Roadmap

for Biomass Technologies in the United States

December 2002

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I. Introduction

A. Purpose

The purpose of this document is to outline a research and development roadmap and identify public policy measures for promoting and developing environmentally desirable biobased fuels, power and products. It represents the collective assessment and expertise of the Biomass Research and Development Technical Advisory Committee. The research strategies outlined in this roadmap will help achieve the goals established by the Committee in the *Vision for Bioenergy and Biobased Products in the United States.*

Exhibit 1
Vision Goals

- ***Biopower*** *- Biomass consumption in the industrial sector will increase at an annual rate of 2 percent through 2030, increasing from 2.7 quads in 2001 to 3.2 quads in 2010, 3.9 quads in 2020 and 4.8 quads in 2030. Moreover, biomass use in electric utilities will double every ten years through 2030. Biopower will meet 4 percent of total industrial and electric generator energy demand in 2010 and 5 percent in 2020.*

- ***Biobased Transportation Fuels*** *- Transportation fuels from biomass will increase significantly from 0.5 percent of U.S. transportation fuel consumption in 2001 (0.147 quads) to 4 percent of transportation fuel consumption in 2010 (1.3 quads), 10 percent in 2020 (4.0 quads), and 20 percent in 2030.*

- ***Biobased Products*** *- Production of chemicals and materials from biobased products will increase substantially from approximately 12.5 billion pounds, or 5 percent of the current production of target U.S. chemical commodities in 2001, to 12 percent in 2010, 18 percent in 2020 and 25 percent in 2030.*

The Committee represents experts from wide-ranging backgrounds relevant to biomass resources, technologies, and markets. A list of Committee members is provided in Appendix I. The Committee was established by the Biomass R&D Act of 2000 {P.L. 106-224}. Its responsibilities include advising the Secretaries of Energy and Agriculture on the technical focus and direction of requests for proposals issued under the Biomass R&D Initiative, and evaluating and performing strategic planning on program activities relating to the Biomass Research and Development Initiative {P.L. 106-224, Sec. 306}. The Committee developed this roadmap at the request of the U.S. Department of Energy and the U.S. Department of Agriculture as a tool to assist in biomass-related research planning and program evaluation. Through the *Roadmap for Biomass Technologies in the United States*, the Committee has provided direction to the Department of Energy, the Department of Agriculture, the Department of the Interior, the Environmental Protection Agency, the National Science Foundation, and the Office of the Science and Technology Policy. The *Roadmap* was developed through a series of public meetings of the Biomass Research and Development Technical Advisory Committee.

B. Relationship to Vision Goals

Environmentally sound biobased fuels, power, and products can make important contributions to U.S. energy security, rural economic development, and environmental quality. Understanding the benefits of these contributions, the Biomass Research and Development Technical Advisory Committee established challenging yet feasible goals for increasing the role of biomass technologies in the U.S. economy. These goals, shown in Exhibit 1, project continued growth in biomass consumption for electricity production, and a significant increase in biomass consumption for the production of transportation fuels and biobased products. These goals were published by the Committee in its *Vision.* This *Roadmap* presents recommended strategies, directions, and plans that should be used to achieve these goals. As shown in Exhibit 1, the *Vision* outlines goals in three specific areas: biopower, biobased transportation fuels, and biobased chemicals and materials. The research needed to achieve these goals falls into several categories:

- Feedstock Production
- Processing and Conversion
- Product Uses and Distribution

As illustrated in Exhibit 2, the majority of research to be performed will have crosscutting applications for biobased fuels, power, and products. In other cases, research will be specific to one or more biobased application. This *Roadmap* describes these research strategies and the public policy measures to support development of economic and environmentally sound biomass resources and technologies. Public policy is the single most important strategy to moving toward a carbohydrate economy. If implemented, the combination of R&D and public policy strategies outlined in the *Roadmap* will:

- increase the scientific understanding of biomass resources and better tailor those resources for a variety of end-use applications;
- improve sustainable systems for developing, harvesting, and processing biomass resources;
- improve efficiency and performance in conversion and distribution processes and technologies for a host of products;
- create the regulatory and market environment necessary for increased development and use of biobased fuels, power, and products;
- improve and enhance the environment;
- enhance access to biomass sources; and
- ensure U.S. world leadership in the development of biomass conversion and enabling technologies.

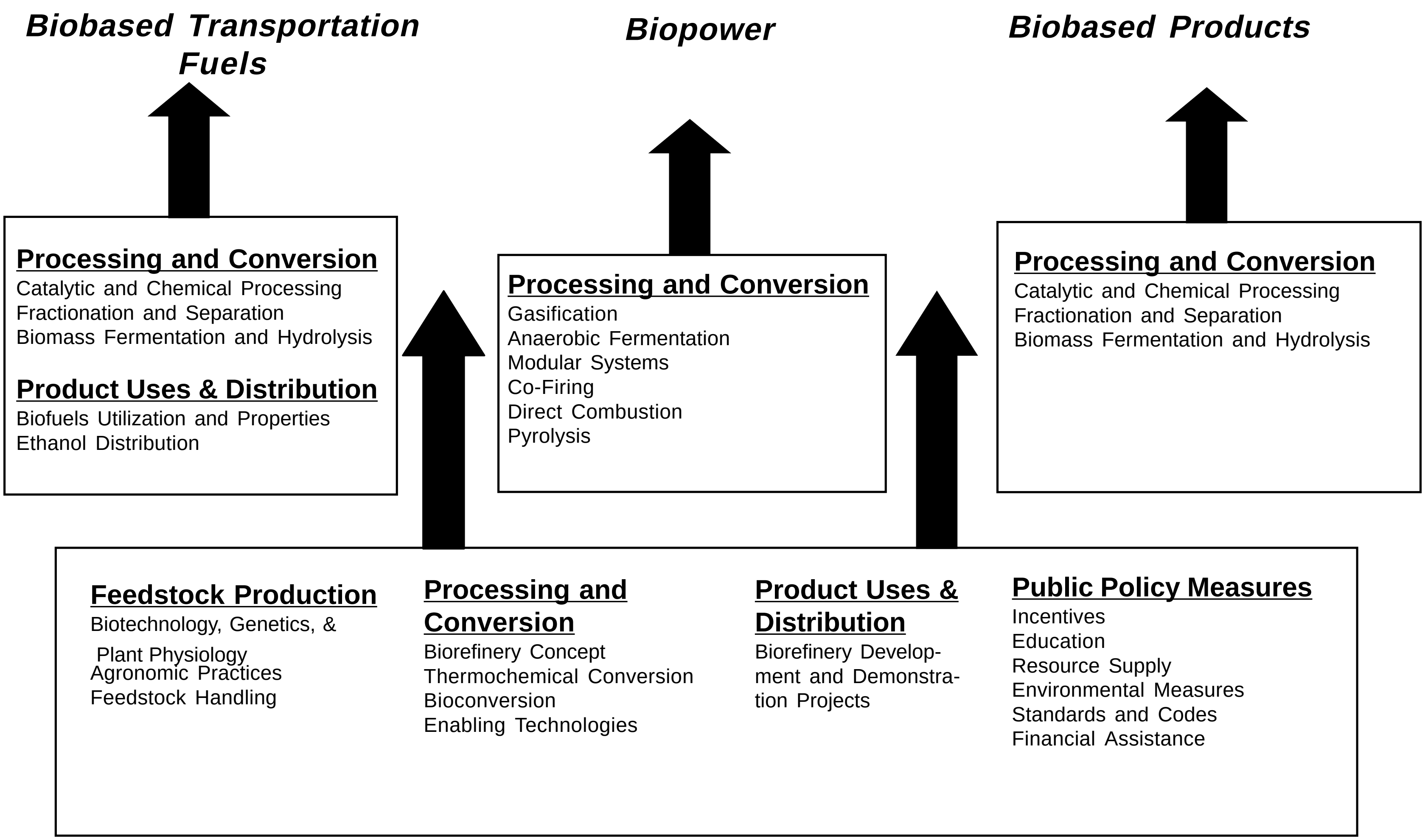
We believe we can achieve the goals set forth in the vision without promoting unsustainable agricultural, forestry, or waste management practices. We envision an emphasis on utilizing cellulosic-based raw materials. Environmentally sound biomass resources are those for which life cycle assessments demonstrate their desirability.

C. Organization of This Report

The *Roadmap* is organized by the major categories of research and development that will be needed to achieve *Vision* goals. These categories include Feedstock Production, Processing and Conversion, and Product Uses and Distribution. A section on Public Policy Measures sets forth the public policies this Committee recommends be adopted or evaluated as means of realizing the full economic and environmental promise of biomass resources and technologies.

Exhibit 2

R&D and Policy Needs for Achieving Vision Goals



* See Exhibit 1 for Vision Goals

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2. Feedstock production

Advances in feedstock production research can reduce the final cost of biobased fuels, power and products. These advances can make it possible to produce plants, trees, and residues with characteristics increasingly well-suited for feedstocks. Feedstock production research can increase biomass yields as well as achieve higher levels of valuable constituents. These constituents can, for example, facilitate component separation and increase the energy density of feedstocks. Improved separation technologies and processes can create plant and residue feedstocks for high value products and end-uses. Improved agricultural and forestry practices can result in higher yields per unit of input. New methods in erosion control, fertilization, and pre-processing can result in improved life cycle performance, sustainable practices, and enhanced feedstock production.

Advances in the area of feedstock production will have crosscutting impacts for biobased fuels, power, and products. However, a number of challenges in feedstock production currently face biomass communities and must be overcome to achieve challenging *Vision* goals:

- A better understanding of plant biochemistry and enzymes is needed.
- Scientific methods to produce and prepare plants and residues so that they meet specifications for end-use applications are needed.
- Agronomic practices must be improved to increase efficiency and reduce the cost of biomass feedstock production and delivery, and to ensure crop sustainability.

Achieving *Vision* goals will require a change in the entire biomass production system, including new and better methods for crop growth and management, harvesting, densification, transportation, storage, and pre-processing. It will require both small, more localized processing plants and/or larger scale ones that take advantage of economies of scale.

Advances in R&D can help to improve storage methods, expand the growth of crops for energy and other products, and assure the quality of feedstocks. At the same time, research into the agronomic, economic and environmental impacts of harvesting lignocellulosic material must be established to ensure that these materials have beneficial life-cycle impacts. A discussion of Life Cycle Assessment that includes feedstock production is provided in Section V of this Roadmap.

Basic research can help to address broad needs for improving development of a number of feedstocks that can ultimately be used as resources for a wide range of biobased applications. At the same time, however, a better definition of high priority applications/products is needed to help growers and the research community focus more applied research in feedstock production.

Finally, continued advances in feedstock production research will face the special challenge of public acceptance. Improved methods for verifying the safety as well as the societal and environmental benefits of genetically engineered plants are needed. Resulting data should be used to engage in broad, multi-party stakeholder dialogue to determine whether to and/or how best to commercialize these technologies. Regarding genetically engineered plants, coordinated leadership from key federal providers of R&D, such as the U.S. Department of Energy and the U.S. Department of Agriculture, will be critical to making these scientific advances, validating their success and safety, and improving public acceptance through dialogue and stakeholder engagement.

Achieving *Vision* goals for biomass technologies will require significant advances in feedstock production. Ultimately, it will require an increased scientific understanding of methods for high yield, low input targeted crops produced in a sustainable and environmentally sound manner. The Biomass Technical Advisory Committee has established specific R&D objectives for feedstock production research. As illustrated in Exhibit 3, the majority of this R&D will have cross-cutting impacts for biobased fuel, power, and products applications. Feedstock research should focus on a representative cross-section of biomass resources including corn stover; dryland crops such as oilseeds; dedicated energy crops; and plant, animal, and other organic waste-based residues. Target crops should include oil and cellulose-producing crops that can provide optimal energy content and usable plant components. Key outcomes of advanced feedstock production research should produce several important results for the biomass communities. Examples include:

- increased yield per acre,
- lower cost per ton of feedstock at plant gate,
- increased value for the outputs of biomass feedstocks,
- reasonable profit for growers, and
- environmentally sound production of biomass.

Exhibit 3
Crosscutting Impacts of Feedstock Production R&D

Major R&D Needs	Biofuels Impact	Biopower Impact	Bioproducts Impact
Biotechnology, genetics, and plant physiology - Improve basic science in plant genetics and biochemistry. - Improve chemical & biological processes for improved feedstocks.	H M H	H M H	H M H
Optimize agronomic practices, including addressing land use availability and soil sustainability issues.	H	H	H
Optimize logistics for collecting, storing and combining multiple feedstocks with diverse applications.	H	H	L
Key Outcomes			
· Identify high opportunity plant and residue feedstocks. · Increase yield per acre. · Reduce feedstock cost per ton at plant gate. · Increase dollar value of biobased outputs. · Reasonable profit for growers. · Environmentally sound production of biomass.	H H H H H H	H H H H H H	H H H H H H

H – High impact
M – Medium impact
L – Low impact

A. Biotechnology and Plant Physiology

***Objective One** - Improve the technical understanding of plant biochemistry and enzymes and develop the ability to engineer enzymes within desired crops.*

Ultimately, the ability to produce high value, environmentally sound biobased fuels, power and products may require lower cost feedstocks (i.e. crops, agricultural plant and animal residues). This feedstock production system will require profit for the grower. Examples of desirable characteristics include high-energy content, increased yield, fast growth, and the ability to withstand drought or other stresses.

Increased knowledge of the metabolic pathways that lead to lignins, proteins, and other plant components is needed. Currently, however, there is a lack of understanding of plant biochemistry as well as inadequate genomic and metabolic data on many potential crops. Specifically, research to produce enhanced enzymes and chemical catalysts could advance biotechnology capabilities. Enzymes and catalysts are necessary to efficiently and cost effectively turn biomass feedstocks into biobased products, fuels, and power.

Research is needed to produce crops with desirable traits for both edible and industrial uses. For example, simply increasing the plant's natural production of a specific component already found in the crop, such as a protein or fatty acid, can increase the ultimate yield of that component and thereby improve efficiency and reduce the cost of bioenergy and biobased product processing and conversion.

Progress in implementing newly developed science can be done with reduced environmental impact. Research pathways and milestones to improving the understanding of plant biochemistry and enzyme production are provided in Exhibit 4.

***Objective Two** - Develop the chemical and chemical/biological pathways necessary to improve the energy density and chemical characteristics of delivered feedstocks.*

The most valuable way to improve the availability and cost competitiveness of biobased fuels, power, and products is to develop advanced methods for overcoming the resistance of agricultural, forest-based, and urban feedstocks to enzymatic and fermentation treatments. Current technologies for creating a treatable/fermentable product from available, environmentally appropriate biomass resources do not meet the economic needs of the industry. Examples of research needs include:

- **Fundamental Structure of Lignocellulosic Materials** - To improve growth rates, research is needed on the fundamental structure of lignocellulosic materials, including the chemistry of its cell wall structures, transport properties, and genetic potential. This research can provide the basis for developing a sufficient quantity of cost-competitive biomass feedstocks necessary to achieve *Vision* goals for biobased fuels, power, and products.

- **Cost-effective Pre-delivery Treatment Processes** - Research should also include development and testing of cost-effective pre-conversion treatment processes to increase energy- and chemical-density of raw materials at the point of harvest.

Research may vary for each feedstock and conversion pathway. Energy crop research will need to be linked to conversion processes and end-uses. Improved utilization of animal wastes and agricultural residues will involve additional factors that may need to be addressed independently. Examples of R&D pathways to improve upon and develop the chemical and biological processes to enhance biomass feedstocks are provided in Exhibit 5.

Exhibit 4
Research Pathways – Plant Biochemistry and Enzymes

<table>
<tr><th colspan="2">0-3 Years</th><th colspan="3">4-10 Years</th><th>10+ Years</th></tr>
<tr><td rowspan="4">Identify major plant characteristics desired for target conversion pathways.</td><td colspan="4">Develop cost effective enzymes.</td><td rowspan="4">Demonstrate two-fold increase in the efficiency of photosynthetic energy capture.

Alter carbohydrate composition of plants (e.g., change lignin and/or cellulose content by 50% depending on end-use need).</td></tr>
<tr><td colspan="2">Identify methods for altering carbon flow into higher energy compounds such as lipids.</td><td colspan="2" rowspan="2">Implement projects to demonstrate increased efficiency of photosynthetic energy capture by 10 - 20%.</td></tr>
<tr><td colspan="2">Perform basic research on lignin and cellulose metabolic pathways.</td></tr>
<tr><td colspan="4">Develop complete functional genomics for at least 3 target feedstocks and target biocatalysts. Understand genetic diversity by screening natural germplasm to identify genes that could be applied in improving feedstock production.</td></tr>
<tr><td colspan="2">Leverage existing genome research for relevant biobased products and bioenergy applications.</td><td colspan="3">Isolate specific genes and/or regulatory elements related to biobased products and bioenergy feedstock production in plants and trees.</td><td></td></tr>
<tr><td colspan="2">Evaluate impacts of genetically enhanced crops on species specific and ecosystem level.</td><td colspan="3">Design 4 – 10 multi-trait crops that can be used for biobased products and bioenergy.</td><td>Test and implement newly designed multi-trait crops.</td></tr>
<tr><td colspan="2">Demonstrate to the general public that alterations to metabolic pathways can provide desired materials for biobased products in a safe and scientifically sound manner.</td><td colspan="3">Design and implement alterations to metabolic pathways in 3 or more existing plant types to increase yield of materials with desired characteristics by 25% or more.</td><td>Design and create novel plant types for a 50% improvement in conversion efficiency.</td></tr>
<tr><td colspan="2">Perform feedstock research to increase level of usable biomass resources from crops per unit of input.</td><td colspan="2">Test methods to increase efficiencies in biomass production.</td><td colspan="2">Improve biomass production and delivery systems to reduce water use, nitrogen input, and salt tolerance.

Increase productivity per acre by a factor of two for selected crops being grown for bioenergy and biobased products.</td></tr>
<tr><td colspan="6">Continually assess and demonstrate to the public that newly developed science is environmentally sound.</td></tr>
</table>

Exhibit 5
Research Pathways: Chemical and Biological Pathways

0-3 Years	4-10 Years	10+ Years
Analyze structural characteristics of lignocellulosic materials.	Identify methods to improve transport properties and genetic potential.	Test and implement biotechnology to improve growth rates of biomass feedstocks.
Identify and test methods to reduce sulfur and phosphorous content in residues used as biomass feedstocks.	Implement methods to reduce sulfur and phosphorous content of residues.	
Research pre-conversion methods to increase energy and chemical density of biomass feedstocks.	Test and demonstrate preconversion methods and technologies.	Achieve a 50% increase in chemical and energy density of biomass feedstocks as collected at the point of origin.
Continually assess and demonstrate to the public that newly developed science is environmentally sound.		

B. Agronomic Practices

***Objective Three -** Optimize agronomic practices for sustainable biomass feedstock production.*

Achieving *Vision* goals will require research to improve and advance agronomic practices. Energy crops will compete for land with existing land uses such as traditional agriculture and forestry. Energy crops also offer the potential to expand the resource base to marginal agricultural land. Research must evaluate methods to ensure the availability of land for producing the biomass feedstocks necessary to achieve *Vision* goals. Examples of key research areas include:

- **Soil Sustainability** - Agronomic practices must ensure soil sustainability. This includes research to ensure proper maintenance of soil nutrients and to identify methods to reduce or eliminate erosion. Improved processes for collecting materials that ensures soil sustainability should be identified and developed as part of best management practices for agricultural harvesting processes. Utilization of perennial species with developed rooting systems may improve the likelihood of success in agricultural (but not forestry) cases.

- **Land Availability -** Other barriers and challenges impacting land availability and key issues surrounding soil sustainability should be identified and addressed.

Research efforts should lead to agricultural and forestry production methods that contribute to maximizing yields of biobased feedstocks that have desired characteristics. This includes establishing optimum agronomic practices for sustainable production, for example optimizing inputs such as fertilizer, water, and pesticides as well as improving tillage practices and residue removal. Analysis of the feedstock production stage of the biomass life cycle is needed to better understand and evaluate the economics of biomass resources as well as carbon cycles and other environmental costs and benefits.

Examples of R&D activities to improve agronomic practices are provided in Exhibit 6.

Exhibit 6
Research Pathways: Agronomic Practices

0-3 Years	4-10 Years	10+ Years
Validate soil organic carbon impact for crop residue removal, applicable to all U.S. growing regions.	Develop systems that sequester soil carbon and enable carbon realloca-tion for energy applications.	Conduct R&D to test and demonstrate a minimal production system with either direct use or recy-cling of all components. Increase the yield of useful biomass per acre by a factor of two or more.
Identify and analyze data on the potential environmental impacts of aggressive, intensive agriculture (e.g. soil erosion, runoff, water use).	Test and demonstrate technology designed to reduce nitrogen and phosphorous run-off.	
Understand, develop, and demon-strate the potential increase in productivity from new crop types.	Develop optimum practices to produce and handle new crops.	
Establish optimum agronomic practices for sustainable produc-tion including existing residue removal.	Develop and test agronomic practices to enhance crop production, improve consistency, and reduce susceptibility to stress.	

C. Feedstock Handling

Objective Four *- Optimize logistics for collecting, storing and combining multiple feedstocks that can be applied for diverse applications in an environmentally sound manner.*

There are a number of opportunities to improve the mechanical systems associated with feedstock handling so that biomass resources can be used for a wider variety of applications. Improvements in feedstock analysis and preparation technologies as well as mechanical harvesting and storage practices should help lower the cost of production and delivery of biomass feedstocks. Research is needed to advance existing technologies and processes in these areas as well as to develop new technologies. This research should enable the handling and storage of unique combinations of biomass feedstocks that are tailored for specific applications, without sacrificing the integrity of the feedstock. Finally, outreach and education are needed to improve public understanding of different applications for animal residue, and the relative environmental impacts of each. Research pathways and example milestones are provided in Exhibit 7. Specific examples of research needs include:

- **Feedstock Density** - Research is needed to improve/develop mechanical technologies that will increase both energy and physical density and reduce moisture content of plant and animal residue-based biomass feedstocks.

- **Sensors** - Quick, cost-effective systems for on-line real-time analysis and maintenance of plant and animal residue-based feedstocks must be developed. These systems should monitor and maintain feedstock quality through the collection, storage, and transportation phases of the product life cycle. They should provide producers with a better understanding of the quality of the feedstock. Additionally, systems should be developed to monitor growth so that harvesting can occur at the optimum time for processing and conversion.

- **Best Practices for Harvesting and Storage** - The biomass/agricultural communities must identify, develop, test, and implement best practices for cost-effective and environmentally sound pre-treatment, collection, storage, and transport of plant and animal residue-based biomass feedstocks. This should lead to improved plant and animal residue recovery, more effective separation, improved handling and storage technologies/procedures, and reduced environmental impacts.

Exhibit 7
Research Pathways: Feedstock Logistics and Handling

0-3 Years	4-10 Years	10+ Years
Evaluate opportunities to increase storage life of feed-stocks.	Test and implement storage systems that enable two or more years of storage without significant degradation of the feed-stock.	
Perform research to overcome major challenges in material handling (e.g. size reduction, drying).	Test and demonstrate improved methods for size reduction, drying, and other material handling improvements that crosscut multiple biomass feedstocks.	Commercialize a range of front-end feed preparation systems that handle a wide variety of biomass feedstocks.
Identify analytical methods for sensor technologies that can be applied to biomass systems.	Test and demonstrate improved low-cost biomass sensors that enable real-time analysis of feedstock characteristics. Use integrated systems in feedstock harvesting and collection.	
Research systems to reduce unit harvesting and storage costs. Evaluate transport innovations, and review lessons learned in other industries and countries.	Test and demonstrate alternative and/or advanced systems for harvest, storage and transportation systems.	Implement machinery and methods that reduce harvesting, storage, and transportation costs by 50% per unit.
Continue to assess and demonstrate to the public that developments in logistics and handling are implemented in an environmentally sound manner.		

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3. PROCESSING AND CONVERSION

Technical advances in biomass processing and conversion technologies will improve conversion efficiencies and increase the output of useful energy and product per unit of input while reducing negative environmental impacts. To facilitate commercially viable and environmentally sound biomass processing and conversion systems for a suite of biobased fuels, power and products, however, research is needed in a number of key areas. As illustrated in Exhibit 8, several of these research areas crosscut biobased fuels, power and products whereas others are specific to one or more end-uses. The remainder of this section describes the research strategy for advancing the efficiency and capabilities of biomass processing and conversion systems.

Expanding the use of biomass for non-food and feed purposes will benefit farmers and rural areas only indirectly and modestly. A more significant development would occur if farmers were able to produce the biofuels or bioproducts themselves, either on the farm or as owners in a local production plant.

Industry, universities, and the national laboratories should work together on pilot plant facilities that focus on evaluating and developing processing technologies for bioenergy and biobased products using a variety of raw material resources. Existing pilot plant facilities should be inventoried and used to prove and optimize production techniques and economics. Special consideration should be given to agriculture and forestry-based cooperatives in licensing technologies developed with government support. Efforts should be made to identify existing facilities that can be converted into or enhanced as biorefineries. Finally, an emphasis should be put on rural-based biorefineries.

Exhibit 8
Crosscutting Benefits of Processing and Conversion R&D

Major R&D Needs	Biofuels Impact	Biopower Impact	Bioproducts Impact
Thermochemical Conversion:			
- Co-Firing	L	H	L
- Direct Combustion	L	H	L
- Gasification	L	H	L
- Anaerobic Fermentation	L	H	L
- Modular Systems	L	H	L
- Pyrolysis	L	H	M
Bioconversion:			
- Physical/Chemical Pretreatment	H	M	H
- Fractionation and Separation	H	M	H
- Residual Solids and Liquids	H	M	H
- Chemical/Enzymatic Conversion	H	M	H
- Catalytic and Chemical Conversion	H	M	H
- Inhibitory Substances	H	M	H
- Separation and Purification	H	M	H
- Biomass Fermentation and Hydrolysis	H	M	H
- Syngas Fermentation	H	M	H
Biorefinery Integration	H	H	H

H – High impact; M – Medium impact; L – Low impact

A. Thermochemical Conversion Pathways

Objective One *- Develop cost-effective, environmentally sound thermochemical conversion technologies to convert biomass feedstocks into useful electric power, heat and potential fuels and products.*

Biomass resources are currently used to produce electric power and/or heat at some industrial facilities across the United States. In addition, biomass is a minor resource for electric utilities across the country. The ability to overcome several significant barriers in thermochemical conversion, however, could increase the role that biomass systems play in providing heat, power, fuels, and products. The initial thrust should be the consumption of residue biomass. Examples of needs in thermochemical conversion research include:

- improvements in biomass gasification technologies to enable the conversion of a wide range of feedstocks, starting with residue biomass,
- the integration of conversion systems with power generation equipment,
- expansion of capabilities to convert low quality gas into electricity,
- methods to overcome technical barriers to thermochemical conversion, such as tar removal, prior to firing biogas in a turbine system, and
- analytical studies on costs, performance, and life-cycle emissions as well as scalability analysis (lab to commercial scale) of thermochemical conversion processes.

The remainder of this section briefly expands upon several areas of research needs. These are further outlined in Exhibit 9.

Co-firing - The environmental benefits of co-firing, as demonstrated in some industrial facilities, include fossil fuel replacement and reduction of negative environmental impacts. In addition, co-firing provides near-term demand for biomass feedstocks that will help develop the infrastructure needed to produce and deliver these resources to stand-alone biomass electric generation facilities and integrated biorefineries. Previous research has led to demonstration projects which show co-firing to be a technically viable option for utilities at the current time. Although technically viable, its use is not widespread. Opportunities still remain to improve operating efficiencies. Greater research as well as increased use in industry could help lead to these improvements. Increased technology transfer and demonstrations from forest products applications could help to increase the spread of co-firing technologies.

Direct Combustion - Direct combustion of biomass is currently in use in the United States. Improvements could still be made, however, to improve operating efficiencies.

Biomass Gasification - Biomass gasification technologies are currently in place. However, there remain a number of technical and economic hurdles to improve their cost competitiveness with other technologies. Specifically, research is needed to reduce the capital costs and improve the operating efficiencies of gasification systems. In addition, research should be performed to enable gasification of a wider range of resources, such as forest and agricultural residues as well as to expand the development and application of black liquor gasification. Gasification technologies should be designed for integration with generating turbines and biorefineries.

Exhibit 9
Research Pathways: Thermochemical Conversion

0-3 Years	4-10 Years	10+ Years
Research to improve thermal efficiency of technologies for co-firing.		Demonstrate co-firing systems that have 40% or greater efficiency than current systems.
Research to improve the efficiency of direct combustions systems. Research methods to reduce water content of feedstock for direct combustion systems.		Enable commercial deployment of direct combustion systems that are cost-competitive with competing systems.
Conduct research to increase rate of decay of resources for anaerobic fermentation. Begin research to reduce capital costs of anaerobic fermentation systems.	Test and demonstrate anaerobic fermentation systems with improved operating efficiencies.	Enable commercial deployment of anaerobic fermentation systems that are cost-competitive with competing systems.
Design technologies to handle low quality gas.	Test and implement technologies to convert low quality gas into useful energy.	
Perform research to reduce capital costs of biomass gasification systems; conduct technology demonstrations.	Demonstrate and deploy biomass (forest and agricultural residue) gasification combined-cycle power generation at capacities up to 1,000 dry TPD.	Enable biomass gasification systems that are cost-competitive with competing commercial systems. Develop and field-test gasification, fermentation, and pyrolysis technologies to produce hydrogen from biomass. Improve biobased power generation efficiencies through wider application in technologies such as fuel cells, microturbines, and other distributed systems.
	Demonstrate and deploy forest products black liquor gasification combined cycle at capacities of 2,000,000 pounds of black liquor solids per day and larger.	
Demonstrate advanced gasification and biosynthesis gas technology suitable for integrated use for power generation on large scale and in distributed systems, in a biorefinery, and for the production of chemicals, materials, and other products.		
Evaluate industry standards for grid connection. Establish standards for modular biomass systems that enable them to connect to the grid.	Enable deployment of modular systems that can operate in a regulated, grid-based system.	
Continue research to improve performance of modular systems.	Conduct testing of modular systems.	
	Demonstrate stand-alone power facilities with 5 to 50MWe capacity, producing electricity from energy crops at an average cost of $0.05/KWh or less.	

Anaerobic Fermentation Gases - Power and fuels can currently be produced from anaerobically generated gases. These include landfill gases, anaerobic digestion of animal manure and food/feed/grain products and by-products, use of wastewater treatment digestion gas, sludge and sewage treatment gases, and other sources. Methane emitted from biomass waste is a potent greenhouse gas, with a global warming potential 21 times that of Carbon dioxide. Over 600 million tons of carbon equivalent methane are produced annually in the United States.[1] There remain opportunities, however, for greater application of anaerobic fermentation. Research should address needs including increasing the rate of decay for residues used in anaerobic fermentation systems. Research is also needed to reduce capital costs and improve operating efficiencies of these systems. Moreover, low intensity methane should be viewed as a resource instead of a waste product. Systems for the use of methane from 10 – 300 Btu/cu. ft. are technically feasible and should be developed and demonstrated. Research on integrating systems with anaerobic digestion provides another opportunity for synergies between technologies.

Modular Systems - Modular systems are currently available and used in the United States and internationally. However, advances need to occur in the development of modular systems and distributed small-scale generation of less than 1 MW. Research to make these systems cost competitive is needed including research to reduce their capital costs. Systems should be developed that can consume small quantities of organic waste or dedicated resources for distributed generation of power and heat locally for use on-farm, on-site, and in small industrial systems. The alternatives developed could include integration of modular biomass systems with fuel cells, microturbines, and other distributed systems. Resources include food/feed/grain processing plant residue, fats and oils, nutshells, corncobs, tomatoes, carrots, fruit, rice hulls, as well as uncontaminated urban wood residue and farm animal waste. Significant R&D opportunities in this area are the development of scaled-down, skid-mounted or mobile installations and fuel concentrators to increase energy density. Significant opportunities for modular systems exist in low value by-products from grain, soy, wood and other processing systems, and in farm and forest residues where the high cost of transporting biomass to larger facilities can be avoided. Rural communities and farmers could benefit if modular systems are developed that can be deployed to offset power costs in grid-based systems in the United States. Industry standards for grid connection should be simplified and new standards developed so that modular biomass systems can be easily connected to the grid. The waste biomass from any biorefinery that has no other value will still be able to be converted into electricity.

B. Bioconversion

Objective Two - *Develop economically viable and environmentally sound bioconversion processes/technologies for commercial application of a range of biobased fuels and products.*

Advances in biochemical conversion processes will increase the variety of biofuels and biobased products that can be cost-competitively produced from biomass resources. For example, research is needed to enable conversion of multiple sugar streams and lignocellulosic materials to useful fuel or value-added products. In addition, research is needed to develop enzymatic pretreatment methods for increasing the efficiency of biofuels production. See Exhibit 10 for examples of research pathways. Examples of bioconversion research needs are in two general categories: Processing and Conversion.

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1. U.S. Environmental Protection Agency, Global Warming Site: National Emissions, http://www.epa.gov/global warming/emissions/national/methane.html.

Processing

- Physical and chemical pretreatment prior to fermentation
- Biomass fractionation and separation technologies
- Utilization of residual solids and liquids

Conversion

- Chemical/enzymatic conversion processes to fermentable sugars
- Addressing the problem of inhibitory substances in sugar streams
- Separations and purification

A discussion of research needs in these areas follows. Assurance of environmental improvement is needed for all these technologies.

Processing

Improved methods and technologies for processing biomass feedstocks are needed to increase both the economics and technical capabilities of bioconversion systems. Specific research needs include:

Physical and Chemical Pretreatment Prior to Fermentation - Improvements are needed to improve physical and chemical pretreatment of biomass feedstocks prior to fermentation. This may include new enzymes and/or new methods for enzyme pretreatment.

Biomass Fractionation and Separation Technologies - Traditional agriculture and forest crops, urban waste, and crop residues represent a major source of readily available complex proteins, oils, and fatty acids as well as simple and complex sugars to be used as raw materials. These materials are available at low cost in localities across the United States. There is a need for R&D to develop low-cost chemical and biological processes including new chemistry and thermochemical synthesis that can break down these molecules and separate the resulting components into purified chemical streams. New concepts need to be developed and past separation technologies should be reexamined to reduce costs in downstream processes.

Utilization of Residual Solids and Liquids - Currently, residual biomass resources exist in the form of plant, animal, and other residues. These residues can be used to develop value-added fuels, chemicals, materials, and other products. Research should be performed to develop cost effective methods for processing solid and liquid residues such that they become economically viable biomass resources.

Conversion

Chemical/Enzymatic Conversion Processes - New cost-effective methods of chemical/ enzymatic conversion should be developed and tested to make greater utilization of biomass resources. Specifically, scalability analysis of biochemical conversion systems is needed.

Catalytic and Chemical Conversion - Catalytic and chemical methods for converting vegetable oils and animal fats into biodiesel are currently in use. R&D is necessary to improve the efficiency of these processes, to develop new processes, and to make processes more cost-competitive with non-biobased products.

Inhibitory Substances in Sugar Streams - Research is needed to overcome the barriers associated with inhibitory substances in sugar streams. For example, methods to enable removal of catalytic inhibitors should be developed. Similarly, catalysts could be engineered to enhance their tolerance.

Separations and Purification - Research is needed on engineering and biological principles as well as combinations of both to improve feedstock separation and product purification.

Biomass Fermentation and Hydrolysis - Research is needed to enhance the fermentation and hydrolysis of fiber, oil, starch, and protein fractions of crop components and processing by-products. In addition to the need to enable more rapid conversion of cellulose to a fermentable substrate, there is a need to develop new fermentation technologies to enable production of base chemicals and chemical intermediates from the wide range of existing crop components.

Syngas Fermentation - Research to improve catalytic synthesis of gases to chemicals as well as to improve pyrolysis to produce chemicals is also needed. Processing systems must optimize both mass transfer of oxygen and nutrients for bioorganisms and the fermentor environment.

Exhibit 10
Research Pathways: Bioconversion

0-3 Years	4-10 Years	10+ Years
Conduct R&D to overcome barriers to conversion of lignocellulosic materials to biomass fuels/products. Develop/test enzymatic pre-treatment methods to facilitate development of biomass fuels/products. Test and demonstrate technologies to lower cost of production for biofuels/products to a level competitive with petroleum-based fuels/products. Demonstrate enzymes and organisms to replace chemical catalysts for use in biochemical conversion, where appropriate. Perform scalability, environmental, and cost analyses of biochemical conversion processes.	Perform R&D to optimize the process developed in years 0-3. Drive down cost of investment and operating costs for the technologies developed. Replace chemical catalysts with new improved enzymes and organisms for use in biochemical conversion, where appropriate. Conduct R&D and test methods for metabolic engineering of microorganisms and feedstocks for biochemical conversion of biomass resources to value-added products in years 0-3. Deploy successful developments and demonstrations.	Perform R&D to enable biological conversion of biomass resources to hydrogen. Improve metabolic engineering for production organisms. Test and demonstrate metabolic engineering of microorganisms.
Separations & Purification: - Investigate barriers to large scale systems with high quality, high purity outputs. - Increase utilization of residual biomass. - Enhance separation and purification procedures including separation of dilute mixtures and separation of single proteins from protein mixtures.	Separations & Purification: - Achieve separation of dilute mixtures. - Achieve separation of single proteins from protein mixtures. - Investigate barriers to large scale systems that have high quality, high purity outputs. Deploy successful developments and demonstrations.	
Perform R&D on the use of biosynthesis gas as a significant feedstock to fermentation. Research improvements in fermentation methods. Test and demonstrate enhanced methods for fermentation and hydrolysis.	Develop more cost-competitive fermentation and hydrolysis systems. Deploy successful technologies.	
Research bioconversion methods to increase use of solid and liquid biomass residues. Test and demonstrate bioconversion methods for a wider range of solid and liquid biomass feedstocks.	Develop cost-competitive bioconversion methods for solid liquid residues.	
Utilize biopulping and other pulping research to develop and demonstrate separation of wood into cellulosic, hemicellulose, and lignin components.	Develop technology to produce multiple value-added products from lignin and other biomass components.	
Research enhanced methods for chemical and enzymatic conversion. Test and demonstrate improved methods for chemical/enzymatic conversion.	Develop more cost-competitive chemical and enzymatic conversion.	
Perform catalytic research to increase the range of biomass feedstocks (e.g. fats and oils); overcome barriers to inhibitors in sugar streams. Test and demonstrate new catalysts for bioconversion.	Enable commercial readiness of catalysts for bioconversion.	
Continually assure that process and conversion developments will lead to environmental improvements.		
Convert residual waste into electricity and heat.		

C. Biorefinery Integration

Objective Three *- Advance the development of biorefineries that 1) efficiently separate biomass raw materials into individual components, and 2) convert these components into marketable products, including biofuels, biopower, and conventional new bioproducts.*

Biorefineries already exist in some agricultural and forest products facilities (e.g. corn wet milling and pulp mills). These systems can be improved through better utilization of residues; new biorefineries can be enhanced by applying the lessons learned from existing facilities to comparable situations.

Biorefineries can become markets for locally produced biomass resources and simultaneously provide a local and secure source of fuels, power, and products. Optimized systems like biorefineries will potentially use complex processing strategies to efficiently produce a diverse and flexible mix of conventional products, fuels, electricity, heat, chemicals, and material products from biomass. Example research pathways are outlined in Exhibit 11. Examples of research needs include but are not limited to:

- Further evaluation, development and deployment of the biorefinery concept for local and regional markets.

- Utilization of existing biomass processing and conversion facilities in the development of biorefineries.

- Development of new cost-competitive biomass technology platforms for additional biorefinery concepts.

- Bioconversion of sugars to products such as polyols or other products that can be used to produce chemicals, materials, or other biobased products.

- Development and commercialization of the conversion of vegetable oils to hydraulic fluids, lubricants, and monomers for a wide variety of uses in plastics, coatings, fibers, and foams to enable a biodiesel / bioproducts biorefinery.

- Development of alternatives to petroleum-based chemicals, polymers, plastics, and synthetic fibers.

- Development of alternatives to petroleum-based additives in the polymer industry including dyes, stabilizers, and catalysts.

- Creation of rural-based biorefineries that are modular, and produce high value products; residual waste from the biorefinery should be converted into electricity and useful heat.

In addition, efforts should be made to perform biorefinery pilot plant demonstration projects. Industry, universities, and national laboratories should work together on pilot plant facilities that focus on evaluating and developing processing technologies for bioenergy and biobased products using a variety of raw material resources. Existing pilot plant facilities should be inventoried and used to prove and optimize production techniques and economics. Special consideration should be given to agriculture and forestry-based cooperatives in licensing technologies developed with government support. Efforts should be made to identify existing facilities that can be converted into or enhanced as biorefineries.

Exhibit 11
Research Pathways: Biorefinery Concept

<table>
<tr><th>0-3 Years</th><th>4-10 Years</th><th>10+ Years</th></tr>
<tr><td rowspan="2">Research bioconversion and other methods to convert sugars to value-added products (e.g. polyols and other chemicals).

Explore and define modular and distributed systems approaches to producing a suite of bioproducts and bioenergy.</td><td>Test and demonstrate advanced applications of bioconversion in biorefineries.

Implement demonstration facilities for biorefining with multiple output types: power, fuels, chemicals, and products.</td><td rowspan="2">Implement small to large scale, multi-product biorefineries.</td></tr>
<tr><td>Demonstrate and commercialize conversion of oils to value-added products and chemicals.</td></tr>
<tr><td></td><td>Design processes for hydrogen production from biomass resources.</td><td>Test and implement cost-competitive processes for hydrogen production from biomass.</td></tr>
<tr><td colspan="2">Advance gasification, pyrolysis, and fermentation technologies to produce hydrogen from biomass resources.</td><td>Test and implement gasification, pyrolysis, and fermentation technologies for biomass-to-hydrogen production.</td></tr>
<tr><td>Initiate biorefinery pilot plants for new biobased products.

Convert existing operations, such as forest products facilities and corn wet mills, into biorefineries.</td><td></td><td></td></tr>
<tr><td>Run an initial analysis of biorefinery locations to encourage rural development.</td><td>Develop and build biorefineries based on the analysis to improve rural economies.</td><td></td></tr>
<tr><td>Develop means to convert intractable residues from the biorefinery into electricity and heat; pilot demonstrations.</td><td>Demonstrate conversion of intractable residues from the biorefinery into electricity and heat.</td><td></td></tr>
<tr><td>Develop means to keep methane from biomass sources out of the air for greenhouse gas value.</td><td>Demonstrate technologies for recovering or converting low-energy methane for greenhouse gas value.</td><td></td></tr>
<tr><td colspan="3">Continually assure that biorefinery development leads to environmental improvement.</td></tr>
</table>

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4. Product uses and distribution

The Biomass R&D Act of 2000 encourages the development of environmentally sound biobased fuels, chemicals, building materials, electric power, or heat. However, there are a number of barriers to the development, distribution, and application of these technologies that will require R&D solutions. Moreover, simply increasing the use of biomass to produce electric power, heat, or other useful products is not the ultimate goal. Ultimately, research should enable a higher level of output of useful fuels, power, and products per ton of biomass inputs. This section describes research strategies to increase the use, efficiency, and sustainability of environmentally sound biobased fuels, power, and products in the economy.

A. End-Products and Distribution Systems

***Objective One** - Advance the understanding of biomass applications to expand existing markets, create new markets, and improve product distribution for environmentally sound bioenergy and biobased products.*

***Objective Two** - Identify and develop high value products from biomass feedstocks.*

***Objective Three** - Identify and develop distribution systems, and locate processing and conversion facilities in proximity to biomass resources, to maximize rural development and minimize negative environmental impacts.*

Before the opportunities available from biomass technologies can be fully realized, targeted research activities are needed to improve markets and distribution systems for environmentally sound bioenergy and biobased products. Research pathways are outlined in Exhibit 12. Specific research needs include:

- **Biofuels Utilization Research** - Research must examine the fundamental properties of biofuels in pure form and in combination with petroleum-based fuels. For example, in the case of ethanol, fundamental research could help overcome questions of vapor pressure, ozone impacts, ethanol life-cycle impacts, and transportation.

- **Properties of Biofuels** - Research and testing activities are needed in several areas to improve the properties and marketability of biofuels. These include:
  - reducing the volatility of ethanol,
  - increasing the flash point of biodiesel, and
  - improving the gel/pour point of biodiesel and reducing NOx emissions.

- **Ethanol Distribution in Pipelines** - Tests and demonstration projects on transporting ethanol by pipeline are needed. These activities must emphasize overcoming the problem of vapor pressure as well as decrease NOx and ozone emissions.

- **Biorefinery Pilot Plant Demonstration Projects** - Industry, universities, and national laboratories should work together on pilot plant facilities that focus on evaluating and developing processing technologies for bioenergy and biobased products using a variety of raw material resources. Existing pilot plant facilities should be inventoried and used to prove and optimize production techniques and economics. Special consideration should be given to agriculture and forestry-based cooperatives in licensing technologies developed with government support. Efforts should be made to identify existing facilities that can be converted into or enhanced a biorefineries. Finally, an emphasis should be put on rural-based biorefineries.

- **Gasification -** Innovative technologies need to be developed to solve the problems of animal litter and manure.

- **Hydrogen** - There are opportunities for biomass resources and technologies to contribute to a future hydrogen economy. Advances are needed in gasification, pyrolysis, and fermentation technologies to produce hydrogen from biomass crops, plant residues, or animal wastes. Federal programs involved in biomass research should coordinate closely with hydrogen research programs to identify and develop opportunities for using biomass to produce hydrogen. Research related to the use and distribution of hydrogen should be taken on by the federal hydrogen program.

- **Standards for Biobased Products** - Consumers should be able to make informed decisions regarding the performance, biodegradability, and other characteristics of biobased products versus competing products. Research should be performed to develop standards for biodegradability of biobased products. Performance standards should be established for biodegradability that are superior to existing standards for competing fossil-based products.

Exhibit 12
Research Pathways: End-Products and Distribution Systems

0-3 Years	4-10 Years	10+ Years
Research fundamental properties of biofuels in pure form and in combination with petroleum. Reduce Reid Vapor Pressure of ethanol / gasoline mixtures.	Improve properties of biofuels (i.e. flash point, volatility, etc.).	
Test and demonstrate transportation of ethanol in an existing pipeline used for petroleum products. Reduce pipeline emissions.	Obtain broad access to petroleum pipeline system for ethanol distribution.	
Develop and commercialize new environmentally sound, higher-value biobased chemicals, products, or materials with sustainable economics.		
Conduct research to develop standards for biodegradability.	Establish performance standards for biobased products that are comparable with those of competing products.	
Evaluate and assure that new biobased products are environmentally beneficial relative to their fossil fuel equivalents.		

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5. Public policy measures to support biomass development

A number of public policy measures can be implemented to improve the status of biomass technologies in the marketplace. For example, consistent long-term federal policies are necessary to ensure the availability of loans and investment funding, encourage venture capital investment, and provide a sound footing for the development of new technologies. Current incentives, such as the ethanol tax incentive, have catalyzed the development of the fuels industry. To maintain the growth of the industry, equitable financial incentives, which would include tradable tax credits, should continue and incentives for other bioenergy and biobased products should be investigated. For example, definitions of biomass used in the U.S. Tax Code (e.g. section 45) should be broadened to ensure that the entire range of environmentally sound biomass resources are included; non-sustainable resources should be excluded. Incentives should apply to both existing and new technologies and facilities.

Moreover, increased integration and/or coordination is needed between the U.S. Department of Energy (DOE), the U.S. Department of Agriculture (USDA), and other federal agencies in performing bioenergy and biobased products research, working with industry to identify research priorities, and transferring research results to industry. Both the Environmental Protection Agency and the U.S. Department of the Interior, as well as states and counties, should be involved in ensuring the greatest positive results for the environment and the use of public lands.

The following specific policy proposals were identified as having potential to advance environmentally-sound biomass technologies and achieve the goals set forth in the Vision. The executive branch of the government should assess the economic and environmental benefits that these policies could produce and clearly recommend to the legislative branch if and how to proceed with these issues.

Objective One *- Promote the commercialization of successfully demonstrated environmentally-sound biobased technologies.*

Objective Two *- Outline the institutional and policy changes needed to remove the barriers to economically sound development of sustainable biomass systems.*

Objective Three *- Ensure that the biomass technologies developed are environmentally sound and move the country in the direction of sustainable biomass systems.*

Objective Four *- Enhance opportunities for rural economic development.*

A. Economic Analysis

Currently, there are many agricultural and energy related policies, incentives, and other programs that may or may not encourage greater use of biomass resources and technologies. An economic analysis of policies to promote the commercialization of successfully demonstrated environmentally-sound biobased technologies should be prepared and widely distributed. This will help to focus future activity in sound policy and incentive development by providing a basis for knowledgeable choices among alternatives and allowing the cost of difficult to quantify benefits, such as energy security and environmental benefits, to be understood.

B. Life Cycle Assessment

Life cycle cost, resource use, and environmental impact assessments must be performed for specific energy resources, chemicals and other products produced from biomass. The results should be compared to similar life cycle analyses on conventional processes for producing energy and chemicals to evaluate the relative costs and benefits of each. Life cycle stages should begin with resource production and continue through transportation, processing, conversion, end-use, and disposal/recycling. This will provide a balanced and meaningful comparison between biobased processes and competing processes in terms of both internal and external costs and benefits. The results of life cycle analyses should also be used to identify where costs and negative environmental impacts can be reduced and, subsequently, to test methods for reducing those costs. Moreover, life cycle cost and benefits of biomass technologies should be a component of public education. Greenhouse gas emission offsets should be considered when conducting economic and life cycle assessment.

C. Procurement and Markets

Federal Procurement - The use of biobased fuels, power, and products should be encouraged through procurement standards for federal fleets, renewable energy purchasing requirements for federal facilities, and procurement requirements for biobased products. Similar programs for states, local governments, and industrial fleets should be encouraged. The government should work to develop these mechanisms with the goal of creating positive environmental and efficiency impacts while driving the fuels market. Federal procurements should favor farmer-owned production facilities; state and local government procurements can be encouraged to do the same.

Performance Standards - Performance standards should be developed for bioenergy and bioproducts with ASTM and other standards organizations.

Renewable Portfolio Standard - The use of biopower should be encouraged through a renewable energy standard that applies to all electricity sellers at retail. Environmentally sound biopower should be eligible to meet the standard and a credit system should be used to simplify meeting the standard where there is little or no indigenous qualifying power.

Renewable Fuels Standard - The use of renewable fuels should be encouraged through a renewable fuels standard that applies to all transportation fuels. This standard should be designed to maximize environmental benefit by distinguishing between the life-cycle environmental impacts of different fuels.

Biofuels in Watercraft - Requirements should be put in place for the use of biolubricants and biofuels in all watercraft. This could reduce some of the threats of hazardous fuel spills in waterways.

Additional Procurement Standards - Standards should be designed to promote products and processes that have both economic and environmental benefits. A number of possible standards and incentives could be implemented to promote biobased fuels, power, and products, including:

- Publish a GSA-approved biobased products list for federal procurement.
- Develop targets for federal government purchases of biobased fuels, power, and products of 10 percent penetration by 2004 and 20 percent by 2006. Develop an internal tracking system to measure federal government use of biobased fuels, power, and products of total relevant fuel, power, and product purchases.
- Favor farmer-owned production facilities in federal procurement.
- Work with states to enact legislation that increases state purchases of biobased products and bioenergy.
- Create incentives to encourage farmers to grow crops used for biobased fuels and products.
- Ensure that policies to reduce greenhouse gas emissions provide incentives to increase the use of environmentally sound biomass resources, recognizing that methane has substantially greater global warming potential than carbon dioxide.

D. Regulatory Measures

Review Current Authorities - Identify existing federal and state authorities that can be used to facilitate, or act as barriers to, early adoption of environmentally-sound biobased technologies and products. This should include a survey of relevant policy and regulatory issues across federal and state governments (e.g. agriculture, forestry, energy, air, water, soil, environmental, grid access, recycling standards, access to biomass sources). Priority should be given to processing biomass related permit applications at environmental agencies. The DOE and USDA should be charged with the task of coordinating an interagency working group on biobased technologies with the potential to positively impact the production of biobased power, fuels, and products. There should not be discrimination among existing and new technologies and facilities.

Develop Regulatory Certainty - While it is essential to periodically review and improve regulatory standards and programs to reflect current knowledge and market experience, regulatory uncertainty has kept biomass-related industries and financial institutions from investing in biomass technologies. To the extent possible, regulatory systems should be consistent over the long term.

Removal of Barriers to Distributed Generation - Because biomass resources are distributed nationwide and can be used to produce electric power in the manufacturing sector, farm communities, and other areas of the economy, biomass represents a viable and flexible resource for distributed generation. DOE and USDA should work together to ensure that investment in environmentally sound biomass technologies is not impeded through the use of unduly burdensome interconnection standards, inflated insurance requirements, or other artificial market barriers. Equitable access to the electricity grid for small, geographically dispersed power generators should be ensured.

Methane Gas - The government should identify and develop regulatory mechanisms to maximize the use of recovered methane from landfills, wastewater treatment facilities, confined area feedlot operations, and other sources for electricity generation.

EPA New Source Review - Evaluate impacts of EPA's New Source Review restrictions for co-firing with biomass and revise them to encourage environmentally sound biopower development.

Environmental and Other Permitting - Develop approaches for fast-track decision-making and streamlined procedures and permitting for environmentally sound, promising, new biobased technologies.

E. Incentives

Federal Incentives - The government should encourage the use of biobased fuels, power and products through the use of equitable financial incentives, which include tradable tax credits, investment credits, and depreciation schedules. Federal incentive programs should favor farmer-owned production facilities (e.g. the CCC match for expanded ethanol and biodiesel facilities). Similarly, USDA energy efficiency and renewable energy incentives under the Energy title of the Farm Bill should favor on-farm, or farmer-owned facilities. These energy efficiency improvements should include changes in cultivation and livestock practices that lower pollution as well as measures to treat pollutants at “the end of the pipe.” Federal incentives should not subsidize the waste disposal costs of businesses. In addition, federal incentives for methane-to-electricity generation should be allotted on a per ton of manure disposed of basis rather than per kilowatt-hour generated.

Financial Support for Existing Facilities - While incentives are often designed to drive investment in new facilities, many existing biomass based facilities are underutilized and warrant financial support to achieve full commercialization.

Public Benefit Funds - The use of biopower could be encouraged through financial incentives collected through a non-bypassable surcharge on all retail electricity sales to support energy efficiency and renewables. Such funds should be available to all electricity users connected to the electric grid.

F. Biomass Resource Supply

Inadequate Rural Infrastructure - Transportation systems (road and rail) need to be improved to facilitate the cost-competitive transport of biomass feedstocks from the farm and forest to the point of conversion. Specific consideration should be given to locating processing and conversion facilities as close to biomass raw materials as possible, thereby improving rural economies and reducing the environmental impacts of transportation.

Enhancing the Supply of Biomass - Some of the land set aside by the Conservation Reserve Program (CRP), and the reduction of fuel loads in overly dense and overstocked forests, could be considered as sources of biomass for use in biopower, biofuels, and biobased products. For example, some CRP lands may be suitable for harvesting perennial grasses, trees, and producing energy crops while preserving soil and providing other benefits including wildlife habitat, carbon storage, and clean water.

G. Education and Outreach

Technology Transfer - Federal agencies should assist in demonstrating novel biomass technologies. Examples include integrated biorefineries that demonstrate the cost-effective sustainable production of a host of biobased fuels, power, and products.

Perception of Biomass - Many in the public are not aware of the benefits and ease of using biomass technologies and biobased products. Education and promotional campaigns are needed to communicate the performance and reliability associated with environmentally-sound biomass technologies, and to distinguish them from those that are environmentally harmful. Science-based education and outreach programs and materials should be developed that are directed toward classroom teaching and consumer education. K-12 outreach programs should also be developed to promote the environmental benefits of biomass technologies and products, and to explain how they compare with existing resources.

Centers of Excellence - Centers of Excellence should be established at colleges and universities to enhance the nation's biobased products and bioenergy research capacity. These Centers of Excellence must play an important role in the education and training of the engineers, scientists, and business leaders that will catalyze the formation of the biobased product and bioenergy sector of the U.S. and world economy. Finally, these Centers of Excellence should contribute to local and regional biobased products and bioenergy economic development initiatives.

Biobased Logo/Labeling - A broad group including biobased industry, non-governmental organizations, etc. should develop a biobased logo to be associated with all environmentally sound biobased products, fuels, and power.

Vehicle Warranties that Accept Biofuels - The biofuels industry should work with automakers to educate them on biofuels and to promote vehicle warranties that apply when biofuels are used.

H. R&D Investment

Technology Verification and Financial Risk - Pre-commercialization costs are very high, making it difficult for small start-up companies to develop and produce new biobased products on a large scale. Moreover, the financial risk associated with developing and verifying biomass technologies precludes many companies from investing in R&D. Similarly, the lack of market experience with many advanced biomass technologies makes financing difficult to obtain.

Fostering Innovation - It is difficult for inventors and innovators to take ideas from the prototype stage to testing and commercialization. Networks should be established to provide technical and/or grant assistance to innovators in the biomass field.

Risk Sharing - Encourage non-federal involvement in research and development by requiring some non-federal economic participation in government funded university research and other research and development efforts. The more basic the science, the less the required participation. By the demonstration phase, non-federal cost share should be at 50 percent. Proposals for federal funding should include economic, energy, and environmental benefits. Information about these benefits should be shared with the merit reviewers.

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APPENDICES

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APPENDIX I
COMMITTEE MEMBERS – 2002

Biomass Research and Development Technical Advisory Committee
List of Members

Name	***Organization***
Roger Beachy	Donald Danforth Science Center
Robert Boeding	National Corn Growers Association
Dale Bryk	Natural Resources Defense Council
Robert Dorsch	Dupont
Glenn English, Jr.	National Rural Electric Cooperative Association
Thomas W. Ewing	Davis and Harman, LLP
Carolyn Fritz	Dow Chemical Company
Stephen Gatto	Bionol Corporation
Brian Griffin	Oklahoma Secretary of Environment
Pat Gruber	Cargill Dow LLC
William Guyker	Life Fellow – IEEE
John Hickman	Deere & Company
Walter Hill	Tuskegee University
William Horan	Horan Brothers Agricultural Enterprises
Jack Huttner	Genencor International, Inc.
F. Terry Jaffoni	Cargill, Inc.
Michael Ladisch	Purdue University
David Morris	Institute for Local Self Reliance
William Nicholson	Potlatch Corporation, Retired
Edan Prabhu	FlexEnergy
William Richards	Richards Farms, Inc.
Philip Shane	Illinois Corn Marketing Board
Larry Walker	Cornell University
John Wootten	Peabody Energy
Michael Yost	Yost Farm, Inc.
Holly Youngbear-Tibbetts	College of Menominee Nation

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APPENDIX II
DEFINITIONS AND TERMS

Agronomy: The science of plant production and soil management.

Anaerobic: Life or biological processes that occur in the absence of oxygen.

Biobased Product: Commercial or industrial products, other than food or feed, derived from biomass feedstocks. Many of these products possess unique properties unmatched by petroleum-based products or can replace products and materials traditionally derived from petrochemicals.

Biocatalyst: Usually refers to enzymes and microbes, but it can include other catalysts that are living or that were extracted from living organisms, such as plant or animal tissue cultures, algae, fungi, or other whole organisms.

Biochemical Conversion Process: The use of living organisms or their products to convert organic material to fuels.

Biodiesel*: Conventionally defined as a biofuel produced through transesterification, a process in which organically- derived oils are combined with alcohol (ethanol or methanol) in the presence of a catalyst to form ethyl or methyl ester. The biomass- derived ethyl or methyl esters can be blended with conventional diesel fuel or used as a neat fuel (100% biodiesel). Biodiesel can be made from soybean or rapeseed oils, animal fats, waste vegetable oils, or microalgae oils. *Note: Biodiesel can in certain circumstances include ethanol-blended diesel. This is an evolving definition.

Bioenergy: Useful, renewable energy produced from organic matter. The conversion of the complex carbohydrates in organic matter to energy. Organic matter may either be used directly as a fuel processed into liquids and gases, or be a residual of processing and conversion.

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

Biogas: A methane-bearing gas from the digestion of biomass.

Biomass: Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood wastes and residues, plants (including aquatic plants), grasses, residues, fibers, animal wastes, and segregated municipal waste, but specifically excluding unsegregated wastes; painted, treated, or pressurized wood; wood contaminated with plastic or metals; and tires. Processing and conversion derivatives of organic matter are also biomass.

Biopower: The use of biomass feedstock to produce electric power or heat through direct combustion of the feedstock, through gasification and then combustion of the resultant gas, or through other thermal conversion processes. Power is generated with engines, turbines, fuel cells, or other equipment.

Biorefinery: A processing and conversion facility that (1) efficiently separates its biomass raw material into individual components and (2) converts these components into marketplace products, including biofuels, biopower, and conventional and new bioproducts.

Biotechnology: A set of biological techniques developed through basic research and now applied to research and product development. In particular, biotechnology refers to the use by industry of recombinant DNA, cell fusion, and new bioprocessing techniques.

British Thermal Unit: Measure of energy based on the amount of heat required to raise the temperature of one pound of water from 59℉ to 60℉ at one atmosphere pressure.

Cellulose: The main carbohydrate in living plants. Cellulose forms the skeletal structure of the plant cell wall.

Co-Firing: The simultaneous use of two or more different fuels in the same combustion chamber of a power plant.

Co-Generation: The sequential production of electricity and useful thermal energy from a common fuel source. Reject heat from industrial processes can be used to power an electric generator (bottoming cycle). Conversely, surplus heat from an electric generating plant can be used for industrial processes, or space and water heating purposes (topping cycle).

Combined Cycle: Two or more generation processes in series, configured to optimize the energy output of the system.

Commercial Sector: An energy-consuming sector that consists of service-providing facilities of businesses; federal, state, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. The commercial sector includes institutional living quarters.

Conservation Reserve Program: A voluntary USDA program whereby agricultural landowners can receive annual rental payments and cost-share assistance to establish long-term, resource conserving covers on eligible farmland. The Commodity Credit Corporation (CCC) makes annual rental payments based on the agriculture rental value of the land, and it provides cost-share assistance for up to 50 percent of the participant's costs in establishing approved conservation practices. Participants enroll in CRP contracts for 10 to 15 years. The program is administered by the CCC through the Farm Service Agency (FSA), and program support is provided by Natural Resources Conservation Service, Cooperative State Research and Education Extension Service, state forestry agencies, and local Soil and Water Conservation Districts.

Corn Wet Milling: A wet mill ethanol plant steeps (soaks in warm water) the corn. This enables separation of the germ, oil, starch, etc.

Densification: A mechanical process to compress biomass (usually wood waste) into pellets, briquettes, cubes, or densified logs.

Electric Utility: A corporation, person, agency, authority, or other legal entity or instrumentality that owns and/or operates facilities for the generation, transmission, distribution, or sale of electric energy primarily for public use. Utilities provide electricity within a designated franchised service area and file form listed in the Code of Federal Regulations, Title 18, Part 141. Includes any entity involved in the generation, transmission, or distribution of power.

Energy Crops: Crops grown specifically for their fuel value. These crops may include food crops such as corn and sugarcane, and nonfood crops such as poplar trees and switchgrass.

Energy Density: The energy content of a material measured in energy per unit weight of volume.

Environmentally Sustainable: An ecosystem condition in which biodiversity, renewability, and resource productivity are maintained over time.

Enzyme: A protein that acts as a catalyst, speeding the rate at which a biochemical reaction proceeds but not altering the direction or nature of the reaction.

Ethanol: Ethyl alcohol produced by fermentation and distillation. An alcohol compound with the chemical formula CH_3CH_2OH formed during sugar fermentation.

Feedstock: Any material converted to another form or product.

Fermentation: The biological conversion of biomass.

Forest Residues: Material not harvested or removed from logging sites in commercial hardwood and softwood stands as well as material resulting from forest management operations such as pre-commercial thinnings and removal of dead and dying trees.

Fossil Fuel: Solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are fossil fuels.

Fuel Cell: A device that converts the energy of a fuel directly to electricity and heat, without combustion.

Gasification: A chemical or heat process to convert a solid fuel to a gaseous form.

Genetics: The study of inheritance patterns of specific traits.

Genetically Engineered Organism: An organism developed by inserting genes from another species.

Genomics: The study of genes and their function.

Greenhouse Gases: Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

Grid: A system for distributing electric power.

Grid Connection: Joining a plant that generates electric power to an electric system so that electricity can flow in both directions between the electric system and the plant.

Hydrolysis: Conversion of biomass into sugars and sugar substrates via chemical or biological processes or through biocatalysis.

Industrial Sector: An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses manufacturing; agriculture, forestry, and fisheries; mining; and construction.

Inorganic Compounds: A compound that does not contain carbon chemically bound to hydrogen. Carbonates, bicarbonates, carbides, and carbon oxides are considered inorganic compounds, even though they contain carbon.

Kilowatt: (kW) A measure of electrical power equal to 1,000 Watts. 1 kW = 3,413 Btu/hr = 1.341 horsepower.

Kilowatt hour: (kWh) A measure of energy equivalent to the expenditure of one kilowatt for one hour. 1 kWh = 3,413 Btu.

Landfill Gas: Gas that is generated by decomposition of organic material at landfill disposal sites.

Lipid: Any of various substances that are soluble in non-polar organic solvents (as chloroform and ether), that with proteins and carbohydrates constitute the principal structural components of living cells, and that include fats, waxes, phosphatides, cerebrosides, and related and derived compounds.

Lignin: An amorphous polymer related to cellulose that, together with cellulose, forms the cell walls of woody plants and acts as the bonding agent between cells.

Life Cycle Assessment (LCA): LCA is an internationally recognized assessment model of a product's impact on energy, economic, and environmental values. LCA extends from "cradle-to-grave": from material acquisition and production, through manufacturing, product use and maintenance, and finally, through the end of the product's life in disposal or recycling. The LCA is particularly useful in ensuring that benefits derived in one area do not shift the impact burden to other places within a product's life cycle.

Methane: An odorless, colorless, flammable gas with the formula CH_4 that is the primary constituent of natural gas.

Municipal Solid Waste (MSW): Garbage. Refuse includes residential, commercial, and institutional wastes and includes organic matter, metal, glass, plastic, and a variety of inorganic matter.

Organic Compounds: Compounds that contain carbon chemically bound to hydrogen. They often contain other elements (particularly O, N, halogens, or S).

Precommercial Thinning: Thinning for timber stand improvement purposes, generally in young, densely stocked stands.

Pyrolysis: The thermal decomposition of biomass at high temperatures (greater than 400℉, or 200℃) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

Quad: One quadrillion Btu (10^{15} Btu). An energy equivalent to approximately 172 million barrels of oil.

Residential Sector: An energy-consuming sector that consists of living quarters for private households. The residential sector excludes institutional living quarters.

Residue: Unused solid or liquid by-products of a process.

Rural: Of or relating to the small cities, towns, or remote communities in or near agricultural areas.

Sewage: The wastewater from domestic, commercial, and industrial sources carried by sewers.

Silviculture: A branch of forestry dealing with the development and care of forests.

Syngas: A syntheses gas produced through gasification of biomass. Syngas is similar to natural gas and can be cleaned and conditioned to form a feedstock for production of methanol.

Therm: A unit of energy equal to 100,000 Btus; used primarily for natural gas.

Transportation Sector: An energy-consuming sector that consists of all vehicles whose primary purpose is transporting people and/or goods from one physical location to another. Vehicles whose primary purpose is not transportation (e.g., construction cranes and bulldozers, farming vehicles, and warehouse tractors and forklifts) are classified in the sector of their primary use.

Urban: Of, relating to, characteristic of, or constituting a city, usually of some size.

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APPENDIX III
EXAMPLE FEDERAL GOVERNMENT PROGRAMS RELEVANT TO BIOBASED PRODUCTS AND BIOENERGY, AND THEIR WEBSITES

U.S. Department of Energy - http://www.energy.gov/
Biomass Research and Development Initiative - http://www.bioproducts-bioenergy.gov
Energy Efficiency and Renewable Energy - http://www.eren.doe.gov/
Biomass Program - http://www.eren.doe.gov/biomass.html
Federal Energy Management Program - http://www.eren.doe.gov/femp/
Hydrogen Information Network - http://www.eren.doe.gov/hydrogen/
Industrial Technology Program - http://www.oit.doe.gov/
Office of Science - http://www.science.doe.gov/
Basic Energy Sciences - http://www.sc.doe.gov/production/bes/bes.html
Office of Fossil Energy - http://www.fe.doe.gov/

U.S. Department of Agriculture - http://www.usda.gov/
Biobased Products and Bioenergy Coordination Council - http://www.ars.usda.gov/bbcc/index.htm
Agriculture Research Service - http://www.ars.usda.gov/
Animal and Plant Health Inspection Service - http://www.aphis.usda.gov/
Commodity Credit Corporation - http://www.fsa.usda.gov/daco/bio_daco.htm
Cooperative State Research, Education And Extension Service - http://www.reeusda.gov/
Economic Research Service - http://www.ers.usda.gov/
Energy Policy and New Use - http://www.usda.gov/agency/oce/oepnu/index.htm
Forest Service - http://www.fs.fed.us/research/
Natural Resources Conversion Service - http://www.nrcs.usda.gov/
Rural Development - http://www.rurdev.usda.gov/

National Science Foundation - http://www.nsf.gov/
Biological Sciences - http://www.nsf.gov/home/bio/
Engineering - http://www.nsf.gov/home/eng/
Mathematical and Physical Sciences - http://www.nsf.gov/home/mps/

Environmental Protection Agency - http://www.epa.gov/
AgStar Program (joint with USDA and DOE) - http://www.epa.gov/agstar/
Comprehensive Procurement Guidelines - http://www.epa.gov/cpg/
Environmental Technology Verification - http://www.epa.gov/etv/
Industry Partnerships, Project XL - http://www.epa.gov/ProjectXL/
Landfill Methane Outreach - http://www.epa.gov/lmop/

Methane Energy - http://www.epa.gov/methane/
Prevention, Pesticides, and Toxic Substances - http://www.epa.gov/oppts/
Research and Development - http://www.epa.gov/ORD/
Science Policy Council - http://www.epa.gov/osp/spc/

Department of Commerce - http://www.commerce.gov/
Advanced Technology - http://www.atp.nist.gov/

Office of Science and Technology Policy - http://www.ostp.gov/

Tennessee Valley Authority - http://www.tva.gov/
Public Power Institute - http://www.publicpowerinstitute.org/