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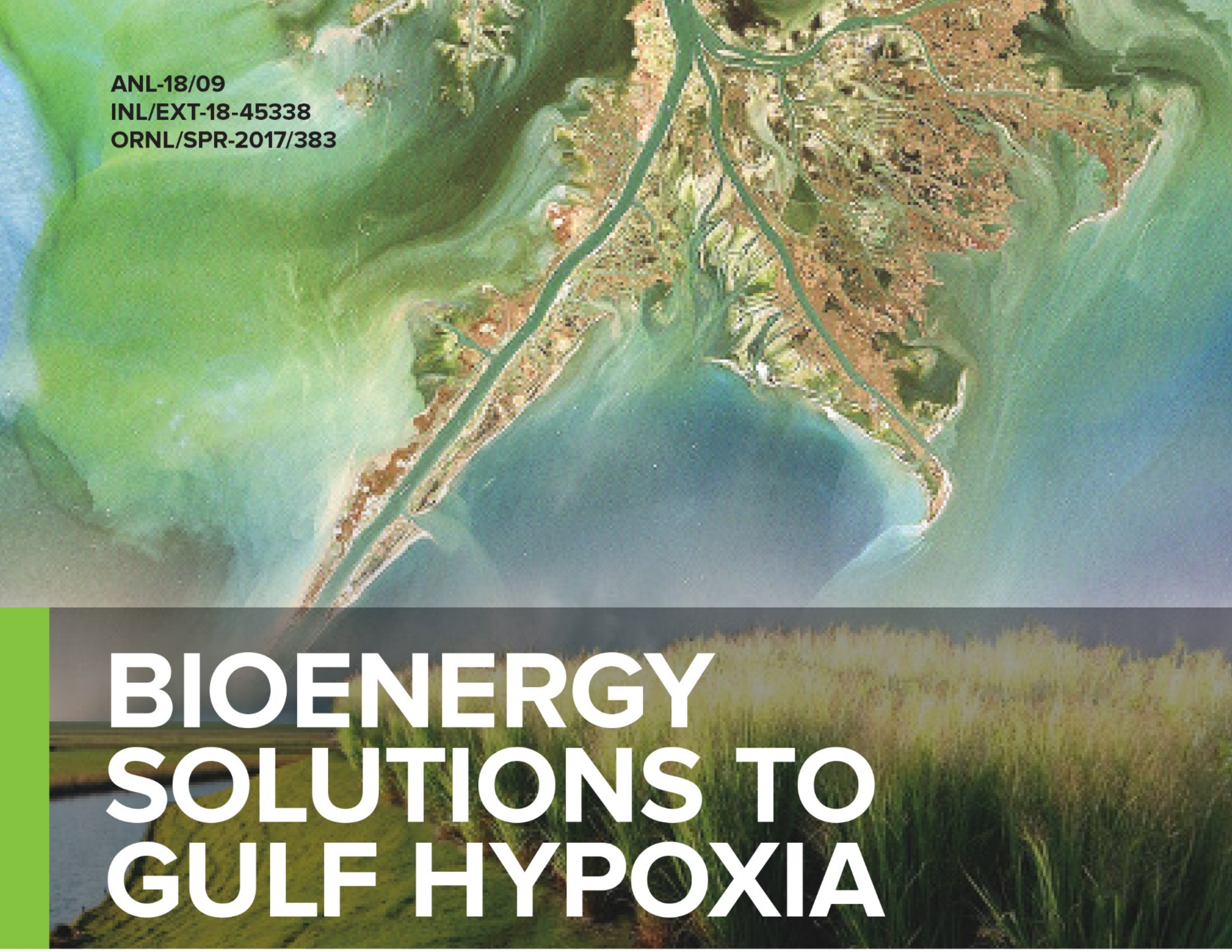

BIOENERGY SOLUTIONS TO GULF HYPOXIA

Workshop Summary Report

Argonne NATIONAL LABORATORY
OAK RIDGE National Laboratory
INL Idaho National Laboratory

On the Cover

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Bioenergy Solutions to Gulf Hypoxia

Workshop Summary Report

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Acknowledgements

The authors gratefully acknowledge the valuable ideas and insights from all of the stakeholders who participated in the Bioenergy Solutions to Gulf Hypoxia Workshop held August 30–31, 2016, in Washington, D.C. The willingness of these experts to share their time and knowledge has helped us identify and better define current and emerging opportunities to develop and implement innovative bioenergy feedstock production. These stakeholders are listed in Appendix A.

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Executive Summary

The Bioenergy Solutions to Gulf Hypoxia Workshop gathered stakeholders from industry, academia, national laboratories, and U.S. federal agencies to discuss how biomass feedstocks could help decrease nutrient loadings to the Gulf of Mexico (Gulf), a root cause of the large hypoxic zone that forms each summer. More broadly, workshop participants discussed the current state of environmental markets in the United States and the state of the science on nutrient management and monetization of the ecosystem services and environmental and social benefits derived from growing energy crops.

A diverse group of participants presented informative perspectives during five sessions: (1) Framing the Problem, (2) Technologies and Practices to Improve Nutrient Management, (3) Monetizing Ecosystem Services, (4) Strategies to Advance Progress, and (5) Research Gaps and Strategies. Multiple breakout discussions designed to elicit stakeholder inputs were interspersed within the presentations.

Framing the Problem

In this session, experts described the growing problem with eutrophic conditions in U.S. waters, including freshwater and coastal systems. Each summer, the Gulf has a large hypoxic zone that is barren of aquatic life. Historical trends revealed that nutrient loadings are highly correlated with the spatial extent and temporal duration of hypoxia. During this session, experts presented on the upstream relationships between nutrient loadings and contributions from rural agriculture, rural and urban municipal sources, and animal wastes. Presenters described the impacts that degraded summer water quality has on aquatic biota, reducing the value of these water bodies for recreation, fisheries, and avoidance of human health impacts. The Gulf supports the largest fishery in the United States, raising concerns about the economic impacts of the hypoxic zone on Gulf fisheries' and aquaculture's ability to meet growing U.S. demand for seafood. National Oceanic and Atmospheric Administration studies show that shrimp and other commercially important fish avoid the hypoxic zone and aggregate near the edges of the Gulf, where they are caught by fishing fleets. Workshop presenters pointed out that remedial upstream actions have cumulative downstream benefits that accrue from local actions to benefit distant water bodies.

After the presentation of this background information, workshop participants discussed the mandate and activities of the U.S. Environmental Protection Agency Hypoxia Task Force. The Hypoxia Task Force includes many federal agencies and states in the Mississippi-Atchafalaya River Basin. The Hypoxia Task Force works with states to develop sediment and nutrient transport models and, in some cases, voluntary nutrient-reduction targets. During this session, attendees also identified stakeholder groups that could benefit from achieving bioenergy production and hypoxia reduction goals.

Technologies and Practices to Improve Nutrient Management

Presentations focused on describing available models that simulate linkages between watershed-scale influences, environmental sustainability, and ecosystem services. In the context of decision support, these models have been used to design agricultural landscapes (e.g., locations of buffer zones and wetlands and areal configurations of crop production) and logistics (e.g., harvesting, baling, transportation techniques, and precision and optimized farming). The goal has been to develop farm-level agronomic practices that result in profitable, integrated production of energy crops and crop residues. These biophysical models help in monetizing the value of water-quality changes associated with crop production and residue harvest.

Monetizing Ecosystem Services

A presentation from the U.S. Department of Agriculture's Office of Environmental Markets (OEM) focused on the link between ecosystem services derived from farmer-level responses to landscape management decisions (e.g., bioenergy crops) motivated by a desire to meet watershed and farmer-level environmental sustainability goals. One incentive OEM provides to farmers is a voluntary water-quality trading (WQT) program. Under this program, urban and industrial point pollution sources (i.e., easily traceable point sources of pollution, specifically nutrients) can buy water-quality credits from farmer(s) to offset their releases; farmer(s) gain credits by implementing prescribed landscape-management practices. The presentation outlined the role of OEM and the tools and services OEM provides to support WQT.

Presenters also discussed the potential for applying the WQT tools to address nutrient-loading conditions throughout the Mississippi-Atchafalaya River Basin. OEM highlighted the potential for combining crop choice, feedlot management, and more-efficient implementation of best management practices in the Ohio River Basin. Presenters also described the implementation of WQT in the Ohio River Basin, and one noted interest in achieving total nitrogen and total phosphorus targets through growing biomass feedstocks in the basin.

The Willamette Partnership described a successful model for credit trading that has been implemented in the Columbia River Basin in the Western United States. In addition to describing the Willamette Valley's model for WQT, the Partnership stated that landowners can potentially stack multiple credits for ecosystem services. In addition to nutrient credits, air and carbon credits offer another potential revenue stream for farmers.

The U.S. Water Alliance described a watershed protection utility (WPU) as a potential alternative under development. A structure like the WPU could serve as a clearinghouse for transactions between point-source polluters and bioenergy producers.

The workshop helped elicit feedback from participants on a number of topics centered on bioenergy market development, ecosystem services, and sustainability, including the following:

- The potential role bioenergy might play in providing ecosystem services of value, including non-energy services. (Attendees made the point that no other renewable source of energy has as much potential for providing ecosystem services as bioenergy.)
- Environmental credits and other approaches for assigning market-based values for conservation practices, such as landscape diversification, riparian buffers, cover crops, and other practices that are applied to biomass-producing landscapes, as well as the potential for bioenergy crops and conservation practices specific to them to be eligible for environmental credits.
- Development of certification standards as an alternative way to secure added revenue for ecosystem services.
- Accounting for multiple ecosystem services so that benefits of each can be attributed to farmer decisions. (This discussion centered on the "delta" between the current price for advanced biomass feedstocks, the farmer's production cost, and the potential for augmenting revenue through payments for ecosystem services.)
- Identification of new niche markets for ecosystem services, such as urban corridors, where bioenergy crops can be produced on empty lots. This would provide multiple benefits, such as adding attractive green spaces, providing additional revenue to municipalities, and helping cities manage storm water and heat island effects. (Marketing the investment in rural bioenergy production to urban populations is a strategic educational opportunity. In addition, Detroit and other large cities in the Rust Belt are viewing green bioenergy projects as an important part of their revitalization strategies.)
- The importance of well-executed communication plans to inform multiple and diverse stakeholders (e.g., farmers and environmental nongovernmental organizations) of the benefits that bioenergy can provide.
- The importance of preserving landowners' anonymity in developing approaches and methods for communicating with multiple stakeholders.

- Identifying demand for the ecosystem services produced by bioenergy growers, including understanding how to engage point-source polluters (e.g., water and wastewater utilities and rural and urban municipalities) and others interested in in deriving value from WQT programs.

As part of the workshop activities, participants brainstormed project concepts. This exercise required discussion of potential project goals and attributes, partnerships, stakeholder engagement, and funding strategies.

Strategies to Advance Progress

The most significant barrier to biofuel adoption is the price gap between biofuels and fossil-based alternatives. In this session, participants discussed that going forward, an important overarching goal should be closing the profitability gap (specifically, by valuing the non-fuel ecosystem goods and services that biofuel production can provide). Participants identified research gaps that, if addressed, would advance progress towards accomplishing ecosystem services valuation, such as providing a foundational framework for comparing ecosystem services from bioenergy systems, commodification of bioenergy, multi-scale biophysical modeling, and certification programs.

Participants suggested that a framework for understanding ecosystem goods and services associated with advanced bioenergy production systems may be helpful in promoting adoption. Research to support the commodification of advanced biofuels might be included as part of such a framework. Attendees discussed the role of ecosystem services valuation in moving toward monetization and commodification (i.e., assigning an economic value to non-energy benefits derived from producing biofuels). They recommended collaborative modeling of bioenergy systems' social, biophysical, and economic aspects as a way to assign economic value to these ecosystem services. This would require integrating data from multiple sources on all aspects of ecosystem services that are involved in bioenergy feedstock production. Workshop participants expressed interest in crosscutting sustainability research to ensure that efforts to increase portfolios of ecosystem services are integrated across the supply chain and communicated among feedstock production, conversion, and logistics programs. They also discussed the potential of working with private entities to define verifiable farm and fuel certification guidelines, thereby promoting commodification of bioenergy and bioproducts with favorable portfolios of ecosystem services.

A number of participants recognized that general public audiences sometimes have skeptical perceptions of bioenergy compared to other renewable energy technologies. They proposed that these perceptions are dominated by (1) both science- and non-science-based discussions around impacts of corn ethanol production and (2) the general public's lack of exposure to advanced biomass feedstocks, including cellulosic perennials, residues, and waste streams. To address this barrier, participants suggested that informing public opinion by producing and disseminating high-quality, science-based results should be a top priority. Discussion centered on the benefits of biomass production in terms of energy and non-energy ecosystem goods and services.

Research Gaps and Strategies

This workshop included discussions of future needs. Regarding technology advancement needs, attendees identified methods and tools for measuring ecosystem services (e.g., crop yield, nutrient and carbon status of crops, soils, and water, and fluxes). These included remote sensing, precision farming systems, drones, and other recent advances in sensor-based feedback to producers. In addition, workshop participants recognized the need for real-time decision-making tools.

Workshop participants also discussed various frameworks that could provide producers with access to payment for ecosystem services through trading, certification schemes, and/or WPUs. Participants suggested that paths toward commodification are needed to advance this central goal.

Bioenergy Solutions to Gulf Hypoxia describes the workshop objectives and structure; highlights technologies and information presented or discussed; and summarizes participant insights for overcoming economic, environmental, and social barriers to the implementation of advanced bioenergy production.

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Bioenergy Solutions to Gulf Hypoxia Workshop Summary Report

1 Introduction

Research suggests that advanced bioenergy production is a promising and practical way to help improve water quality and reduce the migration of non-point pollution nutrients to waterways. This, in turn, supports the reduction of hypoxia in U.S. coastal estuaries (Howarth et al. 2000) and worldwide (Diaz and Rosenberg 2008). The most notable example is the dead zone in the Gulf of Mexico (Gulf), where the oxygen level is too low to support biological life. Because nutrient loadings are a primary contributing cause to Gulf hypoxia, reducing nutrient loadings from the Mississippi-Atchafalaya River Basin (MARB) is critical to shrinking the dead zone in the Gulf (Dale et al. 2010). This objective is synergistic with the nation's need to develop practical ways to scale up bioenergy feedstock production to support a thriving bioeconomy (Langholtz et al. 2016).

Argonne National Laboratory, Idaho National Laboratory, and Oak Ridge National Laboratory organized the Bioenergy Solutions to Gulf Hypoxia Workshop to assess the state of science, as well as to help identify research needs, interagency collaborations, and partnerships various entities could pursue. A workshop format was used because of the interdisciplinary and multijurisdictional nature of this topic, which necessitates bringing people together to generate ideas and new partnerships. The workshop provided a multi-stakeholder-platform discussion of what work is being done, as well as what still needs to be done.

1.1 Why Bioenergy and Why Now?

Developing bioenergy solutions to Gulf hypoxia is a promising way to accelerate the competitiveness of advanced bioenergy while simultaneously scaling up effective conservation practices. It was clear from the synergy of workshop participants' common goals that a window of opportunity may exist to accelerate innovative solutions. This will be discussed further in Section 1.3, "Nutrient Source Identification, Accounting, and Attribution."

The U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO) has sponsored development of a number of tools and capabilities that, when added to BETO's and the industry's collective knowledge and ongoing initiatives, may help the nation meet its hypoxia-reduction goals and achieve other environmental benefits. Landscape design tools (e.g., multi-objective spatial optimizations) are one example of BETO-sponsored tools; these tools are developed to manage bioenergy-producing lands for feedstock production and to support environmental objectives. Other examples include large-scale river basin models linking land-management decisions with water-quality outcomes. When combined with models to estimate ecological value, such biophysical models can help bring environmental considerations into the equation, benefitting both society and individual farmers.

1.2 Shared Understanding of Key Workshop Concepts

For shared understanding, key concepts were defined at the outset of the workshop.

In the context of workshop discussions, participants generally understood "point-source pollution" as air and water pollution from a single, identifiable source, and "non-point-source pollution" as air and water pollution from diffuse sources. This workshop primarily focused on non-point-source pollution, although point-source polluters were considered as potential participants in environmental-related trading programs.

"Bioenergy systems" were defined as systems that deploy second-generation bioenergy crops, such as switchgrass, miscanthus, willow, and other mostly perennial lignocellulosic crops, as well as agricultural residues such as corn stover.

The definition of "ecosystem services" was taken from the Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being Synthesis* (MEA 2005), and includes the following:

- Provisioning services such as food, fuel, water, transportation, fiber, and timber
- Regulating services that improve climate, prevent flooding and drought, disease, prevent erosion, and remove wastes and purify water or dilute pollution
- Cultural services that provide recreation, tourism, existence and preservation values, aesthetic, and spiritual benefits
- Supporting services such as habitat for aquatic and terrestrial wildlife, soil formation, photosynthesis, and nutrient cycling.

In addition to this definition, participants cited research linking ecosystem services and bioenergy production. Gasparatos et al. (2011) identified a number of ecosystem services associated with bioenergy production systems. Ecosystem accounting discussions included a cautionary note about double counting. Provisioning services were considered final, but supporting, cultural, and regulating services were considered intermediate services that do not provide direct benefits to human well-being (Munns et al. 2015). Ecological economists have started to develop ecological production functions that are analogous to economic production functions so that the additive value of biomass production and ecosystem services can be calculated.

Finally, a fundamental discriminator in the definition of ecosystem services was that the endpoint is human well-being, although newer ecosystem services frameworks recognize that there may be different classes of beneficiaries of ecosystem services.

1.3 Hypoxia-Reduction Solution: Bioenergy Feedstock Production

Hypoxia's causes are principally traced to excess nutrients from agricultural production in the MARB and municipal wastewater (Dale 2009). Fertilizer application, inadequate treatment of runoff and agricultural drainage, confined animal feedlots, and urban and other nutrient-laden wastewaters contribute to the problem. Significant research has been conducted to understand and address non-point sources of pollution and, subsequently, to reduce the areal extent and duration of hypoxia in the Gulf of Mexico, as well as in upstream water bodies. Progress has been made, but problems persist in adopting practices and in measuring their effectiveness at different scales. Tools and capabilities developed for advancing the bioenergy industry are reaching technological maturity to meaningfully contribute to hypoxia reduction goals in ways that will help drive feedstock production (Figures 1-1 and 1-2).

A significant body of work on advanced bioenergy systems exists, including work quantifying these systems' effects on sustainability indicators relative to land management in no-bioenergy scenarios (see Section 3.2 for key examples and references). This research indicates that advanced bioenergy systems can help address water quality issues in downstream water bodies, such as the Gulf of Mexico. Solutions from bioenergy are appealing because they can synergize conservation with rural development and directly contribute to the renewable and clean energy sector. Workshop participants pointed out that of the renewable energy sources under development today, biomass is unique in that it can provide environmental and economic benefits in addition to greenhouse gas (GHG) reduction, such as cropping diversification, reduced erosion and nutrient loss, reduced non-point pollution, and wildlife habitat development.

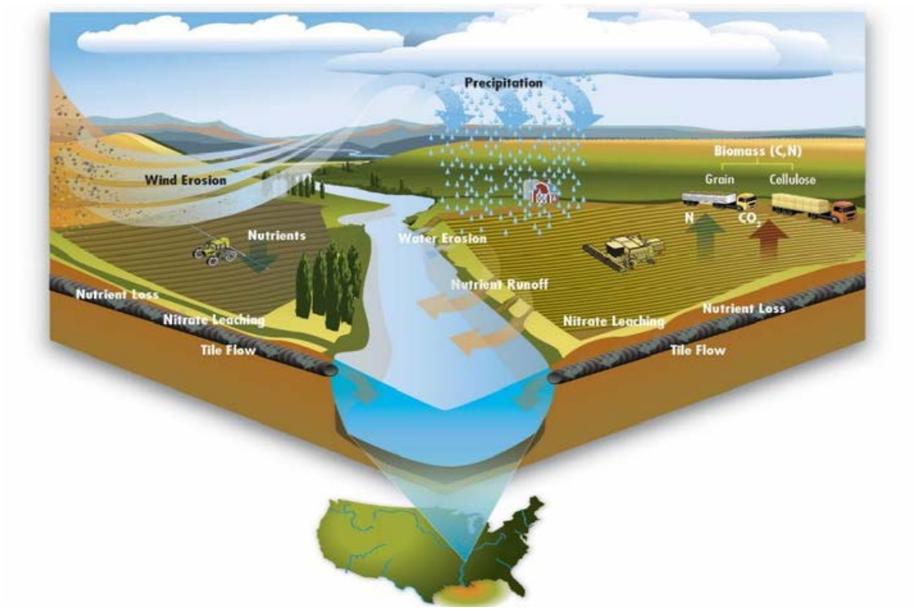

Figure 1-1. A key premise of the workshop is that adequately addressing agricultural non-point sources of pollution near their source will have a measurable positive impact on reducing the Gulf dead zone. Image courtesy of Idaho National Laboratory.

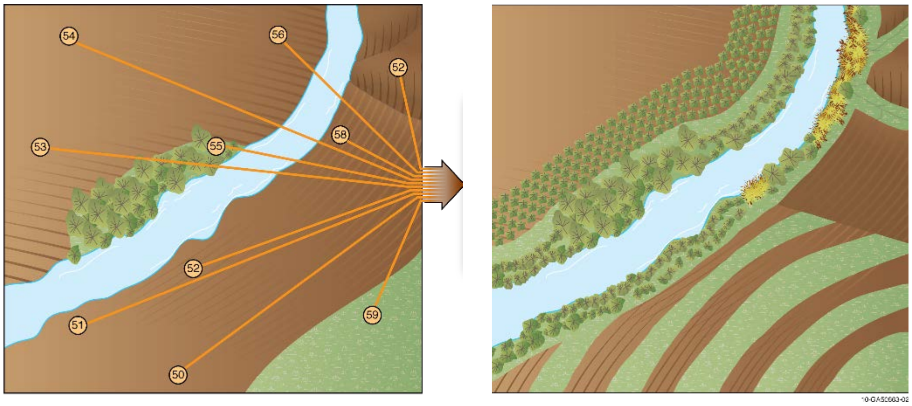

Figure 1-2. A key premise of the workshop is that a watershed-scale land management strategy that includes bioenergy feedstock production can help achieve the agricultural-based nutrient reduction needed to reduce hypoxia. The numbers on the figure on the left suggest various land management options that can be implemented to integrate bioenergy crop production into a landscape (e.g., riparian woody crops, strip farming) to effectively reduce nutrient loading to a stream. Image courtesy of Idaho National Laboratory.

1.4 Ecosystem Services as Market Enabler

An integrated landscape approach to implementing bioenergy supply chains can reduce a number of environmental and socioeconomic risks to the agricultural industry, including public resistance, uncertainties about impacts to environmental quality and food production, and land managers' challenges in producing feedstocks practically and profitably. Sustainability and ecosystem services by design can be part of the strategy to cost-effectively reduce hypoxia (Figure 1-3).

Figure 1-3. A key premise of the workshop is that establishing/capturing the ecosystem services value of bioenergy feedstock production will not only help mobilize sustainable biomass for a thriving bioeconomy, but also motivate practices that reduce Gulf hypoxia while adding socioeconomic and environmental value. Dual-crop smart landscape arrangements such as the corn-willow system (corn in front, willow in the background), shown on the right, can help reduce nutrient losses to water. Images courtesy of the U.S. Department of Agriculture Natural Resources Conservation Service (left) and Argonne National Laboratory (right).

1.5 Benefits of Coupling Bioeconomy and Hypoxia-Reduction Objectives

Locally, there are a number of ways that the nation can benefit from implementing an integrated landscape-management approach to enhance the environmental and socioeconomic value of the landscape and waters draining from it:

- Improved local water quality
- Improved terrestrial and aquatic biodiversity
- Productive aquatic systems leading to fishery and recreational industries
- Diversified business models and employment opportunities for rural communities.

In summary, workshop organizers sought to bring together those working on initiatives to mobilize the nation's biomass resources, those who work on hypoxia reduction, and other stakeholders (including those who are impacted by the hypoxia problem and part of rural economies). These stakeholders were asked to participate in developing strategies for moving toward a bioeconomy that meets multiple objectives (Figure 1-4).

Figure 1-4. This switchgrass field that borders a water body is expected to provide both biomass and ecosystem services related to improved water quality (Johnson 2016).

This report summarizes the presentations and input of workshop participants and is not intended to comprehensively cover all relevant issues.

Presentations and associated discussions are synthesized in Section 2: “Framing the Problem,” Section 3: “Bioenergy as a Solution,” and Section 4: “Ecosystem Service Markets.” Appendix B provides a glossary of terms and acronyms used. An index of presentations and presenters is included in Appendix C. Workshop participant input is summarized in Section 5: “Strategies to Advance Progress,” and Section 6: “Research Gaps and Strategies.”

2 Framing the Problem

Hypoxic zones have grown exponentially in coastal zones around the world (Diaz and Rosenberg 2008), including 60% of U.S. bays and estuaries (Howarth et al. 2002). In addition to coastal areas, the growing problem of hypoxia in lakes (e.g., Lake Erie, Lake Okeechobee) and reservoirs (e.g., Brownlee Reservoir) is unlikely to abate as climate warming progresses (Kao et al. 2016).

The majority of U.S. agricultural biomass is grown in the MARB. The MARB drains roughly 40% of the contiguous United States and extends into two provinces of Canada. Downstream, tributary basins drain to the Mississippi River and the Gulf of Mexico.

Each summer, a huge region across the floor of the northern Gulf of Mexico experiences hypoxia, which is defined as less than 2 mg/L dissolved oxygen. Commonly referred to as the dead zone, the oxygen levels in these waters are too low to support biological life. This has had long-lasting impacts on the productivity of the bottom fauna, which would normally support a food chain of benthic fishes, including shellfish. Mobile fauna are better able to respond by avoiding hypoxic areas (Craig and Crowder 2005), which extends across a zone the size of Connecticut and Rhode Island combined, forming the second largest hypoxic zone in the world (Figure 2-1).

The dead zone blocks migrations or creates disconnected populations of sea turtles, bottlenose dolphins, and tuna (Craig et al. 2001). Production in and around this area of the Gulf supports the largest and most-important fishery in the United States, where market demand for fish, and especially shrimp, has been showing strong growth. Therefore, environmental threats to the Gulf from oil spills and from hypoxia have raised concerns about the long-term economic sustainability of Gulf of Mexico fisheries.

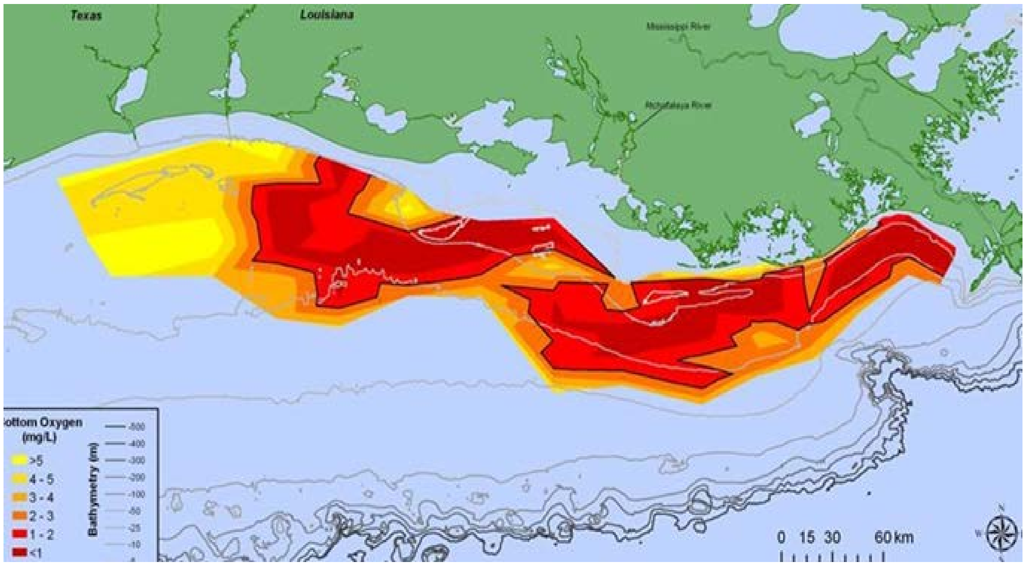

Figure 2-1. Distribution of bottom-water dissolved oxygen from July 28 to August 3, 2015, west of the Mississippi River delta. Areas in red denote dissolved oxygen less than 2 mg/L. Data from N. Rabalais (Louisiana Universities Marine Consortium) and E. Turner (Louisiana State University) reported in the *Times-Picayune* on June 9, 2016.

Growth in the hypoxic area is believed to be caused by excessive nutrient loading to the Gulf, which has been increasing at the rate of 0.13 kg/hectare/year since 1980 (David, Drinkwater, and McIsaac 2010). Historical sediment cores and paleoindicators suggest that hypoxia has increased since the early 1940s and became an annual event in the 1970s (Diaz, Rabelais, and Braitburg 2012). The area of annually recurring dead zone has tripled since the 1950s, varying from 5,000 to over 15,000 km^2 (Dale et al. 2009). This increase has been largely in response to increased nitrogen loads from the Mississippi River (Rabalais et al. 2007). In the 1990s, nitrogen sources were attributed to commercial fertilizer (51%), manure application (30%), nitrogen fixation by legumes (9%), and domestic waste (5%); the remaining 4% was due to atmospheric deposition (Goolsby et al. 2000). Since that time, atmospheric deposition of nitrogen derived from fossil fuel combustion has increased, with current estimates of 8% in the MARB and higher percentages in the Northeast (David, Drinkwater, and McIsaac 2010). In addition, nitrogen deposition, mainly from fossil fuel combustion and fertilizer production and use, is a more significant input than has previously been appreciated (Howarth et al. 1996; Liu et al. 2013). The distribution of nitrogen sources to the MARB is shown in Figure 2-2.

The U.S. Environmental Protection Agency (EPA) Hypoxia Taskforce (HTF), which includes representatives from states and agencies in the MARB, has set a target of shrinking the dead zone from its current average size of almost 15,000 km^2 (about 6,000 square miles) (Figure 2-1) to about 5,000 km^2 (about 2,000 square miles) by 2035. This target was originally set in 2001 and has since been extended several times.

In order to reach this target, the HTF set an interim goal to reduce nitrogen and phosphorous loading by 20% by 2025 to spur immediate planning and implementation actions. The HTF estimates that, to achieve the 2035 goal for the size of the hypoxic zone, the nitrogen and phosphorous entering the Gulf of Mexico must be reduced by at least 45%. Many states and federal agencies are voluntarily setting targets for nutrient reductions.

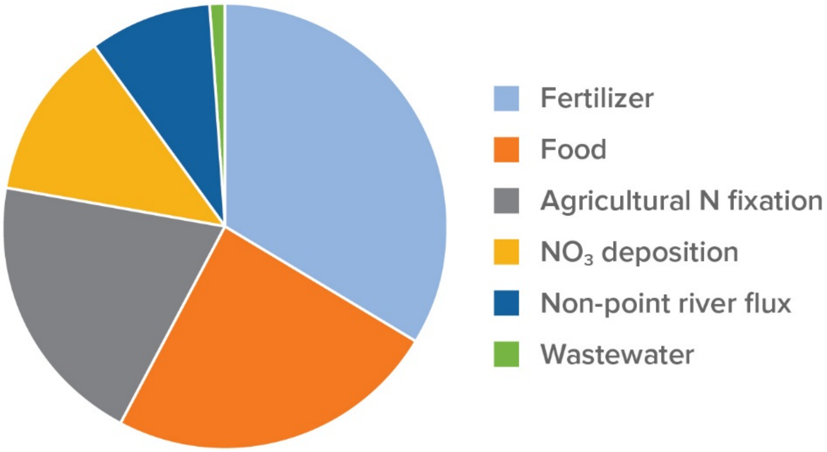

Figure 2-2. Annual flux of nitrogen to the MARB is due to a number of sources, with a total of 5,406 kg/km^2/year (Howarth et al. 1996).

While it is recognized that year-to-year variation in the size of the hypoxic zone responds to local factors (such as summer inflows and currents that influence nearshore mixing processes and stratification), a strong correspondence with nutrient inflows has been demonstrated, including both nitrogen (nitrate) and phosphorus (Alexander et al. 2008). Effectively addressing the contributing factors that determine the current size of the Gulf dead zone has been a grand challenge. Figure 2-3 shows that the hypoxic area is currently trending above the 2035 target. Trend analysis of residuals (removing dependence on stream flow) is under investigation (EPA 2007).

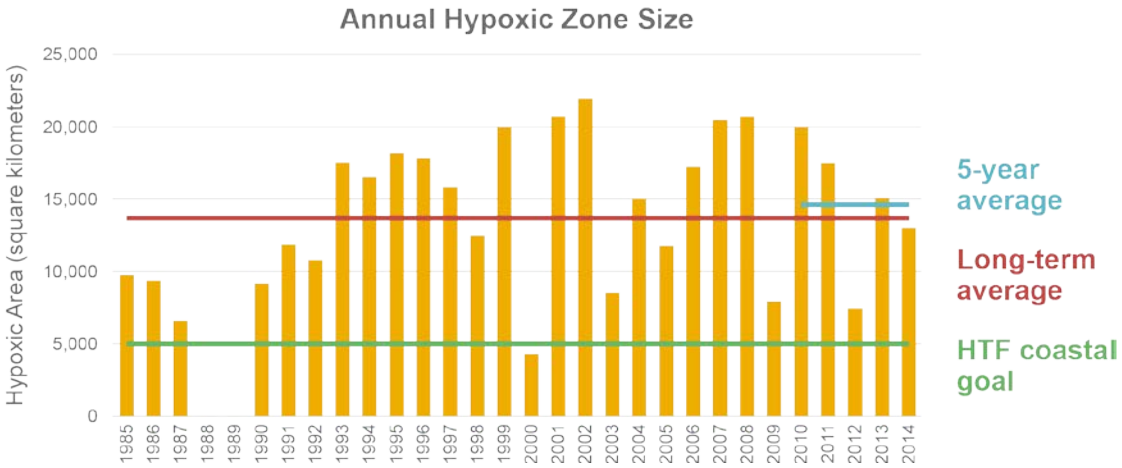

Figure 2-3. Effectively addressing the factors that contribute to the Gulf dead zone has been a grand challenge, and studies indicate a 45% reduction in the nitrate and phosphorus entering the Gulf of Mexico is needed to reduce the size to 5,000 km^2 (EPA 2007; Obenour et al. 2012). This chart was reproduced from EPA 2017b.

According to a recent U.S. Geological Survey report, about 60% of nitrogen loadings and about 50% of phosphorus loadings to the Gulf of Mexico are attributable to excessive use of fertilizer by agriculture (Alexander et al. 2008). Animal agriculture (livestock production) accounts for over 40% of these. Farm fertilizers contribute 27% of phosphorous and 41% of nitrogen nutrient pollution to waterways (Robertson and Saad 2013).

The Natural Resources Conservation Services' (NRCS's) Conservation Effects Assessment Project maps compare the amount of local and Gulf-delivered nutrients, indicating how far upstream phosphorous and nitrogen loading can take place and how. While treatment efforts must be sized exponentially to have the needed downstream impact to reduce the Gulf dead zone (Figure 2-4), they can also have significant local benefits (White et al. 2014).

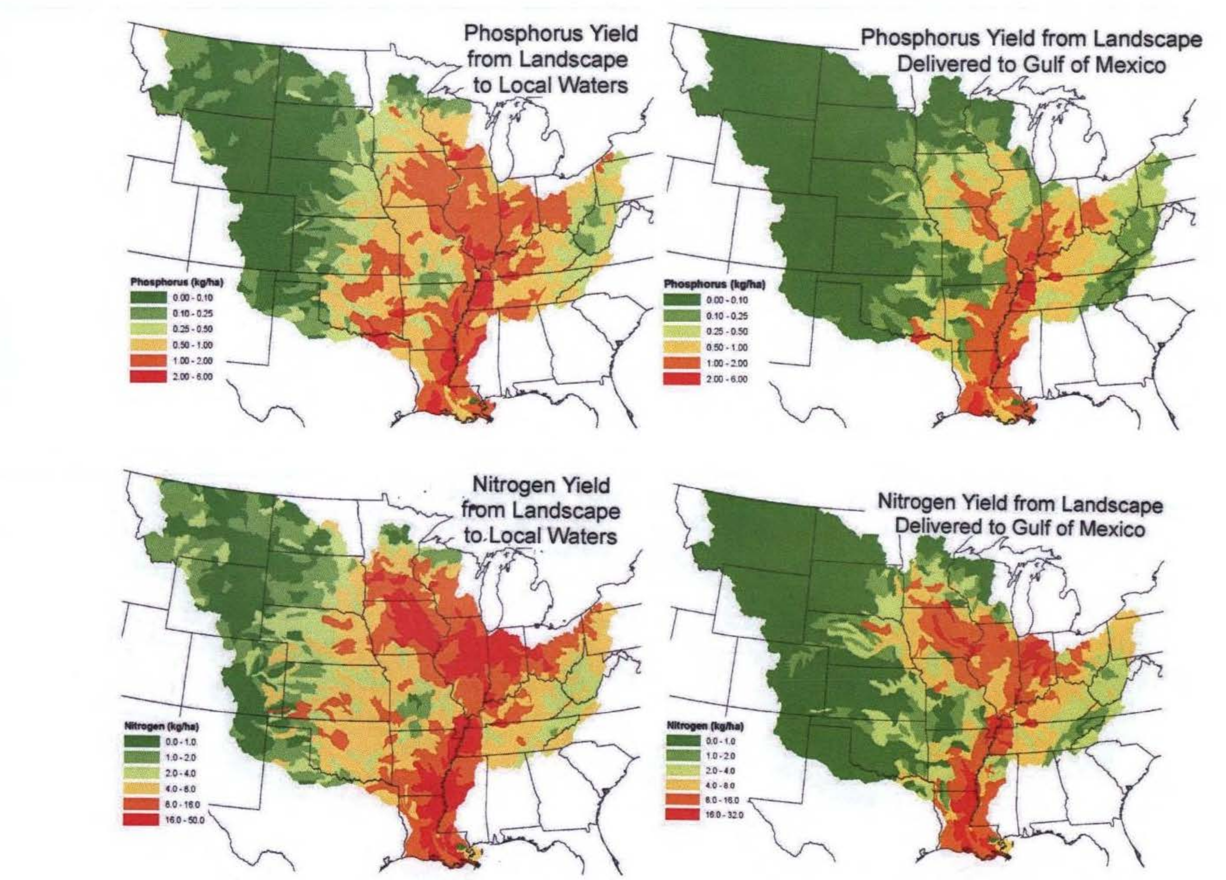

Figure 2-4. Comparison of the difference in phosphorous (*top*) and nitrogen (*bottom*) delivered both to local waterways and to the Gulf; the maps show that phosphorous and nitrogen loading begin far upstream of the Gulf of Mexico (White et al. 2014).

A higher incidence and duration of algal blooms is a risk associated with eutrophication. Several notable freshwater events have had significant impacts in recent years. In 2011, Lake Erie's western basin had a toxic algal bloom that caused drinking water to exceed EPA safe drinking water standards by 1,500 times. Populations in Toledo, Ohio, and Ontario, Canada, lost access to drinking water as a result. Similar events occurred in 2014, 2015, and 2016 (Barber 2016). In the summer of 2016, a bloom of cyanobacteria visible from satellite was observed in Lake Okeechobee, Florida (Figure 2-5), where microcystin posed a significant health threat through inhalation or ingestion. Cattle farms and other agriculture contribute to nutrient inputs to the lake, which then spreads the algae to beaches on both the Gulf and Atlantic coasts. Consequences for tourism have been significant, and persistent algal sliming of beaches is expected to be the new normal for the state (Parker 2016).

Figure 2-5. Top: Satellite photo of the algal bloom in the Gulf of Mexico, taken in November 2009. Photo courtesy of NASA. Middle: The green algal bloom formed a thick surface layer in Lake Dora, Florida, in May 2010. Photo courtesy of Nara Souza, Florida Fish and Wildlife Commission. Bottom: This dead fish is a result of severe eutrophication in China's Dianchi lake in 2007. Photo courtesy of Greenpeace China.

2.1 Impacts/Costs of Gulf Hypoxia

Hypoxia has significant impacts on biota. Saturated oxygen levels in water depend on temperature and salinity, and values near 7 mg/L O_2 are typical. As concentrations fall below 4 mg/L, fish and other mobile fauna move away from areas with low-saturated oxygen. At levels below 2 mg/L, fish, shrimp, and crabs are absent in the Gulf of Mexico. In addition to hypoxia, excess nutrients can cause red tides and other harmful algae to contaminate shellfish in the Gulf of Mexico and other coastal areas, causing gastrointestinal and, sometimes, neurological illnesses. The occurrence of harmful algal blooms is a growing problem. The Gulf States monitor harmful algal blooms, aided by remote sensing imagery from the National Oceanic and Atmospheric Administration.

The fishery in the Gulf of Mexico is the largest in the United States, with over 60% of landings (the brown shrimp fishery alone was worth $200 million in 2012). In addition to fishes in the commercial fishery, sea turtles and bottlenose and Atlantic spotted dolphins feed on discards from shrimp boats in the northwestern Gulf (Craig et al. 2001). A recent modeling analysis estimated 20%–25% decreases in Atlantic croaker (Rose et al. 2017). According to Caddy (1993), increased enrichment results first in declines of fish that live and feed on or near the bottom of large water bodies (demersal zone species), followed later by declines in foraging coastal and oceanic fish (pelagic zone species).

The signal of change in fishery income as a function of annual size of hypoxia has not been strong enough to detect using market-based methods over the relatively short time series of historical data in the Gulf, but this has recently changed (Smith et al. 2017). Studies have shown that mobile fishes, including shrimp, avoid hypoxic areas and collect near the edge of the dead zone, where they are collected by fisheries (Huang et al. 2012), and the market for small shrimp is influenced by imports from Asia. Declines in provision of fish catches have been quantified in other coastal areas of the United States; for example, hypoxia in a North Carolina estuary decreased catches of brown shrimp by 12.9% from 1999 to 2005 (Huang et al. 2010; Craig 2012).

2.2 Current Federal/State Actions to Address the Hypoxia Problem

At the federal level, Gulf hypoxia has been a topic of concern for more than two decades. In 1997, the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (now referred to as the "Hypoxia Task Force" or "HTF") was established within the EPA "to understand the causes and effects of eutrophication in the Gulf of Mexico; coordinate activities to reduce the size, severity, and duration; and ameliorate the effects of hypoxia" (EPA 2016a). Currently, HTF membership includes 5 federal agencies and tribes and 12 state agencies, which are represented by agricultural agencies, environmental agencies, or natural resource agencies. The HTF primarily represents states bordering the Mississippi River and not inland states (less than half of the MARB), and this area includes the states that contribute the highest nutrient loads to the Gulf. The role of the HTF is to provide executive-level direction and support for coordinating participating organizations' work on nutrient management within the MARB. In addition, the HTF provides a forum for state water-quality and agriculture departments to partner on state and local efforts to mitigate nutrient loading, encouraging a holistic approach that takes into account upstream sources and downstream impacts.

A Hypoxia Model Working Group associated with the HTF was established to promote the use of watershed models among states to describe transport of nutrients from agricultural sources to water bodies and assess impacts of agricultural practices on water bodies. The states of Minnesota, Ohio, and Louisiana (among others in the region) are collecting data, and modeling efforts are underway in several states as well. Several states are using the "Region 5" model to assess the improved water quality resulting from conservation practices (Granholm and Chester 1999). This model focuses mainly on sediment and sediment-bound nutrients and does not address nitrate, for example. Other models for evaluating the downstream benefits of upstream practices include empirical models—such as the Spatially Referenced Regressions on Watershed attributes (SPARROW) model—and process-based models—such as the Soil

Water Assessment Tool (SWAT). The SPARROW model, developed by the U.S. Geological Survey, is well-suited under existing or historical conditions, but it is not suitable for representing future changes in landscapes or climate. The EPA office in Raleigh, North Carolina, has developed an EPIC (Erosion Productivity Index)-based model in conjunction with the U.S. Department of Agriculture (USDA) to address air pollution and reactive nitrogen in the MARB. Oak Ridge National Laboratory and Argonne National Laboratory are currently working to understand the potential role that bioenergy feedstock production can play and to identify synergies in hypoxia and biomass modeling efforts.

2.3 Understanding the Stakeholder Landscape

The importance of stakeholder engagement was a recurring theme throughout the workshop. There are already many engaged in addressing hypoxia reduction, and stakeholders' diverse interests and jurisdictions are principal challenges to implementing bioenergy feedstock production as a solution.

Workshop participants proposed that expanding purposeful communication networks and processes that work well at the inter- and intra-agency level, as well as at the state and field level, may improve the effectiveness of existing efforts and accelerate the impact of future advancements. These communication networks can enhance and augment existing networks and continually address grassroots concerns, such as fear of losing decision-making options. This can be done through engaging at the grassroots level and including representation from forestry, agriculture, recreation, and others with regional or unique needs that will impact the outcome of this effort. Workshop participants suggested that communications focus on long-term, state- and regional-level solutions that can be achieved through short-term actions.

One workshop activity was exploring the makeup of the stakeholder base and identifying what individuals, groups, or institutions are relevant to coupling bioenergy with hypoxia-reduction objectives:

- Entities involved in land management, fishing, recreation, and related industries
    - Industrial and family farm operators
    - Businesses and individuals engaged in tourism, including recreation (hunters, fishers, swimmers, kayakers, etc.) and the fishing industry
    - Fishing managers who may be interested in habitat restoration and the indirect effect of hypoxia on catch
    - Fishing boat and fishing equipment suppliers
- Those who can create market demand
    - Industrial organizations that will use the biomass, bio-oil, and/or bioproducts
    - European markets that create U.S. biomass demand
    - Researchers who can make bioenergy/biofuels economical
    - Researchers who can increase crop yields, design equipment, etc.
- Others who can create and/or benefit from a viable ecosystem service market
    - Point-source polluters
    - Private-sector companies
    - Industries, municipalities, and others that use clean water.

3 Bioenergy as a Solution

Currently, agricultural land is often managed to achieve production goals that meet demands for food, feed, and fiber, resulting in landscapes dominated by production and profit objectives. Landscapes are dynamic in the sense that they change under economic and market pressures. A number of workshop participants were already operating under the assumption that the agricultural landscapes of the future can be managed in a way that achieves demand for food, feed, fiber, *and* bioenergy, while providing beneficial environmental and social impacts and remaining profitable at the individual farmer level. Section 3 provides a synthesis of participant discussions of a number of general topics relevant to bioenergy.

3.1 Advanced Bioenergy

Feedstock choice can be an important decision when improving non-energy ecosystem services. In general, cellulosic sources (especially perennial crops) provide benefits; they have root systems that reach deeper soils and take up leached nutrients at times when conventional crops do not, such as early spring and late fall. Consequently, they have demonstrably lower fertilizer input requirements.

Waste streams are another promising feedstock choice. For example, in one biorefinery in China, all of the high-value products were taken out of their corncobs. The lignin was marketed separately, and the cellulose was used in the production of biofuels. In this case, it was the leftovers that were used for bioenergy production rather than dedicated biomass streams for bioenergy production.

Another example suggested by a workshop participant was using animal wastes from confined animal feedlots combined with perennial grasses, which can be used to produce biogas. This system, if applied to all confined animal feedlots, could reduce loadings to the Gulf by 15% (Howarth et al. 1996). Similarly, algal photobioreactors can use wastewater to grow algae, thereby eliminating the need for added fertilizer.

From an environmental perspective, using waste streams as feedstocks for bioenergy is likely to add value because it eliminates or reduces wastes that cause environmental damages.

3.2 Conservation Practices

Farmers are very aware of the importance of conservation and seek practices that meet conservation objectives while maintaining their economic livelihoods. Typically, nutrient management options are handled at the farm scale by focusing on the right nutrient source at the right rate, right time, and right place (4R), and the implementation of conservation practices such as cover crops, bioreactors, and wetlands. To be more effective, farmers can incorporate the 4R practices at the farm scale with feedback from the watershed scale; these practices should also be in line with multi-farm decisions made on entire landscapes affecting individual watersheds. Multi-farm decisions made at the landscape scale involve designs targeting critical areas (e.g., farms, crop rotations, bioreactors, wetlands) for maximum performance on long-term row and energy crop production, environmental sustainability, ecosystem services, and profitability.

The Agricultural Conservation Planning Framework builds on a pyramid-shaped intervention concept in which soil health, water control within and below fields, and riparian management provide multiple layers of intervention (Figure 3-1).

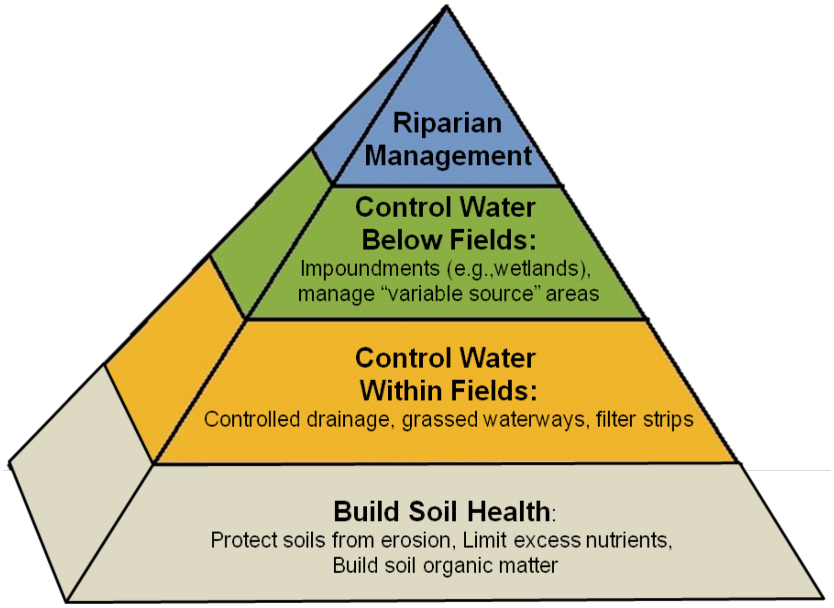

Figure 3-1. The pyramid-shaped conservation planning framework includes soil health, water controls, and riparian management (Tomer et al. 2013).

Riparian buffers are an important conservation practice. When planted in strategic locations, perennials have the ability to scavenge excess nutrients that are in soil water (Ssegane and Negri, 2016; Ssegane et al. 2015; Ferrarini et al. 2017). These benefits would lead to improved nutrient-use efficiency at both the farm and watershed scales (Parish et al. 2012). In the Iowa River Basin, it was estimated that perennial riparian buffers harvested for bioenergy can be cost competitive with other conservation practices and produce significant biomass (Jager et al. 2017). BETO has sponsored field-scale research to understand the environmental benefits of bioenergy buffers.

3.3 Data Sources, Tools, and Capabilities

Workshop participants identified a number of existing data sources, tools, and capabilities that could be leveraged to accomplish joint objectives for both bioenergy feedstock production and reduction of water-borne nutrients that contribute to Gulf hypoxia. Examples include the following:

- Field applications and experimental sites, including those of smaller efforts, from different organizations/agencies
- Existing bioenergy-related markets, including established and developing markets, low-tech biomass digesters, and biomass markets for thermal energy
- Existing projects, including those that can be augmented with other research activities to provide data at reduced cost
- Existing methods for monetizing the cost of water quality, to be used as models for developing methods to monetize other ecosystem services
- Existing or modeled watershed protection utilities (WPUs) as mechanisms for producing ecosystem service payments, including programs that people are already contributing to, like conservation payments for clean water.
- Efforts to move away from monocultures, including existing Federal land-management programs such as USDA's Conservation Reserve Program (CRP), that might qualify for biomass production/hypoxia reduction treatments

- Service models, such as the Federal Grain Inspection Service that is coupled with the Chicago Board of Trade, are examples of certification done centrally and linked to the trading entity directly
- Certification and other mechanisms developed to maintain sustainable deployment of biomass production, which can guide development of an environmental services market
- U.S. corporations that are considering how they can use technology to certify that they are incorporating sustainable practices and reducing contribution to negative environmental impacts.

3.3.1 Bioenergy Sustainability Indicators

Bioenergy sustainability indicators discussed by McBride et al. (2011) can be used to create feedstock production/hypoxia reduction indices, which some workshop participants said would be beneficial for achieving this initiative, but there is concern that vital information is lost when data is rolled into an index tool, providing an unfair assessment.

Dale et al. (2015) created a framework that helps decision makers organize and prioritize the list of potential indicators that might be appropriate for bioenergy to meet environmental, economic, and social sustainability goals. This framework (Figure 3-2) allows stakeholders to articulate their priorities and values and then select the indicators that are most useful in a particular situation. It is therefore valuable for a comprehensive analysis of goals that both increase bioenergy feedstock production and reduce waterway nutrient loading that can contribute to Gulf hypoxia.

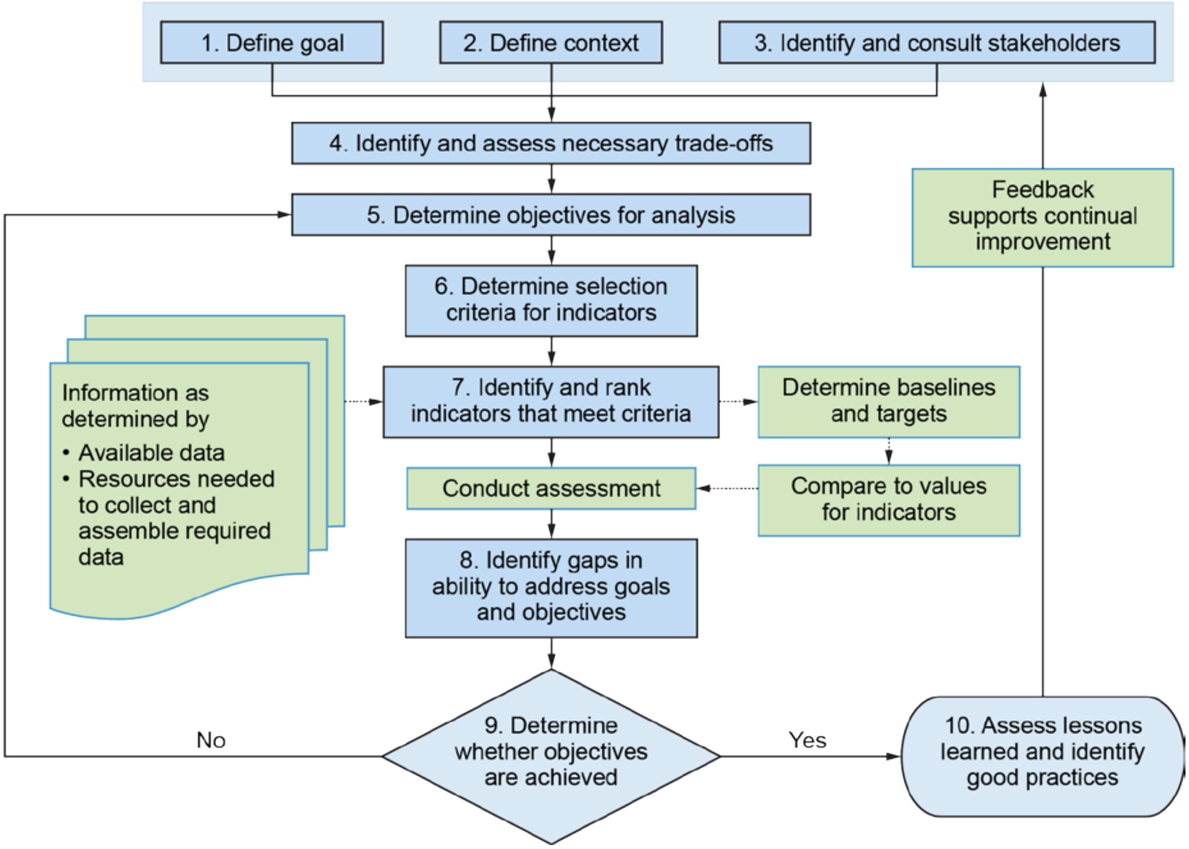

Figure 3-2. A framework for selecting and evaluating indicators of bioenergy sustainability (Dale et al. 2015). Steps for the framework are shown in blue; supporting components of the assessment process are in green. Note that steps 1, 2, and 3 interact and occur concurrently.

Some participants suggested that monetization of ecosystem services, achieved by assessing the value of different sustainability indicators to society, would provide a reasonable way to combine indicators.

3.3.2 Technologies and Landscape Models

Landscape-scale research is difficult as complex interactions between environmental and economic outcomes increase value conflicts and uncertainty for stakeholders. Thus far, research suggests that each watershed and each farm is unique, that both within-field and edge-of-field practices have to be implemented to address nutrient reduction goals, and that maximizing crop production and water quality depends on healthy soils. Nevertheless, the adoption of common tools and methodologies can help in development of deployment strategies that are effective across scales.

A number of modeling tools are available to understand the benefits of alternative practices at the field and sub-field scales. For example, the Landscape Environmental Assessment Framework (LEAF) is a suite of models that quantifies environmental outcomes. Using precision agriculture technology (yield maps), available datasets (SSURGO [Soil Survey Geographic], CDL [Cropland Data Layer], and CLU [Common Land Unit] databases, weather data), and models (RUSLE2 [Revised Universal Soil Loss Equation 2], DNDC [DeNitrification-DeComposition], WEPS [Wind Erosion Prediction System]), LEAF develops accurate maps at the sub-field resolution, baselining current cropping systems, potential bioenergy production scenarios, environmental and yield projections, and identification of sub-field areas of low profitability (Bonner et al. 2014).

A spin-off business and tool developed from DOE-USDA investment, AgSolver's Profit Zone Manager, can provide valuable profitability analysis of land-management schemes. AgSolver concepts are being implemented as part of a BETO-sponsored landscape design project focusing on targeted watershed areas to support advanced bioenergy production in Iowa.

The Biomass Location for Optimal Sustainability Model (BLOSM) incorporates SWAT and analyzes crops, including perennial biomass crops, at the watershed and regional scales (Parish et al. 2012). BLOSM was developed to test the hypothesis that cellulosic crops could be planted according to a landscape design so that the shift in land use positively affects water quality in and downstream of watersheds used for bioenergy crop production, particularly in terms of nitrogen, phosphorous, and sediment runoff.

Existing predictive and simulation models, including climate change models and the Root Zone Water Quality Model (McGinnis 2007), can provide useful predictions for incorporating biomass production to reduce nutrient loading to waterways. Workshop participants suggested that existing bioenergy and agricultural data and databases may be mined and integrated in new ways that will benefit this effort, including remote sensing and Light Detection and Ranging (LiDAR) data that can provide useful information on yield and nutrient flows.

Marginally productive and environmentally sensitive soils can be identified using a framework that incorporates the SSURGO database, sensitivity to nitrate leaching, ponding and flooding frequency, and crop productivity indices (Ssegane and Negri 2016). These land categories could first be targeted to maximize water-quality benefits, as well as to find alternative crops with higher yield potential in soils with these limitations.

Workshop participants also suggested precision agriculture as a technological innovation that may reduce the use of excess fertilizer. It may be possible to intensify production by providing a granular assessment of intra-field variations in soil productivity, environmental vulnerability, and economic returns. Remote sensing is now able to detect the nutrient status of crops, soils, and waters draining from them, suggesting that immediate feedback will be available to farmers and other producers of bioenergy feedstocks. The use of drones to ascertain field conditions has also become feasible.

Workshop participants also suggested that a successful strategy include existing drainage systems. Riparian buffers, including those developed from perennial biomass crops, can be ineffective where fields have artificial drainage systems. Tile drainage bypasses buffers and can direct nitrogen downstream (Petrolia et al. 2006), thereby rendering riparian buffers ineffective unless water drainage patterns are considered. The use of tile-drain mitigation and construction of wetlands to promote denitrification are important strategies that promote downstream ecosystem services from aquatic ecosystems. These solutions have the added advantage of mitigating concerns from food crop production as well as biomass crops grown for energy. A chapter in the recent DOE *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy* (Jager et al. 2017) used the SWAT model to demonstrate the value of riparian buffer strips, cover crops, and plugging tile drains on lands with greater than a 2% slope. In addition, benefits of using no-till conservation treatments were shown for most water-quality indicators.

4 Monetizing Ecosystem Services

A key premise of the workshop is that ecosystem services provided by bioenergy production treatments can simultaneously help address environmental concerns (including water-quality improvement) by reducing agricultural non-point-source pollution.

Sections 4.1 through 4.3 describe groups who either operate markets for credits associated with ecosystem services or provide guidance to establish such markets. Note that additional markets are currently operating in the United States as well (e.g., in the Chesapeake Bay watershed).

4.1 USDA’s Office of Environmental Markets

USDA’s Office of Environmental Markets (OEM) discussed their water-quality trading (WQT) activities to facilitate participation in the environmental markets, with particular focus on farmers, ranchers, and forest landowners. The OEM defined WQT as a voluntary means to reduce the cost of complying with environmental regulations and/or as a means to attain environmental goals.

In a WQT program, a regulated point-source entity who has a pollution release limit will purchase credits from another entity (e.g., a farmer growing bioenergy crops—a non-point polluter), who can reduce pollutant releases at a lower cost, to comply. For WQT to work, there must be a strong regulatory or financial driver to incentivize participation, the participants must have different abatement costs, and the stakeholders and regulators must work together to design and implement training programs. USDA’s OEM plays several roles in facilitating environmental markets, including the following:

- Coordination among federal agencies
- Outreach to stakeholders
- Research on market-related topics
- Development of information products, market tools, and infrastructure for trading.

The OEM actively provides or maintains four key tools and/or services to facilitate a water-quality market: the Nutrient Trading Tool (NTT), EnviroAtlas, the National Network on Water Quality Trading, and the Water Quality Trading Toolkit.

NTT, already integrated into the Chesapeake Bay Nutrient Trading Tool, is currently being developed and parameterized for national application. The user interface allows users to (1) locate the farm or field of interest; (2) retrieve soil, climate, watershed and other local information; and (3) enter information on management practices, including nutrient application rates and timing. NTT then outputs information on nutrient loading, water flow rate, soil carbon, and crop yields.

EnviroAtlas is a web-based tool developed with multi-agency efforts to provide users the ability to view, analyze, and download information to inform decisions on places people live, play, work, and derive resources; for example, it provides nationwide information on ecological services derived from water, carbon, and biodiversity initiatives, as well as locations of water markets in the nation. EnviroAtlas provides interactive resources for exploring the benefits people receive from nature or "ecosystem goods and services." Ecosystem goods and services are critically important to human health and well-being, but they are often overlooked. EnviroAtlas (epa.gov/enviroatlas) allows users to access, view, and analyze diverse information to better understand the potential impacts of various decisions.

The National Network on Water Quality Trading establishes a national dialogue on how water quality trading can best contribute to clean water goals. This includes providing options and recommendations to improve consistency, innovation, and integrity in water quality trading.

Finally, the Water Quality Trading Toolkit consists of templates for developing rules, guidance, and frameworks, while promoting and enabling implementation of trading (ACWA and Willamette Partnership 2016). The Toolkit is discussed in further detail in Section 4.3. OEM believes that these tools and services can be used to promote better water quality through the introduction of bioenergy crops and agricultural best management practices into environmental markets.

4.2 Ohio River Basin Water-Quality Trading

Electric Power Research Institute's (EPRI's) Energy Sustainability Interest Group, in response to the Federal Sustainability Executive Order 13693 (Executive Order No. 13693, 2015), is participating with governmental agencies, state governments, and external advisory groups to put the power industry on the path to sustainability. Some of the sustainability requirements set forth in the executive order include reduction in energy costs, clean energy, reduction in water use, and the appointment of the federal environmental executive as the federal chief sustainability officer.

In the Ohio River Basin WTQ program, a farm implemented best management practices to generate credit and sell to permitted industries who wanted to meet regulatory requirements. Credit purchasers included wastewater treatment plants, the agricultural community, states in the basin, power plants, and environmental groups. The program led to a lower-cost nutrient reduction, improved pollinator habitat, and reduced animal stress and mortality. Additional ecosystem service benefits that accrued from the application of sustainable practices on agricultural lands included habitat enhancement, better agricultural viability, improved water quality and soil health, increased carbon sequestration, and reduced fertilizer use, excessive runoff, and soil erosion.

Focusing specifically on achieving Gulf targets for export of total nitrogen and total phosphorus from WQT alone, it was estimated that the Ohio River Basin would need 100 million acres of cropland, using best management practices that involve cover crops only, to achieve reductions of 228,000–240,000 tons/year in total nitrogen and 10,000–16,000 tons/year in total phosphorus. A reduction of 23 million head of cattle would be needed for the Ohio River Basin to achieve the same reductions using dairy feedlots. Workshop participants recommended a combination of crop, feedlot, and more-efficient best management practices, along with paying for performance, to achieve the total nitrogen and total phosphorus targets.

Workshop participants noted that more corporate buyers are considering investment in conservation farming through WQT. EPRI estimates that the Ohio River Basin Trading Project alone has the potential to move millions of private dollars to help farmers reduce nutrient loadings to local and regional water bodies. More information on EPRI's WQT program is available at wqt.epri.com.

4.3 The Willamette Partnership

The Willamette Partnership (the Partnership) presented its insights to help workshop participants understand how WQT could be successfully implemented and help create a working market for bioenergy feedstock production. The Partnership attributed three keys to its success: (1) clear demand, (2) clear path, and (3) clear communication. The presenter discussed the important role of laws, regulations, and participating funders in establishing demand for credits. Approved standards and protocols for measuring benefits, implementing projects, and verifying project performance against goals were needed to ensure a clear path to WQT. The Partnership found that public trust and stakeholder support were built on transparency and developing opportunities for input.

The presenter described the National Network on WQT (the Network), which is coordinated by the Willamette Partnership, as a collaborative of 18 groups with members from agriculture, environmental nonprofits, U.S. state and federal agencies, utilities, and trading practitioners. The Network was formed to establish a national dialogue on how WQT can contribute to clean water goals.

The Network paves the way for establishing bioenergy markets, with environmental credits generated by the energy crop growers purchased by industries requiring environmental permits and compliance. It was created through a multiagency collaboration that included NRCS (provided funding for the National Network on WQT), USDA and the Association of Clean Water Administrators (provided technical advice), and the Partnership (provided coordination support). The steering committee consisted of multiple investors in agricultural sectors, state and local water and agricultural agencies, EPRI, lawyers, and other private entities.

A number of options and considerations went into building the WQT Program, including reference publications, 11 elements of trading, detailed options and associated pros and cons, trading examples, and consistent definitions and language. The net result was the Water Quality Trading Toolkit, published in August 2016, which consisted of five template documents: rules, guidance, watershed trading framework, National Pollutant Discharge Elimination System permit, and an annual trading report. The Toolkit is available at acwa-us.org.

A workshop participant familiar with environmental markets in the West noted that nutrient credits have been assigned for upstream practices (e.g., river restoration) that prevent downstream eutrophication as a way to offset thermal discharges. This requires regulatory approval. Thus, it is not necessary that the indicator in violation be exactly the one traded—only that there is a scientifically defensible relationship between the two. Establishing such upstream-downstream relationships is therefore important.

4.4 Supply and Demand for Ecosystem Services Credits

A presentation on credits for ecosystem services highlighted existing ecosystem markets for carbon and water-quality credits and opportunities for the agricultural sector in these markets. Three organizations that supply carbon credits are the Verified Carbon Standard, American Carbon Registry, and Climate Action Reserve. The agriculture, forestry, and other land use sectors were dominated by forest carbon credits. Livestock manure management was the most popular agriculture-based project type. Demand for carbon credits has been on an upward trajectory since 2012, and agricultural offsets were pretty stable in that period with an oversupply of credits in the market. However, the credit buyer landscape is changing. Private-sector buyers (diversified industries) and key events (Olympics, Super Bowl) are driving demand. The private sector has been buying credits to meet customer demand, mitigate risks, and prepare for compliance.

The Coalition on Agricultural Greenhouse Gases plays a variety of roles that may be valuable in establishing ecosystem credits. These include (1) creating incentives and value for the agricultural sector to reduce GHG emissions and deliver ecosystem services, (2) developing a spectrum of available eco-asset programs, and (3) analyzing each opportunity and program. Table 4-1 shows a spectrum of

Table 4-1. Spectrum of Agricultural Ecosystem Service Programs: Opportunities and Related Requirements (Reed 2016)

	Conservation Programs	Supply Chain Certification	Payment for Ecosystem Services	Voluntary (Carbon) Markets	Mandatory (Carbon) Markets
Description of Program or Opportunity	Landowner incentives provided to reduce soil erosion, enhance water supplies, improve water quality, increase wildlife habitat, and reduce damages caused by floods and other natural disasters	Official label used to certify that a product meets a prescribed list of criteria—typically linked to sustainability metrics	Payments to landowners for activities or management systems focused on preserving or restoring natural ecosystem service potential	The exchange of credits that represent a reduction in GHG emissions or increase in sequestration to an entity that is not officially regulated	The exchange of credits that represent a reduction in GHG emissions or increase in sequestration to an entity that is regulated under a cap-and-trade system
Data Requirements (not exhaustive)	Landscape- and nutrient-management plans	High-level data to verify enrolled projects Intergovernmental Panel on Climate Change Tier-1 emission factors	Management practice implemented	Field data for model calibration and validation (cal/val) Land specifications	Field data for model calibration and validation (cal/val) Land specifications
Acceptable Uncertainty	High	High-Medium	Medium-Low	Low	Low
Verification/Audit Level	Low-None	Low-Medium	Medium-High	Medium-High	High
Current Opportunities for Agricultural Sector[1]	4	4	2	3	1
Status of Metrics Development[2]	3	2	3	3	3

	Conservation Programs	Supply Chain Certification	Payment for Ecosystem Services	Voluntary (Carbon) Markets	Mandatory (Carbon) Markets
Status of Methods Development[3]	3	1	2	3	2
Stakeholders at Risk[4]	Public Federal agencies	Consumer packaged goods companies	Landowners Project developers	Project developers Investors/buyers	Project developers Investors/buyers
Level of Risk	Low	Medium	Medium-High	Medium-High	High
Highest-Priority Needs for Success	Financing	Appropriate metrics and producer incentives	Establishment of a floor price to increase financing potential Demand for the services Recognition of the services' benefit Accessibility and delivery of value to producers to scale engagement		

[1] Scale: 1 = minimal availability, primarily local; 5 = widespread/global opportunity

[2] Scale: 1 = nominal level of development, with many diverse standards; 5 = fully developed, standardized, and harmonized

[3] Scale: 1 = nominal level of development, with many diverse tool standards; 5 = fully developed, standardized, and harmonized

[4] Risk includes financial liability, loss of credibility, and loss of promised benefits.

ecosystem service programs, which are composed of conservation programs, supply chain certification, payment for ecosystem services, and voluntary and mandatory carbon markets, along with the opportunities, related requirements, and current status, readiness, and risks of various programs in terms of market take-off.

The Ohio River Basin Trading Program was discussed as the most active WQT program in the Mississippi River System. Of roughly 130,000 nutrient credits, the program was able to sell 9,000 credits in the first auction in 2014. Workshop participants discussed challenges for WQT programs: high upfront project development and verification costs, measurement and uncertainty, and soft markets dampen the return on investment, particularly for agricultural projects.

4.5 Eco-Economic Bioenergy Solutions

In current bioenergy production business models, ecosystem services are excluded from the calculation of the total value produced. Workshop participants acknowledged that, in general, there is a concern that society is not willing to pay for ecosystem services and expects to receive energy-with-ecosystem-services at the price that is now paid for energy alone. Some of the challenges going forward that were presented include (1) the potential for uncontrolled development of bioenergy beyond where it could provide regulating ecosystem services and (2) the potential for application of more nitrogen to maximize yields, if biomass crops respond to nitrogen.

WPUs issue credits for upstream conservation practices and downstream restoration activities that improve water quality and tax practices that degrade water quality. Payments and taxes are established through ecological valuation and are therefore more predictable.

Certification establishes criteria for conservation practices that benefit water quality in exchange for branding as a sustainable industry. There is no transaction with a polluter, and payment for certification goes to the certifying entity, which may be seen as a conflict of interest.

In addition to these, government incentives are non-market-based programs that reward biomass producers for using conservation practices. Workshop participants noted the relevance of USDA conservation programs and the Clean Water Act–driven Section 319 program. Conservation Districts and industry service providers trusted by farmers, agricultural retailers, and conservation organizations could also be enlisted as stakeholders who can help support farmers.

5 Strategies to Advance Progress

Section 5 synthesizes workshop participant discussions in breakout sessions and large group discussions. This synthesis focuses on participant input on research needs, as well as other non-technical needs.

5.1 Market Drivers for Sustainability

An important focus of the workshop was to explore the idea that payments or other non-monetary benefits derived from biomass production might close the price gap between advanced biofuels and existing commercial fuels. Biofuels can provide multiple ancillary ecosystem goods and services as co-products from the same land, water, and air resources. Most of these tend to be regulating services, such as water purification and land reclamation, insurance value from managing risk to feedstock supply, and supporting services, such as habitat for wildlife (Jager and Efroymson 2017). The potential to generate “bundles” of services and stack environmental credits from these ancillary services and markets could become important as sources of secondary income, as well as to reduce producer risks. In order to make progress, workshop participants highlighted the need to develop or promote the following:

- Water-quality services markets as a parallel driver for the provisioning of bioenergy and bioproducts

- Co-products (e.g., lubricants, solvents) with greater market appeal (e.g., fungibility or capacity for substitution) to increase their ability to be marketed and sold
- Cultivation practices, such as double cropping, that improve water quality and provide additional biomass
- Biomass pretreatment methods that add flexibility by creating an intermediate feedstock suitable for different end uses.

To move forward with product-to-market opportunities, information needs to be available for consumers, and information and certification available for producers. Workshop participants also discussed issues such as the importance of providing feedstock producers with assurance in their ability to profitably grow bioenergy crops while maintaining the productive capacity of their operations and accomplishing watershed-scale environmental benefits.

Environmental markets are at an early stage of development. For example, buyers of nutrient credits will likely be wastewater treatment plants with compliance concerns, corporations interested in sustainability, and other intermediate markets. Corporate sustainability is one market driver for sustainable practices and products. Consumer bioproducts are expected to be as functional as those from fossil resources. If properly quantified and certified, compensation for ecosystem services may enable the sale of these bioproducts at the same price as their fossil counterparts. During a breakout session, participants created a preliminary list of potentially impacted stakeholders, which included the following:

- Corporate sponsors
- Water treatment plants
- Land-management entities
- Industry organizations or co-ops
- Polluters with total maximum daily load compliance issues, including the fertilizer industry, wastewater treatment plants, and confined animal feedlot operations
- Thermal polluters with compliance issues, including utilities
- Major corporations looking to offer a benefit or gain to consumers based on corporate responsibility/sustainability. For example, the Nature Conservancy has successfully engaged with corporations that own larger brands to incorporate sustainability into their business models. By doing so, they play a role in promoting the mission through their consumer base. One idea was to engage urban residents to contribute to rural sustainability through buying sustainable biofuels.
- Cities using lands in urban areas to grow biofuels would foster multiple benefits, including bioenergy, improved aesthetics, and recreation. As an example, Detroit is looking to redevelop areas that are abandoned into green spaces that are harvested. This may be appealing to municipalities for the extra income, fewer vacant lots, provision of ecosystem services such as storm water management and heat island effect reductions, and improved sense of community in neighborhoods.

Participants in the breakout sessions underscored the importance of finding ways to create one or multiple revenue streams, reduce production and operating costs, and increase sustainability, both in the long term and in an interim period when biomass markets are not yet established. In this interim period, other uses, such as forage, can help develop a market and help industry learn about and gain confidence in new production scenarios.

Participants discussed ideas for potential interim and parallel markets. In China, for example, corncobs are used to develop all the high-value products, lignin is sold for other uses, and cellulose is used to make biofuels. Remaining wastes are used for bioenergy.

Finally, participants noted that water-quality and soil-quality concerns are not limited to bioenergy production lands; therefore, assessment of ecosystem impacts and services of non-bioenergy fuels in a manner similar to assessments performed on biofuels and bioproducts would provide a fair comparison of the benefits of alternate energy systems. A question was raised on whether bioenergy feedstocks require consideration independent of other ecosystem services or whether they should be considered in the larger conversation about ecosystem services and energy systems.

Workshop participants suggested the following are needed to understand the potential of sustainability as a market driver that promotes biomass production:

- Market analysis to evaluate the economic and other production-to-market drivers
- Understanding of whether overlap exists in price ranges that would entice farmers to switch practices and stimulate buyers to purchase credits
- More robust tools for economic valuation of ecosystem services
- An economic framework that reduces uncertainty in farmer income.

Breakout discussions also stressed the importance of developing a process to identify spatial opportunities to develop both yields and other ecosystem services. Participants questioned whether the Corn Belt is the best place to propose biofuel crops and suggested that a better alternative would be to focus on marginal land in the High Plains, for example. The Northern Plains are now seeing a shift in cropping, which provides timely opportunities for sustainable production, as changes in weather patterns are pushing corn productivity and wheat pests northward. The production of ecosystem services by landscape-based bioenergy systems in the Corn Belt offers the opportunity for better penetration of bioenergy cropping.

However, participants noted that it is important that the barriers to deployment of sustainable agricultural landscapes, including impacts on business models, are understood. Land managers are often small-business owners with small profit margins, for whom land-management decisions need to make sense from a business perspective.

A related concern raised by workshop participants was that a market for bioenergy might drive profits up, leading to less environmentally sustainable bioenergy production practices. To offset this risk, it was noted that the successful creation of an environmental services market would ensure that sustainable practices are an integral part of a strong bioeconomy. Timing was identified as both an opportunity and a responsibility; workshop participants stressed that it is important to develop and implement economic safeguards while the technology is advancing and to closely tie the development of guidelines for sustainable practices to be measured against.

Workshop participants felt strongly that projects are needed to verify that the concept of incentivizing sustainable production is feasible and meets the desired objectives, including water quality. They posed questions about the modeling tools available and whether they were adequate to support such projects. Participants generally agreed that, ideally, a good project location on which to develop a model is where there is a market for biomass feedstocks. Environmental markets, if they do not exist, can be simulated based on well-documented analogues. An added benefit is that, if successful, establishing a network of sites could be a useful effort for research and for outreach activities.

While it is important to highlight all ecosystem services, workshop participants asserted that nutrient reduction should be a primary focus of research to reduce Gulf hypoxia. It was noted that upstream stakeholders may be less motivated by downstream hypoxia in the Gulf than by risk to local groundwater and local water quality and the economic losses that they are incurring by wasting fertilizer. One method to engage producers is to focus outreach on local impacts, such as helping farmers understand how farm operation decisions might influence fertilizer waste and the importance of quantifying and communicating how much nutrients are lost from fields and tile drains. (Incidentally, Boyer et al. [2006] finds that under modern agricultural practices, three quarters of nitrogen inputs to rivers is transported to coastal regions.)

Workshop participants pointed out biomass production's benefit in contributing to other valuable ecosystem services, such as providing habitat for wildlife (e.g., waterfowl, fish, shrimp, and oysters). An example of a synergy that might be leveraged is that under the U.S. Farm Bill, biomass from perennial grasses can be harvested on CRP State Acres For wildlife Enhancement (SAFE) designation (CP38) lands designated for pheasant recovery. Another suggestion was that a portion of user fees collected from fishers and hunters could contribute to offsetting the costs of biomass production, capitalizing on the association of biomass production and the additional ecosystem services it provides. In exploring the role of sustainability as a market driver, workshop participants noted the potential of WPUs. The U.S. Water Alliance described WPUs utility-like organizations that are charged with managing nutrient allocations. The WPU differs from trading because it allows for a centralized management of trades with specified values assigned to practices (i.e., value is not market-based). In regions that implement a WPU, funding would come from agricultural and urban areas from wastewater and fertilizer (point-source) surcharges and possibly nutrient taxes. The WPU would administer disbursements that could be distributed to farmers (non-point source) to compensate them for practices that reduce nutrient exports. Ideally, the WPU would have the expertise and decision-making authority to prioritize funding allocations in the most effective way and would work closely with regulators. If cost-effective, the WPU could incentivize the conversion of targeted land from row crops to perennials or other feedstocks that benefit water quality.

As a high-profile issue facing the United States, the Gulf hypoxia challenge can be a good catalyst for building momentum for forming and stabilizing environmental markets. In doing so, one critical research need will be to understand the sectors and geographic distribution of the demand for non-fuel ecosystem services generated by bioenergy.

5.2 Commodification

Because the existence of a market is so critical to the success of implementing biomass production, participants discussed solutions for addressing barriers to commodification during the workshop. Participants identified some of the benefits of the presence of a trading mechanism: (1) an integrated biorefinery could afford to pay farmers more for switchgrass or other eligible feedstocks if they were produced to also generate nutrient reductions, and (2) denser production and higher farmer participation would lower costs and increase benefits from economies of scale.

Production of advanced feedstocks can provide ecosystem services, but there are currently insufficient markets for feedstocks or ecosystem services—a significant barrier to commodification. Participants noted that many farmers are currently unwilling to convert marginal land at cost, so there is a need to find other benefits associated with feedstock production.

Workshop participants identified high transaction costs that undermine financial benefits to traders as a barrier to the success of environmental markets, and they discussed the importance of exploring opportunities for reducing the transaction costs associated with trading environmental credits. One way to reduce transaction costs would be for the biorefineries to perform the trades and pass along credit values to the suppliers, which would greatly reduce the number of direct transactions necessary. Costs could also be reduced through the efficiency gains possible with the use of online trading tools, a well-studied area of research in environmental economics. In addition to cost reduction, workshop participants discussed the importance of engaging motivated stakeholder groups to help establish environmental trading markets.

Ecosystem services are valuable to stakeholder groups like environmental nongovernmental organizations (NGOs). Participants recommended recruiting environmental NGOs to develop this concept from the very start, which will build confidence among influential and general audiences. In addition to NGOs, a number of other stakeholders may enable bioenergy solutions. Organizations that are conducting research in the field can be inventoried to assess their interest in engagement. As clear technological successes are developed and quantifiable benefits are established, corporations could help implement the adoption of sustainable practices and bioproduct use, including certification of ecosystem services. A variety of stakeholder groups can engage in proposing, deploying, and quantifying how bioenergy can be used to address ecosystem services challenges.

A robust communications plan is needed to get the general consumer on board. This plan would be strengthened by promoting a narrative that highlights the benefits to the farmer, while emphasizing the economic advantages of implementing the bioenergy feedstock production solution in areas that are less suitable for grain crop production but would support perennial plantings. Other strategic communications needs identified include the need to educate farmers on how these crops would fit into their farm operations. It was noted that anonymity and good examples may be needed to increase willingness to participate, because farmers may be concerned about potential liabilities if water discharges are monitored for nutrients.

One ongoing strategic communications need is to continue building/scaffolding the case for bioenergy with a science-based baseline established from continuous development of existing models. All bioenergy and other agricultural data can be mined—along with lessons and information derived from research programs, such as the National Science Foundation's Long-Term Ecological Research efforts and USDA's Long-Term Agroecosystem Research efforts—to provide direction and justification for future research and development that helps establish a strong connection between ecosystem services and bioenergy technology advancements.

Specific suggestions from the discussion included establishing a network or consortium of principal investigators across agencies and offices and expanding DOE-BETO's Bioenergy Knowledge Discovery Framework as an information hub for related information from a variety of avenues.

5.3 Metrics/Certification Standards

Transparency is critical to ensure the integrity of certification methods. If the products are certified, then verification of sustainability claims is paramount. The challenge in valuation is that benefits accrue differently to different beneficiaries and may depend on local conditions. Workshop participants identified a need for purposeful design of bioenergy systems to ensure provision and compensation for each ecosystem service. Workshop participants discussed the possibilities of developing a universal quantification of benefits when different practices are employed and more site-specific methods to account for site-specific benefits derived from sustainable practices. Participants noted that tools developed to monetize ecosystem services should be capable of generating site-specific assessments.

Workshop participants also considered the possibility of establishing a new and improved systems-based framework to address the barriers to certification and to better quantify the benefits of energy crops. Currently, there are several models for the certification of ecosystem services. These models show differences, and an integrated multi-model framework may provide a more robust approach to high-fidelity assessment than comparing individual models.

Workshop participants agreed that data support will be needed, as valuation of ecosystem services will be a very data-intense undertaking. The actual certification process will be a matter of policy, but participants noted that the scientific community should provide data so that certification can be based on the best information. To this end, scientific research still needs to be carried out to quantify the benefits of different feedstock choices and management practices used in different contexts and then to incorporate them into a toolkit that can be used by decision makers. Then the scientific community, policy makers, and other stakeholders can help ensure that certification processes include bioenergy.

Workshop participants proposed other considerations for developing metrics and certification standards:

- The accounting basis needs to be broadened to include indirect impacts, with a solid understanding and agreement on system boundaries to provide truly informative scenarios. Allocations need to be thought out carefully in the presence of multiple end uses.
- Environmental NGOs need to be involved in this discussion from the start. They should help set the metrics, avoiding the tendency to cater to stakeholders in a unilateral way. They could provide the seal of approval that builds confidence in the industry.
- Verification of certification need to be explored for opportunities to improve efficiency. Other systems might provide useful models, such as the Federal Grain Inspection certification system.
- The certification system needs to be designed in a way that avoids double payments and makes sure benefits are quantified as a whole from the outset.
- The products that need to be delivered are physical renewable carbon (e.g., biofuels or bioproducts) and the verified ecosystem services and benefits based on the data-driven model.
- A common certification process for all aspects and dimensions is needed that incorporates the complexities that exist due to bioenergy impacting numerous ecosystem services.
- The certification system needs to provide value to the producers, such as enabling cost avoidance and recovery. There is a role for technical assistance that helps farmers with granular planning to avoid monetary loss (like with AgSolver).
- The topic of farm certification needs to be explored. This might include approaches like incorporating bioenergy into best management practices, the Conservation Stewardship Program, and Conservation Innovation Grants (USDA-NRCS), and this certification could potentially be tied to organic farm certification. When combined with other farm projects, perennial crops could potentially be grown.
- Techno-economics can be analyzed to determine if extra revenues coming from other sustainable practices and organic agriculture products could economically enable bioenergy crops. Certification is already in place on the forestry side (e.g., short-rotation woody crops can be certified).

5.4 Conservation Practices

Ultimately, bioenergy solutions will have to be compared to and integrated with other conservation practices. Crop diversity is not a new concept in agriculture, but the current monoculture system has taken hold for economic reasons. It is recognized that monocultures play a role in the high nutrient loading going to the Gulf, but one question that needs to be examined is how the agricultural industry can transition from monocultures to improve water quality and other ecosystem services. Landscape design associated with the development of diverse markets could help reconfigure cropping to increase diversity's value and potentially provide a way to create a revenue stream, reduce production and operating costs, and increase sustainability.

Workshop participants suggested that sustainable conservation practices, including landscape diversification, buffers, cover crops, and other practices that include bioenergy, would be a solid tool for corporate responsibility. Big brand industry is looking at available technology to drive bioproduct use in light of corporate sustainability goals. To drive down the price of sustainably sourced materials, technology needs to provide solutions and certify the benefits of the biomaterials or conservation practices in terms of environmental impacts and GHG reduction. Likewise, a market for ecosystem services from conservation practices also will encourage corporate buy-in.

Unlike grains, bioenergy crops are perennial, but they take several years to establish; therefore, farmers need the long-term guarantee that there will be demand for bioenergy crops to incentivize them to make the switch. Conversely, cover cropping and double cropping could be intermediate approaches; some of the workshop participants stated that, because of economic reasons, there is poor likelihood that there will be a successful full switch to perennials. Miscanthus still has many challenges at this time, while cover crops, for which the famer is more equipped, can yield an appreciable 2–2.5 dry tons per hectare per year, in addition to the main crop.

Farmers cannot be asked to make too many decisions that are against their economic benefit. A philosophical question discussed at the workshop was, “When do societal needs outweigh farmers’ needs?” While there was no clear answer, a discussion followed on whether farmers should be required to carry out pollution control measures to satisfy societal requests for clean air, water, etc.

Targeting selected types of land for bioenergy-based conservation practices is a logical potential starting point. For example, flood-prone land is often productive but at risk. It is still tilled, seeded, and cultivated, but chemicals, fertilizers, and the seeds themselves are at risk of being washed away when floods come. Selecting and breeding bioenergy crops for flood tolerance can provide substantial benefits in these areas, as would the refinement of practices that benefit the downstream water quality (see Section 5.5).

Novel bioenergy systems should explore multiple cropping systems and the incorporation of two harvest systems could be used for bioenergy: one for forage and nutrient capture that incorporates as much nitrogen and phosphorus as possible, and the second with as little nitrogen and phosphorus as possible.

5.5 Water Quality

Water quality is a primary driver for the development of environmental markets to support bioenergy. Ideally, the United States would benefit from developing reactive nitrogen-neutral systems, including reducing nutrient loading (and subsequent hypoxia) to national waterways. Research to support this endeavor will require multi-disciplinary teamwork, involving environmental scientists, agronomists, social scientists, and ecological economists. In addition, a combination of representative pilot studies and regional-scale modeling of water quality and water markets in the Gulf of Mexico might be part of this vision.

Scientific studies might examine where bioenergy can reap measurable and marketable water-quality benefits and assess the value of such benefits. A conceptual framework for organizing feedstock and ecosystem services profiles can help to ensure that local research is representative of larger areas. For example, water is valued differently in different places throughout the world based on region, time, categorization, use, and source. In addition, regional-scale modeling can help to identify representative sites for pilot studies. Some participants proposed validating the selection and performance of a pilot study with willing stakeholders within the fuelshed (feedstock production radius) of one of the DOE-supported cellulosic biorefinery projects. Identifying additional revenue streams from environmentally beneficial projects (e.g., greenways, wildlife corridors, CRP payments) would be an important part of this effort.

The following is a summary of workshop participant considerations:

- An acceptable threshold value for nutrient loading would help guide efforts. While the EPA, in cooperation with individual states, has the authority to set water-quality thresholds for point sources, such thresholds are less clear for non-point sources. In addition, reducing loading is more valuable in some places than in others because benefits are more widespread or because loading is closer to thresholds. Risk assessment methods involving watershed models can be used to develop alternative upstream thresholds capable of meeting a downstream target. Once such options are defined, landowners contributing to exceedance of defined thresholds can trade credits as an alternative to spending to directly improve practices or crop choices. The Conservation Innovation Grant (USDA-NRCS) offers a valuable blueprint.

- Estimates comparing water purification services obtained from different biomass feedstocks to other, more conventional, methods for purifying water are needed. Context-specific guidance can be developed to compare costs and long-term reliability associated with nutrient reduction through alternative means.
- Supporting existing environmental markets is preferable to creating new ones. Existing markets, such as the Chesapeake Bay, the Ohio River Basin, and the Willamette Partnership, are reducing total nutrient loading through permitting. These examples employ barter-type trading. Illinois is discussing a potential initiative based on these blueprints. It includes transaction of credits between non-point-source polluters (e.g., farmers for planting crops) and point-source polluters who need the credits to comply.
- Interagency coordination will be key, and communications professionals can help get information to all stakeholders and solicit feedback.

5.6 Multiple Ecosystem Services

Compared with other energy alternatives, bioenergy offers a more diverse portfolio of ecosystem services. Payments for multiple ecosystem services are appealing as they add multiple uses/products, and therefore markets, for a crop, which will reduce production risks. Earlier in this summary, discussion centered on the value of water-quality improvement, and there is opportunity to expand the valuation of ecosystem services beyond water quality to climate mitigation, wildlife habitat, and other benefits.

Carbon credits: One of the greatest opportunities provided by the growing bioeconomy is the ability to ensure sustained provision of energy with lower GHG emissions than most alternatives. An example of an additional ecosystem service is carbon sequestration. Carbon markets are currently operating in Europe and Canada. Carbon sequestration in soil and crops needs a systems approach to be assessed and quantified. Introducing bioproducts and sustainable practices could help decarbonize carbon-intensive processes, such as beef patty production. This solution hinges on the ability to certify any quantification of carbon balances.

Wildlife habitat: At least one USDA program exists to support wildlife habitat. Lands with a CRP State Acres For wildlife Enhancement (SAFE) designation, also known as CP38, seek to recover pheasant populations by restoring habitat. Limited harvesting of perennial grasses for bioenergy is permitted on these lands, as long as restrictions designed to meet wildlife objectives are met. DOE is currently supporting an effort to understand how Iowa fuelsheds can be designed for pheasant habitat and biomass production. To date, a significant number of acres have been enrolled in CP38.

For all of the final ecosystem services, valuation will be needed, including consideration of uncertainties in value. When developing models such as biophysical models and those for contingent valuation, it is important to design them to provide information needed to support environmental markets. For example, the model should be able to tell credit buyers the price for the benefit associated with a certain transaction. In the case of carbon, reliable quantification is needed for the amount of soil carbon increase, relative to a counterfactual case, and for the associated decrease in GHGs per unit of biomass produced.

Ultimately, a methodology is needed that is based on a detailed model/framework that can aggregate the benefits to show the stackable results, including a life-cycle component. Workshop participants identified the Federal Grain Inspection Service (coupled with Chicago Board of Trade) as an example of a working benefit-verification processes.

5.7 Project Concepts

Workshop participants undertook an exercise to develop project concepts, which allowed them to discuss project goals and attributes, partnerships, stakeholder engagement, and funding strategies. The workshop exercise was a good way help participants think about how bioenergy solutions might be implemented;

however, there was only time for first-draft project concepts, and each had issues that could be addressed to make the project implementable. Two are included here to show topics that multi-jurisdictional teams might consider when developing projects.

Box 5-1. Project Concept: Instituting a Market for Ecosystem Services

- **Project goal:** Institute a market for ecosystem services; identify how credits will be defined, valued, and traded
- **Project team:** Develop an interagency consortium. Engage public/private partnerships that include NGOs and others.
- **Project activities:** Build up measurement units, explore some near-term market opportunities, and identify what exists and what is missing to scope into the larger project
  - Investigate how USDA programs can be better used, including consideration of CRP and growing cover crops on marginal land, which is currently aimed at similar goals and can potentially take advantage of this land for bioenergy uses
  - Align with the timing of other environmental issues (nesting, for example)
  - Investigate how different aspects of ecosystem services can be better understood and how these can help build the bioenergy and water quality markets
  - Include varied opportunities for diverse needs of farmers and regions and allow farmers to optimize their own landowner preferences and needs
  - Design and implement a balance sheet–type system to help quantify ecosystem service market value
- **Project outcomes:** Design tools that help farmers and landowners make decisions on what is needed to achieve the project goals and give them an agronomic or economic advantage
  - Determine what tools are available, what limitations they pose, and how to get around the confidentiality barriers in using them

Box 5-2. Project Concept: Achieving Nutrient Reduction in a Multi-Functional Landscape

- **Goal:** Examine the transition from business as usual to bioenergy feedstock landscape in an area with existing markets
- **Objectives:** Engage diverse stakeholders in proposing, deploying, and quantifying how bioenergy (cellulosic feedstock) can be used to provide energy and ecosystem services, focusing on achieving nutrient reduction in a multi-functional landscape
- **Scale:** Paired watersheds within existing fuelsheds (approximately 50-mile radius around a refinery)
- **Timeframe:** 5-10 years
- **Interests:**
    - Energy market
    - Diverse stakeholders—Energy, agricultural production, local water quality, aquatic life, recreation, pollinator and wildlife habitat, and Gulf hypoxia
    - Monitoring and evaluation
    - Certification
- **Land management partners:** Requires early adopter land managers that have an interest in adopting bioenergy practices and quantifying benefits, including a mix of private and public land managers.
- **Stakeholders:** To be broadly defined to include participation of farm implementers and surrounding community in framing questions
    - Identify local values that drive adoption and social acceptability.
    - Requires a community that is already engaged and working together.
- **Site conditions:**
    - Documented fuelshed (biomass feedstock supply shed)
    - High-nutrient loading—Existing conditions allow detection of change in water quality
    - 12-digit hydrologic unit code watersheds (about 40,000 acres)—Typical area for implementing practices
    - Potential for long-term monitoring, scaling up, and certification demand
- **Evaluation:** Preferred watersheds will have at least a 5-year baseline monitoring history
- **Data needed:**
    - Edge of field and sub-watershed monitoring
    - Water quality—Nutrient and sediment loading
    - Water quantity—To calculate nutrient loading and flow impacts of perennial biofuels
    - Weather
    - Prior land-management practices
    - Human dimensions—Factors affecting barriers and opportunities for engagement to guide extension and technical services
    - Certification-relevant parameters

The exercise prompted a number of suggestions that could be considered when developing effective "Bioenergy Solutions to Gulf Hypoxia" projects:

- **Potential research and development:** Projects should address a variety of research and development needs, such as improvement of marginal lands and marginal croplands, microfinancing schemes to support farmers improving water quality, and demonstration of economic development while considering annual land-management practices. Projects focusing on water-quality conservation would have a strong public-relations component.
- **Project requirements:** Project design requirements should include cost/benefit analysis and verification/validation of monetization of ecosystem services. Stakeholder involvement was repeatedly mentioned as imperative to project success. Projects should build on other existing work and emphasize research gaps and what translates to industry.
- **Project funding and technical expertise:** There may be opportunities to leverage funding and expertise from multiple sources. Examples of relevant programs may include USDA's CRP and Environmental Quality Incentives Program. (The latter is a voluntary program that provides financial and technical assistance to agricultural producers to plan and implement conservation practices that improve soil, water, plant, animal, air, and related natural resources on agricultural land and non-industrial private forestland.)
- **Project teams:** Project teams should include interagency representation and engagement with the HTF. The financial community was identified as a valuable and needed partner in designing financial instruments that foster ancillary ecosystem services. Ideally, stakeholders would have input on project design and the application for participation.
- **Project location:** Projects will, ideally, be located where future water-quality challenges may occur and where demand for nutrient credits may be.

6 Research Gaps and Strategies

Workshop participants identified research areas that may help bring us closer to the goal of promoting sustainable biofuel production and improving other ecosystem services. Each of these requires integration among ecological, economic, and social sciences to evaluate potential economic structures to close the gap on profitability. The research areas identified are not a complete list of gaps and strategies, but instead lay out efforts to advance understanding of the profitability of bioenergy systems along multiple ecosystem services dimensions—rather than focusing solely on the energy dimension. Not only can ecosystem service credits recognize other components of value, but they also increase the number of paths or trajectories potentially leading to market penetration.

6.1 A Framework for Understanding Ecosystem Goods and Services in Bioenergy Systems

A first step in advancing progress is to come to a common understanding of what ecosystem services are and which have the highest potential for commodification. The ecosystem services assessed might include energy (e.g., higher, stable feedstock yields) and other provisioning, regulating, cultural, and supporting services. At local scales, beneficiaries are near where ecosystem services are generated; at coarser spatial scales, ecosystem services reach beneficiaries that are far away from where the ecosystem services are generated. Some types of ecosystem services tend to be local (e.g., pollination services, carbon sequestration, and increased wildlife habitat). Others tend to be spatially displaced and therefore understood using models at coarser scales (e.g., water quality, carbon sequestration, and reduced GHG emissions). One step towards common understanding is defining system boundaries. In life-cycle assessment, boundaries are set for quantifying changes in direct resources used by the bioenergy production system. However, the ecosystem services produced by a system may have spatial influences, expanding the spatial boundaries of effects. Another relevant specification is to define the appropriate time horizon over which to evaluate ecosystem services.

Useful frameworks for understanding ecosystem services: Several conceptual frameworks to classify ecosystem services have been put forward. Variants of these are currently in use in existing certification programs and payments for ecosystem services, as well as for international efforts to assign comparative values to different scenarios. For example, it may be important to focus on final ecosystem services for some applications and on intermediate ecosystem services for others. Because this initiative relies on comparative changes of human activities related to producing bioenergy, some frameworks may be more useful than others, as discussed below.

Reference or baseline scenarios needed to assess the "additionality" of the bioenergy production systems: Note that different baselines may be needed to evaluate alternative bioenergy production systems with respect to their relative impacts on resources—such as land, water, and air—as well as energy and food. For each, it will be important to understand what data are needed to quantify ecosystem services for baselines and for the bioenergy systems to which they are compared. Guidelines for allocation (such as in environmental life-cycle assessment) may also be needed to attribute marginal benefits to bioenergy relative to a specified baseline.

Promising example practices or crops: Workshop participants highlighted promising research areas for reducing the risk of crop failure under future climate. A quantified (monetized) comparison of alternative practices and crops might save government and producers money by avoiding crop failure or loss of soil and land productivity. Research to improve crops was highlighted, for example, to promote use of perennial crops and to select for flood and/or drought-tolerant crop varieties. In addition, participants highlighted potential benefits of promoting polycultures (e.g., to avoid crop failure due to pests) and the need for conversion technologies that are robust for different feedstocks.

6.2 Commodification of Advanced Bioenergy Systems

Most environmental and social benefits are currently experienced externally to markets. Research is needed to understand what kinds of environmental payments or credits bioenergy systems should be eligible for or designed to provide. A number of types of credits were presented and discussed at the workshop. These included Renewable Identification Numbers, potential for water-quality trading for nutrient credits, and potential for trading of carbon credits. Related incentives or payment for environmental services exist through the USDA Farm Bill that might be described as wildlife and/or water-quality credits. Workshop participants identified wildlife credits as something that bioenergy systems may be uniquely qualified to address. To bridge the difference, it may be necessary to allow stacked credits. Understanding the trade-offs and complementarities among ecosystem services and credits can help producers design bundles of ecosystem services suitable for a particular context.

Workshop participants also discussed barriers to environmental markets to permit trading of credits and payments for ecosystem services, including what future markets or other methods of valorization might look like. Participants discussed that it would be helpful to inventory the existing practices or crops used to produce biomass for energy that are currently eligible. If there is no current eligibility, workshop participants suggested the importance of understanding which practices or crops have the highest potential for increasing ecosystem services and the process by which they could be incorporated into environmental markets. A number of workshop participants generally believed that efforts to invest in quantification (e.g., measurement of indicators and ecological valuation of promising advanced biomass systems) will increase the chances that these systems will be incorporated into emerging markets.

Participant discussions suggested exploring unmet research needs associated with environmental markets. Current verification processes used by other industries could be considered. Online tools allowing producers to conduct self-assessments may encourage participation as well. Moreover, transaction costs may be a barrier to market participation, and developing trading tools that bring buyers and sellers together may also help. Workshop discussion pointed out that financial institutions, such as Goldman Sachs, are participating in lending to promote formation of environmental markets (Goldman Sachs n.d.).

Various research needs can move the United States toward the goal of bringing multiple benefits of advanced bioenergy into markets. Recent scientific advances in agronomy, computer science, data integration, social sciences, and multi-scale biophysical modeling may help to realize this vision. Section 6.3 discusses potential activities for collaborative modeling and data integration in defining integrated solutions.

6.3 Multi-Scale Collaborative Modeling

Workshop participants discussed roles for three classes of models: (1) social models of decision processes that influence upstream production systems; (2) biophysical models that link management to biological, chemical or physical outcomes; and (3) economic models to monetize ecosystem services provided to beneficiaries. Open frameworks that integrate social, biophysical, and eco-economic aspects will be required. These can be used to address important research questions at multiple scales. At the local scale, models can help decision makers understand the biomass crop rotations or practices that are needed in a given production system to enhance the ecosystem services portfolio. At the watershed scale, models can help decision makers understand how environmental markets can be designed to support integration of advanced biomass feedstocks and management practices.

6.3.1 Social Decision Models

Social research may be needed to understand priorities and values of stakeholder decision makers that will ultimately shape biomass-producing landscapes. Farmers make decisions that are driven by future price expectations or perception of risk. Therefore, it is important to understand feedbacks of corn and other feedstock prices on farmer incentives to intensify production (for example, by installing tile drainage). Based on historical data and/or farmer surveys, one might, for example, model the marginal effect of change in corn price on the likelihood of adopting practice X or planting of biomass crop Y. Similarly, marginal changes in water quality and other effects may influence decisions.

6.3.2 Biophysical Models

Causal linkages between ecosystems (service-providing units) and ecosystem services are typically described by biophysical models (Jager and Efroymson, 2017). Here, models capable of representing alternative biomass feedstocks and management practices relative to counterfactual cases are important. Research might seek to identify gaps in availability of biophysical models. For example, the following kinds of models might be useful:

- Watershed models linking land management and crop changes with physicochemical water attributes (a water purification ecosystem service) that are valued by society
- Models linking pollinator and other wildlife abundance or diversity (a regulating ecosystem service) with cropland management.

6.3.3 Economic Models

To compare ecosystem services enhancements by biomass feedstock production, it is necessary to monetize (estimate market value for) marginal ecosystem services benefits to understand how different bioenergy systems compare in terms of value across the spectrum of final ecosystems services. This kind of research can help promote commoditization by assigning value to different crops, rotations, and management practices. Once the effects of individual practices are quantified, interactions among practices can be studied. For example, are the effects of riparian buffers and tile-drain mitigations additive (i.e., independent), or are the combined effects smaller than (or larger than) the sum of their individual effects when deployed separately?

Ecological valuation methods exist to estimate both use and non-use value. A subset of use values is tied to market prices, and other use values are revealed by preferences that beneficiaries express. In other cases, indirect measures of value are estimated from related indicators of ecosystem services for which preferences are better defined. Non-use values (e.g., existence values) must be quantified based on willingness to pay or willingness to accept payment for the ecosystem services, which require probability surveys.

Scaling from local valuations to a wider range of beneficiaries requires modeling. For example, hedonic models relate ecological value to attributes of beneficiaries, including distances traveled, and can be extrapolated through knowing the distribution of attributes for society at large. Beneficiaries of ecosystem services can be spatially displaced from the locations where farmer decisions are made and the collective influences of decisions made by individual actors; for example, farmers, other landowners, or credit traders across river basins could interact to produce emergent system-wide changes in ecosystem services, while increasing the representation of bioenergy in the U.S. energy portfolio. Research is needed to identify local entities that might be buyers of credits (e.g., Walmart, P&G, Unilever, Coca-Cola, Boeing) and sellers (presumably bioenergy producers) and to determine where the most important opportunities might exist and how they might be facilitated.

Another role for economic simulation is to compare policy programs alone or in combination, such as understanding which is more beneficial for producers and downstream water users: a fertilizer tax or trading nutrient credits.

6.3.4 Data Integration

Multi-disciplinary data collection efforts are essential to support all aspects of research for ecosystem service–promoted bioenergy. Workshop participants suggested data integration for bioenergy and agriculture, as well as integration with the National Science Foundation and other relevant data sources. Participants expressed broad interest in forming a consortium or network of principal investigators as part of an active research collaboratorium to foster and expand interactions. In addition, workshop participants recommended strong coordination across agencies, with involvement of producers as a reality check. Participants called for future research to be carried out by multidisciplinary teams, a necessity when spanning such different fields as agronomy, ecology, and economics.

A first step might be to identify data to support different research objectives, followed by design of a framework based on the Bioenergy Knowledge Discovery Framework for assembling and providing data access to promote online collaboration. As with models in the previous section, several different classes of data are needed:

- Spatial data characterizing farming practices and production systems, geospatial data to define environmental indicators of sustainability, and production data (i.e., yield)
- Climate drivers and watershed data required as input for biophysical models that link management to biological, chemical, or physical outcomes
- Independent measurements of ecosystem services, such as water quality, which are needed to validate predictions
- Data required to estimate the value of ecosystem services provided to different beneficiaries.

In part, this could begin by both comparing with and contributing to existing economic data repositories relevant to valuing ecosystem services (e.g., EPA EnviroAtlas, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)). A follow-on goal might be to provide an organized framework for collecting future data to address multiple ecosystem services.

6.4 Integrated Solutions

Instead of considering an individual energy feedstock in isolation from other feedstocks, eco-economic analysis requires understanding the additive environmental effects of individual feedstocks and the interdependencies among bundles of ecosystem services provided by bioenergy across the supply chain. Beyond understanding interdependencies, research on integration seeks to improve the efficiency in valued ecosystem services. For example, such research might seek to improve efficiency by reducing inputs and waste streams. Workshop participants highlighted the importance of animal production systems and the use of animal wastes as a feedstock, both of which influence the economics of bioenergy supply and ecosystem services. Grazing and biomass production can coexist at different times, and other interdependencies exist between the systems.

Perennial feedstocks were highlighted in the workshop as an important solution. However, there is a concern that focusing only on these feedstocks could reduce the producer's decision-making abilities and constrain producer participation within an economic system that rewards production of annual food crops unless payments for ancillary ecosystem services can compensate. The perennial cropping solution is one of a larger set of options available to help producers to meet bioenergy feedstock production goals and reduce nutrient pollution to waterways. Research to understand this set of solution options should explore how annual land-management systems that use best practices—such as cover crops, double cropping, mitigation of tile drainage, and establishment of riparian buffers (Ha and Wu 2015; Jager et al. 2017)—can both help mobilize the nation's billion tons of biomass and reduce eutrophication of the nation's waters.

Crosscutting research is needed to ensure that efforts to increase portfolios of ecosystem services are integrated across the supply chain and communicated between feedstock production, logistics, and conversion programs. Thus, decisions made later in the process should not be constrained by earlier engineering decisions. For example, it is generally understood that diverse cropping systems produce healthier habitat for pollinators and other wildlife that provide ecosystem services. When decisions are made to tailor conversion processes used by biorefineries for a single, uniform feedstock, options for improving habitat for wildlife by using diverse feedstocks are closed off.

The full spectrum of research to quantify the value of ancillary non-fuel ecosystem services provided by advanced biomass production has not yet been conducted. The following are two examples of production systems that generate ancillary ecosystem services:

- Biodiesel, which can be produced from algal biomass grown in wastewater and co-located with fossil plants that generate carbon dioxide, thereby purifying water and earning carbon credits as well as fuel.
- Biogas, which can be produced from animal wastes and perennial plant biomass, can help to reduce the significant nutrient exports from Midwest landscapes.

Clearly, uncertainties remain about how and to what extent bioenergy can contribute to achieving hypoxia-reduction goals, but indications are that well-designed production systems can make significant progress.

6.5 Cross-Sector Eco-Economic Research

Economic solutions to making advanced biofuels profitable cannot be achieved in a vacuum or through stove-piped research efforts. Markets are interconnected networks that do not respect sector boundaries. Biofuels have co-products, such as food, wood products, animal feed, lignin-based fiber products, and, in the case of algae, products ranging from dietary supplements to cosmetics. In addition, the fact that environmental markets involve credit purchasers, such as point-source polluters, brings new sectors into the network of interconnected economic entities. Integrated eco-economic research is needed to understand such networks, to identify properties that make them resilient, and to determine how bioenergy co-products, including payments for ecosystem services, will lead to market penetration for bioenergy.

7 Summary—Bioenergy as a Solution to Gulf Hypoxia

This document summarizes research gaps and the strategies that could help diverse stakeholders quantify the ecosystem services and economic value that advanced biomass can provide for nutrient reduction, water quality, carbon, wildlife, and other services, including a potential solution to Gulf Hypoxia.

Regarding technology advancement gaps, attendees identified methods and tools for measuring ecosystem services (e.g., crop yield; nutrient and carbon status of crops, soils, and water; and fluxes). Workshop participants also discussed various frameworks that could provide producers with access to payment for ecosystem services through trading, certification schemes, and/or WPUs. Participants suggested that paths toward commodification may be helpful in achieving both bioenergy feedstock production and other environmental benefits, and several participants mentioned stacking credits for multiple ecosystem services. Having guidance available to landowners about the economic and environmental value of alternative decisions, as well as the availability of environmental markets, would be helpful to landowners and other key stakeholders.

Participants identified two major contributions that funding agencies and other stakeholders can provide: technical expertise and financial support for research and development projects. They also noted that this research is a key aspect of potential future full-scale operations of sustainable bioenergy production pathways.

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Appendix A: Workshop Attendees

First Name	Last Name	Affiliation
Gary	Andersen	Lawrence Berkeley National Laboratory
Kevin	Comer	Antares Group Inc.
Albert	Cox	Metropolitan Water District of Greater Chicago
Neil	Crescenti	Willamette Partnership
Bruce	Dale	Michigan State University
Virginia	Dale	Oak Ridge National Laboratory
Rebecca	Efroymson	Oak Ridge National Laboratory
Jessica	Fox	Electric Power Research Institute
Alison	Goss Eng	Bioenergy Technologies Office
Hazel	Groman	Environmental Protection Agency
Jim	Gulliford	Soil and Water Conservation Society
Miae	Ha	Argonne National Laboratory
Thomas	Hebert	National Corn Growers Association
Richard	Hess	Idaho National Laboratory
Yetta	Jager	Oak Ridge National Laboratory
Steve	John	Agricultural Watershed Institute
Kristen	Johnson	Bioenergy Technologies Office
Shibu	Jose	Missouri Agriforestry Center
Doug	Karlen	U.S. Department of Agriculture – Agricultural Research Service
Madhu	Khanna	University of Illinois
Harbans	Lal	U.S. Department of Agriculture – Natural Resources Conservation Service
Matt	Langholtz	Oak Ridge National Laboratory
Alexis	Martin	Bioenergy Technologies Office
Greg	McIsaac	University of Illinois at Urbana–Champaign
Rob	Mitchell	U.S. Department of Agriculture – Agricultural Research Service
Shyam	Nair	Idaho National Laboratory
Cristina	Negri	Argonne National Laboratory
Leslie	Ovard	Idaho National Laboratory
Vance	Owens	Regional Partnership
Ron	Pate	Sandia National Laboratories
Debbie	Reed	Coalition on Agricultural Greenhouse Gases
Bob	Rose	U.S. Environmental Protection Agency
Andrew	Schmidt	U.S. Department of Agriculture – Natural Resources Conservation Service
Mindy	Selman	U.S. Department of Agriculture – Office of Environmental Markets
Kurt	Solander	Los Alamos National Laboratory
Bryce	Stokes	Allegheny Science & Technology
Matt	Van Deren	U.S. Environmental Protection Agency
Gwenn	White	U.S. Fish and Wildlife Service
Megan	Wiitala	U.S. Environmental Protection Agency
May	Wu	Argonne National Laboratory
Colleen	Zumpf	Argonne National Laboratory

Those grayed out were observers or organizers.

Appendix B: Acronyms and Glossary

Glossary

Advanced Biofuels: For the purposes of this report, advanced biofuels generally refer to biofuels produced from lignocellulosic feedstocks and other non-food crops (e.g., herbaceous and woody energy crops, agricultural and forestry residues, algae) as well as waste streams.

Algal Bloom: Overgrowths of algae in water caused by sunlight, slow-moving water, or nutrient pollution, such as nitrogen and phosphorus. Some produce dangerous toxins in fresh or marine water, creating dead zones, raising treatment costs, and hurting industries depending on clean water (Definition adapted from EPA n.d.).

Best Management Practices: The practice, or combination of practices, that is determined to be an effective and practicable (including technological, economic, and institutional considerations) means of achieving a given goal (Definition adapted from North Carolina Forest Service 2017). Often the goal associated with BMPs is conservation of resources, and so this term is often used within the context of environmental management.

Bioeconomy: From a broad economic perspective, the bioeconomy refers to the set of economic activities relating to the invention, development, production, and use of biological products and processes (Definition adapted from OECD 2016).

Bioenergy: Energy derived from biomass.

Biofuels: Fuels made from biomass resources or their processing and conversion derivatives. Biofuels include ethanol, biodiesel, and methanol, among others.

Conservation Reserve Program: A land conservation program administered by the Farm Service Agency that pays a yearly rental payment in exchange for farmers removing environmentally sensitive land from agricultural production and planting species that will improve environmental quality (Definition from USDA n.d.).

Corn Belt: The midwestern region of the United States where corn is the dominant crop.

Corporate Sustainability: A business strategy where environmental, social, and cultural effects of business operations are taken into account, with consideration of long-term value.

Demersal: Living close to the floor of the sea or a lake.

Eco-Assets: Living natural resources that have financial value in private markets (e.g., wetlands, forests, rivers and watersheds, endangered species, and riparian and upland habitat). Federal guidance and support are in place to preserve the sustainability of some eco-assets.

Ecological Valuation Methods: The estimation of both use and non-use value of ecosystem services. A subset of use values is tied to market prices, and others are revealed by preferences that beneficiaries express. In other cases, indirect measures of value are estimated from related indicators of ecosystem services for which preferences are better defined. Non-use values (e.g., existence value) must be quantified based on willingness to pay or willingness to accept payment for the service, which require probability surveys.

Ecosystem Services: The benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling. (Definition adapted from MEA 2005).

EnviroAtlas: A web-based tool developed with multi-agency efforts to provide users the ability to view, analyze, and download information to inform decisions on places people live, play, work, and derive resources (Definition from EPA 2016b).

Farm Bill: Every 5 years, Congress passes a bundle of legislation, commonly called the “Farm Bill,” that sets national agriculture, nutrition, conservation, and forestry policy (Definition from U.S. Senate Committee on Agriculture, Nutrition, and Forestry).

Feedstock: Raw material for a process (e.g., industrial). Biomass feedstocks are the plant and algal materials used to derive fuels like ethanol, butanol, biodiesel, and other hydrocarbon fuels (Definition adapted from DOE-EERE 2013).

Greenhouse Gas: Natural or anthropogenic gas that can absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surface, the atmosphere, and the clouds. Water vapor, carbon dioxide, nitrous oxide, methane, and ozone are the primary greenhouse gases in the Earth’s atmosphere (Definition adapted from IPCC 2007).

Hypoxia: Hypoxia means “low oxygen” and is primarily a problem for estuaries and coastal waters. Hypoxic waters have dissolved oxygen concentrations of less than 2–3 parts per million. Hypoxia can be caused by a variety of factors, including excess nutrients, primarily nitrogen and phosphorus, and waterbody stratification (layering) due to saline or temperature gradients. These excess nutrients, eutrophication, promote algal growth. As dead algae decompose, oxygen is consumed in the process, resulting in low levels of oxygen in the water (Definition from EPA 2016a).

Integrated Landscape Approach: Landscape approaches seek to address the increasingly complex and widespread environmental, social, and political challenges that transcend traditional management boundaries. Integrated approaches link agricultural practices, institutions, and policies with other landscape-scale activities (Definition adapted from Reed, Deakin, and Sunderland 2015).

Land Management: The process of dealing with or controlling the use and development of land resources. Tillage is an example of agricultural land management.

Land Use: Human management of terrestrial resources, designated purpose of those resources, or benefits derived from those resources (land use may involve vegetation, animals, soil, groundwater, streams, wetlands, minerals, air flow, and other resources).

Landscape Design: In the context of the Bioenergy Technologies Office’s work, a landscape design approach aims to integrate bioenergy production into existing agricultural and forestry systems while maintaining or enhancing environmental and socioeconomic sustainability.

Load (or Loading): The quantity delivered to a water body. Synonymous with yield (nutrient yield, water yield). The term is usually used for sediment or nutrients.

Miscanthus: A sterile triploid with low nutrient requirements and wide adaptability across cropland.

National Network on World Trade Organization: Promotes a national-level dialogue among network participants, coordinators, and technical advisors to provide options and recommendations for improving consistency, innovation, and integrity in the World Trade Organization. Among other things, this service facilitates a water-quality market.

Nutrient Loading: A measure of pollution, this term describes the nutrients in a system (e.g., water body) at a given time.

Nutrient Trading Tool: An Office of Environmental Management tool that takes in information concerning a farm or field’s soil, climate, watershed, and management practices, to produce information on nutrient loading, water flow rate, soil carbon, and crop yields.

Pelagic: Refers to the part of a sea, lake, or ocean that is neither close to the bottom nor near the shore.

Perennial Grasses: Grasses that live for more than 2 years.

Point-Source Pollution: Pollution that comes from a specific, identifiable source, such as a pipe or channel (Definition from EPA 1999).

Poplar: A short-rotation woody crop with potential in the Lake States, the Northwest, the Mississippi Delta, and other regions.

Precision Agriculture: An advanced farming technique using a granular assessment of intra-field variations in soil productivity, environmental vulnerability, and economic returns.

Riparian Buffer: A section of ecosystem (traditionally terrestrial and sometimes aquatic) along a water body that is used to protect the aquatic ecosystem from impacts of adjacent land uses. Benefits of riparian buffers can include bank stabilization and reduction of non-point-source pollution (e.g., nutrient loading), depending on their extent and composition. Inclusion of riparian buffers is considered a best management practice and single component of comprehensive watershed management plans (Definition adapted from Mayer et al. 2005).

Non-Point-Source Pollution: Pollution caused by rainfall or snowmelt moving over and through the ground, picking up and carrying natural and human-made pollutants, depositing them into lakes, rivers, wetlands, coastal waters and ground waters. (Definition from EPA 2017a).

Soil Health: Also known as soil quality, soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. (Definition from USDA-NRCS n.d.).

Sustainability: An aspirational concept denoting the capacity to meet current needs while maintaining options for future generations to meet their needs. To make the concept of sustainability operational, consistent approaches are required that facilitate comparable, science-based assessments using measurable indicators of environmental, economic, and social processes (Hecht et al. 2009; McBride et al. 2011; Dale et al. 2015).

Switchgrass: A model perennial native grass, with wide range and potential distribution.

Total Nitrogen: An essential nutrient for plants and animals, this compound (sum of ammonia, organic and reduced nitrogen, and nitrate-nitrite) is considered a contaminant when found in excess amounts. In waterways, excessive total nitrogen can lead to low levels of dissolved oxygen and negatively alter plant and aquatic life. (Definition adapted from EPA 2015).

Total Phosphorus Concentration in Streams (and Export): A measure of the amount (g) of phosphorus in a given volume (L) of water extracted from a water body (e.g., stream or surface water when considering export or runoff).

Valorization: To give an item value.

Watershed Protection Utility: A system where utilities would be charged with managing nutrient allocations. The watershed protection utility differs from trading because it allows for centralized management of trades with specified values assigned to practices (i.e., value is not market-based). Funding would flow into the watershed protection utility from agricultural and urban areas, supported by wastewater and fertilizer (point-source) surcharges and possibly nutrient taxes.

Water Quality Trading: An industrial point source can buy water quality credits from farmer(s) to offset its releases in exchange for farmer(s)' implementation of prescribed landscape-management practices.

Willow: A short-rotation woody crop assumed to be managed on a 20-year cycle and harvested at 4-year growth stages. It is being commercialized widely in the Northeast.

Acronyms

BETO – Bioenergy Technologies Office

BLOSM – Biomass Location for Optimal Sustainability Model

CRP – Conservation Reserve Program

DOE – U.S. Department of Energy

EPA – U.S. Environmental Protection Agency

EPIC – Erosion Productivity Index Calculator

EPRI – Electric Power Research Institute

GHG – Greenhouse gas

HTF – Hypoxia Task Force

LiDAR – Light Detection and Ranging

LEAF – Landscape Environmental Assessment Framework

MARB - Mississippi-Atchafalaya River Basin

NGO – Non-governmental organization

OEM –Office of Environmental Markets

SPARROW – Spatially Referenced Regressions on Watershed attributes

SWAT – Soil Water Assessment Tool

USDA – U.S. Department of Agriculture

WPU – Watershed protection utility

WQT – Water quality trading

Appendix C: Presenters and Presentations

Framing the Problem: Nutrient Source Identification, Accounting, and Attribution	Gregory F. McIsaac University of Illinois at Urbana–Champaign Agricultural Watershed Institute
Modeling Water Quality in the Mississippi-Atchafalaya River Basins: I. Arkansas-White-Red and Tennessee	Henriette Jager Oak Ridge National Laboratory
Modeling Water Quality in the Mississippi-Atchafalaya River Basins: II. Upper Mississippi, Ohio, and Missouri River	May Wu Argonne National Laboratory
Bioenergy Sustainability and the Food, Energy, Land, and Water Nexus	M. Cristina Negri Argonne National Laboratory
Landscape Environmental Assessment Framework (LEAF) and Sustainable Bioenergy Production	Shyam K. Nair Idaho National Laboratory
Quantifying Costs and Monetizing Benefits of Bioenergy Crops	Rob Mitchell U.S. Department of Agriculture – Agricultural Research Service
Current Federal and State Action to Address Gulf Hypoxia	Megan Wiitala U.S. Environmental Protection Agency
Water Quality Trading and Synergies with BETO	Mindy Selman U.S. Department of Agriculture – Office of Environmental Markets
From Indicators to Ecosystem Services: Challenges and Opportunities (Ecologist's Perspective)	Virginia Dale Oak Ridge National Laboratory
From Indicators to Ecosystem Services: Challenges and Opportunities (Economist's Perspective)	Matt Langholtz Oak Ridge National Laboratory
Making Markets Work	Neil Crescenti Willamette Partnership
Monetizing Ecosystem Services and Other Challenges	Jessica Fox Electric Power Research Institute
Supply and Demand for Ecosystem Credits	Debbie Reed Coalition on Agricultural Greenhouse Gases
What Does Conservation Mean to the Farmer and What Tools Do They Have Now?	Douglas L. Karlen U.S. Department of Agriculture – Agricultural Research Service, National Laboratory for Agriculture and the Environment
Challenges for Conservation Practices and Implications for Bioenergy Solutions	Bob Rose U.S. Environmental Protection Agency – Office of Water
Downstream Aquatic Ecosystem Services Generated by Upstream Perennial Feedstocks	Henriette Jager Oak Ridge National Laboratory

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