Biomass Research and Development Board

Bioenergy Feedstock Best Management Practices: Summary And Research Needs

A Report by the Feedstock Production Interagency Working Group

Cover Photo Acknowledgements:

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BIOENERGY FEEDSTOCK BEST MANAGEMENT PRACTICES: SUMMARY AND RESEARCH NEEDS

Introduction

Biomass is the single renewable resource that has the potential to supply a significant portion of U.S. liquid transportation fuels, chemicals, and substitutes for fossil fuel-intensive products. The development of a significant bio-economic sector can help achieve US energy security, improve environmental quality, and provide economic opportunities. The creation and evolution of a significant economically viable bioenergy and bioproducts sector is critically dependent on the existence of a large, sustainable supply of biomass with appropriate characteristics at a reasonable cost. Developing and deploying sustainable management and utilization options, systems, and practices so land owners and managers can effectively integrate biomass feedstock production into management activities requires science, technology, outreach, and application. It is a dynamic process that considers resource needs, landowner objectives, site capabilities, existing regulations, economics, and the best information available at any given time. This paper summarizes current information on best management practices for sustainable production of herbaceous, forest, and algae biomass feedstocks, and outlines research needs to fill critical gaps in our knowledge.

Herbaceous Biomass Production and Management

This section will focus on the best management practices (BMP) for perennial and annually produced herbaceous biomass for energy. The discussion will cover existing technologies as well as research needed to address the economic and environmental considerations for bioenergy feedstocks. The technology for the planning and implementation of BMPs/conservation practices for herbaceous biomass is developed nationally by the USDA-Natural Resources Conservation Service (NRCS) and then further refined at the state/local level to address local site conditions. BMPs/conservation practices for herbaceous biomass are based on extensive long- and short-term research and field observations relative to soils, soil quality, erosion, wildlife habitat, water quality, and plant productivity, with updates informed by emerging research.

Herbaceous biomass production and utilization is a fundamental element for a sustainable biofuel supply chain. It is critical the production and utilization of the herbaceous biomass be both environmentally and economically viable. Developing dedicated bioenergy crops, designed with specific bioenergy traits, such as increased yields, increased drought tolerance, and increased resource use efficiency are key components of a successful biomass energy system.

Herbaceous biomass consists of those annual and perennial crops that are grown and managed for their contribution to the biofuel. The biofuel produced from energy feedstocks may be in the form of a solid, liquid, or gas form of energy.

Perennial Herbaceous Biomass Crops

The typical perennial herbaceous biomass crops consist of grasses and legumes that are both native to regions of the US as well as introduced species. The primary environmental concerns related to the biomass production and harvest of perennial bioenergy crops include:

- Soil erosion from wind and water

- Soil carbon sequestration
- Water quality
- Water quantity
- Invasive plants
- Productivity

Best management practices for perennial bioenergy feedstocks must address these concerns in order to be sustainable for bioenergy production. The following conservation practices found in the USDA-Natural Resources Conservation Service (NRCS) Field Office Technical Guide provide the technology to address the environmental and production needs of the bioenergy crops.

<u>Perennial Herbaceous -- BMP for soil erosion from wind and water</u>

Much of the area proposed and being converted to perennial crops for the bioenergy feedstock, currently and into the future, are on either marginal cropland or existing pasture or hayland areas that are less well adapted to row-crop production. Much of the potential land proposed for conversion to perennial bioenergy crops will be susceptible to wind and water erosion. The erosion potential is especially high during the conversion and establishment period for the perennial crop. Once the perennial crop is established, erosion is generally not a major concern.

Prior to establishing the perennial crop an assessment should be performed by a qualified individual to access the potential for erosion and then follow those recommendations to control or minimize the soil loss from wind and water during establishment and maintenance of the perennial crop. BMP to control erosion include using one or more of the following:

1. Contouring Farming. Performing the tillage and planting operations on the contour on the sloping fields can reduce erosion substantially during the seedbed preparation and crop establishment.

2. Stripcropping. Establishing the bioenergy crop in alternating strips can reduce the water erosion potential on sloping fields and on fields subject to wind erosion. Tilling and planting strips approximately 50-200 feet wide alternating across the field keeps one-half of the field in protective cover while the other half becomes established. After the first strips become established the remaining alternate strips can be tilled and established to a bioenergy crop.

3. Grassed Waterways. On sloping fields with concentrated water flow the concentrated flow areas need to be protected with perennial grass cover to avoid gully erosion. Where needed, grassed waterways should be established prior to establishing the perennial energy crop.

4. Residue and Tillage Management (No Till and Mulch Till). Many perennial energy crops can be established in a seedbed that has only moderate tillage where a portion of the existing crop cover remains on the soil surface after seedbed preparation which helps to protect the soil from wind and water erosion. In other cases many energy crops can be established using no till technology where the seeds/rhizomes are planted in a narrow seed

slot with no prior tillage and the entire previous crop residue remains on the soil surface for erosion protection.

5. Forage and Biomass Planting. It is critical that a bioenergy crop suited to the field soil conditions be selected. This BMP guides one through the process of selecting crops suitable to the soil and climate conditions.

Perennial Herbaceous -- Soil Carbon Sequestration and Productivity

One of the major benefits of perennial vegetation is that they support the sequestration of carbon in the soil, based on field and modeling research results. However, since major quantities of biomass are removed planning must be done to replace lost soil nutrients to maintain productive growth and carbon sequestration. BMP to address productivity and carbon sequestration include the following:

1. Forage Harvest Management. Controlling how much, when, and how the bioenergy crop is harvested can help maximize yields while better managing crop quality, pest control, yields, carbon sequestration, and nutrient loss.

2. Nutrient Management. A well planned nutrient management plan that is built around a sound nutrient budget will maintain needed nutrients through recycling and adding additional nutrients via fertilizer, manure, or other organic sources.

Perennial Herbaceous -- Water Quality

The major water quality concerns involve sediment, nutrients, and pesticides. The goal is to get more water to soak into the soil and less runoff. In addition, one needs to control the contaminate sources of the water quality (soil, nutrients, pesticides). Generally the same BMP that address erosion, carbon sequestration, and productivity will also address water quality concerns. The one additional BMP may involve the use of Integrated Pest Management (IPM). IPM uses one or more cultural, biological, or chemical methods to judiciously control pests while minimizing the negative impacts on water quality.

Perennial Herbaceous -- Water Quantity

In many locations in the US, water quantity is a major concern either due to lack of rainfall, limited water for irrigation, and or soils that do not store or hold plant available water. BMP to address water quantity include the following:

1. Forage and Biomass Planting. It is critical that a bioenergy crop be selected that is suited to the field soil conditions. This BMP guides one through the process of selecting crops suitable to the soil and climate conditions. Species can be selected based on the available water.
2. Forage Harvest Management. Controlling how much, when, and how the bioenergy crop is harvested can help maximize yields and maximize the utilization of available soil water.
3. Nutrient Management. A well planned nutrient management plan that is built around a sound nutrient budget will maintain needed nutrients through recycling and adding

additional nutrients via fertilizer, manure, or other organic sources to maximize the utilization of available soil water.

Perennial Herbaceous -- Invasive plants

Some of the most productive bioenergy crops are, or could potentially be, invasive plants. Care must be taken in not only selecting the proper species for the site, but must also focus on crop management to keep the crop contained to the production area. BMP to address plant invasiveness include the following:

1. Forage and Biomass Planting. It is critical that a bioenergy crop be selected that is suited to the field soil conditions. This BMP guides one through the process of selecting crops suitable to the soil and climate conditions. Species can be selected based on their potential invasiveness.
2. Forage Harvest Management. Controlling when and how the bioenergy crop is harvested can help minimize the spread of seed and other vegetative parts may contribute to the offsite establishment of the bioenergy crop.
3. Integrated Pest Management. The bioenergy crop growing in its planned environment is considered a crop; however, if the bioenergy crop becomes established offsite it then becomes a pest. IPM is needed to keep the bioenergy plants contained within the planned field(s) and control is needed if that crop should invade other areas. IPM provides the prevention, monitoring, and control strategies to help control plant invasiveness.
4. Field Setbacks. In some cases setbacks or border areas need to be established to avoid the biomass energy crop from potentially invading a non-target area.

Annual Herbaceous Biomass Crops

The annual herbaceous energy crops include those grown and harvested as seed that is produced into bioenergy and those that have all or a portion of their vegetative plant parts harvested for bioenergy. The primary environmental concerns related to the biomass production and harvest of annual bioenergy crops include:

- Soil erosion from wind and water
- Soil carbon sequestration
- Water quality
- Water quantity
- Productivity

Annual Herbaceous Crops -- BMP for soil erosion from wind and water and carbon sequestration

The establishment of annual crops increases the erosion potential for both wind and water erosion. It is even more critical when portions of the crop biomass are removed. Likewise, the establishment of annual crops negatively impacts carbon sequestration and even more so when crop biomass are removed. BMP to address erosion and carbon sequestration for annual crops include:

1. Contouring Farming. Performing the tillage and planting operations on the contour on the sloping fields can reduce erosion substantially during the seedbed preparation and crop establishment. Reduced erosion also reduces soil carbon loss.
2. Contour Buffers. These are narrow grass or grass/legume strips (approximately 20 feet wide) planted on the contour and spaced 50-200 feet apart progressing up and down the slope.
3. Stripcropping. Establishing the bioenergy crop in alternating strips can reduce the erosion potential on sloping fields and fields subject to wind erosion. Tilling and planting strips approximately 50-200 feet wide alternating across the field keeps one-half of the field in protective cover while the other half becomes established in annual crops. Over the course of a few years the alternate perennial vegetation strips are converted to annual crops and the annual crop strips are converted to perennial vegetation. Reduced erosion also reduces soil carbon loss.
4. Grassed Waterways. On sloping fields with concentrated water flow the concentrated flow areas need to be protected with perennial grass cover to avoid gully erosion.
5. Residue and Tillage Management (No Till and Mulch Till). Many annual energy crops can be established in a seedbed that has only moderate tillage where a portion of the existing crop cover remains on the soil surface after seedbed preparation which helps to protect the soil from wind and water erosion. In other cases many energy crops can be established using no till technology where the seeds/rhizomes are planted in a narrow seed slot with no prior tillage and the entire previous crop residue remains on the soil surface for erosion protection. The combination of reduced tillage and maintaining more crop residue on the soil surface reduces erosion and soil carbon losses.
6. Nutrient Management. A well planned nutrient management plan that is built around a sound nutrient budget will maintain needed nutrients through recycling and adding additional nutrients via fertilizer, manure, or other organic sources. This will help produce the planned biomass needed to help maintain soil carbon levels.

Forest Biomass Best Management Practices: Regional Summaries

Forty four states have adopted voluntary or required best management practices (BMPs) for controlling nonpoint source pollution related to forest management activities. BMPs refer to "a practice or usually a combination of practices that are determined by a state or a designated planning agency to be the most effective and practicable means (including technological, economic, and institutional considerations) of controlling point and nonpoint source (NPS) pollution at levels compatible with environmental quality goals." [1] BMPs have been in place in some states since the 1970's, with essentially all states having BMPs in place since the 1990s. BMPs are based on extensive long- and short-term research in areas including soils, erosion, and productivity; road design, construction and maintenance; vegetation and stream dynamics; and forest harvesting. Updates to BMPs are informed by emerging research results. There have been

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[1] HELMS, J.A. (ED.). 1998. *Dictionary of forestry.* Society of American Foresters, Bethesda, MD. 210 p.

a number of compliance surveys and effectiveness studies over the years showing very positive results with routine BMP implementation. Forest management activities are a minor source of NPS pollution compared to other land uses, but can cause important effects without BMP implementation.

While BMPs differ in specifics by state, they are generally focused on ensuring that sediment and pollutants do not enter surface waters, providing forested buffers for streams, and ensuring stable roads and water crossings. In essence, these actions rest on ensuring that the soil resource is protected and stays in place on site. With interest in woody biomass as a bioenergy feedstock increasing, several states have developed BMPs focused on biomass harvesting (Indiana, Maine, Michigan, Minnesota, Missouri, Pennsylvania, and Wisconsin). These guidelines build on existing BMPs. The following sections summarize the primary aspects of the States' BMPs by region and offer suggestions for research needs specific to developing BMPs for forest biomass management activities. An extensive list of selected references is provided at the end of the document.[2]

Southern Region

The Southern Region includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. BMPs in these states address streamside management zones (SMZs), stream crossings, forest roads and skid trails, fertilizer and pesticide application, harvesting and reforestation, and waste disposal.

An SMZ is a strip of land adjacent to a stream or river that is managed to protect water quality and meet productivity goals. All states in the region require or recommend that SMZs be used. Criteria affecting SMZ width differ across the region and include such factors as slope, soil, stream type and stream width. In some cases, specific SMZ guidelines exist for special use waters such as trout streams or municipal water supplies. Some harvesting in the SMZs is generally allowed across the region, with recommended use of harvesting systems and techniques that limit soil, forest floor, and residual vegetation disturbance.

As stream crossings can represent significant opportunities for sediment to move into the water, BMPs across the region advise that harvest operations and roads should be planned to minimize crossings – reducing both sedimentation and costs, and increasing efficiency. BMPs focus on bridges, culverts, fords, and low water crossings and practices for controlling sediment and water movement on approach sections are recommended. Specifics vary by state, but consider varied combinations of slope, soil, stream type and size, drainage area and high flows, and materials.

In addition to providing access for forest management operations, forest roads and skid trails are often also used to provide recreational access to the forest. In some cases, they are far more heavily used for recreational access than for any other reason. Regardless of whether the intended use is only for forest operations access or for recreational or other access as well, roads and trails must be properly planned, constructed and maintained for safety, efficiency, and minimized

[2] This summary draws on the following: National Council for Air and Stream Improvement, Inc. (NCASI). 2009. Compendium of Forestry Best Management Practices for Controlling Nonpoint Source Pollution in North America. Technical Bulletin No. 0966. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

impacts on water quality. State BMPs provide recommendations on location, design, width, stabilization, stream crossings, drainage and maintenance measures, and construction season.

While the actual act of tree felling has little, if any, potential impact on water quality, skidding the felled material can be a source of sediment. In addition, operations associated with regeneration/reforestation have potential for soil and other disturbance. BMPs for skid trails and landings are focused on minimizing sediment movement potential and other disturbances associated with transporting and processing wood on site that could impact soil productivity. BMPs concern planning, and the size, number, placement, construction, and proper closure of landings, roads, and trails. Skid trail BMPs are generally concerned with proper stream crossing and limiting soil disturbance. Skidding logs in a streambed is prohibited, even if the bed is dry. Harvest system BMPs concern the type of equipment for a given set of circumstances based on soil type and wetness, topography, residual ground cover, among other factors.

BMPs for waste disposal address proper collection and disposal of containers, liquids and other wastes to prevent water and/or soil contamination. In addition, the BMPs address recommendations for proper care in equipment maintenance on site.

Western Region

This region includes Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. In most of these states, BMPs are contained in regulatory programs with state-specific Forest Practice Rule (FPR) compliance requirements relative to water quality and additional objectives. The state guidelines/regulations are often quite extensive and differ substantially by forest type and region within a given state and across states. Provisions can include riparian management, erosion prevention, roads, stream crossings, skid trails and landings, harvest systems, site preparation, chemicals, and hazard protection. Best management practices are often prescribed based on stream or water body classification, slope, soils, region of the state, vegetation, and/or special use/designation. Classification schemes for streams and water bodies differ across states as do special use/designations. In the case of states with regulatory programs, generally rules provide codified standards and guides for essentially all aspects of forest management. The following offers a general summary of the main areas addressed.

BMPs for roads include or prescribe location or placement on the landscape, closure, drainage, construction, water crossings, and maintenance. Provisions generally stress planning and road re-use, slope, and minimizing mileage, and can include erosion control measures, materials, bridge and other stream crossing construction, avoidance of specific habitats and land features, and stabilization. The BMPs are intended to minimize potential for sediment movement, site disturbance, erosion, and landslides, and in some cases, to ensure fish passage.

Harvesting BMPs or rules in the region generally focus on landings, skid trails, and harvest systems. Their intent includes preventing negative impacts to water quality, maintaining site productivity, habitat protection and limiting damage to residual trees. Factors addressed can include equipment operation and maintenance, waste disposal, water crossings, felling practices, and operations in sensitive areas, such as wetlands and streamside zones, and slash treatment.

Riparian Management Zone (RMZ) BMPs vary across the states depending on the water body classification scheme, distance from the water, slope, and region of the state. The intent is to protect aquatic resources and related habitat. Management or harvest options in the riparian zone can differ depending on distance from the water body, and can include recommendations or rules regarding allowable harvest equipment, residual densities, felling methods, and snag (stand dead tree) retention.

Rules and BMPs regarding site preparation and chemical use are generally focused on protecting water quality and soil productivity and can specify setback distances and application methods and equipment. The intent is to use any pesticides or fertilizers so that their movement into the water is prevented and to minimize soil disturbance so that erosion potential and sedimentation are minimized.

<u>Midwestern Region</u>

The states in this region that have adopted forestry BMPs are Illinois, Indiana, Michigan, Minnesota, Missouri, North Dakota, South Dakota, and Wisconsin. Five of the states having put forward BMPs for woody biomass are also in this region. The BMP recommendations include SMZs, roads, harvesting and reforestation, stream crossings, pesticide and fertilizer application, and waste disposal.

SMZs are recommended by all states in the region, with recommended minimum widths varying across states and across stream types or classes of waters within a given state. Harvesting is allowed in the SMZs, and although management options vary significantly within the region, the prescriptions generally focus on residual density, vegetative cover, and minimizing soil disturbance associated with harvest operations in the SMZ. In some states, quantitative recommendations for residual density in the SMZ are used while others focus on the amount of shading, canopy cover, or specified harvest systems in SMZs.

Stream crossing BMPs in the region include recommendations that crossings should be avoided if practicable, but provide recommendations on design, installation and maintenance to minimize streambank disturbance. In some states, permits or prior notification is required for intermittent and perennial stream crossing installation. Recommendations are also provided for temporary skidder crossings and fords. Recommendations are based on topography, soil, stream size, drainage area, and season in some cases.

BMPs in the region address both permanent and temporary roads. Temporary roads include skid trails. The BMPs stress proper advance planning, location, drainage, maintenance, summer and winter construction, and decommissioning. The BMPs make recommendations or provide minimum standards in each of these categories. They also address road construction in the context of stream crossings. These components are focused on limiting runoff, erosion, and sedimentation.

Fertilizer use in the region is fairly limited, so is minimally addressed in BMPs, with recommendations to use pesticide application guidelines to protect water quality when applying fertilizers. Site preparation herbicide use is relatively common in the region and BMPs are provided for their use, as well as pesticide use, associated with forest management activities. Recommendations for both aerial and surface application are provided.

BMPs for harvesting and reforestation address landings, water diversion from roads, temporary stream crossings, site preparation, landings, and skid trails. Landing location should be planned prior to road and skid road system layout. Skid trail BMPs focus largely on limiting soil disturbance and protecting streams at crossings. Skid trail number and length should be limited as practicable, with road and trail re-use recommended where practical. Considerations primarily include slope and soil. Skidding should not be done within stream channels and pole ford crossings, with removal immediately following the harvest operation, are recommended.

BMPs for site preparation generally recommend that mechanized site preparation not occur in SMZs, soil movement across the site or into debris piles should be limited, and that proper herbicide use for site preparation is preferable to mechanical site preparation as it minimizes soil disturbance. It is generally recommended that slash be distributed across the site. Waste disposal BMPs focus on chemical collection and disposal, equipment cleaning, and routine equipment maintenance.

Northeastern Region

The states in this region include Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Vermont, and West Virginia. Some of the states in this region have harvest regulations, require permits for certain activities, or have recommended practices, so BMPs in this region reflect a mix of recommendations and legal requirements. In some states, multiple laws regulate forest management activities. Across the region, BMPs generally address SMZs, stream crossings, roads, fertilizers and pesticides, harvesting and reforestation, and waste disposal.

Most states mandate or recommend the use of SMZs along intermittent and perennial streams and provide a range of minimum SMZ widths that may vary with slope, soils, and watershed type. Harvesting in SMZs is allowed across the region. The BMPs differ among states, but generally consider minimizing soil disturbance, residual density or shading, and/or equipment operation in SMZs. Numerous measures for eliminating, minimizing, or restricting soil movement in SMZs are offered in the BMPs, including prevention and mitigation measures.

All states in the region provide some guidance on stream crossing installation, use, and removal. Primary concepts include limiting the number of crossings, minimizing stream bank and bed impacts, limiting flow changes, ensuring fish passage availability, limiting approach runoff, and employing proper retirement/closure procedures. Guidance is provided for planning and designing stream crossings taking topography, soil type, drainage area and expected flows, season, flood events, and fish passage needs into account.

Road BMPS consider maintenance, construction, draining, planning and location, and closing. Recommendations generally include using existing roads and limiting new roads, road length, and stream crossings where practicable. The most important factor in controlling erosion is considered to be design, construction, and maintenance for effective road drainage, and recommendations include a variety of water diversion structures and their appropriate use and placement.

Some of the states have BMPs for fertilizer applications for seeding in logging operation closeouts and at least one state has recommendations regarding type and use of fertilizer to increase tree growth. Pesticide laws in each state provide guidance and requirements on proper use during forest operations. Waste disposal and site cleanup BMPs are currently provided by four states.

Preplanning is a primary emphasis in BMPs for harvest and reforestation operations including landing and skid trail location, and site preparation operations. Skid trail BMPs emphasize soil disturbance limitation, stream crossing protection, and skid trail location relative to soil and slope. Currently, only one state provides site preparation guidelines.

Woody biomass BMPs or recommendations from the states are primarily presented as general guidelines. Guidelines generally include some recommendations on residual or debris removal limits; and base access, harvesting; and water quality protection guidelines on existing state BMPs. Guidelines for maintaining wildlife habitat and/or provisions for maintaining biodiversity are often also provided, as are guidelines for maintaining soil productivity. The guidelines are often based on expert opinion as it is acknowledged that this is an area of active and needed research. There is much that has not been studied and quantified regarding woody biomass removal for energy and bioproduct feedstock.

Research Needs for Herbaceous and Woody Biomass Feedstock Production Best Management Practices

Sustainable production of hundreds of millions of tons of high quality biomass feedstocks will require the development of management strategies, systems, and practices that are adaptable to local conditions. These strategies, systems, and practices must meet the complex objectives of the land owners, biomass conversion facilities, communities, and the Nation.

Developing effective best management practices for biomass feedstock production, management, and utilization requires research in agriculture, silviculture, genetics, genomics, physiology, soils, pest management, crop harvesting, and forest operations research. It must build on the significant body of existing research, including long-term soil and productivity studies, habitat research, genetics and tree and crop breeding, water quality research, and harvesting and logistics operations research. The research can supply foundational information needed to increase production and production efficiency, enhance efficient resource use, produce cost-effective resource delivery and use practices, develop effective management systems, and deliver needed feedstock volume while providing needed goods, services and values. Research needs for developing best management practices for herbaceous and woody biomass feedstock include:

- Develop herbaceous and woody biomass sources with higher yield efficiencies.
- Develop herbaceous and woody biomass sources with improved biofuel and bioproduct characteristics
- Develop herbaceous and woody biomass sources for specific production environments
- Quantify resource demands (e.g., water, nutrient, pest management) in herbaceous and woody biomass production systems
- Develop density-yield relationships for herbaceous and short rotation woody crops and integrated feedstock production systems.

- Quantify soil carbon and nutrient dynamics in feedstock production systems and residue removal levels that conserve/enhance soil carbon, moisture, temperature and nutrient status and retention.
- Quantify relationships between management inputs and productivity in commercial-scale herbaceous crop, short rotation woody crop, and integrated feedstock production systems.
- Develop appropriate harvest timing, frequency, and intensity options for short rotation woody crops and integrated feedstock production systems.
- Develop precision resource delivery systems (e.g. water, nutrient, pest management) for herbaceous and short rotation woody crop systems.
- Develop deployment, production, and management options and practices that enhance nutrient- and water-use efficiency of biomass feedstock production systems.
- Quantify changes in nutrient and chemical runoff from biomass feedstock production areas.
- Develop and test guidelines for appropriate levels of sustainable residue removal to conserve and enhance soil carbon and nutrient retention.
- Quantify habitat relationships for energy crop and integrated woody biomass production systems.
- Develop options and practices that enhance the function and value of marginal sites.
- Develop practices and methods for sustainable production of large scale herbaceous biomass crops, short rotation woody crops, and integrated feedstock production systems.
- Develop and test strategies to integrate forested systems into agricultural landscapes and to effectively deploy agroforestry systems to provide services as well as biomass feedstocks.
- Quantify costs and returns associated with transitioning lands to herbaceous biomass crops and short rotation woody crops and integrating woody biomass production into conventional forest management systems.

Algae Best Management Practices

The development of algae as a renewable fuel does not depend on soil types or availability of soil nutrients for growth because algae are cultivated in water. This section describes microalgae and cyanobacteria as the predominant forms of algae, however the utilization of macroalgae (seaweed) is not covered because it is outside the scope of land based best management practices. The growth of algae as a sustainable fuel requires large quantities of water (which can be fresh, brackish, saline or wastewater) and a source of nutrients. The quality of water and nutrients for the cultivation must be carefully controlled to ensure the health and productivity of the algae. As a potentially new land-use, algae producers will need to work proactively to meet the ecological and sustainability needs of the local community. The production facility must ensure that algae, growth medium and possible contaminants are not discharged to water bodies.

Main Methods of Algae Biofuel Production

There are three main methods of microalgae biofuel production, two of which utilize photosynthesis directly (autotrophic production with closed and open systems) and one of which is a biochemical conversion process (heterotrophic production) that relies on input feedstock derived from an upstream photosynthetic source. First, autotrophic algae production is based on the photosynthetic conversion of CO_2 into biomass that includes lipids that can be converted to fuels with relative ease. The closed autotrophic approach uses photo-bioreactors (PBRs) where the algae are grown in closed bioreactor systems that allow for light input. Closed PBRs allows the algae to grow with sunlight while preventing excessive evaporation of the water. The use of a closed PBR provides additional environmental controls for enhanced productivity and downstream harvesting. This method of algae cultivation is costly because of the relatively high capital and O&M costs associated with installation and operation of PBRs.

A second algae cultivation method that uses closed bioreactor systems without the need for light input is the heterotrophic approach. This cultivation process uses dark fermentation vessels without photosynthesis. In this approach the algae production process is based on the consumption of simple organic carbon compounds, like sugars or acetate, rather than inorganic CO_2, to produce high energy density neutral lipids for conversion to fuels. The cultivation of algae using cellulosic sugars produced from wood and agricultural wastes or purpose grown energy crops is an area of active research and development. In this case, the algae are being used as conversion microbes, much like fungi and bacteria. The primary drawback to the heterotrophic approach is the reliance on photosynthetically-derived feedstock from an upstream process and may have environmental and cost implications which could influence sustainability. The primary advantage of the heterotrophic approach is that it can produce higher density algae cultures with greater neutral lipid content.

The third method for algae production is using open systems (i.e. open ponds). Algae production with large scale open ponds is subject to water loss through evaporation and must be in a geographic setting that has an adequate amount of water and relatively flat terrain to avoid costly earthworks. The capital cost for the open pond process is lower than for closed systems. The challenges of open pond cultivation include having access to an adequate supply of water for growth, susceptibility to wind-born biological agents that can disrupt algal productivity, and containing and or protecting algae during unexpected environmental events. Both open and closed autotrophic algae cultivation approaches also require supplemental CO_2, or a bicarbonate form of inorganic carbon, to enhance algae cultivation.

Land Management

Algae can be cultivated on land that is not suitable for agriculture or forestry production if located in a topography that allows access for cultivation and harvesting. In addition, algae can be cultivated in desert areas, sandy soils, brown fields or contaminated tracks of land that are not suitable for other use. One of the concerns for sustainability in algae production systems is to avoid stressing fresh water supplies where the algae are cultivated. The cultivation of algae using brackish or saline water will greatly reduce the need for fresh water resources. In addition, algae production systems will need to comply with relevant regulations on agriculture and genetically-engineered biotechnology products, especially those governing the release of nonnative or problematic native organisms into the receiving water or soil. Also, harvesting and concentrating algae from the growth media needs to be done with low energy intensity and low cost using approaches that can be scaled up. The optimization of microalgae harvesting technology represents a research gap and additional work is needed to identify the best management practices for the development and commercialization of the emerging algae biofuel industry.

Water Quality

The most important areas of concern for algae cultivation are the issues of water quantity and quality available for algae production. Particularly in some Western states, the source of freshwater for algae biofuel production could be linked to the water rights for the land. The cultivation of algae in other parts of the country could also be a serious contender for freshwater that is required for the irrigation of farm crops and other competing uses. A best management practice is to preserve freshwater for traditional agricultural use and to recommend that algae be cultivated with wastewater, brackish water, or seawater whenever possible. Algae biofuel cultivation with brackish water will also require some quantity of freshwater or low salinity makeup water to maintain a suitable range of salinity for optimal growth. In some agricultural land, the tile drainage water or effluent from a large farming area could be used as the makeup water and a source of nutrients for algae cultivation. In other parts of the country the effluent discharges from a wastewater facility could be used as makeup water and source of nutrients for algae cultivation. Also, the management staff of open pond facilities should monitor incoming water streams on a continuous basis and have procedures in place to prevent unwanted contaminants from endangering the cultivation of algae.

Nutrient Requirements

Another area of concern are the nutrient requirements for the aqueous cultivation of algae, including the availability of inorganic phosphorus and nitrogen, and carbon in either organic form (sugars) for heterotrophic growth or inorganic form (supplemental CO_2 or bicarbonate) for enhanced autotrophic growth. Commercial fertilizers can be used to provide nitrogen, phosphorus, and other micronutrients for algae production, but this could result in a competition with agriculture when the scale-up of algae production occurs. However, the algae cultivation process could utilize nutrients in wastewater from municipal, industrial, and agricultural waste facilities to reduce dependence on commercial fertilizers and carbon sources.

Methods to Reduce the Cost of Operations

A best management practice would be to co-locate algae cultivation facilities in the proximity of a fossil fuel electric generator to utilize the carbon in the emissions of the power producer. Another best management practice would be to co-locate an algae cultivation area in the proximity of a municipal, industrial or agricultural facility to utilize the phosphorus and nitrogen in the effluent wastewaters from those sources.

The availability of nutrients and carbon resulting from such a co-location could foster the growth of algae while reducing the cost of operations. The operator of an algae-based biofuel facility will need to satisfy both state and federal regulatory requirement to insure that heavy metals or other unwanted contaminants taken from waste stream sources will not hinder the cultivation and downstream processing of the algae or make the end product unsuitable for the intended use. Commercial algae biofuel cultivation next to a municipal, industrial or major agricultural processing facility could also help reduce the capital cost for the required infrastructure. The co-location of an algae facility could facilitate the transportation and distribution of biofuels and other co-products to various markets.

Another approach for reducing the amount of process water, commercial fertilizer and carbon inputs would be to locate an algae production facility down-gradient of an agricultural or a forestry management area. Agricultural contaminants from surface water and occasionally ground water could be used as a nutrient source for algae cultivation and reduce excess water pollutants from entering the eco system. The cultivation of algae for biofuel in this scenario could be viewed as a process for ecological water filtration. This approach would also reduce the operating cost for the process water and nutrients that are required by the algae biofuel facility. Another best management practice would be to co-locate an algae biofuel facility near a coastline to take advantage of the phosphorous, nitrogen and bicarbonate available in seawater. Again, this would greatly reduce the requirement for commercial fertilizer and inorganic carbon while providing water needed for algae biofuel production. The use of non-fresh water sources avoids putting additional demands on limited freshwater supplies.

Research Needs for Algae Best Management Practices

For both the open pond and enclosed photobioreactors methods of algae cultivation, the precise location and amount of suitable sites available that would satisfy all of the resource requirements (land, water, access to nutrients) for algae biofuel production at the commercial scale, and yet also possessing the ideal growth conditions (temperature, solar insolation) requires additional research. The results from an initial geospatial modeling and analysis to define such locations were recently published by scientists at the Pacific Northwest National Laboratory. This study focused on open pond algae cultivation and implications for land and water resources within the conterminous United States. Another study completed by the Sandia National Laboratories in parallel elucidated issues connected with nutrients, such as nitrogen, phosphorus, and carbon dioxide, required for commercial scale algal biofuels production. These foundational studies are the beginnings of the resource assessments that should facilitate decision-making and enable sustainable practices for algae biofuels in the future. Beyond national level modeling and analysis, the biological, chemical and physical determinants of algae cultivation and processing need to be researched at a much deeper level locally. The biological consideration for the cultivation of algae biofuel at the local growth area requires additional investigation for several concerns.

First, local conditions will dictate not only the amount of water that is available, but also variables with respect to the quality of the water (i.e. salinity, pH, dissolved organic carbon, dissolved oxygen, transparency, nitrogen and phosphorous levels, inorganic content). Few of these water quality issues have been examined in great detail to determine the impacts of large-scale (i.e. 100-1000 hectare) algae cultivation systems. Second, other biological factors that will also likely influence culture stability and productivity at the local level include competing algae and cyanobacteria, viruses, other microbes (pathogens and benign species), grazers and protist predators (rotifers, amoeba), and larger animals (invertebrates, crustaceans, water fowl, migratory birds). It is unknown how population and food chain dynamics might be affected when algal biofuels production ramps up nationally. Third, the availability, transport, and practical use of nutrients from sources other than commercial fertilizer (i.e. municipal and animal wastewater, landfill leachate) also needs to be researched to mitigate impacts on agricultural crop production. Anaerobic digestion and subsequent recycling of residual algal biomass is an approach to reduce nutrient availability. However, this approach could impact greenhouse gas emissions from fugitive gas emissions and should be elucidated. Fourth, algae production and processing systems must be made more efficient in terms of materials and energy consumption, from reducing the need for plastic or rubber pond liners to devising new ways of harvesting and dewatering algae. Fifth, the economical process of sourcing, delivering, and utilizing carbon dioxide (gaseous or dissolved) in algae production systems remains a big challenge, not only in terms of technological innovations but also in terms of meeting regulatory statutes.

Additional data on the availability, cost-effective accessibility and appropriation of inorganic carbon (i.e. carbon emissions from industrial sources) for autotrophic algae growth is also required to model the scale-up of closed PBR's and open systems. Similarly, additional data is needed to determine the availability and cost-effective accessibility of organic carbon (i.e. crops or agricultural wastes) for to the scale-up of sustainable heterotrophic algae biofuels production. Finally, the harvesting and dewatering of algae biomass in conjunction with the downstream extraction and separation of neutral lipids is too costly and energy intensive. Supplementary research is required to reduce the cost of these processes and to ensure sustainable algae biofuel production.

Summary of Algae Best Management Practices

The sustainability of algae biofuel production scale-up depends greatly on finding low cost non-agricultural land with an ample water supply for the cultivation process and developing new techniques for harvesting and downstream processes. The production of algae biofuel should complement conventional agriculture and related biomass markets. The obvious best practices that can maximize the environmental benefits of algal biofuels production at scale, including co-location of an algae biofuel facility next to a stationary source of carbon dioxide emissions, a wastewater facility, or a source of brackish water will reduce the need for freshwater and commercial fertilizers. In addition, co-locating an algae biofuel facility down gradient of agricultural land can also reduce the amount of freshwater and commercial fertilizers required for algae biofuel production. Other sustainable management practices that address environmental concerns will require additional research, analyses, and field studies to fully characterize and implement. In conclusion, the development of an algae biofuel production facility must be carefully planned and monitored to comply with relevant regulations and local concerns for the sustainable production of biofuels.

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Feedstock Sources/Supply Working Group -- Best Management Practices Team Members

USDA/FS R&D: Marilyn Buford*
USEPA: Andy DuPont*
USDA/NRCS: Norm Widman*
DOE/OBP: John Ferrell
DOI/BLM: McKinley-Ben Miller
DOI/OWFC: Henry Bastian
USDA/ARS: Jeff Steiner
USDA/FSA: Martin Lowenfish
USDA/NRCS: Bruce Wight

*Team co-chair

Note: Joyce Yang, Joanne Morello, Ronald Pate, and Daniel Fishman (DOE/OBP), Mark Segal, Alan Hecht, and Roberta Parry (EPA) contributed to the writing and review of the Algae Best Management Practices section.