Bioenergy Science White Paper
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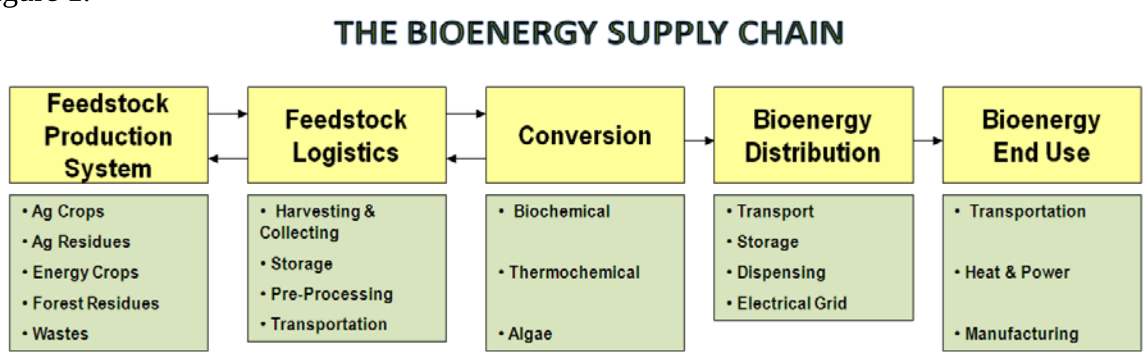
The Nation is aggressively developing the capacity to meet some of our energy needs through biofuels and biopower. The Energy Independence and Security Act of 2007 (EISA) calls for 36 billion gallons per year (BGY) of renewable fuels by 2022 and establishes new categories of renewable fuels, each with specific volume requirements and life cycle greenhouse gas (GHG) performance thresholds.[1,2] As mandated by EISA, the Renewable Fuel Standard was implemented in 2009. Additionally, the Food, Conservation, and Energy Act of 2008 authorized many bioenergy research, demonstration, and deployment efforts currently being implemented by the U.S. Department of Agriculture (USDA) and the Department of Energy (DOE). State and national initiatives such as the National Bioeconomy Blueprint are also exploring the use of biomass to produce high value chemicals, biobased products, and heat and power. All these applications increase demand for biomass production.

Emerging bioenergy systems hold the promise of helping to reduce our dependence on foreign oil, increase rural prosperity, and reduce greenhouse gas emissions. Meeting the energy demands of the future requires the development of transformative, ecologically based agricultural systems that ensure sustainable environmental, economic, and social outcomes. Successful bioenergy systems require strategic approaches that pose many scientific research, economic, data management, and communication challenges. The bioenergy supply chain (Figure 1) that drives these systems depends on the cooperation of researchers, landowners, industrial sectors, and market suppliers.

Figure 1.



Strategic Approaches Needed

A multidisciplinary, integrated systems approach. The significant expansion and modification of existing and new interrelated components of the bioenergy supply chain is creating effective systems. These systems incorporate new partnerships and investments, innovative grower

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[1] 15 BGY of corn ethanol; 21 BGY of "advanced biofuels" with a 50 percent reduction in life cycle GHG emissions, compared with fossil fuels; 16 BGY of that coming from cellulosic sources with a required 60 percent reduction in life cycle GHG emissions. An additional 1 BGY of biomass-based diesel is also required.
[2] This national standard is expected to reduce GHG emissions more than 138 million metric tons per year when fully phased in by 2022.

cooperative models, and small and large business plans. Integrating chemical, biological, engineering, and agronomic knowledge together drives the technical and economic success of the bioenergy sector, its environmental performance, and ultimately commercialization.

Reliable availability of commercial-scale feedstock and conversion technologies for producing biofuels, biobased chemicals, and products that are cost-competitive with products derived from fossil fuels. Supply chain systems that are regionally diverse provide the feedstocks needed to develop cellulosic and other advanced fuels and biobased products. These feedstocks must be of reliable quantities to meet expected demand and have the ability to integrate into landscapes that already produce food, feed, and fiber for existing markets. The *U.S. Billion Ton Update* reported that the United States has the potential to produce more than a billion dry tons of biomass annually by 2050 without affecting other farm and forestry markets (U.S. Department of Energy, 2011). Critical considerations regarding feedstock types include compatibility with conversion technologies and the cost-effectiveness of feedstock growth and development. Conversion technologies that are "feedstock neutral" may have greater economic and risk aversion flexibility. Expanded rural economic opportunities and reduced investment risks to biorefineries improve through the production of chemical intermediates and value-added products.

Feedstocks need to be sustainably integrated with other agricultural production and uses of land, resources, economic systems, and communities. These new supply chains will increase the demand on an already diverse portfolio of natural resources and man-made systems. Understanding these multiple demands and quantifying their benefits and risks using biophysical, economic, and other analyses tools such as life cycle analysis (LCA) can address the impacts of expanded feedstock production on GHG emissions, net energy balance, water quality and quantity, biodiversity, land use, and public health. Comparative LCAs of feedstock/conversion/fuel pathways with other energy options including fossil fuels will provide more information to perform energy production comparisons.

Strategic performance goals, milestones, and critical decision points need prioritization and quantitative measures of success need to be established. The integration of extensive databases and decision-support tools will guide decision-makers to properly perform an LCA to identify economic, environmental, and social benefits and risks. Industry, Federal and State governments, and universities are collaborating to establish a common knowledge base of measures through interdisciplinary scientific approaches. Innovative decision-support tools and communication strategies will help establish priorities; assess strategies; and guide policy, research, demonstration, and development investments (National Agricultural Research, Extension, Education, and Economics Advisory Board, 2010). Through effective management, accessibility, exchange, and integration of data, partners are making sustainable choices in the development of the biofuels industry.

New multidisciplinary research and educational programs and structures for outreach, extension, and workforce development are needed along the bioenergy and biobased product supply chain. Scientific research enables innovative manipulation and management of materials to produce biobased fuels and other products. For new industries to grow, commercial developers of new feedstock varieties must have access to a wide range of genetic diversity.

They also need cost-effective systems that are resilient to unfamiliar pests, diseases, and environmental stresses that will preserve the long-term health of soil, air, water, and other natural resources. Additionally, wilderness and other natural areas must be preserved as biodiversity reserves. Scientific research and science-based policies are required to enable biofuels and bioproducts to compete effectively against petrochemical-based materials and plastics. Private and public landowners will need information and incentives to produce sustainable, cost-competitive biomass feedstocks. There is also an urgent need for technically skilled labor in all parts of the emerging biofuels and biobased products supply chains.

Current State of the Science

In 2010, the United States produced roughly 13.1 BGY of corn-based ethanol. The Environmental Protection Agency (EPA) believes the Nation has the capacity to produce the remainder of the 15.0 billion gallons of corn-starch ethanol that is allowed by the Renewable Fuel Standard (U.S. Department of Agriculture, 2010). In contrast, in November of 2010, EPA waived the required annual volume of cellulosic biofuels from the original statutory goal of 250 million gallons to 6.6 million gallons, due to a lack of U.S. capacity to produce more of it. However, the industry is progressing toward having the ability to produce the volume needed to meet statutory requirements. Even though the projected volume of cellulosic biofuels production for 2012 "is determined to be below the applicable volume specified in the statute" (i.e., approximately 490 million gallons below the 500 million gallon volume), the EPA is applying the standard for the volume of advanced biofuels and total renewable fuels. The rationale is that "other advanced biofuels, such as biomass-based diesel, sugarcane ethanol, or other biofuels may make up shortfalls in cellulosic biofuel volumes" (U.S. Environmental Protection Agency, 2012).[3]

The lack of established cellulosic feedstocks and commercially viable and available conversion technologies are critical barriers to the production of adequate levels of biofuels. EISA's original mandate calls for the production of 5.5 billion gallons of advanced biofuels by 2015, with 3 billion being cellulosic biofuels (2007). Many different biomass/conversion technology/product pathways hold the potential to meet U.S. goals in cellulosic and advanced biofuel production (Regalbuto, 2007). Each region of the United States has the capacity to produce a portfolio of feedstocks for specific end-use markets. Because feedstock production varies according to region and considering differences in soil types, climate, and water availability, the location of components in the supply chain is therefore important.

Biomass transportation expenses can be significant, thus, the proximity of biomass to conversion technologies, infrastructure, and end-use markets to each other greatly influences supply chain costs (Kocoloski, Griffin, & Matthews, 2010). Because the end-use market will play a lead role in determining the type of biomass and conversion technologies that will be deployed, developing a biomass production, conversion, and end-use supply chain is an iterative, decision-making process. The main drivers for which pathways will become commercially available and

[3] In establishing the 2012 renewable fuel standards, EPA announced that only six facilities will produce 10.45 million ethanol-equivalent gallons (i.e., 8.65 million gallons) of cellulosic biofuels for transportation fuels, heating oil, and jet fuel in 2012, with 54 percent being cellulosic ethanol and 46 percent being gasoline or diesel.

where they are located will depend on technical and economic feasibilities and strategies that reduce risks to farmers, industries, consumers, and end-use markets. Just as important, although, not as immediately considered, is how to maximize the environmental performance and social benefits from biofuels.

In 2008, the U.S. Biomass Research and Development Board, which coordinates research and development of biobased fuels, products, and power across the federal government, released a *National Biofuels Action Plan* that identifies key barriers and research needs within the supply chain. Research on all aspects of the supply chain is occurring in both the public and private sectors. This document focuses on USDA's strategic research to 1) incorporate biomass and dedicated feedstock crops into existing agriculture and forestry-based systems; 2) increase feedstock production to increase grower profits and reduce biorefinery transaction costs; and 3) address the uncertainties to avoid negative effects on existing markets and ecosystem services.

Feedstock Production: Determining the sources to meet annual Federal targets affects all other parts of the supply chain (Biomass Research and Development Board, 2008a). Perennial grasses, energy cane, biomass sorghum, sweet sorghum, soy and canola oil seeds, corn stover and straw residues, purpose-grown trees, logging residues, and corn starch ethanol can all serve as sources of feedstock production. Greater production efficiency and sustainability (i.e., maximizing yield, decreasing inputs, and increasing attributes helpful for conversion) are necessary if USDA research is to maximize economic, environmental, and social benefits. Identifying opportunities for integrating these crops into existing and new production systems requires understanding the technical, economic, and social factors that influence land use and productivity.

Feedstock Logistics: Efficient and effective harvesting, processing, storage, and transport mechanisms of feedstocks are critical if low-density biomass is to be converted into liquid transportation fuels on a commercial scale. Strategies are needed to achieve desirable conversion technologies and to develop equipment and systems to harvest, collect, store, pre-process, and transport higher amounts and varieties of biomass. Harvesting technologies and practices will also need to increase environmental, economic, and social benefits while maximizing productivity.

Conversion Technologies: More than 530 biorefineries with an average capacity of 40 million gallons per year are required in order to meet the goals of RFS2 (USDA Biofuels Strategic Production Report, 2010). Research to find cost-effective solutions to conversion barriers include 1) overcoming biomass recalcitrance during biological conversion; 2) efficiently converting feedstocks with varying moisture content, chemical composition, and energy density during thermochemical conversion; 3) developing catalysis or fermentation organisms to convert intermediates into hydrocarbon fuels, alcohols, or biodiesel; and 4) developing and utilizing co-products. Feedstock characteristics can significantly influence these barriers.

Distribution Infrastructure and End-Use Technologies: Cost-effective, well-functioning transportation, storage, and dispensing systems are needed to transport biomass from field production to biorefineries. Better infrastructure will accommodate higher blends of ethanol and other biofuels. Additionally, engines must be optimized to use biofuels. Having such vehicles available will increase the biofuel market share.

Federal efforts to meet these challenges

The EPA (2011) is developing guidance and regulations for Federal agencies carrying out research, demonstration, development, and commercialization projects in collaboration with universities, industry, State governments, and trade associations. Federal research has increasingly focused on the development of feedstocks and conversion technologies suited to cellulosic and advanced biofuels.

Current Research Challenges and Proposed Research Program

USDA plays the lead role in developing transformative, sustainable production systems. USDA also has a long history of conducting research and providing technical assistance to feedstock producers and developers of bioenergy technologies (The White House, 2009). In February 2010, the Biofuels Interagency Working Group identified USDA as having research leadership responsibility to improve non-food biomass crops and woody species, and to develop sustainable production and management systems for biomass and other dedicated feedstocks from farms and forests (The White House, 2010).

The agencies under USDA's Research, Economics, and Education (REE) mission area include the Agricultural Research Service (ARS), Economic Research Service (ERS), National Agricultural Statistics Service (NASS), and the National Institute of Food and Agriculture (NIFA). In partnership with U.S. Forest Service, the REE agencies play fundamental roles in addressing the scientific challenges of developing bioenergy systems. These agencies are able to assess the implications for agricultural markets, resource use, the environment, and the interests of diverse societal groups.

REE research includes improving plants and productivity systems; collecting and analyzing productivity data; and various extension, outreach, and education activities. For example:

- ARS and NIFA are leading the development of integrated regional strategies to produce agriculture-based biofuel, biopower, and biobased products. NIFA's forestry programs also complement research and development efforts by the U.S. Forest Service by focusing on sustainable forest feedstock production, management, and logistics; and the development of biomass conversion technology, bioproducts, and bioenergy decision support systems.
- ERS and NASS lead the national and regional collaborative efforts to collect, manage, document, and analyze data to find trends in agricultural practices, markets, food economics, rural economies, resource use, and financial conditions. This information is critical to understanding the status and economic feasibility of biobased industries.
- NIFA supports the cooperative extension system, which works with private and public landowners to encourage adoption of biomass feedstocks and to ensure a sustainable and economically viable supply. NIFA is also striving to develop the multidisciplined workforce that will develop and support the future biofuels economy.

REE agencies are taking an integrated, supply chain approach to guide the design of high-yielding biomass production systems that aim to optimize economic, environmental, and social benefits. REE agencies are implementing the following strategies to overcome the various challenges associated with biofuel production, distribution, and use:

1. Improving biomass quality and production efficiency to reduce production and biorefinery costs
2. Incorporating biomass and dedicated feedstock crops into existing and new agricultural systems to diversify the rural economy and to sustainably manage land to produce biobased products to serve as fuels to provide heat and power, and to produce high-value chemicals
3. Addressing the uncertainties of expanded biomass and biofuels production to achieve environmental, economic, and social benefits and avoid negative effects on rural communities, economies, ecosystem services, and food, feed, and fiber.

Strategy 1: Maximizing biomass quality and production efficiency to reduce production and biorefinery transaction costs and increase economic opportunities for biobased products

The feedstock characteristics that are most likely to affect the cost-effectiveness of biobased product supply chains include greater yields; lower inputs for feedstock production; greater resistance to disease and pests; better harvest, processing, and storage practices; lower conversion costs; and possibly expanding the array of feedstocks that can be used in specific conversion technologies.

Several tools are available to improve the characteristics of biomass feedstocks. These include nutrient recycling, better seed production techniques, better plant selection and breeding practices, and genetically modifying plants. Therefore, REE research focuses on making improvements to plants as feedstock and feedstock production systems, and incorporating scientific, economic, data management, education, and communication dimensions to reduce costs to producers.

The primary goal of REE research is to guide the development of high-yielding biomass production systems that provide feedstocks with favorable characteristics for conversion and that significantly contribute to life cycle cost-effectiveness, reduced greenhouse gases, minimal environmental and natural resource impacts, and cost-competitive biofuels.

Plant Improvements: Current and proposed research focuses on genetics to improve plants to serve as feedstocks for advanced biofuels and biobased products:

Current USDA Science

- Identifying genes that control biomass characteristics and developing improved germplasm (NIFA, ARS)
- Developing advanced resources to genetically improve biomass crops; implementing marker-assisted breeding and biotechnology strategies to increase crop yield and

sustainability; maximizing biomass crop conversion efficiency; increasing crop resistance to diseases and pests; enhancing abiotic crop stress tolerance; and expanding crop production ranges (ARS, NIFA)

- Expanding the National Plant Germplasm System's capacity and to ability to manage germplasm and identify genetic diversity and to manage thousands of new genomic/genetic seed stocks generated by Federally funded research (USDA, DOE, National Science Foundation)
- Expanding USDA's capability to genotype sorghum, maize, sugarcane/energy cane, switchgrass, and soybean/legumes.
- Expanding the ability of the public and private sectors to evaluate germplasm for high-value traits and associated high-throughput genetic screens under selected environmental stresses
- Expanding USDA's capability to genetically analyze complex traits through quantitative trait locus mapping, genome-wide association studies, nested association mapping, and genomic selection

Anticipated Outcomes

These efforts should lead to greater production through breeding and systems that contribute to sustainable economic, environmental, and social outcomes. In consultation with stakeholders, USDA should conduct strategically chosen phases of feedstock improvement, breeding, selection, and evaluation. Outcomes include developing molecular markers to enhance genetic improvement; strengthening national germplasm collections by phenotyping and genotyping; improving crop genetic maps by incorporating molecular marker and trait data; mapping genes for high-value traits; and identifying relationship between high-value traits and conversion pathways.

Production Systems (Feedstock Production and Logistics): Current and proposed research leverages existing research on soil resource management, water availability and watershed management, new varieties and hybrid feedstocks, and high-yielding production systems.

Current USDA Science

REE is taking a regional and systems approach to examine appropriate management systems for the sustainable production of feedstocks for use as advanced biofuels. REE agencies in partnership with USDA's Office of Energy Policy and New Uses (OEPNU), universities, and other Federal agencies are sharing scientific knowledge and information, and performing economic and statistical analyses of trends in agricultural practices, markets, food economics, rural economies, resource use, and financial conditions. USDA's extension and outreach activities will include information that links biomass production and distribution systems with end-use markets.

- ERS and NASS are identifying agricultural lands, existing bioenergy feedstocks, and where and how they are produced; NIFA and ARS are assessing agricultural lands available for biomass production systems through case studies and field trials.

- ARS and the U.S. Forest Service established five intramural regional biomass research centers. ARS research is targeting soybean oil, energy cane, biomass sorghum, and perennial grasses, camelina and canola oilseeds, grasses, cereal crop residues, municipal solid wastes, and algae. Research and development efforts by the Forest Service are focusing on woody biomass.
- NIFA is leading two Congressionally mandated extramural research programs under the 2008 Farm Bill that will focus on regional biomass production:
  - Regionally based bioenergy coordinated agricultural projects of the Agriculture and Food Research Initiative, under Title VII, Section 7406.
  - The Biomass Research and Development Initiative, under Title IX, Section 9008, jointly implemented by NIFA and the Department of Energy's Office of Biomass Programs. Funds are provided to eligible entities to research, develop, and demonstrate biomass projects; develop biofuels and biobased products; and to assess biofuel sustainability.

Anticipated Outcomes

Coordinated research should result in the development of landscape scenarios that maximize long-term, sustainable biomass production so that biorefineries can produce biofuels and other biobased products to meet national goals. The effects of climate change on water availability and productivity need better research. Each regional biomass development study requires unique goals, outputs, and milestones to evaluate effectiveness.

Strategy 2: Incorporate biomass and dedicated feedstock crops, biobased products, and other clean bioenergy technologies into existing and new agricultural systems and communities

Greater diversity in the rural economy can help mitigate risks to farmers, but it presents both potential benefits and challenges to sustainable land management. The USDA estimates that it will take 27 million acres of cropland, or 6.5 percent of all cropland, to produce the national biofuel targets, not including forest sources or postharvest crop residues from food crops (USDA Biofuels Strategic Production Report, 2010). REE will conduct research to evaluate existing biomass availability and production systems and determine how to diversify the need for crops to supply fuel, heat, power, and other bioproducts into existing supplies of crops grown for food, feed, and fiber.

The primary goal of expanding the base of dedicated biomass and feedstock crops is to create new opportunities and benefits to farms, ranches, rural communities, and the environment.

Current USDA Science

NASS and ERS should collect and analyze survey data on current agricultural practices, available land, markets, food and rural economics, resource use, and financial conditions. USDA has estimated the type and quantities of crops and cropland that would be required to meet the 2022 RFS2 mandates. Extensive mapping of bioenergy investments and biomass availability is available and being updated jointly by the Departments of Energy and Agriculture (U.S. Department of Energy and U.S. Department of Agriculture, 2005; Feedstock Logistics Interagency Working Group, 2010). Several ARS and NIFA research programs focus on on-farm operations and opportunities. Additionally, the Regional Biomass Research Centers, the Agriculture and Food Research Initiative, and the Biomass Research and Development Initiative will collect information on how bioenergy feedstocks and biofuel products can be successfully integrated into existing production systems and how new systems can be developed for this purpose.

Various approaches for integrating biomass production into existing systems include the following:

- Developing and implementing field pilots, and assessing the sustainability of potential multifunctional landscapes through participatory systems research with commercial partners (ARS, NIFA).
- Conducting research to develop high-value co-products such as glycerol-based polymers, a new form of biobased chemical (ARS, NIFA).
- Using the cooperative extension system (e.g., eXtension) and the Agricultural Technology Innovation Partnership Program to link ideas in research, policy, economics, and planning for biorefineries with the needs of farmers, producers, and investors to encourage adoption of these new practices (ARS, NIFA).
- Conducting research to develop on-farm and near-farm production and use of biobased energy products in the following ways:
    - Through the development of scaled technologies to manage the logistics of cellulosic biomass from the field to the biorefinery in ways that will preserve or enhance the quality of the feedstock (NIFA, ARS). The U.S. Departments of Energy and Transportation, and the U.S. Forest Service are research partners in this area.
    - The development of animal manure waste-to-energy systems for bioenergy use (NIFA; ARS).
    - Through the development of conversion technologies and distribution scenarios suitable to near-farm scales (ARS).
    - By efficiently capturing co-products of biofuels production and using them in on-farm production systems (ARS, NIFA).
    - Conducting on-farm surveys of practices, including the On-farm Renewable Energy Production Survey, which has been completed, and the Distillers' Co-products Survey, which is planned (NASS).
    - Undertaking biobased research that 1) replaces the use of petroleum and other strategic materials that would otherwise need to be imported, 2) creating higher-value revenue streams, 3) improving energy efficiency, reducing wastes, conserving limited natural resources, and providing other ecosystem service benefits to the environment and society, and 4) improving the nutrition and well-being of animals and humans.

Anticipated Outcomes

Synergistic opportunities for higher value uses of agricultural and bioenergy wastes will be identified and demonstrated for use as co-products and biobased products. Benefits to be assessed include reductions in GHG emissions, better water quality, and greater economic feasibility and opportunities. REE expects to develop guidelines on best management practices for multifunctional land use in specific regions and for specific landscape types.

Strategy 3: Address the uncertainties and tradeoffs of expanded production of biomass, biofuels, and biobased products

The production of feedstock for use as cellulosic and advanced biofuels could place a greater demand on natural resources and man-made systems. However, if done correctly, this greater production could also present benefits. Understanding the processes and practices of increasing feedstock production for this purpose is essential in order to predict the economic and technical feasibility of using biofuels and other biobased products; quantify the availability of these resources; and assess the carrying capacity and resiliency of these natural resources.

The primary goal of addressing uncertainties and tradeoffs in expanding production is to identify potential pathways of bioenergy and biobased product production while ensuring economically, environmentally, and socially sustainable outcomes.

Current USDA Science

- ARS and the Federal Aviation Administration developed the *Feedstock Readiness Level Tool* for the commercial air transportation industry. The tool is a communication and assessment framework that identifies steps and barriers to development, regulatory compliance, and commercialization of new agricultural or forest-based feedstocks for commercial and military aviation biofuels production.
- In collaboration with the U.S. Forest Service, the EPA and the Department of Energy, NIFA, ARS, and the National Agricultural Library are developing indicators and a data framework for environmental, economic, and productivity performance. NIFA and ARS are obtaining data from research, development, and demonstration projects from the Agriculture and Food Research Initiative, and the Biomass Research and Development Initiative, and Regional Biomass Research Centers. NASS, ERS, and USDA's Office of the Chief Economist are developing a statistical information base to monitor key indicators of the agricultural system, rural communities and environmental resources and to model the effects of biomass production for bioenergy and biobased products. NASS, ERS, and USDA's Office of the Chief Economist are developing short- and long-term projections for crop and livestock production, prices, and trade to evaluate the implications of biomass production for bioenergy and biobased products on farm income, food prices, and other indicators of farm performance. Finally, ARS and ERS are expanding current economic and biophysical models to assess the effects of dedicated biomass feedstock production on natural resources and environmental quality.

Anticipated Outcomes

The outcomes anticipated from these endeavors include indicators and a data framework that will guide the design of biomass production systems to maximize benefits and minimize negative effects on rural communities, economies, ecosystems, food, feed, and fiber. Expanded modeling capacities will allow scenarios to be analyzed to assess resource use and indicators of environmental quality. Information on these models will be made available for scientific and decision-making studies, including EPA's Section 204 Report to Congress as part of the Energy Independence and Security Act.

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