, and it accounts for the largest portion of nitrogen fertilizer use among all feedstocks discussed in this 266 267 report (U.S. EPA, 2010b). By one estimate, which surveyed 19 U.S. states, approximately 96 268 percent of corn acreage received nitrogen fertilizer in 2005, with an average of 138 pounds per 269 acre (NASS, 2006). An Iowa State University study found that each acre of harvested corn also 270 requires about 55 pounds of phosphorus (in the form P_2O_5) (Iowa State University, 2008). 271 Assuming a yield of 154 bushels per acre (NASS, 2010c) and an ethanol conversion rate of 2.7 272 gallons per bushel (Baker and Zahniser, 2006), this results in 0.33 pounds of nitrogen and 0.13 pounds of phosphorus applied per gallon of ethanol produced. Nitrogen discharged from corn 273 274 fields via runoff, sediment transport, tile/ditch drainage, and subsurface flow averages 24 to 36 275 percent of the nitrogen applied (and can range from 5 percent in drought years to 80 percent in 276 flood years) (Dominguez-Faus et al., 2009).

277 Nutrients are applied to fewer soybean acres compared to corn and at much lower rates (U.S. EPA, 2010b). However, losses of nitrogen and phosphorus from sovbeans can occur at 278 279 quantities that can degrade water quality (Dinnes et al., 2002; Randall et al., 1997). In 2006, the 280 USDA's National Agricultural Statistics Service estimated that nitrogen and phosphorus 281 fertilizers were applied to 18 percent and 23 percent of soybean acreage, respectively, with an 282 average of 16 pounds of nitrogen and 46 pounds of phosphate applied per acre fertilized (NASS, 283 2007b). The quantity of nitrogen fertilizer applied to soybean fields ranged from 0 to 20 pounds 284 per acre, while the quantity of phosphate ranged from 0 to 80 pounds per acre. Similar to corn, the conversion of idled acreage to soybeans is estimated to result in losses of nitrogen and 285 286 phosphorus from the soil (Simpson et al., 2008).

287 Corn requires less fertilizer when grown in rotation with soybeans. Therefore, crop 288 rotation provides an effective strategy for reducing the amount of fertilizer and pesticide applied 289 to fields, and therefore runoff and leaching of the pollutants to water. One study estimated that 2 290 to 40 percent of the total nitrogen leached from fields planted alternately with corn and soybeans 291 came from the fields when they were planted with soybeans, meaning that most of the nitrogen 292 runoff was due to corn production (Powers, 2005).

While the total amount of nitrogen lost from corn fields tends to be higher than losses from soybean fields (Powers, 2005), loss of inorganic nitrogen from corn and soybean fields tends to be similar. This suggests that eutrophic effects of nitrogen will be similar for runoff from both corn and soybean fields in surface waters near the fields. However, when considering impacts at the basin scale, it is more relevant to consider the total amount of nitrogen contributed by each crop.

299 Use of corn stover for ethanol production would not necessarily result in increased corn 300 production. However, the removal of corn stover could lead to loss of soil surface cover if NRCS 301 guidelines are not followed, thereby increasing runoff of nitrogen and phosphorus to surface 302 waters, including wetlands (Kim and Dale, 2005). Even partial removal of corn stover can result in nutrient losses to water due to increased runoff (Kim and Dale, 2005; Lal, 2004). In addition, 303 304 corn stover removal can lead to the loss of soil nutrients needed for corn growth, and higher 305 fertilizer rates are likely to be required to sustain crop productivity, increasing the likelihood of 306 increased runoff and transport of non-point source pollutants (Blanco-Canqui and Lal, 2009a). 307 Typically, for each ton of corn stover harvested, an additional 16 pounds of nitrogen fertilizer
and 6 pounds of phosphorus fertilizer must be added to the soil, though these quantities varyconsiderably (Sawyer and Mallarino, 2007).

310 Mitigating the loss of nitrogen and other nutrients to water bodies is a research priority 311 for the USDA. Since drainage systems are a key conduit for nutrient loading, new research is 312 focusing on alternative surface and subsurface drainage solutions. An interagency Agricultural 313 Drainage Management Systems Task Force, formed in 2003 and recently expanded, is working 314 to reduce the loss of nitrogen and phosphorus from agricultural lands through drainage water 315 management (CENR, 2010). One emerging conservation technology that addresses water quality 316 degradation is the creation of wetlands on the perimeter of fields in order to receive surface 317 runoff and filter out nutrients prior to its discharge into streams and rivers. Surface water runoff 318 control, another conservation method used to stop water erosion, reduces the loss of nutrients to 319 the surrounding environment through overland flow, but increases infiltration and loss of soluble 320 nitrogen and phosphorus. A third strategy, lowering the water table during planting and 321 harvesting, has been predicted to lower nitrogen losses in the Chesapeake watershed by 40 322 percent (CENR, 2010). Other strategies, such as planting perennial grasses over subsurface tile 323 drains or placing wood chips in drainage ditches, are also being explored. Implementing 324 strategies such as these on agricultural lands that contribute a disproportionate share of nitrogen 325 loads will maximize the environmental benefit of their application (CENR, 2010).

However, none of these practices guarantee environmentally sustainable biofuel production on an industrial scale. The interactions between various BMPs need to be investigated more closely, as there can sometimes be unexpected adverse consequences from new technologies. For example, the 2010 report by the Committee on Environment and Natural Resources notes that the introduction of tile-drainage systems in the Midwest has improved agricultural yields but worsened water quality by accelerating nutrient-loaded runoff to streams and rivers without allowing natural processes to filter the nutrients (CENR, 2010).

333 Nutrients—Coastal Waters Impacts

334 Nutrient enrichment is a major concern for coastal waters across the U.S., including the 335 Gulf of Mexico, Chesapeake Bay, other estuaries, and the Great Lakes. For example, almost 15 336 percent of the coastal waters in the Gulf of Mexico and Northeast have poor water quality as 337 measured by nutrient concentrations, extent of hypoxia, and water clarity (U.S. EPA, 2008b). 338 The number of U.S. coastal areas documented as experiencing hypoxia increased from 12 in 339 1960 to over 300 in 2008 (see Figure 3-4) (CENR, 2010). While these impacts are due to a 340 number of types of nutrient inputs, such as lawn fertilizers, other agricultural uses, atmospheric 341 deposition, and wastewater discharges, increased corn and soybean production for biofuel will 342 likely increase nutrient loading in those watersheds where increased production occurs (CENR, 343 2010).



344 345 346

Note: Map does not display one hypoxic system in Alaska and one in Hawaii. Source: CENR, 2010.

347 348

Figure 3-4: Change in number of U.S. coastal areas experiencing hypoxia from 1960 to 2008

349 Hypoxia in the Gulf of Mexico has been a long-standing environmental and economic 350 issue that threatens commercial and recreational fisheries in the Gulf (U.S. EPA, 2010b). The 351 primary cause of hypoxia in the Gulf of Mexico is excess nitrogen and phosphorus loadings from 352 the Upper Midwest flowing into the Mississippi River, suggesting that increased corn and soybean production will exacerbate the problem (U.S. EPA, 2010b). U.S. Geological Survey 353 (USGS) SPARROW¹² modeling of the sources of nutrient loadings to the Gulf of Mexico 354 355 estimated that agricultural sources contributed more than 70 percent of the delivered nitrogen 356 and phosphorus to the Gulf of Mexico (Alexander et al., 2008). Corn and soybean production 357 accounted for 52 percent of nitrogen delivery and 25 percent of phosphorus delivery. Modeling of the Upper Mississippi River Basin (upstream of Cairo, Illinois) using SWAT¹³ modeling 358 359 indicated that, on average, it contributes 39 percent of the nitrogen load to the Gulf of Mexico. 360 and 26 percent of the phosphorus load (SAB, 2007). One study estimated that corn production 361 contributes between 60 and 99 percent of the total nitrogen load to the Mississippi River from 362 eastern Iowa watersheds (Powers, 2007). Other studies have also determined that the majority of 363 nitrate in the Mississippi River originates in the Corn Belt (Donner et al., 2004; Goolsby et al., 364 1999). Nitrogen from fertilizers can also volatilize (and then return to water through atmospheric 365 deposition). Atmospheric nitrogen from all sources, including power plant emissions, is 366 estimated to contribute 15 to 20 percent of the nitrogen loading to the Gulf of Mexico (Alexander 367 et al., 2008), and about 30 percent of the nitrogen loading to Chesapeake Bay (Paerl et al., 2002).

¹² SPARROW (SPAtially <u>Referenced Regressions On Watershed</u>) is a watershed model developed by USGS relating water quality measurements at monitoring stations to other watershed attributes. The model estimates nitrogen and phosphorus entering a stream per acre of land, and evaluates the contributions of nutrient sources and watershed properties that control nutrient transport.

¹³ The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by USDA Agricultural Research Service and Texas A&M University System. SWAT is a river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land management practices on different soil patterns and land use patterns.

368 A USDA study projects that reaching 15 billion gallons per year of ethanol from corn starch (i.e., not including stover) will result in a 1.7 percent increase in nitrogen loads to surface 369 370 water, with the greatest increases in nitrogen load occurring in the Corn Belt and Northern Plains 371 (Malcolm et al., 2009). EPA used the SWAT model to predict the impacts of increased corn 372 production to meet the RFS2 corn starch ethanol targets on water quality in Upper Mississippi 373 River Basin, which empties into the Gulf of Mexico. The modeling found a maximum increase 374 in nitrogen load to the Gulf of Mexico of 1.9 percent, and a maximum of 1 percent increase in 375 phosphorus load. The SWAT model also indicated that, by 2022, increased corn yields could 376 reduce the need for increasing the amount of land in corn, so nutrient loads could decrease from 377 earlier peaks (SAB, 2007).

378 Ecological features such as wetlands and riparian buffers play an important role in 379 absorbing nutrients before they run into surface waters. Conserving wetlands where they exist, or 380 creating artificial vegetated riparian buffers between waters and croplands, is a way to mitigate the impacts of nutrient loading. Riparian buffers and filter strips prevent potential pollutants in 381 382 agricultural runoff (sediment, nutrients, pesticides, pathogens) from reaching surface waters. 383 While the effectiveness of these buffers can vary depending on many factors, including slope, 384 width, vegetation used, and how well they are maintained, studies have shown that they can 385 remove up to 78 percent of phosphorous, 76 percent of nitrogen, and 89 percent of total suspended solids (TSS) (Schwer and Clausen, 1989).¹⁴ 386

387 Nutrients—Ground Water Impacts

388 Excess nutrients from fertilizers can leach into ground water, which can discharge to 389 surface waters, thereby contributing to surface water nutrient loading. About two-thirds of the 390 nitrogen lost to subsurface flow eventually returns to surface water (U.S. EPA, 2010b, p. 971). 391 Ground water can also be used for public and private drinking water supplies, and fertilizers can increase the concentration of nitrate in ground water wells, especially shallow wells (less than 392 393 200 feet deep). USGS sampled 495 wells in 24 well networks across the U.S. in predominantly 394 agricultural areas from 1988 to 2004 and found significant increases in concentrations of nitrate 395 in 7 of the 24 well networks. In 3 of the 7 well networks, USGS found nitrate concentrations that 396 exceeded the federal drinking water standards of 10 mg/L of nitrate-nitrogen (Rupert, 2008). 397 Increased corn and soybean production for biofuels could worsen the problem of contaminated 398 well water because of additional nitrogen inputs from fertilizer used to grow more corn. USDA 399 projects that reaching 15 billion gallons per year of ethanol from corn will result in a 2.8 percent 400 increase in nitrogen leaching to ground water, with the greatest increases occurring in the Great Lakes states and the Southeast (Malcolm et al., 2009). Similar estimates for soybean production 401 402 were not identified. Studies of nitrate leaching from corn and soybean rotation cropping systems 403 are inconclusive about whether these systems increase or decrease leaching rates (Kanwar et al., 404 1997; Klocke et al.; 1999; Weed and Kanwar, 1996; Zhu and Fox, 2003).

Fertilizer application management strategies aim to reduce nitrogen leaching by
 maximizing the efficiency of applied fertilizer. Such strategies focus on collecting precise
 information on soil nutrient content in order to better inform application rates. The USDA

¹⁴ See also

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=82.

408 reports that phosphorus accumulation on farms has reached levels that often exceed crop needs

- 409 (ARS, 2003). Better information on these conditions could help reduce nutrient runoff that leads
- 410 to eutrophication. There may also be economic incentives for implementing fertilizer
- 411 management strategies. In 2006, the University of Minnesota Extension, an agricultural research 412 partnership between federal, state and county governments, estimated that 86 percent of
- 412 partnership between federal, state and county governments, estimated that 86 percent of
 413 Minnesota farmers could save more than \$6 per acre and 56 percent could save more than \$10
- 415 Infinesota farmers could save more than 50 per acre and 50 percent could save more than 510 414 per acre in fertilizer costs by following better informed nutrient application rates (Minnesota
- 415 Department of Agriculture, 2010).

416 **3.2.2.2 Sediment**

417 Nutrients and sediment are the two major water quality problems in the U.S., and much attention has been focused on these issues in the Mississippi River Basin and the Gulf of Mexico 418 419 (NRC, 2008, p. 88). Use of soil erosion control practices is widespread, yet 15 percent of acres in 420 the Upper Mississippi River Basin experience excessive sediment loss (NRCS, 2010). The 421 National Water Summary of Impaired Waters stated that in 2008 over 70,000 miles of streams and rivers and over 1.2 million acres of lakes and reservoirs in Mississippi River basin states are 422 impaired because of sediments or turbidity (U.S. EPA, 2010c).¹⁵ Nelson et al. (2006) reported 423 424 that row crops, such as corn and soybean, result in higher erosion rates and sediment loads to 425 surface waters, including wetlands, than non-row crops that might be used as biofuel feedstock, 426 such as grasses. Sedimentation rates in agricultural wetlands can be higher than in natural 427 grassland landscapes; increased sedimentation may, depending on sediment depths, cover viable 428 seeds sufficiently to prevent germination (Gleason et al., 2003). EPA and USDA have evaluated 429 the impact of the RFS2 rule on sediment loads. As reported in the water quality analysis 430 conducted by EPA for the RFS2 rule, it is estimated that annual sediment loads to the Mississippi 431 River from the Upper Mississippi River Basin would increase by 6.22 million tons (15 percent) 432 between 2005 and 2022, assuming corn stover remained on the field following harvest 433 (AquaTerra, 2010). A USDA study estimates that nationally, sediment loads in 2015 will be 1.6 434 percent greater with implementation of RFS2 than without, assuming ethanol production from

435 corn starch only (Malcolm et al., 2009).

436 Removal of corn stover from fields for use in biofuel production is expected to increase 437 sediment yield to surface waters and wetlands, but rates are highly variable depending on soils, 438 slope, management of fields, and the proportion of stover harvested (Cruse and Herndl, 2009; 439 Kim and Dale, 2005). Results of SWAT modeling of the Upper Mississippi River Basin 440 (AquaTerra, 2010) indicated that leaving corn stover on fields helps reduce soil erosion and 441 sediment transport, even when the amount of land in corn production increases. However, the 442 amount of soil erosion that agricultural cropland experiences is a function of many factors, 443 including not only residue left on the field, but also field operations (field preparation, tillage, 444 etc.) in preparation for the next crop, timing of field operations, and other site-specific factors 445 noted above (U.S. EPA, 2010b).

¹⁵ Numbers in text were calculated by summing miles/acres reported by each state in their 305(b) assessments as impaired by "sedimentation/siltation" or "turbidity."

Conservation tillage practices, including no-till, strip-till, ridge-till, and mulch-till,¹⁶ can 446 447 reduce erosion by leaving at least 30 percent of the ground covered by crop residue and by 448 limiting soil disturbance. According to the USDA, 41 percent of planted acreage in the U.S. uses 449 conservation tillage as a mitigation strategy (ARS, 2006). These techniques have been shown to 450 reduce erosion by as much as 60 to 90 percent, depending on the conservation tillage method 451 (Minnesota Department of Agriculture, 2010). In 2002, the USDA Agricultural Research Service 452 studied the effect of ridge tillage on Northern Corn Belt plantations. The study showed that ridge 453 tillage not only reduced erosion and sediment loading but also increased profitability, reduced 454 fuel and labor use, and reduced economic risk relative to conventional tillage for a corn and 455 soybean rotation (ARS, 2006). Additionally, these alternative tillage approaches can reduce trips across the field, lowering fuel use and improving the energy balance of the resulting biofuel. The 456 457 use of conservation tillage, in combination with BMPs, such as cover crops, may partially 458 compensate for the increase in erosion potential caused by cover stover removal (Blanco-Canqui 459 and Lal, 2009b). Depending on the soil type, these practices may allow a percentage of stover to 460 be harvested sustainably (Blanco-Canqui and Lal, 2009b).

461 **3.2.2.3 Pesticides**

According to the National Summary of Impaired Waters (i.e., waters that do not meet the water quality standards) (U.S. EPA, 2009a, 2010d), over 16,000 miles of streams and rivers and over 370,000 acres of lakes and reservoirs in the U.S. were impaired in 2008 because of pesticides, with atrazine (commonly used in corn production) specifically cited by several states (U.S. EPA, 2010c). Atrazine was also estimated to be the most common pesticide lost from agricultural lands in the Upper Mississippi River Basin (NRCS, 2010).

468 Corn production uses more pesticides than predicted for any other potential biofuel crop 469 produced in the U.S. (Pimentel and Patzel, 2005; Pimentel and Pimentel, 2008, p. 380; Ranney 470 and Mann, 1994). USDA's NASS estimates that insecticides were applied to 16 percent of the 471 2006 soybean-planted acreage (NASS, 2007b). USDA also estimates that herbicides were 472 applied to 98 percent of the planted soybean acreage in 2006. Soybean production releases less 473 pesticide to surface and ground water per unit of energy gained (Hill et al., 2006).

474 While effective pest control may be critical to achieving the yield gains that underpin EISA biofuel projections and targets (Perkins, 2009), there are risks associated with the use of 475 476 pesticides. The FIFRA registration process is intended to minimize these risks. Many factors 477 contribute to the relative risks of pesticides on the environment, including fate and transport 478 characteristics, method of application, depth to ground water, and proximity to receiving waters. 479 To protect consumers against risks posed by ingestion of these pesticides, FFDCA requires the 480 establishment of pesticide residue tolerances on food using a standard of reasonable certainty of 481 no harm.

¹⁶ *No-till* refers to the absence of soil tillage to establish a seed bed, meaning the farmer plants the crop directly into the previous year's crop residue. In *strip-till*, only the portion of the soil that is to contain the seed row is disturbed. In *ridge-till*, plants grow on hills that are the product of cultivation of the previous crop and are not tilled out after harvest. In *mulch-till*, plant residues are conserved but a field cultivator or disks are used to till prior to planting to partially incorporate the residue into the soil.

Growing continuous corn (rather than in rotation with other crops) can increase population densities of pests such as the corn rootworm, resulting in increased pesticide applications to control these pest species (Whalen and Cissel, 2009). A USDA study projects that cropland dedicated to continuous corn will increase by more than 4 percent by 2015 to reach the 15 billion gallons per year of ethanol from corn target (Malcolm et al., 2009). In addition, increases in corn acreage and any conversion to corn of crops other than corn will most likely increase total herbicide use. Increased corn and soybean production can result in the increased

489 use of herbicides that can run off or leach into surface water or ground water sources.

490 Integrated pest management (IPM) practices may help reduce pesticide use by tailoring 491 treatment to pest infestation cycles, and by more precisely targeting the amount and timing of 492 applications. IPM focuses on extensive monitoring of pest problems, comprehensive 493 understanding of the life cycles of pests and their interaction with the environment, and very 494 precise timing of pesticide applications to minimize pesticide use. In addition to providing 495 environmental benefits of lower pesticide use. IPM often results in lower chemical pesticide 496 expenses and pest damage to crops, as well as preventing the development of pesticide-resistant 497 pests (Minnesota Department of Agriculture, 2010). The use of cover crops is an IPM practice 498 that can dramatically reduce chemical application and soil erosion. USDA research in the 499 Midwest in 2006 demonstrated that autumn-planted small grain cover crops reduced soil erosion, 500 nitrate leaching, and suppressed weeds (Teasdale et al., 2007).

501National adoption of IPM strategies varies. Corn and soybean growers reported scouting502for weeds, insects, and diseases on 50 percent of acres or more in 2000, but reported adjusting503planting or harvest dates to manage pests on less than 20 percent of acres (Weibe and Gollehon,5042006).

505 **3.2.2.4 Pathogens and Biological Contaminants**

The use of animal manure as a fertilizer has been tied to an increased risk of viruses and bacteria leaching into the water supply. Pathogens such as *Salmonella* sp., *Campylobacter* sp., and *Clostridium perfringens*—along with additives such as livestock antibiotics and hormones may be released into surface or ground water when manure is applied to fields (Brooks et al., 2009; Lee et al., 2007a; Unc and Goss, 2004). The USDA Report to Congress on use of manure for fertilizer and energy reports that approximately 12 percent of corn and 1 percent of soybeans are fertilized with manure (MacDonald et al., 2009).

513 The flow paths by which pathogens can contaminate ground or surface water are the 514 subject of current research. Transport through soil has been shown to remove harmful bacteria in some cases, though this may depend on soil characteristics, the hydrologic regime (i.e., distance 515 516 to surface or ground water) and the pathogens in question (Malik et al., 2004; Unc and Goss, 2004). Contamination rates likely are greater where there is higher runoff relative to infiltration, 517 518 a high water table, or a direct surface-ground water connection. Implementation of manure 519 management practices, such as covering or storage at elevated temperatures prior to application 520 can reduce runoff. In addition, applying manure during times of low runoff potential can reduce 521 the risk of water contamination (Moore et al., 1995; Guan and Holley, 2003).

522 3.2.3 Water Quantity

523 **3.2.3.1** Water Use

524 Over the entire biofuel supply chain (see Figure 2-3 in Chapter 2), crop irrigation is by 525 far the most significant use of water in the ethanol production process, and it tends to be much 526 higher than water use for most other non-renewable forms of energy on an energy content basis 527 (Wu et al., 2009). In some geographic locations this could lead to serious impacts on already 528 stressed water supplies, while in other locations water supply availability impacts are less likely 529 to occur. Future assessment of biofuel feedstocks will need to consider restrictions on water use 530 due to competing demand for water resources (Berndes, 2002).

531 For both corn and soybeans, the source for water used to irrigate crops varies from region 532 to region. In the West, surface water is largely used to irrigate crops; in the Great Plains and 533 Midwest, where the majority of corn and soybean production takes place, farmers rely heavily on 534 ground water (Kenny et al., 2009). In the future, as corn production increases to meet ethanol 535 demands, both geographical factors and the type of land/crop conversion will determine water 536 use impacts. Water use will increase as land in pasture or other low- or non-irrigated uses are converted to irrigated corn production, especially in places like the Great Plains, where water 537 538 demand for corn irrigation is high. Converting other crops, soybeans in particular, into corn will 539 have little effect on water use in the Midwest, but could increase the total amount of water used for irrigation in the Plains because of corn's relatively high water use intensity on a per area 540 541 basis (NRC, 2008).

542 Corn

543 Corn is relatively water-intensive compared to other crops. In some parts of the country, 544 water demands for corn are met by natural rainfall, while in other places supplemental irrigation 545 is required. For instance, in Iowa in 2007, less than 1 percent of the more than 14 million acres 546 planted in corn was irrigated. In contrast, over 60 percent of Nebraska's 9.5 million acres of corn 547 was irrigated in the same year (NASS, 2009).

548 Irrigation use for U.S. corn has been estimated to vary from a low of approximately 8 549 gallons of water per gallon of ethanol on average in Midwest states in one study (Wu et al., 2009) to a high of up to 1,000 gallons for states in the Great Plains in another study (Dominguez-550 551 Faus et al., 2009). While the data and methodology used to calculate these estimates are not uniform across studies, in general, water use is likely to be less than 500 gallons (perhaps 552 553 substantially less) of irrigation water per gallon of ethanol in the Midwest and greater than 500 554 gallons per gallon of ethanol in more arid parts of the country (supporting information for Chiu 555 et al., 2009). Taking into account the total volume of corn starch ethanol produced, this might translate into approximately 5 billion gallons of irrigation water in a single season in places like 556 557 Iowa and Illinois versus 300 billion gallons in Nebraska (Chiu et al., 2009). The 2007 U.S. national ethanol-production-weighted average farm-to-fuel pump water requirement per gallon 558 559 of ethanol in the U.S. was estimated to be 142 gallons (Chiu et al., 2009).

560 *Corn Stover*

561 Allocation of proportionate water use based on the energy captured from corn starch 562 versus stover may be studied in the future as corn stover becomes a more common biofuel 563 feedstock. Water use for corn stover above and beyond corn cultivation is likely to be minimal or 564 negligible if undertaken with resource conservation practices, especially in the most productive corn-growing regions of the U.S. where corn stover is not functionally necessary for retention of 565 566 soil moisture. If, however, corn stover is removed from dry corn cultivation areas with 567 supplemental irrigation (states like Nebraska), loss of soil moisture that would have otherwise 568 been retained by corn stover cover and contributed to productivity of the next season's crop 569 (Blanco-Canqui and L al., 2009b) could necessitate additional irrigation.

570 Soybeans

Water for soybean cultivation, like corn, also comes from both natural precipitation and through irrigation. In some places, the water requirements are largely met with precipitation. For example, in 2007 in the leading soybean-producing state of Iowa, 8.6 million acres of soybeans were grown of which less than 1 percent was irrigated (NASS, 2009). In 2007 Nebraska grew 3.8 million acres of soybeans, of which over 40 percent was irrigated (NASS, 2009).

576 Average nationwide rates of sovbean irrigation are estimated at 3,000 to 6,000 gallons of irrigation water to produce a volume of biodiesel equivalent to a gallon of gasoline (U.S. DOE, 577 2006; Dominguez-Faus et al., 2009). These rates are not applicable to states such as Iowa, where 578 579 most soybeans are grown without irrigation. In Nebraska, however, where irrigation is heavily 580 utilized, greater than 4,000 gallons of irrigation water per gallon of gas equivalent is not an 581 unusual investment of water resources for biofuel production (supplemental information to 582 Dominguez-Faus et al., 2009). Overall, irrigation estimates for soybeans tend to be greater than 583 those needed to produce a volume of corn starch ethanol equivalent to a gallon of gasoline 584 (Dominguez-Faus et al., 2009).

585 **3.2.3.2 Water Availability**

586 Because agriculture accounts for such a large share of water use in the U.S. (35 percent of 587 withdrawals nationwide in 2005, and a much larger percentage in some parts of the country, 588 according to Kenny et al., 2009), changes in agricultural production could impact future water 589 availability. In particular, land conversion to corn for increased production of ethanol could 590 create more demand for water, adding to existing water constraints and potentially creating new 591 ones. The Great Plains states already have shortages, and water availability may decrease further 592 when typically non-irrigated pasture and CRP land is converted to irrigated corn production. 593 Converting other crops, soybeans in particular, into corn will have little effect on water use and 594 availability in the Midwest, but could increase the total amount of water used for irrigation in the 595 Plains because corn requires more water than soybeans on a per area basis in that region (NRC, 596 2008).

597 To a large extent, the current capacity to produce biodiesel from soybeans resides in 598 states with rain-fed soybean cultivation. Such strategic siting of biodiesel production facilities 599 minimizes both demands for irrigation water for biodiesel feedstock and potential conflicts over 600 water availability required for other purposes such as power generation, public water use, and

601 recreation. However, if biodiesel production develops in places requiring greater soybean

602 irrigation such as the Great Plains, water availability could be reduced. This is especially true if

603 irrigated soybean cultivation replaces other low or non-irrigated land uses. Because over 85
 604 percent of irrigation withdrawals come from underground aquifers, ground water availability is

605 likely to be affected the most.

606 Both surface water and ground water withdrawals can negatively impact aquatic life. 607 Surface water withdrawals can reduce flood flows (or peak flow regimes), as well as reduce total 608 flow (or discharge) during summer months when irrigation requirements are high and surface 609 water levels are low (Poff and Zimmerman, 2010). Ground water availability is largely affected by ground water withdrawals for irrigation. The consequences of excessive ground water 610 withdrawal can include reduced water quality, prohibitive increases in the costs of pumping, 611 reduced surface water levels through hydrological connections, and subsidence (Reilly et al., 612 2008). Several regions (e.g., High Plains aguifer, Lower Mississippi River alluvial aguifer) that 613 are already experiencing water shortages could be substantially impacted by increased corn 614 production for ethanol. Ground water withdrawals also have indirect impacts on stream flow. 615 616 Withdrawals from hydrologically connected aguifers can lower base flow to rivers and streams 617 that depend on ground water to maintain year-round stream flow. In some areas, stream flow has 618 been reduced to zero because of ground water depletion, but in other areas, minimum stream 619 flow during the summer has been sustained because of irrigation return flow to streams 620 (Bartolino and Cunningham, 2003).

- 621 3.2.4 Soil Quality
- 622 **3.2.4.1 Soil Erosion**

623 Soil erosion can have substantial negative effects on soil quality by preferentially 624 removing the finest, uppermost soil particles, which are higher in organic matter, plant nutrients, 625 and water-holding capacity relative to the remaining soil (Brady and Weil, 2000). The soil erosion impact of growing corn or soybeans for biofuel will vary, largely depending on the 626 627 particular land use/land-cover change and tillage practices. Conversion of uncultivated land, such 628 as CRP acreage, to corn or soybeans for biofuels is the land use change scenario most likely to 629 increase erosion and sedimentation. The USDA CEAP report on the Upper Mississippi River 630 Basin found that for land in long-term conserving cover, like CRP, soil erosion and sediment loss were almost completely eliminated (NRCS, 2010). Moreover, CRP acreage in riparian areas 631 632 slows runoff, promoting the deposition of sediment, nutrients, and other chemicals. The USDA's 633 Farm Service Agency estimated that, in 2008, CRP land collectively prevented 445 million tons 634 of soil from eroding (FSA, 2009). The soil-erosion effects of converting former or current 635 pasture land to corn will vary depending on prior erosion rates. Pasture land in the U.S. Southern 636 Piedmont region, for example, can exhibit soil stability equal to forested or conservation-tilled 637 land; converting this type of land to conventional corn production will increase soil erosion 638 (Franzluebbers et al., 2000). In contrast, if much of the increase in corn or soybean production 639 comes from a shift from other crops (in 2007, for example, the increase in corn acreage came predominantly from a decrease in soybeans), the effect on soil erosion is likely to be much 640 641 smaller. Allocation of a higher percentage of corn or soybeans for biofuel production to land 642 currently in agricultural use likely will not alter soil erosion rates.

Tillage practices can mitigate soil erosion on current agricultural lands. Conventional 643 tilling¹⁷ breaks up soil aggregates, increasing erosion by wind and water (Lal, 2003). In contrast, 644 645 conservation tillage-defined as practices that maintain at least 30 percent of the ground covered 646 by crop residue (Lal, 1997)—can considerably reduce soil erosion (Cassel et al., 1995; Shipitalo 647 and Edwards, 1998). No-till agriculture, a type of conservation tillage, disturbs the soil only 648 marginally by cutting a narrow planting slit. According to the CEAP report, conservation tillage 649 is practiced on 96 percent of all crop acreage in the Upper Mississippi River Basin, with 23 650 percent in no-till, and only 5 percent in continuous conventional tillage (NRCS, 2010). 651 Conservation tillage practices may also partially mitigate the impact of converting CRP acreage 652 to biofuel corn production (Follett et al., 2009). A majority of CRP acreage in areas of the Midwest are classified as highly erodible land, where tillage practices are generally restricted by 653 654 the conservation compliance provisions of the 1985 Food Security Act (Secchi et al., 2009). 655 These compliance provisions can require corn-soybean rotations with no-till cultivation (Secchi 656 et al., 2009).

657 Finally, removal of corn stover beyond a certain threshold may increase soil erosion 658 rates. Due to this and cost concerns, a recent study suggested that only approximately 30 percent of corn stover¹⁸ would be available for sustainable harvesting in the U.S. if erosion rates were to 659 be kept lower than soil loss tolerances (T-values) as defined by the USDA NRCS (Graham et al., 660 2007). Because of wind erosion, the potential for corn stover removal in the Western Plain states 661 662 may be particularly limited (Graham et al., 2007). Site cultivation practices may partially compensate for the effects of residue removal. If no-till agriculture were universally adopted, 663 664 sustainably harvested corn stover supplies are estimated to increase from approximately 30 to 50 665 percent (Graham et al., 2007). Yet, even with no-till management, corn stover removal rates at or higher than 50 percent have been shown to increase erosion potential (Blanco-Canqui and Lal, 666 667 2009a).

668

3.2.4.2 Soil Organic Matter

669 Soil organic matter is critical because it retains plant nutrients and water, facilitates carbon sequestration, promotes soil structure, and reduces erosion. The impact of corn and 670 671 sovbean production for biofuel on soil organic matter will depend on the cultivated acreage. Corn production will negatively impact soil quality on acreage where organic matter has 672 accumulated over time—for example, grasslands. If conventional tilling is used, a loss of organic 673 matter both to erosion and to the atmosphere as carbon dioxide due to increased microbial 674 675 decomposition is likely to occur (Reicosky et al., 1995). Estimates of carbon loss following conventional tilling of previously undisturbed soils range from 20 to 40 percent-although how 676 677 much carbon is respired to the atmosphere versus lost to erosion is unclear (Davidson and Ackerman, 1993). Assuming carbon loss to the atmosphere, it has been estimated that conversion 678 679 of grasslands in CRP to corn production would create a carbon debt requiring approximately 48 years to repay (Searchinger et al., 2008). In contrast, increased corn or soybean production on 680 681 currently cultivated land will have a smaller effect on soil organic matter, particularly where 682 substantial amounts of crop residues are returned to the soil or a cover crop is used (Adviento-

¹⁷ Defined as any tillage practice that leaves less than 15 percent of crop residues on the soil surface after planting.

¹⁸ It should be noted that the removal of crop residues by percent mass is not the same as by percent soil coverage. All the percentages from the studies discussed here are by percent mass, unless otherwise noted.

Borbe et al., 2007; Drinkwater et al., 1998; Lal, 2003). While soil quality degrades over time,
yields and production can be maintained by the use of fertilizers both commercial and organic.

685 The harvesting of crop residues, such as corn stover, removes plant material that would 686 otherwise remain on and potentially be incorporated into the soil. The removal of corn stover therefore has important implications for soil quality, chiefly via effects on soil retention, organic 687 688 matter content, nutrients, and compaction. Stover removal rates of 25 to 75 percent have been 689 shown to decrease soil organic matter across several soil types even under no-till management 690 (Blanco-Canqui and Lal, 2009a). Therefore, there is concern that high stover removal rates may 691 decrease soil carbon sequestration and lower crop yields (Karlen et al., 2009). Whatever the 692 removal rate for a particular site, it has been recommended that soil erosion and organic matter 693 content be periodically monitored to allow stover removal rates to be adjusted accordingly 694 (Andrews, 2006). The effects of crop residue removals on crop yields have been shown to be 695 highly variable depending on soil type, climate, topography, and tillage management, among 696 other characteristics (Blanco-Canqui and Lal, 2009b). Research to date suggests corn stover 697 removal rates should be determined based on site-specific criteria to maximize soil quality.

698 3.2.5 Air Quality

699 Air quality impacts during cultivation and harvesting of corn and soybeans are associated 700 with emissions from combustion of fossil fuels by farm equipment and from airborne particles 701 (dust) generated during tillage and harvesting. Soil and related dust particles (e.g., fertilizer, 702 pesticide, manure) become airborne as a result of field tillage, especially in drier areas of the 703 country. In addition, emissions result from the production of fertilizers and pesticides used in 704 corn and soybean production, and the application of fertilizers and pesticides to each crop. Air 705 emissions associated with cultivation and harvesting of corn and soybeans for biofuel will mostly 706 occur in sparsely populated areas. Subsequent stages in the biofuel supply chain (see Figure 2-3), 707 including feedstock logistics and biofuel production, distribution, and use, also affect air quality 708 and are discussed in Chapter 4.

709 **3.2.5.1** Cultivation and Harvesting

710 Cultivating and harvesting corn and soybeans require a range of mechanized equipment that utilize different fuels, including diesel, gasoline, natural gas, and electric power (Sheehan et 711 712 al., 1998a). Generally, equipment used to produce corn and soybeans consumes more diesel than 713 for most other crops, while the rate of gasoline consumption is somewhat less than that of other 714 crops. Primary emissions from fuel use include nitrogen oxides (NO_x), volatile organic 715 compounds (VOCs), carbon monoxide (CO), sulfur dioxide (SO₂) (primarily from gasoline), and 716 coarse and fine particulate matter (PM_{10} and $PM_{2.5}$). Gasoline use may also result in benzene, 717 formaldehyde, and acetaldehyde emissions. For corn, approximately 14 gallons of diesel fuel is 718 used per acre for tillage, harvest, and hauling. Fuel use for tillage comprises more than half of 719 this amount; actual usage depends on soil properties and conditions (Iowa State University, 720 2009). With respect to corn stover, additional fuel use depends on the method of stover harvest. 721 For example, methods that can simultaneously collect grain and stover will use less fuel than 722 those requiring multiple passes with a harvester. For this reason, one-pass harvesters are 723 currently being developed and tested (Shinners et al., 2009).

Emissions are also associated with generation of electricity used for irrigation water pumping. Irrigation power needs are estimated to range from 3 to 11 kilowatt-hours (kWh) per irrigated acre, depending on the region, with a national average of 8 kWh per irrigated acre. For soybean cultivation, electricity use is estimated to be 4.6 kWh per acre (Sheehan et al., 1998a). Emissions associated with this use depend on the source of the electricity consumed. Coal is the predominant fuel source for electricity in the Midwest, accounting for 71.3 percent of generation in the 12 primary corn-producing states. Coal-fired power plants are significant sources of SO₂,

 NO_x , carbon dioxide (CO₂), and mercury emissions.

Corn with a moisture content of over 18–20 percent may require drying prior to storage to avoid spoilage (South Dakota State University, 2009). Grain driers use liquid petroleum gas (LPG) and electricity. LPG and electricity use depend on grain moisture content at harvest. For example, typical Midwest grain harvest conditions and yields require 20 gallons of LPG per acre harvested. The exact amount depends on grain moisture conditions at harvest.

737 **3.2.5.2** Fertilizers and Pesticides

Pesticides are commonly used on both corn and soybeans, with corn having more intensive application rates (NRC, 2008, p. 3, as cited in U.S. EPA, 2010b) than soybeans. Corn has the highest nitrogen fertilizer use per acre of any biofuel feedstock. Because soybeans are legumes, they require much lower amounts of fertilizer, particularly nitrogen (NASS, 2006, 2007b). Soybeans have the capacity to derive nitrogen from the atmosphere and therefore require less external nitrogen fertilization than corn, resulting in less nitrogen runoff in the surface water.

Air emissions associated with fertilizer manufacturing and transport include NO_x, VOC, CO, and particulate matter (PM_{10} and $PM_{2.5}$), while pesticide production and blending may result in emissions of 1,3-butadiene, benzene, and formaldehyde.

747 Application of fertilizers and pesticides may result in releases to the air and volatilization of pesticide ingredients. The primary pollutants associated with the releases to air are benzene 748 749 and acrolein. The results described are consistent with another study, which found increases in 750 benzene, formaldehyde, acetaldehyde, and butadiene emissions, although that study included 751 feedstock transport and so is not directly comparable (Winebrake et al., 2001). Emissions of CO, 752 NO_x, and SO₂ increased with the use of corn stover as a feedstock in a hypothetical system (i.e., 753 a simulation based on corn stover life-cycle data), with higher NO_x emissions mainly due to 754 denitrification of increased amounts of nitrogen fertilizers added to farm soils (Sheehan et al., 755 2004).

756 3.2.6 Ecosystem Impacts

757 **3.2.6.1** Eutrophication, Erosion, and Biodiversity Loss

The impact of increased corn and soybean cultivation on ecosystem and biodiversity depends, in large part, on where crop production occurs and what management techniques are used. Major ecosystem-related impacts that could result from additional corn and soybean production are eutrophication, soil erosion and its associated increase in turbidity of receiving waters and sedimentation in basins, and impacts to biodiversity. Eutrophication can occur as fertilizer application increases nutrient loadings (nitrogen and phosphorus) in surface waters such as streams, rivers, lakes, wetlands, and estuaries (U.S. EPA, 2010b). Increased phosphorus
concentration has been correlated with declines in invertebrate community structure, and high
concentrations of ammonia nitrogen are known to be toxic to aquatic animals. Severe oxygen
depletion and pH increases, both of which are correlated with eutrophication, have been known
to cause growth problems and mortality in fish and invertebrates (U.S. EPA, 2010b). In addition,
as aquatic systems become more enriched by nutrients, algal growth can cause a shift in species
composition. Hypoxia threatens commercial and recreational fisheries in the Gulf of Mexico

(U.S. EPA, 2010b) and limits biodiversity (Wang et al., 2007a).

Soil erosion can also lead to an increase in wetland sedimentation, which may, depending
on sediment depths, cover viable seeds sufficiently to prevent germination (Gleason et al., 2003).
In aquatic ecosystems, sediments increase turbidity and water temperatures and bury stream
substrates, limiting habitat for coldwater fish (U.S. EPA, 2006a).

776 In areas where corn production is already significant, increased corn acreage can further 777 reduce landscape diversity (Landis et al., 2008), which might in turn impact other aspects of 778 biological diversity and the ecosystem services associated with biodiversity. In Iowa, Michigan, 779 Minnesota, and Wisconsin, biological control of soybean aphids was found to decline as the 780 proportion of corn in the local landscape increased, resulting in increased expenditures for 781 pesticides and reduced yields (Landis et al., 2008). In the Prairie Pothole region of Iowa, 782 Minnesota, North Dakota, and South Dakota, landscapes with higher proportions of corn acreage 783 had comparatively fewer grassland bird indicator species (Brooke et al., 2009). If landscape 784 diversity decreases (especially in the case of transforming CRP land into corn production), 785 migratory birds will lose habitat and likely decline in numbers. On CRP lands, several grassland 786 bird species have increased in abundance, and it is estimated that, without the 3 million hectares 787 of CRP in the Prairie Pothole region of the U.S., over 25 million ducks would have been lost from the annual fall migratory flights between 1992 and 2004 (Dale et al., 2010). 788

The removal of corn stover residues from agricultural corn fields for ethanol production has potential consequences on aquatic ecosystems and local biodiversity. Removing crop residues from farm fields has been shown to affect both terrestrial and soil biota. Crop residue removal has been correlated with decreases in the diversity of biota (Lal, 2009; Johnson et al., 2006).

794 Intensification of sovbean production and pesticide use may also threaten biodiversity 795 and nearby biota (Artuzi and Contiero, 2006; Koh and Ghazoul, 2008; Pimentel, 2006). The 796 change in local habitat from corn-soybean-corn rotation to continuous corn production may 797 decrease the support for biological control in soybean cropping systems, as reduced landscape 798 diversity decreases the habitat availability of many insects and animals in the local region 799 (Landis et al., 2008). Also, agricultural herbicides affect the composition of local plant 800 communities, which then affects the abundance of natural enemy arthropods and the food supply 801 of local game birds (Taylor et al., 2006). Fungicide pollution from runoff events has been shown 802 to impact algae and aquatic invertebrates in areas where soybeans are intensively grown (Ochoa-803 Acuna et al, 2009).

804 3.2.6.2 Invasive Plants

805 Modern varieties of corn and soybeans under production today in the U.S. pose little risk 806 of dispersing seeds or regenerative plant parts or creating hybrids with related plants that will 807 become weeds or invasive plants in the future. Corn and soybeans rarely overwinter successfully 808 in major production areas, but on occasion, seed from the previous year's crop can emerge in the 809 following year and the plants persist through a single growing season as a weed. Such 810 populations of plants do not become a chronic problem, however, because they do not sustain 811 themselves (Owen, 2005). To date, no cases of invasive corn or soybeans have ever been reported in natural areas in the U.S. However, since U.S. seed and biotechnology companies 812 813 working to improve feedstocks may propagate corn in areas such as Mexico where corn and its 814 progenitors originated, it is possible that novel corn cultivars or their hybrids could spread beyond the cultivated fields and survive. This potential for intermixing genetically modified 815 plants with ancestral land acres is the subject of international scientific and regulatory interest 816 817 (Mercer and Wainwright, 2008).

The extensive cultivation of row crops that are genetically engineered to resist the herbicide glyphosate may result in indirect effects on other weed species and invasive plants. One study correlated the increased use of this herbicide with the appearance of glyphosate resistance in at least ten agricultural weeds in the U.S.; loss of effectiveness of glyphosate could encourage the use of more toxic herbicides (NRC, 2010).

823 3.2.7 Assessment

824 Corn and Soybean Acreage: Between September 2010 and August 2011, approximately 825 38.4 percent of corn consumed domestically is projected to be converted into ethanol biofuel 826 (NASS, 2010a; ERS, 2010c). Corn acreage has increased over 2005 levels in part due to ethanol 827 demand, and planted acreage is expected to increase from 2008/2009 levels of 85.9 million acres 828 to 90 million acres in 2019 to meet the 15 billion gallons per year annual target under EISA 829 (USDA, 2010c). Currently, 5.6 percent of the soybean harvest goes to biodiesel production, and USDA expects this percentage to increase to 7.8 percent by 2012 and hold steady through 2019. 830 831 USDA also expects that soybean acreages will hold steady at 76 million acres, though this 832 number may be higher to meet the EISA target. Moreover, it may be necessary to increase acreage yield, or the portion of the soybean harvest that is devoted to biodiesel in order to meet 833 EISA targets (FAPRI, 2010a). Use of corn stover for ethanol production is not expected to 834 835 increase acreage dedicated to corn.

<u>Land Use/Land Cover Change</u>: Much of the environmental impact of corn starch ethanol
 and soybean biodiesel production depends on the types of land put into cultivation. To date, most
 additional acreage has originated from lands currently in crop production. Expanding corn crop
 production to CRP or previously uncultivated acreage will likely have varying degrees of
 environmental impacts, depending on site-specific characteristics.

<u>Water Quality</u>: Increasing production of corn for ethanol and soybeans for biodiesel may
 have implications for water quality. Increased corn and soybean production could increase
 nutrient, sediment, and pesticide loadings to water bodies, including the Gulf of Mexico, Great
 Lakes, and Chesapeake Bay. Private drinking water wells could see increases in nitrate and

public drinking water systems could see increases in their costs to lower nitrate levels. However,

- some of the potential increased nutrient loadings from corn grown for ethanol might be offset by
- 847 increasing per-acre corn and soybean yields and by implementing comprehensive conservation
- systems. Increased risk of pathogens entering surface waters from application of animal manure
 fertilizers is also possible. Removal of corn stover could lead to loss of soil surface cover,
- thereby increasing runoff of nitrogen and phosphorus to surface waters; harvesting corn stover
- 851 may reduce soil nutrient availability, leading to increased fertilizer applications

852 <u>Water Availability</u>: The magnitude of environmental impact from increased corn and/or 853 soybean production for biofuel will vary geographically. If corn replaces other crops in the 854 Midwest, water availability will be minimally impacted. Increased corn and soybean production 855 in areas requiring irrigation, such as the Great Plains, will increase water usage, potentially 856 decreasing water availability. Removal of corn stover for ethanol will not affect water 857 availability in most parts of the U.S.

858 Soil: Impacts of expanding corn and soybean production will vary, depending on the 859 converted land use. Negative soil quality impacts will arise from converting acreage protected 860 with perennial vegetation to conventional corn and soybean production, which will likely increase soil erosion, sedimentation, and nutrient losses. Removal of corn stover for ethanol may 861 862 lead to a decline in organic matter, decreasing soil carbon sequestration and adversely impacting 863 crop yields. Impacts can be minimized through site-specific BMPs that limit soil erosion and 864 ensure that the amount of residue remaining on the field sustains soil quality and nutrient inputs 865 for subsequent crop productivity.

Air Quality: An increase in the production of corn and soybean for biofuel will likely lead to increased pollution from fossil fuels associated with cultivation and harvesting and from airborne particles (dust) generated during tillage and harvesting. Air emissions also result from the production of fertilizers and pesticides used in corn and soybean cultivation, and the application of fertilizers and pesticides for each crop. Increasing their use will likely increase the volume of emissions.

872 <u>Ecosystem Health/Biodiversity</u>: Ecosystem health/biodiversity impacts include 873 degradation of aquatic life due to eutrophication, impaired aquatic habitat due to sedimentation 874 from soil erosion, and decreases in landscape diversity. Conversion of CRP lands, which are 875 predominantly grasslands, may lead to declines in grassland birds, ducks, and other wildlife that 876 use these lands as habitat.

- 877 <u>Invasive Species</u>: Corn and soybean typically are not invasive in the U.S. corn and
 878 soybean-growing regions.
- 879 **3.2.7.1** Key Uncertainties and Unknowns

Uncertainties and a scarcity of data exist in many key areas concerning environmental
 impacts of biofuel feedstock production. In particular:

• The impacts of additional soybean and corn production are determined by where the production occurs and the types of management practices employed, including

884		the extent of tile drainage. However, it is highly uncertain where production will
885		occur and the extent to which BMPs will be employed. In particular:
886		
887		— Increased corn and soybean yields may offset the need for increased acres
888		in production to achieve EISA goals in 2022. However, the extent to
889		which vield increases will occur is currently unknown, and thus the extent
890		to which increased production of corn and soybeans will occur on
891		marginal lands, CRP, and/or via continuous corn production on existing
892		lands now in rotation with other crops is also uncertain.
893		
894		— The extent to which BMPs are currently implemented on cropland
895		nationally is unknown and the potential for future improvements
896		including improvements in vield management of nutrients pesticides
897		drainage and energy use and erosion control systems is also uncertain
898		
899	•	The ability to track impacts will depend on the quality and consistency of
900		monitoring fertilizer and pesticide usage such as data provided by USDA's
901		National Agricultural Statistics Services.
902		
903	•	The ability to evaluate current and future water shortages associated with ethanol
904		and biodiesel production is limited by the available data. Annual measurements of
905		the extent of irrigation and amounts of surface and ground water used are not
906		systematically collected nationwide, forcing researchers to use incomplete
907		information to calculate crude water use estimates. Estimates of water use to
908		produce soybeans for biodiesel are even less certain than those for corn
909		production. The connection between water use for corn and soybean production
910		and impacts on water availability and water shortages is also surrounded by
911		uncertainty. The availability of fresh water for a particular use is determined by
912		many factors, including rainfall, soil water retention and ground water recharge.
913		water demand for competing uses and water contamination attribution of water
914		shortages to a specific use may be difficult to measure without improvements in
915		data collection (Allev et al. 2002: Reilly et al. 2008)
916		
917	•	The uncertainties regarding the effect of corn and soybean production on soil
918		quality arise predominantly from uncertainties regarding the amount and type of
919		land converted to corn or sovbeans as a result of biofuel demand. For example, if
920		the USDA soybean acreage projections hold and additional soybean acreage is not
921		required to meet biodiesel demand then the impact of soybeans for biodiesel on
922		soil quality is likely to be relatively minimal. However, if soybean acreage
923		increases beyond current levels determining how much land is being converted
923		the previous cron-type of that land and its geographical location will be necessary
925		to assess the impact of this increase on soil quality. More studies on land use/land
926		cover changes as a result of ethanol and biodiesel demand are needed
927		cover enanges as a result of enanor and biodieser demand are needed.
928	•	Secondarily uncertainties regarding the effect on soil quality are caused by lack
929	-	of detailed land management data. For example, more frequent and detailed

930	data—including geographical location—on tillage practices employed would
931	substantially reduce uncertainties surrounding the soil quality response of
932	producing biofuels.
933	
• 934	The key uncertainties with respect to air quality impacts of increased corn and
935	sovbean production are similar to water quality with respect to fertilizer and
936	pesticide use and application. In addition, NO _x emission rates from fertilized soil
937	are highly uncertain and variable as they rely on microbial conversion of fertilizer
938	to nitrate which in turn is influenced by environmental conditions. The extent to
939	which cover crops and tillage practices are employed, both of which can reduce
940	fugitive dust emissions, are also highly uncertain. For corn stover, there are a
941	range of assumptions regarding cropping practices, harvest techniques, and farm
942	inputs that require more study.
943	
944 •	Ecosystem health and biodiversity, including fish and wildlife, are highly
945	impacted by uncertain environmental factors such as nutrient and sediment runoff.
946	Nutrient loadings from row crop production into surface waters depend on a
947	variety of factors, including variations due to weather and are therefore widely
948	variable (Powers, 2007). Regardless, the ability to reduce chemical exposure of
949	biota will be beneficial to the ecosystem and local biodiversity. In addition to
950	resolving uncertainties about those factors, more studies are needed on landscape-
951	level associations between corn and soybean production and terrestrial and
952	aquatic biodiversity, as well as biodiversity-related services such as pollination
953	and natural pest control.
954	-
955 •	There is substantial uncertainty regarding the impacts of climate change on
956	regional precipitation patterns and temperatures, which could significantly change
957	water demand and availability, crop yield, runoff, and soil loss.
958	

959 3.3 <u>Perennial Grasses</u>

960 **3.3.1** Introduction

961 Perennial grasses are herbaceous plants that grow in successive years from the same root 962 system. They lack the sugar and starch content to be converted directly into ethanol using conventional methods, but can be converted using cellulosic conversion technologies. While 963 964 cultivation of perennial grasses has potential environmental advantages over traditional row 965 crops such as corn and soybeans, major technological challenges exist for the development of these more advanced biofuel conversion technologies. Currently, no commercial-scale facilities 966 967 for converting perennial grasses to cellulosic ethanol are operating in the U.S.; however, six 968 switchgrass cellulosic ethanol production facilities are under development (RFA, 2010).

969 The predominant perennial grasses for biofuels are likely to be monocultures of 970 switchgrass (*Panicum virgatum*) or Giant Miscanthus (*Miscanthus x giganteus*), hereafter 971 referred to as *Miscanthus*. Research suggests that an aggressive genetics program to create fast-972 growing strains could increase production of both feedstocks dramatically over current 973 production levels (Vogel and Masters, 1998). The research community is also exploring mixtures 974 of native grassland species—referred to as low-input high-diversity (LIHD) mixtures—as a

- 975 feedstock (see text box on next page). Compared to their constituent monoculture perennial
- 976 grasses, LIHD mixtures have often demonstrated higher bioenergy yields (i.e., gallons of biofuel
- produced per unit of land), and a greater ability to grow in infertile soils, although much less is
 known about their commercial potential (Tilman and Lehman, 2006). Most research and
- development has been conducted on monocultures of switchgrass and *Miscanthus*, therefore,
- 980 these species are the focus of this section.
 - 981 Switchgrass, a native plant of North America, has historically been grown in the U.S. as 982 forage for grazing livestock (Parrish and Fike, 2005). Recently, it has entered breeding programs 983 and agronomic testing as a biofuel feedstock. *Miscanthus*, which is native to Asia, has been 984 developed and tested as a biofuel feedstock largely in Europe. Considerable genetic variation in 985 both these species has yet to be explored to optimize feedstock production and biofuel refining 986 (Keshwani and Cheng, 2009), but promising traits, including low lignin and ash content, and late 987 or absent flowering periods (Jakob et al., 2009), indicate ample potential for high crop yields and 988 efficient conversion to ethanol (Jakob et al., 2009). While standard irrigation, fertilizer, and 989 pesticide use practices have vet to be developed, recent small-scale farming and larger-scale 990 studies, such as those conducted by the U.S. Department of Energy's Regional Biomass Energy 991 Feedstock Partnership, continue to inform estimates of biofuel perennial grass cultivation and 992 resource requirements (Parrish and Fike, 2005). Farm-scale studies have demonstrated that 993 ethanol yield from switchgrass ranges from approximately 240-370 gallons per acre compared to 994 an average of 330 gallons per acre for corn grain (Schmer et al., 2008).
- 995 EISA and Section 211(o) of the Clean Air Act limit land conversion for biofuels to 996 existing agricultural land cleared or cultivated prior to Dec. 19, 2007, or land that was non-997 forested and actively managed or fallow on Dec. 19, 2007 (Clean Air Act, Section 211[o]). As of 998 November 2009, approximately 28 million of the 31.2 million CRP acres were vegetated with 999 mixtures of native or introduced grasses for a variety of environmental purposes, including 1000 wildlife habitat, erosion control, and water quality. Economic modeling of global bioenergy 1001 markets (POLYSYS) estimates that approximately 8-13 million acres of CRP land and 10-23 1002 million acres of agricultural cropland in the U.S. could possibly (but not necessarily likely) be 1003 converted to switchgrass production, depending on economic factors (Walsh et al., 2003). The 1004 gross impact on CRP land already growing switchgrass would be minimal, and the estimated 1005 combined conversion of "idle" and "pasture" lands to switchgrass production could be between 1006 0.78 and 5.58 million acres (Walsh et al., 2003). Comparable quantitative information is not 1007 available for *Miscanthus*, however, high biomass yields on areas with poor soil quality in 1008 southern Illinois demonstrate the potential for Miscanthus on low fertility lands (Pyter et al., 1009 2004). In addition to CRP land, abandoned cropland is hypothetically available for perennial 1010 grass cultivation. Assuming suitable technology and infrastructure exists, an estimated 25 billion gallons of ethanol could potentially be produced annually if switchgrass is grown on the 1011 1012 approximately 146 million acres of abandoned agricultural land in the U.S., as long as these 1013 lands do not fall under restrictions described in Section 211(o) of the Clean Air Act (U.S. EPA, 1014 2010b, Chapter 6).
- 1015
- 1016

1017 Native Grasslands as a Biofuel Feedstock 1018 1019 Recent research has suggested using mixtures of native perennials as a feedstock on marginal or infertile 1020 lands (Tilman et al., 2006; Tilman et. al, 2009; Campbell et al., 2008; Weigelt et al., 2009). This practice 1021 is limited by several technological and management hurdles, yet also enjoys many environmental benefits 1022 not found to the same degree in other feedstocks discussed in this report. Termed "low-input high-1023 diversity" (LIHD) mixtures, they are essentially comprised of several plant species that perform different 1024 functions within the community (e.g., high root mass to prevent soil erosion, nitrogen fixation to reduce 1025 fertilizer inputs) potentially at different times (e.g. spring versus fall) or the same function in a different 1026 manner (e.g., root growth and soil carbon sequestration at shallow versus deeper soil depths). LIHD 1027 mixtures, by definition, have more plant biodiversity than other monoculture-based feedstocks. This 1028 higher plant biodiversity is often associated with a variety of benefits, including higher stability of 1029 production, higher quality of habitat for wildlife, lower potential for invasion of the community, reduced 1030 need for chemical inputs (fertilizers, pesticides), and reduced potential for plant disease and crop losses 1031 (Fargione et al., 2009; Hooper et al., 2005; Loreau et al., 2002; Reiss et al., 2009). When systems are 1032 viewed as a composite of many co-occurring processes (e.g. primary production, soil stabilization, and 1033 decomposition), polycultures sustain higher levels of multiple processes, sometimes termed "ecosystem" 1034 multifunctionality" (Hector and Bagchi, 2007; Zavaleta, 2010). Diverse mixtures also often produce more 1035 biomass than their average constituent species grown in monoculture; however, the productivity of the 1036 most productive constituent species is in many cases similar to that of the mixture (Cardinale et al., 2006; 1037 Loreau et al., 2002; Cardinale, 2007). Although it seems likely that highly productive feedstocks (e.g., 1038 switchgrass and Miscanthus) managed for maximum production will produce more biomass for biofuel 1039 production than LIHD mixtures, there are no direct field-scale comparisons between LIHD and other 1040 feedstocks with which to evaluate this assumption. The only comparison to date found that switchgrass 1041 grown on productive lands across the Midwestern corn belt (Nebraska, South Dakota, North Dakota) out-1042 produced LIHD grown on unproductive land in Minnesota (Schmer et al., 2008). However, monoculture 1043 crops are expected to require more active management (e.g., to prevent losses from pests) than 1044 polycultures such as LIHD (Hill et al., 2006; Tilman et al., 2009; Weigelt et al. 2009). Production of a 1045 feedstock composed of a mixture of species will likely face greater technological and management 1046 hurdles than production of single-species feedstocks. For example, a mixture of species, having variable 1047 tissue densities and arrangements in the cropping system, may be more difficult to harvest, transport, and 1048 process into biofuel than a relatively uniform feedstock grown from a single species. Much more research 1049 is needed in this area to determine the potential role of LIHD as a biofuel feedstock on marginal or 1050 infertile lands.

1051**3.3.1.1**Current and Projected Cultivation

Perennial grasses could thrive across many regions of the contiguous U.S. (see Figure 3-5). Since many of these species, including switchgrass, have historically dominated much of the Midwestern landscape, they are well suited to grow over much of the agricultural region.



1056

Source: Dale et al., 2010, updated from Wright, 1994

Figure 3-5: Generalized Map of Potential Rain-fed Feedstock Crops in the Conterminous United States Based on Field Plots and Soil, Prevailing Temperature, and Rainfall Patterns

1060 **3.3.1.2 Overview of Environmental Impacts**

1061 As production of biofuel from perennial grass becomes technologically and economically 1062 viable, demand for perennial grass will increase. This will result in conversion of qualifying land 1063 to perennial grasses, the location and extent of which will depend on region-specific agricultural 1064 and economic conditions. Perennial grass production will likely require traditional agricultural activities, including pesticide, fertilizer, water, and fuel/energy usage. The intensity of these 1065 1066 activities relative to the land management practices they are replacing will determine the extent to which perennial grass production impacts water quality, water availability, air quality, and soil 1067 1068 quality. Finally, perennial grass feedstock transport, which often involves seed movement, may 1069 result in unintended dispersal and the spread of invasive grasses.

1070 3.3.2 Water Quality

Perennial grasses, sometimes grown as a conservation practice along the margins of agricultural fields to reduce sediment and nutrient runoff into surface water and wetlands, are expected to have fewer water quality impacts than conventional agricultural crops (Keshwani and Cheng, 2009). This will depend, however, on the agricultural intensity of the perennial grass cropping system (e.g., the extent of fertilizer and pesticide use). Table 3-3 shows inputs needed to grow perennial grasses compared to agricultural intensity metrics associated with growing conventional crops.

Metric	Reduction Relative to Corn-Wheat-Soybean Average
Erosion	125 fold
Fertilizer	1.1 fold
Herbicide	6.8 fold
Insecticide	9.4 fold
Fungicide	3.9 fold
Source: Ranney and M	Iann, 1994.

Table 3-3: Comparison of Agricultural Intensity Metrics forPerennial Grass and Conventional Crops

1078 1079

1080 **3.3.2.1** Nutrient Loading

1081 Nutrients—Surface Water Impacts

1082 Relative to annual crops, such as corn and soybeans, production of switchgrass and Miscanthus requires less fertilizer and reduces nutrient runoff. Switchgrass is inherently efficient 1083 1084 in its nitrogen use, as well as its use of potassium and phosphorus (Parrish and Fike, 2005). Switchgrass and Miscanthus are both nutrient-efficient because they store carbohydrates and 1085 1086 nutrients in their roots at the end of the growing season (Beale and Long, 1997; Beaty et al., 1087 1978; Simpson et al., 2008). Therefore, the practice of harvesting the above-ground biomass 1088 reduces the need for fertilization in subsequent growing seasons. A recent study reported that *Miscanthus* can fix atmospheric nitrogen, which could be a large benefit to its use as a feedstock 1089 1090 (Davis et al., 2010). Studies have shown no response in *Miscanthus* growth to nitrogen additions, 1091 suggesting these fertilizers are not needed in its production (Clifton-Brown et al., 2007; 1092 Danalatos et al., 2007). In contrast, switchgrass yields increase with nitrogen fertilization, with 1093 recommended application rates for switchgrass grown for biofuels ranging from 41 to 120 kg nitrogen/ha/year (37 to 107 lbs nitrogen/acre/year), varying by region (McLaughlin and Kszos, 1094 1095 2005). Data for switchgrass and *Miscanthus* have been generally based on experimental plots, 1096 and management and vields may differ at the farm-scale. However, if these lower nitrogen 1097 fertilization rates hold, average nitrogen losses to surface waters should be lower relative to the production of corn starch ethanol (ORNL, n.d.). 1098

1099 Nutrients— Coastal Waters Impacts

1100 As mentioned above, switchgrass and *Miscanthus* cropping systems are expected to 1101 require fewer fertilizer additions compared to traditional row crops, and have been shown to 1102 reduce chemical oxygen demand in runoff when used as filter strips (Keshwani and Cheng, 1103 2009). This will minimize their impact on the hypoxic zones of U.S. coastal waters.

1104 **3.3.2.2 Sediment**

1105 Switchgrass and other perennial grasses have been used as an erosion control 1106 management practice to reduce sediment loads from row crops (Hill, 2007; McLaughlin and 1107 Walsh, 1998; U.S. EPA, 2009a). Perennial grasses have been shown to reduce erosion 125-fold 1108 when compared to an average of corn, wheat, and soybeans (see Table 3-3). Therefore, assuming 1109 good agricultural practices, switchgrass production is not expected to increase sediment loads to 1110 surface waters.

1111 **3.3.2.3 Pesticides**

1112 Perennial grasses, such as switchgrass (native to the U.S.), are generally less susceptible 1113 to pests than traditional row crops (Ovediran et al., 2004; Keshwani and Cheng, 2009). A 2004 controlled greenhouse study found that recovery of a dominant pest (western corn rootworm) 1114 was 0.2 to 82 times more likely from corn than from 20 other grass species native to the Midwest 1115 1116 (Ovediran et al., 2004). However, most species are likely to be more susceptible to pests when grown in monocultures as compared to polycultures. The lack of commercial perennial grass 1117 production as biofuel feedstock therefore makes it difficult to predict how much pesticide would 1118 1119 be needed for this application and what the environmental impacts would be. In non-commercial 1120 production, pesticide releases from perennial grass plantings are much less than from corn or soybeans (Hill et al., 2006). Switchgrass plantings use approximately 90 percent less pesticide 1121 1122 than row crops (Keshwani and Cheng, 2009). However, herbicides are used initially to establish 1123 and maintain switchgrass plantings for harvest. Switchgrass filter strips have been shown to reduce dissolved atrazine and metachlor concentrations in runoff (Keshwani and Cheng, 2009). 1124 Information relevant to potential pesticide use for *Miscanthus* in the U.S. is generally lacking; 1125 1126 however, researchers in Europe have reported that pesticide requirements are low compared to 1127 row crops (Lewandowski et al., 2000).

Of particular concern is how cellulosic feedstock production may impact the spread of the western corn rootworm (WCR), whose soil-borne larval stage is estimated to be responsible for more than \$1 billion in annual losses in the U.S. Corn Belt (Rice, 2003). Recent research reported that WCR is able to use *Miscanthus* and several North American grasses as a host, though not as effectively as corn (Oyediran et al., 2004; Spencer and Raghu, 2009). Similar information on WCR use of switchgrass as a host is not available, though perennial grasses generally are more resistant to pests than corn (Lewandowski et al., 2003; Oyediran et al., 2004).

1135 **3.3.2.4 Pathogens and Biological Contaminants**

1136 The reviewed literature does not directly discuss the effect of perennial grass plantings on 1137 pathogens in runoff or the potential for pathogen loads associated with perennial grass 1138 management (i.e., from manure used as fertilizer). Since perennial grasses require fewer inputs 1139 and take up more impurities from surface water, fewer contaminants are expected from its 1140 growth compared to row crops.

- 1141 3.3.3 Water Quantity
- 1142 **3.3.3.1 Water Use**

1143 Switchgrass is an important native grass in prairies across North America and does not 1144 require additional irrigation. As such, studies that calculate water use for ethanol produced from 1145 switchgrass often assume that the feedstock is rain-fed, requiring no irrigation, and is capable of 1146 tolerating moisture deficits (Dominguez-Faus et al., 2009; Wu et al., 2009). Nonetheless, 1147 greenhouse and field studies indicate switchgrass significantly increases biomass production with

greenhouse and field studies indicate switchgrass significantly increases biomass production with

access to ample water (Barney et al., 2009; Heaton et al., 2004). Thus, farmers may irrigate crops
 to maximize biomass production, though likely at much lower levels than required for row crops.

1150 Two major subtypes of switchgrass that differ in their water use characteristics have been 1151 identified in the wild: an upland and a lowland type. The upland type tends to tolerate dry

1152 conditions, though there is considerable variation in growth characteristics based on

- environment, which is likely due to limited crop selection and improvement. The lowland type
- 1154 requires more water (Parrish and Fike, 2005). Switchgrass farmers may be able to minimize
- 1155 water use by cultivating the upland type of switchgrass.

Miscanthus appears to be at least as efficient at using water for growth as corn and likely
more so (Beale et al., 1999), though considerable variation exists in the productivity of *Miscanthus* based on the identity of the cultivar, where it is grown, and the irrigation regime
(Clifton-Brown et al., 2001; Richter et al., 2008). Published field studies testing *Miscanthus* in
the U.S. are limited, however, and water use practices have not been established.

1161 **3.3.3.2 Water Availability**

Depending on where perennial grasses are grown, whether irrigation is required, and what crops they replace (if any), perennial grass production could improve water availability. Ground water availability, in particular, could be improved in places like Nebraska, where aquifers provide 85 percent of the water to agriculture (Kenny et al., 2009), if perennial grasses replace more water-dependent crops (NASS, 2009). Water availability will be minimally affected in areas requiring little or no irrigation.

- 1168 3.3.4 Soil Quality
- 1169 **3.3.4.1 Soil Erosion**

1170 Both switchgrass and *Miscanthus* have extensive root systems that prevent the erosion of 1171 soil and, unlike corn and soybeans, these perennial grasses are not planted on an annual basis, reducing the frequency of soil disturbance. Currently, switchgrass can be planted in conventional 1172 tillage and no-till systems, whereas *Miscanthus* is planted in tilled fields (Heaton et al., 2008; 1173 1174 Parrish and Fike, 2005). This one-time tillage can increase erosion risk, particularly in 1175 *Miscanthus* where plant growth is slow the first year following planting and does not provide 1176 substantial ground cover (Lewandowski et al., 2000). In subsequent years, however, Miscanthus 1177 stands generally have high yields and dense root mats (Heaton et al., 2008; Lewandowski et al., 1178 2000), and likely provide substantial erosion control benefits relative to annually planted crops. 1179 Erosion control by switchgrass has received more study than that of *Miscanthus*. Switchgrass has been extensively planted on CRP acreage for erosion reduction, and planting switchgrass in 1180 1181 riparian zone grass barriers and vegetation strips has been shown to substantially reduce runoff, 1182 sedimentation, and nutrient loss (Blanco-Canqui et al., 2004).

1183 **3.3.4.2 Soil Organic Matter**

In general, soil organic matter increases more under perennial species than annual species
because of the continuous accumulation of plant material (Sartori et al., 2006). Soil carbon is a
primary constituent of soil organic matter. The production of both switchgrass and *Miscanthus*

1187 can increase soil carbon, but these organic matter benefits are likely to depend on the particular land use replaced and specific management practices. Where perennials are planted on degraded 1188 1189 soils with low organic matter content, soil erosion can be reduced and carbon stocks restored 1190 (Clifton-Brown et al., 2007; McLaughlin and Kszos, 2005). For example, on such a soil, 1191 switchgrass has been predicted to increase soil carbon by approximately 12 percent following one decade of production and harvesting (Garten and Wullschleger, 2000). If perennial grasses 1192 1193 replace annual crops, perennials will likely increase soil organic matter, though direct comparisons are limited (Bransby et al., 1998; Schneckenberger and Kuzyakov, 2007). In one 1194 such study, relative to reported values for corn, soil carbon increased under Miscanthus 1195 1196 cultivation when its above-ground vegetation was harvested annually; however, this result varied 1197 according to soil type, with carbon increasing in a loamy soil but not in a sandier textured soil 1198 (Schneckenberger and Kuzyakov, 2007). Soil organic matter accumulation under these 1199 perennials depends, in part, on harvest frequency, and, in the case of switchgrass, on the potential 1200 application of nitrogen fertilizer (Lee et al., 2007b). On the other hand, the effect on soil organic matter of preparing previously undisturbed land for these biofuel feedstocks has received little 1201 1202 attention to date. Estimates of carbon loss following conventional tilling of undisturbed soils 1203 range from 20 to 40 percent (Davidson and Ackerman, 1993). The amount of time needed for 1204 these perennials to restore soil carbon lost following site preparation is uncertain.

1205 3.3.5 Air Quality

1206 As mentioned earlier, little is known overall about the extent to which fertilizer, 1207 herbicides, and pesticides will be used to increase perennial grass production. Grasses require 1208 significantly less nitrogen fertilizer than corn or soybean, and studies indicate that NO_x emissions 1209 should decrease when switchgrass is used as a feedstock (Wu and Wang, 2006). However, switchgrass is not currently grown on large scales under typical farm conditions. Nitrogen 1210 fertilizer rates are based on field trials, which are not extensive (Wu and Wang, 2006) and may 1211 differ from on-farm conditions (Hill et al., 2009). Similarly, switchgrass has been shown to 1212 1213 require lower amounts of phosphorus (P₂O₅) fertilizer, which translates to lower SO₂ emissions 1214 (Wu and Wang, 2006)

As described earlier in Section 3.3.2.3, perennial grasses are expected to require less pesticide and herbicide than row crops (except when initially establishing perennial grass plantings); however, the lack of experience with commercial perennial grass production as a biofuel feedstock precludes firm conclusions about potential air quality impacts.

1219 As with corn and soybeans, harvesting of switchgrass will involve use of farm 1220 equipment, and thus is expected to generate NO_x and PM emissions. However, VOCs and NO_x 1221 and PM emissions associated with switchgrass harvesting have been found to be much lower 1222 than those associated with corn harvesting (Hong and Wang, 2009). Decreases in VOCs, CO, 1223 NO_x , PM_{10} , $PM_{2.5}$, and SO_2 emissions associated with switchgrass production as compared to 1224 corn or soybean have been reported (Wu and Wang, 2006; Hess et al., 2009).

1225 3.3.6 Ecosystem Impacts

1226 **3.3.6.1 Biodiversity**

1227 Models indicate that a greater diversity of birds are supported by switchgrass than by row crops (corn or soy), though some non-priority species such as horned lark (*Eremophila alpestris*) 1228 1229 and killdeer (Charadrius vociferous) may decline (Murray and Best, 2003; Murray et al., 2003). One study found that perennial grass crops can provide substantially improved habitat for many 1230 forms of native wildlife-including ground flora, small mammals, and bird species-due to the 1231 1232 low intensity of the agricultural management system (Semere and Slater, 2006). Increases in 1233 avian diversity are insensitive to whether switchgrass is strip harvested or completely harvested 1234 (Murray and Best, 2003). However, field studies have shown that different species prefer habitats 1235 under different management regimes, suggesting that switchgrass cultivation under a mosaic of 1236 field ages and management regimes will maximize total avian diversity over a large landscape (Murray and Best, 2003; Roth et al., 2005). Research from Nebraska and Iowa shows that 1237 1238 populations of white-tailed deer are not likely to decline following conversion of land from corn 1239 to native grassland (i.e., dominated by switchgrass), but may experience contraction of home 1240 ranges to areas near row crops, increasing crop losses and the potential for disease transmission among wildlife (Walter et al., 2009). Though similar studies for Miscanthus in the U.S. are 1241 1242 lacking, research from the United Kingdom shows that non-crop plants from a wide range of 1243 families (Poaceae, Asteraceae, and Polygonaceae) coexist within young Miscanthus cropping 1244 systems due to a lack of herbicide applications, and support a greater diversity of bird 1245 populations than annual row crops (especially of passerines, game birds, and thrushes) (Bellamy 1246 et al., 2009). These effects are likely to be transient as fields mature and crop height and coverage become more homogeneous (Bellamy et al., 2009; Fargione et al., 2009). Similar 1247 patterns are likely for the U.S. Use of native mixtures of perennial grasses can restore some 1248 1249 native biodiversity (Tilman et al., 2006).

1250 **3.3.6.2** Invasive Plants

1251 Grasses are successful at reproducing, dispersing, and growing under diverse 1252 environmental conditions. This helps explain their dominance across many areas of the globe, 1253 and contributes to their potential risk as agricultural weeds and invasive plants. The risk that switchgrass or *Miscanthus* will become an agricultural weed or invasive plant depends on their 1254 1255 specific biology and their interaction with the environments in which they are grown. One study noted that well-managed biofuel feedstock production must not only prevent feedstock crops 1256 1257 from invading local habitat, but also prevent the crops from genetically invading native species 1258 (Firbank, 2007).

Switchgrass produces large amounts of seed, a trait that correlates with the ability to
spread, though it remains unclear how much and how far switchgrass seed can disperse.
Switchgrass is being bred for vegetative reproduction, tolerance to low fertility soils, and the
ability to grow in dense stands (Parrish and Fike, 2005), all of which could increase invasive
potential. On the other hand, breeding for traits like sterility can be utilized to reduce the risk of
escape and likelihood of negative impacts. For example, hybrid *Miscanthus* cultivars have been
bred to produce almost no viable seed.

1266 The location where a feedstock is grown and the interaction between the feedstock and 1267 the local environment will be important for determining its invasion potential. Using species 1268 native to the area they are cultivated minimizes the risk of invasion into natural areas. 1269 Switchgrass is native east of the Rocky Mountains, although a variety could be bred or 1270 engineered to be substantially different from local populations. Switchgrass in any form is not native west of the Rockies. One risk assessment of introducing switchgrass to California 1271 1272 indicated that it could become invasive relatively easily (Barney and DiTomaso, 2008). The 1273 potential for switchgrass to become a weed of other agricultural crops, even within its native 1274 range, is not known.

1275 Unlike switchgrass, *Miscanthus x giganteus* (the variety of *Miscanthus* that has been 1276 tested in Europe as a biofuel feedstock) is not native anywhere in the U.S. Little information 1277 exists about the ability of *M. x giganteus* to disperse from cultivation and persist as a weed or invade natural areas. One risk assessment recommended no restrictions on planting in the U.S. 1278 1279 because the plant produces no living seeds and is therefore unlikely to spread easily (Barney and 1280 DiTomaso, 2008). A different study, however, noted that *Miscanthus* can spread vegetatively and 1281 could undergo genetic changes to produce seeds once more-making it potentially invasive 1282 (Raghu et al., 2006). Miscanthus sinensis has been grown in the U.S. for landscaping and 1283 horticultural purposes. Herbarium specimens and field observations indicate that it can disperse 1284 live seeds and persist in areas beyond where it was originally planted. Miscanthus sinensis, a 1285 species related to Giant Miscanthus, has been grown in the U.S. for landscaping and horticultural purposes, and is also being developed as a biofuel feedstock. Herbarium specimens and field 1286 1287 observations indicate that it can disperse live seeds and persist in areas beyond where it was 1288 originally planted, including a variety of habitats like pasture, clearcut forests, and residential 1289 areas (Ouinn et al., 2010). A recent study found that *Miscanthus sinensis* spreads guickly enough 1290 to be labeled invasive (Quinn and Stewart, 2010). Some other grass species that have been considered for use as biofuel currently invade wetlands, including giant reed (Arundo donax) 1291 1292 (Bell, 1997) and reed canary grass (*Phalaris arundinacea*) (Lavergne and Molofsky, 2004).

1293 While feedstock cultivation poses the greatest risk for invasive impacts, reproductive 1294 parts from feedstocks could also be dispersed during transport from the field to storage or 1295 ethanol-processing facilities. Roads, railroads, and waterways can act as man-made corridors for 1296 non-native and invasive plants. Harvested switchgrass possesses living seed and *Miscanthus* can 1297 reproduce vegetatively from plant cuttings, both of which may be dispersed during feedstock 1298 transport.

1299 One mitigation option for reducing the potentially negative environmental impacts from 1300 perennial grass production is avoiding cultivation of feedstocks with a history of invasiveness, 1301 especially in places that are climatically similar to where invasion has already occurred. Another option is to breed feedstocks to limit their dispersal into other fields or natural areas (e.g., the 1302 1303 sterile *Miscanthus x giganteus*). For instance, sterile, seedless switchgrass cultivars would be less 1304 likely to become invasive than current, seed-bearing cultivars. Often, higher reproduction 1305 correlates with lower biomass, so aggressive breeding programs to increase biomass and 1306 decrease seed production could produce multiple benefits.

1307Another strategy for managing potential invasiveness is cleaning harvesting machinery1308and vehicles used to transport harvested feedstock, which would help to decrease unintended

1309 dispersal. Though prevention is most desirable, early detection and rapid response mechanisms

could also be put into place to eradicate persistent populations of feedstock species as they arise, 1310

1311 but before they have the chance to spread widely (DiTomaso et al., 2010). Such early detection

- 1312 and rapid response mechanisms might involve local monitoring networks and suggested
- 1313 mechanical and chemical control strategies (timing and application rate of herbicides, for 1314
- example) devised by local agricultural extension scientists for specific feedstocks.

1315 3.3.7 Assessment

1316 Perennial grasses are likely to require less pesticide, fertilizer, and water than traditional 1317 row crops used for biofuel production (Downing et al., 1995). The benefits of perennial grasses as a feedstock include reduced soil erosion, enhanced soil structure and carbon sequestration, 1318 1319 reduced nitrogen loading and sedimentation to waterways, reduced hypoxia in coastal areas, and 1320 greater support for populations of non-crop plants as well as animals and soil biota (Fargione et al., 2009; Hill, 2007; Williams et al., 2009). Use of perennial grasses as a biofuel feedstock 1321 1322 carries many advantages to ecosystem services and to biodiversity relative to traditional row 1323 crops. The magnitude of these advantages depends on resolving some uncertainties and also on 1324 whether perennial grasses are replacing CRP land, row crop farmland, or other lands such as pasture land, and whether they are grown in a monoculture or in a mixture of species. The 1325 1326 maintenance of landscape-level biodiversity (e.g., including non-cultivated, protected areas nearby) will depend on the spatial arrangement of reserves promoting connectivity and 1327 1328 population persistence, local management practices, and potential for biofuel crops and their 1329 pests to spread beyond managed boundaries.

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3.3.7.1 **Key Uncertainties and Unknowns**

- 1331 Because no commercial-scale facilities exist for converting perennial grasses to • 1332 cellulosic ethanol, many uncertainties remain about how growing perennial 1333 grasses as a feedstock will affect environmental conditions when grown at 1334 commercial scales. This holds for all endpoints documented in this report (soil carbon, leaching, etc.) and highlights the need for large-scale studies comparing 1335 1336 perennial grass cultivated under a variety of management regimes with row crops and other feedstocks. 1337
- 1339 Most existing literature on switchgrass examines the plant's rangeland and • ecological purposes; this literature might not be completely applicable to 1340 switchgrass used as a biofuel feedstock. 1341
- 1343 Much genetic potential for both Miscanthus and switchgrass remains to be 1344 explored for increasing their feasibility as feedstocks. If researchers are able to develop novel cultivars of these plants with significantly improved yields, there 1345 1346 may be less potential for environmental damage from Miscanthus and switchgrass 1347 production.
- 1349 Little is known about usage of fertilizer and pesticides for increasing perennial • grass production. The usage of precision management strategies (e.g., minimal 1350 1351 fertilization, irrigation, and pest management at specific times) may potentially

1352 1353 1354		increase productivity without deleterious ecological impacts. Depending on where these crops are grown and what crops or other land use they are replacing, they may improve water quality relative to the previous land use.
1355 1356 1357 1358		• The water requirements of different grass species in different areas of the country are not documented, and the use and preferred method of irrigation remains to be determined.
1359 1360 1361 1362		• The role of nitrogen fixation in explaining the productivity of <i>Miscanthus</i> requires further study and may have large ramifications on the potential use of <i>Miscanthus</i> as a feedstock.
1363 1364 1365 1366		• The potential invasiveness of switchgrass in the western U.S. and <i>Miscanthus</i> across all the entire U.S. is relatively unknown. Studies to evaluate feedstocks for the biological characteristics associated invasiveness, including rate of seed
1367 1368 1369		production, rate and maximum distance of dispersal from field-scale plots, modes of dispersal (e.g., wind, water, bird), rate of hybridization with already invasive relatives, resistance to chemical or mechanical control, etc., are crucial for
1370 1371 1372		anticipating and preventing negative impacts and for determining which alternative feedstocks might pose lower risks.
1373 1374 1375 1376		• It remains uncertain whether the continual removal of above-ground biomass will deplete soil nutrients over the long term, particularly on marginal soils. On these soils, it may be particularly critical to harvest after translocation of nutrients back into the root systems.
1377 1378 1379		• More landscape-level research is needed to understand how the distribution of multiple land use systems across a large landscape (e.g., row crops interspersed
1380 1381 1382	2.4	with perennial biofuel grasses and native habitat) will affect local and regional biodiversity.
1383	3.4	<u>woody biomass</u>

1384 *3.4.1 Introduction*

1385 Woody biomass includes trees (e.g., removed or "thinned" from forests to reduce fire 1386 hazard or stimulate growth of remaining stands); forest residues (e.g., limbs, tree tops, and other 1387 materials generally left on-site after logging); short-rotation woody crops (SRWCs; i.e., fast-1388 growing tree species cultivated in plantation-like settings) and milling residues. Woody biomass 1389 is an attractive energy source because of its widespread availability and capacity to store carbon. 1390 However, to date woody biomass has been of limited use for energy production, with the exception of pulp and saw mill residues burned to produce heat, steam, and electricity. Woody 1391 biomass has been of particular interest as a biofuel feedstock because some forests might benefit 1392 1393 from thinning and/or residue removal: removing forest residues from forests could reduce the 1394 threat of catastrophic wildfires, at least in some ecosystems, while providing a feedstock for 1395 energy production (Gorte, 2009). No commercial-scale biofuel plants using woody biomass as a

feedstock are yet in operation, but demonstration and development facilities exist, and woodybiomass is projected to be a future source of cellulosic biofuels.

The U.S. has substantial domestic capacity for producing fuel from woody biomass. Estimates of the amount of woody biomass available for biofuel production differ widely and vary by price paid per ton of feedstock. EPA's RFS2 RIA notes that, at \$70 per ton, 40 to 118 million dry tons of woody biomass may be available for biofuel production in 2022 (U.S. EPA, 2010b, p. 49). At a currently demonstrated conversion rate of 80 gallons of ethanol per dry ton, up to 9.4 billion gallons of ethanol could be produced from 118 million dry tons (Foust et al.,

1404 2009). Additionally, the conversion rate of biomass to ethanol will likely improve in the future.

1405 Under the RFS2 requirements, not all woody biomass would be available. The RFS2 1406 limits the origin of woody biomass to "planted trees and tree residue from actively managed tree 1407 plantations on non-federal land cleared at any time prior to December 19, 2007" (U.S. EPA, 2010h, p. 56). Both forest harvesting residues and thinning operations are expected to be the 1408 1409 predominant sources of woody biomass for future biofuel use, but SRWCs may be important as well at higher feedstock prices (Perlack et al., 2005; U.S. EPA, 2010b, pp. 38-49; White, 2010). 1410 1411 In the following sections, the potential impacts of harvest residues, thinning, and SRWCs are 1412 discussed in more detail. For comparison purposes, the environmental impacts of SRWCs are 1413 considered in relationship to annual row crops. However, economic analyses suggest that the 1414 most likely sources of land for SRWC plantations are CRP or fallow agricultural lands, rather 1415 than prime agricultural acres or grasslands; therefore, SRWCs are generally unlikely to replace 1416 row crops (Volk et al., 2006; Walsh et al., 2003).

1417**3.4.1.1**Current and Projected Production Areas

1418 The potential sources of woody biomass vary by region of the country, and only SRWC 1419 plantations are likely to result in land use/land cover changes. Forest harvest residues are 1420 produced in major forest harvesting areas, predominantly in places such as the upper Lake States, 1421 the Southeast and the Pacific Northwest (see Figure 3-6). Since these residues will most likely be collected as a by-product of harvesting operations, the use of forest harvest residues is unlikely to 1422 1423 produce land use/land cover changes (Williams et al., 2009). However, a rise in price paid per ton for woody biomass may provide an incentive for additional harvesting. Woody biomass from 1424 1425 forest thinning will also occur in major forest harvesting areas, and potentially in areas of high 1426 wildfire risk. In contrast, SRWC plantations can have substantial land use/land cover effects.



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Figure 3-6: Estimated Forest Residues by County

1430 **3.4.1.2 Overview of Environmental Impacts**

1431 Several activities associated with woody biomass as a feedstock may impact the 1432 environment. In the case of forest thinning and residue removal, there may be a direct 1433 environmental impact of biomass removal, as well as an impact from operation of forestry 1434 machinery. In the case of SRWCs, traditional forestry and agricultural activities undertaken 1435 during feedstock cultivation and harvest, such as pesticide, fertilizer, water, and fuel/energy use, 1436 have the potential to impact the environment. In addition, the choice of tree species may influence the risk of establishment, invasion, and impact during both feedstock production and 1437 transport. All these activities can alter air quality, water quality, water availability, and soil 1438 1439 quality, with resulting impacts on ecosystems, though the extent of the impacts depends on each 1440 activity's intensity.

1441 3.4.2 Water Quality

1442 Use of woody biomass as a feedstock can impact water quality, primarily through 1443 nutrient runoff and sedimentation. However, the impacts of harvesting trees or removing forest 1444 residues can be limited through implementation of forestry best management practices. The 1445 extent to which SRWCs have a lower water quality impact than conventional crops will depend 1446 on the agricultural intensity of the short rotation woody crops production system (e.g., the extent

- 1447 of fertilizer, pesticide use and replanting interval). Table 3-4 shows inputs needed to grow
- 1448 SRWCs compared to agricultural intensity metrics associated with growing conventional crops.

Metric	Reduction Relative to Corn-Wheat-Soybean Average
Erosion	12.5 fold
Fertilizer	2.1 fold
Herbicide	4.4 fold
Insecticide	19 fold
Fungicide	39 fold

Table 3-4: Comparison of Agricultural Intensity Metrics for Short-Rotation Woody Crops and Conventional Crops

Source: Ranney and Mann, 1994.

1450

3.4.2.1 Nutrients

The literature is mixed on whether residue removal increases (Kreutzweiser et al., 2008) or decreases (Lundborg, 1997) nutrient loads to surface water bodies, including wetlands. The impacts of removing tree harvest residues on nutrient loads vary depending on topography (slope), soil nutrient content, and the chemistry of the residues themselves (Titus et al., 1997). Compared to forest residue removal, moderate forest thinning typically does not increase loss of soil nutrients to ground or surface waters (Baeumler and Zech, 1998; Knight et al., 1991).

1458 Forestry Best Management Practices (BMPs) such as buffer zones (vegetated setbacks 1459 from water bodies) are used to reduce water quality impacts. Careful planning to minimize the construction of roads and stream crossings or the use of portable stream crossing structures can 1460 1461 help reduce erosion and sedimentation (Aust and Blinn, 2004; Shepard, 2006). Other BMPs include: using energy efficient machinery, minimizing traffic in buffer zones and choosing low-1462 impact equipment that is of the appropriate size and scope for the site (Phillips et al., 2000). The 1463 draft 2010 National Report on Sustainable Forests by USDA's U.S. Forest Service suggests 1464 widespread adoption of forestry BMPs to protect water resources, although many states failed to 1465 1466 respond to a request for data (U.S. Forest Service, 2010). If practices are followed, impacts can be minimized; outreach, education, and monitoring to ensure implementation and effectiveness 1467 1468 are ongoing.

1469 As described above, SRWCs are unlikely to directly replace row crops; however, for 1470 comparative purposes, it is noted that nutrient losses from SRWCs are in general considerably less than in annually cropped systems, depending in part on the harvesting and replanting 1471 interval. In willow plantations, the recommended fertilization rate is 89 pounds of nitrogen per 1472 1473 acre (100 kg/hectare) every 3 years, which equates on an annual basis to approximately 22 1474 percent of the average rate for corn production (Keoleian and Volk, 2005; NASS, 2006). In the first year or two following planting, SRWC plantations can exhibit losses of nitrogen at rates 1475 comparable to conventional grain production, yet following this initial establishment phase, 1476 1477 nitrogen losses decline to low levels (Aronsson et al., 2000; Goodlass et al., 2007; Randall et al., 1997). A comparison of nutrient exports from a short-rotation poplar stand and a native forest 1478 1479 found no difference (Perry et al., 1998), and measurements of nitrogen in ground water and

leaching from established willow plantations generally show little eutrophication potential for
aquatic ecosystems (Keoleian and Volk, 2005). In coppiced systems, where trees are harvested at
the ground level and re-grow from the stump, the harvesting of the aboveground portion of the
tree appears to have little impact on nitrogen leaching (Goodlass et al., 2007). Losses can be
substantially higher when the stand is replanted (Goodlass et al., 2007). Longer rotation lengths
would likely improve nutrient retention on-site and reduce losses to waterways.

1486 **3.4.2.2 Sediment**

1487 Forest soils generally exhibit low erosion rates and thus small sediment losses to surface 1488 waterways (Neary et al., 2009). However, when forests are harvested and the soil prepared for 1489 the next stand without using BMPs, erosion rates can increase significantly (McBroom et al., 1490 2008). Harvesting residues left on-site physically shield soil particles from wind and water 1491 erosion, and promote soil stability through the addition of organic matter. Thus, removal of 1492 harvest residues is an element of harvest operations that could increase erosion and associated 1493 sediment loading to surface waters, especially on steeper slopes (Edeso et al., 1999). Thinning 1494 can also increase erosion and sediment loads to surface waters, depending on the site 1495 characteristics and the methods used (Cram et al., 2007; U.S. Forest Service, 2005; Whicker et 1496 al., 2008). Research indicates that proper use of BMPs, such as road design and buffer zones, can 1497 significantly reduce sediment impacts to surface waters (Aust and Blinn, 2004; Shepard, 2006). 1498 In addition, erosion rates at harvested sites decline once vegetation re-colonizes the site (Aust et 1499 al., 1991; Miller et al., 1988). See Section 3.4.4.1 for discussion of impacts of SRWCs on soil 1500 erosion and sedimentation.

1501 **3.4.2.3 Pesticides**

Pesticides might be used with SRWCs; for purposes of comparison, it is noted that the
amount used would be significantly less than that for corn or soybeans (Ranney and Mann,
1994).

- 1505 3.4.3 Water Quantity
- 1506 **3.4.3.1 Water Use**

1507 The utilization of harvest residues from mature stands of trees and thinning does not 1508 require additional water use at the feedstock production stage.

1509 For the most part, growth of SRWCs will likely occur in areas with high water 1510 availability, such as the Northeast, Southeast, and Northwest. Because they are usually not 1511 irrigated, trees require less total water than row crops (Evans and Cohen, 2009). However, they 1512 can still have a large impact on regional water availability due to their much higher 1513 evapotranspiration rate. In places where high-intensity tree plantations replace existing 1514 ecosystems with lower evapotranspiration rates, the potential for increased water consumption is 1515 significant. A study of southern pine in the Southeast found that an additional 865 gallons of 1516 water is consumed per gallon of ethanol produced from woody biomass (roughly 1,300 gallons 1517 of water per gallon of gasoline equivalent), due to land conversion for woody biomass production (Evans and Cohen, 2009). Further, in certain locations and in some years, additional 1518

- 1519 irrigation water may be required to maintain high biomass accumulation (Hansen, 1988).
- 1520 Precision application systems can reduce the amount of water applied.

1521 **3.4.3.2 Water Availability**

Use of forest harvest residues and biomass from thinning should have little or no effect on water availability at the feedstock production stage. Plantations of SRWCs may reduce runoff into streams and rivers compared to traditional row crops like corn and soybeans, potentially benefiting water quality (Updegraff et al., 2004). However, some experts warn that reduced runoff coupled with high water requirements could reduce or eliminate stream flow (Jackson et al., 2005). In places with seasonal flooding, modulation of surface water flow closer to preagricultural development levels could possibly mitigate flooding (Perry et al., 2001).

1529 3.4.4 Soil Quality

1530 **3.4.4.1 Soil Erosion**

1531 The soil erosion impacts of SRWCs will depend on harvesting and planting frequencies; 1532 impacts are lower when time between planting intervals is longer. Short-rotation woody crops 1533 require intensive soil preparation for successful establishment, and it is during this brief establishment phase that erosion rates can be a high (Keoleian and Volk, 2005). For example, 1534 1535 higher sediment losses were observed within the first 3 years of seedling establishment in 1536 sweetgum (Liquidamber styraciflua) plantations compared to no-till corn or switchgrass 1537 (Nvakatawa et al., 2006). The slow-developing canopy failed to provide adequate ground cover 1538 to protect against erosion as a result of rainfall (Nyakatawa et al., 2006). However, in established 1539 SRWC plantations, soil erosion rates are likely much lower than those of annually harvested row 1540 crops. The use of a cover crop can also significantly reduce erosion caused by SRWC 1541 establishment (Nyakatawa et al., 2006), and the soil erosion effects of SRWCs are likely to be 1542 lower under a coppicing system, which reduces the frequency of soil disturbance by keeping the 1543 root systems intact. Willows are generally managed by the coppicing system and harvested at 3to 4-year intervals for a total of 7 to 10 harvests (Keoleian and Volk, 2005). This allows 21 to 40 1544 1545 years between soil disturbances.

1546 **3.4.4.2 Soil Organic Matter**

1547 Harvesting of forest residues removes plant material that could otherwise become soil 1548 organic matter. A review analysis suggested that, on average, a complete, one-time removal of 1549 forest residues slightly decreases soil organic matter in coniferous forests, but may not affect 1550 levels in hardwood or mixed stands (Johnson and Curtis, 2001). Leaving logging residues is important for soils with low organic matter content, and repeated harvesting of residues in the 1551 1552 same location could lead to overall declines in soil organic matter (Thiffault et al., 2006). Further 1553 research is needed to determine the cumulative effect of repeated removals. Thinning of forests 1554 has been shown to reduce carbon in forest floor layers, but less evidence is available regarding 1555 its impact on mineral soil organic matter levels (Grady and Hart, 2006; Jandl et al., 2007). The 1556 effect of thinning over the long-term will depend on both the frequency and intensity of the 1557 specific thinning operations.

1558 Production of SRWCs can add organic matter to the soil, sequestering carbon, but the net soil organic matter benefits of these crops depend on land-use change and time between harvests. 1559 1560 Generally, soil organic matter, including carbon, is initially lost when a forest is planted because 1561 the amount of organic matter entering the soil from the reestablishing plants is typically small 1562 and is exceeded by decomposition (Paul et al., 2002). Over time, substantial amounts of organic matter accumulate in the trees, the forest floor layer and the soil, greatly exceeding the carbon 1563 1564 contained in abandoned agricultural systems (Schiffman and Johnson 1989; Huntington 1995; 1565 Richter et al., 1999). The amount of time it takes for soil carbon to re-accumulate varies. In hybrid poplar plantations in Minnesota, it was estimated to take 15 years to meet the carbon 1566 1567 levels of the agricultural field replaced (Grigal and Berguson, 1998). A review study suggested that on average it can take 30 years to exceed those of abandoned agricultural fields; though 1568 1569 when the forest floor was also considered, carbon accumulation rates were higher, reducing the 1570 time needed to regain carbon from the initial forest establishment (Paul et al., 2002). Overall, if 1571 frequently harvested SRWCs replace longer rotation, managed forest lands, then the net effect on 1572 soil organic matter is likely to be negative; but, if they are grown using longer rotations, 1573 particularly on degraded former agricultural land, substantial amounts of organic matter are 1574 likely to added to the soil (Schiffman and Johnson, 1989; Huntington 1995).

1575 **3.4.4.3 Soil Nutrients**

1576 Use of harvesting residues removes a potential source of soil nutrients that can be utilized 1577 by the regenerating forest. Harvesting with residue removal generally leads to declines in soil 1578 nutrients and forest productivity, but in some cases, it can be sustainable for at least one rotation 1579 (McLaughlin and Phillips, 2006; Thiffault et al., 2006). The cumulative effects of repeated 1580 removals from the same site are likely negative, but require further study. Residue removal has been suggested as a management technique to reduce nitrogen in forests that receive high 1581 atmospheric deposition, such as in the northeastern U.S. (Fenn et al., 1998). However, this may 1582 1583 lead to depletion of calcium and other nutrients critical for plant growth (Federer et al., 1989). 1584 Overall, residue removal may be less problematic on high fertility soils compared to coarser-1585 textured, low fertility soils. The risk posed to soil nutrients by thinning is likely to be much 1586 smaller than that of the removal of harvesting residues (Luiro et al., 2010).

There is concern that continual harvesting of SRWCs will deplete soil nutrients over the long-term (Adegbidi et al., 2001). Commercial fertilizers or organic waste products, such as municipal effluent, can be used to offset these losses (Stanton et al., 2002). Nutrient removal from such effluents by SRWCs may provide an additional environmental benefit, though it remains unclear how much nitrogen, other nutrients, or contaminants might leach from these systems if this technique is used.

1593 3.4.5 Air Quality

Few data are available for evaluating air emissions from SRWCs such as hybrid poplar and willow. As with switchgrass, SRWCs require less tillage (reducing fugitive dust emissions) and fewer applications of fertilizer (reducing emissions associated with fertilizer production and application). However, some species such as poplar and willow that are potential feedstocks for either cellulosic ethanol or biodiesel are significant emitters of biogenic VOCs such as isoprene. Compared to non-woody crops that emit relatively little isoprene, extensive plantations of these trees have the potential to significantly impact ozone concentrations, although this effect will be
highly sensitive to environmental conditions, preexisting vegetative cover, and the presence of
other atmospheric chemicals, especially NOx (Hess et al., 2009; U.S. EPA, 2006b).

1603 3.4.6 Ecosystem Impacts

1604 **3.4.6.1 Biodiversity**

1605 Tree harvesting activities can impact aquatic biodiversity in a number of ways. For 1606 example, removal of woody biomass by harvesting of forest residues or thinning in riparian areas 1607 may reduce the woody debris in headwater streams, which is an important component for aquatic 1608 habitat (Angermeier and Karr, 1984; Chen and Wei, 2008; Stout et al., 1993; Thornton et al., 1609 2000). In addition, tree canopies over streams help maintain cooler water temperatures conducive 1610 to cold-water smallmouth bass, trout, or salmon populations (Binkley and Brown, 1993; U.S. 1611 EPA, 2006c). These benefits may be lost when trees are harvested.

1612 There is some evidence that planting SRWCs can improve species habitat relative to agricultural crops (Christian et al., 1998). Several studies have documented that bird species 1613 1614 diversity on woody biomass plantations is comparable to that of natural shrubland and forest 1615 habitats (Dhondt et al., 2007; Perttu, 1995; Volk et al., 2006), though this is not always the case (Christian et al., 1998). Bird and small mammal species found on SRWC plantations tend to be 1616 habitat generalists that can also use open habitats like agricultural lands, while birds and small 1617 mammal species in mature forests are more specialized and require forest cover (Christian et al., 1618 1619 1998). If understory plants become prevalent in SRWC plantations, species diversity can increase due to increases in habitat complexity (Christian et al., 1998). 1620

1621 **3.4.6.2 Invasive Plants**

Like perennial grasses, woody plants cultivated for biofuel feedstock can become invasive. However, because many woody plants have a longer life cycle than many (though not all) grasses, they tend to reproduce and spread more slowly, making the evidence of their invasion and effects on natural areas less immediate. Trees used in forestry can sometimes be highly invasive, negatively affecting biodiversity and water availability (Richardson, 1998).

1627 Proposed SRWCs, such as willow or poplar, are native or hybrids of natives in the U.S., but Eucalyptus species, which are non-native, may pose an invasive risk. Eucalyptus is an 1628 1629 important genus of forestry plants worldwide, and its future development as a biofuel feedstock 1630 in plantations has been discussed for Florida (Rockwood et al., 2008). Several species of 1631 *Eucalyptus*, including *E. globulus* and *E. grandis*, have been introduced to Florida and bred 1632 conventionally and using biotechnology for traits like cold tolerance. The intent is to expand 1633 their future cultivated range to include much of the Southeast. While introduced Eucalyptus or 1634 their improved varieties have not become invasive in the Southeast, E. globulus is a listed 1635 invasive plant in California, and recently, several cultivars of *E. grandis* were found to be 1636 potentially invasive by the Institute of Food and Agricultural Science at the University of Florida 1637 and are recommended for planting only under limited conditions. Reassessment of the species 1638 will take place again in two years after continued monitoring for invasion.

1639 **3.4.7** Assessment

Current environmental impacts of production and use of woody biomass as a biofuel 1640 1641 feedstock are negligible, since no large-scale, commercial operations are yet in existence to 1642 create demand for this feedstock. However, estimates suggest that the potential for biofuels made 1643 from woody biomass is substantial, with predominant sources coming from forest harvest 1644 residues, thinning, and SRWCs. Of these, the removal of harvesting residues from logging sites 1645 is likely to have the most negative impacts on soil and water quality. Complete removal of 1646 residues poses the risk of increased nutrient and sediment losses to waterways, and decreased plant nutrient availability and forest productivity. In comparison, moderate thinning regimes will 1647 1648 have relatively few impacts on soil and water quality, particularly on stable slopes and finer-1649 textured soils.

1650 The environmental effects of SRWCs as a source of woody biomass are more complex, since these require a shift in land use/land cover type. In general, SRWCs are expected to result 1651 1652 in lower nutrient and sediment loads to surface waters relative to that of row crops, especially 1653 once the canopy is established. Woody biomass species require fewer inputs of fertilizer and pesticides, resulting in reduced runoff of these substances into surface and ground water. Woody 1654 biomass production requires considerable water use, but if undertaken in appropriate regions 1655 1656 with adequate water supplies, water quality benefits may outweigh possible water availability 1657 drawbacks.

1658

3.4.7.1 Key Uncertainties and Unknowns

1659 Woody biomass is not yet converted to biofuel on a large-scale; this creates 1660 considerable unknowns and uncertainties when projecting the potential 1661 environmental effects, both positive and negative, of this feedstock. 1662 1663 Specific environmental impacts will vary, depending on soil type, soil chemistry, • topography, climate, and other factors (e.g., the land use SRWCs would replace). 1664 1665 1666 Lack of information about the amount and relative proportion of woody biomass that would come from harvest residues, thinning, and SRWCs to support large-1667 scale operations creates substantial uncertainty. The potential effects of harvest 1668 1669 residues and thinning are easier to assess because a body of literature from other forestry applications does exist. Even so, uncertainties arise from variations in the 1670 percent of residues removed during harvesting and in the degree of thinning, 1671 which can range from small to large proportions of the existing stand. 1672 1673 1674 Quantifying impacts of SRWCs to ecosystems and biodiversity will depend on • 1675 knowing where and under what agronomic conditions SRWCs are grown and how 1676 they are managed. Uncertainty about these factors limits understanding of the potential impacts of this feedstock. For example, it is not known whether repeated 1677 removal of biomass from SRWCs will deplete soil nutrients over the long term, 1678 1679 particularly on marginal soils. 1680
1681 **3.5** <u>Algae</u>

1682 **3.5.1** Introduction

Algae are of interest as a biofuel feedstock because of their high oil content, low water demand, ability to recycle waste streams from other processes, and ability to grow on marginal lands (EPA, 2010b). Algae production demands much less land area per gallon of fuel produced compared to most other feedstocks.

1687 Research and pilot studies have shown that the lipids and carbohydrates in microalgae¹⁹ 1688 can be refined and distilled into a variety of biodiesel- and alcohol-based fuels, including diesel, 1689 ethanol, methanol, butanol, and gasoline. Algae also have the potential to serve as feedstock for 1690 other types of fuels, including bio-oil, bio-syngas, and bio-hydrogen. This section focuses on the 1691 use of algae for biodiesel, because biodiesel is the most likely near-term pathway for algal use as 1692 biofuel.

1693 There are many different types of algae, methods to cultivate them, and processes to recover oil from them. Algae grown photosynthetically are limited to growth during daylight 1694 1695 hours and require carbon dioxide. Heterotrophic algae, which do not utilize photosynthesis, can 1696 be grown continuously in the dark, but require a fixed carbon source such as sugars because they 1697 cannot use carbon dioxide directly (Day et al., 1991). Cultivation of algae feedstocks can take place in photobioreactor facilities with closed-cycle recirculation systems or in open-system-1698 1699 style impoundments. Open systems use pumps and paddle wheels to circulate water, algae, and nutrients through shallow, uncovered containments of various configurations. Closed systems 1700 employ flat plate and tubular photobioreactors and can be located outdoors or indoors. Variations 1701 1702 include hybrid (combined open and closed) cultivation and heterotrophic cultivation (which uses organic carbon instead of light as an energy source). Different algae cultivation strategies are 1703 being studied to determine which is most suitable for supporting large-scale biofuel production 1704 1705 (Chisti, 2007; U.S. EPA, 2010b).

Harvesting requires that the algae be removed, dewatered, and dried. Dewatering is
usually done mechanically using a screw press, while drying can use solar, drum, freeze, spray,
or rotary techniques (NRDC, 2009). After harvesting, the biofuel production process begins
when oil is extracted from the algae through chemical, mechanical, or electrical processes (U.S.
EPA, 2010b, p. 61). Algal oil can then be refined with the same transesterification process used
for other biofuel feedstocks such as soybeans.

- While the different methods of algae cultivation and recovery will clearly have very
 different environmental impacts, such as energy consumption and chemical use and disposal, it is
 premature to draw definitive conclusions about these impacts, given the nascent state of
- 1715 cultivating algae for biofuel.

¹⁹ The term "microalgae" refers to photosynthetic and heterotrophic organisms too small to be easily seen with the naked eye—distinguished from macroalgae, otherwise known as seaweed. Macroalgae is generally not grown as an energy crop. In this report the terms "algae" and "microalgae" are used interchangeably.

1716 **3.5.1.1 Current and Projected Cultivation**

1717 Land use consideration is one of the primary drivers behind interest in algae as a biomass 1718 feedstock. Relative to other feedstock resources, algal biomass has significantly higher 1719 productivity per cultivated acre. For example, meeting half the current U.S. transport fuel 1720 demand with soybean-based biodiesel would require an arable land area in excess of 300 percent of the area of *all* 2007 U.S. cropland, while the land area required to meet those same fuel needs 1721 1722 using algal biodiesel would be less than 3 percent of all U.S. cropland in 2007 (Chisti, 2007). Moreover, algae cultivation does not require arable land. Algae's lack of dependence on fertile 1723 soil and rainfall essentially eliminates competition among food, feed, and energy production 1724 1725 facilities for land resources (Muhs et al., 2009). Because algae-based biofuel production facilities do not require specific land types, they may be sited closer to demand centers, reducing the need 1726 1727 to transport significant quantities of either biofuel or feedstock from one region of the country 1728 (e.g., the Midwest) to another (e.g., coastal population centers).

1729 Proximity to input sources, such as carbon dioxide sources, and output markets, as well 1730 as the availability of affordable land, will likely drive algae production facility siting decisions. The U.S. Southwest is viewed as a promising location for economic algae-to-biofuel cultivation 1731 due to the availability of saline ground water, high exposure to solar radiation, and low current 1732 1733 land use development. Based on pilot studies and literature on algae cultivation, likely areas for 1734 siting algae-based biofuels facilities also include coasts, marginal lands, and even co-location 1735 with wastewater plants (Sheehan et al., 2004; U.S. EPA, 2010b). Algae grown in conjunction 1736 with animal and human wastewater treatment facilities can reduce both freshwater demands and 1737 fertilizer inputs, and may even generate revenue by reducing wastewater treatment costs. U.S. 1738 companies are already using wastewater nutrients to feed algae in intensively managed open 1739 systems for treatment of hazardous contaminants (Munoz and Guieysse, 2006).

1740**3.5.1.2Overview of Environmental Impacts**

1741 Algae-based biofuel production systems are still being investigated at the pilot stage 1742 using smaller-scale prototype research facilities. Evaluating the potential environmental and 1743 resource impacts of full-scale production is highly uncertain because much of the current 1744 relevant data is proprietary or otherwise unavailable, and many key parameters are unknown, 1745 including where and how algae will be produced and what species and strains of algae will be 1746 used as feedstocks.

Algae cultivation can require the use of pesticides, fertilizers, water, and fuel. Each of
these activities, in turn, can impact air quality, water quality, and water availability. (Soil quality
is not a concern.) In addition to these impacts, there is potential for invasive algae strains to
escape from cultivation (NRDC, 2009). Industrial oil extraction and biodiesel production,
biodiesel and byproduct transport and storage, and biodiesel and byproduct end use also entail
environmental impacts, which are discussed further in Chapter 4.

1753 3.5.2 Water Quality

1754 Scaled production of algae oil for biofuels has not yet been demonstrated; therefore, 1755 water quality impacts associated with large-scale use of algae-based biofuels are currently speculative. Wastewater is a key factor influencing water quality impacts of algae production

- 1757 facilities, including whether wastewater is used as a water source for algae cultivation, and
- 1758 whether wastewater is discharged from the algae cultivation site. According to the National
- 1759 Resources Defense Council, wastewater from the dewatering stages of algae production could be 1760 released directly, sent to a treatment unit and released, or recycled back as make up water,
- depending on the process (NRDC, 2009). Depending on the treatment requirements, release of
- wastewater could potentially introduce chemicals, nutrients, additives (e.g., from flocculation),
- and algae, including non-native species, into receiving waters.

1764 Co-locating algae production facilities with wastewater treatment plants, fossil fuel 1765 power plants, or other industrial pollution sources can improve water quality and utilize waste heat that contributes to thermal pollution, while reducing freshwater demands and fertilizer 1766 1767 inputs (Baliga and Powers, 2010; Clarens et al., 2010). By co-locating these facilities, partially 1768 treated wastewater acts as the influent to the algae cultivation system. Algae remove nutrients as 1769 they grow, which improves the quality of the wastewater and reduces nutrient inputs to receiving 1770 waters. If fresh water or ground water is used as the influent, nutrients must be added artificially 1771 in the form of fertilizer.

1772 Significant environmental benefits could be associated with the ability of algae to thrive 1773 in polluted wastewater. Algae can improve wastewater quality by removing not only nutrients, 1774 but also metals and other contaminants, and by emitting oxygen. Thus, algae can effectively 1775 provide some degree of "treatment" for the wastewater (Darnall et al., 1986; Hoffmann, 1998).

- 1776 3.5.3 Water Quantity
- 1777 **3.5.3.1 Water Use**

1778 Water is a critical consideration in algae cultivation. Factors influencing water use 1779 include the algae species cultivated, the geographic location of production facilities, the 1780 production process employed, and the source water chemistry and characteristics. Estimates for water consumption vary widely, ranging from 25 to 974 gallons of water per gallon of biodiesel 1781 1782 produced (U.S. EPA, 2010b). EPA has estimated that an open-system-type biofuel facility 1783 generating 10 million gallons of biofuel each year would use between 2,710 and 9,740 million gallons of saline water each year; a similar scale photobioreactor-type facility would use between 1784 1785 250 and 720 million gallons of saline water annually (U.S. EPA, 2010b, Table 2.4-56, p. 426).

1786 The harvesting and extraction processes also require water, but data on specific water 1787 needs for these steps are limited (U.S. EPA, 2010b). Compared to the water required for algae 1788 growth, however, demands are expected to be much lower.

1789 **3.5.3.2 Water Availability**

Depending on the cultivation system, algae production could exacerbate or create water availability problems, especially in promising locations like the Southwest, which are already experiencing water shortages. However, the water used to grow algae does not have to be highquality fresh water. Algae can thrive in brackish water, with salt concentrations up to twice that of seawater (U.S. EPA, 2010b), as well as in contaminated wastewater such as agricultural, animal, or municipal effluent; or even coal, pharmaceutical, or metal plating wastewater (NRDC, 1796 2009). Thus, competition for freshwater resources may be mitigated by siting facilities in areas1797 that can provide suitable brackish or wastewater sources.

In addition to the water quality benefits described above, co-locating algae production facilities with wastewater treatment plants can reduce water demands (Clarens et al., 2010). The water availability impacts of algae production for biofuel can also be mitigated in large part using photobioreactors, which require less water and land area than open systems (U.S. EPA, 2010b, Table 2.4-56, p. 426).

1803 3.5.4 Soil Quality

1804 Very little peer-reviewed literature exists on the soil impacts of algae production because
1805 these impacts are likely to be negligible and have therefore not been the subject of much study.
1806 Presumably, the primary mechanism affecting soil quality would be transport and migration into
1807 soil of wastewater, particularly highly salinated wastewater, that has been released into
1808 freshwater ecosystems (NRDC, 2009).

1809 3.5.5 Air Quality

1810 The effects of algae-based biofuels on air quality have received little attention to date in 1811 peer-reviewed literature. As a result, additional research is needed to determine whether anything 1812 unique to algae production processes would raise concern about air emissions.

1813 Open or hybrid open systems appear to have greater potential to impact air quality compared to enclosed photobioreactors, given the highly controlled nature of the latter systems. 1814 No studies are yet available, however, to characterize or quantify emissions associated with open 1815 systems used to produce algae for biofuel. Studies have measured air emissions of open-system 1816 algae ponds that are part of wastewater treatment systems (Van der Steen et al., 2003), but these 1817 1818 studies may have very limited applicability to open systems for commercial-scale production of 1819 algae oil for biodiesel. Additional research will be required to estimate and characterize 1820 emissions from pumping, circulation, dewatering, and other equipment used to produce algae for 1821 biofuel.

1822 3.5.6 Ecosystem Impacts

1823 **3.5.6.1 Biodiversity**

1824 Algal production has fewer biodiversity impacts than production of other feedstocks because algae typically require less fertilizer, pesticide, and water than do other feedstocks, and 1825 1826 because algal production plants may be co-located with wastewater treatment plants. As mentioned above, the location of algae production facilities will be a key factor affecting the 1827 potential for impacts. Using wastewater to capture nutrients for algal growth could help reduce 1828 1829 nutrient inputs to surface waters (Rittmann, 2008). Algae also require low inputs of fertilizers and pesticides compared to other feedstocks, which may translate into fewer ecological impacts 1830 to aquatic ecosystems (Groom et al., 2008). Production facilities for algae that need sunlight to 1831 1832 grow could be located in arid regions with ample sunlight (Rittmann, 2008); however, growing 1833 algae in areas with limited water resources could impact the amount of water available for the 1834 ecosystem because of draws on ground water. It is unknown what impacts an accidental algae

release might have on native aquatic ecosystems, particularly if the algae released have been artificially selected or genetically engineered to be highly productive and possibly adaptable to a

- artificially selected or genetically engineered to be highly productive and possibly adaptable to range of conditions.
- 1838 **3.5.6.2** Invasive Algae

1839 The potential for biofuel algae to be released into and survive and proliferate in the 1840 environment is, at present, highly uncertain. This potential will vary, depending on what species 1841 and strains of naturally occurring, selectively bred, or genetically engineered algae are used and 1842 how they are cultivated.

1843 The risk of algae dispersal into the environment is much lower in closed bioreactor 1844 systems than open system production, though unintentional spills from bioreactors in enclosed 1845 production facilities are possible. High winds blowing across open systems may carry algae long distances, depositing them in water bodies, including wetlands, near and far. Designers of coastal 1846 1847 algae production plants must take into account hurricanes and other severe storms that could disperse algae over large areas. Wildlife, including birds, may also disperse algae. Closed 1848 1849 systems, in addition to limiting algae dispersal, have the benefit of protecting algal media from 1850 being contaminated with other microbes, which could compete with the cultivation strains for 1851 nutrient resources

1852 Effluent from algal biomass dewatering processes may contain residual algae, which 1853 could thrive in receiving waters. Treatment strategies will need to be developed to prevent algae 1854 in effluent from contaminating the surrounding ecosystem.

The ability of cultivated algae to survive and reproduce in the natural environment is unknown: one theoretical study suggests that some, but not all, strains with the most desirable commercial characteristics would be out-competed by native algae (Flynn et al., 2010). Further empirical work is critical to determine competitive and hybridizing abilities of biofuel algae in the natural environment and to measure possible effects on algal community dynamics and ecosystem services.

- 1861 **3.5.7** Assessment
- 1862**3.5.7.1**Current and Future Impacts

1863 With the exception of nutrients, open system cultivation requires far more resources than 1864 photobioreactor systems. Regardless which type of system is used commercially, future increases 1865 in production of algal biomass have the potential to impact water availability and quality, air 1866 quality and atmospheric climate, and ecosystem health and biodiversity. However, due to the 1867 lack of data on commercial-scale algal biofuel production processes, it is uncertain what these 1868 impacts will be.

In some cases, the algal production process could prove environmentally beneficial. For example, use of wastewater effluent, particularly partially treated wastewater, to cultivate algae provides benefits of removing nutrients from the wastewater and reduces the environmental impact of the production process. Combining commercial-scale algae production facilities with 1873 wastewater treatment plants may therefore create synergies that increase algae yields while1874 decreasing environmental impacts of both facilities.

1875 Key points to understanding the potential environmental impacts of using algae for1876 biofuel production are described below.

1877 <u>Water Quality</u>: The water quality impacts of algal biofuel production will depend on both 1878 the source of water used for cultivation and the quality of the water released from the production 1879 facility. Algae production facilities co-located with water treatment plants, fossil fuel power 1880 plants, or other industrial sources of pollution could have a positive impact on water quality. 1881 However, release of wastewater from an algal biofuel production process—especially salinated

1882 wastewater released into a freshwater environment—could adversely affect water quality.

1883 <u>Water Quantity</u>: Water is an important input in the algae cultivation process; increased 1884 production of algal biofuels will impact water availability, especially in areas where water is 1885 already scarce. However, algae may be less water intensive than other feedstocks. Moreover, 1886 because algae can thrive in brackish and untreated waters, they are an ideal feedstock for water-1887 stressed locations.

1888 <u>Soil Quality</u>: Soil quality impacts are likely to be minimal, based on existing studies.

<u>Air Quality</u>: Little is known about how algal biofuel production will affect air quality.
 However, preliminary data suggest that open system cultivation systems have a greater potential
 than photobioreactor systems to adversely affect air quality.

Ecosystem Health/Biodiversity: Little is known about how increases in algal biofuel production might affect biodiversity. Because algae demands substantial amounts of water, its cultivation could adversely impact native species in water-stressed locations. Compared with other feedstocks, however, algae is not water intensive. Also unknown are what impacts an accidental release of algae might have on native aquatic ecosystems. Algae require low inputs of fertilizers and pesticides compared to other feedstocks, which may also translate into fewer ecological impacts to aquatic ecosystems

1899 <u>Invasive Species</u>: The ability of cultivated algae to escape into and survive in the natural 1900 environment is uncertain. Experts speculate that photobioreactor cultivation systems would be 1901 superior to open systems in preventing the escape of cultivated algae.

1902

3.5.7.2 Key Uncertainties and Unknowns

- Most of the uncertainties related to the production of algae for biodiesel stem
 from a lack of knowledge about which technologies may be used in future
 commercial applications, where they will be located, and what species and strains
 of algae will be used.
- Water availability impacts from feedstock growth will depend on where the algae are grown, if open or closed systems are used, and whether water is recycled.
 - This document is a draft for review purposes only and does not constitute Agency policy.1/19/113-53DRAFT—DO NOT CITE OR QUOTE

1911 **3.6 Waste-Based Feedstocks**

1912 3.6.1 Introduction

Diverse wastes, including construction debris, municipal solid waste (MSW), yard waste, food waste, and animal waste, have the potential to serve as biofuel feedstocks. Depending on the waste, conversion system, and product, potential exists for municipalities, industries, and farmers to transform a material with high management costs to a resource that generates energy and profits. In some instances, diverting waste that cannot be recycled or reused to fuel has been found to reduce land-filled materials by 90 percent, helping to also extend the lifetime capacity of the landfill (Helou et al., 2010).

1920 Tapping into waste energy sources has many challenges, including dispersed locations 1921 and potentially high transport costs; lack of long-term performance data; the cost of converting 1922 waste to energy, and the possibility that the resulting biofuel might not meet quality or regulatory 1923 specifications for use (Bracmort and Gorte, 2010).

1924 Use of wastes as biofuel feedstocks will vary based on their availability, the ability of 1925 conversion technologies to handle the material, and the comparative economics of their use for 1926 fuel versus power and other products. Types and quantities of wastes used will vary by region. A large number and variety of waste-based materials are being investigated and implemented as 1927 feedstocks for ethanol and biodiesel, mostly on local scales. For example, several states-e.g., 1928 Massachusetts (Advanced Biofuels Task Force, 2008; Timmons et al., 2008), California (Chester 1929 et al., 2007), and Ohio²⁰—have explored waste availability and its potential to meet regional 1930 1931 energy needs, either for power or for transportation fuel. Feedstocks may be converted to biofuel 1932 or used as an energy source to power a biorefinery.

1933 3.6.2 Municipal Solid Waste

1934 The biogenic portion of municipal solid waste (paper, wood, yard trimmings, textiles, and 1935 other materials that are not plastic- or rubber-based), has the potential to be a significant 1936 feedstock for ethanol and other biofuels. Using 2005 data, the U.S. Energy Information 1937 Administration calculated that 94 million tons (MT) (about 56 percent) of the 167.8 MT of MSW 1938 waste generated that year had biogenic BTU content (EIA, 2007). This estimate included food 1939 waste (the third largest component by weight), which is also potentially viable as a biofuel 1940 feedstock in addition to biogenic material listed above. Some producers claim to have 1941 thermochemically-based technology that can yield 120 gallons of ethanol per ton of MSW, and 1942 therefore, this could serve as a rough MSW yield estimate. (Fulcrum Bioenergy, 2009). 1943 Accepting this estimate, the 94 MT of biogenic MSW generated in the U.S. in 2005 would have 1944 the potential to generate up to 11 billion gallons of ethanol. While this is not a likely scenario (since, for example, some of the biogenic fraction-paper, wood, etc.-would be recycled or 1945 1946 reused), it demonstrates that MSW could be a significant source for biofuel. In addition, there are 1947 significant environmental co-benefits associated with using MSW for biofuel, including

²⁰ Specifically, a partnership between the Solid Waste Authority of Central Ohio and Quasar Energy Group to produce ethanol from municipal solid waste (see http://www.quasarenergygroup.com/pages/home.html), as well as the "Deploying Renewable Energy—Transforming Waste to Value" grant program (see: http://www.biomassintel.com/ohio-10-million-available-waste-to-energy-grant-program/).

diverting solid waste from landfills and incinerators, extending their useful life, and reservingthat capacity for materials that cannot be recycled or reused.

1950 3.6.3 Other Wastes

1951 Several types of waste materials that currently present environmental and economic 1952 challenges have the potential to be harnessed as feedstock for biofuel. These materials include 1953 waste oil and grease, food processing wastes, and livestock waste (Antizar-Ladislao and Turrion-1954 Gomez, 2008; Helou et al., 2010).

- 1955 The U.S. Department of Energy estimates that the restaurant industry generates 9 pounds 1956 of waste oil per person annually, and that the nation's wastewater contains roughly 13 pounds of 1957 grease per person per year (Wiltsee, 1998). Several municipalities and industries have 1958 implemented collection programs, and are converting these wastes to biodiesel.
- Annually, the U.S. generates an estimated 48 million tons of food processing wastes (i.e.,
 food residues produced during agricultural and industrial operations), not including food waste
 disposed and processed through wastewater treatment plants (Kantor et al., 1997). These wastes
 have potential a biofuel feedstocks.
- 1963 The U.S. generates over 1 billion tons of manure, biosolids, and industrial by-products 1964 each year (ARS, n.d.). The amount of manure generated at confined and other types of animal 1965 feeding operations in the U.S. is estimated to exceed 335 million tons of dry matter per year (ARS, n.d.). While much of this manure is applied to cropland and pasture as fertilizer, excess is 1966 1967 often available and could be tapped as a biofuel feedstock. It has been estimated that around 10 percent of current manure production could be used for bioenergy purposes under current land 1968 1969 use patterns once sustainability concerns are met (i.e., this manure is available after primary use 1970 of manure on soils to maintain fertility) (Perlack et al., 2005). Methane emissions from livestock 1971 manure management systems, which account for a significant percentage (10 percent, or 17.0 million metric tonnes of carbon equivalent [MMTCE] [3.0 teragrams, or Tg] in 1997) of the total 1972 1973 U.S. methane emissions, are another potential energy source (U.S. EPA, 1999).
- 1974 Using any of these excess waste materials as biofuel feedstocks has potential to create a1975 higher value use with significant environmental and economic benefits.

1976 3.6.4 Environmental Impacts of Waste-Based Biofuel

- 1977 Waste-based biofuels are expected to have both environmental benefits and impacts. On 1978 the positive side, for example, diverting waste from landfills avoids generation of landfill 1979 methane gases, and diverting waste and trap greases from wastewater treatment plants helps 1980 avoid costly plant upsets that contribute to combined sewer overflow. Biorefineries that use 1981 wastes, particularly MSW, tend to be located in proximity to the waste source, which correlates 1982 well with the densely populated end-users of transportation fuels and helps reduce the GHG 1983 lifecycle footprint of waste-derived fuels (Antizar-Ladislao and Turrion-Gomez, 2008; Williams 1984 et al., 2009).
- 1985 More information is needed to understand and evaluate the environmental effects of 1986 waste-based biofuels. Different wastes have different characteristics, including size, volume,

1987 heterogeneity, moisture content, and energy value. These characteristics will, to a large degree,

- determine feasible and appropriate collection, processing, and conversion methods, which in turn
- 1989 will determine net energy gain, as well as environmental impacts such as air and GHG
- emissions. Research is needed to compare the benefits and impacts of various technologicaloptions for converting MSW to biofuel, and to compare, on a regional basis, the environmental
- benefits and impacts of MSW to other biofuel feedstocks. Currently, data are lacking for such
- 1992 comparisons. Comparative life cycle assessments that consider both the direct impacts or
- benefits and indirect impacts or benefits (e.g., impacts of reduced landfilling of MSW) are
- 1995 needed to understand the true value of waste as an alternative feedstock.
- 1996 Assessment and Uncertainty

1997 There have been comparatively few attempts at assessing the environmental impacts 1998 associated with the production and use of waste-based biofuels (Williams et al., 2009). In 1999 general, waste as a feedstock is expected to have a smaller environmental impact than 2000 conventional feedstocks. However, the choice of waste management options and the particular 2001 technology for energy recovery will influence the environmental medium impacted and the level of impact (Chester and Martin, 2009; Kalogo et al., 2007). As the number of waste conversion 2002 2003 facilities increases, environmental monitoring and research will be needed to address the 2004 information gaps that currently limit environmental assessment.

2005 3.7 <u>Summary of Feedstock-Dependent Impacts on Specialized Habitats</u>

EISA Section 204 requires an assessment of the impacts of biofuels on a variety of environmental and resource conservation issues, including impacts on forests, grasslands, and wetlands. This section provides an overview of impacts on these specific habitats.

2009 3.7.1 Forests

2010 Woody biomass is the feedstock most likely to affect forests; row crops, algae, and most 2011 perennial grasses are unlikely to have an impact on this habitat.

2012 Section 211(o) of the Clean Air Act limits planting of short-rotation woody crops and 2013 harvesting of tree residue to actively managed tree plantations on non-federal land that was 2014 cleared prior to December 19, 2007, or to non-federal forestlands; and limits removal of slash 2015 and pre-commercial thinning to non-federal forestlands. However, as described in Table 3-5, a 2016 variety of activities associated with producing woody biomass feedstock may impact forests.

Feedstock	Forest Impact	Report Section
Row Crops	Unlikely to have impacts.	
Perennial Grasses	Most grass species are unlikely to have impacts.	3.3.6.2
Woody Biomass	SRWC plantations may deplete soil nutrients with repeated, frequent harvesting, particularly on marginal soils, but may sustain levels with coppicing, longer-rotations, and strategic use of cover crops.	3.4.4.3
	SRWC plantations can sustain high species diversity, although bird and mammal species tend to be habitat generalists.	3.4.5.1
	Some tree species under consideration, like <i>Eucalyptus</i> , may invade forests in certain locations.	3.4.5.2
	Harvesting forest residues may decrease nutrient availability, soil organic matter, and woody debris available for species habitat.	3.4.4.2; 3.4.4.3; 3.4.6.1
Algae	Unlikely to have impacts.	

Table 3-5: Overview of Impacts on Forests from Different Types of Biofuel Feedstocks

2018

2019 3.7.2 Grasslands

2020 Production of row crops and perennial grasses for biofuel feedstocks can impact 2021 grasslands, although perennial grasses may also have some positive effects on grasslands.

2022 In addition to the restrictions on forested sources of renewable biomass mentioned above, 2023 Section 211(0) of the Clean Air Act more broadly limits the lands on which any biofuel 2024 feedstock can be produced to those that were cleared or cultivated at any time prior to December 19, 2007, either in active management or fallow and non-forested. Therefore, grassland that 2025 remained uncultivated as of December 19, 2007, may not be converted to grow biofuel. Most of 2026 2027 lands that would be eligible for renewable biomass production under the Clean Air Act, because 2028 they were cultivated at some point prior to December 19, 2007, are now part of the Conservation 2029 Reserve Program (see Section 3.2.1.1). The USDA estimates that the vast majority (78 percent) of lands that will be taken out of the CRP to grown biofuel feedstock will be grasslands (FSA, 2030 2031 2008). Therefore, conversion of CRP lands to grow biofuels will impact grassland ecosystems, as 2032 will other aspects of biofuel feedstock production (Table 3-6).

Feedstock	Grasslands Impact	Report Section
Row Crops	Conversion of grasslands to row crops impacts grassland-obligate species, potentially leading to declines, including declines in duck species.	3.2.6.1
	Higher proportions of corn within grassland ecosystems leads to fewer grassland bird species.	3.2.6.1
Perennial Grasses	Conversion of row crops to switchgrass may improve grassland habitat for some species depending on management regimes.	3.3.6.1
	Conversion of CRP lands to perennial grasses or harvesting of existing grasslands is less likely to have negative impacts on grassland species, particularly if harvesting occurs after the breeding season.	
	Use of native mixtures of perennial grasses can restore some native biodiversity.	3.3.6.1
	Cultivation of switchgrass outside its native range may lead to invasions of native grasslands.	3.3.6.2
	Cultivation of Miscanthus may lead to invasions of pasture and other grasslands.	3.3.6.2
Woody Biomass	Unlikely to have impacts.	
Algae	Depends on siting.	

Table 3-6: Overview of Impacts on Grasslands from Different Types of Biofuel Feedstocks

2034

2035 3.7.3 Impacts on Wetlands

Provisions in both the Food Security Act of 1985 (commonly known as the Swampbuster Program) and Clean Water Act (Section 404 Regulatory Program) offer disincentives that limit the conversion and use of wetlands for agricultural production. Nevertheless, impacts to wetlands are still expected from the feedstocks assessed in this report (Table 3-7).

Table 3-7: Overview of Impacts on Wetlands from Different Types of Biofuel Feedstocks

Feedstock	Wetlands Impact	Report Section
Row Crops	Increased sediment, nutrients, chemicals, and pathogens from runoff flow into downstream wetlands.	3.2.2
	Increased nutrient loadings, leading to changes in wetlands community structure.	3.2.2.1
Perennial Grasses	Reduced sediment and nutrient loadings, leading to improved water quality (but dependant on specific management practice).	3.3.2.1
	Some grass species under consideration may invade wetlands, including giant reed (<i>Arundo donax</i>) and reed canary grass (<i>Phalaris arundinacea</i>).	3.3.6.2
Woody Biomass	Harvesting forest residues and thinning may increase nutrient loads, depending on slopes, soils, any buffer zones, and use of best management practices to reduce runoff.	3.4.2.1
Algae	Algal strains created may escape from cultivation and invade wetlands. As noted in Section 3.5.2, use of algae for biofuel may also have positive impacts: Co-locating algae production facilities with wastewater treatment plants, fossil fuel power plants, or other industrial pollution sources can improve water quality and utilize waste heat that would otherwise contribute to thermal pollution, while reducing freshwater demands and fertilizer inputs.	3.5.6.2

2041 **3.8** <u>Genetically Engineered Feedstocks</u>

2042 Genetic engineering of crops has a history of research, development, and 2043 commercialization that extends back for more than 15 years. Along with the growth of this 2044 biotechnology industry, the U.S. established a coordinated framework for regulatory oversight in 2045 1986 (OSTP, 1986). Since then, the relevant agencies (EPA, USDA, and Food and Drug 2046 Administration) have implemented risk assessment programs that allow informed environmental 2047 decision-making prior to commercialization. These programs have been independently assessed 2048 over the years (NRC, 2000, 2001, 2002) and improvements made to ensure the safety of the products. At the same time, the methodology for biotechnology risk assessment has been 2049 2050 scrutinized and general frameworks created to facilitate robust approaches and harmonize the 2051 processes internationally (Craig et al., 2008; Auer, 2008; Nickson, 2008; Romeis et al., 2008; 2052 Raybould, 2007; Andow and Zwalen, 2006; Conner et al., 2003; Pollard et al., 2004). This 2053 section describes environmental concerns associated with Genetically Modified Organisms 2054 (GMOs) that are currently used as biofuel feedstocks, as well as anticipated concerns for GMOs 2055 that will be developed for the next generation of biofuel feedstocks.

2056 As indicated earlier in this chapter, great advantage has already been taken for genetically engineered corn and soybean, which are now grown worldwide, along with other engineered 2057 2058 crops. Brookes and Barfoot have conducted a series of extensive post-commercialization 2059 assessments of genetically engineered maize, soybeans, cotton, sugar beets, and canola varieties 2060 at 10-year intervals (Brookes and Barfoot, 2006, 2008, 2009, 2010). In these analyses, the 2061 authors found consistent reductions in the amounts of pesticides used and a reduction in GHG 2062 emissions for agricultural systems where these GMO crops are grown. These results are supported by others (Brinmer et al., 2005; Knox et al., 2006), although regional differences in the 2063 reductions have been noted (Kleter et al., 2008). The results for corn and soybean independently 2064 are consistent with the general trends (Brookes and Barfoot, 2010). Assuming that current 2065 genetically engineered varieties of corn and sovbeans receive continued regulatory oversight, no 2066 2067 additional environmental concerns are anticipated with these organisms in their current genetic 2068 configuration, even with an increase in their production. However, as feedstocks for biofuel 2069 change to accommodate cellulosic technologies and algae production, the range of environmental 2070 considerations, including impacts from GMO varieties, will change as well (Wilkinson and 2071 Tepfer, 2009; Lee et al., 2009).

2072 To harness the full potential of biomass, the genetic engineering of feedstocks has been 2073 recognized as a key technology (Gressel 2008; Antizar-Ladislao and Turrion-Gomez, 2008; Sexton et al., 2009). The approaches being considered include increasing plant biomass by 2074 2075 delaying flowering, altering plant growth regulators, and manipulating photosynthetic processes; 2076 modifying traits (e.g., herbicide tolerance, insect resistance) in non-row crop plants that reduce 2077 cultivation inputs: and modifying cellulose/lignin composition and other traits that result in cost reductions in bioprocessing (i.e., facilitating the biorefinery process) (Sticklen 2007, 2009; 2078 2079 Ragauskas et al., 2006; Gressel 2008). These new varieties may have implications for the 2080 environment beyond what has been considered in first generation biotechnology crops, and the 2081 scientific community has begun to examine whether and how well existing risk assessment 2082 procedures will work for bioenergy crops (Wolt, 2009; Chapotin and Wolt, 2007; Wilkinson and Teper, 2009; Firbank 2007; Lee et al. 2009). For example, some first attempts have been made at 2083

- 2084 evaluating feedstocks with particular traits; suggestions for minimizing environmental impacts
- are incorporated (Kausch et al., 2010a, 2010b).

1 4. **BIOFUEL PRODUCTION, TRANSPORT, STORAGE AND END USE**

2 4.1 <u>Introduction</u>

This chapter addresses potential environmental impacts of post-harvest activities of the biofuel supply chain (see Figure 4-1). These activities comprise feedstock logistics (discussed in Section 4.2) and biofuel production (Section 4.3), distribution (Section 4.4), and end use (Section 4.5).

Production of biofuel from feedstock takes place at biofuel production facilities through a variety of conversion processes. The resulting biofuel is transported to blending terminals and retail outlets by a variety of means, including rail, barge, tankers, and trucks. Biofuel distribution almost always includes periods of storage. Once dispensed at the final outlet, biofuel is combusted in vehicles and other types of engines, usually as a blend with gasoline or diesel, or in some cases in neat form.

Biofuel production, distribution, and end use result primarily in impacts to air and water.
 Air emissions may be released by a variety of sources (see Figure 4-1). Many factors affect the

15 quantity and characteristics of these emissions, including the type and age of equipment used,

16 and operating practices and conditions.



17

Figure 4-1: Sources of Criteria Air Pollutant and Toxics Emissions Associated with Production and Use of Biofuel

Air emissions associated with end use of ethanol combustion are relatively independent
 of feedstock or conversion process, whereas biodiesel emissions are highly dependent on

22 feedstock type. As discussed later in the chapter, biofuel combustion may result in higher

emissions of some pollutants compared to gasoline combustion, and lower emissions of others.

Biofuel production may require use of water, which may contribute to ground water depletion or lower surface water flow, depending on the amount of water withdrawn and water availability. Potential water quality impacts include wastewater discharge during the conversion process and the potential for leaks and spills to surface and groundwater during biofuel handling, transport, and storage. Additionally, phosphorus runoff from the manure of animals that have been fed an ethanol by-product, dried distillers grains with solubles, which has a high

30 phosphorus content (Regassa et al., 2008), may have the potential to impact water quality.

Possible air and water impacts associated with ethanol and biodiesel, as well as opportunities for mitigation, are discussed in Sections 4.2 to 4.5. Discussion focuses primarily on the impacts of corn ethanol and diesel from soybean, since these constitute the vast majority of biofuel produced and used in the U.S. as of July 2010.

35 4.2 Feedstock Logistics

36 4.2.1 Handling, Storage, and Transport

Feedstock logistics comprise activities associated with handling, storing, and transporting feedstocks after harvest to the point where the feedstocks are converted to biofuel. The most significant environmental impacts of these activities are the emissions associated with energy use. Both greenhouse gases (GHG) and criteria pollutant emissions result from the combustion of fuels used during transportation. In general, feedstock logistics may be optimized, and emissions reduced, by integrating feedstocks, processing facilities, and consumer demands at a regional scale to minimize transport distances.

44 **4.2.1.1 Ethanol**

Harvested corn is transported to a biorefinery where it is converted to ethanol and a
 number of co-products. Air quality will be impacted by emissions from the combustion of fuels
 used for transportation vehicles and equipment.

48 **4.2.1.2 Biodiesel**

49 After harvest, soybeans are transported from fields to the drying site, storehouse, or 50 collection center, followed by transport to the biodiesel refinery. Air quality may be affected by

51 emissions from the combustion of fuels used for transportation vehicles and equipment.

52 4.3 Biofuel Production

53 4.3.1 Biofuel Conversion Processes

54 **4.3.1.1 Ethanol**

68

As of November 2009, there were 180 corn starch ethanol facilities in the U.S. with a combined capacity of 12 billion gallons per year (bgy) (U.S. EPA, 2010b, footnote 250).²¹ At that time, 27 of these (representing 1,400 million gallons per year (mgy) of capacity) were idled, and another 10 facilities, with a combined capacity of 1,301 mgy, were under construction (U.S. EPA, 2010b, p.137). These facilities are located in the major corn-producing region of the country: Iowa (the largest production capacity and the greatest number of plants) followed by Nebraska, Minnesota, Indiana, and Illinois (U.S. EPA, 2010b).

- 62 Conventional ethanol is produced from the fermentation of corn starch. Two methods are 63 currently utilized:
- Dry milling, in which the corn kernel is first ground into a meal, usually without
 separating out the various component parts of the grain. The meal is then slurried
 with water and cooked at high temperatures to form a mash, which then
 undergoes fermentation. Dry milling is more commonly used than wet milling.
- Wet milling, in which the kernels are steeped in water to separate out the germ,
 fiber, and gluten (fractionation). From this initial separation, co-products such as
 corn meal, corn gluten meal, and corn gluten feed are recovered. The remaining
 mash contains the water-soluble starch, which undergoes further processing for
 biofuel.
- In both processes, soluble starch is subsequently converted to a simple sugar (glucose) through saccharification, an enzyme-catalyzed hydrolysis reaction. This is followed by yeast fermentation of the glucose to ethanol. Following fermentation, the mash is distilled to collect the ethanol as a mixture of 95 percent alcohol and 5 percent water. A subsequent dehydration step is required to remove the aqueous portion to yield 99.5 percent pure ethanol.

Substantial efforts are under way to develop processes to convert feedstocks containing
 cellulose into biofuels. These cellulosic feedstocks are primarily composed of cellulose,
 hemicellulose, and lignin polymers. Currently, two major pathways exist for converting
 cellulosic feedstocks into biofuel:

Biochemical conversion using a physical and chemical process to liberate tightly
 bound cellulose and hemicellulose from lignin. The process uses strong acid or
 enzymes (cellulases) to hydrolyze the cellulose and hemicelluloses to glucose and
 other simple sugars, followed by microbial fermentation of the sugars into
 ethanol.

²¹ Sources include the Renewable Fuels Association's Ethanol Biorefinery Locations (updated October 22, 2009) and *Ethanol Producer Magazine*'s producing plant list (last modified on October 22, 2009), in addition to information gathered from producer websites and follow-up correspondence.

89	• Thermochemical conversion involving gasification or pyrolysis.
90 91 92 93 94	In the gasification process, biomass is heated at high temperatures with a controlled amount of oxygen to decompose the cellulosic material. This yields a mixture comprised mainly of carbon monoxide and hydrogen known as syngas.
95 96 97 98 99	— In <i>pyrolysis</i> , the biomass is heated in the absence of oxygen at lower temperatures than used in gasification. The product is a liquid bio-oil that can be used subsequently as a feedstock for a petroleum refinery.
100 101 102 103	Other cellulosic conversion processes are in various stages of development, from concept stage to pilot-scale development, and to demonstration plant construction. Although no U.S. commercial-scale plants are operating as of July 2010, several companies are expected to have facilities operating within the next few years.

104 **4.3.1.2 Biodiesel**

105 As of November 2009, there were approximately 191 biodiesel facilities in the U.S., with 106 a combined capacity of 2.8 billion gallons per year (bgy) (U.S. EPA, 2010b). Total domestic production of biodiesel in 2009 was 505 mgy-much less than domestic production capacity. 107 The dominant technology used to produce biodiesel involves a transesterification reaction in 108 109 which triglycerides (fats) from the oil are converted to esters in the presence of an alcohol and a 110 catalyst, such as potassium hydroxide. Plant oils (soy, rape, palm, algae, etc.) and other feedstocks (e.g., animal-derived oil such as lard and tallow, recycled oil and grease from 111 112 restaurants and food processing plants) provide sources of triglycerides for conversion to 113 biodiesel. Free glycerol, or glycerin, is a major co-product in transesterification, comprising an estimated 10 percent of the final product (U.S. EPA, 2010b). Table 4-1, below shows the 114 115 breakdown of feedstocks used to produce biodiesel in the U.S. in 2009. Soybean oil made up the majority of biodiesel feedstock, comprising 54 percent. 116

|--|

-	Input		2009 Total (lbs.)	Percentage of Total
Feedstock Inputs	Vegetable Oils	Corn Oil	84	2.3%
		Soybean Oil	1,974	54.0%
		Other Vegetable Oil	7	0.2%
	Animal Fats	Poultry Fat	127	3.5%
		Tallow	524	14.3%
	Animal Fats	White Grease	307	8.4%
		Other Animal Fats	82	2.2%
	Recycled	Yellow Grease	156	4.3%
	Feedstock	Other Recycled Feedstock	13	0.4%

	Input	2009 Total (lbs.)	Percentage of Total
Other Inputs	Alcohol	328	9.0%
	Catalysts	56	1.5%

Table 4-1. 2009 Summary of Inputs to U.S. Biodiesel Production

117 Source: EIA, 2010 118

119 Commercial processes for large-scale algae production and algal oil collection are 120 currently being developed as another plant oil source for biodiesel (U.S. EPA, 2010b). Lipid 121 extraction and drying currently are energy-intensive steps in the algae diesel production process. 122 Other processing techniques are currently being investigated, including enzymatic conversion 123 and catalytic cracking of algal oil, pyrolysis, and gasification of algae. However, lipid extraction via solvents followed by transesterification remains the most commonly used method for algal 124 125 oil processing (U.S. DOE, 2010). Until commercial facilities using mature technologies go into 126 production, the impacts from algal conversion will be uncertain.

In addition to transesterification, other methods for converting seed oils, algal oils, and animal fats into biofuel have been developed recently using technologies that are already widely employed in petroleum refineries (Huo et al., 2009). Hydrotreating technologies utilize seed oils or animal fats to produce an isoparaffin-rich diesel substitute referred to as "green diesel" or

131 renewable diesel (Huo et al., 2008).

Although the transesterification process can generate a much larger amount of diesel
product than the other processes, as noted above, it requires more energy and chemical inputs
(Huo et al., 2008). In the case of biodiesel hydro-generation technology, inputs such as
hydrogen, which are very energy-intensive to produce, must be taken into consideration in a full
life cycle assessment in order to adequately evaluate energy efficiency of each fuel production
process. Compared with conventional diesel and biodiesel, renewable diesel fuels have much
higher cetane numbers (a measure of diesel fuel quality).

139 4.3.2 Air Quality

Air quality impacts associated with the production of biofuels occur throughout the production chain (Figure 4-1). EPA's Regulatory Impact Analysis (RIA) of the revisions to the national Renewable Fuel Standard Program (RFS2) assessed the air pollutant emissions and air quality impacts of the biofuel volumes (see Table 2-1 in Chapter 2) required under the 2007 Energy Independence and Security Act (EISA). The discussion below summarizes the RIA results; the interested reader is referred to the RIA for additional details (U.S. EPA, 2010b).

The RIA analysis^{22,23} focused on the projected impact of the renewable fuel volumes
 required in 2022, and accounted for GHG life cycle emissions, as well as the displaced
 petroleum consumption associated with use of biofuels. The emission impacts of the 2022 RFS2

²² The RIA's assessment of air quality relied on data from the EPA's 2005 National Emissions Inventory, supplemented with the most up-to-date information where possible.

²³ For assessment of electrical energy demand, the RIA used a national energy source profile (i.e., coal, hydro, wind, natural gas) rather than regional source profiles, which can vary across the country.

- 149 volumes were quantified relative to two reference cases: 1) the original RFS program (RFS1)
- mandate volume of 7.5 billion gallons of renewable fuel (6.7 billion gallons ethanol), and 2) the 150
- 151 U.S. Department of Energy (DOE) Annual Energy Outlook (AEO) 2007 projected 2022 volume
- 152 of 13.6 billion gallons of renewable fuels. The RIA analysis found decreases in overall emissions
- 153 for carbon monoxide (CO) and benzene, and increases in overall emissions for nitrogen oxide 154
- (NO_x), volatile organic compounds (VOCs), PM, and several air toxics, especially ethanol and 155 acetaldehyde. Overall emissions of sulfur dioxide (SO₂) exhibited mixed results, depending on
- 156 the fuel effect specified.

157 For biofuel production and distribution, the net change in VOC, CO, NO_x, and PM 158 emissions can be attributed to two effects: 1) emission increases connected with biofuel 159 production, and 2) emission decreases associated with reductions in gasoline production and distribution as ethanol displaces gasoline. Increases in fine particles less than 2.5 micrometers in 160

- diameter ($PM_{2.5}$), sulfur oxide (SO_x), and especially NO_x were determined to be driven by 161
- stationary combustion emissions from the substantial increase in corn and cellulosic ethanol 162
- 163 production. Substantial fugitive dust and particulate increases are also associated
- 164 with agricultural operations.

165 The RIA found that increasing the production and distribution of ethanol would lead to 166 higher ethanol vapor emissions. To a lesser degree, the production and distribution of greater amounts of ethanol would lead to increases in emissions of formaldehyde and acrolein, as well as 167 very small decreases in benzene, 1,3-butadiene, and naphthalene emissions relative to the total 168

- 169 volume of these emissions in the U.S. Emissions of ammonia are expected to increase
- substantially due to increased ammonia from fertilizer use. Additional details on EPA's analysis 170
- 171 of changes in emissions associated with the RFS2 volumes can be found in
- 172 www.epa.gov/otaq/fuels/renewablefuels/regulations.htm.

173 Air pollutant emissions associated with the conversion of biomass to fuel may be 174 mitigated through the use of cleaner fuels during the conversion process and more efficient 175 process and energy generation equipment. The majority of ethanol plants built in recent years, and expected to be built in the near future, utilize dry mill technology (Wang et al., 2007a). 176 177 Because most ethanol plants utilize similar dry milling production processes, differences in environmental impacts among plants are primarily due to each plant's choice of fuel. EPA's RIA 178 179 assumes a dry mill for the base scenario.

180 EPA's RIA examines the impacts of using energy-saving technologies such as combined heat and power (CHP). CHP is an effective means to reduce air emissions associated with biofuel 181 production (both ethanol and biodiesel). CHP generates electricity by burning natural gas or 182 183 biogas, and then employs a heat recovery unit to capture heat from the exhaust stream as thermal 184 energy. Using energy from the same fuel source significantly reduces the total fuel used by 185 facilities along with the corresponding emissions of carbon dioxide (CO₂) and other pollutants. 186 Fractionation, membrane separation, and raw starch hydrolysis are additional technologies examined in EPA's RIA that increase process efficiencies by enabling producers to sell distillers 187 188 grains (a co-product of the corn-ethanol conversion process) wet rather than dry, thereby 189 reducing greenhouse gas emissions and other possible environmental impacts (since drying

190 distillers grains is an energy-intensive process).

4.3.2.1 Ethanol

Ethanol production requires electricity and the use of steam. Electricity is either purchased from the grid or produced onsite, and steam is typically produced onsite from natural gas. Power and the energy used to fuel boilers are responsible for emissions of VOCs, PM, CO, SO_x and NO_x (U.S. EPA, 2010b; Wang et al., 2007b). For corn-based ethanol, fossil fuels such as natural gas are typically used to produce heat during the conversion process, although a number of corn ethanol facilities are exploring new technologies with the potential to reduce their energy requirements.

A number of processes at ethanol production facilities result in emissions of air toxics. These processes include fermentation, distillation of the resultant mash, and drying of spent wet grain to produce animal feed. Emissions of air toxics vary tremendously from facility to facility due to a variety of factors, and it is difficult to determine how differences in the production processes individually impact emissions (U.S. EPA, 2010b). Ethanol vapor and air toxic emissions associated with biofuel production were projected to increase in EPA's RFS2 RIA, but these would be very small compared to current emissions (U.S. EPA, 2010b).

206 **4.3.2.2 Biodiesel**

While the production process for biodiesel is fundamentally different from ethanol, thermal and electrical energy are still required for production. The thermal energy required for biodiesel production is usually met using steam generated using a natural gas boiler. In certain situations, the glycerol co-product may also be burned to produce process heat, or a biomass boiler may be used to replace natural gas.

Air quality issues associated with a natural gas-fired biodiesel production process are similar to those for other natural gas applications such as ethanol production, and include emissions of VOCs, PM, CO, SO_x , and NO_x . Glycerol or solid fuel biomass boilers have emissions characteristics similar to those anticipated for cellulosic ethanol plants, including increased particulates and the potential for VOCs, NO_x , and SO_x .

Biodiesel production using a closed hot oil heater system would have none of the air emissions associated with traditional steam production. Air emissions associated with these systems would be those associated with the production of the electricity, which would take place outside the biodiesel plant boundary.

Additionally, the extraction of vegetable oil to create biodiesel in large chemical processing plants is typically achieved using hexane, a VOC that EPA has classified as a hazardous air pollutant. Hexane is also commonly used to extract algal oils. Fugitive emissions of hexane may result from increased biodiesel manufacture (Hess et al., 2009).

- 225 4.3.2.3 Greenhouse Gases
- Fuel combustion at ethanol and biodiesel facilities releases greenhouse gases. Fermentation to ethanol also releases CO₂. Combustion-related greenhouse gas emissions are released to the atmosphere, but some ethanol facilities capture, purify, and sell their CO₂ associated with fermentation to the beverage industry for carbonation or to food processors for

- flash freezing. Opportunities for CO₂ reuse depend on the proximity of ethanol refineries to local
- users. The industrial gas supplier Airgas estimates that the ethanol industry captures and recovers
- 5 to 7 percent of all CO₂ that it produces from the ethanol fermentation process (spreadsheet
- provided to EPA by Bruce Woerner at Airgas on August 14, 2009, cited in U.S. EPA, 2010b, p.
- 133). Other sources of GHG emissions, such as those from electricity generation produced from
- coal or other GHG-emitting sources, are not currently recovered by the industry.
- EISA Section 204 does not include GHG emissions in the set of environmental issues to be examined in this report. However, EPA did analyze life cycle GHG emissions from increased renewable fuels use as part of the EISA-mandated revisions to the RFS program. The Act established specific life cycle GHG emission thresholds for each of four types of renewable fuels, requiring a percentage improvement compared to life cycle GHG emissions for gasoline or diesel (whichever is being replaced by the renewable fuel) sold or distributed as transportation fuel in 2005. These life cycle performance improvement thresholds are listed in Table 4-2.

Table 4-2. Lifecycle GHG Thresholds Specified in EISA(percent reduction from 2005 baseline)

Renewable fuel ^a	20%				
Advanced biofuel	50%				
Biomass-based diesel	50%				
Cellulosic biofuel	60%				
a _ The 20% criterion generally applies to renewable fuel from new					

243 244

245 EPA's methodology for conducting the GHG life cycle assessment included use of agricultural sector economic models to determine domestic agriculture sector-wide impacts and 246 247 international changes in crop production and total crop. Based on these modeling results, EPA 248 estimated GHG emissions using DOE's GREET model defaults and Intergovernmental Panel on 249 Climate Change (IPCC) emission factors. The GHGs considered in the analysis were CO₂, methane (CH₄), and nitrous oxide (N₂O). Biofuel process energy use and associated GHG 250 251 emissions were based on process models for the different pathways considered. For ethanol and biodiesel, EPA's RFS2 RIA projected that (U.S. EPA, 2010b): 252

253 254 255 256	•	Ethanol produced from corn starch at a new (or expanded capacity from an existing) natural gas-fired facility using advanced efficient technologies will comply with the 20 percent GHG emission reduction threshold.
257 258	•	Ethanol produced from sugarcane will comply with the 50 percent GHG reduction threshold for the advanced fuel category.
259		
260	•	Biodiesel from soybean oil and renewable diesel from waste oils, fats, and greases
261		will comply with the 50 percent GHG threshold for the biomass-based diesel
262		category.
263		
264	•	Diesel produced from algal oils will comply with the 50 percent GHG threshold
265		for the biomass-based diesel category.

a – The 20% criterion generally applies to renewable fuel from new facilities that commenced construction after December 19, 2007.

266 267 268

269

• Cellulosic ethanol and cellulosic diesel (based on the modeled pathways) will comply with the 60 percent GHG reduction threshold applicable to cellulosic biofuels.

Based on the assessment described above, EPA projected a reduction of 138 million
 metric tons of CO₂-equivalent emissions by 2022 compared to projected 2022 emissions without
 the EISA-mandated changes (see the RFS2 RIA [U.S. EPA, 2010b] for details).

273 4.3.3 Water Quality and Availability

274 All biofuel facilities utilize process water to convert biomass to fuel. Water used in the 275 biorefining process is modest in absolute terms compared to the water applied and consumed in growing the plants used to produce biofuel. The impacts associated with water use at conversion 276 277 facilities depend on the location of the facility in relation to water resources. In some regions where water is abundant, increased withdrawals may have little effect. Ground water depletion 278 279 may result in increased costs to pump water from deeper wells, loss of stream flow, and 280 subsidence of the overlying land (Reilly et al., 2008). Several areas of the country that are already experiencing lowered ground water levels (e.g., High Plains aquifer, Lower Mississippi 281 River alluvial aquifer) correspond with regions where increased biofuel production is expected. 282 283 In addition, minimum in-stream flow for aquatic life can be affected by ground water depletion 284 because ground water discharge into streams is a major source of stream base flow. In some 285 areas, streams have run dry due to ground water depletion, while in other areas, minimum stream 286 flow during the summer has been sustained because of irrigation return flow to streams 287 (Bartolino and Cunningham, 2003). In the case of sole source aquifers, ground water depletion 288 may severely impact drinking water availability, since these areas have no readily available 289 alternative freshwater sources (Levin et al., 2002).

290 Comprehensive local, state, and regional water planning, as well as state regulatory 291 controls, are critical to ensure that facilities are located in watersheds that can sustain the 292 increased withdrawal without affecting other uses. The first step in mitigating water availability 293 concerns associated with increased biofuel production is to locate production facilities where 294 water sources are adequate to meet production needs without impacting other uses. Siting of 295 biofuel facilities may also be influenced by state laws and regulations designed to avoid or 296 mitigate conflicts among water uses. These vary by state. For example, withdrawals associated 297 with biofuel production facilities may need a state permit to ensure that the proposed withdrawal 298 does not result in unacceptable impacts on other users or on aquatic life. In addition, different 299 states assign water rights in different ways. Some exercise the prior appropriation rule (i.e., water 300 rights are determined by priority of beneficial use, meaning that the first person to use the water 301 can acquire individual rights to the water); some are based on the English law of absolute 302 ownership (i.e., rights to use water are connected to land ownership); some limit withdrawals 303 based on stream flow requirements for aquatic life; and some have a hierarchy to prioritize uses 304 of the water.

Like water quantity impacts, water quality impacts depend on a number of factors including facility location, water source, receiving water, type of feedstock used, biorefinery technology, effluent controls, and water re-use/recycling practices. Water quality impacts are associated with the wastewater discharge from the conversion process. Biological oxygen

- demand (BOD), brine, ammonia-nitrogen, and phosphorus are primary pollutants of concern
- 310 from ethanol facilities, while discharges of BOD, glycerin, and to a certain extent, total
- 311 suspended solids (TSS) pose the major water quality concerns from biodiesel facility effluent.
- Regulatory controls placed on the quality of biofuel production wastewater discharge can
- mitigate water quality impacts. Discharges to publicly owned wastewater treatment works
 (POTWs) are subject to general pre-treatment standards in the Clean Water Act (40 CFR 403.5
- 314 (POTWs) are subject to general pre-treatment standards in the Clean Water Act (40 CFR 403.5).
 315 Biofuel facilities that discharge their wastewater to POTWs are subject to whatever pre-treatment
- limitations are in force for the receiving POTW. For those facilities that treat and discharge their
- 317 own wastewater, EPA has enforceable regulations to control production facility effluent
- 318 discharges of BOD, sediment, and ammonia-nitrogen through the National Pollutant Discharge
- 319 Elimination System (NPDES) permit program.

Whether effluent is discharged to a POTW or treated onsite at the production facility, BOD can lead to methane emissions during the wastewater treatment process. To mitigate the release of methane to atmosphere, facilities can install anaerobic digesters as a treatment step. Anaerobic digesters treat the biosolids contained in wastewater effluent, generating biogas that is approximately 60 to 65 percent methane. This biogas can then either be flared or captured and used as a clean energy source at the biofuel production facility or elsewhere.

326 Currently there are no effluent limitation guidelines or categorical pretreatment standards 327 that regulate process wastewater discharges from ethanol and biodiesel manufacturing facilities.

328 **4.3.3.1 Ethanol**

In 2007-2008, EPA evaluated biodiesel and corn ethanol manufacturing facilities. No major effluent quality issues were found from corn ethanol plants discharging to either surface waters or to wastewater treatment plants.

332 While some ethanol facilities get their process water from municipal water supplies, most 333 use onsite wells (Wu et al., 2009). However, most untreated ground water sources are generally 334 not suitable for process water because of their mineral content. Ground water high in mineral 335 content is commonly treated by reverse osmosis, which requires energy and concentrates ground 336 water minerals into reject water, with potential water quality impacts upon their release. For every two gallons of pure water produced, about a gallon of brine is discharged as reject water 337 338 (U.S. EPA, 2010b). Methods to reduce the impact associated with reject water high in mineral 339 concentration include (1) further concentration and disposal, or (2) use of in-stream dilution. 340 Some ethanol facilities have constructed long pipelines to access additional water sources to 341 dilute the effluent to levels that meet water quality standards.

342 Once process water is treated, most is lost as steam during the ethanol production process. Water use varies depending on the age of the facility and the type of milling process. 343 344 Older generation production facilities use 4 to 6 gallons of process water to produce a gallon of 345 ethanol; newer facilities generally use less than 3 gallons of water in the production process. 346 Most of this water savings is gained through improved recycling of water and heat in the process. 347 Dry milling facilities consume on average 3.45 gallons of fresh water per gallon of ethanol produced (Wu et al., 2009); newer facilities tend to consume about 27 percent less water. Wet 348 349 mill facilities consume an average of 3.95 gallons of fresh water per gallon of ethanol produced

350 (Wu, 2008). Most estimates of water consumption in ethanol production are based on the use of 351 clean process water and do not include the water discharged as reject water.

Ethanol plants are designed to recycle water within the plant, and improvements in water use efficiency of ethanol facilities are expected through steam condensate reuse and treated process water recycling (Wu et al., 2009). New technologies that improve water efficiency will help mitigate water quantity impacts.

Wastewater effluent from corn starch ethanol facilities is high in BOD (Powers, 2007). For example, one report found that ethanol production from corn produces wastewater with BOD from 18,000 to 37,000 mg/L (Pimentel and Pimentel, 2008, p. 380). Ethanol wastewater effluent can also contain ammonia-nitrogen and phosphorus.

360 Because no large-scale cellulosic ethanol production facilities are currently operating, 361 water demand for production of cellulosic ethanol is not certain. However, for most cellulosic 362 feedstocks, including agricultural residues like corn stover and dedicated energy crops like 363 switchgrass, water demand is estimated to be between 2 and 10 gallons of water per gallon of 364 ethanol, depending on the conversion technology, with volumes greater than 5 gallons of water 365 per gallon of ethanol cited more often (NRC, 2008; Williams et al., 2009; Wu et al., 2009). Some 366 studies assume water demand for processing woody biomass will be similar to processing 367 cellulosic material from agricultural residues or dedicated energy crops (up to 10 gallons of water per gallon of ethanol) (Evans and Cohen, 2009). Other studies state that new technologies 368 369 like fast pyrolysis will require less than half that amount of water per gallon of ethanol (Wu et 370 al., 2009). Consumptive use of water is declining as ethanol producers increasingly incorporate recycling and other methods of converting feedstocks to fuels that reduce water use (NRC, 371 372 2008).

Cellulosic ethanol facilities that employ biochemical conversion would be expected to have similar water requirements and brine discharges as the current operating corn ethanol facilities. The additional steps required to separate the lignin from the cellulose could produce wastewater streams high in BOD that would require treatment onsite or at wastewater treatment plants.

378 4.3.3.2 Distillers Grain with Solubles

One important co-product of ethanol production is dried distillers grain with solubles (DDGS). Due to the increase in ethanol production and the price of corn, DDGS has become an increasingly important feed component for confined livestock. About one-third of the corn processed into ethanol is converted into DDGS; therefore, approximately 45 million tons of DDGS will be produced in conjunction with the 15 billion gallons of corn ethanol produced by 2015.

Livestock producers may partially replace corn or other feeds with DDGS for both economic and production reasons. Different livestock species can tolerate varying amounts of DDGS in their diets. Although specific analysis of DDGS can vary among ethanol plants, DDGS are higher in crude protein (nitrogen) and three to four times higher in phosphorus compared to corn (Regassa et al., 2008). The increase in nitrogen and phosphorus from DDGS in livestock feed has potential implications for water quality. When nitrogen and phosphorus are fed in excess of animals' needs, excess nutrients are excreted in urine and manure. Livestock manure may be applied to crops, especially corn, as a source of nutrients. When manure is applied at rates above the nutrient needs of the crop or when the crop cannot use the nutrients, the nitrogen and phosphorus can runoff to surface waters or leach into ground waters. Excess nutrients from manure nutrients have the same impact on water quality as excess nutrients from other sources.

Livestock producers may limit the potential pollution from manure applications to crops
through a variety of techniques. USDA's Natural Resources Conservation Service (NRCS) has
developed a standard for a comprehensive nutrient management plan to address the issue of
proper use of livestock manure (NRCS, 2009).

401 **4.3.3.3 Biodiesel**

402 Biodiesel facilities use much less water than ethanol facilities to produce biofuel. The 403 primary consumptive water use at biodiesel plants is associated with washing and evaporative 404 processes. Water use is variable, but is usually less than one gallon of water for each gallon of 405 biodiesel produced (U.S. EPA, 2010b); some facilities recycle washwater, which reduces overall 406 water consumption (U.S. EPA, 2010b). However, water use has been reported as high as three 407 gallons of water per gallon of biodiesel (Pate et al., 2007). Larger well-designed facilities use 408 water more sparingly, while smaller producers tend to use more water per production volume 409 (U.S. EPA, 2010b). New technologies that improve water efficiency will help mitigate water 410 quantity impacts.

411 In addition to water use in the washing and evaporation processes, other sources of 412 wastewater include steam condensate; process water softening and treatment to eliminate 413 calcium and magnesium salts, iron, and copper; and wastewaters from the glycerin refining 414 process (U.S. EPA, 2008c). In a joint DOE/USDA study, it was estimated that consumptive 415 water use at a biodiesel refinery accounts for approximately one-third of the total water use, or 416 about 0.32 gallon of water per gallon of biodiesel produced (Sheehan et al., 1998b). New 417 technologies have reduced the amount of wastewater generated at facilities. Process wastewater 418 disposal practices include direct discharges (to waters of the United States), indirect discharges 419 (to wastewater treatment plants), septic tanks, land application, and recycling (U.S. EPA, 2008c).

Most biodiesel manufacturing processes result in the generation of process wastewaters with free fatty acids and glycerin (a major co-product of biodiesel production). Despite the existing commercial market for glycerin, the rapid development of the biodiesel industry has caused a glut of glycerin production, resulting in many facilities disposing glycerin. Glycerin disposal may be regulated under several EPA programs, depending on the practice. However, there have been incidences of glycerin dumping, including an incident in Missouri that resulted in a large fish kill (U.S. EPA, 2010b).

427 Other constituents in the biodiesel manufacturing process wastewater include organic
428 residues such as esters, soaps, inorganic acids and salts, traces of methanol, and residuals from
429 process water softening and treatment (U.S. EPA, 2008c). Solvents used to extract lipids from
430 algae, including hexane, alcohols, and chloroform, could also impact water quality if discharged

431 to surface or ground water. Typical wastewater from biodiesel facilities has high concentrations

- 432 of conventional pollutants—BOD, TSS, oil, and grease—and also contains a variety of non-
- 433 conventional pollutants (U.S. EPA, 2008c).

434 Some biodiesel facilities discharge their wastewater to municipal wastewater treatment 435 systems for treatment and discharge. In some cases, wastewater with sufficiently high glycerin levels has disrupted municipal wastewater treatment plant function (U.S. EPA, 2010b). There 436 437 have been several cases of municipal wastewater treatment plant upsets due to high BOD 438 loadings from releases of glycerin (U.S. EPA, 2010b). To mitigate wastewater issues, some 439 production systems reclaim glycerin from the wastewater. As another option, closed-loop 440 systems in which water and solvents can be recycled and reused can reduce the quantity of water 441 that must be pretreated before discharge.

442 4.3.4 Impacts from Solid Waste Generation

443 Biofuels may also lead to significant environmental impacts stemming from solid waste 444 generated by various production processes. EPA defines "solid wastes" as any discarded 445 material, such as spent materials, by-products, scrap metals, sludge, etc., except for domestic wastewater, non-point source industrial wastewater, and other excluded substances (U.S. EPA, 446 447 2010i). A type of solid waste that is of particular interest in the case of biofuel production is the 448 diatomaceous earth that is used as a filter to remove impurities from methyl esters, such as 449 biodiesel. Several reports have indicated that diatomaceous earth may be spontaneously 450 combustible, and disposal sites consider it a potential hazardous waste (Missouri Department of 451 Natural Resources, 2008; Nebraska Department of Environmental Quality, 2009). The high surface area of the diatomaceous earth and the oil sets up a rapid decomposition that creates heat. 452 453 Further study is needed to investigate this potential hazard and look into mitigation strategies.

454 4.4 Biofuel Distribution

The vast majority of biofuel feedstocks and finished biofuel are currently transported by rail, barge, and tank truck. Ethanol and biodiesel are both generally blended at the end of the distribution chain, just before delivery to retail outlets. Storage of biofuels typically occurs in above-ground tanks at blending terminals, in underground storage tanks (USTs), and at retail outlets (as a petroleum-biofuel blend).

460 The primary impacts related to transport and storage of biofuels relate to air quality (i.e., 461 emissions from transport vehicles and evaporative emissions) and water quality (i.e., leaks and 462 spills).

- 463 4.4.1 Air Quality
- 464 **4.4.1.1 Ethanol**

Air pollution emissions associated with distributing fuel come from two sources: 1)
evaporative, spillage, and permeation emissions from storage and transfer activities, and 2)
emissions from vehicles and pipeline pumps used to transport the fuels (see Figure 4-1).
Emissions of ethanol occur both during transport from production facilities to bulk terminals, and
after blending at bulk terminals.

470 Although most ethanol facilities are concentrated in the midwestern United States. 471 gasoline consumption is highest along the east and west coasts. Fleet transport of biofuel, often 472 by barge, rail, and truck, increases emissions of air pollutants, such as CO₂, NOx, and PM due to 473 the combustion of fuels by transport vehicles. EPA's RFS2 RIA found relatively small increases 474 in criteria and air toxics emissions associated with transportation of biofuel feedstocks and fuels 475 (U.S. EPA, 2010b). In addition, transport and handling of biofuel may result in small but 476 significant evaporative emissions of VOCs (Hess et al., 2009). With the exception of benzene 477 emissions, which were projected to decrease slightly, EPA's RFS2 RIA projected relatively 478 small increases in emissions of air pollutants associated with evaporation (U.S. EPA, 2010b).

479 Pipeline transport decreases air emissions associated with fleet transport of biofuel 480 because fuel is not combusted in the transport process. However, transport of biofuels by 481 pipeline raises potential technical issues, including internal corrosion and stress corrosion 482 cracking in pipeline walls, and the potential to degrade performance of seals, gaskets, and 483 internal coatings. Additionally, ethanol's solvency and affinity for water can generate product 484 contamination concerns (U.S. EPA, 2010b). Dedicated ethanol pipelines may alleviate these 485 issues; however, they are costly to construct. Due to the incompatibility issues with the existing 486 petroleum pipeline infrastructure, the growth in ethanol production is expected to increase 487 emissions of criteria and toxic air pollutants from freight transport, while a corresponding 488 decrease in gasoline distribution would decrease emissions related to pipeline pumping (Hess et al., 489 2009).

490 **4.4.1.2 Biodiesel**

Air pollution emissions from fuel combustion in transport vehicles related to biodiesel
feedstocks and fuels are not materially different than those associated with ethanol. Currently,
pipeline distribution of biodiesel is still in the experimental phase. Significant evaporative
emissions are not expected from storage and transport of biodiesel fuel due to its low volatility
(U.S. EPA, 2010b).

496 4.4.2 Water Quality

497 Leaks and spills from above-ground, underground, or transport tanks may occur during
498 biofuel transport and storage, potentially contaminating ground water, surface water, or drinking
499 water supplies.

500 For bulk transport, the major concern is based on an accident scenario in which the 501 transport tank is damaged and a large amount of fuel is spilled. In addition, leaks might occur 502 during transport because of certain fuel-related factors, such as the fuel's corrosivity. Ethanol is 503 slightly acidic and can corrode some active metals; biodiesel is also slightly corrosive. The 504 possibility of leaks during transport is minimized by the selection of appropriate materials and 505 proper design in accordance with the applicable material standards.

Leaks from storage tanks are also a major concern. Most states report that underground storage tanks (USTs) are a major source of ground water contamination (U.S. EPA, 2000). Preliminary research has shown that any concentration of biofuel in an underground tank also containing petroleum-based fuels increases the potential for groundwater migration (EPA 510 OSWER Biofuels Compendium, http://www.epa.gov/oust/altfuels/bfcompend.htm). A leaking

- 511 UST can also present other health and environmental risks, including the potential for fire and
- 512 explosion.

513 EPA's Office of Underground Storage Tanks is working with other agencies to better 514 understand material compatibility issues associated with older UST systems, in order to assess 515 the ability of these systems to handle new fuel blends (U.S. EPA, 2009b). Because most of the 516 current underground storage tank equipment, including 617,000 active USTs, was designed and 517 tested for use with petroleum fuels, many UST systems currently in use may contain materials 518 that are incompatible with ethanol blends greater than 10 percent (U.S. EPA, 2009c) or biodiesel. 519 Although it is not possible to quantify the risk at this time, EPA is developing modeling software 520 to assess fuels of version an around water (U.S. EPA, 2010b)

520 to assess fuels of varying composition on ground water (U.S. EPA, 2010b).

521 Biodiesel and ethanol blend fuels degrade many non-metallic materials, such as natural 522 rubber, polyurethane, older adhesives, certain elastomers and polymers used in flex piping, 523 bushings, gaskets, meters, filters, and materials made of cork. Biodiesel and ethanol blend fuels also degrade soft metals such as zinc, brass, and aluminum. If a fuel system does contain these 524 525 materials and users wish to fuel with blends over B20 (i.e., with fuel containing more than 20 526 percent biodiesel), replacement with compatible elastomers is needed. In many instances, 527 especially with older equipment, the exact composition of elastomers cannot be obtained and it is 528 recommended they be replaced if using blends over B20.

529 Several measures are already in place to help prevent and mitigate potential water quality 530 impacts. Under the Resource Conservation and Recovery Act (RCRA), owners and operators of 531 regulated UST systems must comply with requirements for financial responsibility, corrosion 532 protection, leak detection, and spill and overfill prevention. Federal regulations require that 533 ethanol and biodiesel storage containers are compatible with the fuel stored. For USTs, leak 534 detection equipment is required and must be functional. Through the Spill Prevention, Control, and Countermeasure (SPCC) rule, EPA has enforceable regulations to control water quality 535 536 impacts from spills or leaks of biofuel products and by-products.

537 Further testing and certification of the acceptability of storage tanks and leak detection 538 systems performance will be crucial to safe storage of biofuels. In addition, developing storage 539 materials that are resistant to biofuel leaks and spills locating will help prevent spills, and 540 locating USTs away from ground water supplies, and will mitigate water quality impacts in case 541 a spill or leak does occur.

542 Additional details specific to ethanol and biodiesel are discussed below.

543 **4.4.2.1 Ethanol**

Ethanol is stored in neat form at the production facility, in denatured form at terminals and blenders, and as E85 (85 percent ethanol and 15 percent gasoline) and E10 (10 percent ethanol and 90 percent gasoline) mixtures at retail. Ethanol is water soluble and can be degraded by microorganisms commonly present in ground water (U.S. EPA, 2009d). In ground water, ethanol's high oxygen demand and biodegradability changes the attenuation of the constituents in gasoline/ethanol blends. This can cause reduced biodegradation of benzene, toluene, and 550 xylene (up to 50 percent for toluene and 95 percent for benzene) (Mackay et al., 2006; U.S. EPA,

- 551 2009d). The presence of ethanol can restrict the rate and extent of biodegradation of benzene,
- 552 which can cause the plumes of benzene to be longer than they would have been in the absence of
- 553 ethanol (Corseuil et al., 1998; Powers et al., 2001; Ruiz-Aguilar et al., 2002). This could be a 554 significant concern to communities that rely on ground water supplies with the potential to be
- 555 impacted by leaks or spills (Powers et al., 2001; Ruiz-Aguilar et al., 2002). In surface waters,
- rapid biodegradation of ethanol can result in depletion of dissolved oxygen with potential
- 557 mortality to aquatic life (U.S. EPA, 2010b).

558 There are other potential hazards in addition to those associated with chemical toxicity. 559 Some spills of gasoline with ethanol may produce methane concentrations in the soil that pose a 560 risk of explosion (Da Silva and Alvarez, 2002; Powers et al., 2001).

561 **4.4.2.2 Biodiesel**

562 In general, if biodiesel is blended with petroleum diesel, another petroleum product, or a 563 hazardous substance, state UST regulations may apply to those blends. One-hundred percent 564 biodiesel contains no petroleum-based products or hazardous substances. Therefore, UST 565 regulations generally do not apply to 100 percent biodiesel.

Biodiesel is not water soluble. Biodiesel degrades approximately four times faster than petroleum diesel. In aquatic environments, biodiesel degrades fairly extensively (Kimble, n.d.). Results of aquatic toxicity testing of biodiesel indicate that it is less toxic than regular diesel (Kahn et al., 2007). Biodiesel does have a high oxygen demand in aquatic environments, and can cause fish kills as a result of oxygen depletion (Kimble, n.d.). Water quality impacts associated with spills at biodiesel facilities generally result from discharge of glycerin, rather than biodiesel itself (Kimble, n.d.).

573 **4.5** <u>Biofuel End Use</u>

574 Most vehicles on the road today can operate on E10. Nearly half of U.S. gasoline is an 575 E10 mixture to boost octane for more complete combustion or to meet air quality requirements (Alternative Fuels and Advanced Vehicles Data Center, 2010). E85 is another form in which 576 577 ethanol is consumed, but it can only be used in flex-fuel vehicles, which can run on either 578 conventional gasoline or ethanol blended into gasoline up to 85 percent. Under current market 579 circumstances, greater deployment of flex-fuel vehicles may be needed to meet the EISA 580 mandated volume standards. Because of biodiesel's chemical properties, it is not interchangeable 581 with petroleum-based diesel fuel. For this reason, its blend level is specifically labeled when it is blended with petroleum diesel (U.S. EPA, 2010b). Biodiesel can be used in its pure form, known 582 as "neat biodiesel" or B100, but most vehicle and engine manufacturers do not recommend its 583 584 use in non-approved engines and vehicles. There are some concerns regarding maintenance 585 issues related to engines operated on biodiesel, because the fuel has been shown to soften and 586 degrade certain types of elastomers and natural rubber compounds over time. This will impair 587 fuel system components such as fuel hoses and fuel pump seals. Such component degradation 588 can lead to leaks, poor performance, and other problems that are likely to result in increased 589 emissions and subsequent environmental impacts.

590 Biofuels for jet aircraft require additional refining or need to be blended with typical jet 591 fuels to meet the standards of commercial aviation fuels. There are few long-term studies of 592 biofuel performance on large diesel engines such as stationary power generators, ships, 593 locomotives, and jet engines.

594 4.5.1 Air Quality

595 The primary impact associated with biofuel end use is air quality. Section 211 (v) of the 596 Clean Air Act requires EPA to study the air quality impacts associated with the use of biofuel 597 and biofuel blends. EPA has already adopted mobile source emission control programs that 598 reduce air pollution emissions and improve air quality. If necessary, EPA will issue further 599 regulations to mitigate adverse air quality impacts as a result of increases in biofuels.

600 **4.5.1.1 Ethanol**

The following discussion is based on E10, because considerably more information is available about its use. A wide variation in evaporative and tailpipe emissions have been reported due to a range of factors, such as the age of the vehicle, the power output and operating condition of the engine, the fuel characteristics, how the vehicle is operated, and ambient temperatures (Ginnebaugh et al., 2010; Graham et al., 2008; Yanowitz and McCormick, 2009).

606 As stated in section 4.3.2, the emission impacts of the 2022 RFS2 volumes in the RFS2 607 RIA were quantified relative to two reference cases: 1) the original RFS program (RFS1) 608 mandate volume of 7.5 billion gallons of renewable fuel (6.7 billion gallons ethanol), and 2) the 609 U.S. Department of Energy (DOE) Annual Energy Outlook (AEO) 2007 projected 2022 volume 610 of 13.6 billion gallons of renewable fuels. In the RFS2 RIA, EPA projected decreases in 611 emissions of carbon monoxide, benzene, and acrolein in 2022 under the RFS2-mandated volumes of biofuels, while NO_x, HC, and the other air toxics, especially ethanol and 612 613 acetaldehyde, were projected to increase. The inclusion of E85 emissions effects would be 614 expected to yield larger reductions in CO, benzene, and 1,3-butadiene, but more significant increases in ethanol, acetaldehyde, and formaldehyde (U.S. EPA, 2010b). 615

616 **4.5.1.2 Biodiesel**

Air emissions from combustion of some biofuels, such as ethanol, are relatively independent of feedstock or conversion process. However, biodiesel emissions may be highly variable depending on the feedstock type (Lapuerta et al., 2008; U.S. EPA, 2002). With respect to carbon content, plant-based biodiesel is slightly higher percentage-wise than animal-based biodiesel in gallon-per-gallon comparisons. For NO_x, PM, and CO, plant-based biodiesel tends to have higher emissions than animal-based biodiesel for all percent blends (U.S. EPA, 2002).

623 Studies of biodiesel and biodiesel blends show varying results depending on the fuel (i.e., 624 type of biodiesel, biodiesel blend, type of base diesel), the vehicle being tested, and the type of 625 testing. In general, combustion of biodiesel has been shown to decrease PM, CO, and HC 626 emissions, increase NO_x emissions, and increase ozone-forming potential (Gaffney and Marley, 627 2009; U.S. EPA, 2002). It should be kept in mind that petroleum-based diesel-fueled vehicles are 628 expected to emit significantly lower amounts of SO_2 because of the Heavy-Duty Engine and 629 Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (2007 Heavy-Duty

- 630 Highway Rule) and the availability of low-sulfur diesel fuel in the marketplace, which must be
- 631 accounted for when considering the emission benefits of low SO_x biodiesel (U.S. EPA, 2001). 632 Blending biodiesel in low percentages will not have much impact on sulfur emissions.
- 633 With respect to carbon content, plant-based biodiesel is slightly higher than animal-based 634 biodiesel percentage-wise. For NO_x , PM, and CO, plant-based biodiesel tends to have higher
- emissions than animal-based biodiesel for all percent blends (U.S. EPA, 2002).
- 636 EPA's RFS2 RIA investigated the impacts of 20 volume percent biodiesel fuels on NO_x,
- 637 PM, HC, and CO emissions from heavy-duty diesel vehicles, compared to using 100 percent
- 638 petroleum-based diesel. Average NO_x emissions were found to increase 2.2 percent, while PM,
- HC, and CO were found to decrease 15.6 percent, 13.8 percent, and 14.1 percent, respectively,
- 640 for all test cycles run on 20 volume percent soybean-based biodiesel fuel. Biodiesel results were 641 included in the EPA analysis; however, the biodiesel contribution to overall emissions is quite
- 642 small (U.S. EPA, 2010b).

1 5. INTERNATIONAL CONSIDERATIONS

2 5.1 <u>Introduction</u>

In the global context, biofuel demands from an increasing number of countries will have direct and indirect impacts, not only on countries that produce biofuels, but on countries that currently rely on imports of agricultural commodities from biofuel producers (Hertel et al., 2010; Pimentel et al., 2009; Zah and Ruddy, 2009). Section 204 of the Energy Independence and Security Act (EISA) calls for EPA to report to Congress the environmental impacts outside the United States caused by U.S. biofuel use. Thus, the following discussion focuses on potential impacts in foreign countries that may result from implementation of the RFS2 standards.

International trade is the primary mechanism through which foreign nations will be
impacted by U.S. biofuel policy. Ethanol and, to a much smaller degree, biodiesel, have become
global commodities. They are produced in many countries (Figure 5-1) and traded in
international markets. Primary producers of ethanol are Brazil, the U.S., the European Union,
India, and China. Brazil is the only significant exporter of ethanol (Fabiosa, 2010). Changes in

- 15 U.S. production and consumption volumes, such as those in RFS2, will result in land allocation
- 16 impacts that have global ramifications through international trade and market price. As a crop
- 17 price rises, land will be reallocated to grow more of that crop in response to market price;
- 18 conversely declining prices for a particular crop will tend to reallocate land away from that less
- 19 profitable crop in favor of a more profitable one. Increased competition for arable land is
- 20 expected to result in more land being allocated for crop production (Fabiosa, 2010).



Source: UNEP/GRID-Arendal, 2009.

Figure 5-1: Biofuel Production Map

Resulting environmental impacts, both positive and negative, include effects from land use change and effects on air quality, water quality, and biodiversity. From a U.S. perspective, the severity of these impacts will depend on the volume and location of future imports and exports both of biofuel and displaced agricultural goods

exports, both of biofuel and displaced agricultural goods.

In 2008, the United States and Brazil together produced 89 percent of the world's fuel

30 ethanol, with the U.S. producing around 9 billion gallons (see Table 5-1) (EIA, n.d. [c]). In 2009,

31 U.S. ethanol production increased to 10.9 billion gallons, and similar increases occurred in most 32 ethanol-producing nations as they attempted to increase the portion of biofuel in their energy mix

32 (EIA, n.d. [c]). As a result, total world production has nearly doubled from 10.9 billion gallons in

34 2006 to 20.3 billion gallons in 2009. Figure 5-1 shows the geographical distribution of biofuel

35 production. Patterns of ethanol consumption generally matched those of production, with the

36 largest producers also being the largest consumers (EIA, n.d. [c]).

Country/Region	2005	2006	2007	2008	2009
United States	3,904	4,884	6,521	9,283	10,938
Brazil	4,237	4,693	5,959	7,148	6,896
European Union	216	427	477	723	951
China	317	369	440	526	567
Canada	67	67	212	250	287
Jamaica	34	80	74	98	106
Thailand	18	34	46	87	106
India	57	63	69	71	89
Colombia	8	71	72	67	80
Australia	6	20	21	38	54
Other	93	216	276	393	274
Total World Production	8,957	10,924	14,167	18,684	20,348

Table 5-1: Top Fuel Ethanol-Producing Countries from 2005 to 2009(All figures are in millions of gallons)

37 Source: EIA, n.d. [c].

38

39 The market for the other major biofuel, biodiesel, is concentrated in Europe, which 40 represented about 60 percent of world production as of 2009 (EIA, n.d. [b]). The other 40 percent of the market is largely made up by the United States, Brazil, Argentina, and Thailand, with U.S. 41 42 production estimated at 505 million gallons for 2009, or about 10 percent of the world total (EIA, 43 n.d. [b]). World biodiesel production has been rapidly increasing over the past decade, from 242 million gallons in 2000 to about 4.7 billion gallons in 2009 (EIA, n.d. [b]). These production 44 45 increases have been driven by increased consumption targets. For instance, Brazil has planned to 46 increase its biodiesel blend from 5 to 10 percent by 2015.

47 5.2 <u>Import/Export Volumes</u>

U.S. biofuel import volumes will depend largely on domestic production capacity,
 including the efficiency of the domestic ethanol-producing sector, the yields attained, and any
 excess demand left to be met via imported biofuel or biofuel feedstocks.

51 With respect to production capacity, as discussed in Chapter 2, the renewable fuel volume mandates under EISA require that U.S. biofuel consumption steadily increase to 36 52 billion gallons by 2022. This biofuel will be comprised of both conventional and advanced 53 54 biofuel (including cellulosic ethanol, algal biodiesel, and other forms of advanced biofuel). Most 55 of the 10.9 billion gallons of conventional ethanol that the U.S. produced in 2009 came from 56 corn starch; by 2015, this figure is expected to increase to the targeted volume provided for in the 57 revised Renewable Fuel Standards (RFS2) program (as required under EISA) of 15 billion 58 gallons (GAO, 2007; U.S. EPA, 2010b). Future production volumes of advanced biofuel that 59 have not yet been commercially developed are not quite as certain. In its RFS2 Regulatory 60 Impact Analysis (RIA), EPA estimated that cellulosic technologies could combine to provide an additional 16 billion gallons of ethanol by 2022, with a substantial portion of this, 7.8 billion 61 62 gallons worth, using corn stover as a cellulosic feedstock source (U.S. EPA, 2010b). In addition, 63 U.S. biodiesel production is projected to increase to roughly 1.3 billion gallons by 2019 (FAPRI, 64 2010d). The RFS2 RIA also projected that the remaining 4 billion gallons needed to meet the EISA 2022 mandate would be comprised of a combination of imported sugarcane ethanol from 65 Brazil as well as "other advanced biofuel," including cellulosic biofuel, biomass-based diesel, 66 67 and co-processed renewable diesel (U.S. EPA, 2010b). Table 5-2 shows the projected import volumes forecasted in the RIA for each year from 2011 to 2022. 68

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
U.S. Corn												
Ethanol	12,070	12,830	13,420	14,090	14,790	15,000	15,000	15,000	15,000	15,000	15,000	15,000
Production												
Projected Imports	160	180	190	200	390	630	1,070	1,510	1,960	1,880	1,810	2,240

Table 5-2: RFS2 RIA Projected Imports and Corn Ethanol Production, 2011-2022

69 Source: U.S. EPA, 2010b, pp. 77-78.

70 Figures are in millions of gallons.

71 As Table 5-2 shows, import volumes will be at or below 200 million gallons in years 72 preceding 2015, followed by a significant increase in import volumes between 2015 and 2022. 73 This is in part because domestic corn starch ethanol production is expected to increase rapidly up 74 until 2015 and then level off, and also because the RFS2 total renewable fuel requirements 75 increase more rapidly in the later years. It should also be noted that 2010 import figures have been much lower than those expected when forecasts were made in 2009. Imports of fuel ethanol 76 77 for the first three-quarters of 2010 (USDA, n.d.) have totaled 17 million gallons -well below 78 EPA's 200 million gallons forecast (EPA, 2010b). Therefore, ethanol imports may be 79 significantly lower than the projections in Table 5-2. U.S. biofuel imports and exports will also 80 be influenced by trade policy, including tariffs and other incentives in the U.S. and in other 81 countries. Even if the U.S. succeeds in meeting the RFS2 targets, the U.S. likely will continue to 82 import and export biofuel as individual producers take advantage of international price

- 83 differences. Over the past decade (2002 to 2009), U.S. ethanol import quantities varied
- 84 considerably (see Table 5-3), mostly due to volatility in the prices of related commodities such
- as corn, sugar, and other feedstocks, as well as prices of energy commodities such as oil.

	2002	2003	2004	2005	2006	2007	2008	2009
U.S. Production	2,140	2,804	3,395	3,904	4,884	6,521	9,283	10,938
Imports	13	12	149	136	731	439	530	198

Table 5-3: Historical U.S. Domestic Ethanol Production and Imports

86 Source: EIA, n.d. [c] for production figures; EIA, n.d. [d] for import figures.

87 Note: Figures are in millions of gallons.

88

89 The bulk of U.S. ethanol imports are sugarcane-based ethanol from Brazil. In 2008, the

90 U.S. was the largest importer of Brazilian ethanol, followed by the Netherlands and a number of

91 Caribbean countries (see Table 5-4). However, foreign-produced ethanol is also imported to the

92 U.S. via these Caribbean countries where the Caribbean Basin Initiative (CBI), a regional trade

agreement, enables up to 7 percent of the biofuel consumed in the U.S. to be imported from CBI

94 member countries duty-free (Yacobucci, 2005; Farinelli et al., 2009). Therefore, most of the

95 Brazilian exports shown as going to CBI member countries such as Costa Rica, Jamaica, El

96 Salvador, Trinidad and Tobago, (see Table 5-4), is eventually re-exported to the United States.

97 Looking closer at these Brazilian export figures in Table 5-4, it is evident that ethanol trade

98 changed somewhat dramatically in 2009, with most destinations experiencing a significant

decline in imports. A large part of this decline is due to the drop in U.S. imports caused by a

100 change in energy prices, as well an increase in sugar prices that made imported Brazilian ethanol

101 less competitive in the U.S. market (Lee and Sumner, 2010). These rising sugar prices, as

Table 5-4: 2008-2009 Brazilian Ethanol Exports by Country of Destination

	Volume (million gallons)			
Destination Country	2008	% of Total	2009	% of Total
Total	1,352.9	100%	870.8	100%
United States	401.6	29.7%	71.9	8.3%
Netherlands	351.9	26.0%	179.2	20.6%
Jamaica	115.3	8.5%	115.6	13.3%
El Salvador	94.1	7.0%	18.8	2.2%
Japan	69.6	5.1%	74.0	8.4%
Trinidad and Tobago	59.3	4.4%	37.0	4.2%
Virgin Islands (U.S)	49.7	3.7%	3.4	0.4%
Korea, Republic of (South Korea)	49.3	3.6%	82.9	9.5%
Costa Rica	28.9	2.1%	26.5	3.0%
Nigeria	25.9	1.9%	30.6	3.5%
United Kingdom	18.4	1.4%	42.7	4.9%

102 103 104

Note: Percentages do not sum to 100 percent because some destinations are not listed. Original data were converted from liters to gallons.

105 well as the recent strengthening of Brazil's currency, could significantly hinder Brazil's ability to

- supply the U.S. market moving forward. Even if the 54-cent-per-gallon tariff on ethanol imports
- 107 does expire as planned at the end of 2010, these factors may limit future imports (USDA,
- 108 2010d).

109 The U.S. also exports biofuel (including ethanol and biodiesel) to foreign countries.

- 110 Canada has been the primary recipient of U.S. exports, with Europe becoming a more prevalent
- destination beginning in 2004 (see Figure 5-2) as its biofuel consumption has increased. U.S. ethanol exports have increased in recent years due to increased production. However, export
- 112 levels, ranging from about 50 million to 175 million gallons, are no more than 1 percent of
- 114 domestic production and are far outweighed by imports. Exports are likely to continue to lag
- behind imports in the near-term as consumption rises.



- 116 117

Note Note

Figure 5-2: Historic U.S. Ethanol Export Volumes and Destinations

Table 5-5 shows the 2008 U.S. biodiesel trade balance. At that time, 46.8 percent of domestically produced biodiesel was exported. Biodiesel export volume has increased dramatically in recent years, from about 9 million gallons in 2005 to nearly 677 million in 2008 (EIA, n.d.[b]). In 2009, biodiesel export volume fell dramatically to only 266 million gallons (USDA, n.d.). Current projections have net U.S. biodiesel exports (i.e., exports minus imports)

- falling for the next few years and then rising back up to around 100 million gallons by the end of
- 127 the decade (FAPRI, 2010d).

¹²⁰
Item	Quantity
U.S. Production	774 million gallons
U.S. Consumption	412 million gallons
Production – consumption =	362 million gallons
U.S. Imports	315 million gallons
U.S. Exports	677 million gallons
Exports – Imports =	362 million gallons

Source: EIA, 2009, n.d.[c].

130 5.3 Environmental Impacts of Direct and Indirect Land Use Changes

131 The issue of land use change inherently includes international considerations, as the 132 demand for biofuel in the U.S. can influence the international availability of crops such as corn 133 and soybeans for both biofuel and agricultural markets, which in turn can incentivize land use 134 changes in other countries to meet that demand. In this report, land use is defined as "the human 135 use of land involving the management and modification of natural environment or wilderness 136 into built environment such as fields, pastures, and settlements". Land use changes are 137 considered either direct or indirect. In the context of biofuels, *direct land use change (DLUC)* 138 refers to land conversion that is directly related to the biofuel supply chain. An example of direct 139 land use change would be the planting of sugarcane on Brazilian land, which was previously 140 native forest or used for another non-biofuel crop, for the purpose of increasing the supply of 141 ethanol to export to the United States. Indirect land use change (ILUC) refers to land conversion 142 that is a market-oriented response to changes in the supply and demand of goods that arise from 143 increased production of biofuel feedstocks. An example of indirect land use change would be the 144 clearing of foreign land to plant corn in response to reduced U.S. corn exports caused by 145 increased U.S. corn ethanol production. Some have argued that these indirect impacts should not 146 be counted as part of the biofuel carbon footprint because they are too difficult to relate back to biofuel production. However, EISA requires that "direct emissions and significant indirect 147 emissions such as significant emissions from land use change" be considered as part of the 148 149 analysis of environmental impacts stemming from domestic biofuel production and consumption.

150 In its RFS2 Regulatory Impact Analysis, EPA estimated greenhouse gas (GHG) impacts of direct and indirect land use change using the FAPRI-CARD model.²⁴ This model predicts 151 152 world prices by equating excess supply and demand across countries. Changes in world prices 153 determine changes in worldwide commodity production and trade. Under this model, two 154 primary domestic effects directly affect a commodity's worldwide use and trade: change in U.S. 155 exports and changes in domestic U.S. prices (U.S. EPA, 2010b). Using this model, along with MODIS satellite data and other models, the RIA analysis compares 2022 crop area and 156 157 production (by crop type and country) predicted to result with and without (i.e., "business as 158 usual") EISA requirements. The results of this analysis are shown in Figures 5-3, 5-4, 5-5, and

²⁴ FAPRI-CARD is a worldwide agricultural sector economic model. For the RIA, the model was run by the Center for Agricultural and Rural Development at Iowa State University on behalf of EPA.

159 5-6 and in Table 5-6. In Figures 5-3, 5-4, 5-5, and 5-6, each column shows the marginal impact 160 of a scenario that focuses on that particular feedstock in isolation

160 of a scenario that focuses on that particular feedstock in isolation.

161 The model forecasts that, by 2022, for every increase of 1,000 gallons of corn starch 162 ethanol production in the U.S., corn exports will have decreased by 4 tons. Similarly, for every increase of 1,000 gallons of soybean-based biodiesel produced domestically, soybean oil exports 163 will have decreased by just over 2 tons (see Figure 5-3) (U.S. EPA, 2010b). Thus, as the U.S. 164 165 increases domestic production of corn starch ethanol and soybean diesel, exports of corn and soybean for agricultural or other uses are expected to decline, which may result in indirect land 166 167 use change in the form of land conversion to agriculture in other countries. This result is 168 consistent with the results of a 2009 study, which predicted that due to production increases 169 required by EISA, U.S. coarse grain exports will decrease to all destinations and this will cause dominant export competitors and trading partners, likely in Latin America, China, and the Pacific 170 Rim, to convert more of their lands to make up the difference (Hertel et al., 2010; Keeney and 171 Hertel, 2009). However, given that RFS2 limits the amount of corn starch ethanol that can be 172 counted toward the mandated volume targets at 15 billion gallons-a level the U.S. is expected to 173 reach by 2015 or sooner (GAO, 2007; U.S. EPA, 2010b), indirect land use change impacts 174 175 resulting from changing trade patterns of corn and other grains may level off at that point. In fact, U.S. biofuel consumption could decrease pressure on conversion of land to agricultural use 176

- 177 if agricultural yield improvements occur or if cellulosic technologies develop to replace
- 178 conventional ethanol production.



179

180 Source: U.S. EPA, 2010b.

181Figure 5-3: Change in U.S. Exports by Crop Anticipated to Result from EISA182Requirements by 2022 (tons per 1,000 gallons of renewable fuel)

The model also predicts that the additional biofuel produced to meet the EISA mandates compared to "business as usual" (2.7 billion gallons of corn starch ethanol, 7.9 billion gallons of switchgrass cellulosic ethanol, 1.6 billion gallons of imported sugarcane ethanol, and 0.5 billion gallons of soybean biodiesel) will lead to the creation of 2 million acres, 3.4 million acres, 1.1 million acres, and 1.7 million acres, respectively, of additional international cropland (see Table 5-6) to supply U.S. biofuel imports and also to make up for the U.S. reductions in exports shown in Figure 5-3 (U.S. EPA, 2010b).

Table 5-6: Changes in International Crop Area Harvested by Renewable Fuel Anticipatedto Result from EISA Requirements by 2022

Feedstock's Marginal Effect Considered	International Crop Area Change (000s acres)	Normalized Crop Area Change (acre / billion BTU)
Corn Ethanol	1,950	9.74
Soy-Based Biodiesel	1,675	26.32
Sugarcane Ethanol	1,063	10.82
Switchgrass Ethanol	3,356	5.56

190 Source: U.S. EPA, 2010b.

191 Note: Figures converted from hectare to acre

192 Further, these direct and indirect land use changes will lead to significant GHG emissions

according to the model (before accounting for GHG savings resulting from petroleum displaced

as the biofuel is consumed). Figure 5-4 shows that, based on the model presented in the RIA,

soy-based biodiesel causes the largest release of international land use change GHG

emissions. The majority of international land use change emissions originate in Brazil in the corn other all and quitch groups other all according. This is largely a consequence of president destruction

ethanol and switchgrass ethanol scenarios. This is largely a consequence of projected pasture

198 expansion in Brazil, and especially in the Amazon region where land clearing causes substantial





201 202

Figure 5-4: International Land Use Change GHG Emissions by Renewable Fuel Anticipated to Result from EISA Requirements by 2022 (kgCO2e/mmBTU)

GHG emissions. Of the renewable fuels analyzed, the model found that sugarcane ethanol causes the least amount of land use change emissions. This was due largely to the EPA projection that sugarcane crops would expand onto grasslands in South and Southeast Brazil, which results in a net sequestration because sugarcane sequesters more biomass carbon than the grasslands it would replace.

208 The GHG emissions shown above can be seen as an international "carbon debt" 209 (Fargione et al., 2008). Clearing forested areas or pasture land for new cropland creates this carbon debt in which microbial decomposition of organic carbon stored in plant biomass (e.g. 210 211 branches, leaves, and fine roots) and soils leads to a prolonged period of GHG emissions. As 212 described in the RIA, the location of land use change is a critical factor determining the GHG impacts of land use change, because these impacts will vary substantially by region (U.S. EPA, 213 2010b). The conversion of higher carbon-storing types of land such as tropical rainforest will 214 lead to more carbon emissions (U.S. EPA, 2010b). A 2008 study forecasted that land conversion 215 of natural ecosystems to cropland would release an estimated 17 to 420 times as much carbon 216 dioxide as the biofuels themselves can reduce per year by displacing petroleum fuel (Fargione et 217 al., 2008). Therefore, biofuel consumption may take many years to "pay down" the carbon debt 218 219 created from production through the GHG savings from displaced petroleum. On the other hand, 220 biofuel made from more sustainable grasses or woody crops using higher-yield cellulosic 221 technologies, or from waste biomass or biomass grown on degraded and abandoned agricultural lands results in much smaller carbon debts and is more likely to lead to overall GHG reductions 222 (Fargione et al., 2008). Figure 5-5 shows forecasted crop area changes by region, with the 223 224 heaviest impacts occurring in Brazil. It should be noted that the FAPRI-CARD model does not 225 predict what type cropland will emerge in foreign countries if land use change does occur. This is an important source of uncertainty as GHG and other environmental impacts could vary 226 227 significantly depending on what crops are grown to offset decreasing U.S. agricultural exports.



Figure 5-5: Harvested Crop Area Changes by Region Anticipated to Result from EISA Requirements by 2022, 2022 (ha / billion BTU)

232 Because Brazil will likely be a major supplier of U.S. ethanol, it is informative to consider land use changes there. Brazil faces challenges of multiple forms of land use change, 233 234 both direct and indirect. Land use changes would occur as Brazil increases ethanol production by 235 converting more land previously used to grow other agricultural goods or pasture lands to grow 236 sugarcane. As pasture lands are converted to sugarcane production, ranchers are pressured to "intensify" livestock on smaller portions of land or clear more land (possibly Amazon rainforest 237 238 or Cerrado woodland) (Bustamante et al., 2009). Figures 5-4 and 5-6 isolate the impacts on 239 Brazil alone. The data presented in Figure 5-6 appear consistent with the prediction that pasture 240 land will decrease in Brazil, while increasing in the rest of the world. However, it is unclear if 241 this will result in rainforest loss or simply mean a greater number of livestock per acre. There are differing opinions on the result of this tradeoff and it is not possible at this time to predict with 242 243 any certainty what type of land use change will result from increased U.S. demand for biofuel 244 and what its environmental consequences will be (Fargione et al., 2008; Goldemberg et al., 245 2008; Searchinger et al., 2008). A recent study (Fabiosa et al., 2010) suggests that sugarcanebased ethanol production in Brazil has less significant impact on existing arable land allocation 246 247 than corn-based ethanol expansion in the United States. Fabiosa also notes that increasing corn starch-based ethanol to 15 billion gallons in the U.S. would increase corn crop area in the United 248 States by nearly 13 percent (corn crop area in Argentina and Brazil would increase by 9.5 and 249 250 4.5 percent, respectively).



- Figure 5-6: Pasture Area Changes in Brazil by Renewable Fuel Anticipated to Result from
 EISA Requirements by 2022 (ha / billion BTU)
- 255 5.4 Other Environmental Impacts

251 252

While production of biofuel feedstocks places only one of many demands on water,
fertilizer, and other inputs, its impacts will increase as its production increases. It has been
suggested that, because biofuel production requires approximately 70 to 400 times as much water

- as other energy sources such as fossil fuels, wind, and solar, an increase in biofuel crop
- 260 production could further strain global supplies of water (Gerbens-Leenes et al., 2008). Studies
- have shown that water tables are already declining in the western United States, North India,
- 262 Pakistan, North China, Mexico, and the Mediterranean (Shah et al., 2007). These trends indicate
- the vulnerability of various regions to water scarcity issues. The choice of feedstock, cultivation
- practices, and the location of cultivation will greatly influence how production of biofuel impacts
 water availability.

266 Water quality and flooding issues are also relevant. As described in Chapter 3, U.S. corn production has been a key driver of hypoxia in the Gulf of Mexico. Similar water quality issues 267 268 could arise or be exacerbated in other countries if agricultural use from feedstock production 269 expands. Conversion of land to feedstock production will have varying impacts, depending on 270 prior ecological function of the converted land and the types of management practices employed. 271 Impacts could include encroachment on wetlands and the discharge of excess nutrients to water resources. For example, Brazilian surface waters suffered from hypoxia during the early stages 272 273 of their biofuel development when the vinasse, a by-product of the sugarcane-ethanol production 274 process rich in nitrogen and potassium, was routinely discarded into rivers, lakes, and reservoirs, causing extensive eutrophication (Simpson et al., 2009). Brazilian federal law has prohibited the 275 276 dumping of vinasse into any water body since 1978. The effluent is now returned to the field as 277 fertilizer, and water quality has improved significantly. However, if other developing countries 278 opt to produce biofuel and do not properly regulate water quality impacts, eutrophication could damage these nations' aquatic ecosystems. Also, if biofuel-related land use change does occur 279 280 and if it results in deforestation and loss of wetlands, then increased flooding, sedimentation, and 281 lower stream base flows are also likely to occur. Examples of this have already been seen around 282 the world. For instance, in Southeast Asia, tropical peat swamps have been degraded because of 283 loss of forest cover due to logging for timber and conversion of forests to oil-palm plantations for 284 biofuel (Wösten et al., 2006). However, biofuel production was not the only cause of land 285 conversion, and it is possible that food-related demands for palm oil would have caused similar 286 deforestation.

287 Biofuel production also affects international air quality. While the displacement of 288 petroleum fuels by biofuels does have a positive impact, the air quality issues associated with 289 biofuel feedstock harvesting, refining, and transport could erode these savings if poor 290 management practices are allowed to occur. For instance, the practice of burning sugarcane 291 fields prior to harvesting is a serious air pollution issue in Brazil. This method has resulted in 292 large aerosol and trace gas emissions, significant effects on the composition and acidity of rainwater over large areas of southern regions, and elevated ozone levels in those areas affected 293 by the burning. However, harvest burning practices are being phased out in Brazil through state 294 regulations. In 2007, state laws ensured that 40 percent of the sugarcane was harvested without 295 296 burning in the state of Sao Paulo, and this is forecast to reach 50 percent by 2010 and about 90 297 percent by 2022 (Goldemberg et al., 2008; U.S. EPA, 2010b). Like many of the effects discussed 298 so far, the severity of air emissions will be highly sensitive to the feedstock chosen, location of 299 production, and management practices.

Finally, if increased biofuel consumption in the U.S. does lead to indirect land use
 changes and more natural habitat is cleared to create agricultural lands, a loss of biodiversity will
 occur. Many biofuel production regions coincide with areas with high biodiversity value. For

example, Indonesia (palm oil), Malaysia (palm oil), and Brazil (sugar ethanol) all contain
 ecosystems with well above average biodiversity. Depending where biofuel feedstock production
 occurs, and the manner in which it occurs, impacts to biodiversity could be significant.

306 5.5 <u>Concluding Remarks</u>

307 Projections indicate that the EISA biofuel targets will likely alter U.S. and international 308 trade patterns. How countries respond to U.S. market conditions could affect net GHG savings 309 derived from biofuel consumption and the environmental impacts that result from biofuel 310 production. As with biofuel production in the U.S., these impacts will depend largely on where 311 the crops are grown and what agricultural practices are used to grow them. To the extent that 312 local environmental impacts will have broader implications, such as contributing to global 313 warming, global mitigation strategies will have to consider the international implications of 314 biofuel production. Decisions made about what feedstocks to use, where to produce them, and what production methods to employ will have significant environmental and economic 315 316 implications.

317

1 6. CONCLUSIONS AND RECOMMENDATIONS

2 6.1 <u>Conclusions</u>

3 A variety of factors make it difficult to draw conclusions about the potential 4 environmental and resource conservation impacts of the increased biofuel production and use 5 mandated by the Energy Independence and Security Act. Of the six feedstocks discussed in this 6 Report, only corn starch and soybean have been implemented at commercial scale to produce ethanol and biodiesel, respectively. Production of biofuel from the other four feedstocks 7 8 discussed in this report is in various stages of research and development. Even for corn starch 9 and soybean, data needed to perform a thorough environmental life cycle assessment are incomplete and the relevant available data often have a high degree of uncertainty. Nevertheless, 10 initial conclusions can be drawn about how increased biofuel production and use likely will 11 12 affect (or is affecting, in the case of corn starch and soybean) water quality and quantity, soil and air quality, and ecosystems (biodiversity and invasive species) based on the data available as of 13 14 July 2010. These conclusions are presented below for the full greenhouse gas (GHG biofuel life 15 cycle (Section 6.1.1) and for stages in the life cycle: feedstock production (Section 6.1.2); biofuel production, transport, and storage (Section 6.1.3); and biofuel end use (Section 6.1.4). (See 16 Figure 2-3 in Chapter 2 for life cycle description.) These conclusions do not account for existing 17 18 or potential future mitigation measures or regulations.

19 6.1.1 Emissions Reduction

Fuel combustion at ethanol and biodiesel facilities releases GHGs. However, when the entire biofuel life cycle is considered (as described in Chapter 4, Section 4.3.2.3), the revisions to the Renewable Fuel Standard (RFS2) program mandated by the Energy Independence and Security Act (EISA) are expected to achieve a 138-million metric ton reduction in CO₂equivalent emissions by 2022.

- 25 6.1.2 Feedstock Production
- 26 **6.1.2.1 Overview**

27 Figure 6-1 provides a qualitative overview, based on EPA's best professional judgment, 28 of the maximum potential range of domestic environmental and resource conservation impacts 29 associated with per unit area production of the six feedstocks discussed in this Report. 30 Qualitative assessment is grounded in information and data published in the peer-reviewed 31 literature through July 2010, which are described in Chapter 3. Range extremes for each impact 32 category were determined by considering plausible conditions under which a "most negative" 33 and "most positive" environmental impact would likely arise. Key assumptions for these 34 conditions appear in Figure 6-1; for full, detailed elaboration of the conditions, which encompass 35 a variety of factors, including land use, feedstock production management choices, region, 36 technology used, regulatory control, and mitigation measures, see Appendix C, Table C-1.

	Maximum Potential		Key Assumptions ¹		
		Range of Environmental	Maximum Potential	Maximum Potential	
	Impact Category	Impacts per Unit Area ¹	Negative Environmental	Positive Environmental	
	(Report Section)		Impact	Impact	
ê	Water Quality (3.2.2)	•••••	Conventionally managed corn replaces CRP	Diversion of existing corn production to fuel	
arch	Water Quantity (3.2.3)		Irrigated (irr.) corn replaces non-irr.	Production of non-irr. corn	
(St	Soil Quality (a.a. ()		Conventionally managed corn	Diversion of existing corn production	
orn			replaces CRP	to fuel	
0	Air Quality (3.2.5)		land	to fuel	
	Biodiversity (3.2.6.1)		Conventionally managed corn replaces CRP	Diversion of existing corn production to fuel	
	Invasiveness (3.2.6.2)	•	Negligible k	nown impact	
	Water Quality (3.2.2)		Soy replaces CRP	Soy replaces corn	
u	Water Quantity (3.2.3)		Irr. soy replaces non-irr. land	Non-irr. soy replaces irr. corn	
/bea	Soil Quality (3.2.4)		Soy replaces CRP	Soy replaces corn	
Soj	Air Quality (3.2.5)		Irr. soy replaces non-irr. land	Non-irr. soy replaces irr. corn	
			Soy replaces CRP	Soy replaces corn	
				Site-specific removal to minimize	
<u>ـ</u>			High removal on erodible land	erosion	
ove	Water Quantity (3.2.3)	□	High removal on irr. land	need for irrigation	
n St	Soil Quality (3.2.4)		High removal on erodible land	Site-specific removal to minimize erosion	
Cori	Air Quality (3.2.5)		Extra harvesting pass required	Single-pass harvest with grain	
	Biodiversity (3.2.6.1)		High removal on erodible land	Site-specific removal to minimize	
	Invasiveness (3.2.6.2)	•	Negligible k	nown impact	
	Water Quality (3.4.2)		Short interval woody crop replaces	Long interval woody crop replaces	
s	Water Quantity (3.4.3)		SRWC that is irrigated	Thinning or non-irr. woody crop	
nas	Soil Quality (3.4.4)		Short interval woody crop replaces	Long interval woody crop replaces	
Biol	A. O. III		mature plantation See "Water Quality" + woody crop	short interval plantation See "Water Quality" + woody crop	
δ	All Quality (3.4.5)		emits isoprene	with low isoprene emissions	
Nov	Biodiversity (3.4.6.1)		mature plantation	short interval plantation	
-	Invasiveness (3.4.6.2)		Woody crop (ex. <i>Eucaluptus</i>)	Non-invasive woody crop used	
s	Water Quality (3.3.2)		Conventionally managed grass	Conservation managed grass	
sse	Water Quantity (a.e.o.)		replaces CRP	replaces conventional corn	
Gra	Water Quantity (3.3.3)		Conventionally managed grass	Conservation managed grass	
nial	Soil Quality (3.3.4)		replaces CRP	replaces conventional corn	
ren	Air Quality (3.3.5)		Irr. grass replaces non-irr. land use	conservation managed, non-irr. grass replaces irr. corn	
Ъе	Biodiversity (3.3.6.1)		Uniformly managed grass replaces	Diversely managed grass replaces	
	Invasiveness (3.3.6.2)		Non-native grasses invade	Non-invasive grasses used	
	Water Quality (3.5.2)		Untreated effluent is discharged	Grown with wastewater	
	Water Quantity (3.5.3)		Freshwater, open pond in dry region	Recycled wastewater, closed	
e	Soil Quality (3.5.4)	•	Negligible k	nown impact	
٩lga	Air Quality (3.5.5)		Manufactured nutrients added	Wastewater nutrients used	
	Biodiversity (3.5.6.1)	4	Negligible k	nown impact	
	Invasiveness (3.5.6.2)	Ц	Algae in open ponds invade	Non-invasive algae in closed	
1				DIOTEdCIOIS	

38

Bars are conditioned on key assumptions described briefly here and fully elaborated in Appendix C, Table C-1. Legend

Magnitude		Type of Effects		Certainty
(length of bar)	Negative effects	Negligible effect	Positive effects	(shading)
Relatively large		0		Least certain
Moderate		0		Moderately certain
Relatively minor	—	•		Most certain

Figure 6-1: Maximum Potential Range of Environmental Impacts (on a Per Unit Area Basis) Resulting from Cultivation and Harvesting of the Six Biofuel Feedstocks Considered in This Report

Impacts shown in this figure are only relative to each other. No attempt has been made to compare impacts to those of petroleum production, nor do impacts represent possible environmental benefits gained by petroleum displacement. In addition, impacts are only relevant for those regions where each feedstock is likely to be grown (see Chapter 3). Impacts for corn stover do not include the impacts of corn production itself but rather impacts of stover removal above and beyond corn cultivation and harvest. Air quality impacts do not include changes in GHG emissions.

Bar direction signifies whether the effect is negative (left) or positive (right). *Bar length* indicates the anticipated magnitude of effect, and *shading density* depicts the associated degree of certainty. A *circle* signifies that no net effect is anticipated. Section numbers next to the impact category indicate where in this Report the information that provides the basis for the bars in this figure can be found.

54 When the potential range of production conditions is considered, four feedstocks 55 (soybean, woody biomass, perennial grasses, and algae) are anticipated to have both negative and positive environmental impacts. The most positive environmental outcome for corn starch and 56 corn stover is no net effect, achieved largely through minimization of land use change and 57 through site-specific agricultural management, including comprehensive conservation practices. 58 59 Most feedstocks (corn starch, soybean, corn stover, woody biomass, and perennial grasses) have the potential to have impacts in at least five of the six environmental categories shown in the 60 figure; algae are anticipated to have impacts in only four of the categories (water quality, water 61 62 quantity, air quality and invasiveness). A higher degree of certainty is associated with the two 63 feedstocks that are already commercially produced (corn starch and soybean) than with those in development (corn stover, woody biomass, perennial grasses, and algae). 64

65 **6.1.2.2 Conclusions**

66 Key conclusions concerning environmental impacts of biofuel feedstock cultivation are 67 as follows:

68 Water Quality. Increased cultivation of feedstocks for biofuel may affect water quality 69 and hypoxia conditions in the Gulf of Mexico and other vulnerable water bodies through increased erosion and runoff and leaching of fertilizers and pesticides to ground and surface 70 71 waters. Cellulosic feedstocks may have less water quality impact than corn starch and corn stover due to projected decreased fertilizer use and decreased soil erosion. Comprehensive 72 73 management systems and practices are one tool that may mitigate some of these impacts if they 74 are widely and effectively implemented. Compared to corn and soybeans, cultivation of some 75 cellulosic feedstocks may provide benefits, including soil stabilization, reduced soil erosion and 76 nutrient runoff, and increased nutrient filtration.

Water Quantity. Effects of feedstock production on water availability vary greatly by feedstock, processes used to produce the feedstock, and location. Corn and soybean cultivation for biofuel production have a greater water demand than perennial grasses, woody biomass, and algae. Regional differences are mostly due to precipitation which, when insufficient, necessitates supplemental irrigation, which can be a significant water use in the biofuel production process. In irrigated regions, the method and efficiency of irrigation can also affect the amount of water used. For both corn and soybeans, the source for irrigation water varies from region to region,

84 potentially affecting water tables and/or surface waters. Removal of corn stover can reduce soil

85 moisture, resulting in a need for increased irrigation. Water quantity effects may be mitigated by 86 growing feedstocks in areas that do not require irrigation and by using efficient irrigation

growing feedstocks in areas that do not require irrigation and by using e
practices, such as reclaimed water use.

88 Soil Quality. Increased cultivation of corn, soybean, woody biomass, and perennial 89 grasses will affect soil quality in various ways, depending on the feedstock. Effects include 90 increased soil erosion, decreased soil organic matter content, increased soil GHG emissions, and 91 increased nitrogen and phosphorus losses to ground and surface waters. Annual crops, such as 92 soybean and corn, will have higher erosion rates than non-row crops, such as perennial grasses 93 and woody biomass. However, cultivation of corn or soybean at higher rates (i.e., greater yield 94 per acre) on existing corn or soybean acreage likely will not alter soil erosion rates significantly. 95 Soil quality impacts from biofuel feedstocks may be ameliorated by the choice of feedstock and 96 by the diligent use of generally accepted conservation practices.

Air Quality. Activities associated with growing biofuel feedstocks emit air pollutants,
 which affect air quality, with effects varying by region. Production of row crops will affect air
 quality more than non-row crops. Pollutants from row crops include farm equipment emissions
 and soil and related dust particles (e.g., fertilizer, pesticide, and manure) made airborne as a
 result of field tillage and fertilizer application, especially in drier areas of the country.

Biodiversity. Increased cultivation of corn and soy feedstocks could significantly affect biodiversity (1) through habitat alteration when uncultivated land is moved into production, and (2) from exposure of flora and fauna to high pesticides concentrations. Aquatic habitat may be impaired by soil erosion and nutrient runoff. Biodiversity impacts can be mitigated by choosing crop and cultivation methods that minimize habitat alteration and runoff.

107 **Invasiveness.** Corn and soybean pose little risk of becoming weedy or invasive in the 108 U.S. In certain regions, some perennial grasses, short-rotation woody crops, and algae strains 109 pose greater, though uncertain, risk of becoming an agricultural weed or invasive in natural 110 areas. Transport of grass and short-rotation woody crop seeds and plant parts capable of vegetative reproduction from the field to biofuel production facilities may increase the 111 opportunity for seeds and plant parts capable of vegetative reproduction to establish themselves 112 113 in feral populations along transportation corridors. Algae produced in photo-bioreactors are less 114 likely to become invasive than algae produced in open ponds.

115 6.1.3 Biofuel Production, Transport, and Storage

As described below, biofuel production, transport, and storage can impact water quality,
water quantity, and air quality.

118 **6.1.3.1 Overview**

Figure 6-2 provides a qualitative overview, based on EPA's best professional judgment, of the maximum potential range of domestic environmental and resource conservation impacts associated with per unit volume production, transport, and storage of ethanol from corn and cellulosic feedstocks and biodiesel from soybean (though biodiesel from algae should not be

- appreciably different). Qualitative assessment is grounded in information and data published in
- the peer-reviewed literature through July 2010, which are described in Chapter 4. As with Figure
- 125 6-1, range extremes for each impact category were determined by considering plausible
- 126 conditions under which a "most negative" and "most positive" environmental impact would
- 127 likely arise. Key assumptions for these conditions appear in Figure 6-2; for full, detailed
- elaboration of the conditions, which encompass a variety of factors, including region, technology
- 129 used, regulatory control, and mitigation measures, see Appendix C, Table C-2.
- 130 Impacts shown in this figure are only relative to each other. No attempt has been made to 131 compare impacts to those of petroleum production, nor do impacts represent possible
- 132 environmental benefits gained by petroleum displacement.
- Bar conventions used in Figure 6-1 are the same as those used in Figure 6-2.
- As Figure 6-2 illustrates, the environmental impacts of biofuel production, transport, and storage are expected to be largely negative (see Chapter 4 for more details). However, for all
- three fuel types, impacts can be minimized through appropriate facility siting, waste treatment, and improved, more efficient technology.
- Water Quality. Pollutants in the wastewater discharged from biofuel production impact water quality. Biological oxygen demand (BOD), brine, ammonia-nitrogen, and phosphorus are primary pollutants of concern from ethanol facilities. BOD, total suspended solids, and glycerin pose the major water quality concerns in biodiesel facility effluent. Actual impacts depend on a range of factors, including the type of feedstock processed, biorefinery technology, effluent controls, and water re-use/recycling practices, as well as the facility location and source and receiving water.
- Water Quantity. Biofuel production facilities draw on local water supplies to produce
 fuel, but the quantity of water used is modest compared to that required to produce biofuel
 feedstocks. Impacts will depend on the location of the facility in relation to water resources.
- 148 Water availability issues can be mitigated by siting production facilities where water is abundant.
- 149 Air Quality. Emissions from biofuel production facilities are generated primarily by the 150 stationary combustion equipment used for energy production. Compared to two scenarios ([1] 151 the original renewable fuel standard of 7.5 billion gallons, and [2] a 2022 renewable fuel volume of 13.6 billion gallons projected by the Department of Energy's 2007Annual Energy Outlook), 152 153 RFS2-mandated increased biofuel production will likely result in decreased emissions of carbon 154 monoxide and benzene, and increased emissions of nitrogen oxides, volatile organic compounds, 155 particulate matter, and several air toxics. Since biofuel production facilities are regulated under the Clean Air Act and subject to state/local permits, enforcement of existing regulations will 156 mitigate air quality impacts. Emissions can be further reduced through use of cleaner fuels (e.g., 157 158 natural gas instead of coal) and more efficient process and energy generation equipment.

		Maximum Potential	Key Assı	umptions ¹
	Impact Category (Report section)	Range of Environmenta Impacts per Unit Volume ^{1,2}	Maximum Potential Negative Environmental Impact	Maximum Potential Positive Environmental Impact
_	Water Quality (4.4.2, 4.6.2)		High BOD effluent; DDG byproduct fed to livestock with poor waste management; underground storage tanks (USTs) leak	Effluent treated; DDG-fed livestock waste managed; USTs do not leak
Corn Ethano	Water Quantity (4.3.3)		3-6 gallons water/gallon ethanol	Improved water use efficiency
	Air Quality ³ (4.3.2, 4.4.1, 4.5.1, 4.6.1)	-	Ethanol facility coal-powered	Ethanol facility natural gas- powered
_	Water Quality (4.4.2, 4.6.2)		High BOD, total suspended solids (TSS), glycerin effluent	Effluent treated
oybean iodiesel	Water Quantity (4.3.3)	+	<1 gallon water/gallon biodiesel	<1 gallon water/gallon biodiesel
ΝЩ	Air Quality ³ (4.3.2, 4.4.1, 4.5.1, 4.6.1)		Biodiesel facility coal-powered	Biodiesel facility natural gas- powered
0	Water Quality (4.4.2, 4.6.2)		High BOD effluent; USTs leak	Effluent treated; USTs do not leak
ellulosi Ethanol	Water Quantity (4.3.3)		10 gallons of water/gallon cellulosic ethanol	Improved water use efficiency
Ŭ	Air Quality ³ (4.3.2, 4.4.1, 4.5.1, 4.6.1)		Ethanol facility coal-powered	Ethanol facility natural gas- powered

¹ Bars are conditioned on key assumptions described briefly here and fully elaborated in Appendix C, Table C-2.

²Comparisons are made on the basis of equal volumes of the biofuels indicated.

³Impacts shown are immediate impacts from biofuel production to end use. No attempt is made in this table

to represent air quality impacts based on displaced gasoline emissions. See Section 4.5 for more information.

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Legend

Г	<u>Magnitude</u>		Type of Effects		Certainty
	(length of bar)	Negative effects	Negligible effect	Positive effects	(shading)
	Relatively large		0		Least certain
	Moderate		0		Moderately certain
	Relatively minor		•		Most certain

Figure 6-2: Maximum Potential Range of Environmental Impacts (on a Per Unit Volume Basis) Resulting from Ethanol and Biodiesel Production, Transport, and Storage

1646.1.3.2Biofuel Transport and Storage

Biofuel transport and storage may impact water and air quality.

Water Quality. Leaks and spills of biofuel from above-ground, underground, and transport tanks can potentially contaminate ground, surface, and drinking water. A leaking underground storage tank can also present other health and environmental risks, including the potential for fire and explosion. Enforcement of existing regulations concerning corrosion protection, leak detection, and spill and overfill prevention will minimize water contamination. Selection and use of appropriate materials and proper design in accordance with the applicable material standards will also prevent biofuel leaks.

Air Quality. Air quality will be affected by emissions from biofuel transport via rail,
 barge and tank truck and by evaporative, spillage, and permeation emissions from transfer and
 storage activities. However, the impacts are not expected to be significant.

176 **6.1.4 Biofuel End Use**

177 Air Quality. Evaporative and tailpipe emissions from biofuel combustion show great 178 variability due to a range of factors, including the vehicle age, how the vehicle is operated, and 179 ambient temperatures. Emissions in 2022 are expected to be higher for some pollutants and 180 lower for others compared to two scenarios (described in 6.1.3.1). In general, biodiesel 181 combustion has been shown to decrease particulate matter, carbon monoxide, and hydrocarbon 182 emissions, increase nitrogen oxide emissions, and increase ozone-forming potential compared to 183 fossil fuel diesel. Emissions from ethanol use are independent of feedstock; in contrast, emissions from biodiesel use differ according to the feedstock. Particulate matter, nitrous oxide, 184 185 and carbon monoxide emissions are higher for plant-based biodiesel than for animal-based 186 biodiesel.

187 6.1.5 International Considerations

188 Increases in U.S. biofuel production and consumption volumes will affect many different 189 countries as trade patterns and prices adjust to equate global supply and demand. This will result 190 in environmental impacts, both positive and negative, including effects from land use change and 191 effects on air quality, water quality, and biodiversity. Direct and indirect land use changes will 192 likely occur across the globe as the U.S. and other biofuel feedstock-producing countries alter 193 their agricultural sectors to allow for greater biofuel production. Many locations where biofuel 194 production is growing are areas of high biodiversity value. For example, Indonesia (palm oil), 195 Malaysia (palm oil), and Brazil (sugar ethanol) all contain ecosystems with well-above-average 196 biodiversity. Depending where biofuel feedstock production occurs, impacts to biodiversity 197 could be significant. Particularly in Malaysia and Indonesia, which have already lost 198 considerable forest cover due to their large timber industries, expansion of palm oil plantations 199 for biodiesel could potentially compound impacts on natural resources. However, because corn 200 ethanol, the biofuel with the greatest potential for international impact in terms of trade pattern 201 changes, is limited by the RFS2 and is likely to reach this limit in the next few years, these 202 international impacts could level off as corn starch ethanol production levels off or is replaced by 203 more advanced technologies.

As with domestic production, the choice of feedstock, how and where it is grown, the resulting land-use changes, and how it is produced and transported will have a large effect on how biofuel production and use affects water quality and availability, air quality (e.g. due to emissions from burning crop residue), and biodiversity. The specific impacts will reflect a country's particular circumstances.

209 6.2 <u>Recommendations</u>

210 EISA Section 204 specifies that EPA include recommendations for actions to address any 211 adverse impacts identified in this report. Responding specifically to this request requires a clear 212 understanding of biofuel impacts and their causes. Impacts from corn starch and soybean production are relatively well understood, however, more information is needed about the 213 214 adverse impacts associated with production of other feedstocks and with the production and use 215 of advanced biofuel. This section presents four recommendations to address adverse impacts. Because biofuel impacts cross multiple topics and EPA responsibilities, EPA likely will address 216 217 these recommendations through continued and strengthened cooperation with other federal 218 agencies and international partners.

219 6.2.1 Comprehensive Environmental Assessment

220 The biofuel industry is poised for significant expansion in the next few years. A variety of new technologies likely will be implemented and old technologies modified to meet the 221 222 demands of affordable and sustainable petroleum fuel alternatives. As emphasized by Congress in requiring triennial biofuel impact assessments, it is important to evaluate the environmental 223 224 implications associated with the ongoing growth of the dynamic biofuel industry. However, as 225 noted earlier, the inherent complexity and uncertainty of environmental impacts across the 226 biofuel supply chain make it difficult to provide assessments that are sufficiently definitive to 227 inform environmental decisions.

228 **RECOMMENDATION: Develop and evaluate environmental life cycle assessments for** biofuels. With this Report, EPA and the U.S. Departments of Agriculture and Energy (USDA 229 230 and DOE) have begun to develop a framework and partnership that provide an important 231 foundation for future assessments. Future assessments will address advanced biofuel production associated with specific feedstocks and associated by-products and provide a comparative 232 233 context to fossil fuels. As described in Chapter 7, future assessments will be comprehensive and 234 will address the major environmental parameters affected by increased biofuel production and 235 use. These assessments will identify gaps and uncertainties in the knowledge base; inform the 236 design and implementation of monitoring strategies and measures for evaluating impacts; 237 provide comprehensive tools for comparing and evaluating development options; and provide the 238 scientific bases for regulatory agencies and the biofuel industry to make environmentally 239 conscious decisions.

240 6.2.2 Coordinated Research

The biofuel industry is expected to expand rapidly and broadly. This expansion will be shaped to a large degree by the research behind the technological developments that make

243 biofuel production feasible. It will be important for the scientific infrastructure that supports

244 policy and decision-making to keep pace with industry developments.

245 **RECOMMENDATION: Ensure the success of current and future environmental biofuel** research through improved cooperation and sustained support. The Biomass Research and 246 247 Development Board, co-chaired by DOE and USDA, currently monitors interagency biofuel 248 research cooperation. The Board recently proposed that an inventory be conducted of federal 249 activities and jurisdictions relevant to environmental, health, and safety issues associated with 250 biofuel production in order to identify issues of concern, research needs, and mitigation options. 251 Efforts to adjust and expand existing research programs to conduct biofuel-relevant research 252 have been initiated. Prioritization and collaboration by the research community will be critical to 253 provide meaningful results in the near term and to meet the wide variety of research needs. 254 including many that have already been identified, that will be important to the industry and to 255 appropriate regulatory oversight.

256 6.2.3 Mitigation of Impacts from Feedstock Production

257 As the biofuel industry expands, it will be important to optimize benefits while minimizing adverse impacts. Since many of the known adverse impacts are due to feedstock 258 259 production, this Report has described the potential for mitigation of those impacts through the 260 adoption of conservation systems and practices on farms. USDA has a variety of programs that help agriculture producers implement these conservation systems. As USDA's Conservation 261 262 Effects Assessment Project (CEAP) report on the Upper Mississippi River Basin demonstrates, 263 much more needs to be done to control pollution from agriculture, especially from nitrogen. A collaborative effort is needed to develop and foster application of consistent and effective 264 265 monitoring and mitigation procedures to protect the environment and conserve biodiversity and 266 natural resources as biofuel production expands and advanced biofuels are commercially 267 produced.

268 **RECOMMENDATION:** Improve the ability of federal agencies (within their existing 269 authorities) and industry to develop and implement best management and conservation 270 practices and policies that will avoid or mitigate negative environmental effects from biofuel production and use. These policies and practices should be aligned and assessed within 271 the context of the environmental life cycle assessment and take a multi-factor and multi-scale 272 273 view of biofuels and their potential environmental effects. Priority areas for development include 274 (1) improved containment processes that minimize environmental exposure from air emissions 275 and runoff into surface and ground water, and (2) methods to monitor, track, and report biofuel 276 environmental impacts.

277 6.2.4 International Cooperation to Implement Sustainable Biofuel Practices

EISA specifically identifies "significant emissions from land use change" as a potential environmental impact stemming from domestic biofuel production and consumption. This concern is relevant to all countries engaged in biofuel production, but as the U.S. increases domestic production of corn starch ethanol and soybean diesel, exports of corn and soybean for agricultural or other uses are expected to decline, which may result in indirect land use change in the form of land conversion to agriculture in other countries. Additional biofuel produced to

- 284 meet the EISA mandates will potentially lead to increases in acreages of international cropland,
- although these increases may level off after 2015 (see Section 5.2).

286 **RECOMMENDATION: Engage the international community in cooperative efforts to** 287 identify and implement sustainable biofuel practices that minimize environmental impact.

287 Identify and implement sustainable biofuel practices that minimize environmental impact. 288 U.S. and international capacity to minimize the consequences of land use change will depend not

only the willingness of governments and industry to make environmentally sound choices

regarding biofuel production, processing, and use, but also on the availability of cost-effective mitigation strategies. The U.S. can significantly contribute to such an effort by actively engaging

- the scientific community and biofuel industry to collaboratively develop the body of knowledge
- 293 needed to support sound environmental decision-making. This effort will be facilitated by a
- greater understanding and appreciation of how increased biofuel demand may impact the
- environment internationally, particularly in countries that are most active, or most likely to
- become active in biofuel production.

1 7. Assessing Environmental Impacts from Biofuels: 2013 to 2022

2 7.1 <u>Introduction</u>

In requiring EPA to report triennially under EISA Section 204, Congress recognized that the environmental and resource conservation impacts of increased biofuel production and use will be dynamic, changing in both nature and scope, based on the amount, type, and location of biofuels produced and used. This first triennial Report to Congress, which reflects the state of scientific knowledge as of July 2010, is a first step toward identifying information that supports future assessment of environmental impacts from increased biofuel production and use.

9 This chapter outlines an approach EPA will use for its future assessments, beginning with 10 the 2013 Report to Congress. In developing future assessments, EPA will work closely with the 11 U.S. Departments of Agriculture and Energy (USDA and DOE) and will seek extensive input 12 from industry and other stakeholders and peer review from the scientific community to create 13 substantive, science-based analyses that facilitate environmental decision-making. Future 14 assessments will benefit from advances in the science of environmental assessment and increased

15 availability of relevant research results on this important topic.

16 EPA anticipates that additional research and analyses will allow for more robust and 17 quantitative assessments of biofuel environmental impacts than are reported here. For example, life cycle assessment (LCA) tools and approaches that are currently used for evaluating "cradle-18 19 to-grave" resource consumption and waste disposal for specific products can be integrated into 20 risk assessment to form a powerful composite approach for assessing environmental impacts. An approach to more comprehensive environmental analyses that is consistent with the integration 21 22 of LCA and risk assessment methods has been used in different assessments (Davis and Thomas, 23 2006; Davis 2007). This approach would necessitate extending consideration of factors across 24 the entire biofuel life cycle, including current and future feedstock production and biofuel 25 conversion, distribution, use. The Agency has already applied LCA to assess greenhouse gas (GHG) emissions as part of its revised Renewable Fuel Standard (RFS2) program (U.S. EPA, 26 27 2010b) and could adapt this approach to analyze other aspects of biofuel production and use, 28 such as water consumption; evaluation of fossil fuels versus biofuels; net energy balance; 29 production and use scenarios; and market impacts (economics).

30 7.2 Components of the 2013 Assessment

31 This section briefly describes key components that EPA plans to utilize in conducting its 32 2013 assessment. Comprehensive environmental assessment (CEA) would provide an organizing framework for evaluating and, where possible quantifying, risk and benefits of biofuel 33 production and use. CEA would integrate LCA, described in Section 7.2.1, and environmental 34 risk assessment, described in Section 7.2.2. The latter could be used to systematically assess 35 environmental risks, both human health (see Section 7.2.3) and ecological, for each stage in the 36 life cycle and potentially cumulative impacts. Conceptual models (Section 7.2.4) will illustrate 37 38 the important factors being considered in each stage of the life cycle and indicate how these 39 factors are interrelated. Where possible, environmental indicators and other metrics (Section 7.2.5) will be developed over the next several years to track the impacts of biofuel production 40 and use throughout its life cycle and measure the effectiveness of regulatory and voluntary 41

42 practices in ameliorating these impacts. A scenario-based approach (Section 7.2.6) is currently

43 envisioned to provide a comparative basis for projecting and assessing how biofuel production

44 and use will affect the environment in future years. Finally, the 2013 assessment will include

45 other components, such as a comparison to fossil fuels, net energy balance, and analysis of 46 market impacts (Section 7.2.7) that are important to evaluating biofuel impacts

46 market impacts (Section 7.2.7), that are important to evaluating biofuel impacts.

47 7.2.1 Life Cycle Assessments

48 LCAs have been widely used to assess the potential and pitfalls for bio-ethanol as a 49 transportation fuel (von Blottnitz and Curran, 2007). The majority of such analyses have focused 50 on particular components such as GHG emissions and energy balances (Hill, 2009), with varied 51 results based on the assumptions and input parameters used to drive assessments. In some cases, 52 the scientific community seems close to reconciling the various assumptions used by different 53 investigators (Anex and Lifset, 2009). To better address the EISA reporting mandate, however, a 54 broader profile of potential environmental impacts should be considered. This approach has been 55 used in several studies (von Blottnitz and Curran, 2007) and applied to evaluating trade-offs for fuel options (Davis and Thomas, 2006). As part of the 2013 assessment, EPA anticipates 56 57 utilizing LCA in a broad context, one that considers a full range of potential environmental effects and their magnitude. A variety of environmental LCA approaches have been developed 58 59 that would prove useful for such an effort (Duncan et al., 2008; Ekvall, 2005; Hill et al., 2006; 60 Puppan, 2002).

61 7.2.2 Environmental Risk Assessment

62 Environmental risk assessment will be fundamental for systematically evaluating the 63 human and environmental impacts of the activities involved in biofuel production and use. 64 Environmental risk assessment can be used to estimate the risks associated with each stage of the biofuel life cycle, from production of raw materials through transportation to waste products. 65 66 Environmental risk assessment is initiated by clearly articulating the problem (i.e., problem 67 formulation), describing the critical factor, pathways, and linkages among these factors, quantifying human/ecological exposure and effects, and subsequently characterizing and 68 69 estimating the risks associated these effects. Environmental risk assessment will identify which 70 stages in the biofuel life cycle contribute the greatest risk so that more informed risk 71 management practices can be developed and implemented for these stages.

72 7.2.3 Human Health Assessment

73 Increasing biofuel use presents the potential for distinct health effects separate from the 74 known impacts of fossil fuels. The fate and transport of these new fuel blends in the environment 75 and the subsequent exposures and human health effects have not been fully studied. Drawing 76 definitive conclusions on health impacts is not realistic at this time, given the unknowns 77 surrounding the feedstocks, technologies, and fuel blends that will be used to meet target 78 volumes, and the relatively limited availability of toxicological data to directly evaluate the 79 potential health effects of the various emissions.

Health effects will be assessed in the 2013 report, provided adequate data are available.
In examining the health risks and benefits of increased biofuel use, it will be important to

- 82 understand the unique characteristics of the new fuel blends; how and when releases occur; the
- 83 fate and transport of these releases; the relevant routes and duration of exposures to humans; and
- 84 the toxic effects of those exposures. Both individual and population exposures will be important
- 85 to consider. For example, populations in regions that both produce and use biofuel will
- 86 experience different exposures than those in regions that only use the fuel. Individuals within the
- 87 same region may experience different exposures (i.e., occupational, consumer, or public
- 88 exposures), and vulnerable populations may be at greater risk of adverse effects, depending on
- 89 their sensitivity.

90 7.2.4 Conceptual Models

A number of tools are available for use in problem formulation, including conceptual diagrams, which hypothesize relationships between activities and impacts. These diagrams can support multiple purposes, including defining system boundaries; enhancing understanding of the system being analyzed; and supporting communication among assessors, between assessors and stakeholders, and, ultimately, with risk managers.

96 The information provided in Chapters 3, 4, and 5 of this 2010 assessment lay a 97 foundation for constructing initial conceptual models to show relationships among biofuel 98 activities and impacts. Figures 7-1 and 7-2 present generalized conceptual models for feedstock 99 and biofuel production, respectively. Appendix D provides detailed conceptual diagrams for each of the feedstocks and fuels considered in this Report. Based on the information gathered during 100 101 this 2010 assessment, the diagrams show the activities (e.g., crop rotation, water use) associated 102 with the model's domain area and how, through a series of relationships indicated with lines and 103 arrows, these activities are associated with products and impacts. These diagrams are the first 104 step in mathematically simulating the system and quantifying impacts. Diagrams such as these 105 will be important tools for assessments in EPA's future Reports to Congress.

106 7.2.5 Monitoring, Measures, and Indicators

107 EPA's ability to accurately assess impacts attributable to biofuels production and use will 108 depend on having timely, relevant, and accurate monitoring information that tracks potential 109 impacts, and how effective regulatory and voluntary management practices, risk management practices, and other measures are in protecting the environment. While current environmental 110 111 monitoring by various agencies can provide helpful information, targeted monitoring for 112 potential biofuel impacts will be needed, requiring a collaborative effort across multiple agencies 113 and other organizations. Indicators and measures will be important for a variety of environmental 114 effects, including GHG emissions, human and ecological health indicators, eutrophication, and many others. These metrics will inform decisions at all levels along the biofuel supply chain and 115 116 well beyond the scope of the individual decision.



Figure 7-1: Conceptual Diagram of the Environmental Impacts of Biofuel Feedstock Production



Figure 7-2: Conceptual Diagram of the Environmental Impacts of Biofuel Production and Use

123 7.2.6 Scenarios

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EPA's 2013 Report to Congress will assess the environmental impacts of all five stages in the biofuel supply chain (Figure 2-3). One approach may be to create scenarios based on volumetric biofuel requirements for 2022 as presented in the RFS2 (see Table 2-1). For example:

- Scenario A: 2022 RFS2-projected feedstock mix produced with comprehensive conservation systems.
- Scenario B: 2022 RFS2-projected feedstock mix produced with existing levels of conservation practice implementation.
 - Scenario C: 2022 conventional feedstock mix (corn starch, corn stover, and soybean) produced with existing levels of conservation practice implementation.
- 135 136 Figure 7-3 shows possible impacts in all six impact categories for these three scenarios based on the feedstocks and fuels discussed in this Report. Scenarios are for illustrative purposes 137 138 only to show the potential rage of environmental impacts given assumptions about feedstock 139 production locations and practices; fuel production, transport, storage, and use patterns and 140 technologies; and target volumes (Appendix C, Table C-3). They do not necessarily represent the most likely future developments in biofuel production systems. The magnitude, direction, and 141 142 certainty of bars (see figure legend) are based on expert interpretation of all available scientific, 143 peer-reviewed literature as of July 2010. Bars are relative to one another and do not reflect a 144 comparison with petroleum-based transportation fuel. Future versions of this Report to Congress 145 will expand and update this assessment.
- As noted earlier, the landscape of feedstock/biofuel production, conversion, and use is highly dynamic and constantly evolving. Which feedstocks and technologies are used and to what extent will be influenced by technological developments and market forces that are difficult to predict. Development of scenarios for future assessments will need to model or otherwise account for key factors that influence the biofuel market dynamics and associated environmental impacts. These factors include:
- 152 Regional considerations. In general, biofuel conversion facilities will tend to be • 153 sited at reasonable distances from feedstock production areas, since cost 154 considerations limit the distances over which biofuel feedstocks can be 155 transported. Consequently, environmental impacts of both feedstock production and biofuel conversion will tend to be concentrated in particular regions. 156 157 158 Scale and volume of future commercial biofuel operations. Future development • 159 and application of commercially viable biofuel technologies will change the 160 nature of energy feedstocks and conversion processes in use, as well as the scale of their operation. While the continued use of corn starch for ethanol will likely 161 not change, the future profile of feedstocks and biofuels could vary from those 162 used in 2010, but which will actually be used and to what extent is highly 163 164 uncertain.

al		Impact Category Production Volume	Sc. A: Envir. impacts from 2022 RFS2 projected feedstock mix produced with conservation/ BMPs and efficient technologies ¹	Sc. B: Envir. impacts from 2022 RFS2 projected feedstock mix produced with minimal conservation/ BMPs and current technologies ¹ 15 BG	Sc. C: Envir. Impacts from 2022 conventional feedstock mix produced with minimal conservation/ BMPs and current technologies ¹ 15 BG
Convention Ethanol	Corn Starch	Water Quality Water Quantity Soil Quality Air Quality Biodiversity Invasiveness	••••		
lo	Corn Stover	Production Volume Water Quality Water Quantity Soil Quality Air Quality Biodiversity Invasiveness	4.9 BG		
Cellulosic Ethar	Woody Biomass	Production Volume Water Quality Water Quantity Soil Quality Air Quality Biodiversity Invasiveness	0.1 BG	0.1 BG	0 BG
0	Perennial Grass	Production Volume Water Quality Water Quantity Soil Quality Air Quality Biodiversity Invasiveness	7.9 BG	7.9 BG	0 BG
-based sel	Soybean	Production Volume Water Quality Water Quantity Soil Quality Air Quality Biodiversity Invasiveness	0.66 BG	0.66 BG	1.0 BG
Biomass Dies	Algae	Production Volume Water Quality Water Quantity Soil Quality Air Quality Biodiversity Invasiveness	0.1 BG	0.1 BG	0 BG

¹ Bars represent total environmental impacts based on impacts from feedstock production on a per area basis;

fuel production, distribution, storage and use on a per volume basis; total volume produced; and assumptions of each scenario fully described in Appendix C, Table C-3.

Legend

Magnitude		Direction of Effect		Certainty
(length of bar)	Negative effect	Negligible net effect	Positive effect	(shading)
Relatively large		0		Least certain
Moderate		0		Moderately certain
Relatively minor		•		Most certain

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Figure 7-3: Cumulative Domestic Environmental Impacts of All Steps in the Biofuel Supply Chain System under Three Scenarios in 2022

169		•	Hybrid processes. Biofuel conversion processes (e.g., biochemical and
170			thermochemical processes) may evolve in the future to be hybrid processes that
171			would produce not only biofuel but also synthetic chemicals and other industrial
172			co-products. Integrated biorefineries may have the ability to make use of a
173			biofuel-only or a hybrid conversion platform. Each new conversion option will
174			present its own range of potential environmental impacts.
175			F
176		•	Changes in vehicle technologies. Changes in vehicle technologies, patterns of
177			vehicle sales, and fueling behavior will be needed to accommodate higher ethanol
178			production volumes. Conversely, changes in vehicle technologies driven by other
179			considerations, such as the development of plug-in hybrid electric or all-electric
180			vehicles, could change the demand for liquid biofuels.
181			
182		•	Changes in agricultural practices due to biofuel production and implications for
183			environmental impacts. Recent increases in ethanol production have expanded the
184			market demand for corn grain, and farmers have responded to this increased
185			demand by changing production practices from corn-soy rotations to corn-corn-
186			soy or even continuous corn production. It is not clear what the effects of
187			production shifts, agricultural residue use, and associated farm-level management
188			practice changes will be in the short term.
189			
100	- - -	01	

190 7.2.7 Other Components

In addition to the above components, the 2013 assessment will include a several analyses
 that provide important perspective for understand and evaluating the impacts of biofuel
 production and use, as described below.

194 **Comparison of Fossil Fuel to Biofuel.** While this report provides a starting point for 195 comparing the relative impacts associated with a range of different biofuel feedstock and 196 production processes, it will also be useful to assess biofuel impacts in the larger context of the 197 conventional petroleum fuels that are being displaced under the RFS2 mandates. Ideally, this 198 comparison would cover the full life cycle for each fuel. Such an evaluation will facilitate 199 comprehensive assessment of the relative costs and benefits of RFS2 beyond GHG impacts, and support identification of effective mitigation measures for key impacts. This type of evaluation 200 201 has been recommended by the National Advisory Council for Environmental Policy and 202 Technology as a means of conducting integrated environmental decision making (NACEPT 203 2008). Given the limitations of currently available information, a comparative assessment of petroleum fuel and biofuel impacts will be largely qualitative, with significant data gaps and 204 205 uncertainties. Nevertheless, EPA anticipates that even a qualitative comparative analysis will be 206 an important component of the 2013 assessment.

207 Net Energy Balance. Net energy balance (i.e., the amount of energy used to develop 208 biofuels compared to the energy value derived from biofuels) is an important metric that will be 209 addressed in the 2013 assessment. It enables comparison of biofuel produced from different 210 feedstocks and via different conversion processes, as well as comparison between biofuel and 211 gasoline. The net energy balance will include consideration of energy embedded in co-products 212 of the fuel conversion process. For example, increases in corn ethanol production will increase

- 213 the amount of co-products used in animal feed, which in turn displaces whole corn and soybean
- meal used for the same purpose; the "displaced" energy is credited to the ethanol system and
- offsets some of the energy required for production (Hammerschlag, 2006; Liska et al., 2008).
- 216 Market Impacts. Biofuels displace fossil energy resources, but also consume petroleum
- 217 products, natural gas, electricity (much of which comes from nonrenewable energy sources), and
- even coal at different points along their supply chain. Consequently, changes in fossil fuel prices will impact the economics of biofuel production in unpredictable ways. The 2013 assessment
- 219 will address market impacts and incorporate modeling of coupled energy systems and
- 220 will address markets and incorporate modering of coupled
- agricultural markets.

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1	Appendix A
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3	Glossary and Acronyms

4 advanced biofuel: A renewable fuel, other than ethanol derived from corn starch that has life 5 cycle greenhouse gas (GHG) emissions that are at least 50 percent less than life cycle GHG 6 emissions from petroleum fuel. A 60-percent reduction in GHG is required from cellulosic 7 biofuels to get credit for being an "advanced" biofuel. 8 9 agricultural residue: Plant parts, primarily stalks and leaves that are not removed from fields 10 used for agriculture during harvesting of the primary food or fiber product. Examples include 11 corn stover (stalks, leaves, husks, and cobs), wheat straw, and rice straw. 12 13 algae: Any plant-like organisms that are usually photosynthetic and aquatic, but do not have true roots, stems, leaves, or vascular tissue, and that have simple reproductive structures. Algae are 14 15 distributed worldwide in the sea, in fresh water, and in wastewater. Most are microscopic, but 16 some are quite large (e.g., some marine seaweeds that can exceed 50 meters in length). 17 **B100:** Pure (i.e., 100 percent) biodiesel, also known as "neat biodiesel." 18 19 B20: A fuel mixture that includes 20 percent biodiesel and 80 percent conventional diesel and 20 other additives. Similar mixtures, such as B5 or B10, also exist and contain 5 and 10 percent 21 biodiesel, respectively. 22 23 **Best Management Practices (BMPs):** Best management practices are the techniques, methods, 24 processes, and activities commonly accepted and used to facilitate compliance with applicable 25 requirements, and that provide an effective and practicable means of avoiding or reducing the 26 potential environmental impacts. 27 28 biodiesel (also known as "biomass-based diesel"): A renewable fuel produced through 29 transesterification of organically derived oils and fats. May be used as a replacement for or 30 component of diesel fuel. 31 32 **biodiversity:** The variety and variability among living organisms and the ecological complexes 33 in which they occur. Biodiversity can be defined as the number and relative frequency of 34 different items, from complete ecosystems to the biochemical structures that are the molecular 35 basis of heredity. Thus, the term encompasses ecosystems, species, and genes. 36 37 biofuel: Any fuel made from organic materials or their processing and conversion derivatives. 38 39 biofuel blend: Fuel mixtures that include a blend of renewable biofuel and petroleum-based fuel. 40 This is opposed to "neat form" biofuel that is pure, 100 percent renewable biofuel. 41 42 **biofuel distribution:** Transportation of biofuel to blending terminals and retail outlets by a 43 variety of means, including rail, barge, tankers, and trucks. This almost always includes periods 44 of storage. 45 46 **biofuel end use:** Combustion of biofuel in vehicles and various types of engines, usually as a 47 blend with gasoline or diesel, or in some cases in neat form. 48

49 **biofuel life cycle:** All the consecutive and interlinked stages of biofuel production and use, from 50 feedstock generation to biofuel production, distribution, and end use by the consumer. 51 52 **biofuel production:** The process or processes involved in converting a feedstock into a 53 consumer-ready biofuel. 54 55 **biofuel supply chain:** The five main stages involved in the life cycle of a biofuel: feedstock 56 production, feedstock logistics, fuel production, fuel distribution, and fuel use. 57 58 **biogenic:** Produced by living organisms or a biological process. 59 60 biomass: Any plant-derived organic matter (e.g., agricultural crops and crop wastes; wood and 61 wood wastes and residues; aquatic plants; perennial grasses). 62 63 biomass-based diesel: See "biodiesel" above. Biomass-based diesel includes non-co-processed 64 renewable diesel, which does not use the transesterification technology. 65 66 cellulosic biofuel: A renewable fuel derived from lignocellulose (i.e., plant biomass comprised 67 of cellulose, hemicellulose, and lignin that is a main component of nearly every plant, tree, and 68 bush in meadows, forests, and fields). Lignocellulose is converted to cellulosic biofuel by 69 separating the sugars from the residual material, mostly lignin, and then fermenting, distilling, 70 and dehydrating this sugar solution. 71 72 Conservation Reserve Program (CRP): A U.S. Department of Agriculture program that 73 provides technical and financial assistance to eligible farmers and ranchers to address soil, water, 74 and related natural resource concerns on their lands in an environmentally beneficial and cost-75 effective manner. It encourages farmers to convert highly erodible cropland or other 76 environmentally sensitive acreage to vegetative cover, such as tame or native grasses, wildlife 77 plantings, trees, filter strips, or riparian buffers. Farmers receive an annual rental payment for the 78 term of the multi-year contract. 79 80 **conservation tillage:** Any cultivation system that leaves at least one third of the land surface 81 covered with residue after planting in order to reduce soil erosion and conserve soil productivity. One example would be "no-till," where fields are not tilled at all and crops are planted directly 82 83 into the existing residue. Other variations include "strip-till" or "ridge-till," which remove some, 84 but not all, of the residue from the harvested area. 85 86 conventional biofuel: In the context of this report, "conventional biofuel" refers to ethanol 87 derived from corn starch that does *not* lead to at least a 50 percent reduction in greenhouse gas 88 emissions compared to petroleum. 89 90 **corn stover:** The stalks, leaves, husks, and cobs that are *not* removed from the fields when the 91 corn is harvested. 92 93 crop yield: The quantity of grains or dry matter produced from a particular area of land. (In this report, crop yield is most often measured in corn or soybean bushels per acre.) 94

direct land use change: In the context of biofuel, "direct land use change" refers to land 95 conversion that is directly related and easily attributable to the biofuel supply chain. For 96 97 example, a U.S. farmer deciding to take land out of the Conservation Reserve Program in order 98 to grow more corn for ethanol would be considered a direct land use change. 99 **double cropping:** The process of planting two different crops (not including cover crops) on the 100 same piece of land over the course of a growing season. 101 dry milling: A process for producing conventional corn starch ethanol in which the kernels are 102 ground into a fine powder and processed without fractionating the grain into its component parts. 103 Most ethanol comes from dry milling. 104 105 **E10:** A fuel mixture of 10 percent ethanol and 90 percent gasoline based on volume. 106 107 E85: A fuel mixture of 85 percent ethanol and 15 percent gasoline based on volume. 108 109 ecosystem health: The ability of an ecosystem to maintain its metabolic activity level and 110 internal structure and organization, and to resist external stress over time and space scales 111 relevant to the ecosystem. 112 113 effluent: Liquid or gas discharged in the course of industrial processing activities, usually 114 containing residues from those processes. 115 116 Energy Independence and Security Act (Public Law 110-140) (EISA): Signed into law on December 19, 2007, this legislation established energy management goals and requirements 117 118 while also amending portions of the National Energy Conservation Policy Act. EISA's stated goals are to move the U.S. toward greater energy independence and security; increase production 119 of clean renewable fuels; protect consumers; increase the efficiency of products, buildings, and 120 121 vehicles; promote research on and deploy greenhouse gas capture and storage options; and 122 improve the energy performance of the federal government. 123 124 environmental life cycle assessment: In the context of this report, an environmental life cycle 125 assessment is an assessment in which the LCA methodology (see "life cycle assessment") is 126 applied to address the full range of potential environmental impacts over all environmental 127 media 128 129 ethanol (also known as "bioethanol"): A colorless, flammable liquid produced by fermentation 130 of sugars. Ethanol is used directly as a fuel and fuel oxygenate. 131 132 eutrophication: Nutrient enrichment of aquatic ecosystems, in which excessive nutrient levels 133 cause accelerated algal growth, which in turn can reduce light penetration and oxygen levels in 134 water necessary for healthy aquatic ecosystems. Eutrophication can cause serious deterioration of 135 both coastal and inland water resources and can lead to hypoxia. 136 137 feedstock: In the context of biofuel, "feedstock" refers to a biomass-based material that is 138 converted for use as a fuel or energy product. 139

140 feedstock logistics: All activities associated with handling, storing, and transporting feedstocks 141 after harvest to the point where the feedstocks are converted to biofuel. 142 143 feedstock production: All activities associated with cultivation and harvest of biofuel feedstock. 144 145 filter strip: A strip or area of herbaceous vegetation that may reduce nutrient loading, soil 146 erosion, and pesticide contamination by removing soil particles and contaminants from overland water flow. 147 148 forest residue: Includes 1) tops, limbs, and other woody material *not* removed in forest 149 harvesting operations in commercial hardwood and softwood stands; and 2) woody material 150 resulting from forest management operations such as pre-commercial thinning and removal of 151 dead and dying trees. 152 153 forest thinning: Removal of residues from overgrown forests to reduce forest fire risk or 154 increase forest productivity. Residues are typically too small or damaged to be sold as round 155 wood but can be used as biofuel feedstock. 156 157 greenhouse gases: Gases that trap the heat of the sun in the Earth's atmosphere, producing the 158 greenhouse effect. Greenhouse gases include water vapor, carbon dioxide, hydrofluorocarbons, 159 methane, nitrous oxide, perfluorocarbons, and sulfur hexafluoride. 160 161 harvesting forest residue: See "forest thinning" above. 162 163 **hemicellulose:** any of various plant polysaccharides less complex than cellulose and easily 164 hydrolysable to monosaccharides (simple sugars) and other products. 165 166 hybrid: A plant species created from the offspring of genetically different parents, both within 167 and between species. Hybrids combine the characteristics of the parents or exhibit new ones. 168 169 **hypoxia:** The state of an aquatic ecosystem characterized by low dissolved oxygen levels (less than 2 to 3 parts per million) due to accelerated algal growth and reduced light penetration 170 171 because of excessive nutrient levels (eutrophication). Low dissolved oxygen can reduce fish 172 populations and species diversity in the affected area. 173 174 indirect land use change: In the context of biofuel, "indirect land use change" refers to land 175 conversion that occurs as a market response to changes in the supply and demand of *goods other* 176 *than biofuel* (e.g., food commodities) that result from changes in biofuel demand. For example, 177 clearing of foreign land to plant corn as a food crop in response to reduced U.S. corn exports 178 caused by increased use of U.S. corn to produce ethanol is considered to be an indirect land use 179 change. 180 181 integrated pest management (IPM): An environmentally sensitive approach to pest 182 management that uses current, comprehensive information on the life cycles of pests and their 183 interaction with the environment to manage pest damage by the most economical means, and 184 with the least possible hazard to people, property, and the environment. 185

186 invasive plants (also called invasives or noxious plants): An alien species whose introduction 187 does or is likely to cause economic or environmental harm or harm to human health. 188 189 land cover: Vegetation, habitat, or other material covering a land surface. 190 191 land use: The human use of land involving the management and modification of natural 192 environment or wilderness into built environment such as fields, pastures, and settlements. 193 194 life cycle assessment: A comprehensive systems approach for measuring the inputs, outputs, and 195 potential environmental impacts of a product or service over its life cycle, including resource 196 extraction/generation, manufacturing/production, use, and end-of-life management. 197 198 life cycle greenhouse gas emissions: The aggregate quantity of greenhouse gas emissions 199 (including direct emissions and significant indirect emissions such as significant emissions from 200 land use changes), as determined by the EPA Administrator, related to the full fuel life cycle, 201 where the mass values for all greenhouse gases are adjusted to account for their relative global 202 warming potential. (See above for definition of "biofuel life cycle.") 203 204 **low-till:** See "conservation tillage." 205 206 milling residues (primary and secondary): Wood and bark residues produced in processing (or 207 milling) logs into lumber, plywood, and paper. 208 209 mitigation: In the context of the environment, action to reduce adverse environmental impacts. 210 neat biofuel: See "B100." 211 212 213 **net energy balance:** In the context of biofuel, refers to the energy content in the resulting 214 biofuel less the total amount of energy used over the production and distribution process. 215 216 nitrogen fixation: The transformation of atmospheric nitrogen into nitrogen compounds that can 217 be used by growing plants. Nitrogen-fixing species, such as soybeans, can accomplish this 218 process directly. 219 220 **nutrient loading:** A process in which compounds from waste and fertilizers, such as nitrogen and phosphorus, enter a body of water. This can happen, for example, when sewage is managed 221 222 poorly, when animal waste enters ground water, or when fertilizers from residential and 223 agricultural runoff wash into a stream, river, or lake. 224 225 **oxygenated fuels:** Fuels, typically gasoline, that have been blended with alcohols or ethers that 226 contain oxygen in order to reduce carbon monoxide and other emissions. 227 228 ozone: A form of oxygen consisting of three oxygen atoms. In the stratosphere (7 to 10 miles or 229 more above the Earth's surface), ozone is a natural form of oxygen that shields the Earth from 230 ultraviolet radiation. In the troposphere (the layer extending up 7 to 10 miles from the Earth's surface), ozone is a widespread pollutant and major component of photochemical smog. 231

232 233 perennial grass: A species of grass that lives more than two years and typically has low nutrient 234 demand and diverse geographical growing range, and offers important soil and water 235 conservation benefits. 236 237 photobioreactor: A vessel or closed-cycle recirculation system containing some sort of 238 biological process that incorporates some type of light source. Often used to grow small 239 phototrophic organisms such as cyanobacteria, moss plants, or algae for biodiesel production. 240 241 renewable biomass: As defined by the 2007 Energy Independence and Security Act, renewable 242 biomass means each of the following: 243 244 Planted crops and crop residue from agricultural land cleared prior to December • 245 19, 2007, and actively managed or fallow on that date. Planted trees and tree residue from tree plantations cleared prior to December 19, 246 • 247 2007, and actively managed on that date. Animal waste material and byproducts. 248 249 Slash and pre-commercial thinnings from non-federal forestlands that are neither • 250 old-growth nor listed as critically imperiled or rare by a State Natural Heritage 251 program. Biomass cleared from the vicinity of buildings and other areas at risk of wildfire. 252 • 253 Algae. • 254 Separated yard waste and food waste. 255 256 **renewable fuel:** A fuel produced from renewable biomass that is used to replace or reduce the use of fossil fuel. 257 258 259 **Renewable Fuels Standard (RFS) program:** An EPA program created under the Energy Policy 260 Act (EPAct) of 2005 that established the first renewable fuel volume mandate in the United 261 States. The original RFS program (RFS1) required 7.5 billion gallons of renewable fuel to be 262 blended into gasoline by 2012. (See below for RFS2.) 263 RFS2: The Renewable Fuels Standard program as revised in response to requirements of the 264 2007 Energy Independence and Security Act. RFS2 increased the volume of renewable fuel 265 266 required to be blended into transportation fuel to 36 billion gallons per year by 2022. 267 268 RFS2 Regulatory Impact Analysis (RIA): EPA's analysis of the impacts of the increase in 269 production, distribution, and use of the renewable fuels need to meet the RFS2 volumes 270 established by Congress in the 2007 Energy Independence and Security Act (EISA). 271 272 **riparian forest buffer:** An area of trees and shrubs located adjacent to streams, lakes, ponds, 273 and wetlands that may reduce nutrient loading, soil erosion, and pesticide contamination by 274 removing soil particles and contaminants from overland water flow. 275 row crop: A crop planted in rows wide enough to allow cultivators between the rows. Examples 276 include corn, soybeans, peanuts, potatoes, sorghum, sugar beets, sunflowers, tobacco, vegetables, 277 and cotton.

270						
278	adimentation. The process of solids sottling out of water due to gravity					
279	sedimentation: The process of solids settling out of water due to gravity.					
280 281 282 283 284 285	short rotation woody crop (SRWC): Fast-growing tree species grown on plantations and harvested in cycles shorter than is typical of conventional wood products, generally between 3 to 15 years. Examples include: hybrid poplars (<i>Populus</i> spp.), willow (<i>Salix</i> spp.), Loblolly pine (<i>Pinus taeda</i>), and Eucalyptus.					
286 287	soil erosion: The wearing away of land by the action of wind, water, gravity, or a combination thereof.					
288 289 200	soil organic matter: Decomposing plant and animal material in soil.					
290	a il analita. The constitute for an a if a laid of a il to found in a mithin metand an analysis of					
291	soli quality: The capacity of a specific kind of soli to function, within natural of managed					
292	air quality and support human health and habitation					
293	an quanty, and support numan nearth and naonation.					
294	sugarcane bagasse. The fibrous material that remains after sugar is pressed from sugarcane					
296	sugarcane bagasse. The norous material that remains after sugar is pressed from sugarcane.					
297	sweet sorghum pulp: The bagasse or dry refuse left after the juice is extracted from sweet					
298	sorghum stalks during the production of ethanol and other sweet sorghum products. The pulp is					
299	usually treated as farm waste in plantations that grow sweet sorohum for biofuel production					
300						
301	transesterification: In the context of biofuel, the chemical process that reacts an alcohol with					
302	triglycerides in vegetable oils and animal fats to produce biodiesel and glycerin.					
303						
304	turbidity: A cloudy condition in water due to suspended silt or organic matter.					
305						
306	vegetative reproduction: A form of asexual reproduction in plants by which new individuals					
307	arise without the production of seeds or spores. It can occur naturally or be induced by					
308	horticulturists.					
309						
310	water availability: In the context of this report, water availability refers to the amount of water					
311	that can be appropriated from surface water sources (e.g., rivers, streams, lakes) or ground water					
312	sources (e.g., aquifers) for consumptive uses.					
313 214	water avality, Water quality is a managure of the suitability of water for a particular use based on					
314 215	salested physical shamical and biological characteristics. It is most frequently measured by					
315	characteristics of the water such as temperature, dissolved oxygen, and pollutant levels, which					
317	are compared to numeric standards and guidelines to determine if the water is suitable for a					
318	narticular use					
319						
320	wet milling: In the context of biofuel a process for producing conventional corn starch ethanol					
321	in which the corn is soaked in water or dilute acid to separate the grain into its component parts					
322	(e.g., starch, protein, germ, oil, kernel fibers) before converting the starch to sugars that are then					
323	fermented to ethanol.					

324

- 325 **woody biomass:** Tree biomass thinned from dense stands or cultivated from fast-growing
- 326 plantations. This also includes small-diameter and low-value wood residue, such as tree limbs,
- 327 tops, needles, and bark, which are often by-products of forest management activities.

328

1	APPENDIX B:
2	
3	SUMMARY OF SELECTED STATUTORY AUTHORITIES
4	HAVING POTENTIAL IMPACT ON THE PRODUCTION
5	AND USE OF BIOFUELS

	Stage of Lifecycle		
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel
	Clean Air	Act (CAA) (http://www.epa.gov/air/caa/)	
The CAA defines EPA's responsibilities for protecting and improving air quality and stratospheric ozone. It requires EPA to set national ambient air quality standards (NAAQS) for widespread pollutants from numerous and diverse sources considered harmful to public health and the environment. EPA and states must develop regulations to achieve and maintain the NAAQS and to control other pollutants.	Vehicles used for the transportation of feedstock may be subject to an inspection and maintenance program for tailpipe emissions and vehicle emission standards for air quality.	 A biofuel plant will need to obtain an air operating permit for day-to-day facility operations. Based on potential-to-emit, a facility may be required to obtain a Title V Air Operating Permit. Operating permits will be issued containing emission limits, monitoring, and record keeping requirements. Pre-construction permits will be required for initial construction and for changes made to the plant. There are two types of major pre-construction permits under the New Source Review (NSR) Program: Prevention of Significant Deterioration permits, and Nonattainment NSR permits. A minor pre-construction permit would be required if major NSR is not required. A vehicle used for the transportation of biofuels may be subject to an inspection and maintenance program. 	The CAA regulates the amount of ethanol mixed in gasoline as part of the reformulated gasoline program.

	Stage of Lifecycle			
	Feedstock Production			
Summary of Statute/Program	and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel	
	Clean Water Act	(CWA) (http://www.epa.gov/watertrain/cwa/)		
The goal of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Entities that discharge to waters of the U.S. through point sources (i.e., pipes, ditches, concentrated animal feeding operations), must obtain a National Pollutant Discharge Elimination System (NPDES) permit. These entities include many municipal, industrial, and construction-related sources of stormwater.	Agricultural storm water and irrigation returns flows are exempted from NPDES permit requirements. Under Section 319, EPA provides grants to states to address non-point sources of pollution.	A biofuel production facility typically uses water for cooling and also for washing the biofuel product to remove impurities. The wastewater is discharged either directly to a water body or indirectly to a municipal wastewater treatment plant. Both are point source discharges, regardless whether the facility uses a septic tank or treatment prior to discharge. Any discharge into a water body by a point source must have an NPDES permit prior to discharge. Permits may be required for discharge to a municipal wastewater treatment system, which could include pre-treatment requirements. Land application of wastewater may be covered by an NPDES permit if it is determined that pollutants run off the application site to a waterway in a discernable channel or pipe.	Management of emergency response oil discharges must be reported to the National Response Center if they are in a quantity that "may be harmful."	
States develop water quality standards (WQS) that define the goals for a water body by designating its uses, setting criteria to protect those uses, and establishing provisions to protect that water body. The CWA requires states to identify waters not meeting WQS and to develop Total Maximum Daily Loads (TMDLs) for those waters. TMDLs identify point and nonpoint source loads that can be discharged to a water body and still meet WQS.		To minimize the impact of site runoff on water quality, a NPDES stormwater permit must be obtained for discharges to waters of the U.S. from any construction activity that disturbs 1 acre or more of land (including smaller sites that are part of a larger common plan of development).		

	Stage of Lifecycle			
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel	
	CWA: Section 404 We	tlands Program (www.epa.gov/owow/wetlands/laws/)		
Section 404 addresses the discharges of dredged or fill material into waters of the United States, including wetlands.	Most ongoing agricultural maintenance practices are exempt from Section 404.	Generally, Section 404 requires a permit before these materials may be placed in a U.S. water, such as a wetland, stream, river, slough, lake, bay, etc., during construction activities.		
Permits are required for activities such as expanded water resource projects (including dams,				
impoundments, and levees) and altering or dredging a water of the United States.				
Comprehensive Environm	ental Response, Compensa	ation and Liability Act (CERCLA) (http://www.epa.go	ov/lawsregs/laws/cercla.html)	
CERCLA provides a federal "Superfund" to clean up uncontrolled or abandoned hazardous-waste sites as well as accidents, spills, and other emergency releases of pollutants and contaminants into the environment. Through CERCLA, EPA was given authority to assure responsible parties' cooperation in site cleanup. CERCLA also regulates the property transfer of these sites.		 Requirements under CERCLA that may apply include: Reporting requirements for hazardous substances. Implementation and periodic revision of the National Contingency Plan. Management by emergency response authorities and responses to discharges of biofuels. 		

	Stage of Lifecycle			
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel	
Emergency P	Emergency Planning and Community Right Know ACT (EPCRA) (http://www.epa.gov/oecaagct/lcra.html)			
The objective of the EPCRA is to: (1) allow state and local planning for chemical emergencies, (2) provide for notification of emergency releases of chemicals, and (3) address communities' right- to-know about toxic and hazardous chemicals.		Section 302 requires facilities with regulated chemicals (extremely hazardous substances) above threshold planning quantities to notify the state emergency response commission (SERC) and the local emergency planning committee (LEPC). Section 304 requires facilities to report a release of an extremely hazardous substance. Section 311 requires the facility to have material safety data sheets (MSDSs) on site for hazardous chemicals, as defined by the Occupational Safety and Health Act, that exceed certain quantities and to submit copies to their SERC, LEPC, and local fire department. Section 312 establishes reporting for any hazardous chemical or extremely hazardous chemical that is stored at a facility in excess of the designated threshold planning quantity. These reports are also known as the Tier II hazardous chemical inventory form. Section 313 (Toxics Release Inventory) requires owners or operators of certain facilities that manufacture, process or otherwise use any listed toxic chemicals, or chemical categories, in excess of threshold quantities to report annually to the EPA and to the state in which such facilities are located.	Electric utilities are subject to EPCRA Section 313 – Toxic Release Inventory Reporting.	

	Stage of Lifecycle		
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel
Federal In	secticide, Fungicide, and I	Rodenticide Act (FIFRA) (http://www.epa.gov/oecaag	ct/lfra.html)
The objective of FIFRA is to provide federal control of pesticide distribution, sale, and use.	EPA reviews and registers pesticides for specified uses and can cancel the registration if information shows continued use would pose unreasonable risk. Consideration is given to worker exposure ecological exposure and food-chain imports.		
Hazardous Mater	ials Transportation Act (F	Regulations codified 49 CFR) (http://www.phmsa.dot.g	ov/hazmat/regs and
	http://www.fmcsa.dot.	gov/safety-security/hazmat/security-plan-guide.htm)	
The Department of Transportation regulations require procedures to be put in place ensuring the safe transport of hazardous materials. Also, regulation HM-232 requires companies to complete a written security assessment and to develop a security plan that is based on the assessment.		Requirements are in place for shippers and carriers of hazardous materials to prepare shipments for transport, placard containers for easy identification of hazards, and ensure the safe loading, unloading, and transport of materials. HM-232 requires companies to complete a written security assessment and to develop a security plan that is based on the assessment.	

	Stage of Lifecycle		
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel
Ν	ational Environmental P	olicy Act (NEPA) (http://www.epa.gov/compliance/nep	a/)
NEPA requires federal agencies to integrate environmental values into their decision making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet NEPA requirements in certain circumstances federal agencies prepare a detailed statement known as an Environmental Impact Statement (EIS).		If federal money is being used to partially or entirely finance the construction of a biofuel plant or any associated facility, such as an access road or water supply facility, then construction of the plant may be subject to NEPA. NEPA requires federal agencies to incorporate environmental considerations in their planning and decision-making and to prepare a detailed statement assessing the environmental impact of activities and alternatives that significantly affect the environment.	
	Oil Pollution Act (OPA)) of 1990 (http://www.epa.gov/lawsregs/laws/opa.html)	
The OPA of 1990 streamlined and strengthened EPA's ability to prevent and respond to catastrophic oil spills. A trust fund financed by a tax on oil is available to clean up spills when the responsible party is incapable or unwilling to do so. The OPA requires oil storage facilities and vessels to submit to the Federal government plans detailing how they will respond to large		Provides that the responsible party for a vessel or facility from which oil is discharged, or which poses a substantial threat of a discharge, is liable for: (1) certain specified damages resulting from the discharged oil; and (2) removal costs incurred in a manner consistent with the National Contingency Plan. Provides for spill contingency plans and mandates development of response plans for worst case discharge; and provides for requirements for spill removal equipment. Oil Spill Plans must be in place prior to operation, at facilities that have the potential to	

	Stage of Lifecycle		
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel
Rene	wable Fuel Standard (RF	S) (http://www.epa.gov/otaq/fuels/renewablefuels/inde	x.htm)
The RFS program was created under the Energy Policy Act (EPAct) of 2005, and established the first renewable fuel volume mandate in the United States. As required under EPAct, the original RFS program (RFS1) required 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012. Under the Energy Independence and Security Act (EISA) of 2007, the RFS program was expanded. EISA also required EPA to apply lifecycle greenhouse gas (GHG) performance threshold standards. The GHG requirement is that the lifecycle GHG emissions of a qualifying renewable fuel must be less than the lifecycle GHG emissions of the 2005 baseline average gasoline or diesel fuel that it replaces. Four different levels of reductions are required for the four different renewable fuel standards: Renewable Fuel (20%); Advanced Biofuel (50%); Biomass-based Diesel (50%); and Cellulosic Biofuel (60%).		If a facility produces 10,000 gallons or more of renewable fuel per year, then it may participate in the RFS program, though it is not required to do so. If a facility chooses to participate in the RFS program, it must satisfy the following criteria: • Register • Generate renewable identification • Transfer RINs with fuel • Provide product transfer documents • Follow blending requirements • Follow blending requirements • Follow non-road use of fuel • Attest engagements • Keep records for 5 years • Report quarterly	

	Stage of Lifecycle		
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel
Resource	ce Conservation and Recov	very Act (RCRA) (http://www.epa.gov/lawsregs/laws/n	rcra.html)
RCRA gives EPA the authority to control hazardous waste generation, transportation, treatment, storage, and disposal of hazardous waste. Facilities that handle hazardous waste are required to obtain an operating permit from the state agency or EPA. RCRA regulates USTs.		 Regulatory issues related to waste generated by biofuel production - solid and hazardous waste include: New regulations on storage and transport of fuel related to expanded use of biofuels. New concerns related to assessing compatibility of fuel storage systems, managing water in storage tanks, protecting against corrosiveness and conductivity, managing methane formation, and detecting, preventing and responding to storage tank and pipe leaks and spills. Management of emergency response authorities and responses to biofuels spills. 	UST leak detection and prevention are required.
	Safe Drinking Wate	r Act (SDWA) (http://www.epa.gov/ogwdw/sdwa/)	
The SDWA is the federal law that protects the safety of water distributed by public water systems. Under SDWA, EPA has National Primary Drinking Water Regulations for more than 90 contaminants and rules regarding monitoring of treated drinking water as well as reporting and public notification.	There are a number of threats to drinking water: anthropogenic chemicals including pesticides and improperly disposed chemicals; animal wastes; and naturally occurring substances. A primary impact to drinking water is nitrate pollution from row crops.	Wastewater from biofuel production facilities or corn starch ethanol facilities and leaking biofuel storage tanks can contaminate surface and ground drinking water resources, requiring treatment under SDWA.	

	Stage of Lifecycle		
Summary of Statute/Program	Feedstock Production and Transport	Biofuel Production, Transport, and Storage	Use of Biofuel
Safe Drinking	Water Act: Underground	Injection Control (UIC) Program (http://www.epa.go	v/safewater/uic/)
The UIC program protects underground sources of drinking water by regulating the construction, operation, permitting, and closure of injection wells that place fluids underground for storage or disposal.	Agriculture drainage wells are Class V UIC wells. They are primarily regulated under state law.	 A biofuels plant is subject to the requirements of the UIC Program if any of the following apply: It is disposing of storm water, cooling water, industrial or other fluids into the subsurface via an injection well; It has an on-site sanitary waste disposal system (e.g., septic system) that serves or has the capacity to serve 20 or more persons; It has an on-site sanitary waste disposal system that is receiving other than a solely sanitary waste stream regardless of its capacity; or It is undergoing a remediation process where fluids are being introduced into the subsurface via an injection well to facilitate or enhance the cleanup. 	
Spill Prevention, Control and	Countermeasure (SPCC)	and Facility Response Plans (FRP) (http://www.epa.g	ov/oem/content/spcc/index.htm)
The SPCC rule includes requirements for oil spill prevention, preparedness, and response to prevent oil discharges to navigable waters and adjoining shorelines. The rule requires specific facilities to prepare, amend, and implement SPCC Plans. The SPCC rule is part of the Oil Pollution Prevention regulation, which also includes the Facility Response Plan (FRP) rule.	The SPCC program requires certain farms (e.g., those that store oil and could reasonably be expected to discharge oil to waters of the US) to prepare and implement an SPCC Plan.	 A biofuel facility is subject to this regulation if the following apply: It is non-transportation related. It has a total above-ground oil storage capacity greater than 1,320 gallons or a completely buried oil storage capacity greater than 42,000 gallons. There is a reasonable expectation of an oil discharge into or upon navigable waters of the U.S. or adjoining shorelines. Secondary containment cannot be provided for all regulated oil storage tanks. 	

	Stage of Lifecycle		
Survey of Statute /Due survey	Feedstock Production	Bisfeel Dusdastion Transmost and Stansmo	Use of Disfuel
Summary of Statute/Program	and I ransport	Biotuel Production, Transport, and Storage	Use of Biofuel
T	oxic Substances Control A	Act (TSCA) (http://www.epa.gov/lawsregs/laws/tsca.ht	ml)
TSCA gives EPA broad authority to	Notification and review	Mandatory notification and approval for new	
identify and control chemical	of new intergeneric	chemicals and new biological products, prior to	
substances that may pose a threat to	genetically engineered	manufacture and commercial use. New uses of	
human health or the environment.	microbes (e.g. bacteria,	chemicals are subject to review for potential	
EPA's Office of Pollution	fungi and algae) used to	environmental hazards under the Significant New Use	
Prevention and Toxics operates	produce biofuels	Notification process. As a result of the review process,	
both the New Chemicals Program	feedstocks.	health and environmental effects testing of existing or	
and the Biotechnology Program		new chemicals that pose unreasonable risk may be	
under Section 5 of TSCA. Both		required. EPA may also restrict use and handling of	
programs were established to help		chemicals or biological products as a result of their	
manage the potential risk from		review.	
chemical substances and			
genetically-engineered			
(intergeneric) microorganisms new			
to the marketplace or applied in			
significant new uses. Additional			
sections of TSCA give EPA the			
broad authority to issue toxicity			
testing orders or to regulate the use			
of any existing chemicals that pose			
unreasonable risk.			

1	Appendix C
2	
3	Basis for Figures 6-1, 6-2, and 7-3
This appendix presents three tables, Tables C-1, C-2, and C-3, which summarize the information providing the basis for Figures 6-1, 6-2, and 7-3, respectively. For each of the six feedstocks included in this report, Tables C-1 and C-2 briefly describe the current production status (Background), as well as the conditions anticipated to result in the most negative environmental effect (Most Negative Future Scenario) and the most positive environmental effect (Most Positive Future Scenario) in each of the environmental media considered. Table C-3 describes the basis for the three scenarios included in Figure 7-3.

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Table C-1: Basis for Figure 6-1 (Maximum Potential Range of Environmental Impacts [on a Per Unit Area Basis] Resulting from Cultivation and Harvesting of the Six Biofuel Feedstocks Considered in this Report)

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
Corn Starch	Most current corn feedstock cultivation for biofuel production is a result of either 1) displacing soy production, 2) diverting existing corn grain to processing for fuel, or 3) placing former agricultural land back into production.	Water Quality	Corn grown with conventional tillage and high chemical inputs replaces lands in the Conservation Reserve Program (CRP).	Corn grown with comprehensive conservation practices replaces corn grown with existing production systems.
		Water Quantity	Irrigated corn replaces non-irrigated land use in drier area.	Production of non-irrigated corn.
		Soil Quality	Corn grown with conventional tillage and high chemical inputs replaces lands in the Conservation Reserve Program (CRP).	Corn grown with comprehensive conservation practices replaces corn grown with existing production systems.
		Air Quality	Irrigated corn grown with conventional tillage and high chemical inputs replaces lands in the Conservation Reserve Program (CRP).	Corn grown with comprehensive conservation practices replaces corn grown with existing production systems.
		Biodiversity	Corn grown with conventional tillage and high chemical inputs replaces lands in the Conservation Reserve Program (CRP).	Corn grown with comprehensive conservation practices replaces corn grown with existing production systems.
		Invasiveness	Negligible known effect.	Negligible known effect.

Table C-1: Basis for Figure 6-1 (Maximum Potential Range of Environmental Impacts [on a Per Unit Area Basis] Resulting from Cultivation and Harvesting of the Six Biofuel Feedstocks Considered in this Report)

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
Soybean	Most current soybean biofuel production comes from increased allocation of existing harvest to biodiesel.	Water Quality	Soy replaces lands in the Conservation Reserve Program (CRP).	Soy grown with comprehensive conservation practices replaces corn grown with conventional tillage and high chemical inputs.
		Water Quantity	Irrigated soy replaces non-irrigated land use in drier area.	Non-irrigated soy replaces irrigated corn.
		Soil Quality	Soy replaces lands in the Conservation Reserve Program (CRP).	Soy grown with comprehensive conservation practices replaces corn grown with conventional tillage and high chemical inputs.
		Air Quality	Irrigated soy replaces non-irrigated land use in drier area.	Non-irrigated soy grown with comprehensive conservation practices replaces corn grown with conventional tillage and high chemical inputs.
		Biodiversity	Soy replaces lands in the Conservation Reserve Program (CRP).	Soy grown with comprehensive conservation practices is diverted from existing production systems.
		Invasiveness	Negligible known effect.	Negligible known effect.

Table C-1: Basis for Figure 6-1 (Maximum Potential Range of Environmental Impacts [on a Per Unit Area Basis] Resulting from Cultivation and Harvesting of the Six Biofuel Feedstocks Considered in this Report)

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
Corn Stover	Not currently produced commercially for biofuel feedstock.	Water Quality	High rate of stover removal on highly erodible land.	Appropriate rate of stover removal to minimize erosion given site-specific characteristics and management practices.
		Water Quantity	High rate of stover removal on irrigated land in drier areas.	Appropriate rate of stover removal to minimize additional irrigation given site- specific characteristics and management practices.
		Soil Quality	High rate of stover removal on highly erodible land with low organic matter soil.	Appropriate rate of stover removal to minimize erosion given site-specific characteristics and management practices.
		Air Quality	High stover removal requires additional harvesting pass and increased subsequent fertilizer applications.	Appropriate rate of stover removal to minimize subsequent fertilizer applications; stover removed with corn in a single harvesting pass.
		Biodiversity	High rate of stover removal on highly erodible land that results in sedimentation to aquatic systems.	Appropriate rate of stover removal to minimize erosion given site-specific characteristics and management practices.
		Invasiveness	Negligible known effect.	Negligible known effect.

Table C-1: Basis for Figure 6-1 (Maximum Potential Range of Environmental Impacts [on a Per Unit Area Basis] Resulting
from Cultivation and Harvesting of the Six Biofuel Feedstocks Considered in this Report)

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
Woody Biomass	Not currently produced commercially for biofuel feedstock.	Water Quality	Short-rotation woody crops (SRWC) with short replanting intervals and high chemical inputs, and without coppicing replace mature, managed tree plantations.	Short-rotation, coppiced woody crops with long replanting intervals, and low chemical inputs replace non-coppiced, managed forests with short replanting intervals, and high chemical inputs.
		Water Quantity	Irrigated SRWCs are grown in drier regions.	Production of non-irrigated SRWC in wetter regions. or Low to moderate rate of forest residue removal or thinning.
		Soil Quality	SRWC with short replanting intervals and without coppicing replace mature, managed tree plantations.	Short-rotation, coppiced woody crops with long replanting intervals, and low chemical inputs replace non-coppiced, managed forests with short replanting intervals, and high chemical inputs.
		Air Quality	SRWC with short replanting intervals, high chemical inputs, high isoprene emissions, and without coppicing replace mature, managed, low-isoprene emitting tree plantations.	Short-rotation, coppiced woody crops with long replanting intervals, low chemical inputs and low isoprene emissions replace non-coppiced, managed forests with short replanting intervals, high chemical inputs, and high isoprene emissions.
		Biodiversity	SRWC with short replanting intervals and high chemical inputs, and without coppicing replace mature, managed tree plantations.	Long rotation woody crop stands replace SRWC with short replanting intervals and high chemical inputs.
		Invasiveness	Woody species (e.g., <i>E. grandis</i>) are grown and become invasive.	Production and harvesting of non-invasive woody species.

Table C-1: Basis for Figure 6-1 (Maximum Potential Range of Environmental Impacts [on a Per Unit Area Basis] Resultin	ig
from Cultivation and Harvesting of the Six Biofuel Feedstocks Considered in this Report)	

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
	Not currently produced commercially for biofuel feedstock.	Water Quality	Perennial grasses established with conventional tillage and grown with a short planting interval and chemical inputs replace land in the CRP.	Perennial grasses established with no till grown with low chemical inputs and a long replanting interval replace corn grown with conventional tillage and high chemical inputs.
		Water Quantity	Irrigated perennial grasses replace non- irrigated land use in drier regions.	Non-irrigated perennial grasses replace irrigated corn.
Perennial Grass		Soil Quality	Perennial grasses established with conventional tillage and grown with a short planting interval and chemical inputs replace land in the CRP.	Perennial grasses established with no till with a long replanting interval replace conventionally tilled row crops.
		Air Quality	Irrigated perennial grasses established with conventional tillage and grown with a short planting interval and chemical inputs replace land in the CRP.	Non-irrigated perennial grasses established with no till and grown with low chemical inputs and a long replanting interval replace irrigated corn grown with conventional tillage and high chemical inputs.
		Biodiversity	Uniformly-managed perennial grasses established with conventional tillage and grown with a short planting interval and chemical inputs replace land in the CRP.	Perennial grasses grown with low chemical inputs replace corn grown with conventional tillage and high chemical inputs.
		Invasiveness	Switchgrass (west of the Rockies) and <i>Miscanthus</i> are grown and become invasive or weedy.	Production of non-invasive native grasses or grass varieties bred for decreased invasiveness or weediness (e.g., sterile varieties).

Table C-1: Basis for Figure 6-1 (Maximum Potential Range of Environmental Impacts [on a Per Unit Area Basis] Resulting from Cultivation and Harvesting of the Six Biofuel Feedstocks Considered in this Report)

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
lgae	Not currently produced commercially for biofuel feedstock.	Water Quality	Untreated effluent from growing algae is discharged to the environment.	Algae are grown with wastewater; treated effluent is recycled for further use.
		Water Quantity	Algae are grown in drier regions (e.g., Southwest) with freshwater in open ponds.	Algae are grown with wastewater in closed bioreactors; treated effluent is recycled for further use.
		Soil Quality	Negligible known effect.	Negligible known effect
\checkmark		Air Quality	Algae grown with added nutrients.	Algae grown with nutrients in wastewater.
		Biodiversity	Negligible known effect.	Negligible known effect.
		Invasiveness	Invasive algae species grown in open ponds escape and proliferate.	Production of non-invasive algae species in closed bioreactors.

Table C-2: Basis for Figure 6-2 (Maximum Potential Range of Environmental Impacts [on a Per Unit Volume Basis] Resulting from Ethanol and Biodiesel Production, Transport, Storage and Use)

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
n Ethanol	As of 2009, 180 corn ethanol facilities were operating in the U.S., mostly in the Midwest. Future corn ethanol production is expected to expand in the same region.	Water Quality	Effluent with high biological oxygen demand (BOD); Dried Distillers Grain (DDG) byproduct fed to livestock with inadequate waste management practices; under-ground storage tanks (UST) leak.	Effluent effectively treated for BOD; DDG-fed livestock waste incorporated into comprehensive nutrient management plan; USTs do not leak.
Coi		Water Quantity	3-6 gallons of water required per gallon of ethanol produced.	Improvement in water use efficiency and recycling.
		Air Quality	Ethanol facility powered by coal.	Ethanol facility powered by natural gas.
iesel	In 2009, 191 biodiesel facilities were operating in the U.S., many producing under their capacity.	Water Quality	Effluent with high BOD, total suspended solids (TSS) and glycerin content.	Effluent effectively treated for BOD, TSS and glycerin.
Soyb Biod		Water Quantity	<1 gallon of water required per gallon of biodiesel produced.	<1 gallon of water required per gallon of biodiesel produced.
		Air Quality	Biodiesel facility powered by coal.	Biodiesel facility power by natural gas.

Table C-2: Basis for Figure 6-2 (Maximum Potential Range of Environmental Impacts [on a Per Unit Volume Basis] Resulting from Ethanol and Biodiesel Production, Transport, Storage and Use)

	Background	Impact Category	Conditions for Maximum Potential Negative Environmental Impact	Conditions for Maximum Potential Positive Environmental Impact
lulosic hanol	As of 2009, there were no commercially operating cellulosic ethanol facilities in the U.S. There is uncertainty about when and where the first facilities will start producing	Water Quality	Effluent possibly with high BOD; USTs leak.	Effluent effectively treated for BOD; USTs do not leak.
		Water Quantity	10 gallons of water required per gallon of cellulosic ethanol.	Improvement in water use efficiency and recycling.
Cel Et	producing.	Air Quality	Ethanol facility powered by coal.	Ethanol facility powered by natural gas.

Table C-3: Description of Scenarios in Figure 7-3 (Cumulative Domestic Environmental Impacts of All Steps in the Biofuel Supply Chain System under Three Scenarios in 2022)

Feedstock	Scenario A 2022 RFS2-projected feedstock mix produced with conservation/best management practices (BMPs) and efficient technologies	Scenario B 2022 RFS2-projected feedstock mix produced with minimal conservation/BMPs and current technologies	Scenario C 2022 conventional feedstock mix (corn starch, corn stover, and soybean) produced with minimal conservation/BMPs and current technologies
Conventional	Ethanol		
		15 BG	
tarch	 No decrease in crop rotation with soybeans. Increases in grain yield primarily due to breeding new varieties that also require fewer production inputs, including fertilizer, pesticides, and irrigation. 	 Increased use of continuous corn production and reduction in crop rotation. Increased grain yields using greater production inputs, including fertilizer, pesticides, and irrigation. 	
in St	• No conversion of marginal lands to corn production.	• Conversion of marginal land to corn require irrigation.	production, including in areas that
Coi	 Increased use of conservation practices, including conservation tillage, nutrient management, and efficient irrigation delivery. Increased fuel conversion efficiency and reductions in fuel production inputs, including fresh water. 	 No increases in conservation practices. 1 No increases in fuel conversion efficiency nor reductions in fuel production inputs. 	

Table C-3: Description of Scenarios in Figure 7-3 (Cumulative Domestic Environmental Impacts of All Steps in the Biofuel Supply Chain System under Three Scenarios in 2022)

Feedstock	Scenario A 2022 RFS2-projected feedstock mix produced with conservation/best management practices (BMPs) and efficient technologies	Scenario B 2022 RFS2-projected feedstock mix produced with minimal conservation/BMPs and current technologies	Scenario C 2022 conventional feedstock mix (corn starch, corn stover, and soybean) produced with minimal conservation/BMPs and current technologies
Centrosic Eth			16 BC
Corn Stover	 Stover harvest limited to acreage with low erosion potential, or erosion is mitigated with conservation tillage. Stover harvested with single-pass harvester. Increased use of conservation practices. 	 Stover harvested on acreage regardless of erosion potential. Stover harvested with multi-pass har No increase in use of conservation procession of the store of	vester. ractices.
	0.1 BG	0 BG	
W oody Biomass	• Biomass produced via light-to-moderate forest thinning or from short-rotation woody crops cultivated with long planting intervals on non-federal land currently in managed forest with short planting intervals.	• Short-rotation woody crops with short planting intervals and high chemical inputs cultivated on non-federal land currently in mature, managed forest plantations.	
	7.9 BG from dedicated energy	y crops	0 BG
Perennial Grass	 Switchgrass production area limited to east of Rocky Mountains. Conversion of land currently in row crop production to switchgrass production. Conversion of low diversity, marginal land to conservation managed switchgrass production. Increased fuel conversion efficiency and reductions in fuel production inputs, including fresh water. 	 Cellulosic feedstock (switchgrass or <i>Miscanthus</i>) produced on marginal land requiring high production inputs, including fertilizer, pesticides, and irrigation. No increases in fuel conversion efficiency or reductions in fuel production inputs, including fresh water. 	

Table C-3: Description of Scenarios in Figure 7-3 (Cumulative Domestic Environmental Impacts of All Steps in the Biofuel Supply Chain System under Three Scenarios in 2022)

Feedstock	Scenario A 2022 RFS2-projected feedstock mix produced with conservation/best management practices (BMPs) and efficient technologies	Scenario B 2022 RFS2-projected feedstock mix produced with minimal conservation/BMPs and current technologies	Scenario C 2022 conventional feedstock mix (corn starch, corn stover, and soybean) produced with minimal conservation/BMPs and current technologies
Biomass-based Diesel			
Soybean	0.66 BG		1 BG
	• Increases in yield primarily due to breeding new varieties that also require fewer production inputs, including fertilizer, pesticides, and irrigation.	• Increases in yield primarily due to higher production inputs, including fertilizer, pesticides, and irrigation.	
	• No conversion of marginal lands to soybean production.	 Conversion of marginal lands to soybean production, including areas requiring irrigation. 	
	• Increased use of conservation practices, including conservation tillage, nutrient management, and efficient irrigation delivery.	 No increase in use of conservation practices (i.e., conservation tillage, nutrient management, and efficient irrigation delivery). 	
	0.1 BG		0 BG
Algae	• Algae production co-located with stationary carbon dioxide source on marginal land.	• Algae produced on land converted from natural cover.	
	• Nutrient inputs from wastewater or other waste sources.	 Large nutrient inputs from non- waste sources. 	
	• Closed bioreactors co-located with publicly owned treatment works and other wastewater treatment facilities.	• Open pond production using fresh water.	

1	APPENDIX D:	
2		
3	CONCEPTUAL MODELS	
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- 6 As described in this report, the activities associated with cultivation of biofuel feedstocks
- 7 and their conversion to fuel result in a complex set of inter-related environmental impacts.
- 8 Conceptual models provide a useful tool to describe, understand, and communicate the complex
- 9 pathways by which these activities lead to impacts. As noted in Chapter 7, EPA anticipates
- 10 developing and using conceptual models as an important tool for the assessment in its 2013
- 11 Report to Congress. The conceptual models presented in this appendix lay a foundation for this
- 12 future effort. Figures D-1 to D-7 present conceptual models for feedstock cultivation and harvest.
- 13 Figures D-8 and D-9 present models for biofuel production and distribution. (Note that models
- are not included for end use of biofuel.) These early renditions graphically present the
- 15 environmental effects most commonly identified in current peer-reviewed literature and, while
- 16 comprehensive, do not attempt to include all possible effects.

Terms and Abbreviations Used in the Conceptual Models From the Legend

- <u>biotic response</u>- Response of living parts of terrestrial or aquatic ecosystems, either in terms of number of species or numbers of individuals of a particular species
- <u>ecosystem service</u>- Direct or indirect contribution of the environment to human well-being
- <u>environmental parameter</u>- A measureable attribute of the environment

From the Diagrams

- <u>aquatic life use support</u>- A beneficial use designation in which the water body provides suitable habitat for survival and reproduction of desirable fish, shellfish, and other aquatic organisms (this is a synthetic quality made up of many different environmental parameters)
- <u>BOD</u>- biological oxygen demand
- <u>contamination</u>- Release of nutrients or pesticides used in feedstock production to waterways or bodies of water
- <u>PM</u> particulate matter
- $\underline{T \& E \text{ species}}$ threatened and endangered species
- <u>VOC</u> volatile organic compound

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18 Feedstock Production

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Figures D-1 to D-7 present seven models for the six feedstocks covered in this report: corn starch; soybean; corn stover; perennial grass; woody biomass (short-rotation woody crops and forest thinning/residue removal); and algae production.

Different pathways are introduced at the top of several of these feedstocks models. These pathways were selected because: (1) they will likely be pursued in combination in order to grow enough feedstock to meet RFS2 2022 biofuel requirements (see Chapter 2 for a description of requirements), and (2) they result in different environmental impacts.

Arrows in the impact boxes (below the initial row of activities) depict whether the impacts are negative or positive. The number(s) by each arrow designate the pathway to which the arrows refer. A few pathways can have both negative and positive impacts (e.g., corn starch cultivation could result in increased or decreased use of ground and surface water). Dotted borders denote impacts that have a relatively large degree of uncertainty due to a lack of

- 32 information. Dotted boxes without arrows depict highly uncertain impacts that nonetheless are
- 33 described in the literature.

34 **Fuel Production and Distribution**

35

Figures D-8 and D-9 present conceptual models for production and distribution of the two biofuels covered in this report: ethanol and biodiesel.

38 Ethanol Production

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Figure D-8 shows the activities and impacts associated with production and distribution
of ethanol from both starch (i.e., corn grain) and cellulosic feedstocks, including corn stover,
perennial grasses, and woody biomass. A single model is provided for these four types of
feedstocks because their impacts and associated uncertainty are largely similar, with a few
exceptions (e.g., water use will likely be slightly higher for cellulose conversion).

As depicted in the upper left of the Figure D-8, conversion of starch to ethanol consists of several sequential steps, including milling, hydrolysis, and fermentation. There currently are two distinct alternatives for converting cellulosic feedstock into ethanol: (1) biochemical conversion (which is preceded by a catalysis step to separate cellulose and hemicellulose from their tightly bound state with lignin), and (2) thermochemical conversion. These alternatives vary slightly in terms of their chemical processes and by-products. As with Figures D-1 to D-7, a dotted border is used to denote impacts with relatively large uncertainty due to a lack of information.

52 Biodiesel Production

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54 Figure D-9 shows the activities and impacts associated with production of biodiesel from

soybeans and algae. Several techniques may be used to convert plant oils into biodiesel,

56 including hydrogenation, catalytic cracking, and transesterification. All these processes produce

57 biodiesel, with glycerin as a by-product.



Figure D-1: Pathways for Potential Environmental Impacts of Corn Starch Feedstock Cultivation





Figure D-2: Pathways for Potential Environmental Impacts of Soybean Feedstock Cultivation



Figure D-3: Pathways for Potential Environmental Impacts of Corn Stover Feedstock Cultivation* *Corn stover is a waste product of corn starch cultivation. The impacts of corn cultivation are shown in Figure D-1. Figure D-3 highlights the environmental impacts of stover removal *above and beyond* those impacts attributable to corn grain production.



Figure D-4: Pathways for Potential Environmental Impacts of Perennial Grass Feedstock Cultivation



Figure D-5: Pathways for Potential Environmental Impacts of Short-Rotation Woody Crop Feedstock Cultivation *These particular land use changes may not currently be allowable under RFS2.



Figure D-6: Pathways for Potential Environmental Impacts of Forest Thinning and Residue Removal



Figure D-7: Potential Environmental Impacts of Algae Feedstock Production



Figure D-8: Potential Environmental Impacts of Producing and Distributing Conventional and Cellulosic Ethanol (Impacts of Fuel Use Not Included)

