The First Fifteen Years

Switchgrass harvest in South Dakota as part of the SGI/DOE Regional Feedstock Partnership. *Photo courtesy of Vance Owens, South Dakota State University.*

SUN GRANT INITIATIVE

NORTH CENTRAL REGION
www.sdstate.edu/north-central-regional-sun-grant-center

NORTHEASTERN REGION
agsci.psu.edu/research/sungrant

SOUTH CENTRAL REGION
sungrant.okstate.edu/

SOUTHEASTERN REGION
ag.tennessee.edu/sungrant/Pages/default.aspx

WESTERN REGION
sungrant.oregonstate.edu/

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Executive Summary

The Sun Grant Initiative (SGI) is a national research program that networks land-grant universities with federal agencies, government research laboratories, and industry partners to promote the development of agriculture and forestry resources for biobased energy, technologies, and products. Five land-grant universities serve as regional SGI centers to foster regionally relevant projects that address national issues. These universities include South Dakota State University (North Central Region), Oregon State University (Western Region), Oklahoma State University (South Central Region), University of Tennessee (Southeastern Region) and Pennsylvania State University (Northeast Region, 2014-present). The Northeast Regional Center was housed at Cornell University from 2002-2014.

The SGI promotes the provision of jobs and new industries through peer reviewed research. Although our principal investigators may spin off new companies or license technology to other companies, our primary role is to develop new knowledge and share that knowledge with other researchers, industry, and government agencies. This new knowledge can then be used to spur other inventions, create new economic opportunity, and form the basis for the new bioeconomy.

The SGI Centers facilitate ongoing and proposed federally funded research, extension and education programs. Each regional center has developed rigorous competitive grant programs to identify relevant bioenergy projects consistent with the SGI's mission and the needs of each region. At this point, projects have been conducted in 47 of the 50 states through regionally directed grants. Through the development, distribution, and implementation of biobased energy technologies, the SGI:

- enhances national security through the provision of alternative fuels that reduce our dependence on fossil fuels while reducing the impacts of climate change;
- promotes diversification in and the environmental sustainability of agricultural production in the United States;
- stimulates economic diversification in rural areas of the United States; and
- enhances the efficiency of bioenergy and biomass research and development programs through coordination and collaboration between U.S. federal agencies (i.e., Department of Agriculture, Department of Energy, and Department of Transportation) and land-grant universities.

Federal funding to date from these agencies, as well as cost share from non-federal partners and types of projects, are shown in *Figure ES 1*.

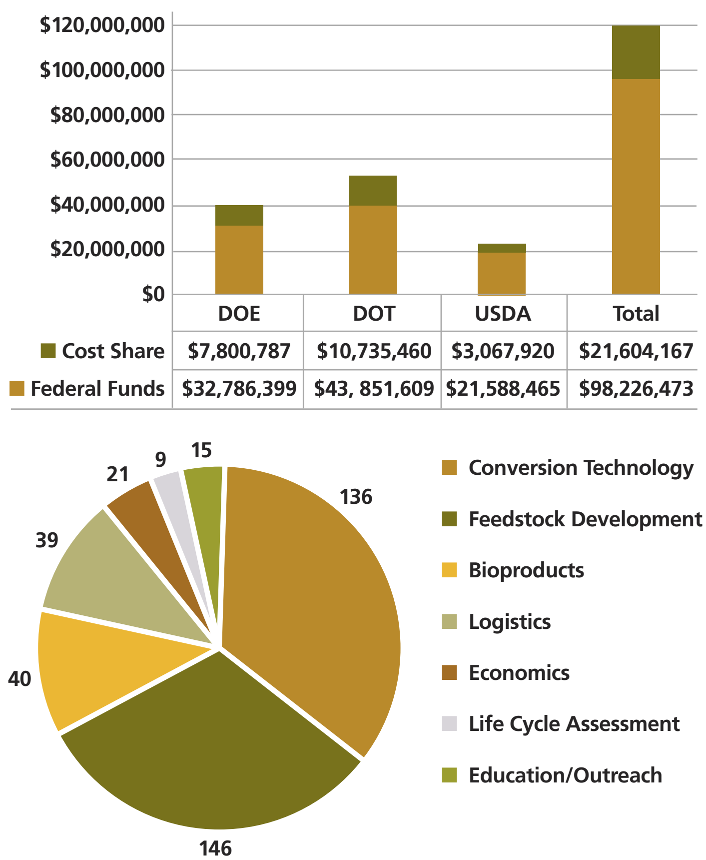

Figure ES 1: Total federal funding to date (including administrative costs) from the U.S. Departments of Energy (DOE), Transportation (DOT), and Agriculture (USDA), along with associated nonfederal cost share is provided at the top. The total number of projects, based on general topic area, funded at all Sun Grant Regional Centers is shown at the bottom. Greater detail by funding agency and primary topic are provided in the body of the report.

Outcomes and products from Sun Grant-funded research have been extensive. The SGI, through funding from the federal agencies, has played a critical role in fostering development of the bioeconomy both regionally and nationally. An economic impact analysis covering the period 2007-2015 estimated SGI's economic impact to be more than $275 million, essentially a three-fold increase over the $90 million federal investment during that 10-year timeframe (English et al., 2016). The authors estimated that nearly 1,000 jobs were created as a result of investments in research projects carried out in each region, and that this economic activity added nearly $174 million to the regional domestic product and the nation.

The SGI has made other significant impacts in terms of knowledge discovery, workforce development, and innovation. As critical elements of this process, a remarkable number of research findings have been published or presented at professional conferences or to other stakeholders, students with the skills for a new industry have been trained, new innovations have been developed, protected, and licensed, and new companies have been started *(Table 1)*.

One of the key outreach pieces was a web-based public resource on biobased energy called the BioWeb (**bioweb.sungrant.org**). BioWeb is a non-commercial, educational website that provides current information about biomass energy and bio-products. The website has three levels of detail suited for diverse stakeholders. There are summaries written for lay audiences, general articles that contain more technical information than the summaries but remain easily readable, and technical articles that include detailed scientific information.

Table 1

Sun Grant impact measures from 2005-2019

Knowledge Discovery Measures	
Peer-Reviewed Publications	780
Abstracts	1,282
Outreach Publications / Web Pages	183
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Workforce Development Measures	
MS Degrees Conferred	200
Ph.D. Degrees Conferred	126
Post-Docs Supported	116
Undergraduate Students Supported	351
Innovation Measures	
Invention Disclosures	50
Patents Filed	21
Provisional Patents	15
Patents Issued	7
License Agreements	15
Plant Variety Protection	3

Corn harvest in Iowa. *Photo courtesy of Matthew Darr, Iowa State University.*

The Vision: Building a Biobased Economy

The Sun Grant Initiative

In early 2001, leaders in the land-grant university community began exploring the idea of building a "bioeconomy" based on the energy received and stored in plants, energy that can be used to create biobased renewable fuels, biopower, and biobased products. The concept was to build a broad collaborative effort of scientists, educators, and extension agents by harnessing and leveraging the U.S. land-grant research and extension system to create the new knowledge and skills for building a bioeconomy. The idea was to create a "Sun Grant Initiative"* with the ultimate goals of creating jobs and building industries reliant on the renewable and environmentally sustainable products of rural America.

Develop the U.S. Bioeconomy

Petroleum is an important starting material or "feedstock" for numerous uses other than energy and transportation fuels. Contemporary plastics, synthetic fibers, lubricants, solvents, paints, and numerous other common products depend on petroleum as a feedstock. Agriculture is a vital source of biobased feedstocks for these products traditionally made from oil. Biobased feedstocks can be an integral alternative for manufacturing pharmaceuticals, cosmetics, building materials, biocatalysts, and numerous other biobased products. The development of biobased products and the emergence of a biobased economy will complement, augment, and serve as an alternative to petroleum-based products.

Address Climate Change

Continued use of fossil fuels contributes to climate change by increasing the amount of carbon dioxide in the atmosphere. Plants can effectively capture the carbon dioxide through photosynthesis and remove it from the atmosphere. By using biobased feedstocks for the production of fuels, energy, plastics, and other biobased products, fossil fuel use is reduced and the concentration of carbon dioxide in the atmosphere can be stabilized and reduced over time.

Meet Our Nation's Energy Needs

The amount of energy we need continues to increase. At times during the past decades, oil production appeared to be leveling off and even declining, while the amount of oil that we consumed continued to grow. Not surprisingly, the price of a barrel of oil and a gallon of gas also went up. Higher prices provided the incentive to the oil industry to develop shale oil, resources that had previously been too expensive to retrieve. To offset the increases in domestic U.S. oil and gas production, international oil production increased and, as would be expected, the price of oil and gas declined again. These price cycles and market fluctuations demonstrate the need to develop sustainable energy systems. Biobased energy resources can serve as a counterbalance to fluctuating petroleum costs and help stabilize energy markets. Bioenergy can also play a critical role in providing high-energy liquid transportation fuels, such as aviation fuels that now come primarily from a barrel of oil.

Support Our Farms and Forests

One of the great things about bioproducts and bioenergy is that we grow it here at home. Plants capture and store energy from the sun; we then harvest the plants and plant residues to release the stored energy in forms we can use. A vibrant bioeconomy provides agricultural producers the opportunity to grow and harvest biobased feedstocks for non-food uses while maintaining their ability to feed a growing population, providing new sources of income to farmers, ranchers, and foresters.

Support Our Rural Communities

In addition to providing new sources of income to agricultural and forest producers, a bioeconomy means jobs in rural communities. It costs too much to move low-density plant material great distances before it is converted to products. This means smaller processing facilities can be deployed instead of only using large and centralized conversion and processing systems. The capital for building facilities and the jobs created in the process can therefore be kept in rural communities.

Make it Work: Research and Education

There are great opportunities provided by the development of a bioeconomy, but we need a sustained commitment to build on current and ongoing efforts if we are going to meet domestic and global challenges. The SGI has leveraged new and emerging scientific and engineering breakthroughs and tools. Genomics, nanobiotechnology, and new computer modeling technologies have been applied to improving our technical understanding of plant biochemistry, developing new enzymatic processes, and creating new and improved biomaterials and bioenergy production processes. While great progress has and is being made, there are many technical, scientific, and economic challenges still to be addressed.

* Originally, the term used to describe this broad initiative was the Sun Grant Initiative, and this is the term used primarily throughout this report. However, within USDA NIFA, it is called the Sun Grant Program.

Renewing the Mission of Land-Grant Universities

The land-grant mission emerged before the administration of Abraham Lincoln. The vision was to create colleges and universities in every state dedicated to developing agricultural sciences and engineering to help our country harness the best of science and technology in order to grow and prosper. There is at least one land-grant institution in every state and territory of the United States, as well as the District of Columbia. Certain southern states have more than one land-grant institution as a result of the second Morrill Act, and some western and plains states have several, including 1994 land-grant tribal colleges *(Figure 1)*.

Land grant universities serve by implementing research, extension, and educational programs to benefit agricultural producers and consumers, to assist rural families and communities, and to conserve the world's natural resources. Agriculture will play an important role in providing power, fuels, and biobased products for America. Because of the unique position land grant universities have in science, service, and education, their engagement is critical in creating and developing the biobased economy.

NIFA LAND-GRANT COLLEGES AND UNIVERSITIES

USDA United States Department of Agriculture National Institute of Food and Agriculture www.nifa.usda.gov @USDA_NIFA

Figure 1: Land-grant universities and colleges across the U.S.

A Regional Approach

The challenge of developing biobased products and biobased energy is that the critical agricultural and forestry feedstocks depend on regional landscapes that are in turn dependent on regional and local soils, topography, weather, and cropping systems. The social and economic infrastructure for supporting the development of biobased products also differs from one region to the next. A new regional approach to research, education, and outreach was proposed in order to more effectively meet the unique regional nature of developing a bioeconomy.

The SGI was created, and a network of five land-grant universities were identified to serve as regional Sun Grant centers: South Dakota State University for the north central, Oklahoma State University for south central, the University of Tennessee for the southeast, and Oregon State University for the west *(Figure 2)*. Cornell served as the center for the northeast region until 2014 at which time Pennsylvania State University assumed the leadership for that region. Each center provides leadership and facilitates collaboration and coordination within its respective region. Each regional center focuses on supporting the emergence of a biobased economy in the context of its unique mix of biogeographical, environmental, agronomic, economic, and social characteristics.

The centers each held stakeholder workshops with participants from academia, national laboratories, state and local governments, the private sector, and non-governmental organizations (NGO). Through workshops and regional stakeholder advisory councils, each center has determined how to best address national bioenergy goals in its biogeographical and economic context, examining which feedstocks and production systems hold promise for development, identifying technical and social impediments to development, and establishing appropriate priorities for research and education projects in its respective region.

Reaching National Goals Through Regional Leadership

The SGI began with strong bipartisan support. Senate leaders Tom Daschle and Bill Frist led the effort to develop the SGI. The SGI began in the 2004 Omnibus Appropriations Bill, which provided an amendment to the 2002 U.S. Farm Bill. This authorization defined the mission and structure for the new initiative.

NORTH CENTRAL REGION
www.sdstate.edu/north-central-regional-sun-grant-center

Center: South Dakota State University

Illinois, Indiana, Iowa, Minnesota, Montana, Nebraska, North Dakota, South Dakota, Wisconsin, and Wyoming

SOUTH CENTRAL REGION
sungrant.okstate.edu/

Center: Oklahoma State University

Arkansas, Colorado, Kansas, Louisiana, Missouri, New Mexico, Oklahoma, and Texas

NORTHEASTERN REGION
agsci.psu.edu/research/sungrant

Center: Pennsylvania State University beginning in 2014 (Cornell University previously)

Connecticut, Delaware, Massachusetts, Maryland, Maine, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and West Virginia

SOUTHEASTERN REGION
ag.tennessee.edu/sungrant/Pages/default.aspx

Center: University of Tennessee – Knoxville

Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia; the Commonwealth of Puerto Rico; and U.S. Virgin Islands

WESTERN REGION
sungrant.oregonstate.edu/

Center: Oregon State University

Alaska, Arizona, California, Hawaii, Idaho, Nevada, Oregon, Utah, and Washington; and Pacific Territories

Figure 2: The five Sun Grant regions.

Mission

Through development, distribution, and implementation of biobased energy technologies, the SGI would:

- Enhance national energy security.
- Provide opportunities for rural economic development in America's traditional agricultural communities.
- Promote environmentally sustainable and diversified production opportunities for agricultural and forestry resources.
- Encourage further bioenergy research collaboration between government agencies and land-grant colleges and universities.

Structure

Other key guidelines that define how the regional Sun Grant centers are to function include:

- Funds were to be allocated evenly among the five regions.
- At least 75% of regional funds were to be allocated in the region through competitive grant processes.
- No more than 25% of regional funds would be used directly for center's programs.
- Research, extension, and educational programs on bioenergy and biobased products would include activities aimed at technology development and technology implementation.

Integrating National and Regional Priorities

The SGI leadership works with the federal agencies to address national bioproduct and bioenergy goals and objectives at the regional and local levels. Each collaborative effort has had a unique blend of projects and activities appropriate to the unique mission and objectives of each agency. The SGI has been supported through the U.S. Department of Agriculture Sun Grant Program. Working with the DOT, the SGI implemented DOT's Biobased Transportation Fuels Research. And working with the DOE, the Sun Grant implemented much of DOE's Regional Feedstock Program. The centers crosswalk the priorities identified by the federal agencies with those identified by the centers in regional listening sessions with stakeholders, so that national priorities can be addressed by the centers at the regional, state, and local levels. In turn, the centers facilitate addressing the goals and objectives of federal agencies to develop biobased products and bioenergy in the context of each region's characteristics, competitive advantages, and unique needs. The resulting Sun Grant programs embrace the multistate, multifunction, multidisciplinary integrated approach that is at the heart of the land-grant method of addressing national problems.

A Comprehensive and Integrated Systems Approach

It has always been clear that creating new biobased products and associated markets would require the development of new partnerships and a strengthening of long-standing collaborative efforts. One of the great challenges in developing bioenergy and bioproduct technologies is that they have to be developed as a complete system to be cost effective and economically viable. For farmers to increase production of biofuel feedstock materials, they need to be assured of a steady demand and have risk mitigation tools at their disposal (e.g., crop insurance). In addition, for bioindustries to develop products, they must be assured of a steady supply of cost-effective feedstocks. Successful development of the bioeconomy requires a systems approach at the local and regional levels, with coordination of feedstock production and conversion technologies.

Cultivating Communication

The SGI facilitated communication and coordination of bioproduct and bioenergy research within their regions, among the regions, and with the federal agencies. In March 2009 and in October 2012, the SGI organized and conducted national conferences to identify and showcase work supported by the SGI, but also to provide an update on the current state of knowledge in the diverse research fields that support bioenergy development. Several hundred university scientists and educators, specialists from the national laboratories and state agencies, federal scientists, and agency officials attended the conferences. At the 2012 forum, over 200 researchers were queried on future research priorities and needs. The SGI also supported presentations at a number of federal agency meetings, including USDA Agricultural Research Service listening sessions, USDA Conferences and Forums, Environmental Protection Agency (EPA) workshops on biomass production and the environment, the annual meetings of the National Research Council (NRC) Transportation Research Board, the annual DOE biomass conferences, the DOT workshop on biomass and transportation needs, Department of Defense (DOD) workshops and conferences on U.S. Air Force and Navy bioenergy needs, and multiagency initiatives. The SGI has provided input to incoming administrations, which has been incorporated into administration policies and position statements. SGI leaders have consistently been appointed to multiagency advisory committees, including the USDA/DOE Biomass Research Development Initiative (BRDI) Technical Advisory Committee (TAC). Sun Grant supported research has regularly been very highly rated in the DOE bioenergy platform review process and the DOT site reviews. SGI leadership consistently participates in professional and scientific associations, including the BIO Pac Rim Summit, the BIO World Congress on Industrial Biotechnology, and the Soil and Water Conservation Society workshops. The SGI sponsored the preliminary workshops that initiated the establishment of bioenergy communities of practice within the American Society of Agronomy.

Energycane group evaluating a demonstration site in Mississippi in 2013.
Photo courtesy of Brian Baldwin, Mississippi State University.

Federal Partnerships

U.S. Department of Agriculture

The SGI was initially authorized in the 2002 USDA Farm Bill and then renewed in the 2008, 2014, and 2018 Farm Bills as the USDA Sun Grant Program. In the 2008 Farm Bill, a Pacific Region subcenter was established at the University of Hawaii as a component of the Western Sun Grant Region. At the request of the Sun Grant leadership, the location of the centers was no longer specified beginning in the 2014 Farm Bill reauthorization; rather, the centers and subcenter were to be selected by USDA as a consortium through a national competitive process.

In the early years of the SGI and, in collaboration with USDA, DOE, and the regional Governor's Associations, each center hosted a series of regional workshops to critically evaluate the goal set forth in the *Billion Ton Vision* by Perlack et al. (2005) of producing a "billion tons" of biomass in the U.S. In conjunction with stakeholders across the biomass value chain, participants discussed strengths and challenges of meeting this national goal based on the unique biomass production and biorefinery needs of each region. Participants were asked to identify potential barriers to the development of biomass and bioenergy sources and to consider possible strategies for moving forward with biomass production and processing within their region. The first workshop was the Southern Regional Biomass Partnership, hosted by the University of Tennessee in 2006. Similar workshops were held by each regional center in 2006 and 2007. As expected, there were commonalities among the regions, but there were also clear distinctions in terms of the types and amounts of biomass that could be developed for supporting bioenergy production, and each region identified a unique mix of logistics and management challenges. Each region developed a report on their findings, and the results of the workshop were used to identify research priorities and develop programs appropriate to meet the needs of each region.

Based on results from workshops like that described above and regular, ongoing discussions with user groups, regional advisory councils, and other stakeholders, research needs for each region were included in regional requests for proposals (RFP). With USDA funding support, a total of 144 awards covering a diverse range of topics have been made to investigators across the U.S. *(Figure 3, top)*. Although the vast majority of awards have been multidisciplinary in nature, the primary research emphasis of more than 80% has been some aspect of conversion technology, feedstock development, or bioproducts. Funding to-date for USDA-supported research projects has exceeded $18 million, and awardees have provided more than $3 million in additional non-federal cost share to increase their research capabilities and outcomes *(Figure 3, bottom)*.

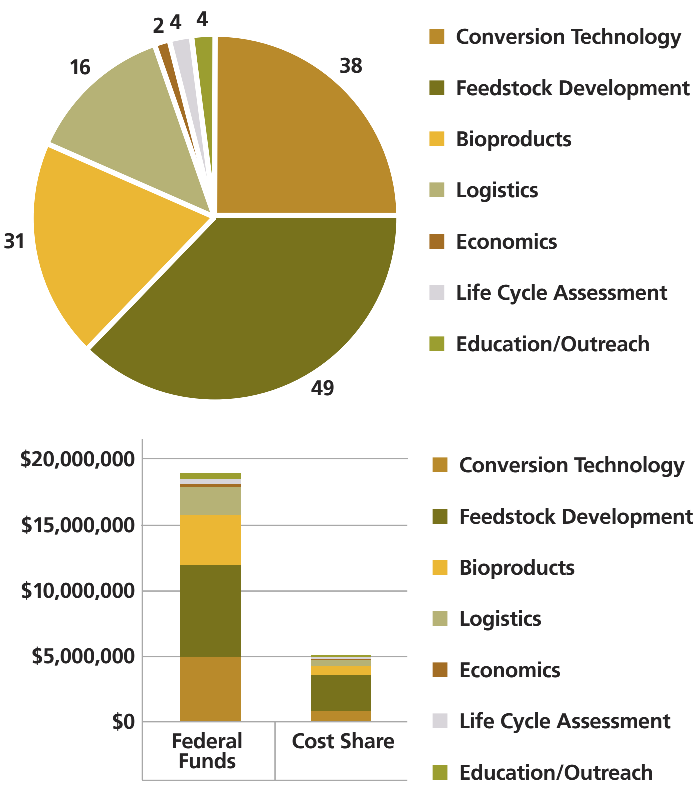


Figure 3: Number of funded projects by topic area (top) and the associated funding (bottom) from the U.S. Department of Agriculture and from non-federal partners providing cost share from 2005-2019. Note: Administrative costs are not included in this figure.

U.S. Department of Energy

The SGI and the DOE completed two important collaborative projects in the past 15 years: 1) the Regional Feedstock Partnership; and 2) a congressionally directed project.

The ***Regional Feedstock Partnership***, initiated in 2008, was a collaborative effort between the SGI and DOE's Bioenergy Technologies Office (DOE-BETO) with funding from DOE-BETO exceeding $20 million. This partnership followed a series of town hall-style meetings held across the country to gather input on some of the most promising biomass feedstocks and to ascertain research priorities associated with these feedstocks. The meetings generated insight into each region's unique capacity to contribute to the goal of producing a billion tons of biomass annually across the nation. While regional differences were apparent, questions associated with ecological and environmental impacts and the need for resilient systems were also highlighted. In each region, the potential production of diverse biomass feedstocks was evaluated, obstacles and knowledge gaps were considered, and research needs and priorities were identified. Teams of the nation's leading scientists were then formed to further assess biomass feedstock potentials, to conduct field trials of the most promising options at the regional and national level, and to estimate the nation's bioenergy production potential of selected feedstocks through the findings from this research and other data. The breakdown of funding from DOE-BETO for the Regional Feedstock Partnership, as well as cost share from non-federal sources, is shown in Figure 4.

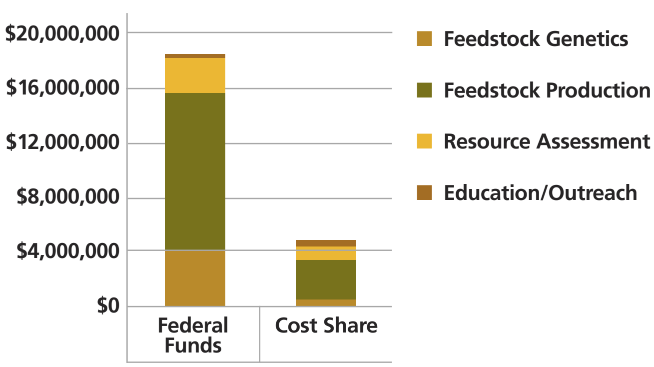


Figure 4: Federal funding, excluding administrative costs, and cost share support by topic area for the SGI/DOE-BETO Regional Feedstock Partnership. The Regional Feedstock Partnership included field trials and other research across the U.S. and was carried out from 2008-2017.

The ***congressionally directed project***, led by South Dakota State University, was initiated in 2008 and completed in 2017. Although the focus was on projects relevant to the North Central Region, nationwide RFAs were developed and projects were selected from across the U.S. Three specific RFAs were utilized, each focusing on a different bioenergy topic as selected by SDSU and the DOE. The RFAs focused on biomass feedstock logistics, sustainable biomass production systems, and biomass productions systems across diverse landscapes. Ultimately, 33 projects were selected, with DOE funding totaling around $10 million and cost share from non-federal partners around $3 million *(Figure 5)*.

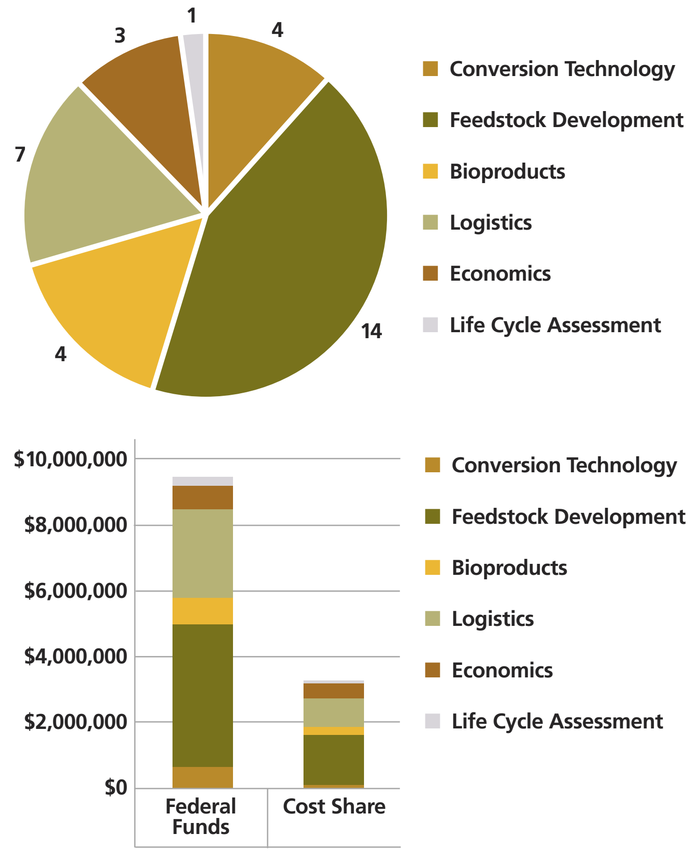


Figure 5: Number of funded projects by topic area (top) and the associated funding (bottom) from the U.S. Department of Energy and from non-federal partners providing cost share from 2008-2017. These activities were part of a congressionally directed project led by the North Central Regional Sun Grant Center at South Dakota State University. Note: Administrative costs are not included in this figure.

U.S. Department of Transportation

The SGI, through DOT funding, administered a competitive research program for land-grant universities and their partners. Each center managed its own competitive grants program to best meet the challenges of bioenergy and biomass research and education needs within its respective region. Each center utilized approximately 75% of its total funding for competitive grant projects. The remaining funds were used internally to build center capacity. Working with the SGI, the DOT Research and Innovative Technology Administration (RITA) organized a team of federal agency specialists to identify the nation's leading research priorities to be addressed in order to develop renewable biobased transportation fuels. These national priorities for renewable transportation development included: biofuel feedstock development, biofuels conversion processes, biofuel system analysis, economics, marketing and policy, and environmental impacts. More than 200 projects were selected for funding from the DOT competitions with total DOT support at approximately $35 million *(Figure 6)*.

Cup plant, a native forb with high biomass potential, growing in South Dakota. *Photo courtesy of Vance Owens, South Dakota State University.*

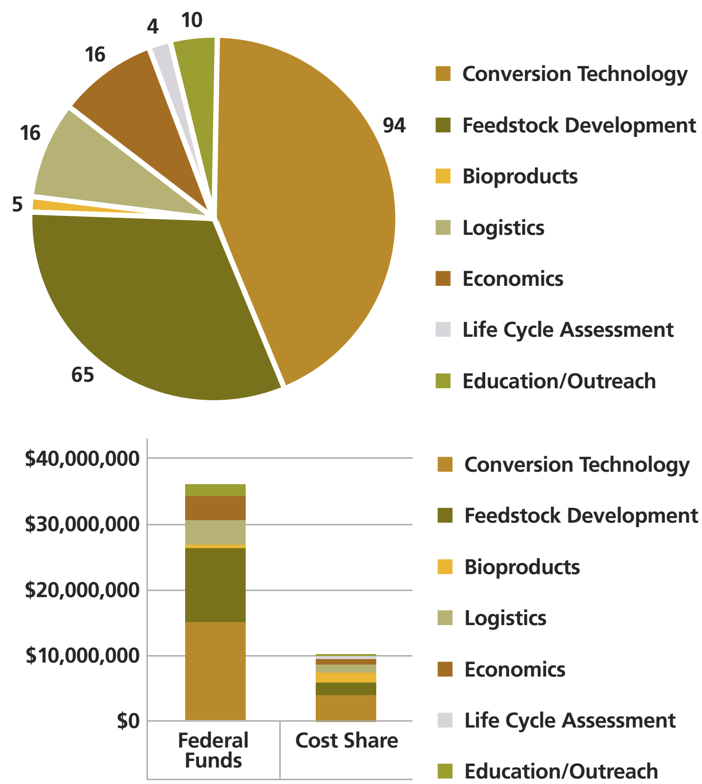
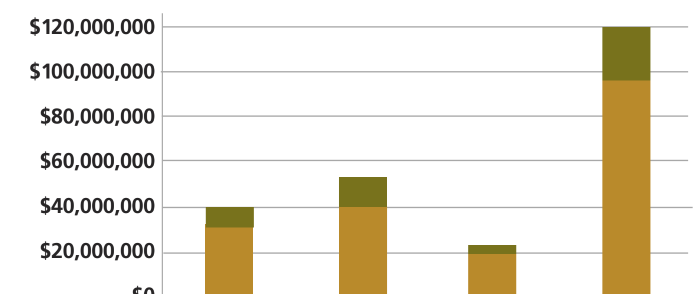


Figure 6: Number of funded projects by topic area (top) and the associated funding (bottom) from the U.S. Department of Transportation and from non-federal partners providing cost share from 2008-2018. Note: Administrative costs are not included in this figure.

National Impacts

Overview

From 2005 to 2019 and with nearly $100 million in funding from USDA, DOE, and DOT, the Sun Grant Initiative employed regional competitive grant programs and center initiatives to advance the bioeconomy *(Figure 7)*. Although funding varied annually from each federal agency, research, education, and outreach activities have steadily helped fill gaps in regional knowledge related to bioenergy, thus advancing the bioeconomy across the nation. More than 400 research projects, from applied to fundamental in nature, have been completed. Although more than 50% of projects have dealt with some aspect of feedstock development or conversion technology, other projects have covered the entire bioenergy value chain *(Figure 8)*.



	DOE	DOT	USDA	Total
Cost Share	$7,800,787	$10,735,460	$3,067,920	$21,604,167
Federal Funds	$32,786,399	$43, 851,609	$21,588,465	$98,226,473

Figure 7: Total federal funds (includes administrative costs) from the U.S. Departments of Energy, Transportation, and Agriculture, and cost share from non-federal partners in support of Regional Sun Grant projects between 2005 and 2019.

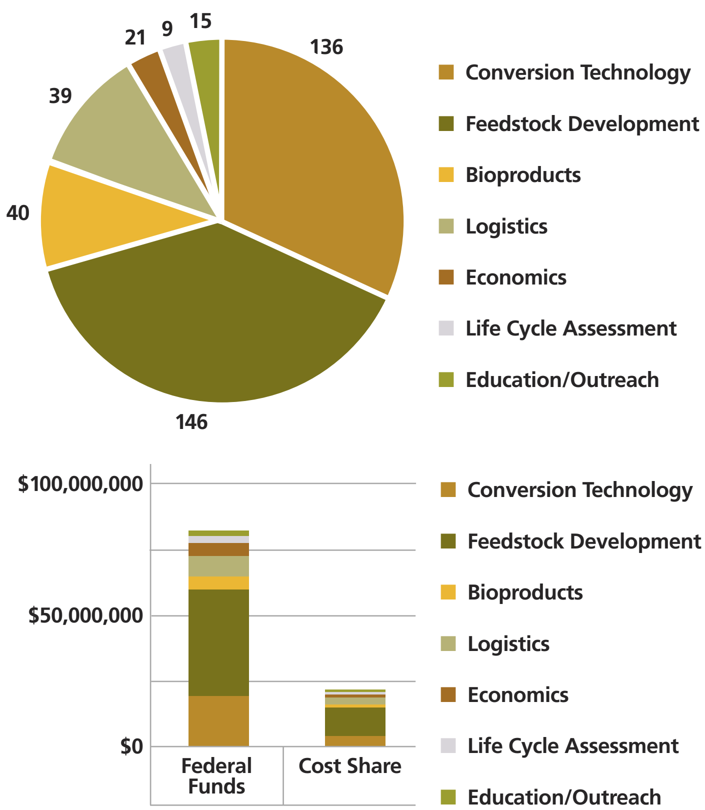


Figure 8: Total number of projects (top) and associated funding (bottom) within various bioenergy areas of focus that have been completed by SGI awardees. Funding for these projects was provided by the U.S. Departments of Agriculture, Energy, and Transportation. Note: Administrative costs are not included in this figure.

Measuring greenhouse gas emissions in a switchgrass stand. *Photo courtesy of Vance Owens, South Dakota State University.*

Outcomes and Impacts: Economic Development, Knowledge Discovery, Workforce Development and Innovation

The SGI, through funding from the various federal agencies, has played a critical role in fostering development of the bioeconomy both regionally and nationally. An economic impact analysis covering the 2007-2015 time frame estimated the economic impact of the SGI to be more than $275 million, essentially a three-fold increase over the $90 million federal investment during this 10-year timeframe (English et al., 2016). The authors estimated that nearly 1,000 jobs were created during this period as a result of investments in research projects carried out in each region, and that this economic activity added nearly $174 million to the regional domestic product and the nation.

The SGI has made other significant impacts in terms of knowledge discovery, workforce development, and innovation. As critical elements of this process, a remarkable number of research findings have been published or presented at professional conferences or to other stakeholders, students with the skills for a new industry have been trained, new innovations have been developed, protected, and licensed, and new companies have been started *(Table 1)*.

The achievements noted in Table 1 were the result of the many regional Sun Grant projects dedicated to the fields of sustainable feedstock development, use of crop residues, conversion technologies, logistics, product testing and evaluation, and the cross-cutting fields of economics, environmental sustainability, and education and outreach. Some key topic areas are highlighted below.

Sustainable Feedstock Development

As shown in Figure 8, sustainable feedstock development has been a key focus of many regional Sun Grant projects. Feedstock development activities have included field-scale and small-plot yield and management trials of numerous species (e.g., dedicated energy crops such as switchgrass, energy sorghum, and energycane; woody crops such as hybrid poplar and shrub willow; non-food oilseeds such as Ethiopian mustard; crop residues such as corn stover and small grain straw), genetic evaluations and breeding of some of these same species; soil health parameters associated with their growth and production; and economics. Recognizing the local and regional adaptation of many feedstock species, more than 90% of the states have been involved in some aspect of a Sun Grant project where feedstocks were evaluated.

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Innovation Measures	
Invention Disclosures	50
Patents Filed	21
Provisional Patents	15
Patents Issued	7
License Agreements	15
Plant Variety Protection	3

One of the key sustainable feedstock development projects led by the North Central Sun Grant Center was the SGI/U.S. DOE Regional Feedstock Partnership that took place from 2008-2017. The Partnership evolved into an expansive and complex program engaging more than 100 leading researchers from land grant universities, national labs, USDA, and industry, with feedstock field trials in almost 40 states *(Figure 9)*. The team was charged with assessing and developing potential biomass resources across the U.S. as well as providing outreach efforts to stakeholders based on its findings. Several of the most promising bioenergy feedstocks were evaluated including 1) corn residue, 2) cereal residue, 3) herbaceous energy crops (switchgrass, energycane, energy sorghum, giant miscanthus, and mixed grasses on Conservation Reserve Program [CRP] land), and 4) woody energy crops (poplar and willow).

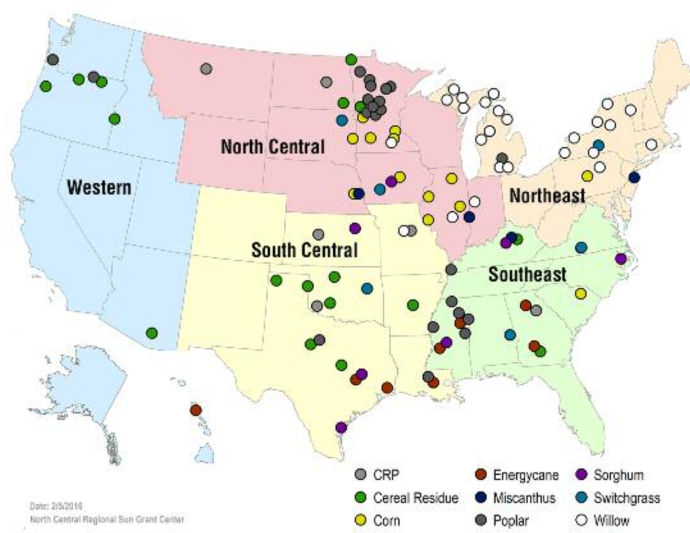


Figure 9: Map of field trials carried out in the Regional Feedstock Partnership.

Based on field trial and other data, one crucial outcome of the Regional Feedstock Partnership was the development of national maps estimating the yield potential of the feedstocks evaluated *(See Appendices for all maps)*. To develop these maps, members of Oregon State University's PRISM Climate Group and personnel from Oak Ridge National Laboratory held face-to-face meetings with each feedstock species group during 2013 and 2014. These "best-estimate" maps show the potential relative yield distribution of each species across the lower 48 states under long-term, average climate conditions using the PRISM ELM environmental suitability model.

Other outcomes of the Regional Feedstock Partnership include volumes of field trial yield data that has contributed to our scientific understanding of these feedstocks in the scientific and lay communities, contributions to DOE's 2016 Billion-Ton Report

(DOE, 2016), more than 130 peer-reviewed publications, and numerous opportunities for training of undergraduate and graduate students. A comprehensive report of the Regional Feedstock Partnership can be found at **https://www.osti.gov/servlets/purl/1463330/**. Species evaluated in the Regional Feedstock Partnership as well as through other Sun Grant projects are highlighted below.

Energycane trials in Louisiana (top) and switchgrass harvest in South Dakota (bottom) as part of the SGI/DOE Regional Feedstock Partnership. *Photos courtesy of Brian Baldwin, Mississippi State University (top) and Vance Owens, South Dakota State University (bottom).*

Herbaceous Crops

Background

In the U.S., much of the effort to develop new bioenergy crops has focused on herbaceous crops that can serve as sources of lignocellulose. Efforts have centered on utilization of residue from annual crops or from the development of annual and perennial crops that can be produced with high yields on large acreages using commercial agricultural production systems and equipment. Many of the herbaceous crops can be grown on land that is less suitable for commercial crops and thus may provide additional ecosystem and environmental benefits such as reduced soil erosion, improved soil and water quality, and increased wildlife habitat. Many crop species have been investigated to determine the most appropriate species for a given region. To date, some of the individual species studied have included those in the Regional Feedstock Partnership (i.e. sorghum, switchgrass, *Miscanthus* x *giganteus*, energycane, and CRP mixed grasses) as well as big bluestem, indiangrass, prairie cordgrass, Napier grass, *Arundo donax*, cup plant, alfalfa, and tall wheatgrass. The diversity of species evaluated underscores the importance of the regional approach used by the SGI in determining funded projects.

Program Targets

The SGI, through the regional centers, targeted the opportunities and costs associated with the production of numerous herbaceous crops across the value chain. Various species have been evaluated for their potential yield and economic return, conversion capabilities, environmental attributes, contributions to other ecological goods and services, and acceptability by producers. Harvest and transportation logistics associated with certain species have also been identified. Solicitations developed at each center provided opportunities to improve production capacity of known species (e.g., switchgrass breeding in Oklahoma), ascertain adapted species (e.g., multiple species in Minnesota), develop best management practices (e.g., cutting frequency and nitrogen rate on cool-season grasses in Georgia), and improve conversion processes (e.g., Napier grass conversion in Hawaii).

Outcomes

Herbaceous crop potential to produce various biofuels and bioproducts was highlighted through the various projects funded through the centers. Possible challenges associated with the production and transport of herbaceous crops were also evaluated. Agronomic best management practices were examined to reduce the footprint associated with herbaceous crop production; further, the production of herbaceous crops was demonstrated to often have positive effects on other ecological goods and services (e.g., improved wildlife habitat, reduced soil erosion, improved soil and water quality, and carbon sequestration). As some herbaceous crops may have low bulk density when harvested, various densification methods to reduce transportation costs were evaluated.

For species included in the Regional Feedstock Partnership, an extensive network of sites was monitored over a period of five to seven years *(Figure 9)*. By itself, the herbaceous crop data cover a much broader range of climate and environmental conditions than previous studies, thus providing both producers and end users valuable information about specific locations, agronomic practices, and in some cases the specific varieties of each crop that show the greatest yield potential. Species adaptation maps generated in conjunction with the Regional Feedstock Partnership provide a first look at the distribution of potential biomass production for most promising herbaceous species *(see Appendices for maps of each species evaluated)*.

Information Gaps

Through the SGI, important work has been done on regionally and nationally important herbaceous feedstocks. In fact, many of the modest, regional-funded projects have greatly improved our understanding of these crops. Nonetheless, work remains to identify key species of choice for specific areas and conditions. For example, utilizing certain herbaceous crops to reclaim salt-affected land or to use on mine tailings may offer great potential in increasing total biomass availability while maintaining prime cropland for food crop production. Since herbaceous crops are diverse in nature, continued identification of best management practices associated with these species across varied environments also remains. Yield maps, developed from the RFP research, will need further refinement in the future as cropping systems evolve and weather patterns change. Finally, many of the herbaceous crops are perennial in nature. Because of this, long-term trials over the course of five or more years will be highly beneficial, but there remains much to be done in this regard for the numerous herbaceous species that could be used throughout the country.

Woody Biomass

Background

Woody biomass represents an important feedstock source that is available in every Sun Grant region. In the southeast alone, almost 35 million tons of forest residues are generated from ongoing harvest operations in support of the pulp and paper and forest products industries. Importantly, it is a biomass source that is available today for production of fuels and chemicals. Although handling and logistic systems are in place for woody material, collection and preprocessing to a quality feedstock for fuels conversion remains a challenge.

There is strong interest in advancing intensive management practices to maximize productivity of trees grown specifically for fuels and chemicals. Widely known as short-rotation woody crops (SRWC), this approach is essentially a hybrid system that lies between conventional forest plantation management and agricultural approaches. Focused primarily on hardwood crops with favorable processing behavior in biochemical and thermochemical platforms, SRWC offers many attractive characteristics that include the potential for rapid improvement in performance properties through molecular genetics and breeding. To date, development efforts have centered on brushy willow in the northeast region, and wide-ranging hybrid poplar across the nation. It's important to note that SRWC practices are relevant to many hardwood species, as well as softwoods like southern pine, with the goal of maximizing productivity of purpose-grown crops for energy.

Program Targets

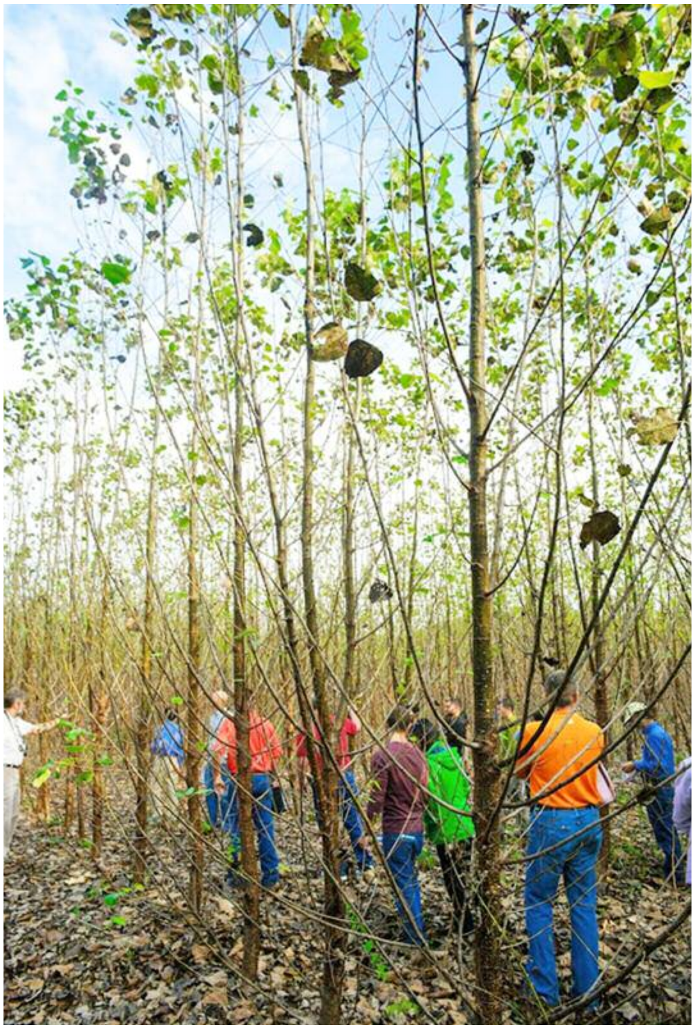
The SGI research portfolio in woody biomass has targeted both the challenges and opportunities presented by this resource. Research has advanced knowledge on woody biomass availability, refining information needed for optimal biorefinery siting decisions. This work has evaluated the economics and environmental attributes of woody biomass systems, provided new approaches for identifying woody crop sites, and explored alternative management approaches to optimize biomass yield and quality. A significant investment has integrated conversion issues, studying approaches to reduce recalcitrance of short-rotation hardwoods, as well as expand coproduct options.

In collaboration with the DOE, the Regional Feedstock Partnership was structured to baseline the yield potential of key SRWC systems, documenting recent genetic gains and developing sustainability metrics. The Regional Feedstock Partnership established an extensive network of field trials for both hybrid poplar and willow *(Figure 9)*. This highly coordinated program generated growth and yield data for further analyses, and provided biomass material for quality studies. As noted earlier, the Regional Feedstock Partnership created the research infrastructure for development of new harvest equipment, production economics information, and improved management practices for these key energy crops.

Willow trial in New York. *Photo courtesy of Timothy Volk, State University of New York.*

Information Gaps

In many ways, the SGI's grant program seeded a number of valuable projects that advanced innovative opportunities to increase yield, improve quality, and extend the value of wood as a chemical feedstock. Far-reaching questions remain to fully realize the potential of this resource. Specifically, there is a need to maintain the vital genetics and breeding program assets established by Sun Grant's Regional Feedstock Partnership to ensure continuous improvement of short-rotation woody crops. Additionally, to optimize performance for broader sites, new species (i.e., sycamore and sweetgum) need to be considered. Despite the fact that forest residue is a readily available resource for the biofuels industry, very little work has addressed logistical challenges. Regardless of the wood source, it is imperative that research on preprocessing and feedstock quality characteristics be accelerated. This work



Poplar trial in Tennessee. *Photo courtesy of Jessica McCord, University of Tennessee.*

needs to focus on the greater challenge presented by operational biomass, identifying new technologies for size reduction, moisture control, ash removal, and consistency.

Forest residues and residues from woody feedstocks also present an opportunity for sequestering carbon in soils. Biochar, which is wood residue heated in a low oxygen environment (think charcoal) has demonstrated tremendous potential as a soil amendment that can increase water and nutrient holding capacity as well as greatly improving soil organic carbon. Once incorporated in the soil, the carbon becomes sequestered and improves the ability of the soil to sequester atmospheric carbon. Plant growth and yield is improved as is the soil microbiome. Additional work is required to further investigate the differences among different types of woody biomass for biochar production as well as the supply curves for creating a market, logistics issues, and economics.

Logistics

Background

Harvest and storage processes will also result in feedstock variability. Baled feedstocks that have absorbed precipitation frequently harbor molds and other fungi. Moldy feedstocks can also result in reduced value for a fermentation-based industry.

Despite expected variation in feedstock composition, robust conversion technologies will be needed to establish a sustainable bioenergy industry. Lignin and contamination are serious detriments to a fermentation-based industry. Thermochemical processes such as gasification and pyrolysis are more robust, however, and would enable the industry to capture value from lignin and other recalcitrant substances in the feedstocks.

Jessica McCord (University of Tennessee, Center for Renewable Carbon) and colleagues planting hybrid poplar cuttings in east Tennessee. *Photo courtesy of Jessica McCord, University of Tennessee.*

During the past 30 years, there have been great advances resulting from research on feedstock production and bioenergy conversion technologies. It is often said, however, that the logistical details of delivering feedstocks from the field to the biorefinery is the greatest challenge to the industry. Again, guidance exists from other industries that have distributed supply chains. The wheat milling, woods products, and dairy industries, and more recently the corn dry-grind industry, all began in a highly distributed fashion. The distributed nature of crop production gave rise to a distributed network of grain elevators to segregate and coordinate the flow of grain to the processing industry. Later, a network of rail lines added new infrastructure to improve efficiency.

Fledgling markets warranted the initiation of these distributed industries. Research, innovation, technology, and infrastructural advances empowered these distributed industries to evolve, become more efficient, and become less distributed.

One-pass harvest of corn grain and stover in Iowa. *Photo courtesy of Doug Karlen, USDA ARS.*

For lignocellulosic feedstocks, a corollary to the grain elevator would be a distributed network of collection points within 10 to 20 miles of production fields. These collection points would not be used for long-term storage, but would instead be sites for feedstock receiving, segregation, and pre-shipment processing. Through preshipment processing, the collection points would provide value to the conversion industry through densification, pretreatment, or initial processing of feedstocks. Examples include pelleting, fiber expansion, gasification, or production of crude bio-oil from pyrolysis processing.

Program Targets

SGI-conducted research emphasizes regional issues and development of local and regional feedstock production technologies. New intellectual property is managed and commercialized in order to bring about rural economic development. Land-grant university research is directly connected to student training and higher education, resulting in an educated workforce for biobased industries. Additionally, the SGI provides science-based information to stakeholders and policy makers so that public discourse can be based on the latest research findings and developments.

SGI was engaged in initial work with U.S. DOT to better describe transportation infrastructure limitations for moving nearly 1 billion tons of biomass. Since that time, infrastructure has continued to deteriorate and there is increasing demand from international markets for pelleted biomass to produce energy as well as emerging markets for aviation fuels and biobased products made from lignocellulosic biomass. Additional research is needed to enhance local transportation infrastructure for the collection, transportation, and aggregation of these materials as well as a national system developed for export to foreign markets.

Outcomes

Densification of biomass early in the supply chain is a key component in developing a pathway for corn stover to become a viable commodity in the bioeconomy of the 21st century. Multi-pass harvesting is one option of harvesting corn stover but it comes with a penalty of increased soil contamination, resulting in ash contents in excess of 6-8%. Single-pass harvesting has the preferred ash content of the stover of around 3.5%. The issue with single-pass harvesting is the reduction in combine productivity in-field during harvest due to the additional draft loads of a baler and processing of the corn stover. Researchers found a productivity reduction of 11% when a combine towed a baler through the field and a 25-50% reduction in the combine's productivity in processing and separating the extra stover from the grain. There is a cost inherent to the reduction in productivity. Additionally there is a cost in the equipment required to support baling both on the grain harvest side and stover collection side of the harvest. Using a model developed at Iowa State University that relies on field collected data and current machinery cost, researchers determined that the cost of harvesting stover ranged from $20-$30 per ton based on a range of stover collection rates from 0.5 ton to 1.75 tons per acre.

In a parallel study, this same group implemented advanced real time monitoring and reporting of loading machines to increase the daily number of loads hauled. Their results reduced the overall cost to deliver biomass from the field to a storage site by $2/ton. Road damage cost was estimated to be $0.05-0.25 per ton of dry feedstock supplied depending on the types of semitrailer used and feedstock transportation mode. Potential best management practices for biobased feedstock transportation include using trucks with multiple axles, minimizing gravel road travel distances, and increasing repair and maintenance frequency. For a 30 million gallon biorefinery, the average estimated biorefinery gate-delivered corn stover cost and greenhouse gas emissions, including the nutrients removed with field stover removal, were estimated to be around $56 per ton and 209 lb.-$CO_2$ per ton, respectively. More about this study is included in the North Central Region section below.

Conversion Technology

Background

The SGI projects have researched conversion technologies aimed at improving existing processes, while exploring and developing new, cost-effective conversion technologies addressing biofuels, bioenergy, and bioproducts. Researchers from different SGI Centers investigated conversion technologies that transform lignocellulosic biomass into renewable fuels that does not compete with the food supply. The development of renewable fuels is an alternative way to minimize U.S. dependence on imported petroleum as a primary source of fuel and raw materials for industrial production, reduce further increase of CO_2 and other greenhouses gases in the Earth's atmosphere, and improve a biobased rural economy.

There are two primary conversion technologies available in converting feedstocks into fuels, energy, and products—biochemical and thermochemical. In biochemical conversion, feedstocks undergo pretreatment and hydrolysis, which often includes enzymes that break down the biomass structure to release sugars. These sugars are then biologically (e.g. fermentation) or chemically converted to produce intermediates and/or final products *(Figure 10)*.

In thermochemical conversion, biomass is heated rapidly to temperatures ranging from 350 to over 900°C under no or low oxygen environments to produce a gas (often called producer gas or syngas) and/or liquid (pyrolysis oil) *(Figure 11)*. These intermediate products are then catalytically upgraded to a fuel or product. The producer gas can also be burned directly (e.g. to generate steam) or as a fuel in an internal combustion engine to produce electricity.

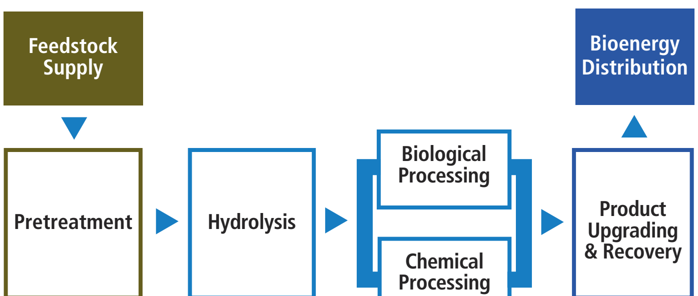


Figure 10. Diagram of the biochemical platform used to convert biomass feedstocks into bioenergy products.

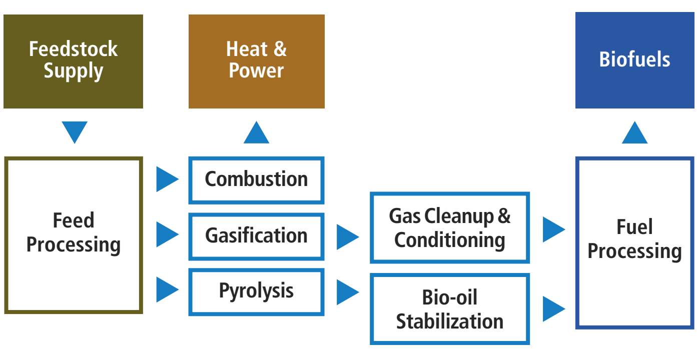


Figure 11. Diagram of the thermochemical platform used to convert biomass feedstocks into bioenergy products.

Program Targets

Conversion technologies projects funded by DOT-RITA and USDA through SGI aimed to improve existing, cost-effective conversion technologies while exploring and developing new technologies to develop biofuels, bioenergy, and bioproducts. Because there is not one conversion technology that fits all situations, the SGI has supported a wide range of technologies, leading to more in-depth understanding of processes and how to improve process sustainability.

Outcomes

Several conversion-related projects have resulted in new technologies, which are important steps to commercialization. For example, the South Central Center supported a project that led to the patenting of a unique downdraft gasifier capable of utilizing low bulk density feedstocks. The gasifier was fabricated and extensively tested, efficiently converting switchgrass, wheat straw, wood shavings and pellets, and corn fermentation byproducts into high quality syngas. A patent "Downdraft Gasifier with Internal Cyclonic Combustion Chamber," No. 8,657,892, was issued. A scale-up of the laboratory reactor has been fabricated and is being tested at Oklahoma State University. The gasifier will be the primary component in a mobile electricity generation unit that could be deployed in remote locales in the U.S. and overseas, utilizing local biomass feedstocks. This gasifier is being licensed.

Using the biochemical conversion pathway, the hybrid gasification-syngas fermentation technology for the conversion of renewable feedstocks into fuel (primarily alcohols) and chemical was developed at a commercial scale. This method produced 26 times the ethanol concentration compared to a conventional method and resulted in a U.S. Provisional Patent Application titled "Method to Sustain Culture Activity, Gas Uptake and Improve Selectivity for Ethanol Production during Syngas or Producer Gas Fermentation in Bioreactors." This research has also generated two patent disclosures "Feedback Control of Gas Supply for Ethanol Production via Syngas Fermentation" and "Fermentation Control Algorithm to Optimize Energy Conservation, Product Selectivity and Fermentation Rate in Conversion of CO and H_2 to Fuel and Chemicals." These findings provided valuable guidance towards designing large-scale bioreactors with increased alcohol productivity and syngas utilization.

Another project developed modular biomass thermal conversion systems (for heat and power) for the different agricultural industries in the region that generate enormous amounts of residues and wastes. Economic and systems analysis studies have shown numerous potential applications in several key industries in the regions, including cotton gins in Texas and animal farms in both Texas and Louisiana. In fact, numerous Texas cotton gins have the potential to generate as much as 3MW of electrical power from gasification of cotton gin trash. Outputs of this project included a provisional patent "Design and Operation of Mobile Slow and Fast Pyrolysis System for Various Biomass Feedstocks to Generate High Grade Bio-oil (Serial No. 61/302,001). This technology was licensed to SDL Citadel Global (Dallas, Texas) which has provided additional funding in order to prepare the technology for full-scale demonstrations and commercialization. In addition, two disclosures were made: "Production of Fuels and Chemicals from Ligno-Cellulosic

Biomass" and "Sustainable Thermal Conversion of Renewable Biomass Fuels Characterized as Having Ash with a Low Eutectic Points (Low Melting Temperatures)." Also, a patent "Biomass Gasifier System with Low Energy and Maintenance Requirements," No. 7,942,943 was issued for a gasifier that has a provision to hold tar-cracking catalyst internally within the gasifier and deliver syngas with very low tar concentrations. The results of this research will be used primarily for future commercialization initiatives concerning modular gasification technologies for both fixed bed and fluidized bed systems.

About half of the regional competitive projects and one-third of the internal projects funded through the Southeastern Center focused on investigating conversion technologies. Among the many conversion technologies explored, two projects are highlighted.

Little research has been done using fast pyrolysis bio-oil. A continuous catalytic ketonization was performed using an inexpensive catalyst synthesized from red mud that deoxygenates and removes organic acids from fast pyrolysis oil that were generated from Southern Pine. Researchers from the University of Georgia used the red mud, which was obtained from Rio Tinto, Alcan, Canada, in a packed bed reactor to treat fast pyrolysis oil mixed with methanol. Conversions of formic acid, acetic acid, hydroxymethylfurfural (HMF), and furfural in the bio-oil were 76, 45, 74, and 100%, respectively. Acetone and a series of C3-C9 methyl esters were produced from this continuous catalytic reaction. The total conversion was nearly 100% and yields were 22 mol% ketones (400˚C and mass to feed ratio of 6 h) from a mixture of acetic acid, formic acid, and acetol; and 15-20 mol% ketones (400-425˚C and mass to feed ratio of 1.4-4 h) utilizing water extracted from fast pyrolysis oil. The catalyst developed also reduced acidity and generated upgradable liquid fuel intermediates. A patent on "Production of Higher Quality Bio-oils by In-line Esterification of Pyrolysis Vapor" was issued (serial number 8,900,416) for this technology.

Scientists at The University of Tennessee's Center for Renewable Energy study novel catalysts to improve pyrolysis oil quality. *Photo courtesy of Jessica McCord, University of Tennessee.*

Lignin and lignin carbohydrate complexes such as the hemicellulose (i.e. xylan in hardwood) are two major barriers in the conversion of lignocellulosic feedstocks into biofuels. Acid pretreatment, which is costly, is usually done to remove xylan, while lignin is essentially not affected and remains a barrier for a complete hydrolysis process. A project was codesigned for both feedstock systems and enzymatic processes, allowing biological conversion alone to adequately complete wood saccharification and minimize use of exogenous enzymes. This project aimed to replace acid pretreatment for xylan removal during the ethanol production process by specific in situ xylan hydrolysis of the wood cell walls. Scientists from North Carolina State University genetically engineered endo-1, 4- -D-xylanase (xynA) and -xylosidase (xyD) from *Thermotoga maritima*, which is the most thermophilic xylan-degrading bacteria and more active at about 90°C, in poplar wood. Specifically, the goals of this research were to generate transgenic poplar trees overexpressing xynA and xyD and to test enzymatic hydrolysis in these transgenic woods. Through extensive genetic transformations of hybrid poplar NM6 (*Populus maximowiczii* x *nigra*) at a very high transformation rate of 25 to 40%, transgenic NM6 poplars c overexpressing xynA and xynA+xyD were successfully produced. Moreover, xynA and xynA+xyD were also successfully transformed into the low lignin NM6 plants that have approximately 50% lignin reduction. When using transgenic wood, auto-hydrolysis showed that xynA retained its xylan-degrading activity after the wood is in the dry condition for three months. Therefore, transgenic NM6 wood reduced lignin pretreatment by acid to hydrolyze xylan allows nearly complete hydrolysis of cellulose by cellulases. A more complete xylan hydrolysis and more efficient cellulose hydrolysis could be obtained with the combination of xylan auto-hydrolysis and lignin content reduction.

A major impediment to the use of forest biomass for biofuels and platform chemicals is the difficulty of separating the polysaccharides from lignin in wood. The problem is mostly due to ether bonds, likely to be nonglycosidic, between lignin and hemicelluloses. Western Center researchers employed synthetic model fluorogenic compounds to bioprospect for enzymes that can break the problematic bonds; these model compounds (chemical "probes") were designed to fluoresce when the bond is successfully broken. Enzymatically cleaving the carbohydrates from lignin instead of using current environmentally unfriendly, high-stringency chemical procedures enhances the efficiency of biofuel production from lignin-containing biomass. Three types of model compounds have been synthesized and are being investigated, each containing a mannose and a fluorogenic component (6MPN) that is linked to the mannose via a specific site and linkage: Probe I with -linked mannose, Probe II with -linked mannose, and Probe III with phenolic-linked mannose. Avenues toward higher yields were pursued, and initial bioprospecting has revealed some promising microbial cultures.

Reactive intermediates produced from cellulosic biomass, such as furfural, HMF, levulinic acid (LA), and formic acid (FA), can be catalytically converted into drop-in fuels that are compatible with existing petroleum infrastructure. However, most catalytic conversions of these compounds have been with pure compounds in water; experience in catalytic processing of reactive intermediates from actual biomass streams is limited and yields from cellulosic biomass are low by conventional aqueous processing. Western Center principal investigators evaluated processes that provide commercially attractive high yields of RIs derived from dehydration of cellulosic biomass. An assessment of lignocellulosic biomass availability in California was also being pursued. The team discovered that in acid-catalyzed dehydration experiments with maple wood, the presence of tetrahydrofuran (THF), an organic solvent miscible with water), as a solvent enhanced hydrolysis and conversion of glucan (from cellulose) and xylan (from hemicellulose), production of furfural and levulinic acid, and removal of lignin and insoluble residue. Recent work suggests that $FeCl_3$ is a promising solid acid catalyst for this process, and a patent application for its use is in progress.

During the pyrolysis of lignocellulosic materials, a sizable fraction of the biomass (8–15 mass %) is converted into C1-C4 oxygenated organic compounds with little economic value. Production of these small molecules is a serious environmental problem that limits the deployment of pyrolysis units. However, if the C1-C4 molecules could be converted into methane or lipids as a Western Center team proposed, consumption of fossil methane in a rural bio-oil refinery could potentially be reduced or eliminated and the profitability of torrefaction units increased. Biomethane could be used to produce the hydrogen needed for bio-oil hydrotreatment (81 kg for one ton of bio-oil) or directly commercialized as a fuel in Otto or biofuel diesel engines. Lipids produced could be converted into transportation fuels either by transesterification or by hydrotreatment. In a related effort, this team has also made progress in the development of genetically modified microorganisms able to ferment the sugar levoglucosan to lipids.

Education and Outreach

National Conferences

Frontiers in Biorefining International Conference

National and international bioenergy and advanced biofuels research is being monitored closely with the expectation that it will ultimately be used to develop a new industry. As research programs throughout the world continue to build state-of-the-art technologies, scientific conferences to facilitate networking, exchange ideas, and further collaboration between scientists and research institutions are timely. To contribute to this need, the Southeastern Sun Grant Center organized and co-hosted the scientific conference entitled "Frontiers in Biorefining: Chemicals and Materials from Renewable Carbon." This meeting was unique in that it assembled scientists from around the world to share recent progress, explore information needs, and present ideas that advance the integrated biorefinery concept. An opening plenary session highlighted key developments in engineered feedstock, pretreatment chemistry and platform chemicals by invited scientists. The technical program emphasized pathways to valuable chemicals and materials from biomass through presentations by selected speakers.

The first five Frontiers In Biorefining (FIB) conferences, held in 2010, 2012, 2014, 2016, and 2018, attracted an international cohort of highly influential researchers and established FIB as an attractive science venue. In total, 70 to 90 scientists attended each meeting and the agenda consisted of one plenary and six parallel sessions over a three-day period. The conference has grown with each installment, garnering consistently favorable reviews from participants. In 2020, (the highly anticipated 10-year anniversary) this conference will continue to provide a venue for scientists and students to share advances in knowledge which impact the future of the bioeconomy. Abstracts and presentations from this conference have been archived at www.frontiersinbiorefining.org.

2012 Sun Grant National Conference—Science for Biomass Feedstock Production and Utilization

The 2012 Sun Grant National Conference was held Oct. 2-5, in New Orleans, Louisiana. Advances in the state of technology of supply chain operations were highlighted throughout the conference. The SGI, with sponsorship from DOE-BETO, assembled a program to promote collaboration between academic, industry, and government partners. The conference structure allowed developments in crop production, conversion technologies, sustainability considerations, preprocessing, logistics, and policy to be presented from

A public tour of a wetland area at the EcoSun Prairie Farm. *Photo courtesy of Craig Novotny.*

different perspectives. More than 120 presentations on a wide array of topics were provided in both parallel and poster sessions. A special issue published in *BioEnergy Research* (Vol. 7, Issue 3) highlighted 12 presentations from the conference. Conference proceedings can be found in the online archive at **https://ag.tennessee.edu/sungrant/2012nationalconf/Pages/default.aspx**.

Web Pages

The Sun Grant BioWeb (**bioweb.sungrant.org/**) is an online resource that serves as a comprehensive reference for biomass and bioenergy information. The BioWeb has drawn from some of the country's top biomass authorities to provide a comprehensive analysis of the current state of biomass and alternative paths for biomass development and to quantify impacts associated with biomass industry development where possible. Content of the BioWeb is outlined along four major areas: feedstocks, biofuels, biopower, and bioproducts. In each area, research coordinators have assembled teams of research expertise. The coordinators facilitate and organize the contributions of the invited expert advisers (in various capacities) representing the spectrum of expertise in the biomass arena. A team of technical writers works with the research coordinators and expert contributors and advisors to prepare and publish the online monograph. Each of the four major areas of the outline includes a general overview, a technological assessment, an economic and market assessment, and a policy assessment. Content sections are delivered in one of three versions, each successively providing more detail than the previous. One version provides an overview or abstract look at content. This is a short, condensed summary. The second version, tailored for general public audiences, has more detail than the overview, but does not include detailed scientific procedures, data, and information. The third and most detailed version is termed the "academic" version. This level has the entirety of the content, with every detail included, and is aimed at academic and professional audiences. The BioWeb has been developed and maintained with lead support from the University of Tennessee.

Regional Impacts

Southeast Region

The Regional Story

The Southeastern Regional Sun Grant Center, housed within the University of Tennessee Institute of Agriculture (UTIA) in Knoxville, Tennessee, is the administrative unit for the region composed of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, Puerto Rico, and U.S. Virgin Islands.

An important outcome of the 2006 Regional Feedstock Partnership Workshop for the Southeast Region was the recommendation to emphasize the development of a dedicated biomass supply chain, improving the technology that goes into lignocellulosic fuel production, and the development of a road map to commercialization.

In 2010, the USDA Biofuels Strategic Production report stated that 50% of the next generation of biofuels would come from the Southeast. Ultimately, this translated to an opportunity by providing potential economic activity in rural areas of the South. With more than 30 million acres of plantation pine and approximately 83.4 million acres of cropland and pasture, the Southeast can produce a variety of biomass feedstocks including herbaceous crops such as switchgrass, dedicated woody crops, and forest residues. These are just some of the characteristics that directed the regional structure of the program. Another unique element for the region lies in the inherent productivity of the agricultural lands, aided by a generally temperate climate and long growing season. Additionally, the region holds rich potential to produce crops for biobased markets and products.

Accomplishments

At the Southeastern Center, significant investment was directed toward building a commercialization pathway for biofuels and for growing the bioeconomy. Economic development and environmental sustainability are the twin pillars of the Southeastern Center's efforts. With research that covers sustainability and economic development, the Southeaster Center and its partners in the regional competitive grants program lead the Southeast in biofuels development.

The UT Biofuels Initiative

In 2007, the state of Tennessee invested nearly $71 million toward a comprehensive and integrated research, development and demonstration program to create a biofuels industry. Building on a foundation created by SGI funding, the University of Tennessee Biofuels Initiative (UTBI) was created as a farm-to-fuel demonstration. UTBI was designed to demonstrate the entire integrated value chain for cellulosic biofuels from local energy crops and to advance and facilitate the development of a commercial biomass energy industry in Tennessee. The approach remains unique, and the program has positioned Tennessee as a recognized national leader in fuels and chemicals produced from lignocellulosic biomass.

The biomass innovation Park (Vonore, Tenn.) is the site of logistics research on preprocessing of herbaceous crops.

Decision Tool Framework

The Southeastern Center and its regional partners have developed new tools that give state agencies and private companies the power to consider supply chain logistics when they establish process facilities. One of the center's most successful projects, the Biomass Site Assessment Tool (www.biosat.net), provides a web-based economic decision making tool for agricultural and forestry biomass. The center leveraged support for BioSAT from the U.S. Forest Service and Oak Ridge National Laboratory, among others. The Biofuels Facility Location Analysis Modeling Endeavor (BIOFLAME), another highly successful resource, is a comprehensive geographic information systems modeling system that assesses potential feedstock and identifies ideal locations for biorefineries and preprocessing facilities.

Co-Products

The Southeastern Center supports research in the region that focuses on lignin as a low-cost precursor for carbon fiber manufacturing. Researchers at North Carolina State University and UTIA are analyzing manufacturing scenarios and approaches to provide new insights about lignin development. This technology may lead to low-cost carbon fiber that can create lighter, stronger materials and, ultimately, lighter vehicles. Lightweight materials require less fuel for transport and reduce maintenance needed for infrastructure. Additional efforts are being made within the region to develop new industrial biobased products from alternative materials.

South Central Region

The Regional Story

Located on the campus of Oklahoma State University in Stillwater, the South Central Sun Grant Center is the administrative unit for the region composed of Arkansas, Colorado, Kansas, Louisiana, Missouri, New Mexico, Oklahoma and Texas.

As an outcome of the 2007 Regional Feedstock Partnership Workshop for the South Central Region, the center focused on feedstock development and production; enhancing existing and developing new conversion technologies for production of biofuel, bioenergy, and bioproducts; development of energy efficient and cost-effective logistics systems; and economic systems analyses and modeling to quantify the environmental and economic impact of land conversion when biorefineries are established.

Accomplishments

Eighty-three projects, 57 DOT and 26 USDA, were funded through the region. Among funded projects, a large portion of funds were awarded to research areas that focused on feedstock development and production as well as those that investigated conversion technologies for the transformation of lignocellulosic feedstocks into bioenergy and bioproducts. Other funded projects focused on logistics, economics, product evaluation and testing, and education and outreach. The following are a selection of the many outcomes that resulted from the funded projects conducted by the region's institutions: startup jobs created (13); intellectual property such as disclosures (19), patent applications (12); provisional patents (7); patents issued (4), and license agreements (7); degrees conferred (69 M.S. and 45 Ph.D.); peer-reviewed publications (195); professional presentations (489); abstracts (275); and extension/outreach publications and web pages (55).

Feedstock Development

To maintain an active feedstock development program to provide improved feedstock varieties for biomass production, work was conducted at Oklahoma State University in collaboration with University of Arkansas, Texas A&M University, and Kansas State University to develop switchgrass cultivars with higher biomass production potential than the standard commercial cultivars for the region. Genetically improving the switchgrass biomass yield potential is among the most effective means to enhance its commercial value. A new switchgrass cultivar, "Cimarron," was released by Oklahoma Agricultural Experiment Station in 2008.

"Cimarron" produced about 10% more biomass than the best commercial variety "Alamo" and 25% more than "Kanlow." "Cimmaron" switchgrass was licensed to Johnston Seed Company at Enid, Oklahoma, for seed production and commercialization. Nineteen new experimental cultivars were bred and developed in the project that will provide new germplasm for farmers and researchers in the testing states (Oklahoma, Kansas, Arkansas and Texas) to select the best cultivar(s) for their biomass production based on biomass yield and adaptation information.

Another project conducted at Texas A&M University developed a novel approach to increase biomass yield through overexpression of the prohibitin gene, PHB8, which can improve plant size, biomass accumulation, and seed yield. A disclosure, U.S. patent application (Yuan, J. "Prohibitin genes to improve plant biomass and seed yield"), and a license to Benson Hills Biosystems for engineering crops and bioenergy feedstock to improve seed and biomass yield resulted from this project.

Logistics and Economics Systems Analysis and Modeling

There is a critical need for a widely accessible, cradle-to-grave software that can integrate and utilize information from multiple distributed databases, and make use of existing agricultural models. Oklahoma State University together with USDA-ARS, Maryland, and OK Small Business Development Center developed a Software as a Service (SaaS) platform using OSU's Geospatial Logistics and Agricultural Decision Integration System (GLADIS), which can generate economic decision information based on user inputs from

Four switchgrass cultivars including the new cultivar "Cimarron." *Photo courtesy of Yanqi Wu, Oklahoma State University.*

Switchgrass harvest. *Photo courtesy of Oklahoma State University.*

multiple databases and agricultural models. The team compiled information, economics models, and supply chain relationships needed for robust evaluation of a switchgrass bioenergy industry. Using this information, the team developed an integrated modeling framework for holistic data analysis based on stakeholder input that links current feedstock growth, financial, sustainability, and environmental models in a publicly-available online software program. The modeling framework provides opportunities for stakeholders to either use these models or modify these models to fit their needs. SaaS will help stakeholders estimate costs and profits, identify potential risks, and better understand how to optimize their specific supply chain system.

Conversion Technologies

During gasification, biomass is converted into producer gas or syngas, which consists of carbon monoxide (CO), hydrogen (H_2), and carbon dioxide (CO_2). Syngas can be fermented to liquid fuels and chemicals using microorganisms such as acetogenic bacteria (acetogens). Commercial biological gas conversion processes require stable operation, high substrate conversion, product specificity, and productivity. The main issues in this emerging gasification-fermentation technology are stabilizing the fermentation process, low microbial cell density, and gas-liquid mass transfer limitations. Consequently, a research team, led by H. Atiyeh, from Oklahoma State University and Brigham Young University developed and obtained a U.S. patent (10,053,711) on a novel method to sustain culture activity, gas uptake, and improve selectivity for ethanol production during syngas fermentation in the continuous stirred tank reactor. The newly patented method resulted in the production of twenty-six times the ethanol concentration compared to the conventional method. Atiyeh's team also obtained a U.S. patent (10,017,789) on a novel control method to optimize gas supply to maintain constant pH for a stable continuous fermentation required for commercial production of alcohols. Over 95% of the CO and H_2 were converted into alcohol by the acetogen during continuous syngas fermentation. Ethanol production more than doubled using the patented control method compared to the conventional process.

A mobile pyrolysis unit developed at Texas A&M University. *Photo courtesy of Sergio Capareda, Texas A&M University.*

North Central Region

The Regional Story

The North Central Regional Sun Grant Center office is located at South Dakota State University in Brookings and is the administrative unit for the region composed of Iowa, Illinois, Indiana, Minnesota, Montana, North Dakota, Nebraska, South Dakota, Wisconsin, and Wyoming.

The region encompasses an area with highly productive soils; much of the Corn Belt lies within this region. In 2013 alone, 61 million acres (roughly 70% of the total) of corn were harvested in the region. In areas with sufficient corn yield, this represents a significant source of lignocellulosic biomass for biorefineries. In fact, one of the first commercial-scale cellulosic ethanol refineries (Project LIBERTY by POET-DSM) opened in Emmetsburg, Iowa, in 2014 and uses sustainably harvested corn residue as the feedstock source. Other potential feedstocks grown in the region include annuals (e.g., winter wheat, spring wheat, soybean, sorghum), herbaceous perennials (e.g., switchgrass, big bluestem, prairie cordgrass, other warm- and cool-season grasses), and woody species. Other research efforts in the region include feedstock conversion (both biochemical and thermochemical), economics, and sustainability.

Accomplishments

The center awarded funds for both external and internal research projects evaluating the logistics and sustainability of biomass feedstock production, biofuel and bioproduct development, biofuels conversion processes, bioenergy system analysis, economics, marketing and policy, environmental impacts of biomass systems, and biomass logistics (harvesting, handling, transportation, storage, and densification). Collectively, these projects have had tremendous impact on the bioeconomy; but a few key projects and their accomplishments are highlighted.

Collecting corn stover bales using an intelligent bale-staging system evaluated by researchers at Iowa State University. *Photo courtesy of Matthew Darr, Iowa State University.*

EcoSun Prairie Farm

In 2008, EcoSun Prairie Farms, a nonprofit corporation, began establishing monocultures and mixtures of native perennial species in eastern South Dakota on farmland previously used to grow commercial grain crops. The goal was to demonstrate the viability and environmental sustainability of these types of systems for land-owners throughout the region. Diverse income streams were developed, including the use of lignocellulose for bioenergy. This seven-year experiment generated considerable quantitative data on: 1) production, management, and marketing of biomass feedstock for a nascent cellulosic bioenergy industry; 2) ecosystem services provided by this type of management system including wildlife habitat, soil and water quality, and soil erosion; and 3) economic viability. Researchers at the EcoSun Prairie Farm have documented and disseminated their findings in numerous scientific and lay venues and developed important standards by which some measures of eco-system services can be valued. A final report can be found at **www.ecosunprairiefarms.org/pubs/07-5001-2015.pdf**.

Hay produced from native plant mixtures at the EcoSun Prairie Farm. *Photo courtesy of Craig Novotny.*

Corn Stover Densification and Storage

Densification of biomass early in the supply chain is a key component in developing a pathway for corn stover to become a viable commodity in the bioeconomy of the 21st century. This research, conducted by Matt Darr and colleagues at Iowa State University, addressed novel in-field densification methods and investigated the impact of densification on field logistics and long-term storage quality as key components of an integrated corn stover supply system. Researchers demonstrated single-pass harvesting technologies that reduced soil contamination during harvesting by 300%, and they were able to quantify a 20% improvement in bale collection efficiency when using an intelligent bale-staging system. The work allowed researchers to develop new guidelines for nutrient replacement recommendations associated with harvesting corn stover. Further work demonstrated that storage methods have no impact on biofuel conversion quality of torrefied corn stover. It also showed dry matter loss to be the most influential economic driver to storage methods. The reason this research was crucial is that it can save energy companies the time, trouble, and expense of doing those front-end studies for themselves. Ultimately, this research helped the conversion industry eliminate some of the risk and learn some key elements associated with storage and feedstock quality; and it also helped a sector of the machinery industry that is beginning to pay more attention to corn stover as a potential energy crop.

Prairie AquaTech

A project on feedstock densification at SDSU created the opportunity for researchers to discover a way to treat soybean meal and dried distillers grains from corn ethanol plants to make a protein-rich fish feed that can fully replace fishmeal in aquaculture diets. This work led to a patented process and a Brookings-based startup company to commercialize the technology— Prairie AquaTech (**www.prairieaquatech.com/**). Prairie AquaTech has grown to 30

Prairie AquaTech's process of converting plant-based meal to high value animal feed products. *Photo courtesy of Prairie AquaTech.*

employees since inception and is currently finishing construction of a 300,000 square foot, $60 million commercial facility with plans to hire 35 additional employees once the plant is operational. Prairie AquaTech has the capability to help solve the global problem of high-quality animal feed ingredients, help secure the world's food supply, and provide a solution to America's problem of the largest natural resource trade deficit by starting more aquaculture farms with a locally available feed ingredient.

Northeast Region

The Regional Story

In the beginning years of the SGI, the Northeast Regional Sun Grant Center was housed at Cornell University. The center was relocated to Penn State in 2014. The region includes Connecticut, Delaware, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and West Virginia, as well as the District of Columbia.

The region's residents comprise 30% of the total U.S. population. Once a significant farming region, the face of agriculture in the Northeast has changed dramatically over the last decades. Farmland is being rapidly converted to other uses, such as housing and commercial developments. Traditional natural resource and manufacturing jobs have been in decline for decades. In the Northeast, over 90% of rural counties have fewer residents today than in 2000, with a striking loss of residents in their prime workforce years. The regional center has a major goal of stemming the loss of jobs from rural communities through participation in the bioeconomy.

The Northeast Sun Grant Center has been investing in innovation to support the regional bioeconomy. During that period a collaborative process has developed and adapted to regional priorities, starting with a 2007 Northeast Regional Feedstock Partnership Workshop that developed a Regional Roadmap of research and education priorities, which was updated in 2011 and 2018:

- Biomass Feedstocks: Feedstock development, sustainable production, land-use optimization and issues, equipment technologies for sustainable biomass harvest. Regional feedstock priorities include solid wastes and forest and agricultural residuals.
- Conversion Technologies: Integrating thermochemical and biochemical systems, bioproducts production in bioenergy conversion systems, and integrated processes research.
- Environmental Impacts and Opportunities: System-wide environmental impacts analysis, Northeast Region land use and water resource inventory. Ecosystem services, including water quality, biodiversity, soil health, and both terrestrial and geologic carbon sequestration.
- New Product Opportunities, including advanced biofuels, biochemicals, and biomaterials, as well as strategies to monetize the ecosystem services described above.
- Transportation and Distribution: Transportation infrastructure impacts, densification and transportation mode analysis, biomass transportation, and storage logistics.
- Social Factors: Economic impacts, social factors and policy analysis, and market analysis.
- Education, Extension, and Economic Development Outreach: Workforce development, teacher summer sabbaticals and classroom tools, opportunities for undergraduate projects, demonstration to students, farmers, and local planning experts, development of outreach tools to assist rural development business planning, collaborative efforts with other universities focused on transportation research.

Accomplishments

Biomass Feedstocks:

Enhancing the plant-soil-microbe ecosystem to advance sustainable switchgrass production.

Work at Rutgers University led by Stacy Bonos investigated the beneficial effects of switchgrass-associated microbes to estimate the potential benefit of microbes to the establishment of new switchgrass fields for biofuel production. Initial screening of fungal and bacterial isolates in Petri dishes, then further screening in Magenta jars of soil and field sites, discriminated environments in which microbes can increase switchgrass production. A New Jersey Pine Barrens (NJPB) switchgrass seed-derived *Pseudomonas* isolate, and the NJPB switchgrass root-derived fungus *Acidomelania panicicola* were introduced at seeding to two New Jersey locations—"Adelphia" with high-quality agricultural soil and "Chatsworth" with poor-quality, sandy NJPB soil. Benefits at the Adelphia site were limited. However, at the Chatsworth site, first-year establishment in the upland variety Carthage was significantly higher with the combination treatment of both the bacteria and the fungus, and in the lowland variety "Kanlow" it was improved in the presence of both the fungus alone and the combination treatment. Some of these benefits continued into the second year, with Kanlow taller at midsummer in both of these treatments as well. The team expects second-year biomass to reflect these trends. Because sustainability for switchgrass as a biofuel also must reflect its economic viability, attitudes toward the use of microbial biofertilizers on switchgrass were surveyed among 1,200 energy consumers in the Northeast. Although only 19.5% of consumers were aware of switchgrass as a biofuel, the survey found a high prevalence of willingness to pay for renewable energy (67.4%) and, if buying energy based on switchgrass, 92.1% would be willing to pay for it to be produced with reduced chemical inputs.

Biomass Feedstocks:

Optimizing nutrient uptake in shrub willow and switchgrass to provide multiple ecosystem services.

Managing the nutritional needs of perennial biomass crops such as switchgrass and shrub willow on marginal agricultural land has been an ongoing challenge, due mainly to the multitude of causes of marginality and the relatively recent development of these crops. Research led by Larry Smart at Cornell University provides valuable data for estimating the yield response of commercial cultivars grown on marginal land in relation to soil moisture gradients. The work adds important insights to a very small body of literature describing within-plant nitrogen (N) cycling for shrub willow. The team also demonstrated the reliability of a genetic marker closely associated with foliar N content. This information could be key for directing breeding efforts toward luxury N uptake in the context of designing more efficient riparian buffers. This project demonstrated that switchgrass can have significantly lower nutrient runoff compared to conventional corn production, even when switchgrass receives fertilizer.

Willow coppice regrowth. *Photo courtesy of Timothy Volk, State University of New York.*

Conversion Technologies:

Optimizing torrefied biomass in the regional supply chain.

Torrefaction, the mild thermochemical treatment of biomass, holds great promise as a value-added step to the bioenergy supply chain in the northeast United States. It can reduce overall costs and risks to the system. Daniel Ciolkosz at Penn State led a project addressing that opportunity by studying the bioenergy supply chain and developing optimized supply chain configurations and scales for utilizing torrefied biomass.

Results of this project include a staged model of supply chain operations that examines the impacts of system design, competing end uses, and other operational factors. A literature review was conducted of torrefied biomass supply chain issues, and a book chapter was written on the role of torrefied biomass in the circular economy. A short course was held that focused on torrefied biomass and biochar.

This project led to $248,839 in subsequent funding from USDA Forest Service (Wood-to-Biochar Business Opportunity Development) and $24,465 from Penn State Regional Extension Impact Grant (Using Biochar to Enhance Regional Water Quality).

Environmental Impacts and Opportunities:

Deployment of bio-energy carbon capture and sequestration technologies: Case study of the Northeast and Mid-Atlantic.

Gal Hochman and colleagues at Rutgers University found that although storing emissions offshore increases the lowest total costs of carbon capture and storage (CCS) to over $60 per ton CO_2, offshore storage may be preferred or necessary because: 1) the "world class" nature of geological carbon storage reservoirs located offshore of the northeastern U.S. minimizes geological risks; 2) the influence of politically and culturally based aversions to industrial activity is reduced away from the onshore population centers; and/or 3) it represents a cost-efficient option to store CO_2 emissions if onshore formation pressures are prohibitive at large-scale deployment of CCS. Up to 8 Gt of total CO_2 emissions from this region can be stored for less than $60 per ton CO_2.

The work also showed that the introduction of intermittency results in a non-constant elasticity of substitution between renewable and fossil energy, thus suggesting efficacy and welfare effects of carbon taxes and renewable subsidies vary geographically. Subsidizing research into battery technology can mitigate this distributional side effect.

Building on the above analysis, a Computable Regional general Equilibrium Bioenergy (CREB) model was developed and used to conclude that the opportunity for CCS and bioenergy carbon capture and storage (BECCS) could come in the form of power plants that are facing pressure to refuel or repower with more environmentally sound technology.

Hochman's team was awarded subsequent funding from the U.S. Department of Energy for the projects "Mid-Atlantic U.S. Offshore Carbon Storage Resource Assessment" (DOE Award Number DE-FE0026087; $90,000) and "Midwest Regional Carbon Sequestration Partnership Program" (DOE Award Numbers DE-FC26-0NT 42589; $486,037).

New Product Opportunities:

Biobased lubricants and fuels: Integration of chemical catalysis with mixed culture fermentation.

University of Maine scientists Thomas Schwartz and Peter van Walsum used mixed culture fermentation to convert lime-pretreated hardwood to a mixture of organic acids that are suitable for downstream upgrading. The presence of either ethanol or lactic acid increases the production of the acids and increases their carbon content (i.e., their carbon chain length). These acids can be removed from the fermentation media by extraction with oleyl alcohol, which will also allow for increased productivity because the acids themselves inhibit the fermentation process above a certain concentration. These acids are then coupled with ethanol to convert them to volatile esters, which can subsequently be reacted over a catalyst that further increases the carbon chain length and decreases their oxygen content. This is the first time that mixed culture fermentation has been combined with a catalytic process to increase the carbon content of the fermentation products. This work demonstrates the concept that a low-complexity bioprocess that outputs a mixture of products (i.e., mixed-culture fermentation) can be combined with a highly specific catalytic process to yield fuel- and lubricant-range products.

Education, Extension, and Economic Development Outreach:

Development of biofuel feedstock information for eXtension

Agricultural producers, communities, educators, service providers, industry, and other stakeholders need credible information about energy production and use to make sustainable choices. A multi-university project made available objective, research-based information in order to understand viable and profitable methods and technologies on which to base energy decisions. Bridging expertise in the Sun Grant community with the educational capacity of the eXtension Farm Energy Community of Practice (CoP), this project capitalized on the popularity of the internet, and facilitated the delivery of resources on many agricultural energy topics. These materials were developed by a cadre of specialists, using a variety of resource types to suit different learning styles.

Information produced through SGI projects is now available through **eXtension.org**, some of it directly published on the site, and some of it through an index: Bioenergy Resources from the Sun Grant Initiative. The "train the trainer" Bioenergy Curriculum incorporates knowledge from Sun Grant researchers. We appreciate that the quality, credibility, and depth of the eXtension Farm Energy website has been enhanced by incorporating research-based information and resources from the SGI.

Western Region

The Regional Story

The Western Regional Sun Grant Center, housed at Oregon State University in Corvallis, Oregon, is the administrative unit for the region composed of Alaska, Arizona, California, Hawaii, Idaho, Nevada, Oregon, Utah, Washington, and Pacific Territories. A sub-center is housed at the University of Hawaii, Manoa.

Sun Grant-funded researchers in the Western Region have made continued progress toward a sustainable biobased economy. Western Region research falls into three priority program areas: feedstock enhancement and development, biomass conversion and biofuel/bioenergy processing, and bioproducts. Within these three areas, research projects address three critical overarching themes: sustainability, decentralization, and transferability.

Accomplishments

Feedstock Enhancement Projects

Sun Grant-funded research has resulted in important advances in our understanding of regional crops that could be used as feedstocks, including poplar, algae, camelina, perennial tropical oilseed trees and shrubs, and sweet sorghum. Recently completed projects in this research area include a study that assessed production and transportation practices for sweet sorghum and another that investigated lesquerella as a low-water-use biofuel crop. A current project is studying Russian dandelion as a source of natural rubber and ethanol. Algae research has shown considerable promise for sustainable fuels and chemical production and algal biomass has substantial promise as a potting medium to replace peat. Giant reed and Western juniper have been evaluated as potential feedstocks to produce electricity in existing coal-fired power plants. Yield, suitability, spatial distribution maps, and production potential for most purposely grown biofuel crops and crop residues have been completed for all 50 U.S. states.

Camelina

Camelina, a member of the mustard family, shows promise as a Pacific Northwest feedstock. A multistate team, including Oregon State University's Russell Karow, grew this ancient oilseed in four unique regional settings, and determined that it could become a rotation crop in biofuel production. The trials have led to renewed regional interest in growing camelina and several other oilseed crops, including canola and Ethiopian mustard. As a low-input crop that can be grown on marginal land, camelina has potential as a rotation crop with wheat, thus preserving soil that would otherwise erode from fallow fields. However, it is sensitive to residual herbicides in the soil. Scot Hulbert of Washington State University has identified and characterized camelina mutants with increased resistance to commonly-used herbicides. With seeds of

Camelina growing in mid-summer in South Dakota. *Photo courtesy of Thandiwe Nleya, South Dakota State University.*

these plants now available to camelina breeding programs, the research team continues to move this newfound resistance into camelina lines. Seed from the highest-yielding, resistant lines will be collected for advancement and release. These enhanced varieties will encourage adoption of the crop, particularly in intermediate rainfall areas of the Pacific Northwest, by making it less risky for growers to fit the oilseed into crop rotations.

Hybrid Poplar

Hybrid poplar, a fast-growing tree, is a well-known biomass feedstock. Requiring infrequent tillage and only a small amount of fertilizer, poplars can also be irrigated with wastewater to enhance soil carbon storage and removal of excess nutrients. Jeff Kallestad and Mark Swanson of Washington State University-Puyallup, have coupled poplar production research with its end-use conversion into ethanol: a holistic approach that addresses issues of produtivity, quality and economic value. Along the way, the team has identified productive cultivars, investigated optimum planting density, determined desirable chemical characteristics in feedstock, and assessed the economic feasibility of scaling up production to a commercially-viable level. The Western Region worked closely with ZeaChem using their proprietary microbes at their pilot plant in Boardman, Oregon, to demonstrate the potential of hybrid poplar as a feedstock for the production of lignocellulosic ethanol and a number of valuable platform chemicals.

ZeaChem pilot plant near Boardman, Ore. *Photo courtesy of John Talbott, Oregon State University.*

Algae

Algae research has the potential to solve two issues for the price of one: meet growing biofuel needs while also sequestering carbon. John Cushman of the University of Nevada-Reno explored how to increase the use of salt-loving microalgae as a biofuel crop. Nonseasonal and renewable algae have a higher annual oil yield than some terrestrial crops, and can be grown on marginal lands with otherwise unusable salt or brackish water — welcome news to the arid southwestern U.S.

Scientists have classified algal strains with the highest oil potential and characterized their genetic profiles with a view toward increasing lipid quality and quantity. Algae with high lipid content are valuable as feedstocks for biodiesel, while strains with high starch are promising for bioethanol. These photosynthetic organisms can also serve as a part of treatment systems to remove nutrient loads from wastewater, reducing treatment costs while still producing biofuels.

Evaluation of algae strains at Oregon State University. *Photo courtesy of Ganti Murthy, Oregon State University.*

Dairy effluent is a natural fertilizer and soil conditioner and, if managed effectively, can enhance pasture growth and improve soil structure. On dairy farms, effluent is liquid waste made up of manure and urine from milking sheds and yards. It contains nutrients, salts, and organic matter. Oregon State's Shannon Andrews has aimed to use algae to treat dairy effluent and employ the residual biomass as a potting medium for nurseries. Andrews showed that selling algal meal as an organic fertilizer would return more revenue to dairy producers than reuse as a biomass feedstock, which could promote sustainable manure management. The research promotes economic diversification by increasing the number of saleable products from dairy operations, thus reducing risks associated with volatile milk prices. The adoption of algae biomass as a substitute for peat would have significant global impacts to preserve tropical and temperate forest systems and to sequester carbon.

Biomass Conversion Projects

Sun Grant researchers have pursued improved and novel processes for pretreating lignocellulosic biomass and converting it into hydrogen and ethanol, as well as production of reactive intermediates for conversion to drop-in fuels, bio-oils, and resins through pyrolysis, and methane and lipids from compounds produced during pyrolysis and torrefaction. Thirty-one different feedstocks have been evaluated for their suitability as a feedstock for torrefaction and pyrolysis. In a recent project, a team bioprospected for enzymes that can break lignin-hemicellulose bonds in wood biomass. Currently researchers are studying use of tropical feedstocks in an anaerobic digestion biorefinery, producing aviation fuel hydrocarbons and phenolic compounds from lignin, and converting dairy manure to fuel and chemicals.

Pyrolysis, or oxygen-free heating, can produce crude bio-oil using residue feedstocks. Placing pyrolysis machines near forest residues provides a model for biofuel production in the Pacific Northwest, especially in rural areas. Economic value would be enhanced, and forest residues better utilized, if rural refineries produced marketable materials from unusable bio-oil products. Pyrolysis facilities can produce stabilized bio-oil for refineries of transportation fuels and chemicals.

Karl Englund of Washington State University has developed such a value-added refinery product — an environmentally safe, sustainably produced, reliable, and formaldehyde-free resin system obtained from pyrolyzed bio-oils. A collaborating research team, headed by Washington State's Manuel Garcia-Perez, has also investigated the optimization of pyrolysis-based processes for forest residues. When pyrolysis converts lignocellulosic material into bio-oil, leftover organic compounds currently have little economic value. Researchers seek to use these molecules to generate both methane needed for refining of bio-oil and lipids for fuels.

Processing beyond pyrolysis can produce transportation fuels and high-value chemicals. Garcia-Perez has documented pyrolysis conditions that increase the sugar yield in bio-oils obtained from forest residue and his research team has proven that these sugars can be fully converted into valuable ethanol and lipids. Also, for the first time, they demonstrated the direct conversion of the sugar levoglucosan into lipids, a process that may reduce production costs.

Bioproducts Development Projects

Bioproducts

Sun Grant-funded research has furthered developments in biomass conversion processes and systems analyses that yield bioproducts with positive market and economic impacts. For example, a past study investigated the use of waste streams and mixed microbial consortia to produce biodegradable polyesters as replacements for fossil fuel-based thermoplastics. A current project is addressing use of mobile pyrolysis units to convert invasive pinyon-juniper to fuel and chemicals. Hybrid poplar has been investigated as a potential source of biopolymers through genetic manipulation and enhancement.

The overarching goal of the Juniper Biomass Optimization Project (JuBop) is to determine if an integrated strategy for juniper utilization can overcome the barriers to profitably combine sagebrush steppe restoration with production of juniper bioproducts. JuBop researchers investigated whether biochar production from low-value residuals could enhance such a strategy and further promote sagebrush steppe restoration. The JuBop research project is primarily based on data collected in Wheeler County, Oregon, on land within the North Slope Ochoco Holistic Restoration Project, which is managed by the Wheeler County Soil Water Conservation District.

Sustainability

Conversion of cellulosic feedstocks into liquid biofuels is critically dependent on the processing technology. Choice of pretreatment technology, while dependent on feedstock, is also a function of energy use, capital costs, downstream processing, and possible environmental impact. The center addressed these issues in a comprehensive and objective manner through development of engineering and economic models. Specifically, this research has focused on conversion of grass straws to cellulosic ethanol. The researchers completed a comprehensive compositional analysis of grass and wheat straws, followed by a life cycle analysis to identify the key areas in the fuel production cycle where environmental impact can be reduced.

Straw remaining after grass seed harvest is a promising source of low-cost, abundant nonfood material for conversion into bioethanol. As an agricultural residue, it can be used without significant changes in land use. Using experimental data, engineering, and economic models, Ganti Murthy of Oregon State University assessed the environmental, economic, and energy benefits of using grass straw as a feedstock for biofuels production in the Pacific Northwest, where grass seed production is concentrated. A "well to pump" analysis — including biomass and ethanol production, transportation and distribution — showed a 57% to 113% reduction in fossil energy use compared to gasoline. The grass seed-to-ethanol production process is key to the potential reduction in fossil fuel use and greenhouse gas emissions.

Decentralization

The center has evaluated the potential of decentralized systems to provide biopower and to produce biofuels. This research has involved evaluation of small-scale conversion of camelina to biodiesel, production of heat, power, and biochar via HTC, and the use of cereal and grass straws as a feedstock for cellulosic ethanol production. This research involved economic and logistics analysis as well as a comprehensive life cycle analysis for all applications.

The Path Forward

There are many regional distinctions driving opportunities for the bioeconomy; however, there is a common theme between each center: the need to bring a regional focus to the national priority of reduced dependence on petroleum. Much progress has been made by individuals and teams who have been selected in SGI regional competitions, but much remains to be done to improve the technical and scientific feasibility of growing the feedstock, getting it to the processing facility, preparing it for conversion, and finally converting to the desired products. In addition to the technical feasibility, projects selected in the future must continue to demonstrate the economic, social, and environmental sustainability of the processes proposed and evaluated.

The SGI will continue to collaborate with and leverage important work being done by the federal agencies, national laboratories, other universities, and the private sector to continue the development of a robust bioeconomy. Advisory councils for each regional center include individuals from each of these and other stakeholder groups to help direct the best path forward. It is well understood by the SGI that bioenergy research has to be organized in a way that takes a comprehensive and systems approach across the bioenergy value chain, and we are committed to meeting the challenge.

Giant miscanthus and switchgrass trial in Illinois. *Photo courtesy of Thomas Voight, University of Illinois.*

Appendices

References

Daly, C., M.D. Halblieb, D.B. Hannayway, and L.M. Eaton. 2018. Environmental limitation mapping of potential biomass resources across the conterminous United States. GCB Bioenergy 10:717-734, doi: 10.1111/gcbb.12496.

English, B.C., K. Jensen, J. Menard, J. McCord, and T. Rials. 2016. Analysis of economic impacts from Sun Grant Initiative program funded projects. 2016 Conference Proceedings, Mid Continent Regional Science Association, IMPLAN Group, LLC., 9-11 June 2016, Charlotte, NC.

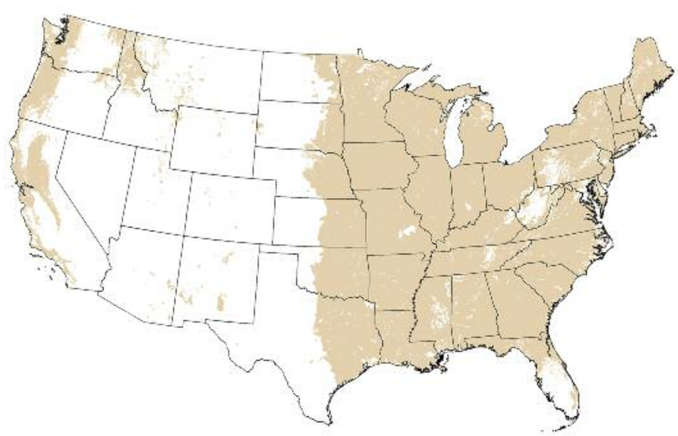
Perlack, R.D., L.L. Wright, A.F. Turnhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory

U.S. Department of Energy. 2016. 2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks. M. H. Langholtz, B. J. Stokes, and L. M. Eaton (Leads), Ornl/Tm-2016/160. Oak Ridge National Laboratory, Oak Ridge, TN. 448p. doi: 10.2172/1271651. http://energy.gov/eere/bioenergy/2016-billion-ton-report.

National Yield Potential Maps

These maps were developed using the PRISM-ELM (Daly et al., 2018) model with data from the Sun Grant Initiative/Department of Energy Regional Feedstock Partnership field trials and other published sources.

Mixed Grasses on CRP Land

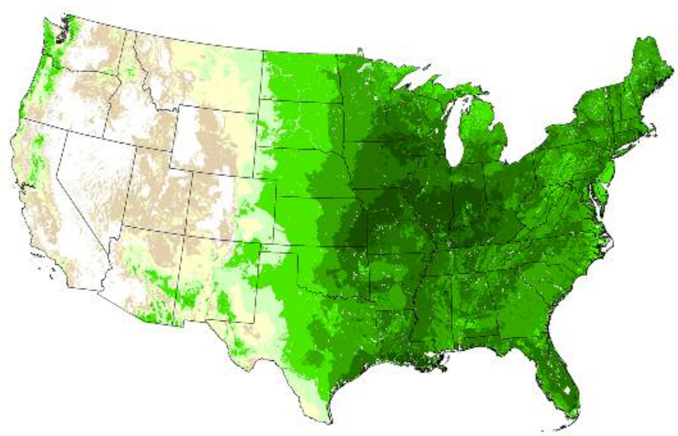


30-year Average Yield (dry tons/acre):

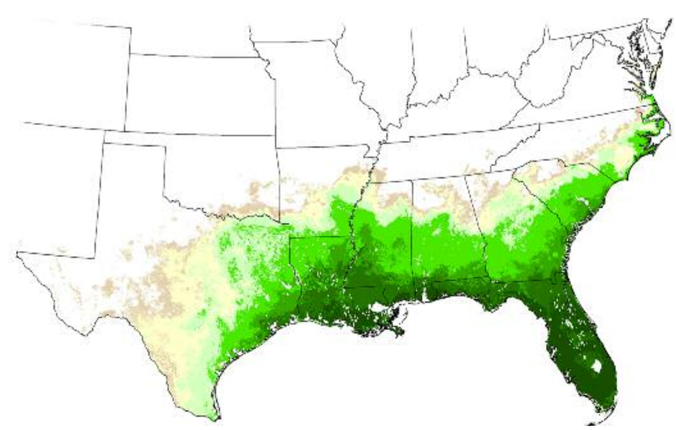
<1 | 1.1-2 | 2.1-3 | 3.1-4

4.1-6 | 6.1-8 | 8.1-10 | >10

Giant Miscanthus



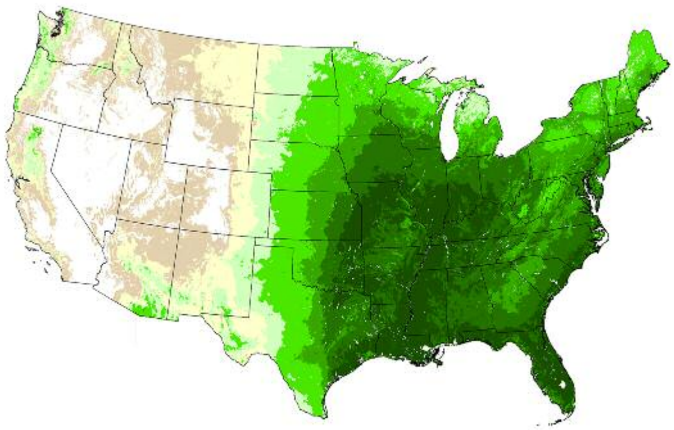
Energycane



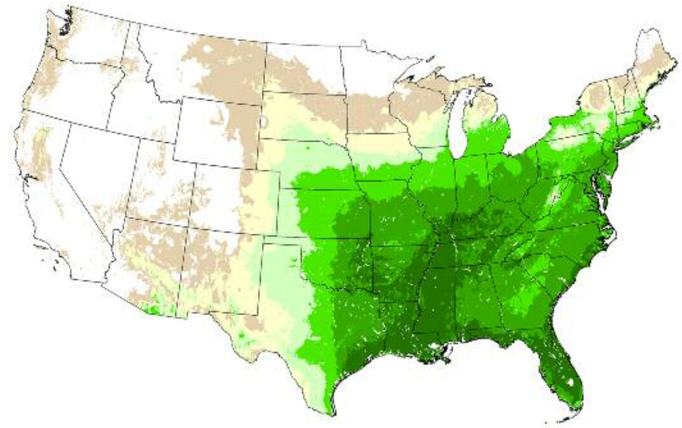
Maps continue on next page.

30-year Average Yield (dry tons/acre): <1 | 1.1-2 | 2.1-3 | 3.1-4 | 4.1-6 | 6.1-8 | 8.1-10 | >10

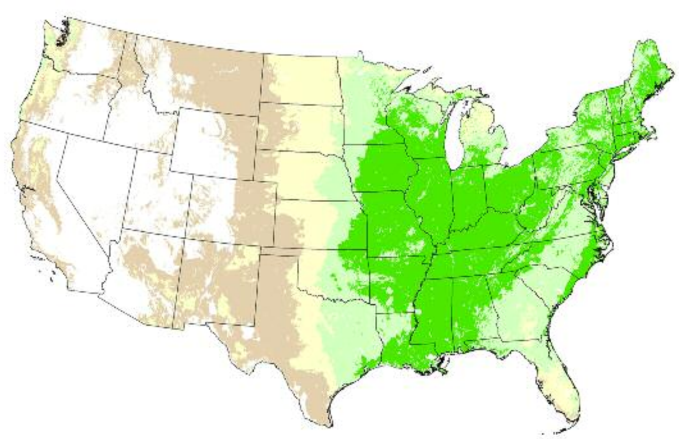
Sorghum



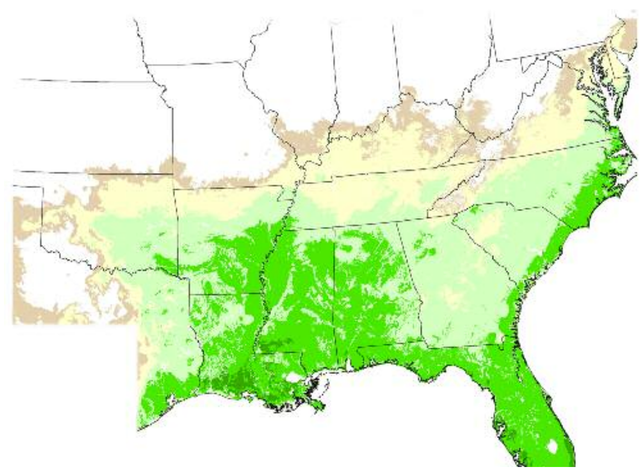
Lowland Switchgrass



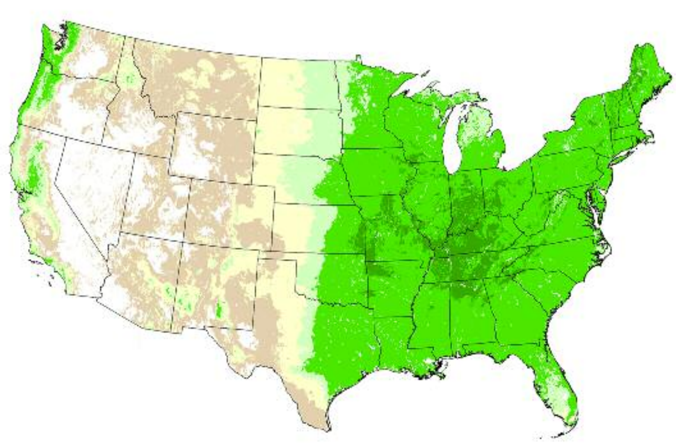
Upland Switchgrass



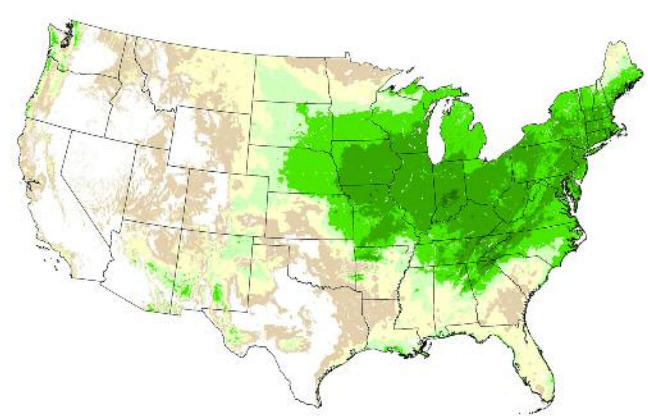
Southern Pine



Poplar



Willow



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