# Multi Year Program Plan
## 2007-2012

Office of the Biomass Program
Energy Efficiency and Renewable Energy
U.S. Department of Energy

**August 31, 2005**

Biomass

# Program Manager's Outlook

As Program Manager of the Biomass Program it is with pride that I present our Multi Year Program Plan. The last couple of years have been extremely exciting and productive for the Program. We have had significant technical breakthroughs through our R&D efforts, have engaged in partnerships with a broad representation from industry, and have, in our opinion, made major improvements in the way we manage and administer our program. Before I discuss our vision and plans for the next five years it is incumbent on me to discuss the changes and events that have allowed us to sharpen our focus and develop a realistic plan designed to optimize efficiency and accelerate the deployment of our technologies. I must also make you aware that this document, as any good program or business plan, is a living document and as we further improve our structure and knowledge base will change to reflect new realities and opportunities especially with the passage of the 2005 Energy Policy Act and our skyrocketing energy costs.

The last couple years have seen us break many technological stalemates. Through industrial partnerships with the National Renewable Energy Laboratory and the largest two enzyme producers we have essentially removed the cost of cellulose enzyme as the major barrier to the economical conversion of cellulose to fermentable sugars. We have through partnerships with industry and our National Laboratory network, proven that biomass derived chemicals are not only achievable but desirable. We are looking forward to near term commercialization of several of these enabled products. We have broadened our technological horizons by developing our platform for products by investments in fungal research and catalysis at the Pacific Northwest National Laboratory. At the same time, our investment at the National Renewable Laboratory in advanced surface characterization and pretreatment capabilities will allow us to accelerate our understanding and improvement in the kinetics of the conversion of cellulosic biomass.

We have also changed the way we do business. We have initiated the development of a "pathway approach". This will allow us to fully integrate fundamental research and applied research utilizing existing feedstocks and infrastructure to accelerate technology deployment in the near term and aiding in the progression toward our long term pathways and goals. We have established a systems integration approach. This, as it develops, will be an important portfolio decision making tool ensuring that R&D gaps are filled, the right partners are engaged and that low impact, poor performing projects do not squander limited resources. The Program has fully embraced and implemented the Project Management Center. This has allowed our technology managers to focus on program and portfolio management, our national laboratories to focus on research and our PMC team to fully focus on managing projects. We have instituted a revamped analysis plan to not only look at the long term but to also define the points at which technology has developed to enable a pathway. We are also taking a comprehensive approach to define the benefits that the program's elements and pathways will provide and the outcomes they will enable. Finally, we continue consultations with the industrial, engineering and financial communities to determine the best and most effective way to plan our procurement activities and solicitations such that they technological systems developed lead to the highest possible likelihood of commercialization.

The plan for the next five years, in short, is continuing and building on our accomplishments. We are working with our current industrial biorefinery and products partners as well as other potential partners for a major solicitation in 2008. We are planning to accelerate the use of agricultural residues as a supplemental feedstock in the solicitation. The solicitation will lead to pre-commercial facilities validating the technical viability and economic feasibility of the near term pathways. The criteria for the validation will be based on the requirements outlined in our deployment discussions with engineers and financiers. It is our expectation that in 2012 the validations will be complete and commercialization along the near term pathways will be enabled. We will continue our drive to produce lower cost sugars and clean syngas enabling our next set of pathways. Our efforts in products will continue to provide economic incentives for continued biorefinery investment and development. In the near term, we will engage the pulp and paper as well as the forest products industries as funding permits. Assuming the availability of funds in out years we will continue to progress down our pathway hierarchy to our programmatic goal of meeting 30 percent of the nations transportation fuel needs as outlined in the joint USDA/DOE Billion Ton Study.

In summary, the plan as we have outlined it, will allow the program to progressively enable increasing amounts of biofuels and biomass derived chemicals and materials from a widening array of feedstocks. The approach we have chosen will not only have a significant impact on oil displacement, at the earliest opportunities, and will facilitate the paradigm shift to renewable, sustainable energy and chemicals in the future.

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# **Section I**: Program Overview

This program overview provides an introduction to the Biomass and Biorefinery Systems R&D Program ("Biomass Program"), including an examination of the external context in which the program operates, the program's history, and reasons for funding a Federal program in this area. In that context the program's mission, vision, goals, outputs and outcomes are described. Also included is a description of the markets in which the program operates.

This section also sets the stage for the remainder of the Biomass Multi-Year Program Plan including:

- Section 2 – Program Critical Functions,
- Section 3 – Technology Research and Deployment Plan, composed of 5 elements, and
- Section 4 – Program Administration.

## 1.1 External Assessment and Market Overview

Over the next 20 years, energy consumption in the U.S. is projected to rise by 30 percent; yet domestic energy production is only expected to grow by 25 percent. Petroleum imports already supply more than 55 percent of U.S. domestic needs, and they are expected to grow to more than 68 percent by 2025 as worldwide oil demand continues to rise and domestic oil production continues to decline. This increased reliance on imported sources of energy threatens our national security, economy and future competitiveness. Biomass is the only domestic, sustainable and renewable primary energy resource that can provide liquid transportation fuels and organic chemicals and materials currently produced from fossil sources. Biomass also supports a technology transition to a hydrogen economy through either gasification or the production and reforming of liquid intermediates such as ethanol, methanol, or bio-oil.

### 1.1.1 Current and Potential Markets

The three major current and potential markets for biomass and biomass related technologies are:

- Transportation Fuels
- Organic Chemicals and Materials
- Electricity

Table 1-1 below shows the primary energy resources that supply these current markets, organized into two groups: biomass resources and non-renewable resources. Table 1-2 shows the primary energy resources that could supply these markets in the future, organized into three groups: biomass resources, non-renewable resources, and non-biomass renewable resources. These are not exhaustive lists, but are intended to help understand complexities of the competitive environment for biomass resources and technologies, both today, and in the future. Priority areas for the Biomass Program are highlighted in Table 2, with the highest priority areas also underlined. Each product market is discussed in more detail below. Competing technologies are discussed in Section 1.1.3, organized by primary energy resource that each of the technologies rely on.

**Table 1-1:** Primary Energy Supplies for Current Markets for Transportation Fuels, Organic Chemicals and Materials, and Electricity

| Primary Energy or Feedstock Source | Product Markets | | |
|---|---|---|---|
| | **Transportation Fuels** | **Chemicals and Materials** | **Electricity** |
| **Current Biomass Resources and Product Markets** | | | |
| Grains | Ethanol | Starches, Sugars, Animal Feeds, Organic Chemicals | |
| Oil Seed Crops | Biodiesel | Industrial Oils, Animal Feeds, Organic Chemicals | |
| Wood | | Paper, Pulp, Wood Products | Steam Cycle, Co-firing with Coal |
| MSW | | | Anaerobic Digestion, Landfill Gas, Combustion w/ steam cycle |
| **Current Non-Renewable Resources and Product Markets** | | | |
| Petroleum | Gasoline, Diesel, Jet Fuel | Petrochemicals | (minor contribution) |
| Natural Gas | (minor contribution) | Organic Chemicals, Inorganic Chemicals | Combined Cycle |
| Coal | (minor contribution) | (minor contribution) | Steam Cycle |
| Nuclear | N/A | N/A | Steam Cycle |

**Table 1-2:** Primary Energy Supplies for Current Markets for Transportation Fuels, Organic Chemicals and Materials, and Electricity

| Primary Energy or Feedstock Source | Product Markets | | |
|---|---|---|---|
| | **Transportation Fuels** | **Chemicals and Materials** | **Electricity** |
| **Current Biomass Resources and Product Markets** | | | |
| Grains | Ethanol | Starches, Sugars, Animal Feeds, Organic Chemicals | |
| Oil Seed Crops | Biodiesel | Industrial Oils, Animal Feeds, Organic Chemicals | |
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| Petroleum | Gasoline, Diesel, Jet Fuel | Petrochemicals | (minor contribution) |
| Natural Gas | (minor contribution) | Organic Chemicals, Inorganic Chemicals | Combined Cycle |
| Coal | (minor contribution) | (minor contribution) | Steam Cycle |
| Nuclear | N/A | N/A | Steam Cycle |
| **Future Biomass Resources and Product Markets** | | | |
| Grains | Ethanol | Starches, Sugars, Animal Feeds, Organic Chemicals, Petrochemical Replacements | |
| Oil Seed Crops | Biodiesel | Industrial Oils, Animal Feeds, Organic Chemicals, Petrochemical Replacements | |
| Wood | Ethanol; Gasoline, Diesel and | Paper, Pulp, Wood Products, Organic | Gasification Combined Cycle |

| | | | |
|---|---|---|---|
| (Forest Products Industry) | other fuels via Biomass-to-Liquids (BTL), pyrolysis with upgrading; H2 | Chemicals and Petrochemical Replacements | |
| Ag. Residues and Energy Crops | Ethanol; Gasoline, Diesel and other fuels via Biomass-to-Liquids (BTL), pyrolysis with upgrading; H2 | Organic Chemicals, Petrochemical Replacements | Gasification Combined Cycle |
| **Future Non-Renewable Resources and Product Markets to Fill the Petroleum Gap** | | | |
| Natural Gas | Gasoline, Diesel and other fuels via Gas-to-Liquids (GTL); H2 | Organic Chemicals, Inorganic Chemicals | Combined Cycle |
| Coal | Gasoline, Diesel and other fuels via Coal-to-Liquids (CTL), Coal Liquifaction, Pyrolysis with upgrading; H2 | Organic Chemicals, Petrochemical Replacements | Gasification Combined Cycle |
| Nuclear | H2 via electricity | N/A | Steam Cycle |
| Tar Sands, Oil Shale | Fuels via Extraction or Pyrolysis and Upgrading | Organic Chemicals, Petrochemical Replacements | (minor contribution) |
| **Future Non–Biomass Renewable Resources and Product Markets to Fill Petroleum Gap** | | | |
| Solar | H2 via electricity; Photobiological H2; Photoelectrochemical H2; CSP Driven H2 | N/A | Photovoltaics, Concentrating Solar Power (CSP) |
| Wind , Hydro | H2 via electricity | N/A | Wind Turbines, Water Turbines |

### 1.1.1.1 Transportation Fuels

The U.S. transportation sector is almost entirely dependent on oil (97 percent), using only small amounts of bioenergy, natural gas, and electricity. In fact, two-thirds of the oil used in the U.S. goes to support our transportation fleet. The most direct and near-term alternative to oil for supplying liquid transportation fuels to the nation could be biofuels derived from biomass. Advantages of using biofuels include: fuel can be added to the existing gasoline and diesel market through a blending strategy; and the customer experiences no noticeable change in how the fuel is pumped into the tank.

Today, biomass-derived fuels—ethanol and biodiesel—play a small, but increasing role in the U.S. transportation market. Although demand for fuel ethanol more than doubled between 2000 and 2004, fuel ethanol accounted for just over one percent of U.S. transportation energy demand in 2004.[1] For the year, 81 ethanol plants located in 20 states produced a record 3.41 billion gallons, a 21 percent increase from 2003, and 10 percent since 2000.[2] Demand for ethanol is expected to increase, and new plants and expansions are currently under construction, representing an additional 750 million gallons of fuel ethanol production capacity. In addition, biodiesel production was estimated at 20 million gallons in 2001. Biodiesel capacity is between 60 and 80 million gallons per year.[3]

[1] DOE/EIA, July 2005 Monthly Energy Review, Table 2.5 http://www.eia.doe.gov/emeu/mer/pdf/pages/sec2_11.pdf
[2] Renewable Fuels Association, 2005 Ethanol Outlook, http://www.ethanolrfa.org/outlook2005.pdf
[3] National Biodiesel Board.

In the longer term, synthetic liquid transportation fuels, including diesel, methanol, di-methyl ether, and hydrogen, can be produced from biomass using the thermochemical conversion technologies developed for gas-to-liquids (GTL) processes (i.e., Fischer-Tropsch). Because biomass-to-liquids (BTL) fuels are dense in hydrogen and virtually sulfur free, they are cleaner, more efficient and offer advantages for fuel cell application. European industries are already beginning to invest in this technology development. Choren Industries is building a 13,000-metric ton BTL demonstration facility in Germany; the plant will produce synthetic diesel fuel from wood and other biomass. Both DaimlerChrysler and Volkswagen are collaborating with Choren Industries on the production of what the company calls SunDiesel. The USDA estimates that Fischer-Tropsch diesel using biomass as the feedstock BTL could replace up to 13 percent of Germany's current diesel use.[4]

### 1.1.1.2 Chemicals and Materials

Petroleum-derived chemicals and materials play an integral role in the U.S. economy. About one-eighth of the total oil consumed in the U.S. is used to make these materials—industrial and consumer goods, organic chemicals, lubricants and greases.[5] Currently, of the one hundred million metric tons of fine, specialty, intermediate, and commodity chemicals produced annually in the U.S., only 10 percent are biobased.[6] Many petrochemically-derived products can be replaced with industrial materials and products processed from biomass. Organic chemicals, including plastics, solvents and alcohols (175 billion pounds in 2001), represent the largest and most direct market for bioproducts based on similar basic components (building blocks).[7] The market for specialty chemicals, much smaller than organic chemicals, is growing at a rate of 10 to 20 percent annually, and offers opportunities for high-value biobased products.[8]

Today, the established pulp and paper and forest products industries operate thousands of facilities, producing a wide variety of bioproducts. In addition, there are about 250 companies that produce a range of bio-based product lines.[9] Some of the biobased products manufactured today include soybean oils and inks, pigments and dyes, paints and varnishes, soaps and detergents, industrial adhesives, biopolymers and films, composite materials, activated carbon, oxyfuel additives, phenols and furfural, specialty chemicals, acetic and fatty acids, industrial surfactants, and agricultural chemicals.[10]

The price of bioproducts remains high compared to petroleum based products, largely due to the high conversion costs for biobased chemicals and materials. Even so, the market for bioproducts

[4] Green Car Congress, March 2005, http://www.greencarcongress.com/biomasstoliquids_btl/
[5] Winning the Oil Endgame: Innovation for Profits, Jobs, and Security, Amory B. Lovins, et al., Rocky Mountain Institute, 2004.
[6] NRC
[7] Winning the Oil Endgame: Innovation for Profits, Jobs, and Security, Amory B. Lovins, et al., Rocky Mountain Institute, 2004.
[8] Biobased Industrial Products: Research and Commercialization Priorities, NATIONAL ACADEMY PRESS, Washington, D.C. (2000) http://www.nap.edu/books/0309053927/html
[9] "Fostering the Bioeconomic Revolution in Biobased Products and Bioenergy - An Environmental Approach" by the Biomass Research and Development Board, January 2001 http://www.bioproducts-bioenergy.gov/existsite/pdfs/strategicplan.pdf
[10] Biobased Industrial Products: Research and Commercialization Priorities, NATIONAL ACADEMY PRESS, Washington, D.C. (2000) http://www.nap.edu/books/0309053927/html

is growing. A number of key players in the chemical industry are partnering with traditional agricultural processing companies in the development of bioproducts, including Cargill's NatureWorks venture to commercialize polylactic acid polymers (biomaterials) derived from corn starch; Metabolix's PHA polymer production; and DuPont's 3GT polymer platform.[11] Ventures like these will allow companies to leverage each other's expertise, and effectively explore biobased plastics and other areas together. In 1999, the National Research Council predicted that bio-materials could ultimately displace over 90 percent of petrochemical feedstocks. Vigorous industrial activity to exploit today's even better techniques suggests the first 1 Mbbl/d (what unit is this?) is realistic by 2020.[12]

In the future, biobased chemicals can also be produced from biomass using the thermochemical conversion technologies developed for gas-to-liquids (GTL) processes (i.e. Fischer-Tropsch). In addition to producing middle distillates for transportation fuels, the process also produces naphtha for chemical feedstocks, and normal paraffin for detergent feedstocks and lubricant base oils.

#### 1.1.1.3 Electricity

Fossil fuels dominate U.S. electricity production, accounting for about 77 percent of electricity produced (coal-51%, natural gas-16%, oil-3%). Although the construction of new natural gas-fired, combined cycle plants will significantly increase the natural gas contribution to total electricity generation (24%), coal-fired power plants are expected to continue supplying most of the nation's electricity through 2025 (50%). Oil will continue to play a very small role in U.S. electricity production, so substituting biomass for oil in this sector will have little direct impact on reducing U.S. oil dependence.

The biomass power industry grew rapidly from the late-1970s through the mid-1990s—from less than 200 MW of biopower capacity in 1979 to 7,000 MW today. In recent years, the growth rate of the biopower industry has slowed, and currently, bioenergy—in pulp and paper plants, domestic wood burning, and waste to energy—accounts for just 1 percent of total electricity generation. With more than 500 facilities in the United States using wood or wood waste to generate electricity, the forest products industry is the largest contributor to the biopower generation capacity in the U.S.[13] Electricity from biomass combustion is projected to more than double by 2025 (1.4 percent of total electricity generation), with 49 percent of the increase coming from dedicated power plants, and the rest primarily from combined heat and power.[14]

In addition to direct combustion of biomass, co-firing biomass in coal-fired boilers is a straightforward and inexpensive way to diversify the fuel supply, reduce coal plant air emissions, divert clean biomass from landfill disposal, and stimulate the biomass power industry. Biomass is the only renewable energy technology that can directly displace coal use. Because coal-based

[11] Winning the Oil Endgame: Innovation for Profits, Jobs, and Security, Amory B. Lovins, et al., Rocky Mountain Institute, 2004.
[12] Winning the Oil Endgame: Innovation for Profits, Jobs, and Security, Amory B. Lovins, et al., Rocky Mountain Institute, 2004.
[13] Lori Bird/Maggie Mann
[14] Annual Energy Outlook 2005: Market Trends - Electricity Demand and Supply, http://www.eia.doe.gov/oiaf/aeo/electricity.html

power plants dominate U.S. electricity production, compared to undertaking efficiency improvements or removing and sequestering $CO_2$, co-firing with biomass fuel is the most economical way to reduce greenhouse gas emissions.

### 1.1.2 State, Local and International Political Environment

#### 1.1.2.1 State and Local Political Environment

States exercise a critical role in developing energy policies by directing how much we pay for power, and where and when we build our energy facilities. States also can influence the types of energy technologies that we use. Over the last two decades, U.S. states collectively have implemented hundreds of policies to promote the adoption of renewable energy, for reasons ranging from energy diversification, to economic development, to air-quality improvement and greenhouse gas reductions. Some of the mechanisms used by states include subsidies, tax credits, rebates, tax incentives, and various other monetary rewards and incentives for producing and using renewable energy. States also participate in regional consortiums to leverage efforts in promoting renewables. For example, the nine states of the Western Governors' Association have agreed upon clean energy and energy efficiency standards for the region; and the six states of the New England Governors Conference have created a Climate Change Action Plan with the Eastern Canadian premiers, agreeing to set greenhouse gas reduction goals for the region. Cities can impact energy use as well. For example, 173 mayors in 37 states have signed on to the U.S. Mayors Climate Protection Agreement to meet Kyoto Protocol targets in their own communities.[15]

To promote alternatives to petroleum for transportation, many states offer financial incentives for the production of alternative fuels, alternative fuels vehicle use, and alternative fuels infrastructure development. In some cases, the use of ethanol and/or biodiesel are specifically called out. Currently, Minnesota is the only state to mandate the use of ethanol and biodiesel.[16] Eighteen states and Washington D.C. have implemented minimum renewable energy standards (RES), which require electric utilities to gradually increase the amount of renewable energy resources—such as wind, solar, and bioenergy—in their electricity supplies. Of the 10.6 gigawatts of new nonhydroelectric renewable energy capacity projected to enter service from 2003 through 2025 in the electric power sector, 1.6 gigawatts is projected as a result of state requirements and goals (wind 1.3 gigawatts, geothermal and landfill gas each 0.1 gigawatt, plus smaller amounts of biomass, waste, and solar capacity)[17].

The states with biomass incentives are identified in Figure 1-1.[18]

[15] http://www.ci.seattle.wa.us/mayor/climate/
[16] Minnesota Biobased Fuels, Power, and Products State Fact Sheet, January 2003, http://www.bioproducts-bioenergy.gov/State/pdfs/MN_03.pdf
[17] Annual Energy Outlook 2005, Market Trends - Electricity Demand and Supply http://www.eia.doe.gov/oiaf/aeo/electricity.html
[18] Database of State Incentives for Renewable Energy (DSIRE) search on biomass technologies, December 2004, http://www.dsireusa.org/

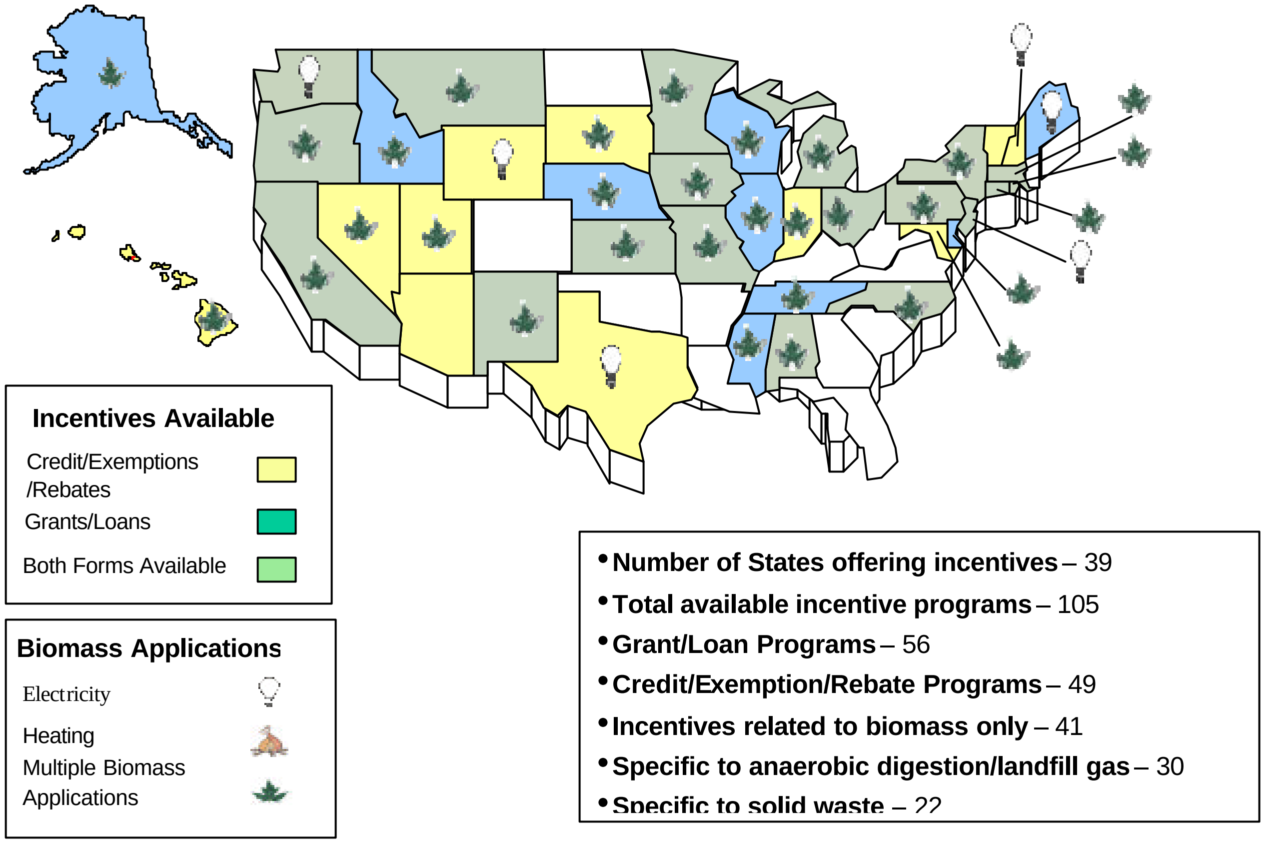


**Figure 1-1:** States with Biomass Incentives

Approximately one-quarter of the U.S. population lives in rural areas, which encompass 83 percent of the country's land. State leaders encourage the establishment of biomass-based industries to create opportunities for economic growth, particularly in rural communities, which face challenges related to demographic changes, job creation, capital access, infrastructure, land use and environment. Growth in the ethanol and biodiesel industry creates domestic jobs through plant construction, plant operation, plant maintenance, and plant support. According to the Renewable Fuels Association, the ethanol industry has grown to 81 plants in 20 states, which support 147,000 jobs in the United States, mostly in rural communities. At the end of 2004, 16 plants and 2 major expansions were under construction, representing an additional 750 million gallons of production capacity. On average, an ethanol plant supports 41 full-time jobs and nearly 700 jobs throughout the entire economy. In addition, a 40 million gallon per year ethanol facility expands the local economic base by $110.2 million each year through the direct spending of $56 million, and increases state and local tax receipts by $1.2 million.[19]

Biomass power can help meet the increased demand for electricity in rural areas as the population expands beyond urban and suburban areas. Building large baseload power plants is no longer desirable for meeting energy demand, especially in more remote areas. Smaller biopower

[19] RFA Ethanol Outlook 2005 http://www.ethanolrfa.org/outlook2005.pdf

facilities have less environmental impact and can operate with locally produced feedstocks. Using crop residues as fuel resources can improve the economics of farming by reducing disposal costs and providing alternative sources of income. Using forest biomass generated from hazardous fuels mitigation and forest restoration activities can reduce the risk and cost of forest fires and provide a new source of electricity for remote areas. The use of agricultural and forest residues and energy crops for power production in the future opens a whole new market for agriculture and forestry that has the potential to provide a steady source of income to rural communities.

### 1.1.2.2 International Political Environment

World energy consumption is projected to increase from 412 quadrillion British thermal units (Btu) in 2002 to 645 quadrillion Btu in 2025, an overall increase of 57 percent. Emerging economies account for nearly two-thirds of this increase, surpassing energy use in the mature market economies for the first time in 2020. Primary energy consumption in the emerging economies as a whole is projected to grow at an average annual rate of 3.2 percent between 2002 and 2025. In the mature market economies, energy use is expected to grow at a much slower average rate of 1.1 percent per year over the same period. As shown in Figure 1-2, oil is expected to remain the dominant energy source through 2025. Worldwide oil consumption is expected to rise from 78 million barrels per day in 2002 to 119 million barrels per day in 2025.[20]

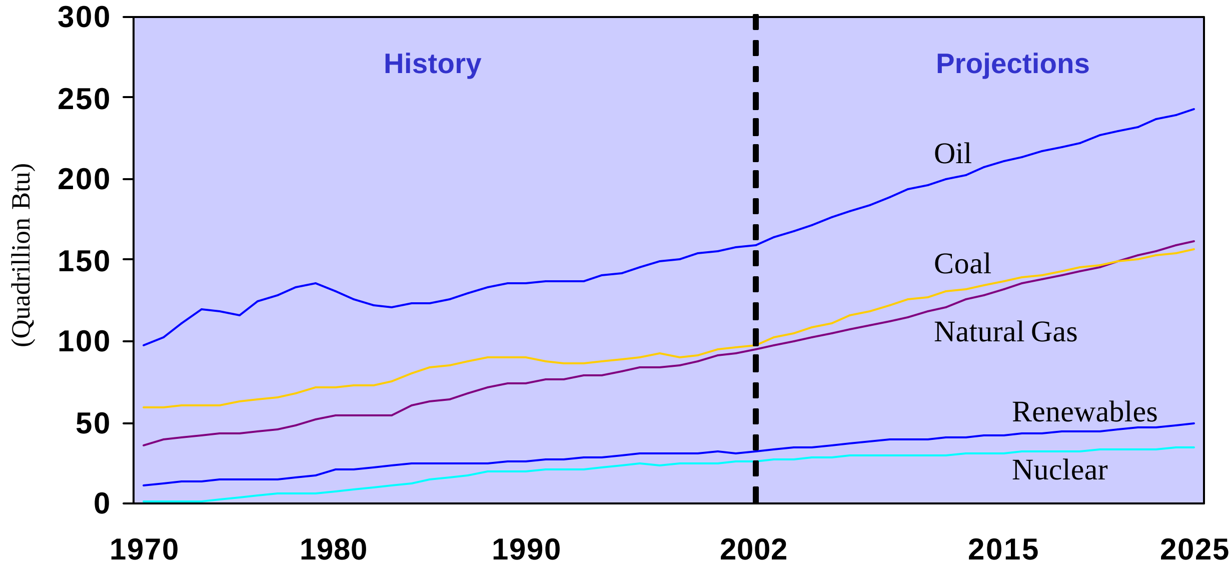


**Figure 1-2:** World Primary Energy Consumption by Energy Source, 1970-2025

Energy use in the transportation sector continues to be dominated by petroleum fuels, and the use of alternative fuels is expected to remain relatively modest through 2025. In 2002, the emerging economies accounted for about 31 percent of world energy use for transportation. In 2025, their share is projected to be 43 percent, as the gap between transportation energy consumption in the emerging economies and in the mature market economies narrows. Energy use for the transportation sector is poised for its strongest growth in the Asian emerging economies. China is

[20] International Energy Outlook 2005, DOE/EIA, http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2005).pdf

the key market that will lead regional consumption growth. India is also on a rapid growth path, and the region's mid-sized markets, such as Thailand and Indonesia, also are projected to post strong growth. In China, the number of cars has been growing by 20 percent per year, and the potential growth is enormous. If the present patterns persist, China's car ownership would exceed the U.S. rate by 2030; however, large infrastructure barriers will have to be overcome for this to occur.

Many nations are seeking to reduce petroleum imports, boost rural economies, and improve air quality through the increased use of biomass. In 2004, world ethanol production rose to nearly 11 billion gallons. [21] World production of biofuels for transportation is led by Brazil and the U.S, both concentrating on bioethanol (Europe is the leading producer of biodiesel). Brazilian production of bioethanol began in 1975, using sugar cane as the raw material; since then, Brazil has remained the world's largest producer. Today, all gasoline sold in Brazil contains about 25 percent ethanol. Brazil's bioethanol production in 2003 was 9.9 million tonnes (3.3 billion gallons).

In 2003, the EU adopted the biofuels directive to promote the substitution of conventional transport fuels – diesel and gasoline derived from oil – by biofuels derived from agricultural crops, notably biodiesel and bioethanol. The biofuels directive sets targets for the biofuel share of all transportation fuels at 2 percent by 2005, and 5.75 percent by 2010. [22] Today, most biofuels in commercial production in Europe are based on sugar beet, wheat, and rapeseed, which are converted to bioethanol/ETBE and biodiesel. Total biofuel production in EU-25 grew by 28 percent in 2003. Biodiesel production for 2003 in EU-25 totaled 1.5 million tonnes from nine countries, led by Germany, France and Italy. EU-25 bioethanol production for 2003 was 446,140 tonnes in five countries—Spain, Poland, France, Sweden and the Czech Republic. Other EU member states are conducting pilot projects for biofuels production and demonstrating the use of biofuels in public vehicle fleets.

Ethanol programs have also been developed in several other countries and are under discussion in many more. For example, China, the third largest producer of ethanol in the world today, has selected several provinces to use trial blends of 10 percent ethanol to meet growing demand for gasoline. India, the fourth largest ethanol producer, requires oil companies in some parts of the country to sell gasoline made up of 5 percent ethanol. [23] Many other countries are developing distinct regulations for ethanol: a number of Canadian provinces are implementing ethanol blending requirements for gasoline; Thailand requires all gasoline stations in Bangkok to sell 10 percent ethanol blends; Argentina is moving to 5 percent ethanol blends over the next five years; and Colombia requires 10 percent ethanol blends in large cities. [24]

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[21] Homegrown for the Homeland: Ethanol Industry Outlook 2005, Renewable Fuels Association, http://www.ethanolrfa.org/outlook2005.pdf

[22] Promoting Biofuels in Europe: Securing a Cleaner Future for Transport, European Commission, Directorate-General for Energy and Transport, 2004 http://europa.eu.int/comm/energy/res/publications/doc/2004_brochure_biofuels_en.pdf

[23] http://www.planetark.com/dailynewsstory.cfm/newsid/31182/story.htm

[24] Homegrown for the Homeland: Ethanol Industry Outlook 2005, Renewable Fuels Association, http://www.ethanolrfa.org/outlook2005.pdf

Growth in biofuels production is expected to accelerate as countries work to comply with the greenhouse gas (GHG) emissions limits contained in the Kyoto Protocol. On February 16, 2005, the international agreement to address global climate change became law for the 141 countries that have ratified it to date. It requires that participating "Annex I" countries reduce their carbon dioxide emissions collectively to an annual average of about 5 percent below their 1990 level over the 2008-2012 period. According to the Pew Center on Global Climate Change, the increased use of renewable fuels, such as ethanol, provides the best option for reducing GHG emissions from the transportation sector over the next 15 years. According to Argonne National Laboratory, 10 percent ethanol blends reduce GHG emissions by 12-19 percent. Ethanol produced from cellulose could reduce GHG emissions even further.

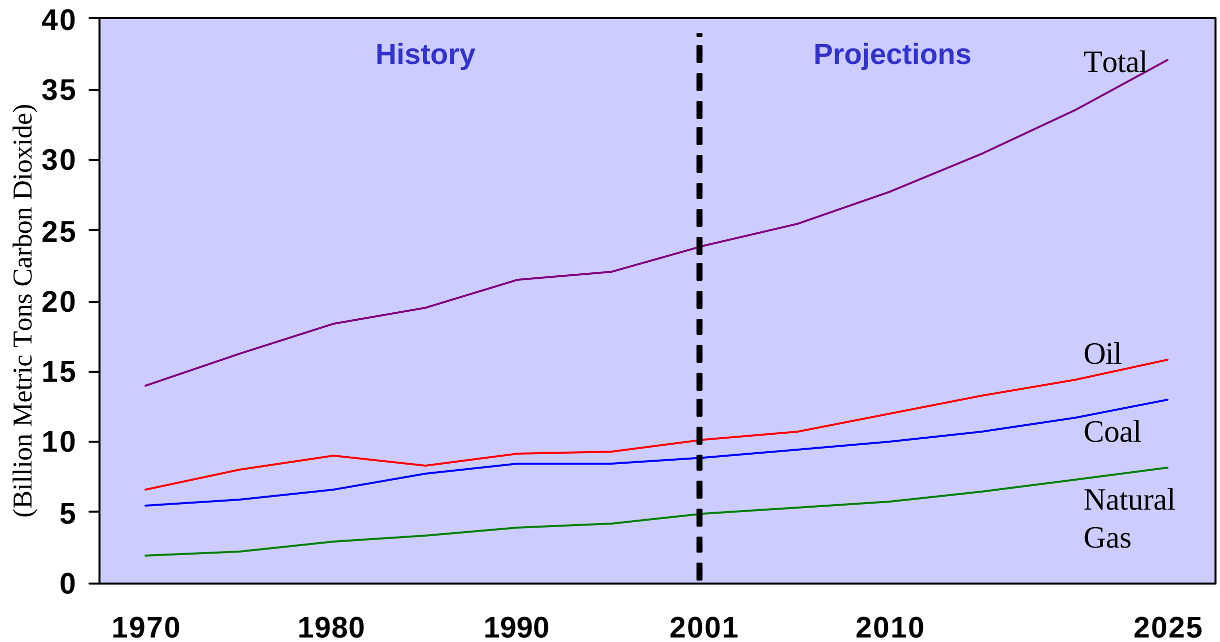


**Figure 1-3:** World Energy-Related Carbon Dioxide Emissions by Fuel Type, 1970-2025

### 1.1.3 Current and Potential Future Competing Technologies

The principal competing technologies rely on continued use of fossil sources to produce transportation fuels, chemicals and materials, and electricity in conventional refineries, petrochemical plants and power plants. Figure 1-4 shows U.S. energy production by primary fuel type. Notice that petroleum is the only source that has been on a relatively steady decline since 1970, while others, except hydropower, have steadily risen.

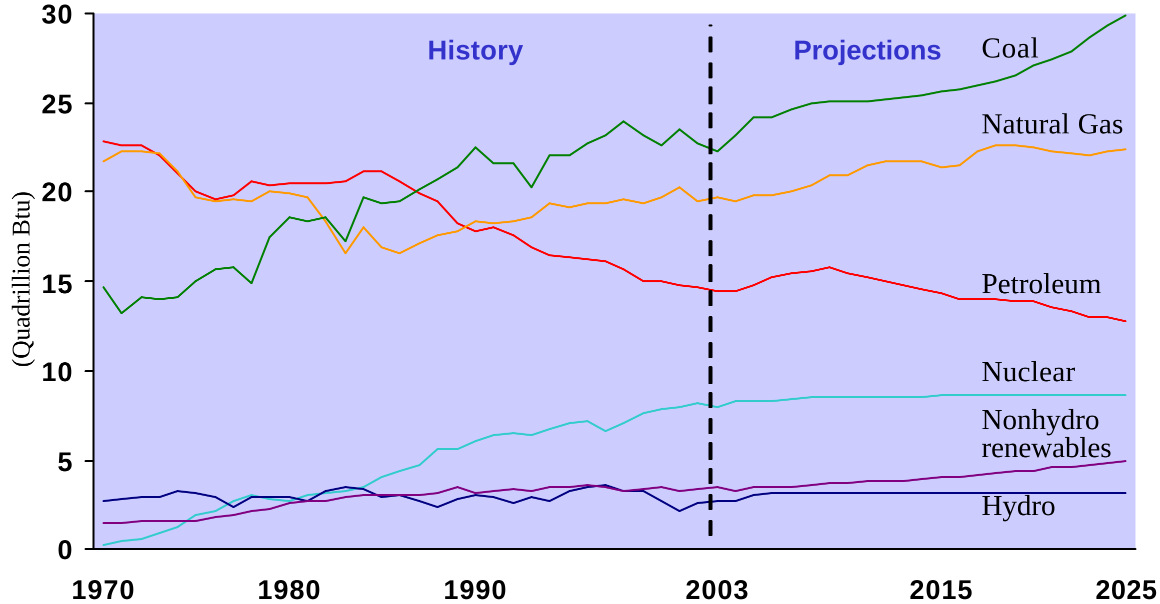


**Figure 1-4:** U.S. Energy Production by Fuel Type, 1970-2025

### 1.1.3.1 Petroleum

In January 2005, there were 148 operating refineries in the U.S. with a total crude distillation capacity of 17.1 million barrels per day, an increase of 0.6 million barrels per day since 2001.[1.2] The U.S. produced over 135 billion gallons of fuel in 2004, and demand for refined petroleum products is expected to increase about 3 percent to more than 18 million barrels per day of crude, assuming normal weather conditions and a continuing economic expansion of about 2 percent annually.[1.3] U.S. refinery output may increase about 4 percent, expanding through conventional projects (e.g., adding a catalytic cracking unit) and through debottlenecking investments, which are marginal investments that effectively create additional refining capacity from the same physical structure.

According to EIA, demand for domestic petroleum is forecast to increase by about 1.5 percent and is projected to be 54.4 quads by 2025 with 80 percent due to increased fuel use for transportation. Net petroleum product imports are forecast to increase about 43 percent, expanding from 750 thousand barrels per day to more than 1 million barrels per day. Much of this increase could stem from a demand for motor gasoline, which is expected to increase almost 3 percent Motor gasoline's share of petroleum product consumption is projected to fall from 45 to 43 percent, despite increasing approximately 2 percent annually over this period. The average U.S. crude oil price is projected to decline from current levels to $24.50 per barrel (2003 dollars) in 2010, before increasing to $30.00 per barrel in 2025. The U.S. price of oil, unlike natural gas, is set in the international marketplace. In the high world oil price case, the U.S. crude oil price is projected to be $33.65 per barrel in 2010, and $38.84 per barrel in 2025. In the low world oil

[1.2] NPRA United States Refining and Storage Capacity Report, January 2005.
[1.3] EIA Energy Outlook Report Summary 2004.

price case, the lower 48 states price declines to $20.44 per barrel in 2010, then remains relatively stable through 2025.

EIA also projects alternative fuels to displace 207,000 barrels of oil equivalent per day in 2010 and 280,500 barrels per day in 2025. The fuels, consisting mostly of ethanol used in gasoline blending (71 percent in 2025) grow from 1.7 percent in 2003 to 2.2 percent in 2025.

EIA projections aside, it is the uncertainty of oil price and supply that represents a danger to our economic security. Why is uncertainty such a problem? One reason is that such instability makes future planning impossible. As a case in point, consider the U.S. Department of Energy's official forecast for oil prices. The Energy Information Administration (EIA) data for historical oil prices plotted along with this year's projections for future oil prices, shown in Figure 1-5, offers a shocking contrast. Today we are facing record high oil prices, nearly twice the level projected by EIA.

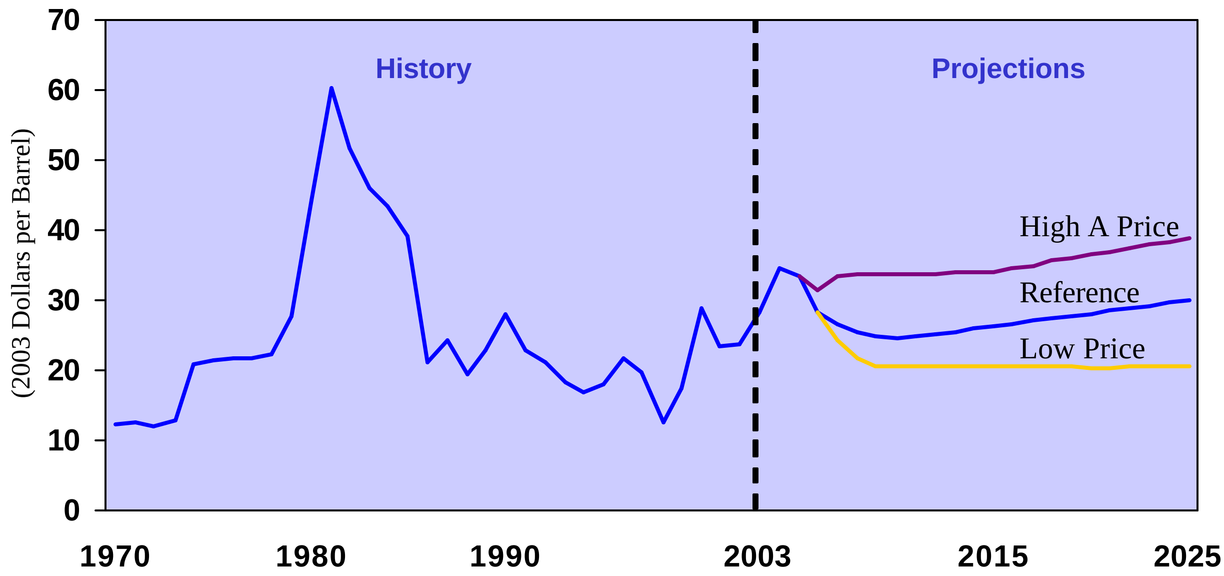


**Figure 1-5:** U.S. Wellhead Oil Prices, 1970-2025

The projection data is for EIA's "Reference Case," deemed a more likely estimate of future prices, but by no means a "prediction." As EIA rightly points out, "[t]he projections… are not statements of what will happen but of what might happen, given the assumptions and methodologies used. The projections are business-as-usual…." Modesty is an important characteristic for modelers attempting to deal with something as complex as our energy supply. But, does any forecast showing the kind of stability we see here make any sense in the context of the past thirty five years of oil price history? Probably not.

But how are we to deal with this uncertainty? We do not have an answer to that question. What will not work is to build energy policy on the kind of simplified view of the world reflected in EIA's projections. This is not a criticism of EIA's forecasting prowess. It is merely a statement that models will only go so far in helping make political and even technological choices that affect our energy future. What we believe about the future of oil prices and supply has a significant impact on energy decisions. These forecasts affect policy, R&D, and commercial decisions. We must come to the point where judgment and values enter into the public discussion of cost versus risk.

**1.1.3.2 Natural Gas**

Total U.S. natural gas consumption is projected to increase from 22.0 trillion cubic feet in 2003 to 30.7 trillion cubic feet in 2025. In the electric power sector, natural gas consumption increases from 5.0 trillion cubic feet in 2003 to 9.4 trillion cubic feet in 2025, accounting for 31 percent of total demand for natural gas in 2025, as compared with 23 percent in 2003. The increase in natural gas consumption for electricity generation results from both the construction of new gas-fired generating plants and higher capacity utilization at existing plants. Industrial consumption of natural gas, including lease and plant fuel, is projected to increase from 8.1 trillion cubic feet in 2003 to 10.3 trillion cubic feet in 2025. The industrial sectors with the largest projected increases in natural gas consumption growth from 2003 through 2025 include metal-based durables, petroleum refining, bulk chemicals, and food. Natural gas consumption in the transportation sector remains at around 3 percent of total U.S. natural gas consumption, increasing from 0.66 trillion cubic feet in 2003 to 0.93 trillion cubic feet in 2025.[25]

Average lower 48 wellhead natural gas prices are projected to decline from the 2004 level to $3.64 per thousand cubic feet (2003 dollars) in 2010 and then increase to $4.79 per thousand cubic feet in 2025. Technically recoverable natural gas resources are expected to be adequate to support projected production increases. As lower 48 conventional natural gas resources are depleted and wellhead prices rise, an increasing proportion of U.S. natural gas supply is projected to come from Alaska, unconventional production (tight sands, shale, and coal bed methane), and LNG imports. Net imports of natural gas are projected to increase from 3.2 TCF in 2003 (15 percent of total) to 8.7 TCF in 2025 (28 percent of total).[26]

In the future, as oil demand and price continue to increase, gas-to-liquids processes may fulfill some of the transportation fuel needs of the U.S.

**1.1.3.3 Coal**

U.S. coal production has remained near 1,100 million tons annually since 1997. In the forecast, a projected increase in coal use for electricity generation leads to an increase in production, to 1,238 million tons in 2010. After 2010, coal production increases with projected additions of new, unplanned coal-fired generating capacity, particularly from 2015 to 2025. Between 1990 and 1999, the average mine mouth price of coal declined by 4.9 percent per year, from $28.26 per ton (2003 dollars) to $18.01 per ton. Increases in U.S. coal mining productivity of 6.3 percent per year during the period helped to reduce mining costs and contributed to the decline in prices. Since 1999, growth in U.S. coal mining productivity has slowed to 1.3 percent per year, and

[25] Annual Energy Outlook 2005: Market Trends - Natural Gas Demand and Supply http://www.eia.doe.gov/oiaf/aeo/gas.html
[26] Annual Energy Outlook 2005: Market Trends - Natural Gas Demand and Supply http://www.eia.doe.gov/oiaf/aeo/gas.html

mine mouth coal prices have remained virtually unchanged despite some short-term fluctuations. The average in 2003 was $17.93 per ton.

In the future, as oil demand and price continue to increase, coal-to-liquids processes may fulfill some of the transportation fuel needs of the U.S. During the early 1990s, DOE's Office of Fossil Energy (FE) funded a number of projects investigating the production of coal-derived liquids using under its Clean Coal Technology Demonstration program. FE is currently sponsoring research on coal-to-hydrogen technologies.[27]

### 1.1.3.4 Other Non-Renewable Primary Energy Resources

Nuclear Energy

Nuclear energy is used to produce electricity, although it can be used to produce hydrogen fuel indirectly, via water electrolysis. The U.S. is the world's largest supplier of commercial nuclear power.[28] The U.S. currently has 104 commercial nuclear reactors licensed to operate. Although no new nuclear power plants have been ordered since 1973, and none are expected through 2025, the plants currently on line are being operated more efficiently, and are thus producing more power. The U.S. nuclear industry generated 788 billion kilowatt hours of electricity in 2004, reaching a new U.S. (and international) record. This is the industry's fifth annual record since 1998. For example, nuclear power plant capacity factors have been raised from 78 percent in 1998 to 88 percent in 2000.[29] A key mission of DOE's Office of Nuclear Energy, Science and Technology Program (NE) is to strengthen basic technology and chart the way toward introduction of the next generation of nuclear power plants.[30]

Oil Shale and Tar Sands

Oil shale is a type of rock formation that contains large concentrations of combustible organic matter that when processed, can yield significant quantities of shale oil. Various methods of processing oil shale to remove the oil have been developed. A common element among those methods is the use of heat to separate out the oil from the rock. The U.S. has significant oil shale resources, amounting to more than 2 trillion barrels, primarily within the Green River Formation in Wyoming, Utah and Colorado.[31] These oil shale resources underlie a total area of 16,000 square miles and represent the largest known concentration of oil shale in the world. Precipitated by the oil price spikes of the early 1970s, companies showed significant interest in exploring domestic oil shale development. While this oil shale research showed some promise from a technological standpoint, the extraction process was energy-intensive and not economically viable. FE has a small program in oil shale focused on reviewing the potential of oil shale as a strategic resource for liquid fuels. Activities include reviewing: the strategic value of oil shale development; public benefits from its development; possible ramifications of failure to develop

[27] http://www.fossil.energy.gov/programs/fuels/index.html
[28] U.S. Nuclear Generation of Electricity, DOE/EIA, May 2005, http://www.eia.doe.gov/cneaf/nuclear/page/nuc_generation/gensum.html
[29] AER 2000, Table 9.2.
[30] http://www.ne.doe.gov/
[31] Is Oil Shale America's Answer to Peak Oil Challenge?, James Bunger, et al. Oil and Gas Journal, http://www.fossil.energy.gov/programs/reserves/publications/Pubs-NPR/40010-373.pdf

these resources; and related public policy issues and options. The FE program is also involved in characterizing the oil shale resource, assessing oil shale technology, summarizing environmental and regulatory issues, and reviewing tar sand commercialization in Canada as an analog for oil shale development in the United States.[32]

Elsewhere in the world, continuing efforts have resulted in the successful development of oil shale resources. For example, in Gladstone, Queensland, Australia, there is a large-scale demonstration project where, from June 2001 through March 2003, 703,000 barrels of oil, 62,860 barrels of light fuel oil, and 88,040 barrels of ultra-low sulfur naphtha were produced from oil shale. In January 2003 alone, the operation produced 79,000 barrels of oil. Significant oil shale reserves also exist in the Republic of Estonia, where active oil shale deposits amount to about 1,200 million tons and, at current levels of consumption, are forecast to last one hundred years.[33]

Tar Sands (also called oil sands) contain bitumen or other petroleum with high viscosity, which is not recoverable by conventional means. The petroleum is obtained either as raw bitumen (through in-situ recovery) or as a synthetic crude oil (via an integrated surface-mining plus upgrading process). Although natural bitumen and extra-heavy oil occur worldwide, the Alberta, Canada natural bitumen deposits comprise at least 85 percent of the world's total bitumen in place, but are so concentrated as to be virtually the only such deposits that are economically recoverable for conversion to oil. The deposits amount to about 1,700 billion barrels of bitumen in place. Similarly, the extra-heavy crude oil deposit of the Orinoco Oil Belt, a part of the Eastern Venezuela basin, represents nearly 90 percent of the known extra-heavy oil in place. Total output from Canadian oil sands in 1999 was 323,000 b/d of synthetic crude and 244,000 b/d of crude bitumen from the in-situ plants; together these represented 22 percent of Canada's total production of crude oil and NGL. In 1999, Venezuela exported 4.9 million tonnes of Orimulsionâ (a product made from bitumen emulsified with water) for use in a variety of power generation applications. The U.S. tar sands resource of 58.1 billion barrels is widely distributed throughout the nation, with 33 percent located in Utah, 17 percent in Alaska, and the remaining 50 percent in California, Alabama, Kentucky, Texas and elsewhere. There are eight giant (> 1 billion barrels) deposits of natural asphalt in-situ, which represent nearly 80 percent of the total U.S. demonstrated and inferred resource.[34]

### 1.1.3.5 Renewable Energy Resources

Renewable resources—wind, solar, geothermal, and hydropower—are used to produce electricity rather than fuels, although they can be used to produce hydrogen fuel indirectly, via water electrolysis. Renewable electricity generation is projected to grow as a result of technology improvements and increasing fossil fuel costs; however, grid-connected generators using

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[32] http://www.fossil.energy.gov/programs/reserves/npr/NPR_Oil_Shale_Program.html

[33] Statement Of Thomas Lonnie Assistant Director for Minerals, Realty & Resource Protection, Bureau of Land Management, U.S. Department of the Interior, before the Senate Energy and Natural Resources Committee Oversight Hearing on Oil Shale Development Efforts Bureau of Land Management April 12, 2005 http://www.doi.gov/ocl/2005/OilShaleDev.htm

[34] World Energy Council Survey of Energy Resources 2001 http://www.worldenergy.org/wec-geis/publications/reports/ser/bitumen/bitumen.asp

renewable fuels are projected to remain minor contributors to U.S. electricity supply through 2025. From 359 billion kilowatthours in 2003 (9.3 percent of total generation), renewable generation increases to only 489 billion kilowatthours (8.5 percent) in 2025. [35]

Conventional hydropower remains the major source of renewable generation through 2025; however, with little new capacity expected, hydropower generation is projected to increase from 275 billion kilowatthours in 2003 (7.1 percent of total generation) to just 307 billion kilowatthours (5.3 percent of the total) in 2025. Biomass, including combined heat and power systems and biomass co-firing in coal-fired plants, is the largest source of other renewable generation in the forecast, with electricity from biomass combustion increasing from 37 billion kilowatthours in 2003 (1.0 percent) to 81 billion kilowatthours in 2025 (1.4 percent). [36]

Significant increases in electricity generation are projected from both geothermal and wind power. In the West, geothermal output increases from 13 billion kilowatthours in 2003 to 33 billion kilowatthours in 2025. Wind-powered generating capacity increases from 6.6 gigawatts in 2003 to 11.3 gigawatts in 2025, and generation from wind capacity increases from less than 11 billion kilowatthours in 2003 to 35 billion in 2025.

Solar technologies generally are projected to remain too costly to be competitive in supplying power to the grid. Central-station photovoltaic capacity increases in the forecast from about 40 megawatts in 2003 to 400 megawatts in 2025, and solar thermal capacity increases from about 400 megawatts to more than 500 megawatts. In contrast, individual grid-connected photovoltaic installations grow rapidly, from about 60 megawatts in 2003 to nearly 1,800 megawatts in 2025. Grid-connected photovoltaics and solar thermal, which together provided about 0.7 billion kilowatthours of electricity in 2003, are projected to supply nearly 6 billion kilowatthours in 2025. [37]

### 1.1.4 Program Level Market Barriers

The establishment of integrated biorefineries has been inhibited by a variety of market barriers which exist at local, State, and Federal levels. As a result of these and other barriers, the production of fuels and chemicals from lignocellulosic biomass has yet to be demonstrated as cost effective at a significant scale. Consequently, a market for residues and energy crops has not been developed or established creating a gap between the agricultural community and the vision of the biorefinery concept. This is a classic, if multi-dimensional, supply and demand dilemma. To be economical biorefineries require cost-effective feedstocks, however, the development of a cost effective and sustainable feedstock supply infrastructure requires economically proven biorefineries to ensure a demand for the developed feedstocks. Consequently, these developments must occur in tandem. Initially regulatory and policy assistance for support of the biorefinery concept will grow through their economical demonstration. The development of

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[35] Annual Energy Outlook 2005,Market Trends - Electricity Demand and Supply, DOE/EIA http://www.eia.doe.gov/oiaf/aeo/electricity.html

[36] Annual Energy Outlook 2005,Market Trends - Electricity Demand and Supply, DOE/EIA http://www.eia.doe.gov/oiaf/aeo/electricity.html

[37] Annual Energy Outlook 2005,Market Trends - Electricity Demand and Supply, DOE/EIA http://www.eia.doe.gov/oiaf/aeo/electricity.html

feedstock supplies and infrastructures require both independent support for the long term realization of energy crop and the progressive advancement and success of existing biorefineries. As biorefinery technology advances, new feedstocks need to be introduced to supplement and compliment the existing feedstock supply. At a higher level, the lack of sufficient political awareness of the biorefinery concept coupled with the perception that biofuels can only play a minimal role in energy independence hinders development and implementation of the incentives, programs and policies needed to remedy this situation. Major market barriers are described below.

**Cost of Production.** The overarching market barrier for biomass technologies is the inability to compete, in most applications, with fossil primary energy supplies and their associated pre-existing facilities and infrastructure:

- Petroleum to produce transportation fuels, and chemicals and materials
- Natural gas to produce chemicals and materials, and electricity
- Coal and nuclear energy to produce electricity

A major complicating factor in trying to plan for how to compete with products from fossil energy resources is the uncertainty in the primary energy price and supply.

Reductions in production costs all along the biomass supply chain are required. There are some applications where biomass-based products can compete in the marketplace (see Table 1-1), and some of these, like ethanol and biodiesel, have been assisted by public policy. OBP sponsors extensive R&D of biomass technologies with a focus on improving the technologies to ultimately reduce the costs of producing biomass derived products so that they can compete in the marketplace.

**High Risk of Large Capital Investments**. Once emerging biomass technologies have been developed and tested, they must be commercially deployed in real-world markets. Financial barriers are the most challenging aspect of technology deployment. Capital costs for commercially viable facilities are relatively high and because the technology is not yet proven, securing capital is extremely difficult. In order for private investors to confidently finance biomass technology, it must be proven and demonstrated to be technically and commercially viable. Therefore, it is at this stage in the technological development timeline that government assistance is critical to eventual deployment.

**Agricultural Sector-wide Paradigm Shift.** Significant energy production from biomass requires a complete rethinking of U.S. agricultural potential and practices that will likely involve dramatic changes that take time to bring about. The current perception that agricultural resources manifested as biofuels and biopower will not make a significant impact on the energy profile of the United States must be dispelled, It is acknowledged that bioenergy is not the panacea, however, recent DOE/USDA studies have shown that the can in deed have a significant impact.

**Lack of Infrastructure Throughout the Supply Chain.** Dramatic capital investments in the overall biomass industry are required from feedstock production, through conversion processing and product delivery. The situation for each link in the chain presents a classic supply and demand dilemma. The uncertainty of a sustainable supply chain an associated risk is a major barrier to procuring capital for start-up biorefineries. Likewise the lack of the biorefinery infrastructure to create a demand for biomass energy feedstocks is a barrier to the development and production of bioenergy crops.

**Lack of Industry Standards and Regulations.** The lack of local, state, and federal regulations, inconsistency among them, or existing regulations that constrain biomass development result in obstacles leading to the unwillingness or inability of industry and financial institutions to accept the risks. The long lead time associated with developing and understanding new and revised regulations for new technology stifles commercialization. In the case of permitting the situation is a lack of standard or consistent implementation of existing general regulations, while existing regulations concerning weight and dimension of biomass supply loads constrain transportation and delivery options.

**Industry and Consumer Acceptance and Awareness.** In general to be successful in the marketplace, biomass-derived products must cost the same or less and perform the same or better than existing fossil energy based products. Industry partners and ultimately consumers must believe in the quality and value of biomass derived products. Consumers must also be aware of the products and their benefits. Currently, there are over 4 million E-85 flexi-fuel vehicles on the road yet a small fraction of their owners realize that they are driving ethanol empowered vehicles.

## 1.2 Internal Assessment and Program History and Progress

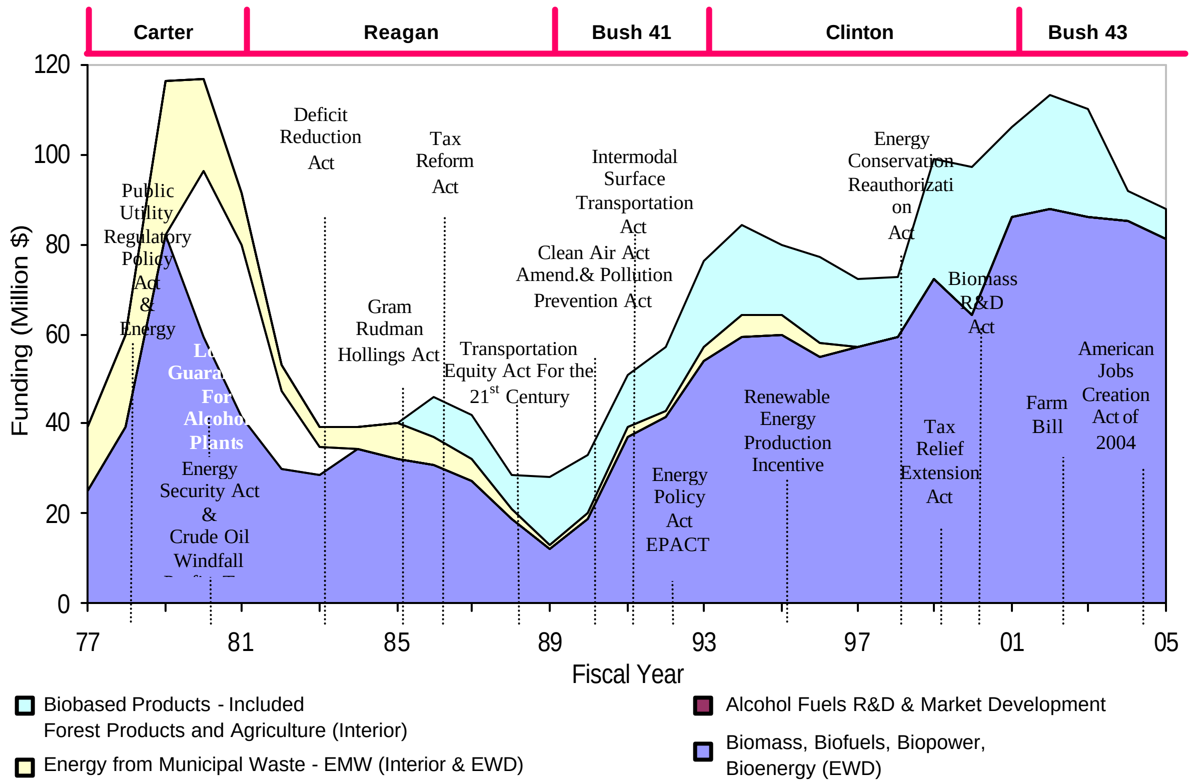
### 1.2.1 Program History

In response to the promise of biomass, in the late 1970s, efforts in bioenergy were initiated by the National Science Foundation (NSF). These projects were transferred to the Energy Research and Development Administration (ERDA) and finally to DOE as a result of the Federal Non-Nuclear Energy R&D Act of 1974, the Solar Energy Research and Development Act of 1974, and the DOE Organization Act of 1977. Early projects focused on biofuels and biomass energy systems, but were reorganized to accelerate accomplishments in the 1990s to a sector-based R&D effort in the following programs:

- The Biofuels Program (BFP) in the Office of Transportation Technologies (OTT)
- The Biopower Program (BPP) in the Office of Power Technologies (OPT)
- Biomass-related elements of the Industries of the Future Program, Agriculture and Forest Products, in the Office of Industrial Technologies (OIT)

In 2002, the current Office of the Biomass Program (OBP) was formed, through the consolidation of these sector programs into one, comprehensive, research, development and deployment effort. The strategic goal of the current Program is to develop biorefinery-related technologies to the point that they are cost- and performance-competitive and are used by the nation’s transportation, energy, chemical and power industries to meet their market objectives.

From the 1970s to the present, approximately $1.4-1.5 billion (year 2000 dollars) has been invested in a variety of RDD&D programs covering biofuels, ethanol in particular, biopower, feedstocks, municipal wastes, and a variety of biobased products, including those in forest products and agricultural processing industries. Key policy shifts, major new legislation, and federal funding levels are shown in Figure 1-6. While steady progress has been made in many technical areas over time, considerable progress remains to be made before biomass technologies are broadly competitive in the marketplace. In particular, the majority of technologies to grow, harvest, and utilize the broad spectrum of potential lignocellulosic feedstocks still have not been integrated or deployed.




Financial incentives were found on the OBP webpage www.eere.energy.gov/biomass

**Figure 1-6:** Major Policy Shifts, Key Legislation, and Federal Funding Levels for Biomass-Related R, D & D, 1977-2005

Regulations, financial incentives, and executive orders that have influenced biomass R&D over the past 25 years include:

- Public Utility Regulatory Policy Act & Energy Tax Act (1978)
- Energy security Act & Crude Oil Windfall Profits Tax Act / Loan Guarantees for Alcohol Plants (1980)
- Economic Recovery Tax Act (1981)
- Surface Transportation Assistance Act (1982)
- Transportation Equity Act for the 21st Century (1988)
- Pollution Prevention Act (1990)
- Energy Policy Act EPACT (1992)
- Energy conservation Reauthorization Act (1998)
- Biomass R&D Act of 2000

- Farm Bill, Title IX (2002)
- Executive Orders:
  - Alternative-Fuel Vehicles: 12844 (1997), 13031 (1997)
  - Biobased Products Increased Use by the Federal Government: 13101 (1998)
  - Biobased Products and Bioenergy Increased Use: 13134 (1999)
  - Increased Renewable and Energy Efficiency in Government Use: 13123 (1999)
  - Developing and Promoting Biobased Products and Bioenergy: 13134 (1999)

### 1.2.2 Program Organization and FY06 Activities

The Program is organized into five R&D elements or R&D areas, and one management element as shown in Figure 1-7. The first four R&D elements are focused on core R&D in a specific functional technical area:

1. Feedstock Interface Core R&D
2. Sugars Platform Core R&D
3. Thermochemical Platform Core R&D
4. Products Core R&D

The final R&D element, Integrated Biorefineries, is focused on development and demonstration of integrated biorefinery technologies through public-private partnerships. The management element includes program-wide activities such as budgeting, execution, technical integration, strategic analysis, as well as crosscutting activities such as communications and outreach.

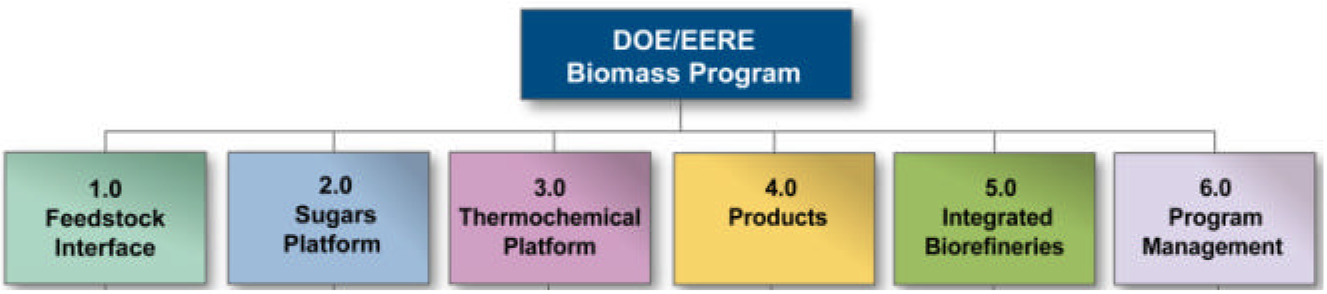



**Figure 1-7:** Biomass Program High Level Work Breakdown Structure

Program efforts for FY06 in each R&D area are described below.

<u>Feedstock Interface Core R&D</u>

- Evaluate integration of feedstock harvesting, storage and preparation with sugar platform conversion technologies for agricultural residues

<u>Sugars Platform Core R&D</u>

- Evaluate and develop integrated pretreatment and enzymatic hydrolysis technologies on broader range of feedstocks, including energy crops such as switchgrass and poplar.
- Continue fundamental R&D on recalcitrance of biomass
- Evaluate the application of hydrolysis technologies on broader range of feedstocks, including energy crops such as switchgrass and poplar.

- Continue fundamental R&D on recalcitrance of biomass including exploring surface characterization to further understand and improve the kinetics of hydrolysis
- Continue advanced conversion enhancements such as increased solids loadings, improved separations and milder conditions, as funding permits.
- Evaluate the feasibility of pentose extraction and conversion in pulp mills.
- Support conversion technologies being applied by industrial partners

Thermochemical Platform Core R&D

- Evaluate themochemical processing of sugars platform residue streams
- Continue syngas cleanup and conditioning core R&D

Products Core R&D

- Start and Continue projects from FY04 Products solicitation, as funding permits
- Continue projects with current industrial partners to produce chemicals and materials from sugars and oils.
- Evaluate the integration of chemical and material production projects with a fuels production component.

Integrated Biorefineries

- Continue biorefinery projects from FY 2002 solicitation
- Support biorefinery and products projects such that they may be ready for demonstration in FY 2008
- Begin scoping FY 2008 solicitation for biorefinery demonstrations with a focus on meeting the pre-commercialization requirements of the financial community
- Develop primers to aid in deployment based on input and pre-commercialization requirements from the industrial, financial, and engineering communities

### 1.2.3 Program Accomplishments

Examples of some of the important accomplishments made in recent years, organized by R&D element, include:

Feedstock Interface:

- Crop Management - combining agronomic studies with integrated crop management systems while evaluating the environmental impact of these systems.
- Modern Plant Genetics - yielded high producing clonal varieties of Poplar and Switchgrass that were successfully field tested.
- Hybrid Poplar - 60,000+ acres of hybrid poplar grown by James River, Potlatch, and Westvaco pulp and paper companies due to the improved pulp yields.

Sugars Platform:

- Novozymes, Genencor, and NREL (R&D 100) – Progress of Enzyme Companies in Cellulase Cost Reductions (20x decrease in the cost of enzymes)

Thermochemical Platform:

- Georgia Pacific – Steam Reforming of black liquor gasification, construction completed.

- Vermont Gasification Project (R&D 100) – Commercialization of the Future Energy Resources Corporation (FERCO) Burlington Gasifier.
- Community Power Corporation Small Modular BioPower – Commercialization of 12.5 kW power system.
- New York Salix Project – Closed loop biomass power production has been conducted successfully at Niagara Mohawk's Dunkirk Steam Station in Dunkirk, NY, as part of the Salix project.
- Spent pulping liquor gasification technology has been developed and two commercial scale spent pulping liquor gasifiers are operating in the U.S.

Products:

- Use of Bark-derived Pyrolysis Oils as a Phenol Substitute in Structural Panel Adhesives.
- Chemicals from Biologically-Derived Succinic Acid (R&D 100).
- Natural-Based Insulation Fluid (R&D 100) – ABB Power T&D Co. Inc developed BIOTEMP Fluid, a completely biodegradable insulating fluid made from vegetable oil sources.
- Metabolix's Natural Plastics won the Presidential Green Chemistry Challenge award.

Integrated Biorefineries:

- NatureWorks – PLA – NatureWorks LLC started up the world's first large (300 M lbs./yr.) PLA plastic manufacturing operation.
- Fractionation of Corn Fiber and Subsequent Conversion to High Value Chemicals - Traditionally in the corn wet milling process the by-product fiber was sold as corn gluten feed. In the new process, which has been successfully tested at pilot scale by ADM, NCGA and NREL, fiber is hydrolyzed and separated into its representative fractions: sugars, cellulose and fermentation extract.
- Development and demonstration of a new front-end pretreatment operation for a dry mill by Broin that increases ethanol yield and produces more valuable high protein animal feed.
- Analyzer Examines Wood in Several Stages (R&D 100) – The Real-Time Mass Analysis can identify the material composition of wood-derived samples for only $10, compared to an $800 wet-chemistry analysis.
- New Energy Company of Indiana (R&D 100) – Ethanol from Corn Fiber in a Dry Mill Facility.

## 1.3 Program Justification & Federal Role

### 1.3.1 National Need

The National Energy Policy (NEP) states that the imbalance between domestic energy supply and domestic energy demand underlies our nation's energy challenge. In short, the U.S. consumes much more energy than it produces domestically. Ensuring that the supply-demand imbalance does not undermine our economy, our standard of living, or our national security is the fundamental energy challenge confronting the nation. The NEP maintains that in order to meet the energy imbalance challenge, the U.S. must use its technological know-how and environmentally sound new technologies to:

- Promote energy conservation;
- Repair and modernize the energy infrastructure; and
- Increase our energy supplies in ways that protect and improve the environment.[38]

Over the next 20 years energy consumption in the U.S. is projected to rise by 30 percent, yet domestic energy production is only expected to grow by 25 percent. Petroleum imports already supply more than 55 percent of U.S. domestic needs and they are expected to grow to more than 68 percent by 2025 as worldwide oil demand continues to rise and domestic oil production continues to decline. Biomass is the only domestic, sustainable, and renewable primary energy resource that can provide liquid transportation fuels and organic chemicals and materials currently produced from fossil sources. Biomass also supports a technology transition to a hydrogen economy.

### 1.3.2 Federal Role

The overarching Federal role is to ensure delivery of reliable, affordable and environmentally sound energy supply. Billions of dollars have been spent over the last century to construct the nation's energy infrastructure based on fossil energy, including the current transportation fuel production infrastructure based on petroleum. The production of alternative transportation fuels from new primary energy supplies, like biomass, and the introduction and penetration of new or blended fuels into the market will be no small endeavor. The appropriate Federal government role is investing in high risk, high value biomass and biorefinery-related technology RD&D that is both critical to the nation's future and would not be sufficiently conducted by the private sector acting on independently. States, associations, and industry have roles as Program stakeholders and are expected to be key participants in deployment of biomass technologies once the risks have been reduced sufficiently by the Federal government investments.

Federal legislation has helped to drive the Program's momentum. The most recent major Federal legislation is the Energy Policy Act of 2005 signed into law on August 8, 2005. Included in this Act, is funding specifically aimed at improving the technology associated with biomass systems and increasing the amount of biopower, biofuels, and bioproducts used in U.S. Through the EPAct, Congress made significant changes to the Biomass R&D Act of 2000. The technical areas are now focused on advanced feedstock production and harvesting, overcoming recalcitrance of cellulosic biomass, the diversification of biobased products from a biorefinery, and analysis that provides strategic guidance for biomass technologies. For funding projects in these technical areas, the EPAct has increased the authorization of funding from $54 million to $200 million and includes guidance for the distribution of projects funded through the Initiative. Additionally, the Secretary of Energy is required to update the Vision and Roadmap documents prepared by the Committee in 2002.

Other major federal legislation drivers of the current program include the following:

- Energy Policy Act of 1992 (EPAct)

[38] DOE EERE Strategic Plan, October 2002, p. 4

EPAct grew out the efforts of the previous Bush Administration to establish a national energy policy. It has been a failure in terms of its intent to encourage the use of alternative fuels in the transportation sector. EPACT focused too much on purchases of alternative fueled vehicles, without paying enough attention to its real goal of seeing alternative fuels enter the marketplace. Flexible fuel vehicles such as the kind that can use ethanol or gasoline have indeed found their way into the marketplace, but few fleets and car owners are actually using the fuel. The NEP report acknowledged this failure and suggested that "[r]eforms to the federal alternative fuels program could promote alternative fuels use instead of mandating purchase of vehicles that ultimately run on petroleum fuels."

- Biomass R&D Act of 2000[39]
  In 2000, the Biomass Research and Development Act created the Biomass R&D Initiative (http://www.bioproducts-bioenergy.gov/), a multi-agency effort to coordinate and accelerate all Federal biomass R&D. It also created a Biomass R&D Board and a Biomass R&D Technical Advisory Committee. The Board's role is to coordinate interagency R&D and minimize any duplicative efforts. The Technical Advisory Committee, comprised of industry and academia representatives, ensures that the Federal effort does not duplicate industry's efforts by reviewing the two agencies' annual progress and making recommendations for future activities. The R&D Board and technical advisory committee are described in more detail in Section 4.1.

- Farm Bill of 2002, Title IX[40]
  Included several sections important to biomass including:
  - Federal Procurement of Biobased Products (Section 9002),
  - Renewable Energy Systems and Energy Efficiency Improvements (Section 9006),
  - Biomass Research and Development (Section 9008) includes the joint DOE/USDA solicitation for FY 2002-FY 2004, and
  - Continuation of the Bioenergy Program (Section 9010)

### 1.3.3 Program Uniqueness in Federal Role

The Biomass Program is the major Federal program supporting RD&D of biomass and biorefinery-related technologies through public-private partnerships. It is guided by the Biomass R&D Initiative, part of the Biomass R&D Act of 2000.

The Program complements efforts by the USDA derived from Title IX of the Farm Bill of 2002 and the Healthy Forest Restoration Act of 2003, Title II.

## 1.4 Program Vision

A well established, economically viable, sustainable, bioenergy and biobased products industry strengthens U.S. energy independence, protects and enhances our environment, provides

[39] Biomass R&D Act summary, http://www.bioproducts-bioenergy.gov/about/bio_act.asp
[40] http://www.usda.gov/farmbill2002/energy_fb.html

economic security, delivers improved products to consumers and creates new economic opportunities for rural America.

## 1.5 Program Mission

The mission of OBP is to partner with U.S. industry to foster research and development on advanced technologies that will transform our abundant biomass resources into clean, affordable, and domestically produced biofuels, biopower, and high-value bioproducts through the development of biorefineries. The results will be energy supply options, energy security, and economic development.

## 1.6 Program Approach

The measure of Program success and impact is the development and deployment of integrated biorefineries. The Program approach to achieving its mission involves a combination of fundamental core research on feedstocks, sugars and thermochemical conversion platforms, and biobased products to create the scientific and technical underpinnings of the new bioindustry, and the application of these technologies by development of integrated biorefineries through public-private partnerships. The general integration strategy employed by the Program is depicted in Figure 1-8. Government support of the fundamental research is appropriate because it is very high risk, and therefore will not be undertaken by industry alone. Government cost share of pilot and demonstration scale integrated biorefineries is essential due to the combination of risk for first-of-a-kind processing facilities and the high capital investment required.

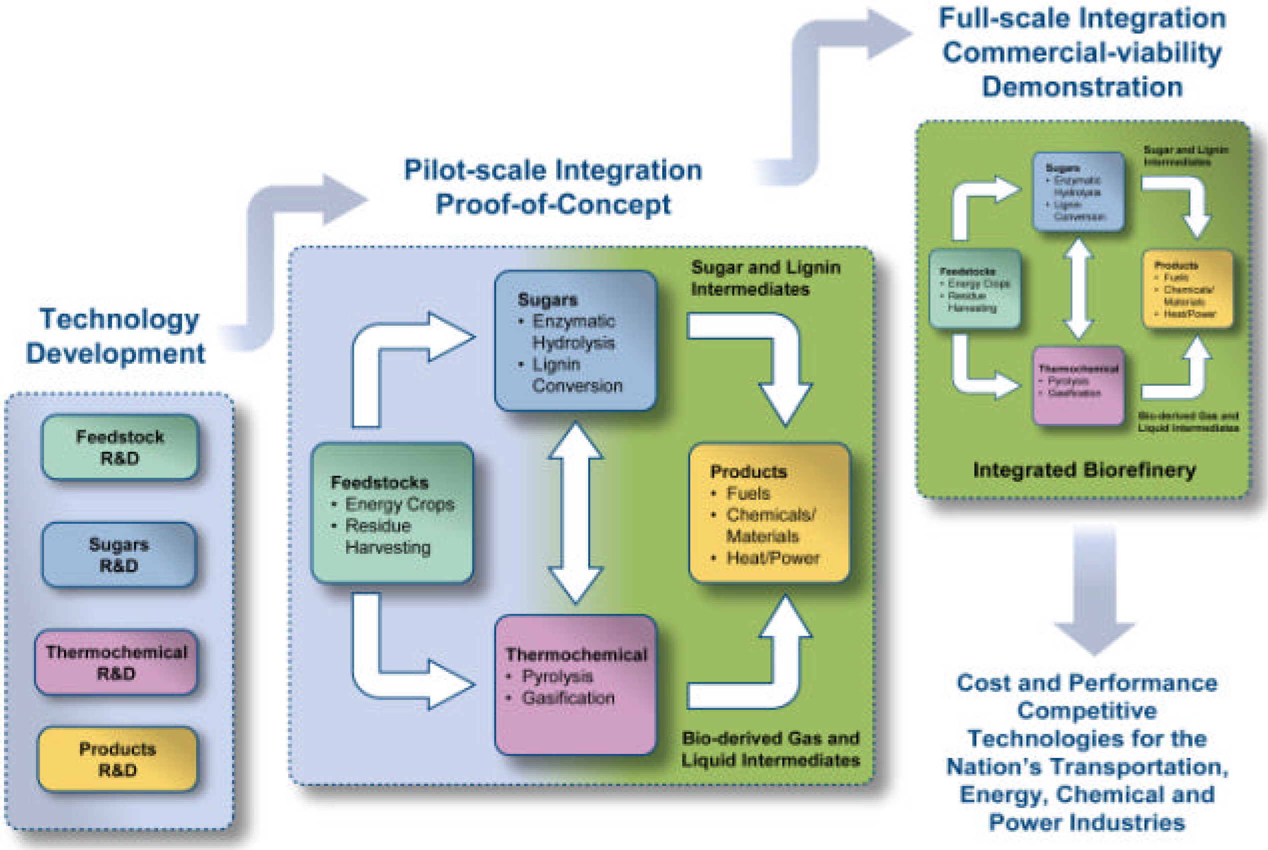



**Figure 1-8: General Program Technology Integration Strategy**

As biomass technologies get closer to commercialization, understanding the specific biorefinery context is critical to success. However, due to the many possible combinations and permutations of biomass technologies, it would be inefficient, if not impossible, for the Program to evaluate every possible biorefinery configuration. Consequently the program has developed an approach for defining generic biorefinery pathways to streamline evaluation of opportunities and setting priorities. Each pathway is linked to a specific portion of the biomass resource base and a processing configuration that is either represented in an existing segment of the current bio-industry or is envisioned as a future market segment.

A recent joint DOE/USDA publication, *Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*[41], describes the potential biomass supply that could be generated from U.S. agricultural and forest land resources. Figure 1-9 shows the types of biomass feedstocks considered in the study.

[41] Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply[41], Robert D. Perlack, et al., USDA/DOE, DOE/GO-102005-2135, April 2005

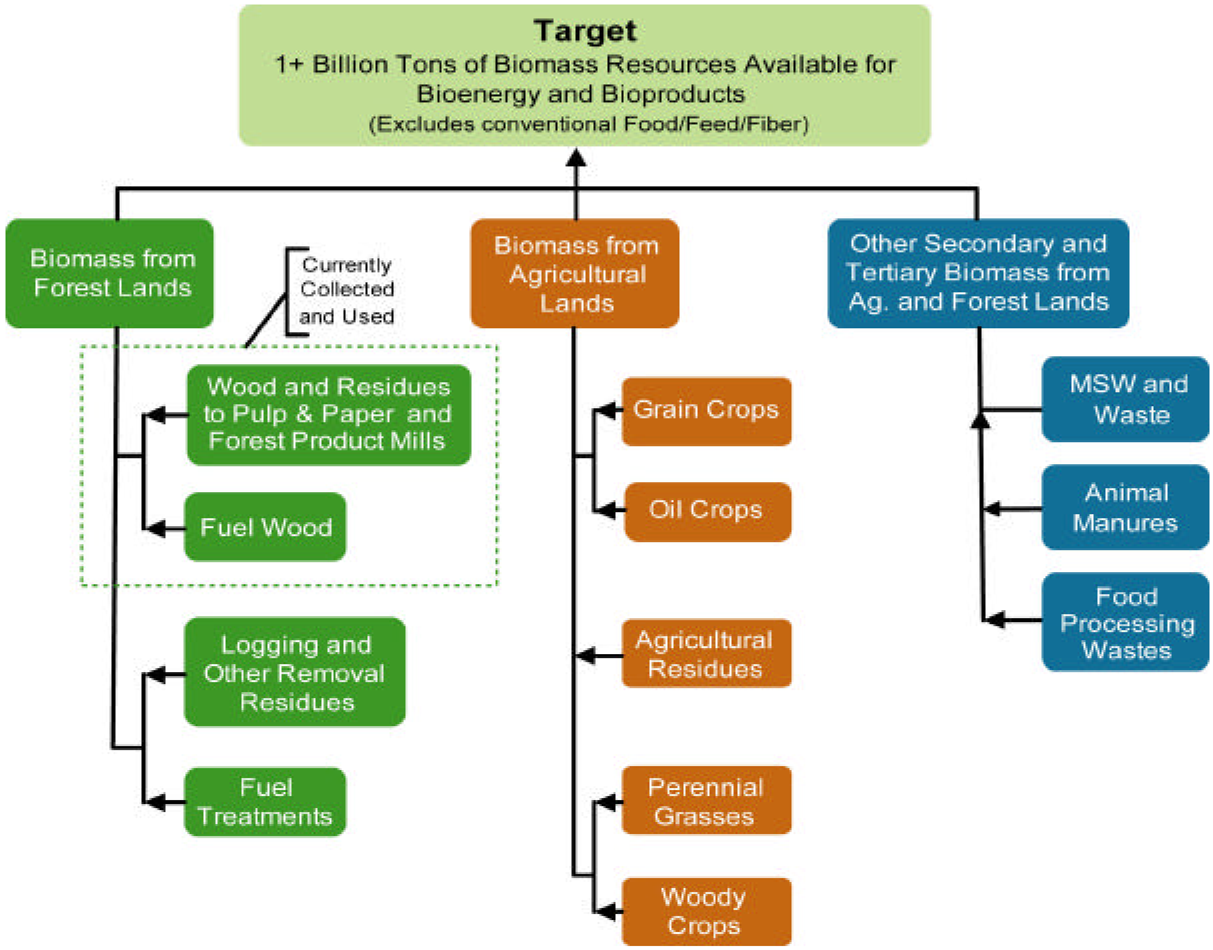



**Figure 1-9:** Biomass Resource Categories

Figure 1-10 depicts the Program's pathway approach and the seven biorefinery pathways identified that are either under development or being considered at this time. They include:

Agricultural Sector:

1. Wet Mill Improvements
2. Dry Mill Improvements
3. Oil Processing Improvements
4. Agricultural Residue Processing
5. Perennial Crop Processing

Forest Sector:

6. Pulp and Paper Mill Improvements
7. Forest Products Mill Improvements

All seven pathways are described in detail in Section 2.1. Pathways 1, 2 and 4 are the current priorities of the Program. Other pathways, such as those related to Forest Residues and Non-Forest Wood Wastes have not been defined in detail as they do not currently represent a significant portion of the overall Program investment.

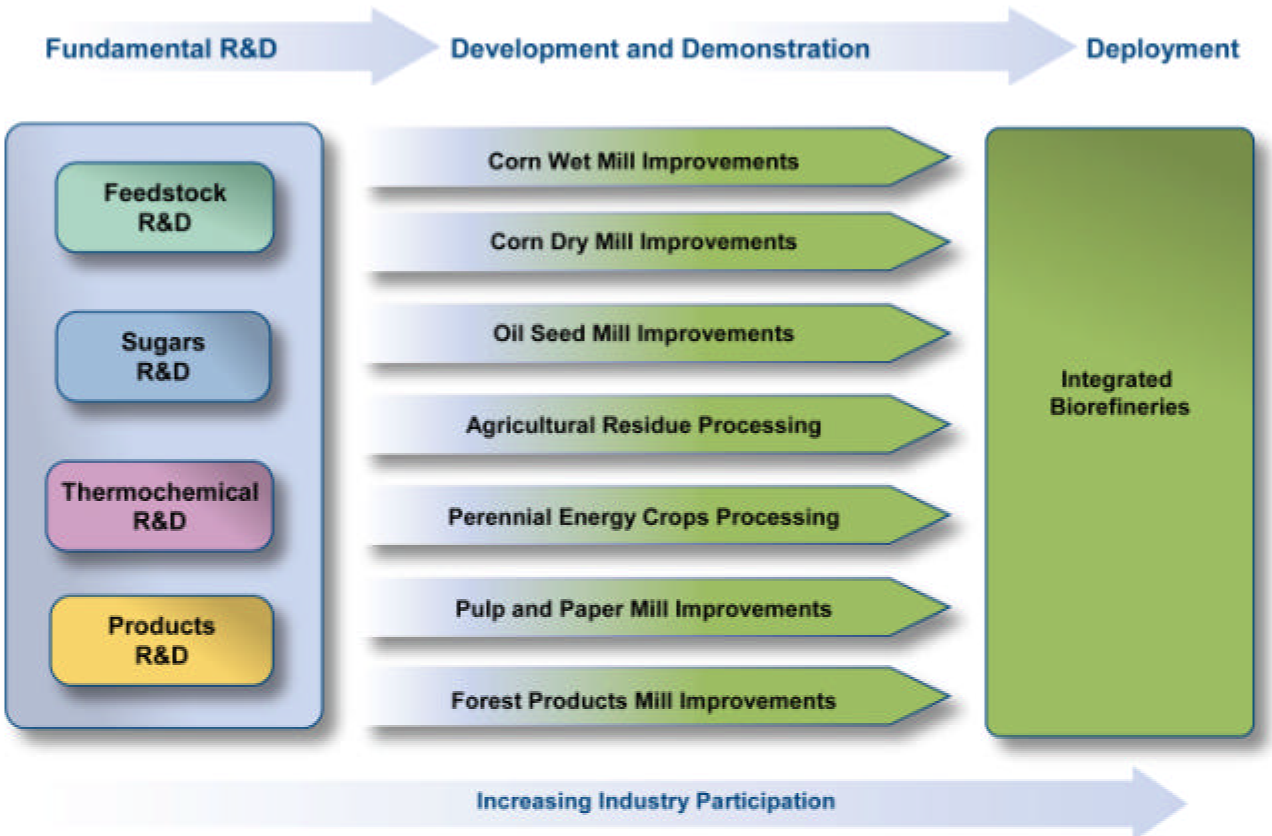



**Figure 1-10:** Program Pathway Approach

While integrated biorefineries are the measure of Program success, the different pathway options are not equivalent. Some, like the corn wet and dry mills, are more completely developed than others with significant capital infrastructure already in place. These pathways provide nearer term opportunities for improving operation of existing processing facilities and introducing new biomass technologies, thereby meeting significant performance goals and achieving measurable Program outputs. Efforts on these types of pathways serve a two fold purpose, the first being the acceleration of technology deployment. Deploying the technology into an existing infrastructure with a readily available feedstock lowers the entry fee and associated risk. The technology advances through this deployment are transferable to most other pathways. The second benefit is increasing the rate at which new plants are built. For example, by improving yields, efficiencies and consequently profitability, the next generation of grain-based ethanol plants are much more likely to find commercial financing.

Other biorefinery pathway options, such as agricultural residue processing and energy crop processing, are longer term and require significant research and development for technologies across the supply chain from feedstock development through product evaluation. While development time is longer for these options, their impact on displacing imported oil by producing transportation biofuels and other products is potentially significantly larger. The program approach is to examine and develop the range of biorefinery pathways and focus research to enable these on a time scale commensurate with Program goals.

## 1.7 Program Performance Goals

Performance goals are a visible and critical part of program planning. The Program has established Year 2012 cost goals specific to the main intermediates produced by the core R&D conversion platforms, sugars and syngas, which are the basis for producing fuels, chemicals, heat and power. The main products core R&D element goal addresses the number of new products, chemicals and materials from biomass that will be enabled by efforts in the products area. The culmination of the Program's activities is the demonstration and validation of integrated biorefineries along the various identified pathways. The pathways, as previously described, are resource based they also, however, represent near term opportunities (dry mill, wet mill, oilseed) intermediate term opportunities (agricultural residues, pulp and paper mills, forest products mills) and the future vision of energy crops (perennial crops). Progress toward the achievement of the platform and products element goals identify the entry ramp to a given pathway. This identification defines the intersection of the work breakdown structure and the pathways. It allows the various R&D elements to be integrated into a biorefinery utilizing existing infrastructure in the near term, building on existing infrastructure in the intermediate and ultimately enabling green field biorefineries based on energy crops. Technology managers use these goals as the benchmarks for measuring the distance the technology must progress to succeed in the long term, when the developments could be used to enable various pathways and to determine how well research projects contribute to realizing those goals.

**Sugars** - Estimated cost for production of a mixed, dilute sugar stream suitable for fermentation to ethanol decreases from 15 cents/lb in 2003 ($2.75 per gallon of ethanol) to 10 cents/lb by 2012 ($1.75 per gallon of ethanol) – Ethanol and sugar cost continue to decrease toward their targets. These decreases will first enable the conversion of corn fiber along the wet and dry mill pathways further decreases will enable the agricultural residue pathway and ultimately perennial crops.

**Syngas** - Production of cleaned and reformed biomass-derived synthesis gas decreases from $7.25 per million Btu in 2003 to $4.34 per million Btu by 2012. In the short term progress toward this goal will allow the economic production of heat and power from process residues when integrated into a biorefinery. Continued cost reductions will enable clean syngas to be a true intermediate for chemical, materials and fuels.

**Value-added Products** - By 2010, establish the technical and market potential, through pilot-scale testing and industry cost shared commercial demonstration, of four new value-added chemicals and/or materials (the baseline is 0 in 2002). Demonstrated products can be integrated into biorefineries providing an economic driver.

In an effort to bring the newest generation of biorefineries to fruition a major solicitation is planned for FY08. This solicitation will build on the previous FY02 integrated biorefinery projects, the FY04 thermochemical projects and the FY05 Products solicitation with the goal of demonstrating the technical feasibility and economic viability of integrated biorefineries. A successful culmination of this solicitation will result in biorefineries along the nearest term pathways to be ready for commercialization.

Table 1-3 below includes the annual performance targets in the FY07 budget request to Congress. The organization of the targets is based on the budget organization. The translation between the budget categories and the OBP work breakdown structure are as follows:

- Platforms Research and Development = Core Sugar R&D and Core Thermochemical R&D Platforms
- Utilization of Platform Outputs R&D: Products Development = Core Products R&D
- Utilization of Platform Outputs R&D = Integrated Biorefineries

**Table 1-3:** Annual Performance Goals and Targets from FY07 Congressional Budget Request

| FY | Platforms Research and Development | Utilization of Platform Outputs R&D: Products Development | Utilization of Platform Outputs R&D |
|---|---|---|---|
| 06 | Complete laboratory and economic assessment of 2 different feedstocks, identifying operating conditions that link pretreatment with enzymes that could be scaled-up and have the potential of achieving the goal of $0.13 per pound sugar by 2007.<br><br>Develop a fluidizable tar-reforming catalyst for synthesis gas production. | Identify at least one sugar-derived or biomass oil-derived bio-based chemical or material (among those being evaluated) that possesses sufficient potential to enter into the scaled-up developmental phase of R&D from the previous bench-scale phase.<br><br>Develop a preliminary process flow diagram showing the integration of a sugar-derived or biomass oil-derived bio-based chemical or material in an integrated biorefin ery, as well as a preliminary analysis showing the economic viability of an integrated biorefinery. | Complete experimental plan for pilot scale testing aimed at producing additional ethanol and enhancing co-product value using the existing plant feed for either a wet or dry mill. This is one of the key steps necessary for transitioning from starch to corn fiber and eventually to corn stover, achieving the FY 2012 cost targets for sugars and ethanol. |
| 07 | Complete integrated tests of pretreatment and enzymatic hydrolysis in conjunction with existing fermentation organisms at bench scale that validate $0.125 per pound sugars on the pathway to achieving $0.10 per pound in 2012. | Establish that at least one bio-based chemical or material at developmental scale, possesses sufficient potential to be demonstrated in a biorefinery based on cost estimates from bench-scale data showing comparability to a non-biomass competitor.<br><br>Complete the revision of the process flow diagram showing the integration of a bio-based chemical or material in an integrated biorefinery. | Establish the feasibility of economic converting recalcitrant starch to ethanol in a corn ethanol biorefinery The target is to achieve at least a 5 percent increase in ethanol output at the same corn throughput by 2012 such that the average ethanol production cost will not increase relative to another plant that does not implement this technology. |
| 08 | Complete a core R&D engineering design and techno-economic assessment of an integrated wet storage - biomass field pre-processing assembly system with a pretreatment process that could be scaled up to produce sugars at about 12 cents per pound on the path to achieving 10 cents per pound by 2012. | | Select one to three advanced technologies suitable for integratio n into a biorefinery for the 2012 system-level demonstration.<br><br>Demonstrate the economic conversion of recalcitrant starch to ethanol at the developmental scale for a biorefinery (developmental scale is a range of pilot scales in the stage-gate process that come after bench-scale work). |
| 09 | Demonstrate alternative pretreatment technologies at bench scale using advanced cellulase enzymes that have the potential of achieving 11.5 cents per pound of sugars on the pathway to 10 cents per pound by 2012. | | Demonstrate the economic conversion of corn fiber to ethanol at the developmental scale in a biorefinery. The target is to achieve at least a 5 percent increase in ethanol output at the same corn throughput by 2012 such that the average ethanol production cost will not increase relative to another plant that does not implement this technology. |

| | | |
|---|---|---|
| **10** | Utilize the extensive capabilities of the Biomass Surface Characterization Laboratory at NREL to gain a detailed understanding of plant cell wall's ultra structure and function to formulate improved enzyme mixtures and pretreatments that could further reduce the cost of sugars from 11.5 cents per pound. Make available information and recommendations to stakeholders. | Finalize a process flow diagram with material and energy balances for an integrated biorefinery with the potential for 3 bio-based products. |
| **11** | Complete integrated runs of pretreatment and enzymatic hydrolysis at pilot scale to validate that an integrated biorefinery potentially could produce mixed, dilute biomass sugars at 10.5 cents per pound. | Establish the economic viability of converting agricultural waste to ethanol and other products using cost estimates for the addition of residue to an existing dry mill based on bench-scale data. |
| | | Demonstrate the conversion of corn fiber and/or recalcitrant starch to ethanol (at demonstration scale) and estimate the cost for this advanced dry mill. |

## 1.8 Program Strategic Goals

The Program's overarching strategic goal is to develop biorefinery-related technologies to the point that they are cost- and performance-competitive and are used by the nation's transportation, energy, chemical and power industries to meet their market objectives. This helps the nation by expanding clean, sustainable energy supplies while also improving the nation's energy infrastructure and reducing our dependence on foreign oil and greenhouse gas emissions.

This strategic goal is in alignment with DOE and EERE strategic goals as shown in Figure 1-11 and described below.

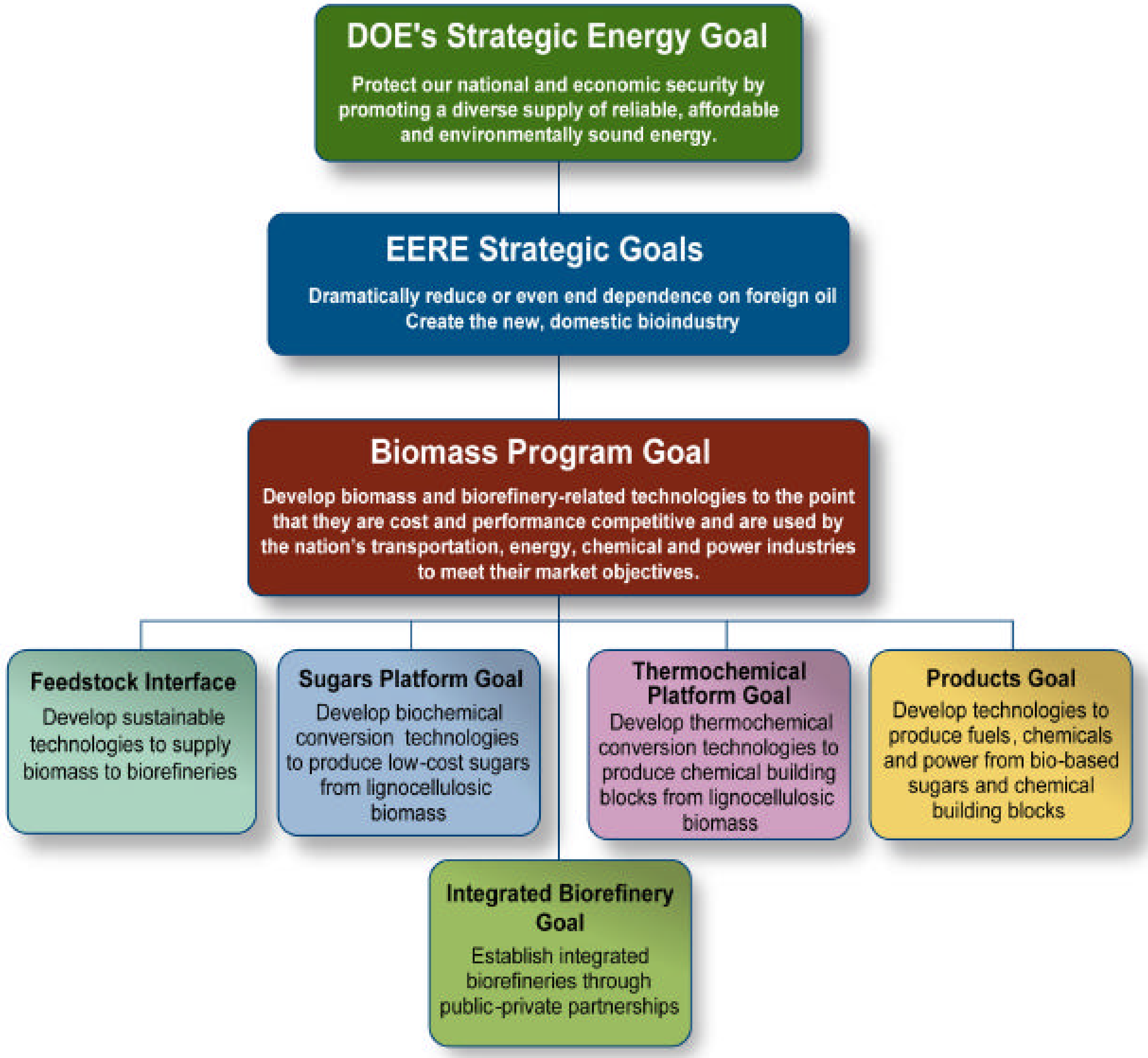



**Figure 1-11:** Biomass Program Strategic Goal Hierarchy, including goals for the R&D Elements

The Department of Energy (DOE) Strategic Plan[42] identifies four strategic goals (one each for defense, energy, science, and environmental aspects of the mission) plus seven general goals that tie to the strategic goals. The Energy strategic goal is "To protect our national and economic security by promoting a diverse supply and delivery of reliable, affordable, and environmentally sound energy." One strategy identified to achieve this goal was to "Research renewable energy technologies—wind, hydropower, biomass, solar and geothermal—and work with the private sector in developing these domestic resources."

The Department adopted seven long-term general goals to implement the strategic goals. The Biomass Program supports General Goal 4: "Improve energy security by developing technologies that foster a diverse supply of reliable, affordable and environmentally sound energy by providing for reliable delivery of energy, guarding against energy emergencies,

[42] Department of Energy Strategic Plan, 2003, http://strategicplan.doe.gov/hires.pdf

exploring advanced technologies that make a fundamental improvement in our mix of energy options, and improving energy efficiency."

According to the EERE Strategic Plan[43], the EERE mission is to strengthen America's energy security, environmental quality, and economic vitality through public-private partnerships that:

- Enhance energy efficiency and productivity;
- Bring clean, reliable, and affordable energy production and delivery technologies to the marketplace; and
- Make a difference in the everyday lives of Americans by enhancing their energy choices and their quality of life.

The EERE strategic goals and objectives supported by the Biomass Program include:

- Dramatically reduce or even end dependence on foreign oil:
  - Develop non-petroleum fuels and related infrastructure technologies through innovative R&D investments
- Create the new, domestic bioindustry:
  - Advance technologies for converting biomass to fuels, power, and products through R&D involving industry partners
  - Advance technology for biomass harvesting, storage and handling to support viable biorefineries through R&D partnerships
  - Condition markets for significant penetration of biomass-based technologies

The Biomass Program is also aligned with recommendations in the Administration's National Energy Policy (NEP)[44], released in May 2001. The NEP outlines a long-term strategy for developing and using leading edge technology within the context of an integrated national energy, environmental and economic policy. The following recommendations are particularly relevant to the Biomass Program.

**NEP Chapter 6: Nature's Power (Renewable and Alternative Energy):**

> *"The NEPD Group recommends that the President direct the Secretary of Energy to conduct a review of current funding and historical performance of renewable energy and alternative energy research and development programs in light of the recommendations of this report. Based on this review the Secretary of Energy is then directed to propose appropriate funding for those research and development programs that are performance based and are modeled as public -private partnerships."*

This is the most critical of the recommendations. Our ability to assemble an in-depth and accurate story of the program's history is vital. There are a few key notions we should keep in mind as the Department moves ahead with this recommendation. First, we should avoid the temptation to set unrealistic goals. While they may serve us in the near term, they will, in the end, come back to haunt us. Second, we must take an active role in the process. Too much is at

[43] DOE Office of Energy Efficiency and Renewable Energy Strategic Plan, http://www.eere.energy.gov/office_eere/pdfs/fy02_strategic_plan.pdf
[44] National Energy Policy Report, 2001, http://www.energy.gov/engine/content.do?BT_CODE=AD_AP

stake. We need to better understand what is meant by "public-private partnership." We should work to ensure that industry partnership means more than handing over funds for building commercial facilities. What is needed is a genuine partnership in which DOE researchers and industry researchers work collaboratively on solving the high risk technology problems associated with bioethanol and biomass production.

> *"The NEPD Group recommends that the President direct the Secretary of Treasury to work with Congress to continue the ethanol excise tax exemption."*

This recommendation reiterates the President's commitment to the ethanol tax credit, and lends it further significance as an integral part of the NEP.

**NEP Chapter 7: America's Infrastructure**

> *"The NEPD Group recommends that the President direct the Administrator of the EPA to study opportunities to maintain or improve the environmental benefits of state and local boutique clean fuel programs while exploring ways to increase the flexibility of the fuels distribution infrastructure, improve fungibility, and provide added gasoline market liquidity. In concluding this study, the Administrator shall consult with the Departments of Energy and Agriculture, and other agencies as needed."*

OBP has a stake in how the United States moves ahead with its upgrading of our energy distribution system—particularly its pipelines. The Program should try to ensure compatibility of the pipeline infrastructure with ethanol for blending or for alternative fuel applications.

**NEP Chapter 8: Strengthening Global Alliances**

> *"The NEPD Group recommends that the President direct the Secretaries of Commerce, State and Energy to promote market-based solutions to environmental concerns; support exports of U.S. clean energy technologies and encourage their overseas development…."*

> *"The NEPD Group recommends that the President direct federal agencies to support continued research into global climate change; continue efforts to identify environmentally and cost-effective ways to use market mechanisms and incentives; continue development of new technologies; and cooperate with allies, including through international process, to develop technologies, market-based incentives, and other innovative approaches to address the issue of global climate change."*

> *"The NEPD Group recommends that the President seek to increase international cooperation on finding alternatives to oil, especially in the transportation sector."*

All three of these recommendations offer the opportunity for the program to more aggressively seek international opportunities for biomass technology deployment. This is an opportunity to seek markets where biomass technologies may be better suited than in the domestic arena.

## 1.9 Program Outputs

The outputs of the Biomass Program are the A-level milestones for each of the seven pathways. The A-level milestones are the culmination of the successful achievement of all lower level cost (B-level milestones) and technology (C-level milestones) performance goals (see Section 2.1.2.[1-7].2 for milestone details). Each A-level milestone signifies the successful demonstration and validation of the integrated set of technologies and systems needed to enable the commercialization of a pathway-specific biorefinery, and as such signify the Program's off-ramps. The outputs for each pathway are summarized as follows:

- **Corn Wet Mill Improvements Pathway:** The program output from the corn wet mill improvements pathway is a complete systems-level demonstration and validation of technologies to improve corn wet mill facilities using corn grain feedstock by 2009 (A Milestone: M1). This pathway is based on improving today's commercial corn wet milling process by incorporating new technologies that use residues/intermediates from the existing corn wet mill process (corn fiber, residual starch and corn oil) to increase yields of ethanol, produce new high-value products, improve plant efficiency, and reduce operating costs.

- **Corn Dry Mill Improvements Pathway:** The program output from the corn dry mill pathway is a complete systems level demonstration and validation of all technologies to improve corn dry mill facilities by 2012 (A Milestone: M2). This pathway is based on improving today's commercial dry milling operations by incorporating new technologies that use residues and intermediates (fiber and spent grain products) from the existing corn dry mill process to increase yields of ethanol, produce new high-value products, improve plant efficiency, and reduce operating costs.

- **Natural Oil Crops Improvements Pathway:** The program output from the natural oil processing mill improvements pathway is a complete systems level demonstration and validation of all technologies to improve oil processing facilities by 2012 (A Milestone: M3). This pathway is based on improving today's biodiesel/oleochemical facilities by incorporating new technologies to produce high-value chemical intermediates from the oil and glycerol streams, and evaluating new low-cost oil seed feedstocks.

- **Agricultural Residues Pathway**. The program output from the agricultural residues pathway is a complete systems level demonstration and validation of all technologies to utilize agricultural residue feedstocks in existing or new facilities by 2015. (A Milestone: M4). This pathway is focused developing new commercially-viable technologies and processes that convert agricultural residues (and lignin intermediates) to fuels, chemicals, and heat and power, initially, as pilot and demonstration applications in existing facilities and ultimately, in new dedicated commercial-scale facilities.

- **Perennial Energy Crops Pathway**. The program output from the perennial grasses and woody energy crops pathway is a complete systems level demonstration and validation of all technologies to utilize perennial energy feedstocks in existing or new facilities by 2020. (A Milestone: M5). This pathway is based on developing new commercially-viable technologies and processes that convert dedicated energy crops to fuels, chemicals, and heat and power, initially, as pilot and demonstration applications associated with existing facilities and ultimately, in new dedicated commercial-scale facilities.

- **Pulp and Paper Mill Improvements Pathway**. The program output from the pulp and paper mill improvements pathway is a complete systems level demonstration and validation of all technologies to improve pulp and paper mill facilities and/or produce additional products (fuels, chemicals and/or power) from wood feedstock in a pulp and paper mill environment by 2010. (A Milestone: M6). This pathway is based on improving the existing commercial operations through more efficient utilization of residuals (hog fuel and black liquor) for the production of new intermediates (e.g., sugars, pyrolysis oils, syngas) that can be used to produce a variety of fuels, chemicals, and heat and power.

- **Forest Products Mill Improvements Pathway**. The program output from the forest products mill improvements pathway is a complete systems level demonstration and validation of technologies to improve forest products mill facilities and/or produce additional products (fuels, chemicals and/or power) from wood feedstock in a forest products mill environment by 2018. (A Milestone: M7). This pathway is based on improving the existing commercial process through more efficient utilization of residuals (bark and hog fuel) for the production of new intermediates (e.g., pyrolysis oils, syngas)

## 1.10 Program Outcomes

The overall desired outcomes of the Biomass Program are to dramatically reduce the nation's dependence on foreign oil and to create the new, domestic bioindustry. In short, the Biomass Program is poised to facilitate a paradigm shift in the source of the nation's energy and petroleum derived chemical and material supply chain. The Program's mission and vision will be realized by the development of technology through core R&D followed by industrial partnerships to prove and ensure the technical viability of the research culminating in the development of integrated biorefineries. The development of these biorefineries will be the result of further collaboration and resource leveraging with industry. The Program's outputs will be biorefinery technologies validated on a systems level which will prove the technical viability and economic feasibility and sustainability of these biorefineries. A systems validated biorefinery is defined by the financial and engineering communities. By meeting and/or exceeding the technological requirements of the groups that will be asked to take the risks in the engineering, construction, financing and ultimate commercialization of the biorefinery, the Program will have optimized its input toward the prospects of a commercialized biorefinery.

The utilization of the pathway approach allows the technology to be deployed and outcomes to be enabled at the earliest possible time with minimized risk. This approach allows the program to accelerate its outputs increasing the potential of outcome realization. It further allows the Program to build on early success to enhance future potential. The Program is convinced that this step wise progression will lead to the highest probability of success and outcome realization.

The pathways are resource based. They progress from the nearest term which are focused on existing feedstock and industrial infrastructure as well as mature R&D efforts through the long term realization of the longer term pathways utilizing new enhanced feedstocks and advanced grass roots processing facilities. The nearest term pathways (improved corn wet mill, dry mill and natural seed oil processing operations) will allow developing conversion technologies to utilize feedstocks already in existing plants to increase both the quantity and quality of the industry's outputs. In grain plants the conversion of fiber streams will increase biofuels outputs and enhance co-product quality. In both grain and oil seed plants the addition of complementary co-products will also improve output quality and enhance revenues. The outcome from the realization of these pathways will be two fold. The first outcome will be an increase in biofuels and bioproducts from the existing industry. The second and far more dramatic of the outcomes is the increased efficiency and profitability the incorporation of the Program developed technologies will have on the existing biofuels industry. This will allow the current industry to realize its ultimate potential at a drastically accelerated rate. The Program anticipates that if fully implemented the biofuels output from the existing industry will increase by upwards to 20 percent. It is further anticipated that growth rate within the existing industry has the potential of doubling due to the Program's efforts.

The mid term pathways (improved pulp and paper mill, forest products mill operations, and new processes and products from agricultural crop residues*)* will continue to make use of existing industry infrastructure. Although the technology is not quite as well developed, the application of developing technology to existing pulp and forest products mills will again leverage infrastructure with technology development. The production of additional products and biofuels from these facilities will increase their self sufficiency. The program outputs will result in the potential outcomes within these industries of improved global competitiveness with additional benefits of biomass derived chemicals, materials and fuels. A further and potentially larger outcome is the application of thermochemical platform technologies turning these large net energy importers to being nearly energy self sufficient and with technological advances potential net energy exporters. The ultimate benefit and outcome in the pulping sector is the reinvention of the industry as a globally competitive force. The agricultural residue pathway has a natural, logical and progressive fit in the dry and wet mill pathways. The initial technological deployment will be the addition of this material as supplemental feedstocks utilizing minimal infrastructure addition and making use of the economies of scale liberated by advances in the near term pathways. Although there is currently a limited supply, storage and delivery infrastructure for these feedstocks, there relationship to the grain feedstocks currently being used will accelerate their supply chain development.

The long term pathway (New processes and products from energy crops) will build on the technological advances within the program and the learning curve of industrial partners. It is anticipated that energy crops will first be introduced along the mid term pathways as additional supplemental feedstocks and as an infrastructure develops will give rise to stand alone biofuels production facilities. These facilities will be based on agricultural residues and regionally logical energy crops. As these long term pathways are realized the Program will enable the outcome outlined in the joint DOE/USDA billion ton feedstock study and will enable the production of over one third of the nation's energy supply for transportation fuels to be biomass derived biofuels.

As the program outputs of enabling the currently outlined pathways are achieved, the Biomass Program will enable the production of more than 14 billion gallons of ethanol and 150 million pounds of bio-products, increasing energy supplies, increasing energy security, enhancing economic development opportunities in rural areas, and accelerating the protection and improvement of the environment such as reducing carbon emissions.

Estimates of annual non-renewable energy savings, energy expenditure savings, carbon emission reductions, oil savings, and natural gas savings that result from the realization of Biomass Program goals are shown through 2050in the current budget submission. found at (www.eere.energy.gov/office_eere/budget_gpra.html) The level of cellulosic ethanol production expected as a result of realizing the program goals is also reported. These estimates do not include other benefits such as local air quality improvements and represent a conservative initial effort at assessing the benefits of the Biomass Program activities and are likely to significantly underestimate the benefits from integrated biorefinery production options that are yet to be modeled. In addition, these estimates do not yet address some of the more fundamental technologies being developed in the Integrated Biorefinery and Bioproducts processes.

# **Section II**: Program Critical Functions

The critical functions of the Biomass Program are to *integrate* the technologies developed through its Core R&D activities: Feedstocks, Sugars, Thermochemical, and Products; and then *demonstrate and validate* them in Integrated Biorefineries. This section describes the program structure, portfolio decision-making process, analysis, performance measurement, performance assessment, logic models, benefits, and relationship to other EERE, DOE and federal programs.

## 2.1 Program Structure

### 2.1.1 Biomass Program Technology Elements

The Biomass Program is structured around five R&D technology elements. The first four elements focus on core research and development (R&D) that emphasizes enabling technology for biorefineries. The fifth element focuses on integrating these core technologies into specific commercial biorefinery scenarios, or pathways.

- **Feedstock Interface Core R&D.** Focused on developing new sustainable agricultural and feedstock infrastructure technologies and methods that will be required to supply lignocellulosic feedstocks to future large-scale biorefineries.
- **Sugars Core R&D.** Focused on fundamental and applied research and technology development for producing low-cost sugars from lignocellulosic biomass.
- **Thermochemical Conversion Core R&D.** Focused on developing cost-effective, efficient thermochemical technologies for producing intermediate products (e.g., syngas, pyrolysis oil) from lignocellulosic biomass and biomass-derived biorefinery residues.
- **Products Core R&D.** Focused on converting low-cost sugars and thermochemical platform intermediates into fuels, chemicals, and heat and power.
- **Integrated Biorefineries.** Focused on demonstrating and validating the integration of the technologies and systems developed in the four Core R&D platforms in commercial-scale biorefineries.

The Biomass Program Work Breakdown Structure (WBS) is based on these five program technology elements as illustrated in Figure 2-1. This functional organization of the work allows the program to allocate its federal funding resources toward pre-commercial, enabling technology development. This can lay the groundwork for future commercialization without competing with, or duplicating work in the private sector. The key Biomass Program WBS tasks conducted under each program element are described in Table 2-1. Each of the five R&D elements is described in detail in Section 3. The Program Management organization and activities are discussed in Section 4.0.

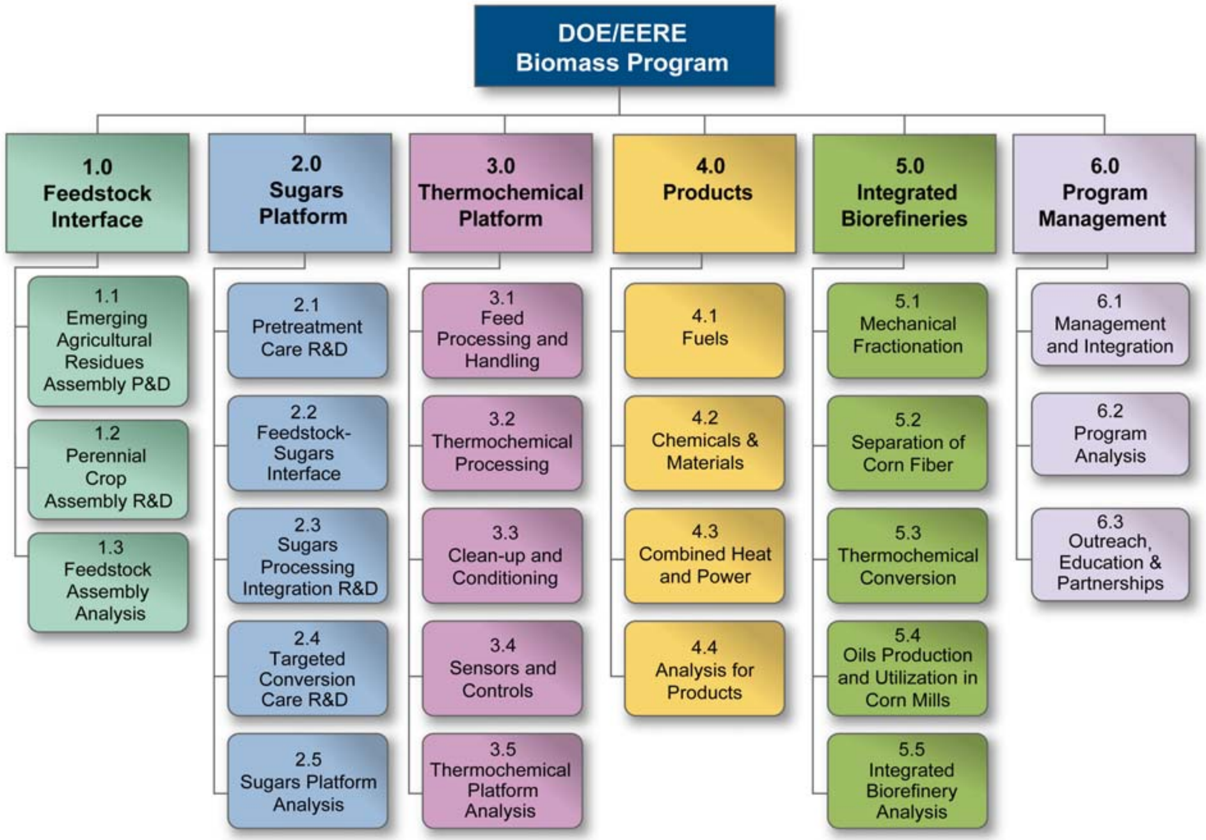



**Figure 2-1:** Biomass Program Work Breakdown Structure

**Table 2-1:** Biomass Program Element Tasks

| Sub-element | Description |
|---|---|
| 1.0 Feedstock Interface | |
| 1.1 Agricultural Residues Assembly R&D | Migrating the feedstock assembly system from the traditional technologies used, which primarily served the smaller distributed livestock and forage industry, to an assembly system specifically designed for the biorefinery industry. |
| 1.2 Perennial Crops Assembly R&D | Addresses key operations in the integrated biorefinery by providing credible, industry-accessible data on current and future feedstock supplies. |
| 1.3 Feedstock Assembly Analysis | Strategic analysis to identify barriers and guide research; and core R&D analysis to determine cost, quality, and consistency parameters of the feedstock. |
| 2.0 Sugars | |
| 2.1 Pretreatment and Enzymatic Hydrolysis | Developing cost-effective pretreatment step to release hemicellulose sugars and improve the ability to hydrolyze cellulose. Focused on developing cost-effective enzymes to catalyze the hydrolysis of cellulose to glucose. |
| 2.2 Feedstock-Bioconversion Interface | Developing cost and quality specifications for feedstock assembly technologies that are compatible with biorefinery pathway technologies. |
| 2.3 Sugars Processsing Integration | Collaborating with industry to facilitate the commercialization of enzymatic hydrolysis-based technology for sugar production from |

| | |
|---|---|
| | cellolosic feedstock. |
| 2.4 Targeted Conversion Research | Increasing understanding of the root causes of the recalcitrance of biomass and developing and evaluating new process concepts. |
| 2.5 Sugar Platform Analysis | Evaluating the technical, economic, and environmental aspects of biomass sugar production and conversion. |
| 3.0 Thermochemical Conversion | |
| 3.1 Feed Processing and Handling | Developing in-plant feedstock handling systems that can economically convert a wide range of feedstocks to a consistent form that existing feeders need to function reliably. |
| 3.2 Thermochemical Processing | Increasing understanding of biomass gasification and pyrolysis chemistry, formation and destruction of tars, and catalyst requirements, and developing equipment design. |
| 3.3 Clean-up and Conditioning | Gas cleaning and conditioning to remove contaminants such as tar, particulates, alkali, ammonia, chlorine, and sulfur; and pyrolysis oil stability and upgrading. |
| 3.4 Sensors and Controls | Developing new sensors and analytical instruments needed to optimize control systems for thermochemical processes. |
| 3.5 Thermochemical Platform Analysis | Performing technoeconomic analyses to determine the costs of producing biofuels and chemicals using currently available technologies and comparing analyses of the syngas pathways with those of other platforms |
| 4.0 Products | |
| 4.1 Fuels | Producing biobased fuels for transportation from mixed sugars and Fischer Tropsch liquids from biomass-derived syngas |
| 4.2 Chemicals and Materials | Developing processes to produce building block intermediates and high value chemicals from sugars, syngas and residual biomass streams including lignin, protein and char |
| 4.3 Combined Heat and Power | Evaluating the efficient use of residue streams to help satisfy some or all of the biorefinery heat and power requirements. |
| 4.4 Analysis for Products | Identifying products with the potential to enter into, large volume chemical markets and serve as the economic driver for the biorefinery. |
| 5.0 Integrated Biorefineries | |
| 5.1 Mechanical Fractionation | Evaluating the use of multiple tools that separate grain and other feedstocks into their component parts for processing and conversion to reduce cost and improve yield |
| 5.2 Separation of Corn Fiber | Developing improved processes and process equipment to separate, clean and concentrate fiber sources. |
| 5.3 Thermochemical Conversion for Power, Heat, Materials | Identifying processes to transport, store and gasify a range of fuel types for a biorefinery. |
| 5.4 Oils Production and Utilization in Existing Corn Mills | Developing and evaluating processes to separate and produce a clean oil product from a range of feedstocks. This task is also closely coupled to the Mechanical Fractionation task to provide a feed that is easily handled, transported within the plant, and processed. |
| 5.5 Integrated Biorefineries Analysis | Analyze the technical and economic improvements of different processes, including mass and energy balances will be developed along with capital and operating cost estimates for syngas production and sugar production. |

The interactions between the program technology elements are illustrated in Figure 2-2. Biomass feedstocks are collected and pre-processed for conversion to sugars or thermochemical intermediates, and then converted to fuels, chemicals, and/or heat and power. In addition, residual materials from the biomass-to-sugars conversion process (e.g., lignin) can be converted to fuels, chemicals and/or heat and power in thermochemical processes. These interactions between the core R&D technologies provide the framework for the full-scale integrated biorefinery concept.

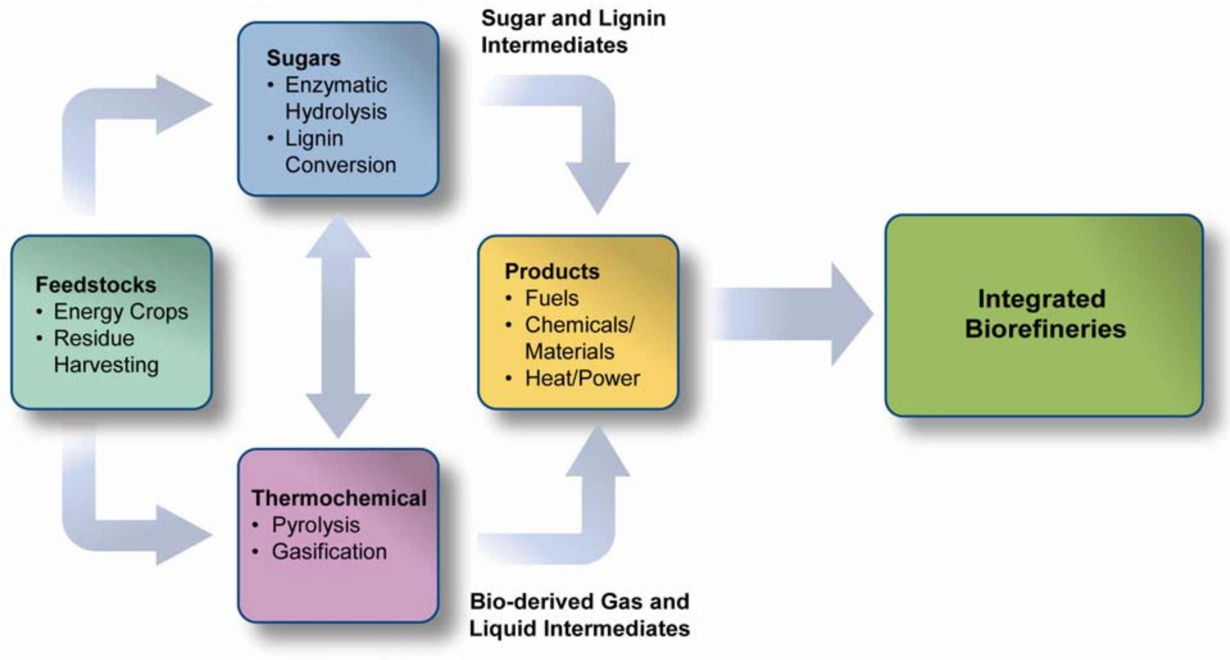



**Figure 2-2:** Interaction between Program Technology Elements

In addition, because of the wide diversity of biomass feedstocks, conversion technologies, integration scenarios, and potential products, a multitude of biorefinery options are possible. To narrow the possibilities to those that align with the program goals, the Biomass Program has developed a new pathway structure based on the biomass feedstock resource, the conversion and utilization technologies employed, the product portfolio and the maturity level of the related bio-industry. In addition, the program has instituted a systems integration approach that will help the program to focus on the activities critical to success. The systems integrator, working with HQ technology leads, is able to integrate and network the pathways and the program elements. This enables the identification of the components that are vital for the success of a pathway and facilitates the determination as to how components of one pathway could affect several others. In times of budget variability, these tools will prove invaluable in maximizing the program's effectiveness. Figure 2-3 shows the relationships between the program elements and the program goals.

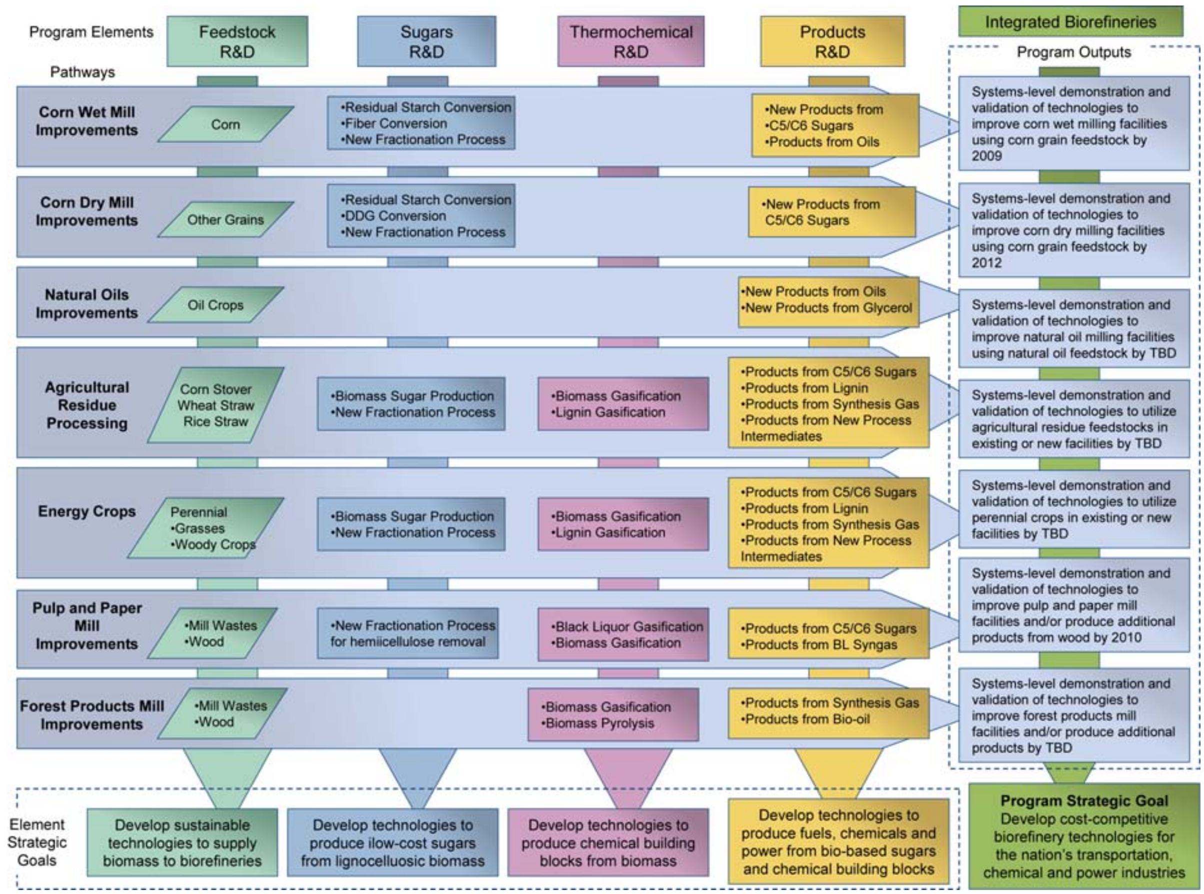



**Figure 2-3:** Biomass Program Structure

### 2.1.2 Pathways

The Biomass Program has defined seven primary technology pathways to guide the research efforts and identify the key interfaces that will enable the establishment of commercially-viable integrated biorefineries. These technology pathways are linked to the resource base identified in the joint DOE/USDA Billion Ton Vision study[1], the existing segments of today's bio-industry where possible, and future bio-industry market segments where envisioned. Each pathway represents a generic set of potential biorefinery scenarios for a specific biomass resource base. The pathways are divided into the agricultural sector and the forest products sector and incorporate the program technology elements described in section 2.1.1. Pathways 1, 2 and 4 are the current priorities of the program.

**Agricultural Sector**

1. Corn Wet Mill Improvements
2. Corn Dry Mill Improvements
3. Oil Processing Improvements
4. Agricultural Residue Processing
5. Perennial Energy Crop Processing

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[1] Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, DOE/GO-102005-2135, DOE/USDA, April 2005 (http://feedstockreview.ornl.gov)

**Forest Sector**

6. Pulp and Paper Mill Improvement Pathway
7. Forest Products Mill Improvement Pathway

These pathways are also designed to distinguish near-term and long-term opportunities for biomass. For example, the wet mill and dry mill pathways identify the technologies needed to enable the increased production of ethanol from the fermentable sugars in feedstock materials already brought into existing grain-based ethanol production facilities. These pathways are near term and have high cost-share industrial partners. Deploying the technology into an existing infrastructure with a readily available feedstock lowers the entry barriers and associated risk, and serves to accelerate technology deployment and increase the rate at which grain-based ethanol plants are built. The technologies advancing through this deployment are transferable to most other pathways.

Other pathways such as the agricultural residues and energy crops pathways are being pursued over the mid- to long-term timeframe. The program's core R&D is focused on overcoming the significant technological barriers facing the cost-effective conversion of lignocellulosic biomass to fuels, chemicals, and heat and power. Industry cost-share partnerships are focused on the intermediate pathways (e.g., agricultural residues) and the highest risk research associated with the long-term pathways (e.g., perennial energy crops) are generally pre-competitive and either fully funded by the Program, such as much of the work done at the National Laboratories, or require only modest cost share.

In the following sections, each pathway, its relationship to the Program elements, a market overview of the relevant bio-industry, the Program's past efforts and future plans, and Program strategic and performance goals are summarized.

**Pathway Diagrams.** A diagram is provided for each pathway, which identifies the current process and current products including fuels, chemicals and power (if it exists today), the options for improvements under evaluation by the Program and the associated new products. The diagrams are color-coded to make them easier to understand and compare. In each diagram, the relationship of process steps to the program elements is indicated by color coding: the feedstocks R&D is indicated in green, the sugars R&D in blue, the thermochemical R&D in pink, and the products R&D in yellow. Uncolored boxes indicate existing processing steps in current biorefineries. The existing fuels and products are shown in gray and the new product slate is indicated in orange. The pink diamond shapes with an "o" in the center on a process stream indicates that an option exists on how to process the stream. The options must be evaluated and compared against each other through analyses, such as trade-off studies, sensitivity analyses, and risk assessments, to identify the best overall pathway configuration. For pathways representing existing industry segments the options analysis must include the status quo. The options analysis may compare options that would take the full stream or fractions of the full stream. The ability to add and evaluate options throughout the duration of R&D on a pathway results in a flexible framework for considering innovative new ideas in the future. A generic pathway diagram example is provided in Figure 2-4. Full page pathway diagrams are provided in Appendix A.

**Pathway Milestones.** Each biorefinery pathway under development has one "A" milestone which is the Program output for the pathway as described in Section 1.9. Completion of the "A" milestone indicates that OBP work on the pathway is complete and the Program output has been successfully achieved because risk has been reduced to a level needed to prompt private investment in deployment. This point of technology development is also synonymous with being at the end of "Stage 4" in the stage gate management process used by the program (described in Section 2.5.4.3). This means that industry is a Gate 4 ready to make the commercialization decision. Each "A" milestone will have multiple "B" milestones which are defined as cost targets for portions of an overall biorefinery pathway that have been demonstrated and validated. Each cost target is developed through analysis and is associated with a specific feedstock, biorefinery pathway configuration, and detailed process design. Achieving a "B" milestone cost target indicates that OBP work is complete on that portion of the overall biorefinery pathway. Each "B" milestone has multiple "C" milestones which are technical performance targets, or lower level cost targets, determined through analysis to be essential for meeting its higher level "B" milestone. "C" milestones are also the first level of project milestones and exist at all stages of development, not just at the demonstration and validation stage. However, there must be a "C" milestone at each gate in the stage gate progression that signifies the DOE decision point for the future of the project; go, no go, recycle, or hold. As a result there may be multiple projects with the same or similar "C" milestone(s). Preliminary pathway "B" and "C" DOE decision point milestones are shown in tables in each pathway section. The Program is in the process of developing the analytical basis for the highest priority "B" milestones and plans to confirm the cost targets and underlying technical targets with industry-specific stakeholder groups.

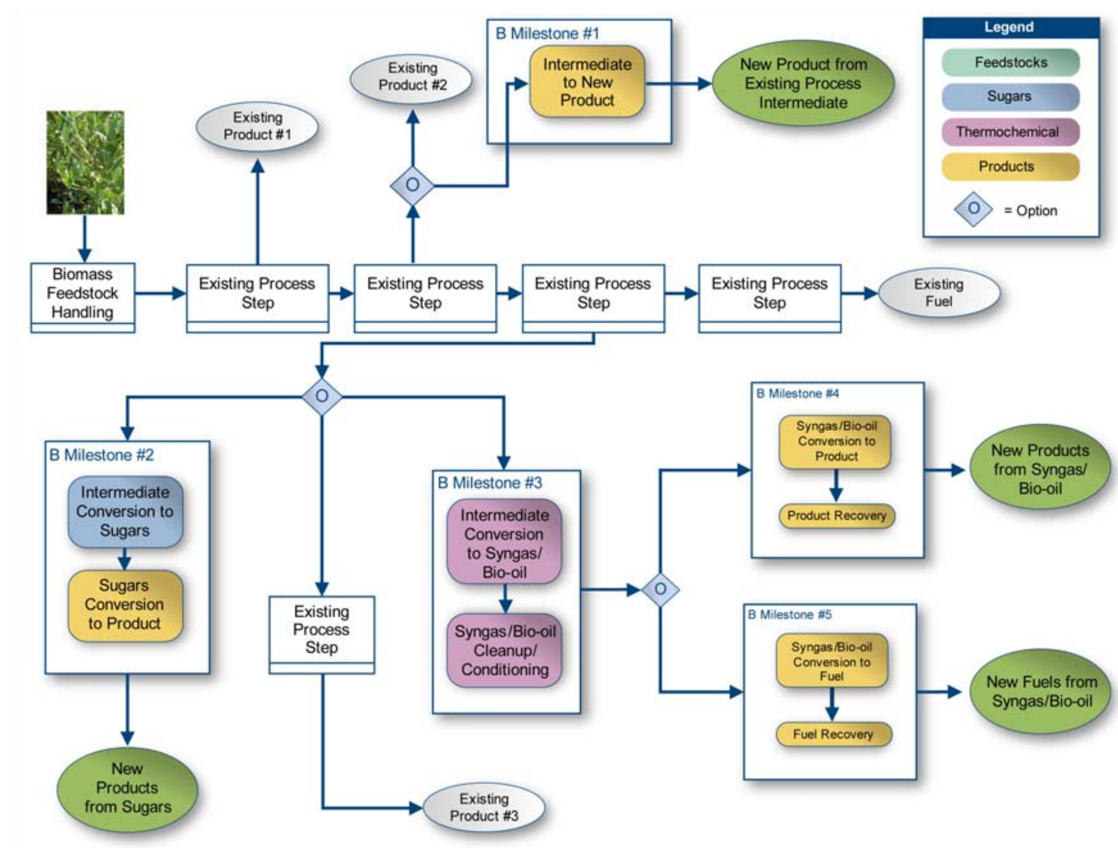


**Figure 2-4:** Generic Pathway Diagram

### 2.1.2.1 Corn Wet Mill Improvements Pathway

The corn wet mill pathway is based on improving the existing commercial process through the utilization of corn fiber and residual starch conversion to produce additional ethanol and other bioproducts, including the conversion of oils, as shown in Figure 2-5. The new product slate includes additional ethanol, new fiber products, organic chemicals and petrochemical replacements.

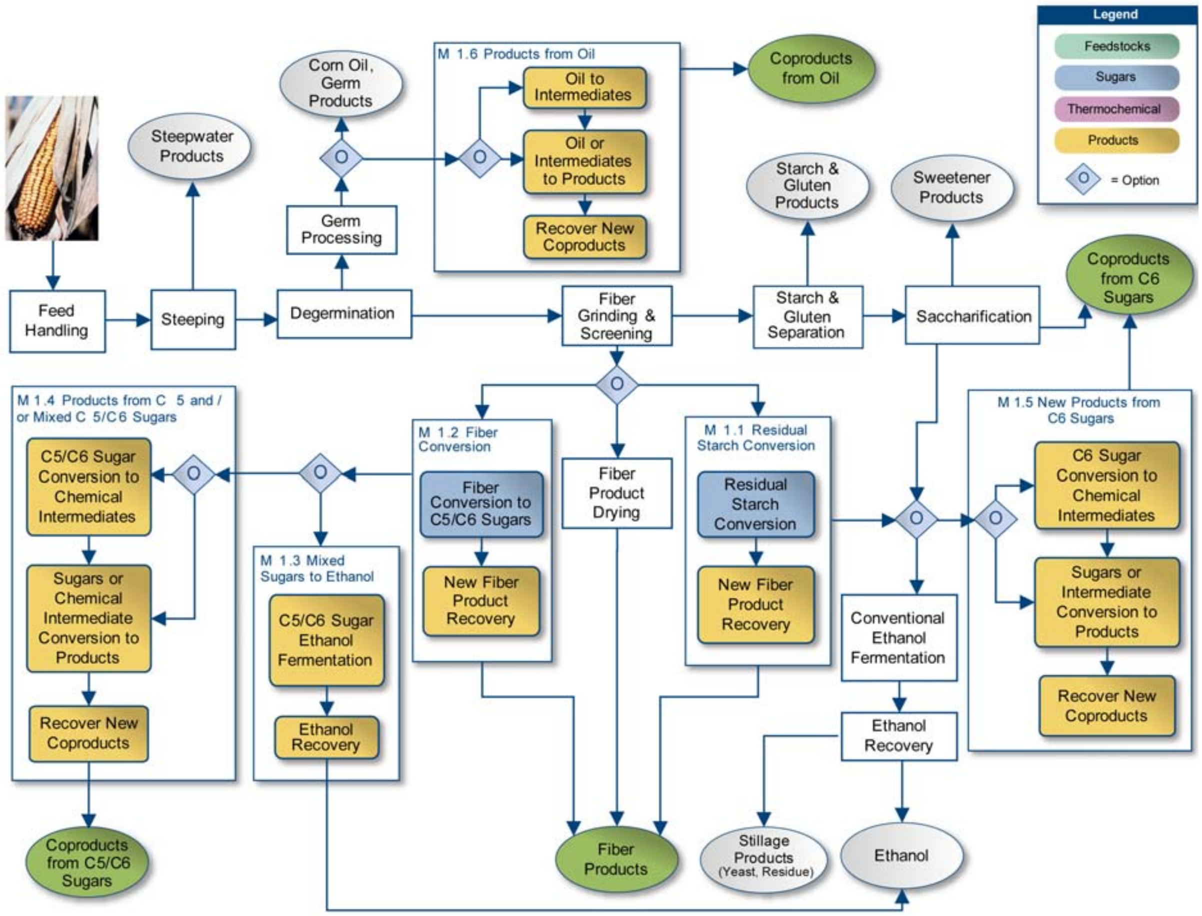


**Figure 2-5:** Wet Mill Improvements Pathway Diagram

#### 2.1.2.1.1 Corn Wet Milling Market Overview and Outlook/Potential

The wet milling process was first introduced in the 1880s to produce corn starch and corn oil. By 1973, the industry was processing over 660 million bushels of corn to produce high-fructose corn syrup (HFCS), oil, and starch. After the oil crisis of 1970s wet milling became the dominant technology to produce ethanol when Archer Daniels Midland (ADM) added alcohol production to their HFCS plants. The process produces pure starch, unrefined corn oil, corn gluten feed and corn gluten meal. Corn-derived starch is used to produce over 50 products including high fructose corn syrup, ethanol and a variety of modified starches and fermentation products.

Today, the wet milling process accounts for about 25 percent of the U.S. fermentation ethanol capacity. This percentage has been declining as new dry process mills continue to be built, while new wet mills are not because their existing product markets, except ethanol, are largely satisfied by existing wet mill capacity. The advantages of wet mill fermentation are lower unit capital cost (due to larger capacity), lower energy requirements, higher byproduct credits and product output flexibility. The major disadvantage of the wet mill process is that the producer must be relatively large in the food products business to take advantage of the scale of operation needed to efficiently convert by-products to usable products. The major wet mill ethanol producers in the U.S. include ADM, Cargill, Grain Processing, Minnesota Corn Processors, Williams Bio-Energy and A. E. Staley.[2]

#### 2.1.2.1.2 Performance Goals

The performance goals (i.e., "B" and "C" milestones) for the corn wet mill improvement pathway are summarized in Table 2-2. Current program focus areas and the level of technology development are being developed.

**Table 2-2:** Corn Wet Mill Improvement Pathway Performance Goals

| B Milestones | C Milestones |
|---|---|
| M 1.1 Demonstrate and validate economical residual starch conversion in a wet mill by 2007 | M 1.1.1 Convert residual starch in fiber stream to ethanol |
| | M 1.1.2 Evaluate new feed product |
| | M 1.1.3 Validate integrated process at pilot scale |
| | M 1.1.4 Validate new process in wet mill |
| M 1.2 Demonstrate and validate economical fiber conversion to C5 and/or mixed C5/C6 sugars in a wet mill by 2007 | M 1.2.1 Solubilize hemicellulose in fiber to C5 sugars |
| | M 1.2.2 Hydrolize cellulose to C6 Sugar |
| | M 1.2.3 Validate integrated process at pilot scale |
| | M 1.2.4 Evaluate new feed product |
| | M 1.2.5 Validate new process in wet mill |
| M 1.3 Demonstrate and validate economical conversion of mixed sugars to ethanol in a wet mill by TBD | M 1.3.1 Convert released sugars to ethanol |
| | M 1.3.2 Validate integrated process at pilot scale |
| | M 1.3.3 Validate new process in wet mill |
| M 1.4 Demonstrate and validate economical new products from C5 or mixed C5/C6 sugars in a wet mill by 2008 | M 1.4.1 Convert released C5 sugars to products |
| | M 1.4.2 Convert C5 sugars to building block chemicals |
| | M 1.4.3 Convert mixed sugars to products |
| | M 1.4.4 Convert mixed sugars to building block chemicals |
| | M 1.4.5 Convert Building block chemicals to products |
| | M 1.4.6 Product separation specification |
| | M 1.4.7 Demonstrate and validate economical new products from C5 sugars for a wet mill application |
| | M 1.4.8 Demonstrate lab scale conversion of C5 sugars to products |
| | M 1.4.9 Demonstrate and validate economical new products from mixed sugars for a wet mill application |
| | M 1.4.10 Validate integrated process at pilot scale |
| | M 1.4.11 Validate new process in wet mill |
| M 1.5 Demonstrate and validate economical new products from C6 sugars in a wet mill by 2008 | M 1.5.1 Convert C6 sugars to products |
| | M 1.5.2 Convert C6 sugars to building block chemicals |
| | M 1.5.3 Convert building block chemicals to products |
| | M 1.5.4 Validate integrated process at pilot scale |
| | M 1.5.5 Validate new process in wet mill |

[2] SRI CEH Marketing Research Report, ETHYL ALCOHOL, Robert E. Davenport et al. May 2002 http://www.sriconsulting.com/CEH/Private/Reports/644.5000.

| | |
|---|---|
| M 1.6 Demonstrate and validate economical new products from corn-derived oils in a wet mill by 2008 | M 1.6.1 Convert corn derived oils to products |
| | M 1.6.2 Product separation specification |
| | M 1.6.3 Validate integrated process at pilot scale |
| | M 1.6.4 Validate new process in wet mill |

### 2.1.2.1.3 Approach and Program Output

The Biomass Program is working with partners in the corn wet mill industry to improve the overall operation of today's corn wet mill ethanol production facilities by incorporating new technologies that use residues/intermediates from the existing corn wet mill process to increase yields of ethanol, produce new high-value products, improve plant efficiency, and reduce operating costs. The program output from the corn wet mill pathway is a complete systems level demonstration and validation of all technologies to improve corn wet mill facilities using corn grain feedstock (Milestone M1).

### 2.1.2.2 Corn Dry Mill Improvements Pathway

The corn wet mill improvements pathway is based on improving the existing commercial process through the utilization of corn fiber and residual starch to produce additional ethanol and other bioproducts, and biomass to produce heat and power, as shown in Figure 2-6. The new products slate includes additional ethanol, new feed products, organic chemicals and petrochemical replacements, and heat and power.

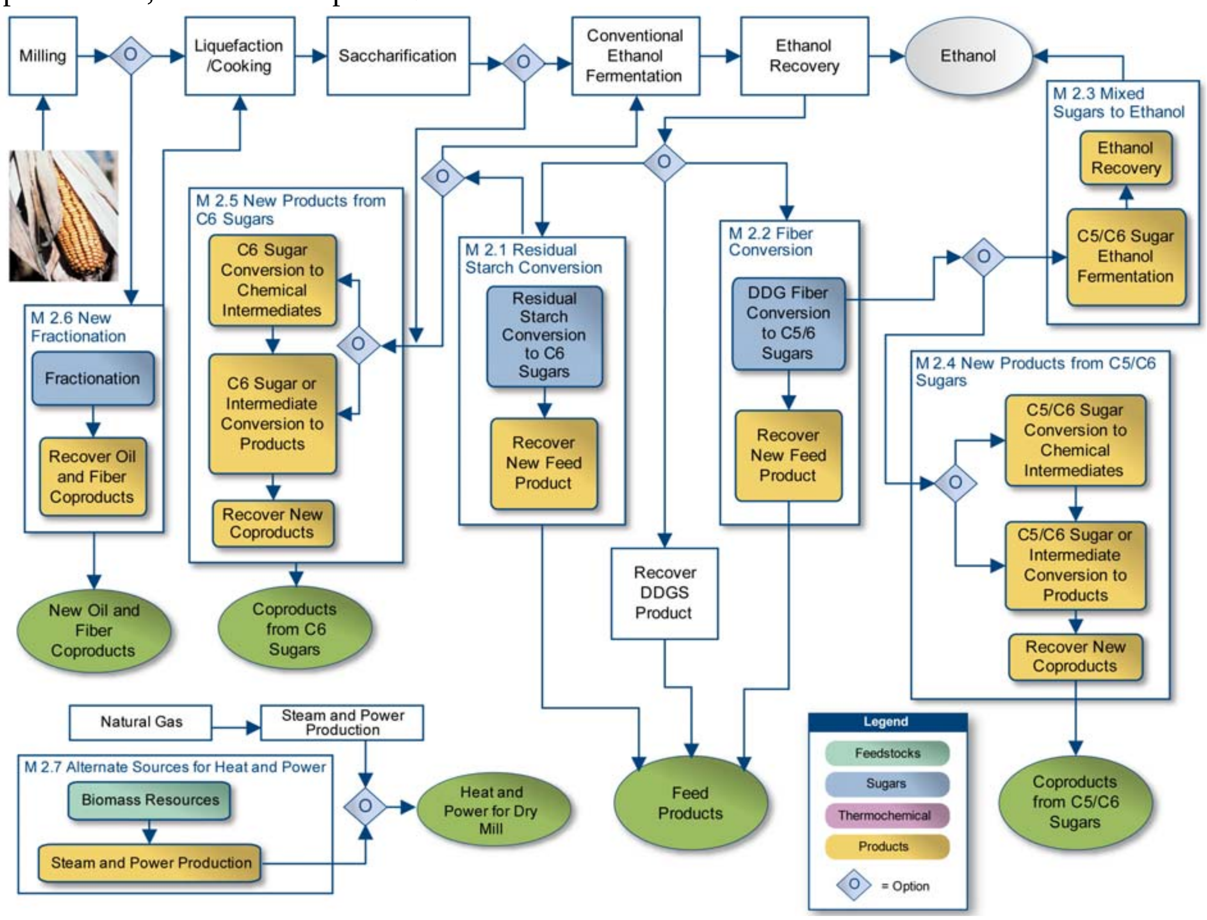


**Figure 2-6:** Corn Dry Mill Improvements Pathway

#### 2.1.2.2.1 Corn Dry Mill Industry Market Overview and Outlook

In the late 19th century, the beverage ethyl alcohol distilling industry pioneered the recovery of the nutrients from the residual grain that had undergone fermentation as a source of dairy cattle feed. Since then, the world oil crisis in the 1970s and recent clean air legislation have contributed to an expanded dry mill industry. In the mid-1980s, ethanol prices dropped along with oil prices and dry mill fuel ethanol plants began to focus on increasing the ethanol yield and lowering operating costs. Dry mills, which produce ethanol and only one basic co-product, distillers dry grain and solubles (DDGS), were forced to search for innovative technologies to reduce operating and capital costs. Since the 1980s, ethanol yields have increased by more than 22 percent, from 2.2. gallons per bushel of corn to 2.7 gallons per bushel. The products are fuel grade ethanol, DDGS, and carbon dioxide ($CO_2$) gas.

The corn dry mill industry has seen unprecedented growth over the past three years and there are major plans for additional facilities to be constructed in the next two years. Today, the dry milling process accounts for about 75 percent of U.S. fermentation ethanol capacity; however, more ethanol plants use this process and the size of units is generally smaller than in wet milling plants. The major dry mill ethanol producers in the U.S. include Archer Daniels Midland, New Energy Corp. of Indiana, Broin, Abengoa Bioenergy, and Midwest Grain. Almost all of the U.S. major dry mill plants sell a majority of their product into the fuel market.[3]

Demand for corn grain for ethanol is projected to increase from 714 million bushels in 2001 to 1750 million bushels in 2014 or from 7.5 percent to about 14 percent of total corn grain production. With a 50 percent increase in corn yield, over 3,950 million bushels of grain would be available for ethanol or bioproducts in 2014.[4] Urbancheck (2001) projected that ethanol use could increase to 8.8 billion gallons in the future; this amount would require 2,464 million bushels. Thus, significant potential exists for meeting increased corn grain demand for both ethanol and bioproducts.[5]

#### 2.1.2.2.2 Performance Goals

The performance goals (i.e., "B" and "C" milestones) for the corn dry mill improvement pathway are summarized in Table 2-3. Current program focus areas and the level of technology development are being developed.

**Table 2-3:** Corn Dry Mill Improvement Pathway Performance Goals

| B Milestones | C Milestones |
|---|---|
| M 2.1 Demonstrate and validate economical residual starch conversion in a dry mill | M 2.1.1 Conversion of residual starch to glucose Conversion of converted glucose to ethanol. |
| | M 2.1.2 Evaluate new feed product. |
| | M. 2.1.4 Validate integrated process in a dry mill. |
| M 2.2 Demonstrate and validate economical fiber conversion in a dry mill. | M 2.2.1 Convert fiber to monomer sugars |
| | M 2.2.2 Evaluate new feed product |
| | M 2.2.3 Validate integrated process at pilot scale |

[3] SRI CEH Marketing Research Report, ETHYL ALCOHOL, Robert E. Davenport et al.,May 2002 http://www.sriconsulting.com/CEH/Private/Reports/644.5000/

[4] Billion ton…..

[5] Billion ton..

| | |
|---|---|
| | M 2.2.4 Validate new process in dry mill |
| M 2.3 Demonstrate and validate economical conversion of mixed sugars to ethanol in a dry mill. | M 2.3.2 Convert released sugars to ethanol |
| | M 2.3.4 Validate integrated process at pilot scale |
| | M 2.3.5 Validate new process in dry mill |
| M 2.4 Demonstrate and validate economical conversion of mixed sugars to products in a dry mill. | M 2.4.1 Conversion targets from C6 sugars to building blocks |
| | M 2.4.2 Conversion targets from building blocks to products |
| | M 2.4.3 Product separation specification |
| | M 2.4.5 Validate new process in dry mil |
| M 2.5 Demonstrate and validate economical new products from C6 sugars in a dry mill | M 2.5.1 Conversion targets from C6 sugars to building blocks |
| | M 2.5.2 Conversion targets from building blocks to products |
| | M 2.5.3 Product separation specification |
| | M 2.5.4 Validate integrated process at pilot scale |
| | M 2.5.5 Validate new process in dry mill |
| M 2.6 Demonstrate and validate economical front end fractionation processes in a dry mill | M 2.6.1 Derive additional value added products from front end fractionation |
| | M 2.6.1.1 Mechanical Separation targets |
| | M 2.6.1.2 Evaluate new feed coproducts |
| | M 2.6.3 Validate integrated process |
| | M 2.6.4 Validate new process in dry mill |
| M 2.7 Investigate alternate sources for dry mill heat and power | M 2.7.1 Thermochemical processing of fiber stream to heat, power |
| | M 2.7.2 Thermochemical processing of Residues (corn Stover) to heat, power |
| | M 2.7.3 Validate integrated process at pilot scale |
| | M 2.7.4 Validate new process in dry mill |

#### 2.1.2.2.3 Approach and Program Output

The Biomass Program is working with partners in the corn dry mill industry to improve the overall operation of today's corn wet mill ethanol production facilities by incorporating new technologies that use residues and intermediates (fiber and spent grain products) from the existing corn dry mill process to increase yields of ethanol, produce new high-value products, improve plant efficiency, and reduce operating costs. The program output from the corn dry mill pathway is a complete systems level demonstration and validation of all technologies to improve corn dry mill facilities (Milestone M2).

### 2.1.2.3 Natural Oil Crops Improvements Pathway

The natural oil crops improvements pathway is based on improving the existing commercial process by incorporating new technologies to produce high-value chemical intermediates from the primary oil and glycerol byproduct streams, and evaluating new oil seed feedstocks, as shown in Figure 2-7. The new products slate includes organic chemicals and petrochemical replacements.

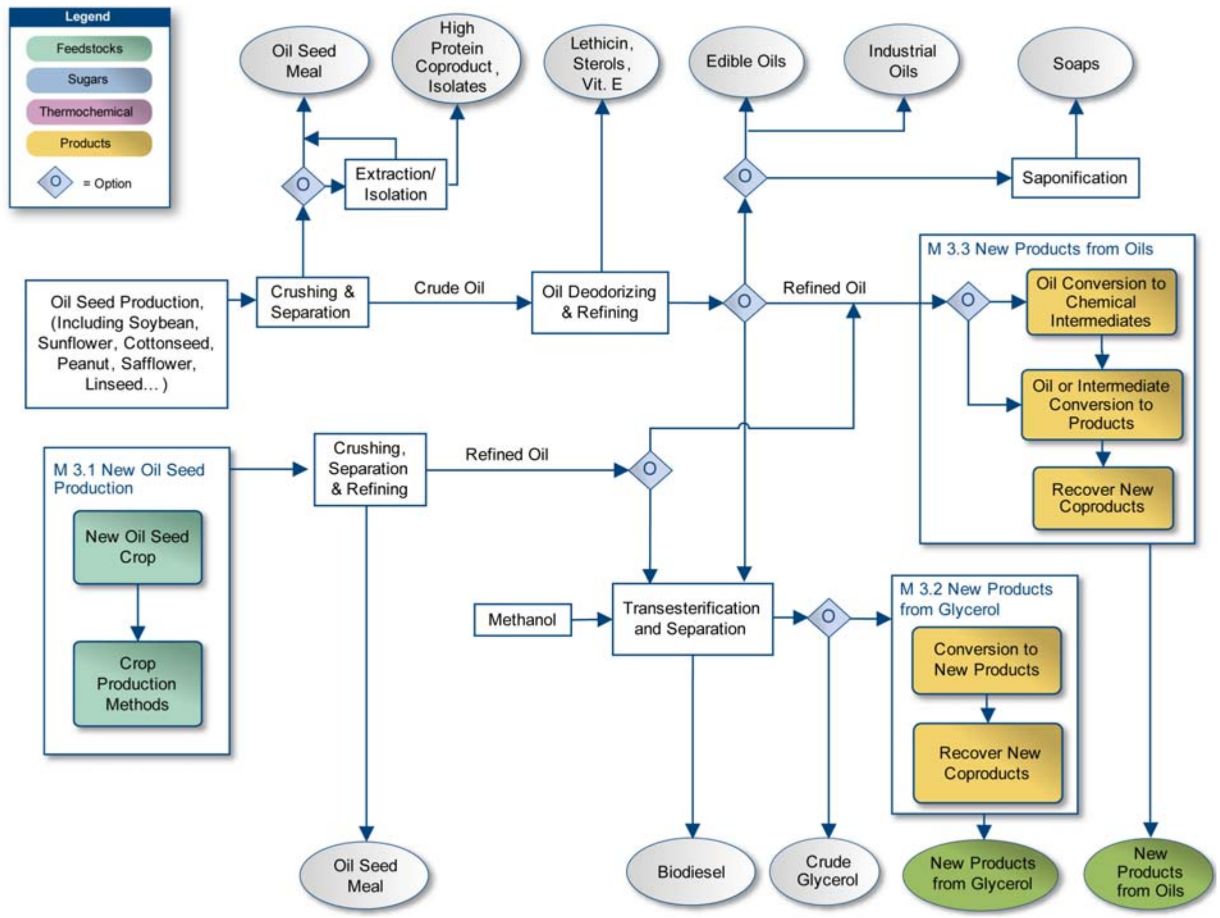


**Figure 2-7:** Natural Oil Crops Improvements Pathway

### 2.1.2.3.1 Oil Crops Improvements Pathway Market Overview

Biomass oil biorefineries, better known as oleochemical plants, are mature technologies that consumed 2.6 billion pounds of biomass oils and produced almost 4 billion pounds of oil-derived products in the United States in 2001. The earliest biorefineries were established before the United States Civil War and produced soaps, detergents, lubricants, solvents, and explosives among other minor products.[6] In the late 1800s, the idea of using vegetable oil for fuel was proposed in conjunction with the invention of the diesel engine.[7] In the early 20th century, however, diesel engines were adapted to burn petroleum distillate, which was cheap and plentiful. The energy supply concerns of the 1970s renewed interest in biodiesel, and commercial production began in the late 1990s. The National Biodiesel Board claims that dedicated biodiesel plants with a total capacity of 60 to 80 million gallons per year (3,414 to 5,219 barrels per day) have already been built. In addition, 200 million gallons (13,046 barrels per day) of capacity are available from oleochemical producers, such as Proctor and Gamble.[8] Biodiesel production

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[6] Biomass Oil Analysis: Research Needs and Recommendations, K. Shaine Tyson, et al., NREL/TP-510-34796, June 2004, http://www.nrel.gov/docs/fy04osti/34796.pdf

[7] Biodiesel Performance, Costs, and Use, Anthony Radich, U.S. DOE Energy Information Administration, 06/08/2004, http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/index.html

[8] Biodiesel Performance, Costs, and Use, Anthony Radich, U.S. DOE Energy Information Administration, 06/08/2004, http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/index.html

facilities also produce by-product glycerol, used in cosmetics, pharmaceuticals, and for other high value products.

Biodiesel can be produced from a wide variety of biomass oils including corn oil, canola rapeseed (castor) oil, cottonseed oil, etc.; restaurant waste oils; animal fats; trap grease, etc.[9] Today, soybean oil is the most popular biodiesel feedstock in the U.S; biodiesel production from soybeans more than doubled from 12.5 million gallons in 2001 to more than 25 million gallons in 2004. Expectations are that demand will continue to rise.[10] The estimated maximum amount available is 297 million bushels, which could result in 415 million gallons of pure biodiesel.[11]

### 2.1.2.3.2 Performance Goals

The performance goals (i.e., "B" and "C" milestones) for the natural oil mill improvement pathway are summarized in Table 2-4. Current program focus areas and the level of technology development are being developed.

**Table 2-4:** Natural Oil Mill Improvement Pathway Performance Goals

| B Milestones | C Milestones |
|---|---|
| M 3.1 Demonstrate and validate economical and sustainable new oil seed crop production | M 3.1.1 |
| M 3.2 Demonstrate and validate economical new products from glycerol in a natural oil processing mill by 200? | M 3.2.1 Convert glycerol to products |
| | M 3.2.2 Recover new products |
| | M 3.2.3 Validate integrated process at pilot scale |
| | M 3.2.4 Validate new process in natural oil processing mill |
| M 3.3 Demonstrate and validate economical new products from oils in natural oil processing mill by 200? | M 3.3.1 Convert oils to products |
| | M 3.3.2 Convert oils to building block chemicals |
| | M 3.3.3 Convert building block chemicals to products |
| | M.3.3.4 Recover new products |
| | M 3.3.4 Validate integrated process at pilot scale |
| | M 3.3.5 Validate new process in a natural oil processing mill |

### 2.1.2.3.3 Approach and Program Output

The Biomass Program is working with partners in the natural oil processing mill industry to improve the overall operation of today's biodiesel/oleochemical facilities by incorporating new technologies to produce high-value chemical intermediates and products from the oil and glycerol streams, and evaluating new low-cost oil seed feedstocks. The program output from the natural oil processing mill improvements pathway is a complete systems level demonstration and validation of all technologies to improve oil processing facilities (Milestone M3).

### 2.1.2.4 Agricultural Residues Pathway

The agricultural residue pathway is based on developing new commercially-viable processes and facilities based on the utilization of farm residues from current grain crop production activities

[9] Business Management for Biodiesel Producers:
August 2002–January 2004, NREL/SR-510-36242, July 2004 http://www.eere.energy.gov/biomass/pdfs/36242.pdf
[10] Billion ton…..
[11] Billion ton….

(e.g., corn stover and wheat straw) in integrated biochemical and thermochemical conversion processes, as illustrated in Figure 2-8. The potential new products slate includes ethanol; gasoline, diesel, and other biomass-to-liquids (BTL) fuels; hydrogen; organic chemicals and petrochemical replacements; and electricity.

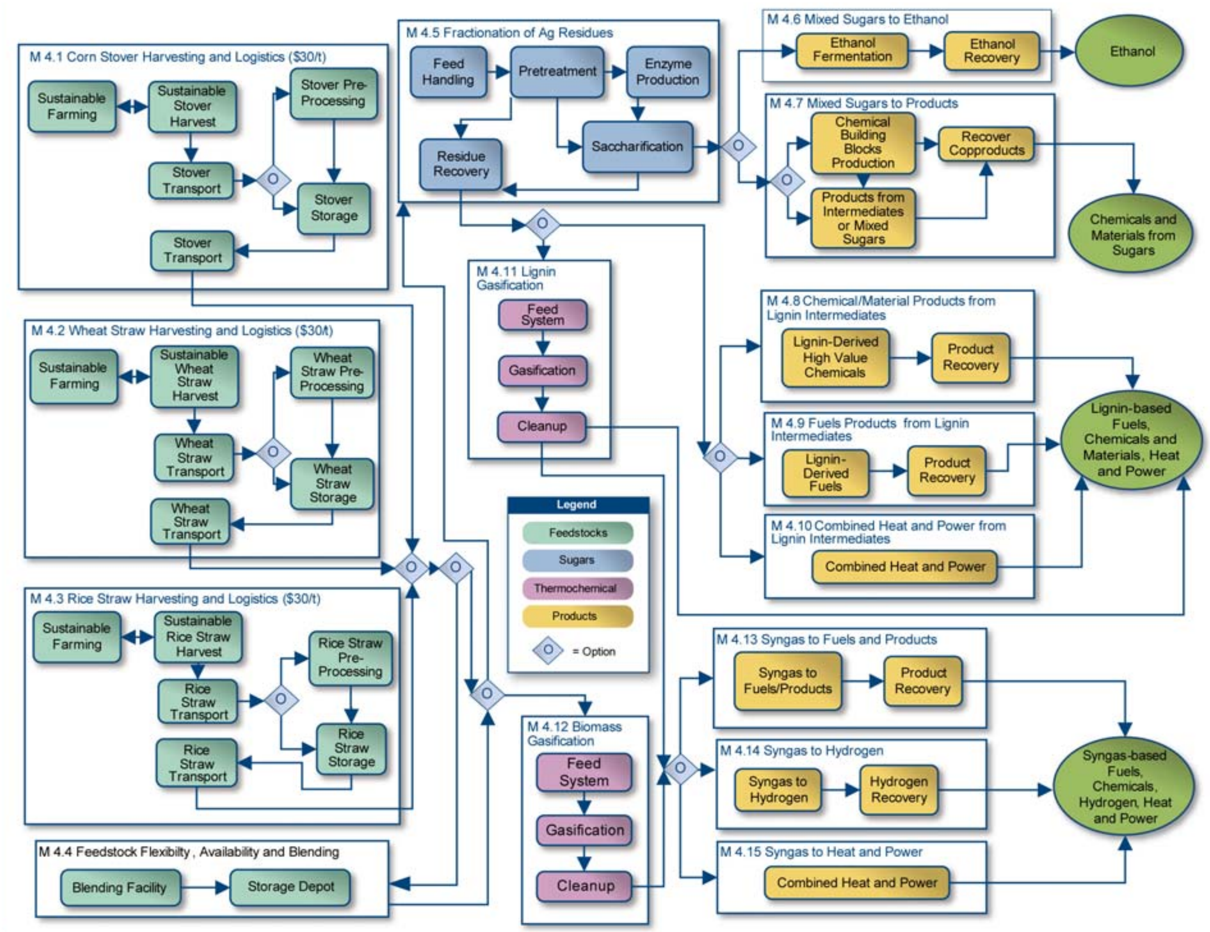


**Figure 2-8:** Agricultural Residues Pathway

### 2.1.2.4.1 Agricultural Residues Pathway Market Overview

Agricultural residues are seen as a possible intermediate source of fuel production bridging the gap between near-term niche, low-cost biomass supplies and long-term high volume dedicated energy crops. Corn stover, wheat straw and rice straw represent a tremendous resource base and, over the long term, could be the sources of biomass that support substantial growth of bio-industries. Feedstock-flexible integrated biorefineries that produce ethanol, other fuels, a wide spectrum of products, and heat and power from available agricultural residues are envisioned for the future.

Today, collection of residues from primary crops (e.g., corn, wheat and rice) results in about 40 percent removal of stover or straw on average. Future residue collection technology with the potential of collecting up to 75 percent of the residue is envisioned where land is under no-till cultivation and crop yields are very high.[12] Assuming that 60 percent of the 250 million tons of

[12] Billion Ton…

stover produced each year could be collected, between 25 and 35 billion gallons per year of fuel ethanol could be produced.[13] After corn stover is fermented to produce ethanol, the remaining residue is about 70 percent lignin. This lignin can be thermochemically converted to syngas, which can be used to produce a multitude of fuels and chemicals, in addition to heat and power. The bulk agricultural residues can also be directly converted to syngas (i.e., no biochemical pretreatment) and used in the same applications.

**2.1.2.4.2 Performance Goals (outputs?)**

The performance goals (i.e., "B" and "C" milestones) for the agricultural residues pathway are summarized in Table 2-5. Current program focus areas and the level of technology development are being developed.

**Table 2-5:** Agricultural Residues Pathway Performance Goals

| B Milestones | C Milestones |
|---|---|
| M 4.1 Demonstrate and validate integrated corn stover harvesting logistics supporting xx tons/yr at $35/ton by ? | M 4.1.1 Demonstrate sustainable corn agronomic practices that account for corn stover harvesting |
| | M 4.1.2 Demonstrate wet and dry corn stover harvesting |
| | M 4.1.3 Demonstrate wet and dry corn stover storage |
| | M 4.1.4 Demonstrate wet and dry corn stover transportation |
| | M 4.1.5 Demonstrate wet and dry quality and quantity of corn stover available |
| | M 4.1.6 Demonstrate corn stover preprocessing benefits |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration |
| | M 4.1.7 Validate integrated corn stover logistics at pilot scale |
| | M 4.1.8 Validate integrated corn stover logistics at demonstration scale |
| M 4.2 Demonstrate and validate integrated wheat straw harvesting logistics supporting xx tons/yr at $35/ton by 2030? | M 4.2.1 Demonstrate sustainable wheat agronomic practices that account for wheat straw harvesting |
| | M 4.2.2 Demonstrate wet and dry wheat straw harvesting |
| | M 4.2.3 Demonstrate wet and dry wheat straw storage |
| | M 4.2.4 Demonstrate wet and dry wheat straw transportation |
| | M 4.2.5 Demonstrate wet and dry quality and quantity of wheat straw available |
| | M 4.2.6 Demonstrate wheat straw preprocessing benefits |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration |
| | M 4.2.7 Validate integrated wheat straw logistics at pilot scale |
| | M 4.2.8 Validate integrated wheat straw logistics at demonstration scale |
| M 4.3 Demonstrate and validate integrated rice straw harvesting logistics supporting xx tons/yr at $30/ton by 2030 | M 4.3.1 Demonstrate sustainable rice agronomic practices that account for rice straw harvesting |
| | M 4.3.2 Demonstrate wet and dry rice straw harvesting |
| | M 4.3.3 Demonstrate wet and dry rice straw storage |
| | M 4.3.4 Demonstrate wet and dry rice straw transportation |
| | M 4.3.5 Demonstrate wet and dry quality and quantity of rice straw available |

[13] Is Ethanol from Corn Stover Sustainable? Adventures in cyber-farming, John Sheehan et al., National Renewable Energy Laboratory, December 2002 draft report (in review).

| | |
|---|---|
| | M 4.3.6 Demonstrate rice straw preprocessing benefits |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration |
| | M 4.3.7 Validate integrated rice straw logistics at pilot scale |
| | M 4.3.8 Validate integrated rice straw logistics at demonstration scale |
| M 4.4 Feedstock Flexibility and Availability via Blending Depot or Elevator | M 4.4.1 |
| | M 4.4.2 |
| | M 4.4.3 |
| | M 4.4.4 |
| | M 4.4.5 |
| M 4.5 Demonstrate and validate ag residue fractionation to produce $0.064/lb (2002 $) mixed, dilute biomass sugars by 2020 (with feedstock cost $35/ton) | M 4.5.1 Validate cellulase enzyme cost at the equivalent of $0.xx/lb sugar |
| | M 4.5.2 Validate pretreatment technology cost at the equivalent of $0.xx/lb sugar |
| | M 4.5.3 Demonstrate ability to economically satisfy internal heat and power demands |
| | M 4.5.4 Capital cost limit metric? Is it a design basis for least cost as opposed to an industry financing hurdle? |
| | M 4.5.5 Validate integrated pretreatment and enzymatic hydrolysis at pilot scale |
| | M 4.5.6 Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale |
| | M 4.5.7 Feed flexibility |
| M 4.6 Demonstrate and validate ethanol from 5 biomass sugars that are econonomically viable (need multiple cost targets for specific products?) | M 4.6.1 Validate fermentation of all 5 sugars to produce ethanol |
| | M 4.6.2 Optimize ethanol separation |
| | M 4.6.3 Optimize integrated production of ethanol from sugars at pilot scale |
| | M 4.6.4 Optimize integrated production of ethanol from sugars at demonstration scale |
| M 4.7 Demonstrate and validate chemical building blocks, chemicals or materials from 5 biomass sugars that are economically viable (need multiple cost targets for specific products?) | M 4.7.1 Optimize chemical building blocks production (PLA) |
| | M 4.7.2 Optimize high value chemical production |
| | M 4.7.3 Optimize product separation |
| | M 4.7.4 Optimize integrated production of product(s)from sugars at pilot scale |
| | M 4.7.5 Optimize integrated production of product(s)from sugars at demonstration scale |
| M 4.8 Demonstrate and validate high value chemical and material products from lignin intermediates | M 4.8.1 Demonstrate high value chemical/material production from lignin |
| | M 4.8.2 Validate product separation |
| | M 4.8.3 Validate integrated production of product(s)from lignin at pilot scale |
| | M 4.8.4 Validate integrated production of product(s)from lignin at demonstration scale |
| M 4.9 Demonstrate and validate fuel products from lignin intermediates | M. 4.9.1 Demonstrate direct fuel production from lignin |
| | M 4.9.2 Validate fuel product separation |
| | M 4.9.3 Validate integrated production of fuel(s) from lignin at pilot scale |
| | Validate integrated production of fuel(s) from lignin at demonstration scale |
| 4.10 Demonstrate and validate combined heat and power from lignin intermediates/residues | M 4.10.1 Demonstrate combined heat and power production from lignin |
| | M 4.10.2 Validate integrated production of heat and power from lignin at pilot scale |
| | M 4.10.3 Validate integrated production of heat and power from lignin at demonstration scale |

| | |
|---|---|
| M 4.11 Demonstrate and validate lignin gasification to produce syngas for $0.xx/MM Btu by 20xx | M 4.11.1 Validate feeder system performance |
| | M 4.11.2 Validate gasification performance |
| | M 4.11.3 Validate gas cleanup performance |
| | M 4.11.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount |
| | M 4.11.5 Validate integrated gasification and gas cleanup at pilot scale |
| | M 4.11.6 Validate integrated gasification and gas cleanup at demonstration scale |
| M 4.12 Demonstrate and validate biomass gasification to produce syngas for $4.89/MM Btu by 2020 | M 4.12.1 Validate feeder systems to reliably feed solid biomass to high pressure (30 bar) systems |
| | M 4.12.2 Validate gasification performance |
| | M 4.12.3 Validate gas cleanup performance |
| | M 4.12.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount |
| | M 4.12.5 Validate integrated gasification and gas cleanup at pilot scale |
| | M 4.12.6 Validate integrated gasification and gas cleanup at demonstration scale |
| | M 4.12.7 Feed flexibility |
| M 4.13 Demonstrate and validate products (i.e. ethanol from mixed alcohols) from lignin or biomass derived syngas for $0.60/gal by 2025 | M 4.13.1 Demonstrate ethanol production from mixed alcohols |
| | M 4.13.2 Demonstrate high value chemical/material production (C3-C5 alcohols)from syngas |
| | M 4.13.3 Validate product separation |
| | M 4.13.4 Validate integrated production of product(s)from syngas at pilot scale |
| | M 4.13.5 Validate integrated production of product(s)from syngas at demonstration scale |
| M 4.14 Demonstrate and validate hydrogen production from lignin or biomass derived syngas for $xx/kg by 2025 | M 4.14.1 Demonstrate optimized hydrogen production from syngas |
| | M 4.14.2 Validate hydrogen separation/recovery |
| | M 4.14.3 Validate integrated production of hydrogen from syngas at pilot scale |
| | M 4.14.4 Validate integrated production of hydrogen from syngas at demonstration scale |
| M 4.15 Demonstrate and validate combined heat and power production from lignin or biomass derived syngas for by 2025 | M 4.15.1 Demonstrate combined heat and power production from syngas |
| | M 4.15.2 Validate integrated production of heat and power from syngas at pilot scale |
| | M 4.15.3 Validate integrated production of heat and power from syngas at demonstration scale |

#### 2.1.2.4.3 Approach and Program Output

The Biomass Program is working with partners in the agricultural and chemicals industries to develop new cost-effective technologies that convert agricultural residues and lignin residues from biochemical conversion processes to fuels, chemicals, and heat and power, initially, in pilot and demonstration applications associated with existing primary facilities and ultimately in new dedicated commercial-scale facilities. The program output from the agricultural residues pathway is a complete systems level demonstration and validation of all technologies to utilize agricultural residue feedstocks in existing or new facilities. (Milestone M4).

### 2.1.2.5 Perennial Grasses and Woody Energy Crops Pathway

The perennial grasses and woody energy crops pathway is based on developing new commercially-viable processes and facilities based on the utilization of dedicated energy crops (e.g., switchgrass and willow) in integrated biochemical and thermochemical conversion processes, as illustrated in Figure 2-10. The potential new products slate includes ethanol; gasoline, diesel, and other biomass-to-liquids (BTL) fuels; hydrogen; organic chemicals and petrochemical replacements; and heat and power.

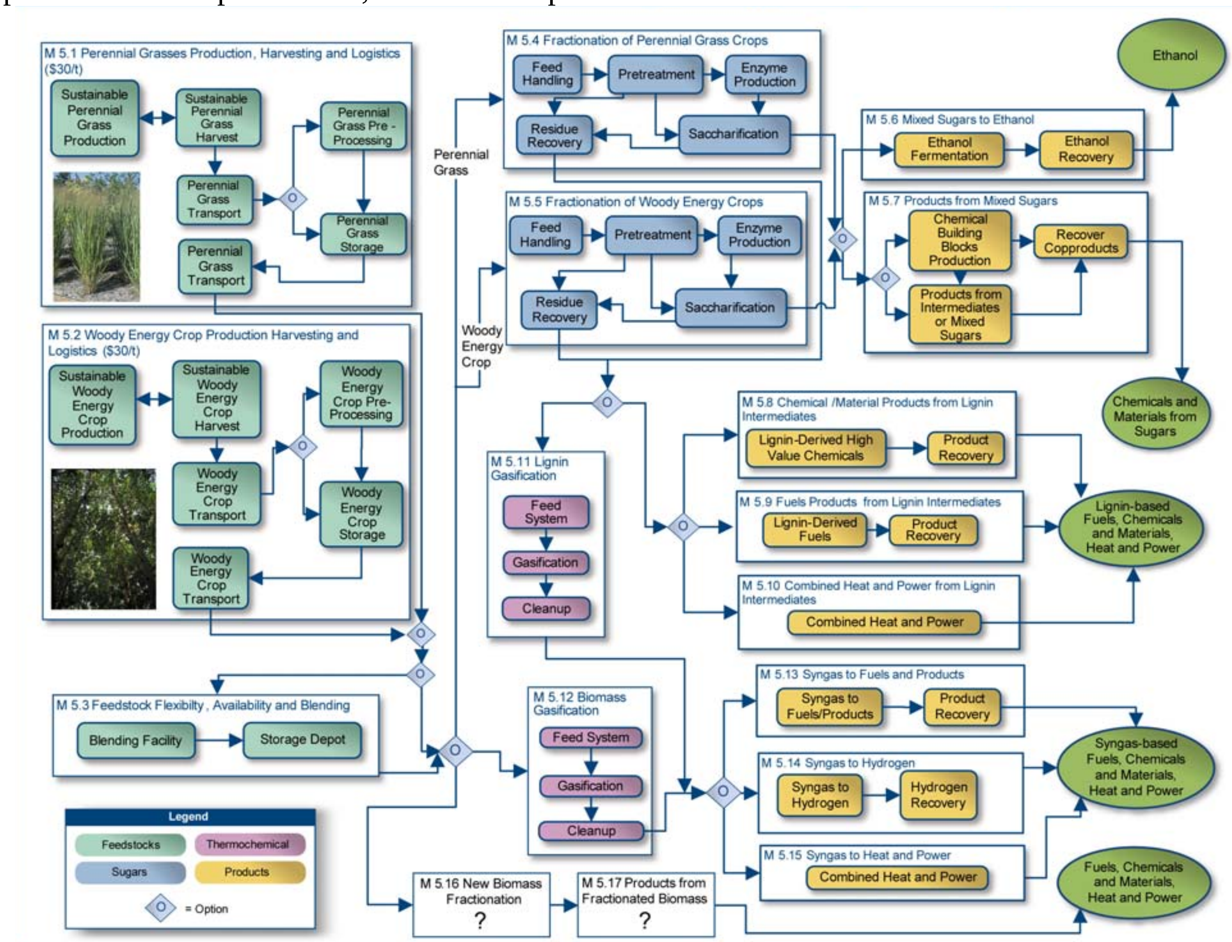


**Figure 2-9:** Perennial Grasses and Woody Energy Crops Pathway

### 2.1.2.5.1 Market Overview and Outlook

In the future, a dedicated feedstock supply system based on short-rotation woody crops (e.g., hybrid willow and hybrid poplar) and herbaceous perennial crops (e.g., switchgrass) could dramatically expand the assured availability of biomass for energy applications. The technologies required to cost effectively produce and convert perennial energy crops to fuels, chemicals, and heat and power are still under development and have not yet been proven commercially. Integrated biorefineries that produce ethanol, other fuels, products, and heat and power from dedicated perennial energy crops are envisioned for the future.

Significant amounts of land could shift to the production of perennial crops if a large market for bioenergy and biobased products emerges. If a farm gate price of about $40 per dry ton were offered to the farmers, perennial grass crops producing an average of 4.2 dry tons per acre (a level attainable today) would be competitive with the current crops on about 42 million acres of cropland and Conservation Reserve Program (CRP) land.[14] In the future, average yields for both grasses and woody crops are projected to increase to at least 8 dry tons per acre and as many as 60 million acres of cropland, cropland pasture, and CRP are projected to be available for perennial crop production, including grass and woody crops.[15] Whether the perennial crops are primarily wood or grass may depend on whether the bioenergy emphasis is on fuels and chemicals or power.

### 2.1.2.5.2 Performance Goals

The performance goals (i.e., "B" and "C" milestones) for the energy crops pathway are summarized in Table 2-7. Current program focus areas and the level of technology development are being developed.

**Table 2-6:** Energy Crops Pathway Performance Goals

| B Milestones | C Milestones |
|---|---|
| M 5.1 Demonstrate and validate integrated switchgrass production and harvesting logistics supporting xx tons/yr at $35/ton by 2030? | M 5.1.1 Demonstrate sustainable switchgrass agronomic practices |
| | M 5.1.2 Demonstrate wet and dry switchgrass harvesting |
| | M 5.1.3 Demonstrate wet and dry switchgrass storage |
| | M 5.1.4 Demonstrate wet and dry switchgrass transportation |
| | M 5.1.5 Demonstrate quality and quantity of switchgrass available |
| | M 5.1.6 Demonstrate switchgrass preprocessing benefits |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration |
| | M 5.1.7 Validate integrated switchgrass logistics at pilot scale |
| | M 5.1.8 Validate integrated switchgrass logistics at demonstration scale |
| M 5.2 Demonstrate and validate integrated woody crop harvesting logistics supporting xx tons/yr at xx/ton by 20xx? | M 5.2.1 Demonstrate sustainable woody crop agronomic practices |
| | M 5.2.2 Demonstrate woody crop harvesting |
| | M 5.2.3 Demonstrate woody crop storage |
| | M 5.2.4 Demonstrate woody crop transportation |
| | M 5.2.5 Demonstrate quality and quantity of woody crops available |
| | M 5.2.6 Demonstrate woody crop preprocessing benefits |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration |
| | M 5.2.7 Validate integrated woody crop logistics at pilot scale |
| | M 5.2.8 Validate integrated woody crop logistics at demonstration scale |
| M 5.3 Feedstock Flexibility and Availability via Blending Depot or Elevator | M 5.3.1 |
| | M 5.3.2 |
| | M 5.3.3 |
| | M 5.3.4 |
| | M 5.3.5 |
| M 5. 4 Demonstrate and validate switchgrass fractionation to produce $0.064/lb (2002$) dilute, mixed | M 5.4.1 Validate cellulase enzyme cost at the equivalent of $0.xx/lb sugar |
| | M 5.4.2 Validate pretreatment technology cost at the equivalent of $0.xx/lb sugar |

[14] Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasilibility of a Billion-Ton Annual Supply, Robert D. Perlack, et al., USDA/DOE, DOE/GO-102005-2135, April 2005

[15] Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, Robert D. Perlack, et al., USDA/DOE, DOE/GO-102005-2135, April 2005

| | |
|---|---|
| biomass sugars by 2020 | M 5.4.3 Demonstrate ability to economically satisfy internal heat and power demands |
| | M 5.4.4 Capital cost limit metric? Is it a design basis for least cost as opposed to an industry financing hurdle? |
| | M 5.4.5 Validate integrated pretreatment and enzymatic hydrolysis at pilot scale |
| | M 5.4.6 Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale |
| | M 5.4.7 Feedstock flexibility |
| M 5.5 Demonstrate and validate woody crop fractionation to produce $0.064/lb (2002 $) mixed, dilute biomass sugars by 2020 (with feedstock cost $35/ton) | M 5.5.1 Validate cellulase enzyme cost at the equivalent of $0.xx/lb sugar |
| | M 5.5.2 Validate pretreatment technology cost at the equivalent of $0.xx/lb sugar |
| | M 5.5.3 Demonstrate ability to economically satisfy internal heat and power demands |
| | M 5.5.4 Capital cost limit metric? Is it a design basis for least cost as opposed to an industry financing hurdle? |
| | M 5.5.5 Validate integrated pretreatment and enzymatic hydrolysis at pilot scale |
| | M 5.5.6 Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale |
| | M 5.5.7 Feed flexibility |
| M 5.6 Demonstrate and validate ethanol from 5 biomass sugars - similar to ag residues with different biorefining opportunities | M 5.6.1 Validate ethanol production |
| | M 5.6.2 Validate ethanol separation/recovery |
| | M 5.6.3 Validate integrated production of product(s)from sugars at pilot scale |
| | M 5.6.4 Validate integrated production of product(s)from sugars at demonstration scale |
| M 5.7 Demonstrate and validate products from 5 biomass sugars (need multiple cost targets for specific products?) - similar to ag residues with different biorefining opportunities | M 5.7.1 Validate chemical building blocks production |
| | M 5.7.2 Validate high value chemical production |
| | M 5.7.3 Validate product separation |
| | M 5.7.4 Validate integrated production of product(s)from sugars at pilot scale |
| | M 5.7.5 Validate integrated production of product(s)from sugars at demonstration scale |
| M 5.8 Demonstrate and validate high value chemical and material products from lignin intermediates | M 5.8.1 Demonstrate high value chemical/material production from lignin |
| | M 5.8.2 Validate product separation |
| | M 5.8.3 Validate integrated production of product(s)from lignin at pilot scale |
| | M 5.8.4 Validate integrated production of product(s)from lignin at demonstration scale |
| M 5.9 Demonstrate and validate fuel products from lignin intermediates | M 5.9.1 Demonstrate direct fuel production from lignin |
| | M 5.9.2 Validate fuel product separation |
| | M 5.9.3 Validate integrated production of fuel(s)from lignin at pilot scale |
| | M 5.9.4 Validate integrated production of fuels(s)from lignin at demonstration scale |
| M 5.10 Demonstrate and validate combined heat and power from lignin intermediates/residues | M 5.10.1 Demonstrate combined heat and power production from lignin |
| | M 5.10.2 Validate integrated production of heat and power from lignin at pilot scale |
| | M 5.10.3 Validate integrated production of heat and power from lignin at demonstration scale |
| M 5.11 Demonstrate and validate | M 5.11.1 Validate feeder system performance |

| | |
|---|---|
| lignin gasification to produce syngas for $0.xx/MM Btu by 20xx | M 5.11.2 Validate gasification performance |
| | M 5.11.3 Validate gas cleanup performance |
| | M 5.11.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount |
| | M 5.11.5 Validate integrated gasification and gas cleanup at pilot scale |
| | M 5.11.6 Validate integrated gasification and gas cleanup at demonstration scale |
| M 5.12 Demonstrate and validate biomass gasification to produce syngas for $4.89/MM Btu by 2020 | M 5.12.1 Validate feeder systems to reliably feed solid biomass to high pressure (30 bar) systems |
| | M 5.12.2 Validate gasification performance |
| | M 5.12.3 Validate gas cleanup performance |
| | M 5.12.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount |
| | M 5.12.5 Validate integrated gasification and gas cleanup at pilot scale |
| | M 5.12.6 Validate integrated gasification and gas cleanup at demonstration scale |
| M 5.13 Demonstrate and validate products (i.e. ethanol from mixed alcohols) from lignin or biomass derived syngas for $0.60/gal by 2025 | M 5.13.1 Demonstrate ethanol production from mixed alcohols |
| | M 5.13.2 Demonstrate high value chemical/material production (C3-C5 alcohols) from syngas |
| | M 5.13.3 Validate product separation |
| | M 5.13.4 Validate integrated production of product(s)from syngas at pilot scale |
| | M 5.13.5 Validate integrated production of product(s)from syngas at demonstration scale |
| M 5.14 Demonstrate and validate hydrogen production from lignin or biomass derived syngas for $xx/kg by 2025 | M 5.14.1 Demonstrate optimized hydrogen production from syngas |
| | M 5.14.2 Validate hydrogen separation/recovery |
| | M 5.14.3 Validate integrated production of hydrogen from syngas at pilot scale |
| | M 5.14.4 Validate integrated production of hydrogen from syngas at demonstration scale |
| M 5.15 Demonstrate and validate combined heat and power production from lignin or biomass derived syngas for by 2025 | M 5.15.1 Demonstrate combined heat and power production from syngas |
| | M 5.15.2 Validate integrated production of heat and power from syngas at pilot scale |
| | M 5.15.3 Validate integrated production of heat and power from syngas at demonstration scale |
| M 5.16 Demonstrate and validate new fractionation process to produce intermediates/building blocks to compete with sugar, lignin and/or syngas intermediates/building blocks | M 5.16.1? |
| | M 5.16.2? |
| | M 5.16.3? |
| | M 5.16.4? |
| | M 5.16.5 Validate integrated new fractionation process at pilot scale |
| | M 5.16.6 Validate integrated new fractionation process at demonstration scale |
| M 5.17 Demonstrate and validate new fractionation/consolidated process from intermediates | M 5.17.1? |
| | M 5.17.2? |
| | M 5.17.3? |
| | M 5.17.4? |
| | M 5.17.5 Validate integrated new process at pilot scale |
| | M 5.17.6 Validate integrated new process at demonstration scale |

### 2.1.2.5.3 Approach and Program Output

The Biomass Program is working with partners in the agricultural and chemicals industries to develop and implement new cost-effective technologies that convert dedicated energy crops to fuels, chemicals, and heat and power, initially, in pilot and demonstration applications associated with existing primary facilities and ultimately in new dedicated commercial-scale facilities. The program output from the perennial grasses and woody energy crops pathway is a complete systems level demonstration and validation of all technologies to utilize perennial energy feedstocks in existing or new facilities. (Milestone M5).

### 2.1.2.6 Pulp and Paper Mill Improvements Pathway

The pulp and paper mill improvements pathway is based on improving the existing commercial process through more efficient utilization of residuals (hog fuel and black liquor) for the production of new intermediates (e.g., sugars, pyrolysis oils, syngas) that can be used to produce a variety of fuels, chemicals, and heat and power, as shown in Figure 2-10. The potential new products slate (indicated in orange) includes ethanol; gasoline, diesel, and other biomass-to-liquids (BTL) fuels; hydrogen; organic chemicals and petrochemical replacements; and heat and power.

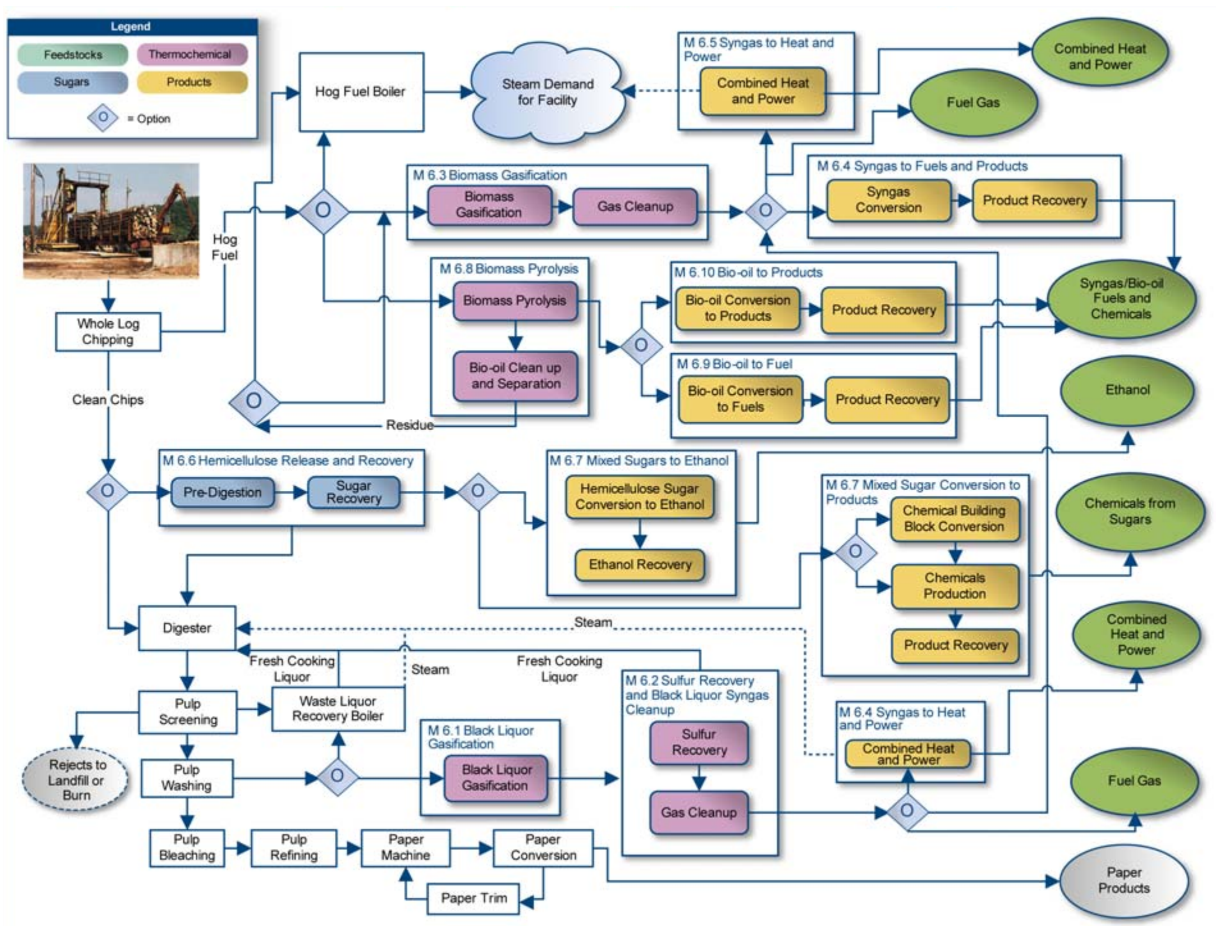


**Figure 2-10:** Pulp and Paper Mill Improvements Pathway

### 2.1.2.6.1 Pulp and Paper Mill Market Overview

Each year, the U.S. pulp and paper industry converts about 6 billion cubic feet of wood into fiber using a variety of established pulping technologies.[16] In Kraft pulping, the most common processing technology used today, about half the wood is converted to fiber and the other half becomes black liquor, which contains unutilized wood fiber and valuable chemicals. Today, the pulp and paper industry is the largest producer and consumer of renewable energy in the U.S.—accounting for about 42 percent of current U.S. biomass energy consumption[17] and self generating nearly 60 percent of its energy needs by combustion of biomass, in the form of pulping liquors and wood wastes (a.k.a. hog fuel) in recovery boilers and bark boilers, respectively.[18] Approximately 1.2 quads of black liquor and 0.4 quads of hog fuel were generated and consumed annually in the U.S. paper industry in the mid-1990s.[19] Increasing energy and raw material costs have prompted companies to find improvements in pulping yield, chemical recovery, energy conservation, forest management, and solid waste minimization. Currently, the pulp and paper industry, in partnership with DOE, is looking at black liquor gasification to convert pulping liquors and other biomass into gases that can be combusted much more efficiently or used in combined-cycle systems to generate heat and electricity. These improved biomass conversion technologies, combined with improvements in forest productivity, will create new value streams and improve the overall economics and energy efficiency of pulp and paper mills.

### 2.1.2.6.2 Performance Goals

The performance goals (i.e., "B" and "C" milestones) for the pulp and paper mill improvement pathway are summarized in Table 2-7. Current program focus areas and the level of technology development are being developed.

**Table 2-7:** Pulp and Paper Mill Improvement Pathway Performance Goals

| B Milestones | C Milestones |
|---|---|
| M 6.1 Demonstrate and validate reliable and economic gasification of spent pulping liquor and recycle liquor causticization in a pulp mill | M 6.1.1 Validate reliable and economic performance of gasification of spent pulping liquor |
| | M 6.1.2 Validate cost effective causticization and return Na based pulping chemicals |
| | M 6.1.3 Validate advantages of co-gasification of spent pulping liquors and other forms of biomass (woody, recycle paper streams, and bio-oil) |
| | M 6.1.4 Validate integrated black liquor gasification and causticization process at pilot scale |
| | M 6.1.5 Validate integrated black liquor gasification and causticization process in pulp and paper mill |
| M 6.2 Demonstrate and validate gas cleanup and process chemical | M 6.2.1 Validate process chemical recovery from spent pulping liquor syngas |

[16] Forest Products Industry Analysis Brief, Energy Information Administration/DOE, http://www.eia.doe.gov/emeu/mecs/iab98/forest/index.html
[17] Forest Products Industry Analysis Brief, Energy Information Administration/DOE, http://www.eia.doe.gov/emeu/mecs/iab98/forest/index.html
[18] Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, Robert D. Perlack, et al., USDA/DOE, DOE/GO-102005-2135, April 2005
[19] Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, Robert D. Perlack, et al., USDA/DOE, DOE/GO-102005-2135, April 2005

| | |
|---|---|
| recovery and recycle from spent pulping liquor syngas | M 6.2.2 Validate gas cleanup technologies on spent pulping liquor syngas |
| | M 6.2.3 Validate integrated chemical recovery and gas cleanup process at pilot scale |
| | M 6.2.4 Validate integrated chemical recovery and gas cleanup process in pulp and paper mill |
| M 6.3 Demonstrate and validate cost-effective biomass gasification of wood residues and other process residues and synthesis gas cleanup in a pulp and paper mill environment | M 6.3.1 Develop cost effective gasification designs for syngas production at appropriate scale |
| | M 6.3.2 Validate feeder system performance to reliably feed solids to high pressure (30 bar) systems) |
| | M 6.3.3 Validate gasification performance |
| | M 6.3.4 Validate cost-effective gas cleanup performance |
| | M 6.3.5 Validate integrated biomass gasification and syngas cleanup process suitable for a pulp and paper mill at pilot scale |
| | M 6.3.6 Validate integrated biomass gasification and syngas cleanup process in pulp and paper mill |
| M 6.4 Demonstrate and validate production of DME/mixed alcohols/FT liquids or other products from syngas in a pulp mill at a price competitive with current commercial practice | M 6.4.1 Identify economically viable product(s) from syngas (evaluate technologies for mixed alcohols, DME and FTL) |
| | M 6.4.2 Produce mixed alcohols from syngas |
| | M 6.4.3 Produce DME from syngas as a LPG substitute |
| | M 6.4.4 Produce FTL from biomass syngas |
| | M 6.4.5 Validate integrated process at pilot scale |
| | M 6.4.6 Validate new process in pulp and paper mill |
| M 6.5 Demonstrate and validate syngas utilization in a pulp mill for CHP and direct fuel gas including clean cold gas | M 6.5.1 Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment |
| | M 6.5.2 Validate CHP from syngas and/or direct use of syngas in process equipment |
| | M 6.5.3 Validate integrated process at pilot scale |
| M 6.6 Demonstrate and validate cost-effective extraction of C5 and C6 sugars from hemicellulose upstream of the pulp digestor in a pulp mill without negatively impacting paper quality | M 6.6.1 Meet yield target for C5 and C6 sugars without negatively impacting paper quality |
| | M 6.6.2 Meet sugar upgrading requirements |
| | M 6.6.3 Meet targets for recovery of other intermediates |
| | M 6.6.4 Validate integrated sugar extraction process at pilot scale |
| | M 6.6.5 Validate sugar extraction process in pulp and paper mill |
| M 6.7 Demonstrate and validate ethanol production from sugar extract | M 6.7.1 Validate fermentation of all sugars in the extract to ethanol |
| | M 6.7.2 Validate ethanol separation |
| | M 6.7.3 Validate integrated production of ethanol from extracted sugars at pilot scale |
| | M 6.7.4 Validate integrated production of ethanol from extracted sugars in pulp and paper mill |
| M 6.8 Demonstrate and validate cost-effective conversion of extracted C5 and C6 sugars to products | M 6.8.1 Validate chemical building blocks production |
| | M 6.8.2 Validate high value chemical production |
| | M 6.8.3 Validate product separation |
| | M 6.8.4 Validate integrated process at pilot scale |
| | M 6.8.5 Demonstrate and validate new process in pulp and paper mill |
| M 6.9 Demonstrate and validate bio-oil production to a stable intermediate | M 6.9.1 Validate bio-oil production |
| | M 6.9.2 Validate bio-oil intermediate recovery |
| | M 6.9.3 Develop and test field prototypes for pyrolysis |
| | M 6.9.4 Demonstrate and validate new process in pulp and paper mill |
| M 6.10 Achieve cost-effective conversion bio-oil intermediate into | M 6.10.1 Validate production of products from bio-oil |
| | M 6.10.2 Validate bio-oil product(s) recovery |

| | |
|---|---|
| product(s) in a pulp and paper mill | M 6.10.3 Validate integrated process for producing bio-oil product at pilot scale |
| | M 6.10.4 Validate integrated process in a pulp and paper mill |

**2.1.2.6.3 Approach and Program Output**

The Biomass Program is working with partners in the pulp and paper industry to improve the economics of the existing pulp and paper industry by incorporating more efficient and effective processes for utilizing wood components (i.e., cellulose, hemicellulose, and lignin) and residues from wood preparation processes for the production of value-added biobased fuels and chemicals, in addition to self-generated biomass-derived process heat and power, without negatively affecting the manufacture of pulp and paper products. The program output from the pulp and paper mill improvements pathway is a complete systems level demonstration and validation of all technologies to improve pulp and paper mill facilities and/or produce additional products (fuels, chemicals and/or power) from wood feedstock in a pulp and paper mill environment. (Milestone M6).

**2.1.2.7 Forest Products Mill Improvement Pathway**

The forest products mill improvements pathway is based on improving the existing commercial process through more efficient utilization of residuals (bark and hog fuel) for the production of new intermediates (e.g., pyrolysis oils, syngas) that can be used to produce a variety of fuels, chemicals, and heat and power, as shown in Figure 2-11. The potential new products slate includes gasoline, diesel, and other biomass-to-liquids (BTL) fuels; hydrogen; organic chemicals and petrochemical replacements; and heat and power.

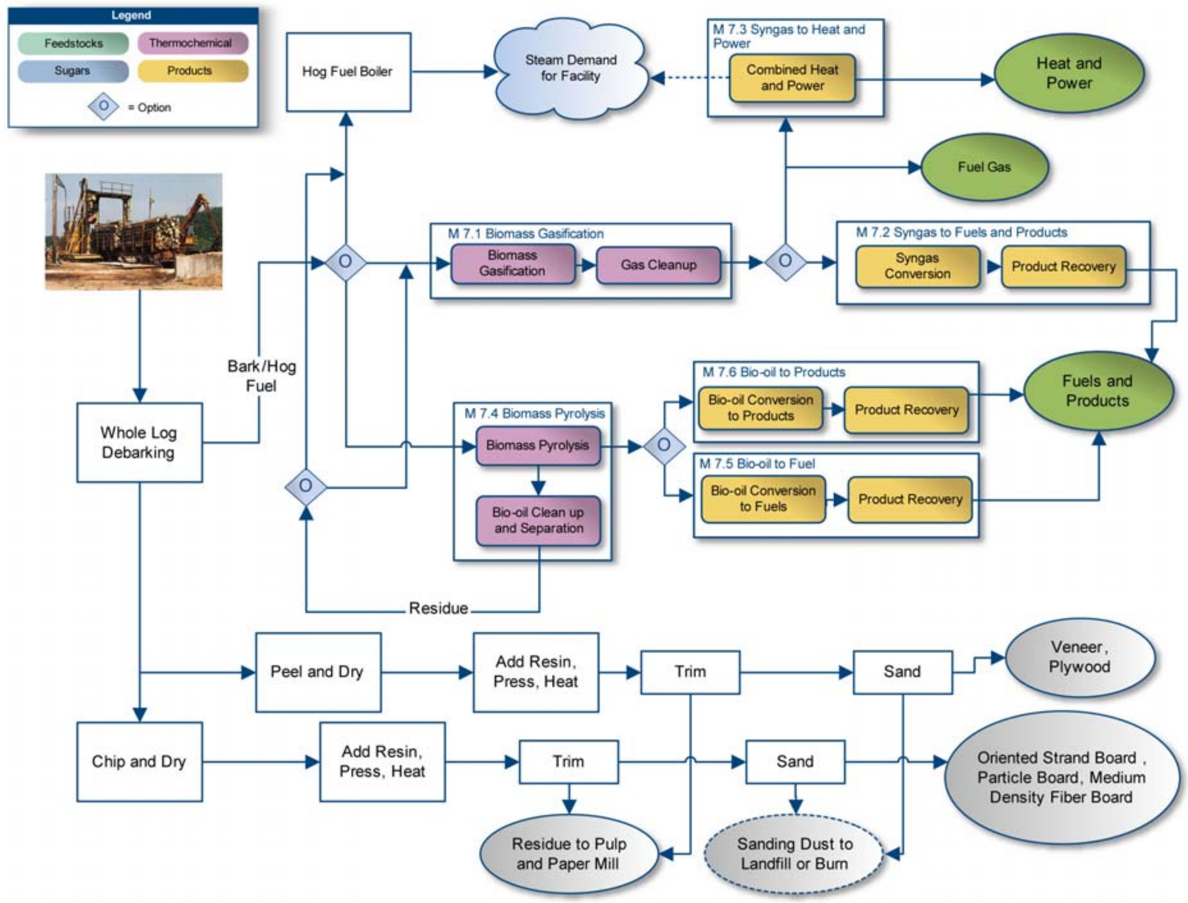


**Figure 2-11:** Forest Products Mill Improvements Pathway

### 2.1.2.7.1 Forest Products Mill Market Outlook

The forest products industry is comprised of a wide array of businesses including feedstock collection and harvesting, lumber, engineered wood products manufacture, and derivative specialty chemical manufacture. Primary wood processing mill residues (i.e., bark; chunks and slabs; shavings and sawdust) are desirable for energy and other purposes because they tend to be clean, uniform, and concentrated and have a low moisture content (< 20 percent). These desirable physical properties, however, mean that very little of this resource is currently unused. Primary timber processing mills (facilities that convert roundwood into products such as lumber, plywood, and wood pulp) produced 91 million dry tons of residues in the form of bark, sawmill slabs and edgings, sawdust, and peeler log cores in 2002. Nearly all of this material is recovered or burned, leaving slightly less than 2 million dry tons available for other bioenergy and biobased product uses.[20] Additional bioconversion or thermochemical processes can be built around existing mills (either as extensions of the mill or as "across-the-fence" operations) to generate bio-energy or manufacture bio-products. This presents industry with dramatic potential to increase the productivity and profitability of its manufacturing infrastructure. (Agenda 2020)

[20] Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, Robert D. Perlack, et al., USDA/DOE, DOE/GO-102005-2135, April 2005

### 2.1.2.7.2 Performance Goals

The performance goals (i.e., "B" and "C" milestones) for the forest products mill improvement pathway are summarized in Table 2-8. Current program focus areas and the level of technology development are being developed.

**Table 2-8:** Forest Products Mill Improvement Pathway Performance Goals

| B Milestones | C Milestones |
|---|---|
| M 7.1 Demonstrate and validate cost-effective biomass gasification of wood residues and other process residues and synthesis gas cleanup in a forest products mill environment | M 7.1.1 Develop cost effective gasification designs for syngas production at appropriate scale |
| | M 7.1.2 Validate feeder system performance to reliably feed solids to high pressure (30 bar) systems) |
| | M 7.1.3 Validate gasification performance |
| | M 7.1.4 Validate cost-effective gas cleanup performance |
| | M 7.1.5 Validate integrated biomass gasification and syngas cleanup process suitable for a forest products mill at pilot scale |
| | M 7.1.6 Validate integrated biomass gasification and syngas cleanup process in forest products mill |
| M 7.2 Demonstrate and validate production mixed alcohols/DME/FT liquids or other products from syngas in a forest products mill at a price competitive with current commercial practice | M 7.2.1 Identify economically viable product(s) from syngas (evaluate technologies for mixed alcohols, DME and FTL) |
| | M 7.2.2 Produce mixed alcohols from syngas |
| | M 7.2.3 Produce DME from syngas as a LPG substitute |
| | M 7.2.4 Produce FTL from biomass syngas |
| | M 7.2.5 Validate integrated process at pilot scale |
| | M 7.2.6 Validate new process in a forest products mill |
| M 7.3 Demonstrate and validate syngas utilization in a forest products mill for CHP and direct fuel gas including clean cold gas | M 7.3.1 Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment |
| | M 7.3.2 Validate CHP from syngas and/or direct use of syngas in process equipment |
| | M 7.3.3 Validate integrated process at pilot scale |
| | M 7.3.4 Validate new process in a forest products mill |
| M 7.4 Demonstrate and validate bio-oil production to a stable intermediate | M 7.4.1 Validate bio-oil production |
| | M 7.4.2 Validate bio-oil intermediate recovery |
| | M 7.4.3 Validate integrated process for producing bio-oil at pilot scale (prototypes) |
| | M 7.4.4 Demonstrate and validate new process in a forest products mill |
| M 7.5 Achieve cost-effective conversion bio-oil intermediate into product(s) in a forest products mill | M 7.5.1 Validate production of products from bio-oil |
| | M 7.5.2 Validate bio-oil product(s) recovery |
| | M 7.5.3 Validate integrated process for producing bio-oil product at pilot scale |
| | M 7.5.4 Validate integrated process in a forest products mill |

### 2.1.2.7.3 Approach and Program Output

The Biomass Program is working with partners in the forest products industry to improve the economics of the existing forest products industry by incorporating more efficient and effective processes for utilizing primary wood residues (i.e., bark, hog fuel) and residues for the production of biobased fuels and chemicals, in addition to self-generated biomass-derived process heat and power. The program output from the forest products mill improvements pathway is a complete systems level demonstration and validation of technologies to improve forest products mill facilities and/or produce additional products (fuels, chemicals and/or power) from wood feedstock in a forest products mill environment. (Milestone M7).

### 2.1.3 Program Interaction with Other EERE Programs

Coordination and cooperation among EERE's eleven programs serves to maximize the effectiveness of DOE's investment in R&D resources and leverage technical knowledge across the entire EERE Office. The Biomass Program interacts with three other EERE programs, as shown in Table 2-9. The details of these relationships and the program's relationships with other DOE and Federal Programs are presented in Section 2.8.

**Table 2-9:** Biomass Program Interaction with EERE Programs

| EERE Program | Relevant Activities | Related Biomass Program Element |
|---|---|---|
| FreedomCAR and Vehicle Technologies | Advanced Petroleum-Based Fuels and Non-Petroleum-Based Fuels activities | Products: Fuels |
| Hydrogen, Fuel Cells and Infrastructure Technologies | Biomass to Hydrogen Production | Products: Fuels |
| Industrial Technologies | Industries of the Future: Chemicals<br>Industries of the Future: Forest Products | Products: Fuels, Chemicals and Materials, Heat and Power |

## 2.2 Portfolio Decision-Making Process

The EERE strategic goals to "dramatically reduce or even end dependence on foreign oil" and "create the new, domestic bioindustry," coupled with the OBP strategic goal to "develop biomass and biorefinery-related technologies to the point that they are cost and performance competitive and are used by the nation's transportation, energy, chemical, and power industries to meet their market needs" form the basis for virtually all portfolio decisions. With this basis, decision making is based on three criteria:

- Does the portfolio conduct R&D that meets the Program strategic goal?
- Does the portfolio develop technology that can produce competitively priced biobased fuels for the transportation sector of the United States?
- Does the portfolio lead to establishing the bioindustry in the United States?

With these end outcomes in mind, decision making can be facilitated by following the high-level logic model shown in Figure 2.12. While the diagram does not identify all the steps from inputs to outcomes; it does show the key steps and reflects the measurement points required under the Government Performance and Results Act (GPRA)[21].

[21] Performance Planning Guidance (GPRA Data Call) FY 2004-2008 Budget Cycle. Produced by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Draft version. April 1, 2002. – According to PBA staff, the April 1, 2002 draft version is the most up to date.

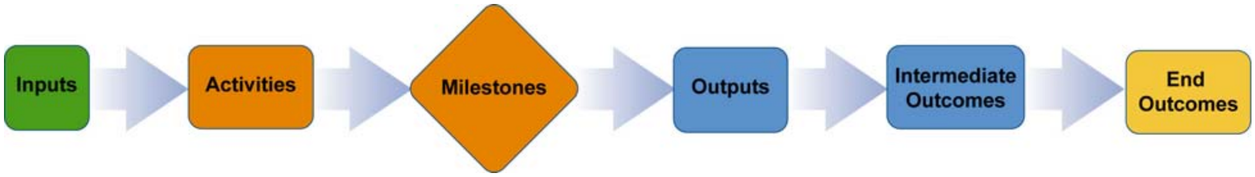


**Figure 2-12:** Program Decision-Making Logic Model

### 2.2.1 General Description of Portfolio Decision Making Process

The integrated biorefinery element strategic goal of "Establishing integrated biorefineries through public-private partnerships" provides a direct means to produce biofuels and it clearly enables the establishment of the bioindustry. Each core R&D element—feedstocks, sugars, thermochemical, and products—is designed to assist in achieving the integrated biorefinery goal through technology development or facilitating integration of unit operations within a biorefinery. A refining operation is a complex facility that must address most or all of the following: feedstock delivery and processing, conversion processes, recovery systems, purification systems, process control operations, analytical systems for process control or product quality assessments, emissions controls and monitoring, and packaging or delivery of products. Each of these has technology needs and economic and technological barriers. Through evaluation and peer review, the major barriers have been identified. Analysis prioritizes cost impacts of these barriers and identifies gaps. Programmatic priorities are then based on addressing these barriers and filling needed gaps.

Program decisions about research directions and priorities are guided by input obtained from external experts on biomass technologies. The potential benefits of the Biomass Program technologies are evaluated against the R&D Investment Criteria's assessments of risk, years to commercialization, and market barriers, relative to the potential benefits.

In conjunction with external review and input, the program uses pathways analysis and an assessment process consisting of three steps:

- Step 1 - characterize and develop a hierarchy of the technical barriers;
- Step 2 - identify needed R&D, focusing on areas of possible cost reduction or performance enhancement;
- Step 3 - set priorities and allocate resources within expected budget. The work breakdown structure and multi-year technical plan group all activities according to which technical barrier each activity addresses.

Since the strategic goal involves seeing technology mature into potential commercial launches, the program must operate analogous to industries that develop processes such as the chemical, petrochemical, ag processing, and forest products industries. These industries rely on obtaining and analyzing data and information that can help make decisions to proceed or stop development. In a similar manner, OBP solicits, maintains, and employs a large range of information and data that can help make resource allocations and investments. For early stage research, analysis of technical potential is a critical factor as long as the impact for economic return can be shown to occur in the future. For process development, stage-gate analyses that require more rigor in assessing technical, economic, market, and environmental/regulatory risks are employed. In demonstrations involving public private partnerships, the credibility of the industrial entity bolstered by independent analysis, stage-gate decision making, and analyses by the PMC contribute to risk assessments and go no/go decisions.

Figure 2.13 depicts the information and input flows into the decision making body of the Biomass Program Management Team. The Program employs five technology managers who provide the input to the program management team. The Technology managers lead each of the five program technology elements. Hence, there are five technology manager recommendations to be considered by the program management team.

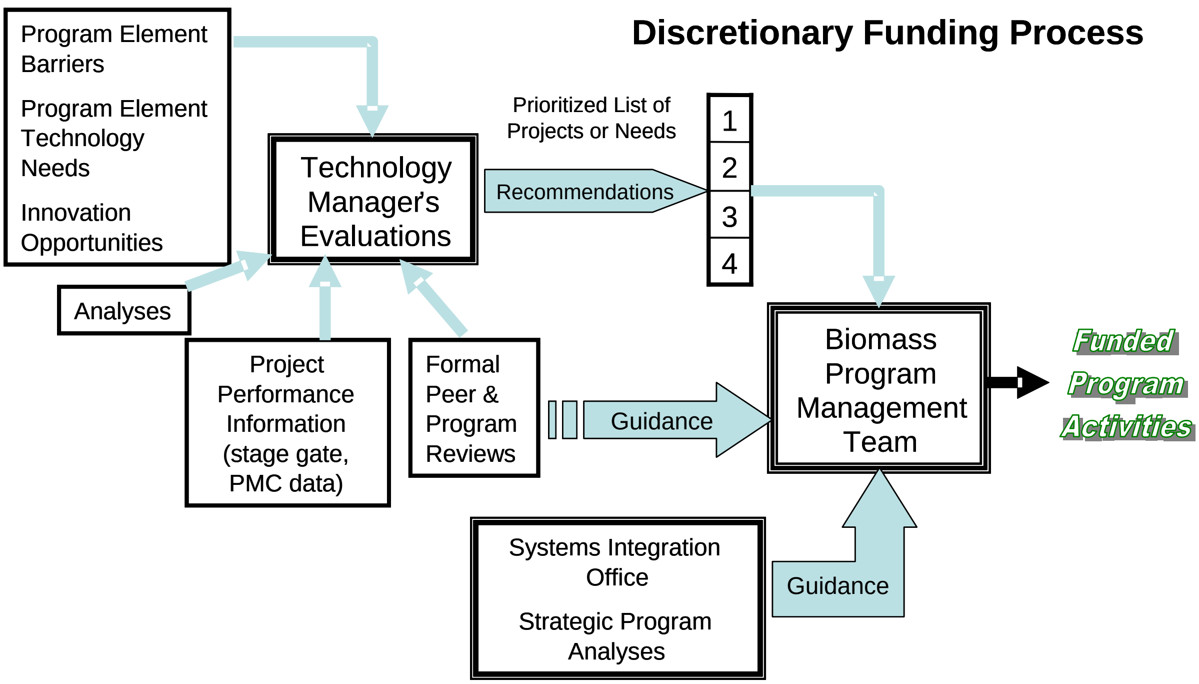


**Figure 2-13:** Diagram of Portfolio Decision-Making Process

This figure depicts the internal decision making process. There are also EERE performance measures that factor into resource allocations, as noted above in Figure 2-13. These are also considered by the program management team in making portfolio decisions.

Since information is paramount to making rational portfolio decisions, the following are examples of the key components of information and data that are used by technology managers to make portfolio decisions relative to priorities and funded program activities.

1. Analyses
   a. Strategic
   b. Systems
   c. Engineering & Technoeconomic
   d. Categorizing innovation potential

2. Project Management & Performance Information
   a. Data from Stage Gate Reviews
   b. Peer reviews (program or individual)
   c. Financial tracking by PMC and HQ

d. Due diligence by Recipients
e. Assessments of technical and economic risks

3. Technology Development
    a. State of technology
    b. Investments required to achieve measurable impacts on performance metrics
    c. Addressing the technology gaps critical to sustaining pathway development
    d. Use of program capital investments and leveraging investments by other Offices within DOE and other agencies
    e. Necessary capital investments to impact progress in pathways or program element R&D
    f. Innovation potential

4. Budgetary Constraints
    a. Current FY funding profile
    b. Budgetary planning commensurate with program goals
    c. Allocation of resources for demonstrations

5. Systems Integration
    a. Organized database of portfolio contents that permits analysis
    b. Project information and state of development of each project
    c. Integration with PMC databases
    d. Integration with Program Analysis functions

No decision making process is infallible. The OBP strives to obtain as much information and data to make prudent allocations of resources, cease non-productive work, assess risk and invest in high-potential projects. The next section outlines the strategies and use of analysis in the program.

### 2.2.2 Optimizing Returns on Investment

There are two primary levels at which the program seeks to optimize the return on investment: the project level and the portfolio level.

At the project level, stage gate management, described in Section 2.5.4.3, is used to optimize return on investment. One of the advantages of this process is that the commitment of funding on a project is low to start and increases as more work is done and confidence increases (through the Gate reviews) that the project will be ultimately successful. Efforts are focused on the most critical and uncertain elements early in the life of a project thereby minimizing spending. By conducting a thorough background study of the potential for the technology; who will use it; its expected economics; and the anticipated effort to develop, OBP can make the best decisions regarding spending greater sums on money on the best projects. The expectation is that projects with significant technical and/or market problems are weeded out from the Program portfolio sooner rather than later, so that the "big" spending is reserved for those projects that have the greatest potential for success.

At the Program portfolio level, all of the information developed at project level is useful, but with well over 100 projects in the portfolio, the project information must be summarized and synthesized in order to support decision making.  One of the benefits of instituting the pathway approach is that projects can be logically grouped according to the type of feedstock and/or biorefinery configuration they are working on.  Evaluation of the potential technical improvement opportunities associated with a project is based on their expected relative competitive advantage to other projects working on improvements to the same pathway.

In this approach of systematic risk evaluation, the Biomass Program has developed a new pathway model as a means to assess risk, evaluate all of the factors, and incorporate strategies to minimize its impact.  This includes a continued focus on technical and economic analyses within the work breakdown structure elements of each platform; however, it also includes strategic analyses across the WBS elements by integrating a matrix of technologies to achieve the program metrics.  Through this approach, and by integrating it with the Stage Gate Process, the program can assess technical, managerial, financial, environmental, and strategic risk factors.

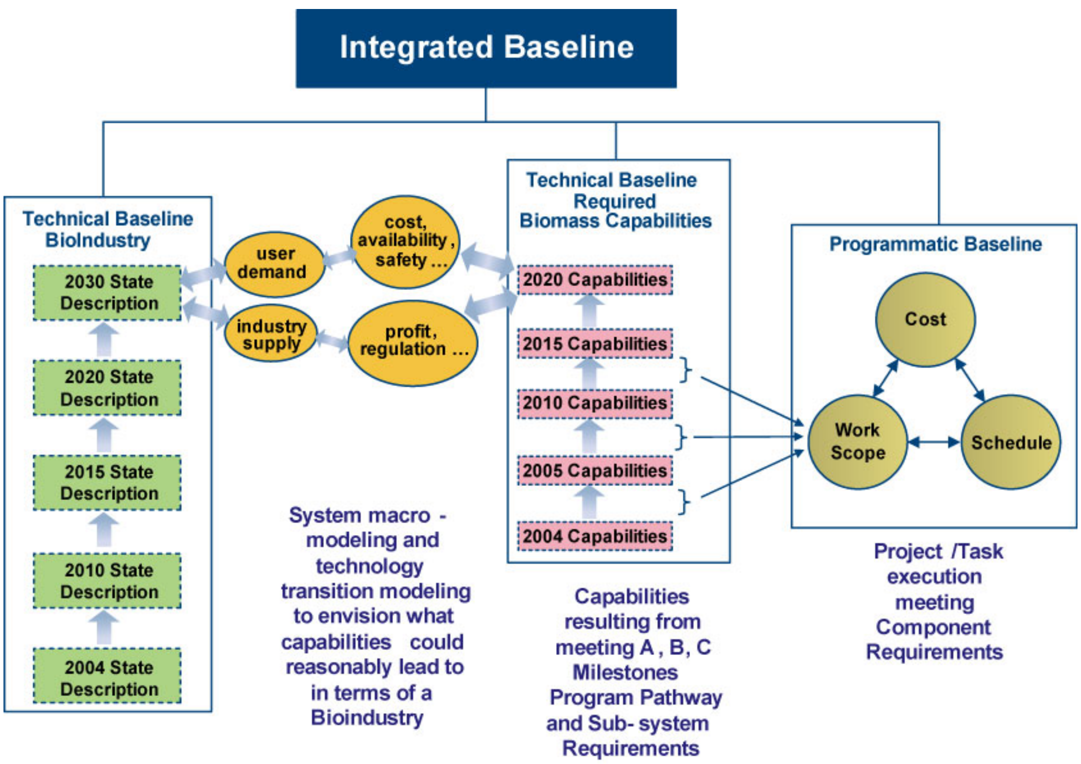


**Figure 2-14:** Integrated Baseline Diagram

### 2.2.3 Peer Review and External Feedback

Section 2.5.2 describes the peer review approach used by the Program, and Section 2.5.3 describes other technical reviews that are designed to gather external feedback. Elements of both the peer review and other technical review approaches include reviews at both the portfolio and project levels, with the project level reviews either following the Stage Gate management process directly, or at least incorporating the same criteria in the process used.  Table 2-10 below shows the four primary types of reviews where the Program collects information and feedback from independent external sources, including the documentation content and public accessibility.

**Table 2-10:** Portfolio and Project Level Reviews that Support Decision-Making

| Portfolio or Project Level | Review Type | Frequency | Reviewers | Documentation |
|---|---|---|---|---|
| Portfolio | Total Program Peer Review | Biennially | Independent industry, academia selected by independent steering committee | Public summary document including OBP response |
| | Biomass R&D Technical Advisory Committee | Every 2-3 years | | Report to Congress, including OBP response |
| Project | Element Portfolio Peer Review of Projects | Annually | Independent industry, academia, other government | Public summary document including OBP response |
| | Stage Gate Reviews | Annually or as needed | DOE only for public-private partnership projects, DOE plus independent industry, academia, other government for pre-competitive R&D projects | Internal reports for public private partnerships, public information for pre-competitive R&D projects |

### 2.2.4 Risk Assessment

Risk assessment is a significant factor in portfolio decision making.[22] The identification, quantification, and evaluation of risk can be used to better focus resources where they are most critical, and thus help manage risks. Clearly addressing the potential showstoppers may also encourage greater private sector investment once the showstoppers are addressed. The more systematic delineation of risks may also encourage greater attention to identifying and evaluating multiple pathways to address key bottlenecks and thus support budget requests. To realize these opportunities, the tools must be credible for industry, lab researchers and managers.

Note that application of risk analysis tools to research programs is much different than the application of risk tools to a financial portfolio, as a research program has critical elements that must be accomplished, whereas a financial portfolio can simply drop some investments and reallocate funds across the portfolio. The risk analysis should be paired with benefits analysis and consider cases with partial success.

The methodology used by the Biomass Program for estimating risk will identify, and to the extent possible, control known biases. To the extent possible, estimates of a particular risk should be similar across different groups of experts during the stage gate processes. Their

[22] DOE is developing corporate risk assessment guidance for Energy and Science R&D programs to be released in FY06. OBP staff are participating in this effort. See Section 4.1.4.2.

estimates should be repeatable within some range of error that will be discussed during the initial briefings. These considerations will require the use of peer-developed estimates and/or reviews by teams that are independent of, but work collaboratively with, the project team. This can also provide more transparent, auditable, and credible estimates of risk.

In this approach of systematic risk evaluation, the Biomass Program has developed a new pathway model as a means to assess risk, evaluate all of the factors, and incorporate strategies to minimize its impact. This includes a continued focus on technical and economic analyses within the work breakdown structure elements of each platform; however, it also includes strategic analyses across the WBS elements by integrating a matrix of technologies to achieve the program metrics. Through this approach, and by integrating it with the Stage Gate Process, the program can assess technical, managerial, financial, environmental, and strategic risk factors.

## 2.3 Program Analysis

The Biomass Program uses analysis to support decision-making, show progress to goals and direct research activities. Figure 2-15 shows how analysis aids the progression of R&D projects to deployment. Information (data) is used in a variety of assessments. These assessments feed broad strategic analyses, which culminate in technology transfer. Used in combination, different assessments provide a complete understanding of the technologies under development, providing information and recommendations to the program to quantify the benefits, drawbacks, and risks of different biomass utilization scenarios.


**Figure 2-15:** The Role of Analysis in Moving R&D to Deployment

### 2.3.1 Description of Analytical Methodologies and Tools

The Biomass Program uses a variety of analytical methodologies and tools to guide its RD&D efforts. Each of these methodologies provides information and recommendations to the Program, and when used in combination, they provide a sound understanding of program technologies. Maintaining these capabilities at the cutting edge is essential to ensure that the analysis provides the most efficient and complete answers to the technology developers and the Program. Analysis methods for biomass processes are as new as the processes themselves. Although some methods and tools from other industries (especially the process industries such as petroleum refining and petrochemical processing) can be used with modification, others, such as biomass physical property estimation methods, must be developed. The analysis methodologies and tools used by the Biomass Program are outlined below.

**Biomass Resource and Infrastructure Assessment**. Resource assessment determines the quantity and location of biomass resources on state, county, and land type levels. Additionally, resource analysis quantifies the cost of the resources as a function of the amount available for utilization. Geographic Information Systems (GIS) modeling are used to portray and analyze resource data (ARC/INFO, ORIBAS). A variety of integrated modeling tools (POLYSYS, BIOCOST), dynamic production models (EXTEND), and databases (ORRECL) are used for estimating current sustainable feedstock supplies and forecasting supplies from new resources such as energy crops. These modeling tools encompass economic, geographic and environmental constraints in assessing the availability of biomass wastes, agricultural residues, forest residues, and energy crops. Biomass feedstock infrastructure assessment identifies the optimal methods for collection, transportation, and storage of biomass feedstocks. The Integrated Biomass Supply Analysis and Logistics (IBSAL) model simulates innovative biomass collection, transport, and storage options and optimizes the supply chain for the least delivered cost of biomass.

Other types of infrastructure assessments identify the existing infrastructure throughout the supply chain that could be leveraged by the emerging bioindustry as well as the developments needed to support industry growth in the future. Examples include infrastructure assessments of the U.S. liquid transportation fuel distribution network or the characteristics and expected changes in national vehicle stocks and the implications for acceptance of alternative fuels.

**Technical and Economic Feasibility Analysis**. The majority of technical and economic analysis is performed as part the core R&D element analysis activities where it provides direction, focus, and support to the development and introduction of feedstock production, and processing and use technologies. Technical and economic feasibility analysis determines the potential economic viability of a process or technology and helps to identify the most significant opportunities for improvement and which technologies have the greatest likelihood of economic success. Results from technology feasibility analysis provide input to decisions regarding portfolio development and technology validation plans. The economic competitiveness of a technology is assessed by evaluating its implementation costs for a given process compared with the costs of either current technology or other future options. These analyses are useful in determining which projects have the highest potential for near-, mid-, and long-term success. Parameters studied include production volume benefits, economies of scale, process configuration, materials, and resource requirements. Tools used for technology feasibility analysis include unit operation design (e.g., FLUENT, CFX5, ABAQUS), process design and modeling (e.g., Aspen Plus© [23] and ChemCAD), capital and operating cost determination, cash flow analysis (e.g., Excel spreadsheet models), and Monte Carlo sensitivity analysis/risk assessment (e.g., Crystal Ball).

**Integrated Biorefinery Analysis.** Integrated biorefinery analysis is a sub-set of technical and economic feasibility analysis that combines individual technology assessments to determine the optimal mix of technologies to produce a slate of products (i.e., fuels, chemical and material, and/or heat and power). The models developed as part of this effort will be critical to evaluating options and opportunities relative to the baseline characterizations of the integrated biorefinery pathways. In this way it provides direction and focus to the overall research program. A spreadsheet-based linear program model (BioRefine) is used to study the possible options before investing in development or deployment activities. As new production technology designs are completed in the platform analysis projects, they will be added to the biorefinery process design work and to BioRefine. The purpose of this selection is not to pick winners, but to find model products that will allow a complete analysis of the biorefinery process designs. Additional advanced methods, tools, and partnerships will be required as integrated biorefineries come closer to commercial reality, and the Program will need to make important funding decisions regarding high-cost projects such as pilot scale integration, large scale demonstration, and loan guarantees.

**Environmental Analysis.** The Program uses environmental analysis to quantify the environmental impacts of biomass production and utilization technologies. Specifically, life cycle assessment (LCA) is used to identify and evaluate the emissions, resource consumption, and energy use of all processes required to make the process of interest operate, including raw material extraction, transportation, processing, and final disposal of all products and by-products. Also known as cradle-to-grave or well-to-wheels analysis, the methodology is used to better understand the full impacts of existing and developing technologies, such that efforts can be focused on mitigating negative effects. Standardized LCA methodologies and established databases of material and energy flow inventories for common chemical and energy processes (e.g., Tool for Environmental Analysis and Management [24] – TEAM; and its supporting database, Data for Environmental Analysis and Management – DEAM), are used to evaluate the impact of complete processes on the environment. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation[25] (GREET) model is used to estimate fuel-cycle energy use and emissions associated with alternative transportation fuels and advanced vehicle technologies.

**Bioindustry Analysis**. Bioindustry analysis is used to:

- Identify and evaluate paths by which biomass can make a large contribution to meeting future demand for energy services, to answer questions such as:
    - Which technologies are most likely to be a part of the biobased future?

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[23] Aspen Plus© is a process modeling tool for steady state simulation, design, performance monitoring, optimization and business planning widely used in the chemicals, specialty chemicals, petrochemicals and metallurgy industries. The web site is at http://www.aspentech.com/product.cfm?ProductID=69.

[24] TEAM™ enables the user to describe any industrial system and to calculate the associated life cycle inventories and potential environmental impacts according to the current ISO 14040 series (for LCA) of standards. The website is at http://www.ecobalance.com/uk_team.php.

[25] The GREET website is http://www.transportation.anl.gov/software/GREET/index.html .

- What are the interactions between these technologies and other established technologies?
- What are the scenarios for biomass use in energy, transportation, and chemical markets?
- What market penetration pathways are likely?

- Determine what can be done to accelerate biomass energy use and in what timeframe associated benefits can be realized, by understanding:
  - What external economic factors are most important?
  - What are the most likely bottlenecks or limiting factors?
  - What are the effects of government policy drivers?

Industry specific transition models, such as the bioindustry model shown conceptually in Figure 2-16 below, are built using commercially available dynamic systems models, such as STELLA™[26] or EXTEND™. In the bioindustry case, the model is organized around the supply chain for production and use of fuels made from biomass, starting from biomass production and collection, through conversion to fuel and its eventual distribution and end use. The dynamics of the growth of each component in the supply chain are determined by the timing of the build-up of the infrastructure associated with each step. Ultimately, the build up of the infrastructure for each component of the supply chain is determined by the dynamics of investor decisions. Investor response is, in turn, driven by the performance and cost competitiveness of the fuels and the potential demand for them in the marketplace. Finally, government policy and external economic factors are evaluated as to their impact on the relative attractiveness of investing in new biofuels technology.

[26] The STELLA Software website is at http://www.hps-inc.com/softwares/Education/StellaSoftware.aspx .

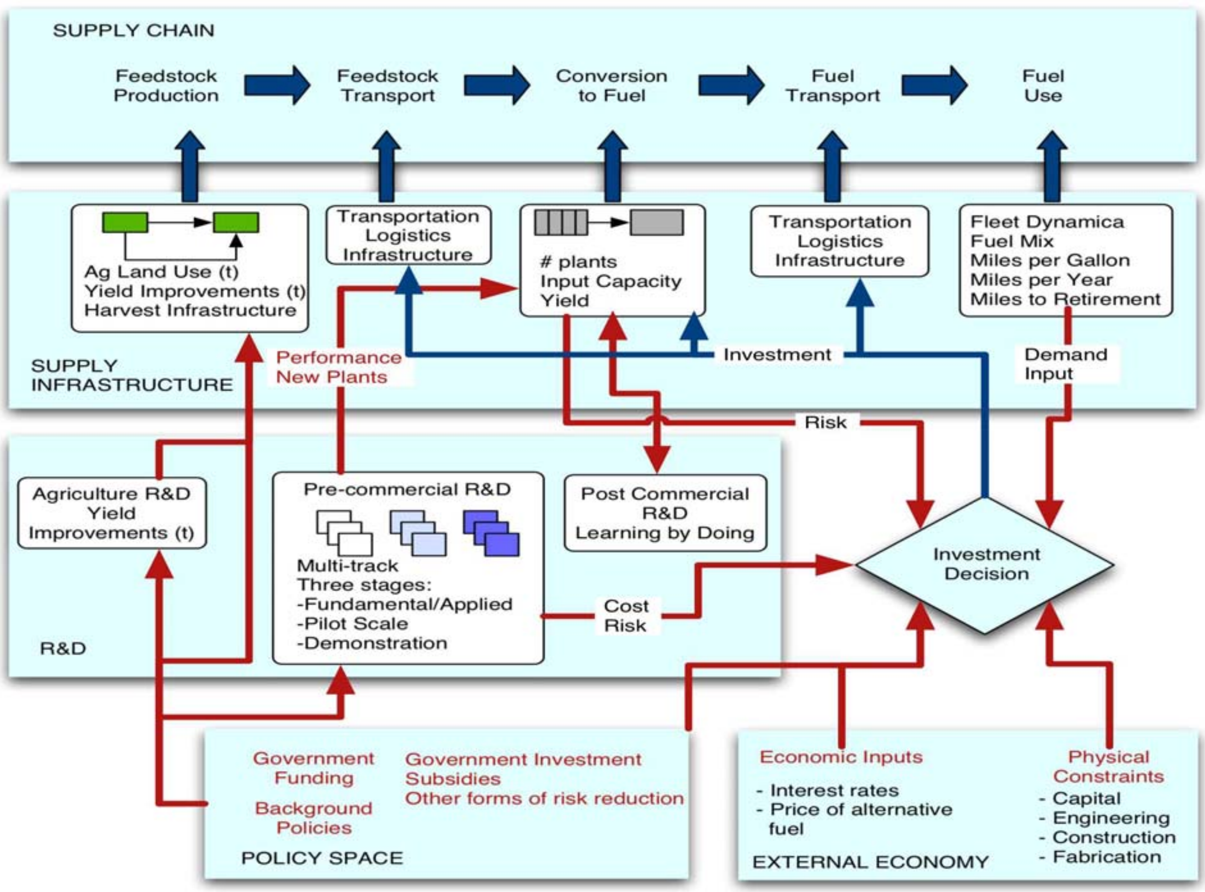


**Figure 2-16:** Conceptual Schematic of Bioindustry Transition Model

**Benefits Analysis.** Benefits analysis helps the program quantify and communicate the overarching outcomes from biomass research, development, and deployment—such as imported oil displacement and greenhouse gas mitigation. This is discussed in more detail in Section 2.7.

### 2.3.2 Analytical Work in the Biomass Program

The analysis work planned for the next five years builds on past efforts to understand the economic factors and key uncertainties related to biomass technologies and systems. Continued public-private partnerships with the biomass scientific community and multi-lab coordination efforts will help to ensure that the analysis results from the program are transparent, transferable, and comparable. Analysis activities are mainly conducted through the technology elements (platforms) and are focused as follows.

**Biomass Resource and Infrastructure Assessment.**
**Technical and Economic Feasibility Analysis**

***Feedstocks Analysis.*** Feedstocks analysis will continue to evaluate biomass collection, transport, and storage options and optimizes the supply chain for the least delivered cost of biomass. Analytical models and tools will be regularly upgraded and validated with the emerging feedstock field data from the DOE/USDA projects and the supply data from biorefinery projects.

The goal is to define minimum cost pathways for biomass collection and handling at a cost goal of $35/dry ton.

***Sugar Platform Analysis*.** Sugar platform analysis will continue to support the ongoing research in biochemical conversion of lignocellulosic biomass in support of an integrated sugar/thermochemical biorefinery. Specifically, the three goals are to (1) track research improvements as to their contribution to reducing the cost of sugars production to 6.7 cents per pound (corresponding to $1.09 per gal ethanol) in 2020; (2) direct research to the areas that will provide the largest cost reductions; and (3) support a biorefinery analysis combining biochemical conversion of carbohydrates with thermochemical processing of residues.

***Thermochemical Platform Analysis*.** Thermochemical platform analysis will continue to support the ongoing research on the thermochemical conversion of lignocellulosic biomass in support of an integrated sugar/thermochemical biorefinery. Specifically, the goal is to reduce the estimated cost for production of an intermediate clean, reformed biomass-derived synthesis gas produced from a mature gasification plant integrated within a biorefinery, from $7.25 per million Btu ($6.88 per GJ) in 2005 to $5.25 per million Btu ($4.98 per GJ) by 2010.

***Products Platform Analysis.*** Products platform analysis will continue to support the on-going research on the impact of products on the overall economic viability of biorefineries. The work will be as broad as possible, and will include assessments of biorefineries based on agricultural and forest feedstocks, and both chemical and biochemical product synthesis technologies. These analyses will be designed to provide bases for defining technical barriers for converting sugars and lignin to fuels and chemicals that form the core technology efforts to enable product development.

***Integrated Biorefineries*.** Integrated biorefineries analysis will continue to support the advancement of biomass-based technologies into integrated systems. Specific objectives include continued development of biorefinery pathway models based on near-term existing industries based on grain and wood, mid-term pathway models based on agricultural residues, and long-term pathways based on energy crops.

**Bioindustry Analysis.**
***Transition Analysis.*** The goal of the planned transition analysis work is to develop and validate a detailed system dynamics model for assessing future transitions to a bioindustry, emphasizing near-term strategies that take advantage of the existing biomass industry and related infrastructure. Of particular interest are the deployment strategies involving the existing corn grain ethanol industry in terms of their ability to accelerate deployment of long-term technology for converting lignocellulosic biomass to ethanol. The modeling tool will build off work done on the RBAEF project but will be much larger and technically rigorous in scope. The model will be modular in nature at each major stage in the supply chain and will need the ability to mix and match different combinations of feedstocks, conversion technologies, and fuel/product end-uses.

### 2.3.3 Impact on Program R&D and Deployment Decision Processes

Analysis gives the Biomass Program context and justification for decisions at all levels by providing quantitative metrics. Macroscopic benefits analysis shows yearly progress toward DOE and EERE goals, while microscopic technical analysis directs R&D projects on a daily basis. Overall, analysis quantifies goals, targets, and results, and provides alternative directions. Analysis plays three main roles in the Biomass Program decision-making process:

- Defines and validates performance targets for biomass technologies and systems
- Guides program planning functions, R&D project selection, and assessment of progress
- Provides engineering knowledge for biorefinery development

**Performance Targets.** The information and assessment functions in analysis (see Figure 2-15) define the performance targets required to overcome barriers that then form the basis for developing funding priorities. Design case studies have yielded specific sugars and syngas production cost targets. These cost targets help define the research agenda, such as the program's pretreatment focus in the sugars program element, and the program's gas clean up and conditioning in the thermochemical program element. The improvements garnered by R&D translate into feedback mechanisms to improve the analyses, allowing the program to better define targets that lead to defining the program's portfolio.

Because a considerable portion of the program is devoted to public-private partnerships, analysis from the private partnerships often assists both the industrial partner and DOE in decision making processes. Most of the major projects must make go/no-go decisions based on performance and cost targets. These are often the basis for moving from one stage of development to another.

**Guidance for Program Planning.** Analysis provides direction and guidance to OBP for program planning by helping select and show progress on R&D projects. Engineering and analysis are used in all stages of the stage gate management process to determine the technical feasibility and competitive advantage of projects. The level of rigor of the analysis depends on the stage of project development, the level of maturity of the technology, and the intended application. As the projects move along the development pathway, the technical and economic assessments become more robust and accurate as data is collected and utilized. For new projects, simply developing a process design may identify showstoppers that must be overcome before the idea can become commercially viable. A more advanced project could require material and energy balance closures and capital cost quotes or even site-specific designs in order to assess the resource needs.

The projects in the Biomass Program portfolio undergo stage gate reviews to assess development and readiness to move into further stages of development. These reviews, supported by analyses of the R&D data produced, form the basis for decision making in each project. This clarifies the resource needs within the project, assisting program planning.

**Engineering Knowledge for Biorefinery Development.** Engineering knowledge is necessary to construct and operate a successful commercial bioindustry, and to develop the feedstock infrastructure to support it. Engineering and analysis provides interested parties with the information they need to potentially commercialize biomass. This dissemination of biomass information is necessary to enable widespread investigation of biomass processing, and better understanding of the commercialization process can help reduce the financial risk associated with pioneer plants. Kinetic models applicable to multiple scales, improved physical property data/estimates, and uncertainty analysis can all help to reduce the risks associated with biomass commercialization. The Biomass Program disseminates its engineering knowledge through the publication of comprehensive design reports. These reports establish the credibility and transparency of the program's work and enable integration across biomass research areas, both in the program and in the biomass community at large.

### 2.3.4 Key Assumptions

Again, the program is heavily involved in assessing various processes and systems directed towards the production of biofuels, chemicals and materials and heat/power. Each process or system has its own set of specific assumptions. However, a general set of assumptions can be applied to all efforts:

Fuels – All near- and mid-term biofuels must be fungible with existing liquid fuels and the existing liquid fuel distribution infrastructure. This does not apply to fuels produced and consumed within a biorefinery. Production of hydrogen fuel is a long-term biofuels option.

Chemicals and materials – For bioderived products replacing an existing chemical or material within the market, the performance and cost must be competitive with the comparable product derived from petrochemicals. For bioderived products providing new functionality or applications, the performance and costs must be competitive within the market application.

Heat and Power – These energy products must be fungible.

Integrated Biorefineries – An integrated biorefinery is defined as an operation using biomass feedstocks that produces a fungible biofuel and includes the following components: production of a biobased product by thermochemical or biological processes; or hybrids of both and integrated heat recovery, all of which are necessary for the economic feasibility of the integrated operation.

### 2.3.5 Analytical Publications Used to Guide the Analysis

The Biomass Program has developed the *Office of the Biomass Program: Multi-Year Analysis Plan*, FY 2004-FY2008, DOE/EERE, DOE/GO-102004-2032, 2004, http://www.nrel.gov/docs/fy05osti/36999.pdf, which fully explains the analysis strategies, methodologies and plans for the Biomass Program through 2008. The Analysis Plan will be updated to reflect this MYPP. Representative publications, which document the recent analysis results of each program technology element (platform) and which serve as the basis for continuing analysis efforts, are summarized below.

**Biomass Resource and Infrastructure**

- *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, DOE/GO-102005-2135, DOE/USDA, April 2005 (http://feedstockreview.ornl.gov)
- *Roadmap for Agriculture Biomass Feedstock Supply in the United States*, DOE/NE-ID-11129 Rev 0, 2003 http://devafdc.nrel.gov/pdfs/8245.pdf.

- *Transportation and Infrastructure Requirements for a Renewable Fuels Standard*, Subcontract Report, Reynolds, Robert E., Downstream Alternatives Inc., August 2002 http://devafdc.nrel.gov/pdfs/6637.pdf

**Technical and Economic Feasibility Analysis**.

**Sugar Platform Analysis**

- *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover,* A. Aden, M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, and B. Wallace, NREL/TP-510-32438, National Renewable Energy Laboratory, Golden, CO, 2002, http://www.nrel.gov/docs/fy02osti/32438.pdf

**Thermochemical Platform Analysis**

- *Biomass to Hydrogen Production Detailed Design and Economics Utilizing the Battelle Columbus Laboratory Indirectly-Heated Gasifier*, Spath**,** P.;Aden, A.;Eggeman, T.;Ringer, M.;Wallace, B.;Jechura, J., NREL/TP-510-37408. National Renewable Energy Laboratory, Golden, CO, 2005 http://www.nrel.gov/docs/fy05osti/37408.pdf
- *Preliminary Screening--Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas*, Spath, Pam; Dave Dayton, NREL/TP-510-34929, (December 2003), http://www.nrel.gov/docs/fy04osti/34929.pdf

**Products Analysis**

- *Top Value Added Chemicals from Biomass Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas*, T. Werpy and G. Petersen, Editors, DOE/GO-102004-1992, August 2004, http://www.nrel.gov/docs/fy04osti/35523.pdf

**Biorefineries Analysis**

- The first reports on biorefinery modeling and analysis are under development are expected to be published in FY 2006.

**Environmental Assessment**

- *Mobility Chains Analysis of Technologies for Passenger Cars and Light-Duty Vehicles Fueled with Biofuels: Application of the GREET Model to the Role of Biomass in America's Energy Future (RBAEF) Project* (July 2005), http://www.transportation.anl.gov/pdfs/TA/344.pdf
- GM Study: Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems — A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions (May 2005), http://www.transportation.anl.gov/pdfs/TA/339.pdf
- *Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol*, Journal of Industrial Ecology Special Issue on Biobased Products, Vol.7, Sheehan, John; Andy Aden, Keith Paustian, Kendrick Killian, John Brenner, Marie Walsh, Richard Nelson, (June 2004), http://devafdc.nrel.gov/pdfs/8427.pdf
- Fuel-Cycle Energy and Emission Impacts of Ethanol-Diesel Blends in Urban Buses and Farming Tractors, (July 2003), http://www.transportation.anl.gov/pdfs/TA/280.pdf
- *The Energy Balance of Corn Ethanol: An Update* (July 2002), http://www.transportation.anl.gov/pdfs/AF/265.pdf
- *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus*, Sheehan, J.;Camobreco, V.;Duffield, J.;Graboski, M.;Shapouri, H, NREL/SR-580-24089, (May 1998), http://devafdc.nrel.gov/pdfs/3813.pdf

**Bioindustry Analysis**

The first Bioindustry transition model using the dynamic systems model STELLA is under development as part of a current project entitled "The Role of Biomass in America's Energy Future (RBAEF). Project reports, including documentation of the Bioindustry model, are expected in FY 2006.

## 2.4 Performance Measurement

For performance measure, the program uses production costs specific to the main biorefinery platforms, sugars and syngas that are the basis for economically producing fuels, chemicals, heat and power. The program has recently developed biorefinery technology pathways such as corn wet mill or agricultural residue pathway, and the cost and technical performance measures used to validate each pathway. The sugars and syngas cost targets are important indicators within most of the pathways being considered. An additional critical performance measure is the number of bio-based products for which technical and market potential will be established through the year 2010.

Standard, consistent analysis methods, described in Section 2.3, are used to develop production cost estimates for agricultural residue feedstock, sugar from agricultural residues and, syngas ethanol, and other fuels and chemicals (these are reviewed and monitored by managers).

**Table 2-11.** Biomass Program Performance Measurement

| | 2004 State of Technology | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| Feedstocks | | | | | | | |
| Delivered Cost of Feedstock ($/dry ton) | 53 | | | | | | 45 |
| Biochemical | | | | | | | |
| Minimum Sugars Selling Price ($/lb) | $0.135 | 0.12 | 0.11 | 0.10 | 0.095 | 0.095 | 0.095 |
| Sugars Yield (lb/dry ton) | 1,089 | | | | | | 1,124 |
| Minimum Ethanol Selling Price ($/gal) | $2.50 | | | | | | 1.75 |
| Ethanol Yield (gal/dry ton) | 68 | | | | | | 72 |
| Thermochemical | | | | | | | |
| Syngas selling price ($/GJ, LHV) | 6.88 (2005) | | | | 4.98 | | |
| Syngas selling price ($/MMBtu, LHV) | 7.25 (2005) | 6.84 | 6.14 | 5.76 | 5.25 | 5.15 | |
| Products | | | | | | | |
| Chemical or biological transformation cost for the conversion of platform building blocks ($/lb) | | | | 0.03-0.09 | | | |
| Separation cost for recovering products from | | | | <0.05 | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| dilute (less than 25% product) aqueous solutions ($/lb) | | | | | | | |
| Cost of aerobic fermentations for the production of chemical building blocks ($/lb) | | | | | | | <0.35 |
| Cost of selective aqueous phase catalytic and bio-catalytic transformations of carbohydrates for the production of building blocks ($/lb) | | | | | | | <0.25 |
| Cost of anaerobic fermentations for the production of chemical building blocks ($/lb) | | | | | | | <0.25 (2015) |
| Integrated Biorefinery | | | | | | | |
| Demonstrate increased ethanol yield from fiber conversion and recalcitrant starch (%) | | 5-20 | | | | | |
| Wet mill pilot-scale demonstration of ag. residues to ethanol with increased revenues (%) | | | 5-10 | | | | |
| Dry mill pilot-scale demonstration of bio-based product with increased revenues (%) | | | | 5-10 | | | |
| Dry mill pilot-scale validation of process economics | | | | | TBD | | |
| Dry mill pilot-scale demonstration of energy crops to bioproducts cost ($/lb) | | | | | | | 0.25 |

## 2.5 Performance Assessment

Performance assessment includes performance monitoring and program evaluation. It provides the means to measure relevant outputs and outcomes that can aid the Program in reevaluating its decisions, goals, and approach, and get a good sense of the actual progress being made. By design, the assessment processes provide the Program with input on Program progress and effectiveness from stakeholders and independent expert reviewers.

The basic types of performance assessments used by EERE programs are:

- ***Results-based performance reporting*** using DOE's Joule Performance Measurement Tracking System, the White House Office of Management and Budget's (OMB) Program Assessment Rating Tool (PART)[27], and OMB's R&D Investment Criteria[28].

[27] The OMB PART web site at http://www.whitehouse.gov/omb/part/index.html provides guidance documents and links to competed assessments of many Federal programs.

- ***Peer reviews*** by outside independent experts of both program and subprogram portfolios to assess quality, productivity, and accomplishments; relevance of program success to EERE strategic and programmatic goals; and management.[29]
- ***General program evaluation studies*** performed by outside independent experts to examine market needs/baseline, process, outcomes and impacts, or cost-benefit, as necessary.[30]
- ***Technical program reviews*** by EERE Senior Management, Technical Teams, or Advisory Committees

The specific types of reviews carried out by the Program are listed in Table 2-12 along with the frequency of reviews and the program life cycle stage during which they occur. Each review is described in more detail in subsequent subsections.

**Table 2-12:** Biomass Program Performance Assessments, Frequency and Program Life Cycle Stage

| Assessment Type | Frequency | Program Stage |
|---|---|---|
| ***Results-based performance reporting*** | | |
| Joule Performance Measurement | Quarterly | During Operations |
| PART | Annually | During Operations |
| R&DIC | ? | During Operations |
| ***Peer Reviews (In-progress)*** | | |
| Program Peer Review | Biennially | During Operations |
| Element Review – Project emphasis | Annually | During Operations |
| ***General program evaluation studies*** | | |
| Needs/Market Assessment | As necessary | Early Planning and During Operations |
| Systems Integration – Integrated baseline | Continuous | During Operations |
| GPRA Benefits Analysis | Annually | During Operations |
| Ex-post (process, impact, or cost benefit) Evaluation(s) | Once | After Program End |
| ***Technical program reviews*** | | |
| EERE Senior Management | Annually | During Operations |
| Biomass R&D Technical Advisory Committee Portfolio Review | Annually | During Operations |
| Project Gate Reviews | As required by project decision points | During Operations |

### 2.5.1 Results-based Performance Reporting

There are primary performance reporting processes carried out by the Biomass Program including:

[28] OMB Applied R&D Investment Criteria are listed in the EERE Strategic Plan (2002), p. 9, http://www.eere.energy.gov/office_eere/pdfs/fy02_strategic_plan.pdf.

[29] Peer Review Guide (August 2004), prepared by the EERE Peer Review Task Force, provides detailed expectations and recommendations for EERE program peer reviews based on a survey of best practices for in-progress peer review, http://www.eere.energy.gov/office_eere/ba/pdfs/2004peerreviewguide.pdf.

[30] A separate guide on general program evaluation is forthcoming - EERE Guide for Managing General Program Evaluation Studies: Getting the Information You Need (Draft issued February 2005).

- Quarterly and annual assessment of program and management results based performance through Joule milestone reporting system which constitutes the DOE quarterly performance progress review of budget targets. Joule targets for FY 2006 through FY 2011 from the FY 2007 budget request to Congress are provided in Table 1-3 in Section 1.7. For each Joule target, the Program develops quarterly milestones for each target and then reports on milestone status quarterly to assess progress toward meeting the targets.
- PART, the common government-wide program administered by OMB to review the management and results of Federal programs. The Biomass Program went through the PART process for the first time in the second half of FY 2005 and is awaiting its score. Any deficiencies identified by the PART report will be addressed by the Program, as necessary, in FY 2006.
- OMB's Research and Development Investment Criteria (R&DIC) are intended to ensure that EERE program dollars are used efficiently and effectively with clear Program "off ramps" or termination points. Annual internal review of performance planning and management of R&D programs against specific criteria is expected.

### 2.5.2 Peer Reviews

The EERE Peer Review Guide defines in-progress peer review as:

*A rigorous, formal, and documented evaluation process using objective criteria and qualified and independent reviewers to make a judgment of the technical/ scientific/business merit, the actual or anticipated results, and the productivity and management effectiveness of programs and/or projects.*

The Biomass Program follows the EERE guidance, and implements the overall process through a combination of annual element peer reviews and biennial total Program peer reviews. The emphasis of the total Program Review is on the portfolio as a whole to determine whether or not it is balanced appropriately, and if the "right projects are being done." In contrast, the emphasis of the element reviews is on the projects in the element and whether or not "the projects are being done right."

#### 2.5.2.1 Program Peer Review

A total Program peer review is conducted biennially to evaluate the R&D element portfolios as well as the processes, organization, management and effectiveness of OBP. The Program Peer Review is led by an independent steering committee who selects independent outside experts to review of both the Program and technical element portfolios. The scope of the review typically covers 80-90 percent of $RD^3$ funding and supporting business analysis and management activities. Earmarks are included in the review and treated on the same basis as other activities. Each technical portion of the Program reviewed is judged against the same criterion identified in Section 2.5.2.1 below. The results of the review provide the Program and stakeholders with feedback on the performance of the Program and its portfolio. The feedback helps to identify opportunities for improvement in program management and gaps or imbalances in funding, which need to be addressed. By addressing these gaps and imbalances, the Program will continue to stay focused on the highest technical priorities. The first Biomass Program peer review in accordance with the EERE peer review guidance is scheduled for November 2004.

#### 2.5.2.2 Program Element Peer Reviews Incorporating Stage Gate Management Criteria

The Program carries out annual in-progress peer review of projects in the portfolio elements. Information and findings from the element peer reviews are incorporated in the overall biennial Program peer review discussed in Section 2.5.2.2 above. The objectives of the element peer review meetings are to:

- Review and evaluate RD&D accomplishments and future plans of OBP projects in an element following the process guidelines of the EERE Peer Review Guide, but also incorporating the project evaluation criteria used in the OBP Stage Gate Management Process (February 2005).
- Define and communicate program strategic and performance goals applicable to the projects in the element.
- Provide an opportunity for stakeholders and participants to learn about the projects in the OBP portfolio and help shape the future efforts so that the highest priority work is identified and addressed.
- Foster interactions among industry, universities and National Laboratories conducting the R&D, thereby facilitating technology transfer.

Technical experts from industry and academia are selected as reviewers based on their experience in various aspects of biomass technologies under review. Each reviewer is required to sign a conflict-of-interest form. In advance of the meeting, background program documents and individual project summaries are provided to the review panel and made available via the internet.

After each presentation, the reviewers provide numeric scores for five aspects of each project on an evaluation form. The five aspects are:

1. Relevance to overall objectives.
2. Approach to performing the R&D.
3. Technical Accomplishments and Progress
4. Success Factors and Showstoppers
5. Proposed Future Research approach and relevance.

The reviewers are also asked to provide qualitative comments on the five research aspects as well as the specific strengths, weaknesses, technology transfer opportunities and recommendations for additions/deletions to project scope.

The Program reviews all the information gathered at the review and develops a response to the findings for each project. All of the information, including Program response, is documented in a published review report that is made available to the public through the Program's web site[31].

### 2.5.3 Program Evaluation Studies

The Biomass Program sponsors several activities and processes, described below, that are aligned with the intent of program evaluation studies as described in the draft EERE Guide for

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[31] Recent element review web sites include: Products: http://www.productstagegate.biomass.govtools.us/ , Sugar (Pretreatment/Hydrolysis): http://www.eere.energy.gov/biomass/progs/biogeneral/obp_gate/pehindex.html , Thermochemical Conversion: http://www.eere.energy.gov/biomass/progs/biogeneral/obp_gate/tcindex.html , Feedstocks: http://feedstockreview.ornl.gov/.

Managing General Program Evaluation Studies. When the guide is officially published, the Program will evaluate its current practices and adjust as necessary to meet the guidance.

According to the draft guide, there are five types of general program evaluations:

- **Needs/Market Assessment Evaluations** which assess market baselines, customer needs, target markets and how best to address these issues. Findings help managers decide who constitutes the program's key markets and clients, and how to best serve the intended customers. When performed at the beginning of a program, this type of evaluation can also establish baselines for comparison of future progress.
- **Process or Implementation Evaluations** which examine the efficiency and effectiveness of program implementation processes.
- **Outcome Evaluations** which estimate the success of outputs in achieving intended outcomes in a specific time frame.
- **Impact Evaluations** which estimate whether the programs caused the outcomes attributed to it. These evaluations take outcome evaluations one step further.
- **Cost-benefit Evaluations** which compare program benefits and costs.

The Biomass Program's recently defined seven primary Biorefinery pathways, described in Section 2.1.2, are linked to the existing market segments of today's bio-industry where possible, and future bio-industry market segments where envisioned. The current definitions of pathway scope and performance targets are based on discussions with industry partners and stakeholders, as well as an assessment of the kinds of progress needed to advance the Program's strategic goals. The Program plans to carry out more detailed pathway assessments with industry representatives to reach consensus on scope and targets within the constraints of what is considered an appropriate government role. This effort should cover the intent of the Needs/Market Assessment Evaluations.

One of the major goals of the new systems integration activity in the Biomass Program is to develop and maintain the integrated technical and programmatic baselines for the biorefinery pathways so that the Program always has up-to-date information available on market needs, technical targets, technical progress, project plans and relative risks to enable and enhance decision making. Information available through implementing systems integration processes should cover the intent of the Process or Implementation Evaluations. The difference between the systems integration approach and carrying out discrete evaluations is that with systems integration the relevant information is available when you need it, not months after commissioning an evaluation.

What largely amounts to Outcome Evaluations and Impact Evaluations have been carried out by the EERE Office of Planning, Budget and Analysis (PBA) which conducts analyses of key market and technology issues. PBA also coordinates the assessment of Government Performance and Results Act (GPRA)[32] benefits and performance measures for EERE programs and analyzes near- and long-term issues. GPRA benefits estimates document some of the economic, environmental, and security benefits (or outcomes) from achieving program goals. PBA evaluates Program benefits annually to better understand the extent to which the funded efforts will lead to technology and market improvements (outputs), which in turn will make energy

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[32] See the GPRA website at http://www.whitehouse.gov/omb/mgmt-gpra/gplaw2m.html

more affordable, cleaner, and more reliable (outcomes). PBA publishes updated annual GPRA benefits estimates for each EERE program, which are submitted as part of the fiscal year Budget Request.[33] The most recent Biomass Program GPRA benefits are described in more detail in Section 2.7.

### 2.5.4 Technical Program Reviews

The Biomass Program uses several forms of technical review to assess progress and promote Program and project improvement. Several key processes are:

- Internal EERE strategic program reviews
- Technical portfolio review by the Biomass R&D Technical Advisory Committee
- Technical project reviews according to the Biomass Program Stage Gate management process.

#### 2.5.4.1 EERE Strategic Program Reviews

EERE senior management holds annual strategic program review meetings with Program managers in preparation for Congressional budget submission.

#### 2.5.4.2 Biomass R&D Technical Advisory Committee Portfolio Review

The Biomass Technical Advisory Committee periodically reviews the USDA and DOE Biomass-related R&D portfolio and provides advice to the Secretary of Energy, the Secretary of Agriculture, and other Federal points of contact concerning the technical focus and direction of the portfolios. The most recent report to Congress by the Committee[34] includes a summary of their FY03 portfolio review.

#### 2.5.4.3 Stage Gate Project Reviews

Stage Gate management of Biomass Program research and development activities was introduced in 1998. The Stage Gate process is an approach for making disciplined decisions about research and development that lead to focused process and/or product development efforts.[35] Specifically, OBP uses it to:

- Guide decisions on which projects to include in the Program's portfolio,
- Align R&D project objectives with Program objectives,
- Provide guidance on project definition including scope, quality, outputs and integration, and
- Review projects to evaluate progress and continuing fit in the Program portfolio.

The current Stage Gate process used by the Program is shown schematically in Figure 2-17. The basic approach is that there is a series of "Gates" to review projects and a series of "Stages" to accomplish the work necessary to move the project forward. There are two paths, or tracks, that a project can take depending on the planned outcomes from the project. The commercial track is for projects where the outcome is a commercial process or product. The research track is for

[33] EERE/PBA GPRA web site includes the report provided with the FY06 budget request.

[34] Annual Report to Congress on the Biomass Research and Development Initiative for 2003 February 2005), http://www.bioproducts-bioenergy.gov/pdfs/Biomass%20Initiative%20Report%20to%20Congress%20FY03.final.doc.

[35] Stage Gate Management in the Biomass Program, (Revision 2, January 2005) is a guide to the process used by the Program.

more fundamental, pre-competitive scientific projects. Typically projects on the commercial track are public-private partnerships which have significant intellectual property associated with them. For these projects, detailed gate reviews are carried out by DOE and the partner(s) without external reviewers to allow confidential discussion of all aspects of the project. These projects are included in the Program peer review process, although in that forum intellectual property is not shared and the project description is generally at a higher level. Projects on the research track have generally had gate reviews that included external reviewers with meetings open to the public.

The Stage Gate Process is used to manage the portfolio of projects in the Biomass Program. Portfolio management is a critical area of Program Management because it integrates a number of key decision areas, all of which are difficult: project selection and prioritization, resource allocation across projects, and implementation of the business strategy. The gates and gate reviews allow us to weed out poor projects and reassign resources allowing more resources for the best projects and/or open the way for new projects to get started.

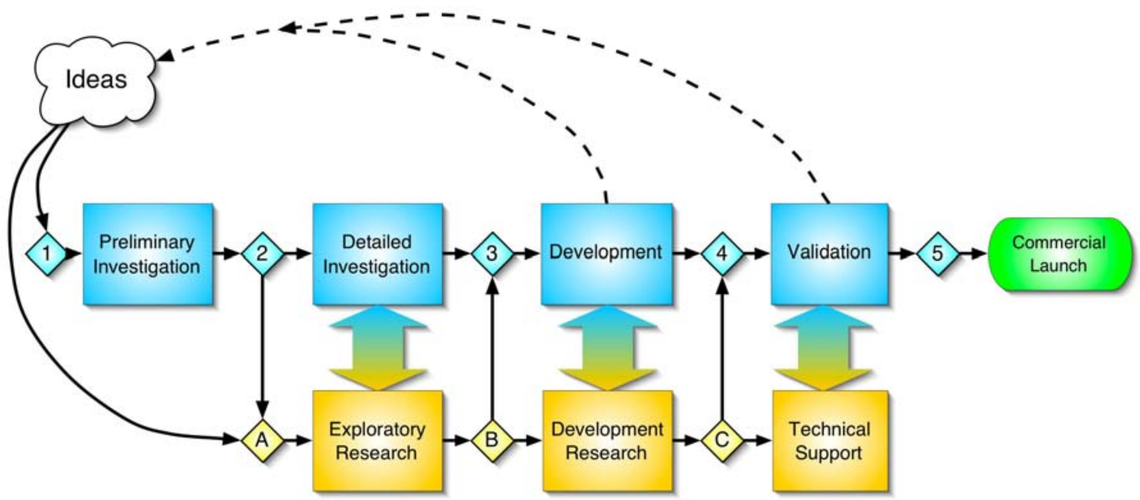



**Figure 2-17:** Stage Gate Management Process

We have adopted a version of the extended stage gate process used by Exxon Research and Engineering[36] which is an integrated "basic - exploratory research - development" stage gate system. The expected effect is to bring science and technology to application sooner, at lower cost, and with improved probability of success. This extended stage gate process has added both clarity and flexibility in the application of this decision making model to OBP.

Each stage gate review covers multiple gates, or decision points, which must be passed through before the work on the next stage can begin. Gate reviews are conducted by a combination of internal management and in the case of pre-commercial fundamental R&D, outside experts, the Gate Keepers. We have developed a set of seven types of criteria against which a project is judged at each gate including:

- Strategic Fit

[36] Cohen, L.Y., P.W. Kamienski, and R.L. Espino, *Gate System Focuses Industrial Basic Research.* Research Technology Management, 1998: p. 34-37.

- Market/Customer
- Technical Feasibility and Risks
- Competitive Advantage
- Legal/Regulatory Compliance
- Critical Success Factors and Show Stoppers
- Plan to Proceed

The second half of the gate review involves the plan to proceed. The project leader must propose a project definition and preliminary plan for the next stage including objectives, major milestones, high level work breakdown structure, schedule, and resource requirements. The plan must be presented in sufficient detail for the reviewers to comment on the accomplishments necessary for the next stage and goals for completion of the next gate. While external gate keepers may be included in the process, the final decisions at gate reviews are exclusively the responsibility of DOE.

## 2.6 Logic Models

Logic models can be used to guide program planning, structure, performance and evaluation. A basic logic model diagrams the sequence of causes (inputs (i.e., resources), activities, and outputs) that produce the effects (outcomes) sought by the program. The process of developing a logic model helps to focus on/identify all of the relationships in the program that contribute to its goals, i.e., the links between resources and achievements, and thus the links between resources and performance. Figure 2-18 shows a simplified logic model for the Biomass Program.

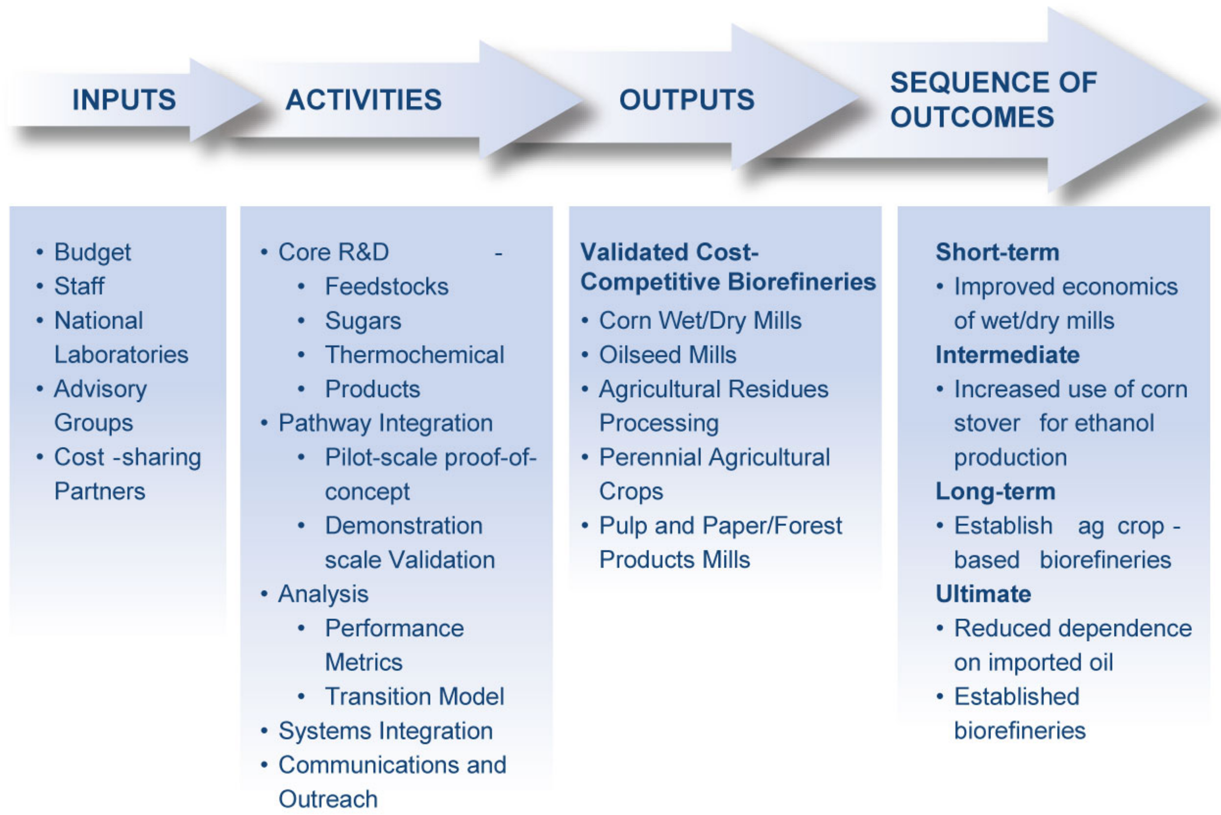



**Figure 2-18.** Simplified Logic Diagram for the Biomass Program

This simplified diagram does not capture the complexities of the relationships of the inputs, activities and outputs of the Biomass Program. Because multiple technologies must be integrated and validated via multiple pathways, the program is using systems engineering processes and procedures to manage this complexity and achieve the program strategic goal of validated cost-competitive integrated biorefineries. The systems engineering approach links the budget, schedule, barriers, performance metrics (B and C milestones), program element tasks, projects, and organizational responsibility, as illustrated in Figure 2-19. The relationships established by the systems engineering model (CORE)[37] will serve to integrate the program tasks/activities, track progress toward achieving performance goals, clarify the impacts of changing budgets on program scope, schedule and outputs, and facilitate the program's decision-making process.

[37] CORE is a model-based systems engineering software suite developed by Vitech Corporation http://www.vitechcorp.com/ . It is used by both the DOE Hydrogen Program and the DOE/EERE Biomass Program.

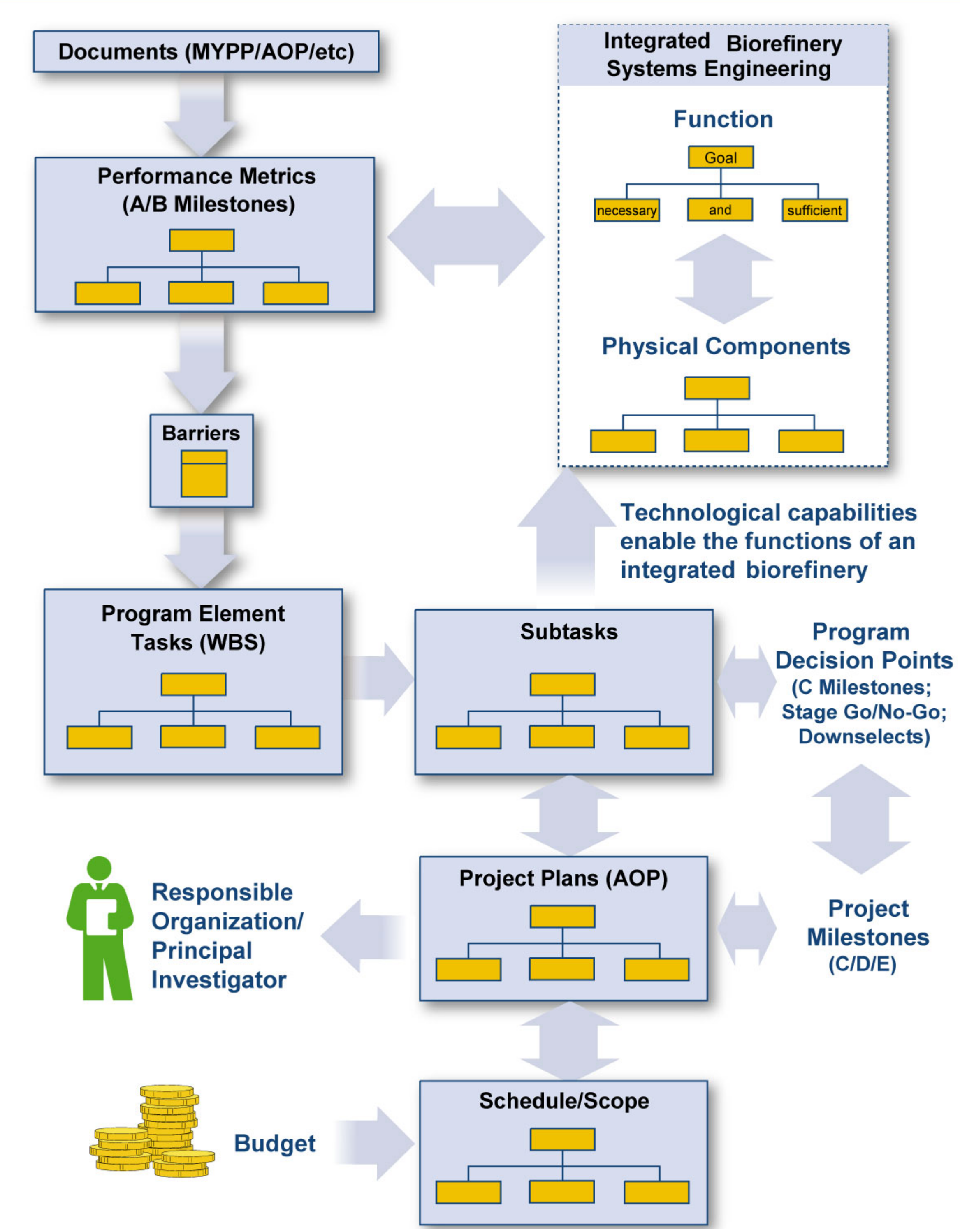



**Figure 2-19:** Systems Engineering Approach for the Biomass Program

## 2.7 Program Benefits

Benefits analysis helps the program quantify and communicate the overarching outcomes from biomass research, development, and deployment—such as imported oil displacement and greenhouse gas mitigation—using integrating models such as NEMS and MARKAL. The scenarios that are developed and the costs and benefits that are quantified are used to develop a broad understanding of the most viable routes for achieving biomass utilization. Results are useful in crosscutting benefits analysis and are one of the key inputs to decision-making across all renewable technologies in the EERE portfolio. Additionally, all the analysis capabilities described in the analysis pyramid will be synthesized into energy market analysis models to develop a broad capability for analyzing the development of possible biomass utilization pathways. This is especially important in the area of environmental analysis, in which renewable technologies are not well characterized.

### 2.7.1 EERE Corporate Benefits Data and Standards

Using the program-provided outputs and assumptions, PBA works with the Benefits Analysis Team to prepare the technical assumptions needed to run the GPRA-NEMS and GPRA-MARKAL models. These models estimate the economic, energy, and environmental outcomes that would occur over the next 20 to 50 years if the program is successful and the future unfolds according to the business-as-usual scenario. PBA then compares the outcomes of model runs that include EERE's programs with the outcomes of runs without EERE's programs. The benefits of EERE programs are determined by the improved economic, energy, and environmental outcomes provided by EERE's activities.

In the coming years, PBA will extend its benefits estimation tools to address a range of uncertainties. PBA is developing alternative scenarios that will be used to illustrate the value of the current EERE portfolio under different futures along with tools and methods to explore how alternative program goals, budgets, and schedules can make EERE's benefits more robust to withstand uncertainties.

### 2.7.2 Current Benefits Projections (FY 2006 Budget)

The program's success will reduce national susceptibility to energy price fluctuations and potentially lower energy bills; reduce several EPA-criteria pollutants and other pollutants; enhance energy security and reliability by increasing the production and diversity of domestic fuel supplies; and strengthen our domestic energy resource infrastructure. In addition to these "EERE business-as-usual" benefits, realizing the program goals would provide the technical potential to reduce conventional energy use even further if warranted by future energy needs. Estimates of annual non-renewable energy savings, energy expenditure savings, carbon emission reductions, oil savings, and natural gas savings that result from the realization of program goals are shown in the table below from 2020 through 2050.

The benefits analysis assumes that funding levels will be consistent with the President's commitment and assumptions in the 2006 Congressional Budget. Congressionally directed projects, by reducing resources available for the program's planned activities, frequently limit the choice of technology development pathways that are important to future technical success. This can lead to a reduction in estimated benefits.

### 2.7.3 Unquantifiable Benefits and Externalities

The analysis is constrained by GPRA rules such as only current policy and laws may be modeled. Therefore the modeling does not assume the monetization of carbon reduction benefits. The analysis conducted to date represents a conservative initial effort at assessing the benefits of the Biomass Program activities and likely underestimate the benefits from integrated biorefinery production options.

### 2.7.4 Program Impact in 2020 Through 2050

The results shown in the benefits tables (see below) are estimates based on initial modeling of some of the possible program technologies such as cellulosic ethanol and bio-based products. The benefits are "net", i.e., projected benefits of EERE RD&D (the "program case") minus the "baseline" which comprises the benefits associated with industry's own efforts, had EERE and the Biomass Program not existed.

**Table 2.13:** GPRA Benefits Estimates (February 2005) for Biomass Program

| Mid-Term Benefits | 2020 | 2025 |
|---|---|---|
| Cellulosic ethanol production (million gallons) | 260 | 1,570 |
| Primary nonrenewable energy savings (Quads) | 0.06 | 0.12 |
| Energy bill savings (Billion 2002$) (mmtce) | ns | ns |
| Carbon emission reductions (mmtce) | 2 | 3 |
| Oil savings (MBPD) | 0.01 | 0.01 |
| Natural gas savings (Quads) | ns | 0.02 |

| Long-Term Benefits | 2030 | 2040 | 2050 |
|---|---|---|---|
| Cellulosic ethanol production (million gallons) | 1,586 | 5,598 | 8,772 |
| Primary nonrenewable energy savings (Quads) | 0.2 | 0.7 | 1.1 |
| Energy system cost savings (Billion 2002$) | 0 | 0 | 1 |
| Carbon emission reductions (MMTCE) | 4 | 12 | 19 |
| Oil savings (MBPD) | 0.09 | 0.29 | 0.40 |
| Natural gas savings (Quads) | 0.02 | 0.06 | 0.16 |

In 2020, cellulosic ethanol use is estimated at 318 million gallons per year, rising to 13.4 billion gallons per year by 2050. This ethanol is made from agricultural residues, forest wastes, and energy crops. These are before subtracting out the baseline (no-EERE case). Aside from cellulosic ethanol, dry corn mills (the dominant type of corn ethanol plants) are assumed to succeed in increasing their output by 10% after deploying technologies for corn fiber and residual starch conversion.

In the FY 2007 budget's analysis, the use of more recent cost targets provided by the program will likely result in higher biorefinery benefits than those reported for the FY 2006 budget.

### 2.7.5 Base Case *Without* Program Activities in 2020 Through 2050 (FY 2006 Budget)

In 2020, cellulosic ethanol use is estimated at 58 million gallons per year, rising to 4.6 billion gallons per year by 2050. Without EERE and the Biomass Program, it is assumed that industry would invest much less in technology development based on their perception of technical risks. No significant addition of bio-based products is assumed for the baseline.

## 2.8 Relationship to Other EERE, DOE and Federal Programs

Coordination with other program offices is essential for the success of the Biomass Program and EERE. The following are specific examples of OBP's coordination efforts:

**Hydrogen, Fuel Cells & Infrastructure Technologies Program**. Biomass is one of the near-term primary energy sources for hydrogen production. The OBP activities in biomass feedstocks interface R&D and elements of the thermochemical, sugar, and products platforms directly support the goals of the HFCIT Program. In the HFCIT Program, a systems analysis approach to hydrogen energy RD&D is used, with exploratory research as the foundation for breakthroughs in technology, while coordinating R&D strategy programs within the EERE and Fossil and Nuclear Energy Offices at DOE.

**FreedomCAR and Vehicle Technologies Program**. Research on the use of non-petroleum fuels, particularly renewable diesel and E-diesel, are coordinated and co-funded with the FCVT.

**Weatherization and Intergovernmental Programs**. OBP coordinates with several Intergovernmental Programs including:

- International Activities: OBP provides technical assistance on international biomass related inquiries and projects.
- Tribal Energy Activities – The Bureau of Indian Affairs of the Department of Interior recognizes biopower as a renewable electricity source that, in small and modular scale, fits in with applications and the culture of many Indian reservations. Although this R&D effort is winding down, OBP will continue to coordinate tribal support activities through the Tribal Program staff.
- Clean Cities: The Clean Cities Program supports public-private partnerships that deploy alternative fuel vehicles and build supporting alternative fuel infrastructure. OBP cooperates with the Clean Cities Program by providing public documents in the Biomass Program's document database to the Alternative Fuels Data Center, which is the primary source of alternative fuels information for Clean Cities stakeholders.
- State Energy: OBP contributes to the State Energy Program (SEP) and the State Technologies Advancement Collaborative (STAC) Program. RD&D awards from these programs for biofuels, biopower, and bioproducts augment the OBP portfolio.

**Industrial Technologies Program (ITP)**. Biomass-based technologies for gasification and the production of biobased fuels, chemical, materials, heat, and electricity are of interest to ITP Chemical and Forest Products Subprograms.

**EERE Communications Office**. OBP's outreach efforts support and are coordinated with the broader corporate efforts managed by the EERE Communications Office.

**EERE Business Administration, Planning, Budget Formulation, and Analysis (PBFA).** OBP analysis activities are determined, in part, by the information needed by PBFA to carry out EERE crosscutting corporate analysis.

**DOE Office of Science.** Fundamental research related to Sugars Development is funded through DOE's Office of Science. Efforts in 2005 have more closely aligned the fundamental research with OBP. A joint solicitation is being planned for FY 06 (assuming funds availability) for cellulosic ethanol utilizing the sugars platform. A joint Office of Science/EERE (OBP) workshop is also being planned for fall of 2005. Genomes to Life programs have supported the sequencing maize and will soon begin sequencing of switchgrass. An increased level of collaboration is expected during the MYPP out-years between the Office of Science and EERE's OBP.

**DOE Office of Fossil Energy (FE).** FE supports R, D&D and commercial demonstrations in clean coal technologies, which are synergistic with OBP technologies. Past collaborations include the co-firing of biomass and coal to reduce emissions and decrease output of fossil carbon dioxide. Current FE efforts explore FutureGen - tomorrow's "pollution-free power plant" which produces hydrogen, electricity, and carbon dioxide. An industrial consortium representing the coal and power industries, over the next 10 years, is expected to complete a plant that will become a test bed for advanced concepts carbon sequestration projects; results are to be shared among all participants, and the industry as a whole.

**USDA**. The Biomass R&D Act of 2000 directs the DOE and USDA to integrate technology R&D programs to foster a domestic bioindustry producing fuels, power, and chemicals. OBP works closely with USDA in a number of ways. The Biomass R&D Board established under the Biomass Act coordinates strategic planning for biomass activities at member agencies including the Department of Energy and Agriculture (co-chairs from respective agencies), Department of Interior, National Science Foundation, Environmental Protecion Agency, Office of the Federal Environmental Executive, and the Office of Science Technology and Policy. The technology base for products and energy within USDA is provided by the USDA Agriculture Research Service (ARS) through programs conducted at the five USDA regional agricultural utilization laboratories and their partners. Similarly, the USDA Forest Service has the Forest Products Laboratory to address use and resource conservation, including forest management. USDA soil conservation laboratories conduct scientific research on soil and water conservation. DOE/OBP-USDA interagency collaborations include the following:

- Solicitations: The Biomass R&D Initiative has been conducted every fiscal year since FY 2003 to ensure projects are meritoriously selected and fit under the Biomass R&D Act of 2000. In alternative years the procurement process has been administered by DOE and USDA.
- Joint Stage Gate Meetings such as the Feedstock Portfolio Review of March 14-16, 2005
- Joint analytical efforts such as the corn-to-ethanol energy balance and the Billion Ton Study which defined the potential biomass resources in the United States.
- Pulp and Paper Industry: USDA Forest Products Laboratory and DOE's National Renewable Energy Laboratory are evaluating the potential of converting hemi-cellulose from pre-digester feed streams to fuels and chemicals and the effects of the resulting substrate on downstream paper quality.

# Section III: Technology Research, Development and/or Deployment Plan

This section presents the technical plan for both R&D and deployment elements of the Biomass Program. Each program element: Feedstocks, Sugars, Thermochemical, Products and Integrated Biorefineries is clearly outlined and detailed as if it were a separate program, with goals, approaches, markets, challenges and barriers.

## 3.1 Feedstock Platform

The success of the biorefinery is critically dependent on having a large, sustainable supply of reasonable-cost, high-quality biomass. The primary mission of the Feedstock Platform is to conduct the necessary R&D to meet the feedstock needs for conversion of biomass to fuels and chemicals. The feedstock resources as defined by the joint DOE and USDA study entitled, "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply," are comprised of three biomass resource categories, including agriculture crop residues, perennial energy crops, and forest residues. These resources could collectively annually supply 1.3 billion tons of biomass in the U.S. Developing this biomass supply will be done in close collaboration with OBP's sugars, thermochemical, and products R&D platforms, as well as with USDA. The feedstock technology development needs and barriers are defined in the DOE document entitled, "Roadmap for Agriculture Biomass Feedstock Supply in the United States." Current technologies and agricultural practices are inadequate to meet this goal. Meeting the long-term needs of any given biorefinery as well as the bioindustry in a sustainable manner will require fundamental changes, not only in the agricultural collection system, but also in the biomass feedstock infrastructure system.

The Feedstock Platform and Feedstock–Sugars Interface R&D (the Feedstock-Sugars Interface R&D task is included as part of the Sugars Platform Element, section 3.2) focus on developing the new technology and methods necessary to produce and supply over one billion tons of biomass feedstock per year in a sustainable manner at $35/dry ton or less. This will require working closely with USDA, growers, feedstock equipment manufacturers, and processors to bring about the necessary changes in the agricultural and forestry systems and to form the integrated partnerships needed to supply fully-operational biorefineries.

### 3.1.1 External Assessment and Element Market Overview

#### 3.1.1.1 Current Potential

The major focus and long-term goal of the Feedstock Platform is to enable the sustainable supply of at least one billion dry tons/year of high quality, cost-effective biomass feedstocks to the biorefinery industry. It is estimated that this will enable the industry to meet 1/3 of our nation's transportation fuel demand while still meeting our food, feed, and fiber needs. Achieving this goal will require technologies that can increase utilization of currently available and underutilized feedstocks, such as agricultural and forest residues, improvements in yields and harvesting technologies for grain production, adoption of no-till cultivation, and changes in land use to allow the development of dedicated perennial agricultural crops (e.g., switchgrass and poplar). The total potential of the biomass resources available in the U.S. is summarized in Table 3.1-1[1].

**Table 3.1-1:** U.S. Biomass Resource Potential[1]

| Biomass Resource | Estimated Potential (million dry tons/year) |
|---|---|
| **Forestlands** | **368** |
| Residues from forest products and pulp and paper mills | 145 |
| Residues from logging and site-clearing operations | 64 |
| Fuel treatment operations to reduce fire hazards | 60 |
| Fuelwood harvested from forests | 52 |
| Urban wood residues | 47 |
| **Agricultural Lands** | **998** |
| Crop residues | 428 |
| Perennial crops | 377 |
| Animal manures, process residues and other miscellaneous feedstocks | 106 |
| Grains for biofuels | 87 |

This full resource potential could be available by mid-21st century when commercial-scale biorefineries are likely to exist. This annual potential is based on a more than seven-fold increase in production from the amount of biomass currently consumed for bioenergy and bio-based products.

The existing feedstock supply infrastructure—harvesting, collecting, storing, preprocessing, and transporting—will need to be expanded significantly (>3.5 times today's corn industry) to accommodate this large increase in biomass production.

### 3.1.1.2 Political Environment Nuances

DOE, in partnership with USDA, has been committed to expanding the role of biomass as an energy source for many years. Specifically, these organizations support biomass fuels and products as a way to reduce the nation's dependence on foreign oil, to offer new opportunities for economic growth in rural communities, and to foster the establishment of new domestic biorefineries throughout the U.S. The Biomass R&D Technical Advisory Committee, established by Congress in 2000 to guide federally-funded biomass R&D, has established a goal that biomass will replace 30 % of the country's petroleum consumption by 2030. More recently, the Energy Policy Act of 2005 highlights the need to move away from a petroleum-based transportation sector and toward increased use of renewable fuels such as ethanol and biodiesel, especially in the medium time range. This bill includes tax incentives and requirements for the increased production and use of renewable transportation fuels to promote these goals. In

[1] Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, DOE/GO-102005-2135, DOE/USDA, April 2005 (http://feedstockreview.ornl.gov)

addition, the large increases in the cost of petroleum observed during the first half of 2005 are bringing a new urgency to these efforts.

#### 3.1.1.3 Competing Technologies

Initially the Feedstock Platform is focusing on the underutilized, low-cost residues and by-products of the existing agricultural and forest industries; currently, there is little competition for these feedstock materials. In the longer term, dedicated energy crops offer the greatest potential for providing increased biomass feedstock for the biorefineries of the future (see Table 3.1-1 above). The amount and quantity of the agricultural-based feedstock biomass economically available for a biorefinery depends on annual growing conditions, the amount that needs to be left in the field for sustainability, the efficiency of harvest, the transportation infrastructure, and post-harvest losses associated with storing and handling. In addition, farmers, as practical businessmen and women, make decisions about what crops to grow on their land based on economics (i.e., What crops and agricultural practices will maximize my profit?) so the dedicated energy crops of the future must be sustainable and profitable to compete with other agricultural land use options. Most of the forest residues produced from the forest products and pulp and paper industry are already recovered or combusted for on-site steam and power production. New uses for the residues generated by these facilities will need to fit with the industry's continuing goals of improved energy efficiency and plant profitability.

### 3.1.2 Internal Assessment and Program History

#### 3.1.2.1 Element History

For over a decade, ORNL conducted feedstock R&D on topics including resource assessment and modeling, and feedstock development. In collaboration with university and USDA researchers, they worked on developing suitable plant strains for energy crops including poplars and switchgrass among others. During the reorganization of the DOE biomass programs in 2002, it was decided that plant/crop development was the proper purview of USDA, and since that time, ORNL has focused on resource assessment and feed system logistics modeling.

Today, biomass feedstock availability is being fostered by the activities of two DOE national laboratories: Oak Ridge National Laboratory (ORNL) and Idaho National Laboratory (INL). These laboratories work in close collaboration with researchers at many USDA research laboratories and with private industry.

Scientists at ORNL, in collaboration with their research partners in private and public institutions, have been engaged in developing and applying analysis tools in support of biomass feedstock development and supply systems for the past 15 years. Their research targets two highly integrated objectives: 1) providing robust forecasts and analyses of feedstock supply and 2) designing and implementing risk analysis tools for the development of supply logistics for biorefinery enterprises. The feedstock forecasts and analyses are designed to facilitate biorefinery development strategies, to support life cycle analyses of bioenergy and bioproducts, to support policy studies and policy development, and to respond to DOE's need to provide reliable estimates of energy feedstocks.

Researchers at INL, in partnership with equipment manufacturers, growers and academia, have made considerable progress in the feedstock infrastructure area over the past few years. These efforts focus on developing improved bulk processing, handling, storage and transport technologies and methods to sustainably and cost-effectively supply biomass feedstocks to the biorefinery.

### 3.1.2.2 Element Organization and FY06 Activities

The Feedstock Platform is organized around three key tasks, as shown in the work breakdown structure (WBS) in Figure 3.1-1. The core R&D and analysis tasks of the Feedstock Platform focus on fundamental harvest and collection, storage, preprocessing, and transportation issues that apply to the corn wet and dry mill, and agricultural residue-based pathways. As technology develops, the R&D and analysis will focus on advanced assembly systems and additional feedstock types that will apply to other pathways such as perennial and oil crop processing, pulp and paper mill improvements, and forest product improvements. The current efforts are focused on feedstock quality and consistency issues in harvesting and collection, preprocessing, and storage with the goal of having technology ready for planned proposal to the FY08 Biorefinery solicitation.

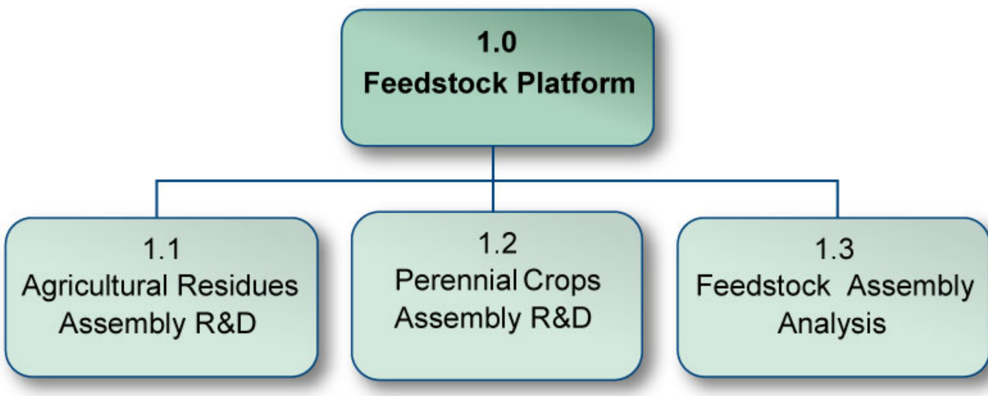



**Figure 3.1-1:** Feedstock Platform Work Breakdown Structure (WBS).

### 3.1.2.3 Element Recent Accomplishments

ORNL personnel have developed computer models and the underlying data and assumptions to provide forecasts and credible analyses of feedstock supply issues; ORNL has developed a set of integrated modeling tools (ORIBAS, POLYSYS, and BIOCOST) and databases (ORRECL) for estimating current sustainable feedstock supplies and for forecasting supplies from new resources such as energy crops. These modeling tools account for economic, geographic, and environmental constraints in assessing the availability of biomass wastes, agricultural residues, and potential energy crops. Biomass resource estimates are sensitive to environmental and soil conservation issues, the scale of the processing facility, and the economics of farming. The models can be applied to provide estimates of the impacts of different development and policy scenarios on the cost and availability of biorefinery feedstocks.

Recently, ORNL, in concert with NREL and Kansas State University, developed a soils and crop management based approach for estimating sustainable removal of crop residues and used that approach to estimate current and future potential agricultural residue supplies from all important corn and wheat soils in the United States.

ORNL research also focuses on the development and application of a logistics model for supplying feedstock from an agricultural setting to specific biorefineries. The model takes into account constraints on the supply chain from local climatic conditions, farm size and yields, transportation and storage networks, supply and demand schedules, and feedstock quality specifications. This supply-chain model projects costs and energy and utilization rates of current or future agricultural residue collection systems.

INL, in partnership with equipment manufacturers, has made considerable progress in the feedstock infrastructure area over the past few years. Specifically, projects of the ongoing, highly successful, DOE - OBP-sponsored Selective Harvest and Multi-Component Program have made, considerable progress on determining what components of agricultural residue biomass should be left in the field to address soil health and sustainability concerns and what parts can be harvested as biorefinery feedstocks. Also, these projects have developed numerical and computational models for mechanical fractionation and air-stream biomass separation and integrated them into a format that can be analyzed in virtual reality. This allowed development of models for virtual engineering analysis of various biomass selective harvest techniques and of harvest methods that can be employed in a single-pass mode without negatively impacting the grain harvest. This innovative approach will significantly reduce the time and resources compared to conventional engineering prototype approaches.

Initially, processors thought that feedstock needs could be largely met with existing harvest and collection technology and methods. However, more detailed analysis has shown this is not the case and that new technology and methods are needed to meet the feedstock needs of the biorefinery. This puts the biorefinery concept in a precarious chicken-or-egg scenario that could significantly delay or threaten the eventual success of the biorefinery. The virtual engineering prototyping approach towards development and implementation of single-pass sustainable biomass harvester technology is necessary for meeting the biorefinery feedstock availability and price targets.

In partnership with growers and academia, INL has also evaluated bulk processing, handling, and transport technologies and methods as a more desirable, lower cost alternative to conventional baling for biorefinery feedstocks. Several concepts have been developed and conceptually evaluated that show promise for meeting the feedstock availability and price targets. Additionally, INL has evaluated several long-term storage technologies for wet and dry storage options that are low cost with minimal degradation and losses. These storage concepts need to be developed to support the long-term storage demands of the biorefinery.

The status and recent major accomplishments of the Feedstock Platform core R&D are summarized below.

**Feedstock Core R&D**

- A DOE study (*Roadmap for Agricultural Biomass Feedstock Supply in the United States*) has identified the strategic goals, performance targets, and major technical barriers associated with production, harvesting and collection, storage, preprocessing, transportation, and systems integration for feedstock core R&D.

- Successful proof-of-concept demonstration of a single-pass harvesting system.
- Preferential deconstruction of biomass tissue is demonstrated, showing the potential for targeted fractionation of biomass for increased equipment efficiencies and throughputs.
- Baseline feedstock assembly scenarios have been evaluated that could achieve the $35/ton cost target for dry biomass (less than 15% moisture) systems.

**Feedstock Assembly Analysis**

- A joint DOE and USDA study (*Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*) has identified the potential for 1.3 billion tons of biomass that could be sustainably processed annually in the U.S.
- Baseline feedstock assembly scenarios have been analyzed with the Integrated Biomass Supply Analysis and Logistics (IBSAL) model showing the potential to achieve the $35/ton cost target for dry biomass (less than 15% moisture) systems.
- Sophisticated engineering simulation tools have demonstrated unprecedented integration of advanced computational models and experimental data sets creating a unique tool for analyzing and optimizing complex engineering systems.

## 3.1.3 Federal Role

### 3.1.3.1 Element Contribution to National Need

The Feedstock Platform funds R&D to develop technology that will economically harvest and collect, store, preprocess, and transport biomass (in various forms) for use in sugars, thermochemical, and product conversion systems. The technologies being developed by the Feedstock Platform have a high level of technical and economic risk, are not yet commercially available, and offer significant potential rewards for the whole nation. Support from the Federal government will reduce the technical and commercial risks so that the benefit of reduced foreign oil imports can be realized. The Feedstock Platform utilizes partnerships between national laboratories, universities, U.S. industries, and individual states to guide and perform the R&D that will develop these technologies.

### 3.1.3.2 Interaction with Other Federal Programs

Several of the technologies being developed to harvest and collect, store, preprocess, and transport biomass for application in a biorefinery are unique to the Feedstock Platform. There are programs within USDA authorized to perform similar R&D, but very few directly link the research to applications process elements within a biorefinery. Further, the USDA only minimally funds R&D that is directly linked to the technical barriers defined by the OBP. The Feedstock Platform R&D not only compliments other federal programs, it leads the effort to develop technology for sugars and thermochemical based biomass conversion.

The DOE's Office of Science (OS) has recently agreed to increase focus and funding in support of fundamental research related to Feedstock and Sugars Development. In 2005, a plan to join efforts with OBP has started. In the past, Genomes to Life (GTL) programs have sequenced maize and will soon begin sequencing switchgrass. In the future OS is planning to use GTL technologies in several areas to support the biorefinery pathways barriers. An increased level of collaboration is expected during the MYPP out-years between the OS and EERE's OBP.

## 3.1.4 Approach

### 3.1.4.1 Element Approach and Role within Program

The role of the Feedstock Platform within the Biomass Program is to develop sustainable technologies that are capable of supplying lignocellulosic biomass to biorefineries producing fuels, chemicals, heat and power at a cost of $35/dry ton or less. The Feedstock Platform conducts core R&D, addressing performance targets and key technical barriers; industrial development and demonstration projects, addressing integration and system scale-up; and analysis, addressing research direction and feedstock metrics. National laboratories, industry, and universities perform the core R&D where industry and university partners are selected through solicitations targeting specific technical issues.

The core R&D of the Feedstock Platform focuses on fundamental harvest and collection, storage, preprocessing, and transportation issues. The industrial development and demonstration projects serve to address the critical process interface issues that can be examined only in an integrated feedstock supply – processing plant system with specific technologies. The Feedstock Platform relies on strategic analysis to identify barriers and guide research, and core R&D analysis to determine cost, quality, and consistency parameters of the feedstock. This analysis function defines and evaluates the overall impact of feedstock assembly technologies and the benefits of specific technology sub-elements in reducing the costs of feedstock intermediates.

### 3.1.4.2 Element Contribution to Pathway and Program Outputs

One of the critical components of a successful biorefinery is a secure, reliable and affordable feedstock supply. Technology advancements made in the Feedstocks Platform will ultimately contribute to all seven of the biorefinery pathways either under development or being considered by the Biomass Program. Initially, the core R&D and analysis tasks of the Feedstock Platform will focus on fundamental feedstock logistics and infrastructure issues that apply to the corn wet and dry mill, and agricultural residue-based pathways. As technology develops, the R&D and analysis will focus on advanced assembly systems and additional feedstock types that will apply to other pathways such as perennial and oil crop processing, pulp and paper mill improvements, and forest product improvements. The Feedstock Platform activities will directly benefit the program goal of establishing integrated biorefineries by providing technologies that can be implemented in the business plan of commercial biorefineries for securing a sustainable and cost effective supply of feedstock biomass.

## 3.1.5 Performance Goals

The performance goals of the Feedstock Platform are to ensure a sustainable and profitable feedstock supply to a biorefinery by being able to characterize equipment efficiencies and throughputs, and the cost, quality, and consistency of a range of feedstocks suitable for sugars (high carbohydrate content) and thermochemical (high lignin content) conversion.

Key performance goals:

- The 2010 goal is to reduce the cost of delivered feedstocks to a biorefinery to $45/dry ton from the 2003–2005 estimated cost of $53/dry ton.

The Feedstock Platform goals will directly contribute to the program goal of synthesizing fuels and chemicals from biomass. By developing and implementing improved feedstock logistics and infrastructure technologies, the Feedstock Platform directly helps the program complete its planned pathways and thus, its goal to reduce dependency on foreign oil.

Each focus area associated with the feedstock supply chain –harvest and collection, storage, preprocessing, and transportation– has an associated milestone guiding the reduction in cost for that area. The Feedstock Platform performance goals are summarized in Table 3.1-2. Figure 3.1-2 shows the incremental cost reductions that occur with the introduction of each area showing the minimum final market target of $35/dry ton (from technology advancements alone) being achieved.

**Table 3.1-2:** Feedstock Platform Performance Goals

| | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| Delivered Cost of Feedstock ($/dry ton) | 53 | 45 | 35 | < 35.00 |

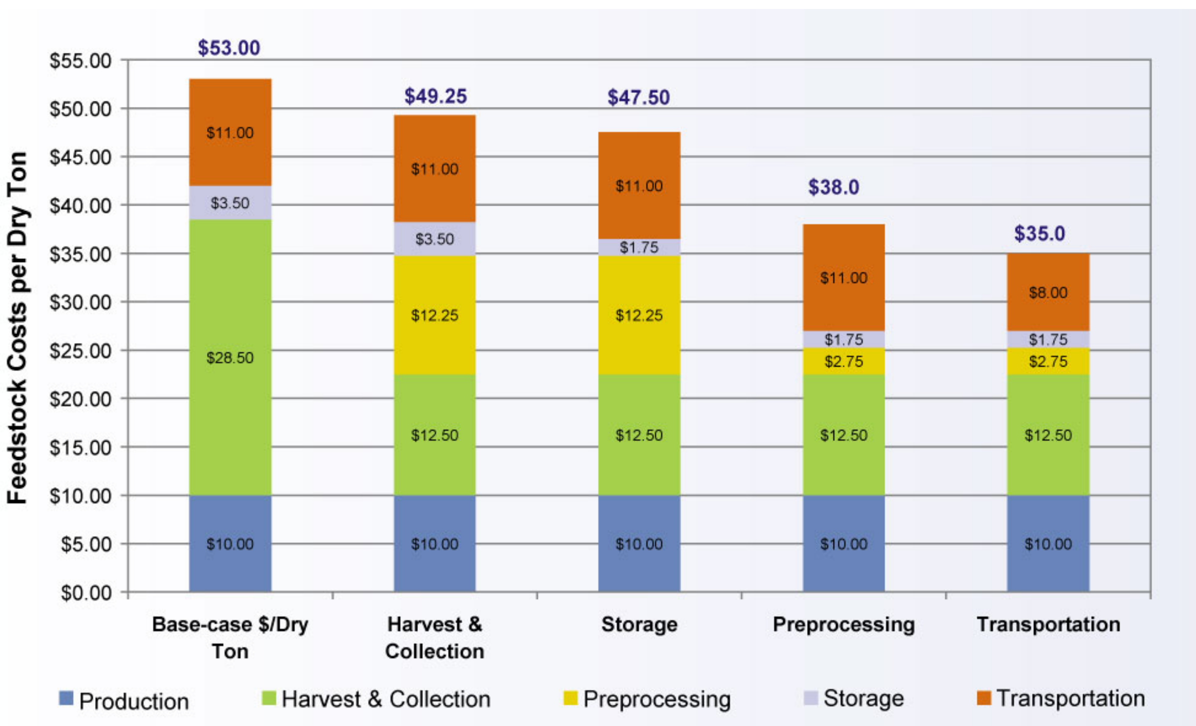



**Figure 3.1-2:** Cost Reductions in each Feedstock Platform Barrier

### 3.1.6 Strategic Goals

The Feedstock Platform strategic goals, in support of the EERE Strategic Goals, will enable the development of key technologies that are capable of supplying lignocellulosic biomass to biorefineries producing fuels, chemicals, heat and power at a cost of $35/dry ton or less. Four strategic goals have been identifies that will lead to the development of these technologies.

### 3.1.7 Market Challenges and Barriers

**Feedstock R&D Market (Non-Technical) Barriers**

**Fm-A. System Profitability.** System profitability is highly sensitive to crop inputs and yields, residue collection rates, and effects on other farming operations. Genetic modification of commodity crops to improve residue characteristics may affect grain values. Biorefinery feedstock price targets combined with costs of current technologies and methods allows a very small margin for growers. The uncertainty and concern for feedstock supply risks is a major barrier to procuring capital funding for start-up biorefineries. The uncertainty and risks surrounding a reliable and cost-stable feedstock supply is a major barrier to procuring capital funding for start-up biorefineries.

**Fm-B. Agricultural Sector-wide Paradigm Shift.** *Perennial* (or "energy") crops cannot simply be added to the list of crops that are grown and collected by U.S. farmers. Energy production from biomass calls for a complete rethinking of farming, and it may involve dramatic changes in the U.S. agriculture system that will take time to evolve.

**Fm-C. Market and Policy.** A number of market and policy barriers exist at the local, State, and Federal level. As a simple example, regulations concerning weight and dimension of biomass loads constrain transportation and delivery options. At a higher level, the lack of sufficient political awareness of the biorefinery concept hinders development and implementation of the needed incentives programs. As both a cause and effect of these and other barriers, the use of biomass for production of fuels and chemicals from cellulosics has not been demonstrated to be cost effective at a significant scale. As a consequence, a proven market for residues and energy crops has not been demonstrated and support at the grass roots from the agricultural community for the biorefinery concept is limited. This is a classic, if multi-dimensional, chicken-and-egg dilemma – economical biorefineries require cost-effective feedstocks which require economically proven biorefineries which initially require regulatory and policy assistance the support for which grows out of economical demonstrations of the biorefinery concept.

### 3.1.8 Technical (Non-Market) Challenges/Barriers

The Biomass Program, through feedstock core R&D, must address the barrier of a lack of a sustainable supply of biomass. This is not to say that a biomass supply does not exist, but that the accessible amount, cost, and impacts of using current or new supplies of biomass cannot be stated with certainty. The U.S. Department of Energy and U.S. Department of Agriculture recently completed a study entitled, "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion Ton Supply." This study provides a conservative assessment that demonstrates sufficient U.S. resources to potentially produce 1.3 billion tons of biomass for biorefinery conversion to fuels and chemicals. However, independent and incremental improvements in conventional feedstock assembly systems may not provide sufficient economic incentive for the critical investments needed to access agricultural residues and energy crops at a large scale. Furthermore, simply improving feedstock assembly systems to reduce the economic and environmental costs of feedstock supplies will not achieve the necessary feedstock quality improvements to address all biorefining process variables in an integrated biorefinery. Using a "biorefinery pathway" development approach, feedstock assembly R&D can be expressly directed at solving biorefining and end product challenges.

## Feedstock R&D Technical Barriers

### Production

**Ft-A. Resource Availability and Cost.** The lack of credible data on price, location, quality and quantity of biomass creates uncertainty for investors and developers of emerging biorefinery technologies. There are no periodic national surveys of lignocellulosic biomass production, and current estimates of feedstock resources are limited in scope and do not consider how major technological advances in production technologies will impact biomass availability. Feedstock supply is a significant cost component of bio-based fuels, products, or power.

**Ft-B. Sustainable Production.** Existing data on the environmental effects of feedstock production and residue collection are not adequate to support life-cycle analysis of biorefinery systems. The lack of information and decision support tools to predict effects of residue removal as a function of soil type, and the lack of a selective harvest technology that can evenly remove only desired portions of the residue make it difficult to assure that residue biomass will be collected in a sustainable manner. Until the residue issue is addressed, particularly with regard to corn stover, deployment of the Agricultural Residue Pathway will be severely constrained. The production and use of perennial energy crops also raise a number of sustainability questions (such as water and fertilizer inputs, establishment and harvesting impacts on soil, etc.) that have not been comprehensively addressed.

**Ft-C. Genetically-Modified Crops.** There is inadequate information on plant biochemistry as well as inadequate genomic and metabolic data on many potential biomass crops. Genetic modification of ~~dedicated~~ energy crops for improved characteristics may create risks to native populations of related species. Genetic modification of commodity crops to improve residue characteristics may affect grain values.

### Harvesting, Collection, and Transportation

**Ft-D. Sustainable Harvest.** Current crop harvesting machinery is unable to selectively harvest desired components of biomass and address the soil carbon and erosion sustainability constraints. Site-specific quantifiable data are needed on the value of the residue left in the field for sustainability (i.e., impact to farming operations, yields, crop rotations) versus value to the grower as a biorefinery feedstock. There is a lack of data on how residue removal could potentially negatively or positively impact no-till operations in certain areas.

**Ft-E. Engineering Systems.** Biomass variability places high demands and functional requirements on biomass harvesting equipment. Current systems cannot meet the capacity, efficiency, or delivered price requirements of large cellulosic biorefineries, nor can they effectively deal with the variability that is inherent in biomass feedstock supplies. In addition, feedstock specifications and standards against which to engineer harvest equipment, technologies, and methods do not currently exist.

**Ft-F. Bulk Handling Equipment Limitations.** Current bale-based methodologies for harvesting, collecting, storage, and transport of the biomass are too costly and inefficient for handling million ton quantities of biomass required by large cellulosic biorefineries.

**Storage**

**Ft-G. Feedstock Quality and Monitoring.** Physical, chemical, microbiological, and post-harvest physiological variations in feedstocks arising from differences in variety, geographical location, and harvest time are not well understood. Passive, noninvasive analytical tools and sensors for real-time compositional measurements for cellulosic feedstocks are needed. In addition, processor standards and specifications for feedstocks are not currently available.

**Ft-H. Dry Storage Systems.** Requirements for large-scale dry bulk storage have not yet been defined. Engineering analyses of unconventional dry storage methods, including centralized versus distributed systems are needed to define storage requirements, yield losses, and infrastructure for packaged and bulk year-round dry storage systems as a function of feedstock source, climate, and harvest time relative to the grain harvest.

**Ft-I. Wet Storage Systems.** High moisture biomass is susceptible to spoilage, rotting, spontaneous combustion, and odor problems that will result in significant to complete loss of ~~the~~ biomass ~~if~~ this is not stored and handled properly. Information on the physical and chemical requirements of biomass and storage water requirements are needed for the engineering design of wet storage systems tailored to different feedstocks, climates, and biorefinery processes. Analyses of wet storage methods, year-round storage and supply of wet biomass, and centralized versus distributed wet storage systems are needed to define storage requirements and yield losses, as a function of feedstock source, climate, and harvest time relative to the grain harvest.

**Preprocessing**

**Ft-J. Biomass Material Properties.** Data on biomass quality and physical property characteristics for optimum conversion are limited. Information on functional moisture relations on quality and physical properties for biomass as affected by crop variability and climatic conditions during harvest and post-harvest operations is incomplete. Methods and instruments for measuring physical and biomechanical properties of biomass are lacking.

**Ft-K. Biomass Physical State Alteration (i.e., grinding, densification, and blending).** High levels of impurities in harvested biomass may foul downstream preprocessing and processing systems. Harvest season for most crop-based cellulosic biomass is short, especially in northern climates, thus requiring preprocessing systems that facilitate stable biomass storage as well as year-round feedstock delivery to the biorefinery.

**Ft-L. Biomass Bulk Material Handling and Transportation.** The capital and operating costs for the existing package-based (i.e., bales, stacks, and pellets) equipment and facilities are high. The low density and fibrous nature of cellulosic biomass make it difficult to collect, handle and transport.

**Integration**

**Ft-M. Overall Integration.** Existing biomass collection, handling, and transport systems are not designed for the large-scale needs of the integrated biorefinery. Feedstock infrastructure has not been defined for various locations, climates, feedstocks, storage methods, etc. The lack of experience with integrating time-sensitive collection, storage, transportation and delivery operations to assure year-round supply of large amounts of biorefinery feedstock is a barrier to widespread implementation of biorefinery technology. The lack of data on variability of biomass resources and how this variability affects shelf life and processing yields are further barriers. In addition, it may be possible to better integrate one or more aspect of the feedstock supply system either alone or in combination with biorefinery operations. The lack of a quantitative analysis that assesses the benefits and drawbacks of these potential integration options is a potential barrier to cost savings and biorefinery efficiency improvement.

## 3.1.9 Strategies for Overcoming Barriers/Challenges

**Feedstock Market Barriers**

**Fm-A. System Profitability.** Through the Office of Science/EERE (OBP) and DOE/USDA collaboration, an increased level of fundamental research in the areas of genetic modifications, crop inputs and yields, and grower payments is expected. This work, along with analyses targeted at providing credible, industry-accessible data on current and future feedstock supplies will alleviate the uncertainty and concerns surrounding the feedstock supply as major barrier to procuring capital funding for start-up biorefineries. For example, the joint DOE and USDA study, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, has identified the potential for 1.3 billion tons of biomass that could be sustainably processed annually in the U.S., thus addressing the risk of an adequate feedstock supply.

**Fm-B. Agricultural Sector-wide Paradigm Shift.** Research is being performed between national laboratories, USDA, and industry partners that address the barriers associated with cropping practices such as no-till options and *perennial* crop introduction in order to identify the respective cost and implementation risks. This research will help identify the methods and technologies that can incrementally move the farming sector toward utilizing biomass residues and perennial crops for fuels, chemicals, and bio-products.

**Fm-C. Market and Policy.** A number of projects and analyses are directly or indirectly addressing a number of market and policy issues relating to biomass supply. These include the impacts of financial market conditions and policy measures incorporated into "transition modeling" such as the Role of Biomass in America's Energy Future (RBAEF) study. Projects such as the Chariton Valley switchgrass co-firing project are examining the impacts of policy measures such as green power sales, partial harvesting from USDA CRP-enrolled land and market barriers such as use of co-fired ash in concrete. This and other projects are examining the viability of various business models involving the biomass producers and users. As additional strategic analyses are conducted and demonstration projects implemented additional market and policy issues will come to light and the Program will take steps to evaluate and, where possible address or resolve them.

**Feedstock R&D Technical Barriers**
To overcome the technical barriers and challenges associated with Feedstock R&D, three laboratories and one facility have been created that leverage and integrate key multi-disciplinary capabilities and capital equipment resources to technically integrate and coordinate the various R&D efforts being performed. The efforts of these laboratories and facility focus on assessing the performance of feedstock assembly equipment and of exploiting the diversity of feedstock material as it impacts the cost, quality, and consistency of the biomass, through identifying, characterizing, and modeling the feedstock physical and chemical properties. A description of these laboratories and facility are given below.

**Biomaterials Deconstruction and Composition Laboratory (BDCL) –** Utilizes advanced composite theory, microscopy, and NIR analysis to understand and utilize the chemical and mechanical characteristics of biomass materials to enhance harvesting, preprocessing, and pretreatment systems.

**Computational Engineering and Simulation Laboratory (CESL) –** Couples state-of-the-art compositional modeling and simulation tools to allow real-time integration, analysis, and design of biological systems, harvesting and preprocessing equipment, and industry infrastructure and processing interface.

**Post-Harvest Physiology and Storage Laboratory (PPSL) –** Characterizes the impact of biomaterial genomic diversity and the post-harvest physiology of stored biomass on the biochemical and physical properties of biomass in order to enhance the quality and processablitiy of tailored bioindustry feedstocks.

**Feedstock Assembly and Preprocessing Facility (FAPF) –** Utilizes advances in laboratory fundamental research to design and implement full scale equipment configurations to demonstrate the capabilities of feedstock assembly and preprocessing systems to meet and potentially exceed feedstock cost, efficiency, and quality targets.

**Production**

**Ft-A. Resource Availability and Cost.** OBP will continue to assess the availability and sustainability of various feedstock resources through national laboratory technical communication and collaboration with USDA-funded projects. An example of this type of collaboration is the joint DOE/USDA report "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply." Further technical collaboration can occur as national laboratory researchers build relationships between key USDA research centers and USDA funded projects.

**Ft-B. Sustainable Production.** Through technical collaboration with USDA, universities, and national laboratories, a project has been initiated to address the sustainable agricultural residue removal issue. This project will review and summarize both published and unpublished reports on corn stover removal. The project will also initiate a field study, starting with the 2005 harvest, of the impact of corn stover removal on future years' corn production. It is expected this field study will leverage already funded DOE/USDA corn stover research.

**Ft-C. Genetically-Modified Crops.** The DOE's Office of Science (OS) has recently agreed to increase focus and funding in support of fundamental research related to Feedstock and Sugars Development. In 2005, a plan to join efforts with OBP has started where technologies developed through the OS Genomes to Life (GTL) program will support the biorefinery pathways barriers.

**Harvest, Collection, and Transportation**

**Ft-D. Sustainable Harvest.** Current research on the benefits of new crop harvesting technologies is being developed to selectively harvest desired components of biomass and address the soil carbon and erosion sustainability constraints. This research utilizes the capabilities and resources of the BDCL and CESL to achieve the necessary technical advancements.

**Ft-E. Engineering Systems.** Utilizing the capabilities and resources of the BDCL, CESL, and FAPF, the fundamental operation and technical needs of harvesting and preprocessing systems are being evaluated. In some cases the fundamental research, based on bioconversion requirements and current equipment configurations, is applied to full scale machinery in order to evaluate improvements in cost, capacity, and efficiency.

**Ft-F. Bulk Handling Equipment Limitations.** Integrated time and motion studies are being conducted through the FAPF and CESL that evaluate current bale-based methodologies against bulk handling options for harvesting, collecting, and transporting biomass. These studies investigate more efficient and possibly cost effective bulk handling options to feed the large quantities of biomass to a biorefinery.

**Storage**

**Ft-G. Feedstock Quality and Monitoring.**
Through the use of the PPSL and BDCL, chemical composition, preprocessing economics, and quality estimations are determined for several biomass varieties, growth locations and harvesting practices for integration into specific biorefinery utilization processes. The PPSL and BDCL utilize NIR technology to determine in real-time the compositional factors and quality metrics from a variety of biomass feedstocks that affect key biorefinery processes. In addition, optimal biorefinery biomass utilization standards are being defined by assessing the effects of preprocessing on biorefinery-specific operations, as well as providing appropriate feedstocks to private sector entities that utilize biomass feedstocks.

**Ft-H. Dry Storage Systems.** The requirements for large-scale dry bulk storage are being defined to include engineering analyses of unconventional dry storage methods. Parameters being assessed are centralized versus distributed systems with regional specific estimation of yield losses and infrastructure handling capabilities for packaged and bulk year-round dry storage systems. The characteristics of these storage systems are a function of feedstock source, climate conditions, and harvest time, relative to the grain harvest.

**Ft-I. Wet Storage Systems.** Utilizing the capabilities of the PPSL, requirements for long-term wet storage are being determined based on the physical and chemical parameters impacting biomass storage with respect to different feedstocks, climates, and biorefinery processes. Based on these requirements, the effects of preprocessing and storage on biorefinery-specific operations are being assessed. The PPSL also provides appropriate stored feedstocks to private sector entities that utilize biomass feedstocks in order to leverage emerging technologies and coordinate USDA, university, and non-proprietary industry research. Such activities will assist the development of well defined optimal feedstock formats for long-term storage systems.

### Preprocessing

**Ft-J. Biomass Material Properties.** Fundamental biomass quality and physical property characteristics for optimum conversion are identified and quantified with in the BDCL. The BDCL utilizes fundamental composite theory and traditional mechanical testing methods to develop new instrumental and techniques for measuring and characterizing biomass material properties. The laboratory also relates the biomass physical properties with the chemical and structural characteristics to identify results with implements these microscopy, imaging systems, and s to determine the fundamental physical properties of biomaterials.

**Ft-K. Biomass Physical State Alteration (i.e., grinding, densification, and blending).** The BDCL and FAPF integrate fundamental biomass fractionation characteristics with empirical data collected from pilot and full scale equipment. The implementation of the fundamental fractionation and densification processes are quantified through modeling and simulation in the CESL.

**Ft-L. Biomass Bulk Material Handling and Transportation.** The FAPF has been created to implement pilot scale and full scale feedstock assembly and preprocessing equipment to determine optimal handling and transportation metrics. The facility incorporates core R&D results produced by INL's BDCL, CESL, and PPSL and NREL's BSCL to optimize the integration and operation of handling and transportation systems and identify and test the primary barriers associated with full scale systems integration.

### Integration

**Ft-M. Overall Integration.** The CESL has been created to develop and apply advanced prediction and simulation tools that enable the complex integration of various unit operations of the feedstock assembly and bioconversion interface processes. The CESL utilizes various computational tools including object oriented modeling, systems engineering analysis, computational fluid dynamic (CFD), finite element stress analysis, empirical correlations, and measured data to identify overall process bottlenecks, inefficiencies, and connectivity. The Integrated Biomass Supply & Analysis (IBSAL) model is one example of a sophisticated systems engineering analysis tool that assesses the integrated performance of feedstock assembly components. This laboratory's core R&D and underlining analysis provides an overall view and integration of key feedstock-bioconversion interface systems and processes.

### 3.1.10 Tasks

The WBS tasks for the Feedstock Platform are shown in Table 3.1-3. The WBS is structured so that analysis guides and evaluates the work performed (task 1.3), and the R&D targets the barriers and performance targets defined above (tasks 1.1 & 1.2).

The analysis involves modeling the overall assembly system and individual core R&D technoeconomic benefits of the Feedstock Platform and Feedstock–Sugars Interface R&D. Both require that the ongoing R&D activities provide reliable data on the performance and the economics of individual unit operations within the feedstock assembly system. The overall integration and technoeconomic analysis activities are closely coupled to insure that the work will have an impact of the costs targets of the Feedstock Platform.

**Table 3.1-3:** Feedstock Platform R&D Tasks

| Task | Title | Duration (years) | Barriers Addressed | Pathways Supported |
|---|---|---|---|---|
| **1.1** | Agricultural Residues Assembly R&D | 5 | 1A, 1B, 1C, 1D, 1E, 1F, 1H, 1I, 1J, 1K, 1L | Corn Wet Mill<br>Ag Residues<br>Perennial Crops<br>Pulp/Paper Mill |
| **1.2** | Perennial Crops Assembly R&D | 5 | (Kevin Craig) | Corn Wet Mill<br>Ag Residues<br>Perennial Crops<br>Pulp/Paper Mill |
| **1.3** | Feedstock Assembly Analysis | 5 | 1A, 1B, 1E, 1G, 1J, 1K, 1M | Corn Wet Mill<br>Ag Residues<br>Perennial Crops<br>Pulp/Paper Mill |

**Task 1.1 Agricultural Residues Processing R&D**
Feedstock assembly systems are key operations in the integrated biorefinery, and can potentially improve equipment costs, efficiencies, and biomass characteristics that lead to enhanced biochemical and thermo-chemical conversion performances. Critical feedstock attributes that must be addressed and controlled for biorefining processes include both equipment specifications, such as cost, throughput, and efficiencies; and biomass specifications, such as composition, cost, format, and consistency. These attributes are generally defined by sugars and thermochemical processing performance parameters (i.e., process efficiency and end product yield) which flow from biorefinery to feedstock supplier. Thus, the Feedstock Platform R&D connects feedstock assembly system improvements with biorefining processes through distributed unit operations or integrated preprocessing pretreatment operations (depot concept) as

outlined in Figure 3.1-3. A tight coordination of the flow of quality assurance and quality control (QA/QC) information from biorefining processes and flow of qualified biomass into pretreatment processes is essential to the success of the entire operation.

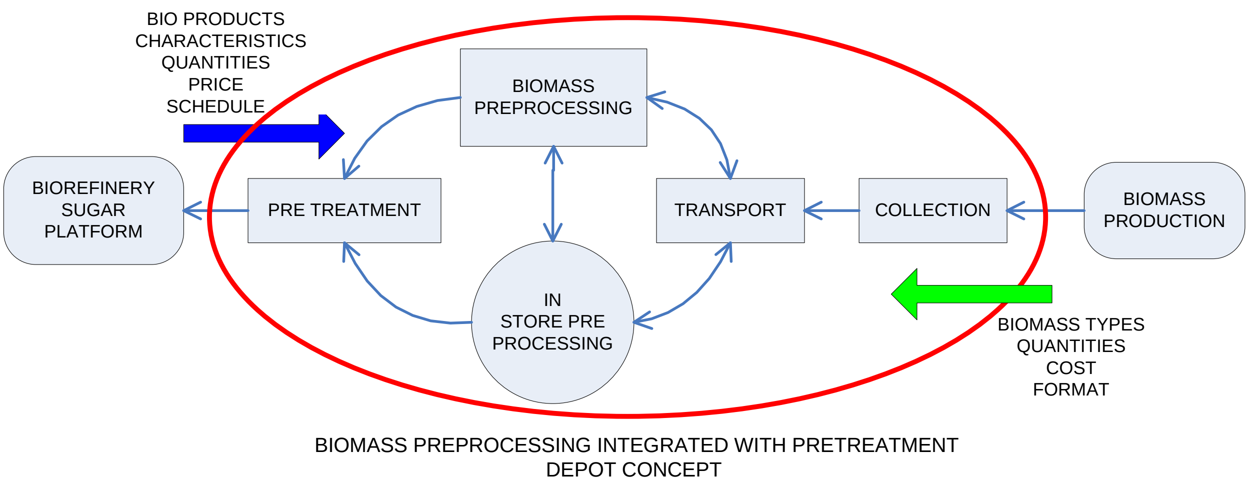



**Figure 3.1-3:** Distributed and Integrated Feedstock Assembly Flow and Preprocessing Systems

The feedstock assembly core R&D task specifically focus on migrating the feedstock assembly system from the traditional technologies used, which primarily served the smaller distributed livestock and forage industry, to an assembly system specifically designed for the biorefinery industry. This new design considers alternatives to delivery of bales to the biorefinery and includes bulk handling of biomass, preprocessing as an integrated component of feedstock assembly, and biomass fractionation. The new feedstock system design effectively makes the feedstock assembly an extension of the biorefinery, since the feedstock can now be formatted and fractionated to optimize conversion efficiencies as part of the assembly process. Equipment improvements and biomass modification for improved value to the biorefinery can take place at any step through the supply chain (Figure 3.1-2). For example biomass characteristics can be can be enhanced during collection by selective harvest methods, fractionated during preprocessing, and/or biomass can be partially degraded (i.e., early stage pretreatment) during storage. These preprocessing operations not only add value to the biomass for pretreatment, but also could be an effective way to deal with low bulk densities and/or high moisture biomass characteristics that reduce feedstock assembly efficiencies.

A key improvement to traditional feedstock assembly systems is the development of a more centralized biomass preprocessing concept (often referred to as the depot or grain elevator concept), where critical unit operations for transforming biomass to a readily usable feedstock can be implemented on a very large scale and from multiple feedstocks simultaneously. Depending upon the biomass type(s) received at the depot(s), it may be cleaned, sorted, ground, dried, or densified before transfer to the biorefinery pretreatment reactors. A significant benefit of the depot concept is that a biorefinery does not have to store large quantities of feedstock on-site, since the storage and preprocessing operations takes place at the satellite depots/elevators.

**Objectives:**

The DOE feedstock platform R&D investment establishes the value of, and requirements for feedstock assembly and preprocessing systems to biorefining processes. The products of this task, which define feedstock equipment specifications and biomass formatting characteristics for each relevant biorefining pathway, include:

- Determining feedstock equipment cost, efficiency, and throughput specifications
- Identifying feedstock equipment capabilities to fractionate, separate, and densify biomass to meet ideal storage and pretreatment conditions, and
- Developing centralized preprocessing concepts (depot) that synergistically integrate feedstock assembly technologies to optimize cost, efficiency, throughput, and biomass quality compatible with biorefining pathway technologies.

These feedstock core R&D objectives enable the overall goal of developing sustainable technologies and systems capable of accessing, processing, and supplying over one billion tons of lignocellulosic biomass for the production of fuels, chemicals, heat, and power each year. Specific research objectives include:

1. Define and document feedstock harvest and collection, storage, preprocessing, and transportation requirements based on the best available technologies,
2. Assess the multiplicity of feedstock resources and assembly combinations for coupling to near-term biorefinery pathway technology designs,
3. Select the best near-term and long-term feedstock assembly and preprocessing options based on feedstock types and platform technology trade-off decisions, and
4. Develop feedstock supply assembly models and analysis tools necessary to optimize feedstock supply chains to biorefineries and reduce supply risks.

**Task 1.2 Perennial Crops Processing R&D**

In order to achieve the ultimate goal of producing one third of our nation's transportation fuels from biomass as well as expanding the diversity and quantity of biomass-based products and chemicals, perennial energy crops will be an essential part of the feedstock mix. As has been noted; however, the inputs, management and logistics of energy crops are sufficiently different from existing food/feed/fiber crops that simply adding energy crops to the potential list of crops that farmers might grow is unlikely to be effective for developing a robust energy crop supply system. While the DOE R&D for harvesting, storage and logistics of crop residues will have application to some perennial crops there are other technical and non-technical issues to be resolved. These include such issues as required inputs (fertilizer, water, etc.) and harvest timing as well as interaction with existing incentive programs (USDA's Conservation Reserve Program, etc.) and issues of sustainability (soil carbon, erosion, soil nutrient content, etc.)

Land that may be attractive for perennial energy crops may be that which is of less value for traditional crops. This may include land that is currently enrolled in the USDA's Conservation Reserve Program (CRP) and planted with a cover crop such as switchgrass or that is otherwise not currently in production. Since the land is not as productive, some combination of tailored crop species and fertilizer inputs may be required to achieve economically-viable yields. Development or modification of crop species is the purview of USDA and, as an example; they have an active and productive R&D effort on switchgrass.

The timing of harvest is also an issue. Harvesting of crop residues is tied to the harvest time for the primary product (e.g. corn) whereas perennial energy crops can be harvest based on when the optimal feedstock properties (e.g. low moisture and alkali content) are present. This requires research on the behavior and condition of the crops across the seasons as well as practical issues of when equipment can get onto the fields (i.e. condition of the ground – frozen, muddy, etc.) Wildlife issues also come into play since many perennial crops are attractive to birds and other species.

A number of non-technical issues pertain somewhat uniquely to perennial energy crops. These include the interactions with existing crop and conservation programs (e.g. CRP) as well as issues of sustainability as it relates to soil carbon and soil nutrient content. A number of collaborative efforts between DOE and USDA have taken place in the past on these subjects.

Many of the foregoing issues relate to primarily herbaceous or even perhaps "shrubby" (e.g. willow) energy crops. Should fast-growing tree energy crops (e.g. poplar) ever become part of the biomass feedstock supply chain, it is possible that additional R&D will be required. Forest husbandry is well understood by the pulp-and-paper and wood and wood-products industries; however there may be unique issues that require investigation if trees become and energy-only crop. Some supporting research on poplars is on-going that is funded by USDA and managed by DOE.

Because the time horizon for the use of perennial energy crops is longer than the use of crop and/or forest residues and because many of the issues surrounding energy crops are more appropriately the focus of USDA, the DOE program does not have a large effort in this area. The recently-completed Salix project in New York (willows grown for co-firing in fossil fuel power plants) was the last significant OBP-initiated project that focused on perennial energy crops. However, there are a number of Congressionally-directed project that employ or relate to energy crops. These include the Chariton Valley switchgrass co-firing project (originally awarded competitively but more recently a Congressionally-directed project) that is examining many of the technical and non-technical issues identified above. Otherwise,

**Objectives:**
The objective of the perennial crop processing task is to ensure that these crops will be economically and sustainably available to supplement the biomass residue feedstock stream when needed. Preliminary estimates indicate that available residues should be sufficient to attain the Program strategic goals through at least the year 2010; however, to achieve the ultimate goal of replacing up to 30% of the nation's transportation fuel, perennial energy crops will eventually be needed.

These objectives will be achieved by:

- Leveraging results from the residue harvesting, storage and logistics tasks as they apply to perennial crops,

- Collaborating with USDA and the DOE Office of Science to identify desirable properties for perennial energy crops in order to facilitate crop development efforts by those organizations,
- Facilitating incorporation of energy crops into analyses of the overall feedstock supply system and bioindustry (e.g. in transition modeling)
- Directing where possible and extracting and communicating results from Congressionally directed projects in the area of perennial energy crops to resolve barriers and supply information surrounding crop management, sustainability and economic and business models
- Soliciting, where needed, projects that address gaps in the information outlined in the preceding activities.

**Task 1.3 Feedstock Assembly Analysis**

The feedstock assembly analysis task addresses key operations in the integrated biorefinery by providing credible, industry-accessible data on current and future feedstock supplies. These data are largely in the form of supply schedules (i.e., quantities and costs) and supporting information, such as feedstock characteristics and their geographic distribution, that will enable industrial and government decision makers to identify viable biomass resources. Emphasis is placed on resources that have the greatest current and future potential to supply large quantities of feedstocks – agricultural residues, perennial crops, forest residues, and urban wood wastes.

This task is directly linked to the feedstock core R&D task, which seeks to develop feedstock assembly technologies and appropriate infrastructure necessary to meet near- and long-term quantity and price targets. Data from the feedstock core R&D task are used to inform the analysis tools and produce quality analysis results in order to guide field research and direction. The process diagram, shown in Figure 3.1-4, provides an example of the relationship between feedstock assembly components and the connection to the conversion platforms. The Integrated Biomass Supply Analysis & Logistics (IBSAL) model utilizes process diagram relationships to perform its integrated analysis of various feedstock assembly scenarios.

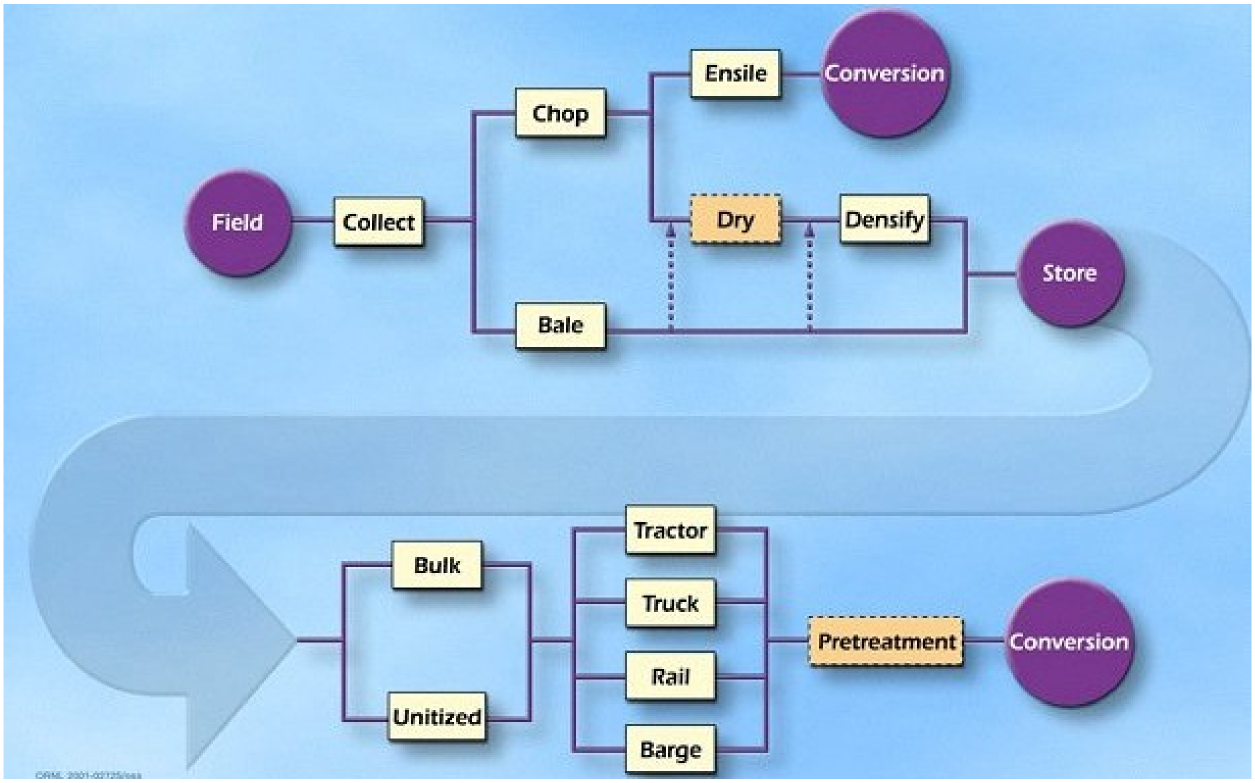


**Figure 3.1-4.** Process Diagram Example

The feedstock assembly analysis task will overcome two fundamental barriers that an emerging biorefinery industry faces in the near- and long-term with regard to biomass feedstock availability:

1. Inadequate information on the spatial distribution of feedstock quantities, physical characteristics, and costs, and
2. Inadequate information on the sensitivity of feedstock supplies to alternative agricultural/energy policies and current/future food and fiber demands.

**Objectives:**
The DOE feedstock assembly analysis investment provides strategic analysis to identify barriers and guide research; and core R&D analysis to determine cost, quality, and consistency parameters of the feedstock. This analysis function defines and evaluates the overall impact of feedstock assembly technologies and the benefits of specific technology sub-elements in reducing the costs of feedstock intermediates.

The products of the feedstock assembly analysis task directly addresses cost reduction potential stated in the Systems Integration C-Level Milestone (see *Feedstock Platform Milestones & Decision Points* section *milestone 8* below) by providing credible, industry-accessible data on current and future feedstock supplies (price, quantity and location) and evaluating equipment and infrastructure options. This milestone enables the demonstration of an integrated feedstock supply system that reduces the overall delivered costs of biomass feedstocks from agricultural and perennial residues from $53 to $35/dry ton.

### 3.1.11 Feedstock Platform Milestones & Decision Points

| | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Corn Wet Mill Improvement Pathway | | | | | |
| Agricultural Residues Assembly R&D | | | | | $\Diamond_{3}\Diamond_{5}$ |
| Perennial Crops Assembly R&D | | | | | |
| Feedstock Assembly Analysis | | | | | $\Diamond_{5}$ |
| Corn Dry Mill Improvement Pathway | | | | | |
| Agricultural Residues Assembly R&D | | | | | $\Diamond_{3}\Diamond_{5}$ |
| Perennial Crops Assembly R&D | | | | | |
| Feedstock Assembly Analysis | | | | | $\Diamond_{5}$ |
| Agricultural Residue Processing Pathway | | | | | |
| Agricultural Residues Assembly R&D | $\Diamond_{2}$ | $\Diamond_{8}$ | | $\Diamond_{5}\Diamond_{6}\Diamond_{7}$ | $\Diamond_{3}\Diamond_{4}$ |
| Perennial Crops Assembly R&D | | | | | |
| Feedstock Assembly Analysis | | $\Diamond_{1}\Diamond_{8}$ | | $\Diamond_{5}\Diamond_{7}$ | |
| Perennial Crop Processing Pathway | | | | | |
| Agricultural Residues Assembly R&D | | | $\Diamond_{2*}\Diamond_{8*}$ | | $\Diamond_{3*}\Diamond_{4*}\Diamond_{5*}\Diamond_{6*}\Diamond_{7*}$ |
| Perennial Crops Assembly R&D | $\Diamond_{9}$ | $\Diamond_{10}$ | | $\Diamond_{11}$ | $\Diamond_{5*}\Diamond_{12}$ |
| Feedstock Assembly Analysis | | | $\Diamond_{8*}$ | $\Diamond_{1*}$ | $\Diamond_{5*}\Diamond_{7*}$ |

* As applicable to perennial energy crops (mainly herbaceous)

| | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Oil Crop Processing Pathway | | | | | |
| Agricultural Residues Assembly R&D | | | | | |
| Perennial Crops Assembly R&D | | | | | |
| Feedstock Assembly Analysis | | | | | |
| Pulp and Paper Mill Improvement Pathway | | | | | |
| Agricultural Residues Assembly R&D | | | | | |
| Perennial Crops Assembly R&D | | | | | |
| Feedstock Assembly Analysis | | | | | |
| Forest Products Mill Improvement Pathway | | | | | |
| Agricultural Residues Assembly R&D | | | | | |
| Perennial Crops Assembly R&D | | | | | |
| Feedstock Assembly Analysis | | | | | |

**Milestones**

1. Validate analysis and optimization tool to support feedstock supply chain integration.
2. Identify sufficient, sustainable agricultural residue supply at $10/dry ton grower payment.
3. Resource data with national coverage for all significant existing agricultural residue resources is up-to-date, documented, and readily available via the internet.
4. Develop technologies and methods to harvest and collect nationally 300 M tons/year of agricultural residues with a 50% cost reduction when compared to current (2003) technologies. ($12.50/dry ton)
5. Develop and demonstrate innovative storage methods so that the impact on cost, accounting for losses, is less than 50% compared to current (2003) dry bale based systems. ($1.75/dry ton)
6. Demonstrate transportation cost reductions resulting in average transportation costs of $8/dry ton or less.
7. Demonstrate preprocessing technologies that produce agricultural residue resources with bulk and flowability properties similar to other large solid commodities so that it can be handled with traditional high-volume conveyance thus reducing cost by 50% when compared to bale-based systems. ($2.75/dry ton)
8. Develop optimized process and cost models for feedstock supply systems and validate analytically that agricultural residue feedstocks could be supplied to biorefineries at $35/dry ton.
9. Complete "baseline" demonstration of conventional (bale-based) switchgrass supply system including economics and sustainability impacts.
10. Define desired characteristics for engineered perennial herbaceous feedstock crops.
11. Verify applicability of residue harvest, collection and storage technology to herbaceous energy crops.
12. Complete analysis and resource assessment demonstrating economic viability of perennial energy crops employing current or advanced harvest, storage and transport methods developed for agricultural residues.

## 3.2 Sugars Platform

This platform is a major program structural element focused largely on fractionating the lignocellulosic matrix of biomass into its component parts. Five of the seven pathways contain a component of pretreatment and fractionation. In the case of corn and wet mill pathways, commercial and economic operations already exist although some improvements are still possible. This platform or program element has the most impact on the pathways involved in Agricultural Residues, Energy Crops and to some extent Pulp and Paper Mill Improvements. It is in these areas that the potential for producing biofuels on very large scales becomes possible. However, until the technology to "crack biomass" as readily and economically as we can "crack crude oil" is available, the vision of the program cannot be fully realized in producing 30% of the nation's transportation fuel needs. This difficulty or recalcitrance of biomass to being fractionated into its component parts is one of the major barriers to the use of biomass for fuels, products, and energy. Hence, this program element evaluates routes to obtaining molecular sugars and lignin to be used as intermediates for conversion into fuels, chemicals, materials or heat/power. Production of such commodity products falls under the Products Core R&D and Integrated Biorefinery elements of the program's work breakdown structure. Figure 3.2-1 illustrates the key role this platform plays in the overall program structure along with the thermochemical platform. As the Venn diagram shows, the intersection of the feedstock, biorefinery operations and product output are dependent upon the cost-effective fractionation of lignocellulosic biomass.

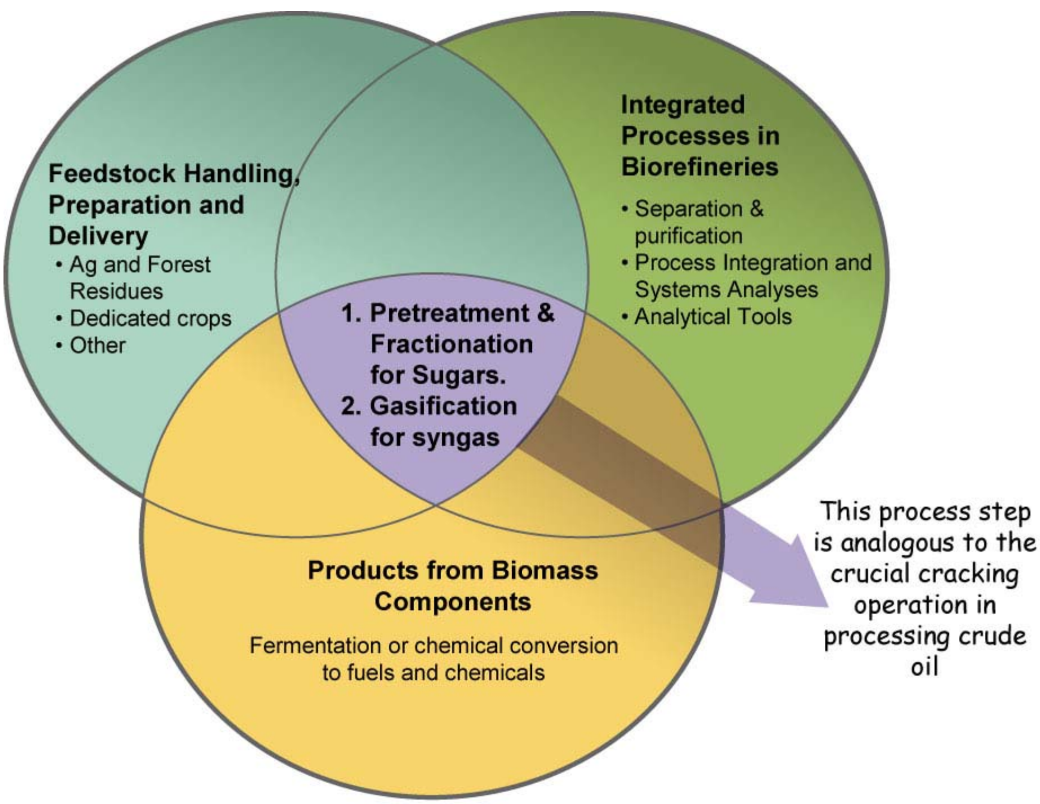



**Figure 3.2-1:** Interfaces between Sugars Platform and Other Program Elements

### 3.2.1 External Assessment and Element Market Overview

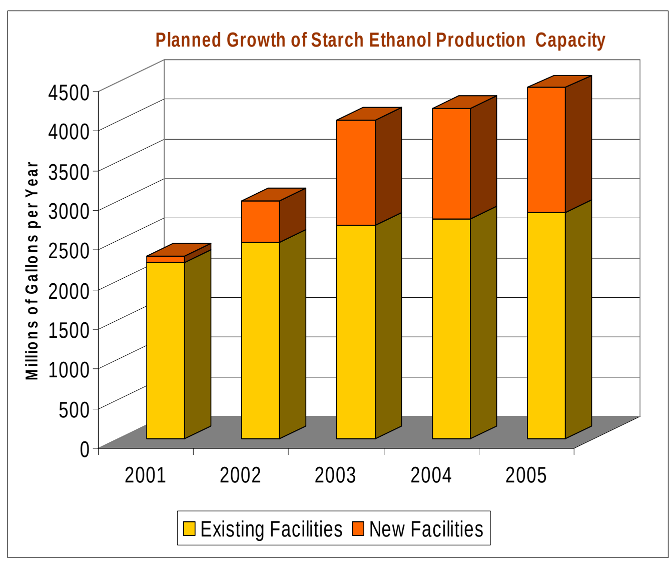
#### 3.2.1.1 Overview of Current and Potential Markets for the Technologies

Today's industrial sugar platforms are based on starch from grain or sucrose from sugar cane and sugar beets rather than lignocellulose. In the United States, the lowest cost sugars are being produced in the corn processing industry using both wet and dry mill facilities. In these operations, starch in corn grain is hydrolyzed to glucose, which is then used to produce fuel ethanol and other chemicals. A variety of other food and feed co-products are also produced in these processes. In its early days, this industry hydrolyzed starch to produce glucose using acid hydrolysis. Today, acid technology has been replaced by enzymes that can hydrolyze starch to glucose much more efficiently – at higher yields and with significantly lower energy usage - and cost effectively. Even the enzymatic corn starch hydrolysis technology is experiencing dramatic improvements that increase plant efficiency. Applying the learning curve of the industry to lower cost, higher volume cellulosic feedstocks will result in a more significant penetration of ethanol into the fuels market and expand the US energy supply.

Figure 3.2-2 provides a snapshot of the current grain and starch industries relative to production of ethanol. Note that current numbers for ethanol production are nearly twice that shown in this figure. The production of clean sugars from grains comprises a major industry in the US with significant infrastructure already in place.

## Sugar Platform: Grain/Starch Current Status

- **U.S. Industry**
  - –Began in early 1980s
  - –1.8 billion (b) gallon capacity in 2002
  - –Expected market of 5 b gal in 2012.
  - –Over 40 manufacturers; ADM, Broin, Cargill, ...
  - –Feedstock primarily corn, but also wheat and milo
- **Key process elements**
  - –Enzymatic starch hydrolysis developed in mid-1980s dramatically reduced cost relative to acid hydrolysis
  - –Microbial (yeast) fermentation of glucose
  - – Dry milling today requires 50% less energy than in the '80s, ethanol yields increased 22%/bushel and capital costs decreased to $1.50/gallon produced ethanol from $2.00/gallon.
- **Ongoing R&D**
  - –Improved, lower cost saccharification enzymes
  - –New products and improved value of co-products
  - –Engineering improvements to reduce capital and operating costs, enhance process and quality control
  - –Biocatalyst capable of producing higher ethanol levels




***Source: "U.S. Ethanol Industry, Production Capacity Outlook", CEC, August, 2001***

**Figure 3.2-2:** Status of Grain and Starch Industries

There are three major messages inherent in this assessment. One, sugars produced from lignocellulosic biomass are too expensive to produce with current technology. Two, sugars produced from starches such as corn and other grains can be used to make biofuels, but they are not yet fully competitively economic with oil in producing a fuel. Three, the R&D in the program has steadily impacted the cost of sugars.

**3.2.1.2 Political Environment Nuances**

DOE, in partnership with USDA, has been committed to expanding the role of biomass as an energy source for many years. Specifically, these organizations support biomass fuels and products as a way to reduce the nation's dependence on foreign oil, to offer new opportunities for economic growth in rural communities, and to foster the establishment of new domestic biorefineries throughout the U.S. The Biomass R&D Technical Advisory Committee, established by Congress in 2000 to guide federally-funded biomass R&D, has established a goal that biomass will replace 30 % of the country's petroleum consumption by 2030. More recently, the Energy Policy Act of 2005 highlights the need to move away from a petroleum-based transportation sector and toward increased use of renewable fuels such as ethanol and biodiesel, especially in the medium time range. This bill includes tax incentives and requirements for the increased production and use of renewable transportation fuels to promote these goals. In addition, the large increases in the cost of petroleum observed during the first half of 2005 are bringing a new urgency to these efforts.

**3.2.1.3 Potential Competing Technologies**

The value of the technologies being evaluated in this program element can be best demonstrated by examining the world market for sugars and the impact of producing low cost sugars. A market target of sugar at six cents per pound is selected to allow for comparison to other sugar costs. Figure 3.2-3 illustrates the impact of having 6 cents a pound sugar relative to other sugar markets. Being able to produce cheap, clean sugars will enable industry to make commercially viable and competitive products. US policies hold the prices of sugar up in the U.S; likewise, world sugar markets are also derived from worldwide agricultural policies. If more free trade were to occur, it could lead to a situation similar to pulp/paper/wood products where the U.S. industry is challenged by southern hemisphere countries that have much higher productivity and lower processing costs including labor.

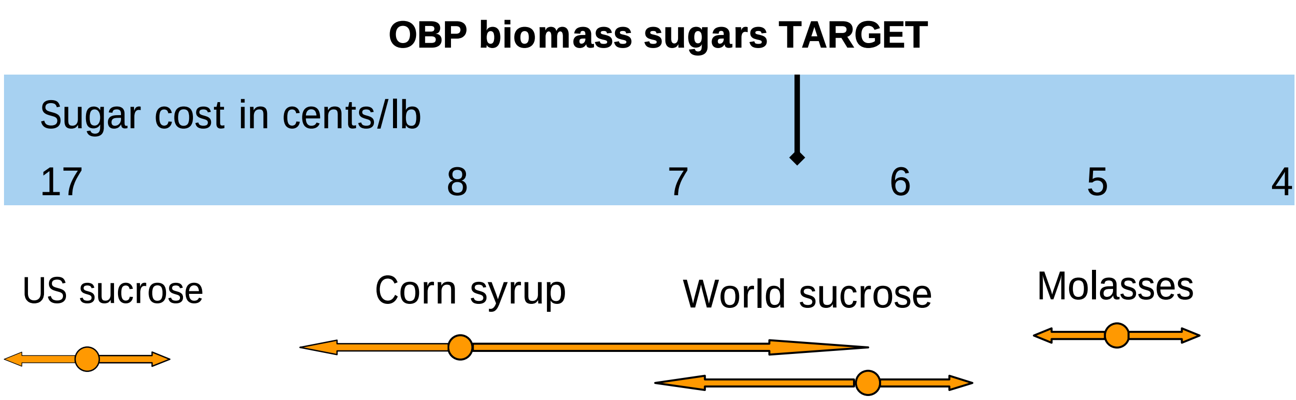



**Figure 3.2-3:** Sugars Produced from Various Sources.

### 3.2.2 Internal Assessment and Program History

### 3.2.2.1 Element History

The previous Office of Transportation Technologies within EERE had a biofuels component which focused on the biological conversion of cellulosic biomass into fuel ethanol. The reorganization of EERE and the creation of the Office of the Biomass Program allowed for a new internal construct for OBP. In the Sugars Platform, work is now been framed around the means and technologies that produce fermentable and chemically convertible sugars and chemically tractable lignin from lignocellulosics.

### 3.2.2.2 Element Organization and FY06 Activities

The major approaches to dealing with the barriers associated with obtaining sugars from biomass involve pretreatment and hydrolysis. Most research in this program element surrounds addressing the barriers in these two approaches. The work breakdown structure in Figure 3.2-5 illustrates the structure and organization of tasks within the Sugars Platform.

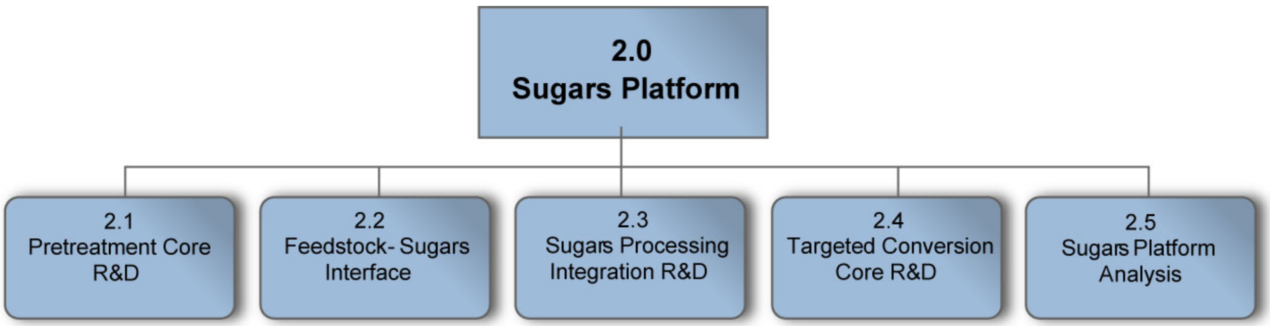



**Figure 3.2-5:** Sugars Platform Work Breakdown Structure.

The program will examine the sustainable conversion of almost all of the corn plant, or corn stover, the sugar cane and beet residues as sources of sugars and lignin for processing into fuels and chemicals. This should be applicable to other agricultural residues as well. Pretreatment and fractionation options involve both chemical and biological approaches. The conversion of the non-fermentable fractions to products such as heat, power or chemicals is an area being evaluated and developed in the Thermochemical Platform.

### 3.2.2.3 Element Recent Accomplishments

A brief description highlighted accomplishment of this element follows. Since this is core R&D, these findings are all directed towards elucidating the mechanisms of biomass pretreatment and hydrolysis such that the appropriate strategies can be implemented in true biorefinery operations.

**Pretreatment**

- Improved cellulose digestibility has been demonstrated with pretreated and hot washed woody biomass (poplar) as well as a better understanding of the differential reactivity of the anatomical fractions of corn stover during dilute acid pretreatment
- The chemistries of wood components during pretreatment and the mechanism and factors limiting catalyst transport have been better elucidated permitting better process control

**Enzymatic Hydrolysis**

- Two major enzyme-producing companies and a national laboratory, Genencor International, Novozymes, and the National Renewable Energy Laboratory provided 20-30-fold reductions in the projected cost of using cellulases for commodity biomass conversion applications. This accomplishment received a R&D 100 award in 2004.
- Routes to improving enzyme efficiencies include use of better enzyme preparations, development of enzymes with better heat tolerance and higher specific activities and development of high-solids enzymatic hydrolysis to lower capital costs.

**Feedstock-Sugars Interface**

- The structural complexity and compositional variability of biomass has been shown to greatly affect the efficiencies of feedstock assembly/preprocessing systems and pretreatment (i.e., biomass format and quality does matter).
- The integration of biomass preprocessing into feedstock assembly operations has been demonstrated to improve assembly system efficiencies (i.e., enabling bulk handling) and impact pretreatment.

**Sugars Processing Integration**

- Dilute acid pretreatment has been demonstrated at solids levels up to 35% weight/weight
- Rapid analysis methods have been developed for corn stover and pretreated corn stover solids that facilitate improved processing and control options.
- Significant quantities (>100 kg) of lignaceous process residue solids have been produced to enable gasification and co-product testing efforts to proceed under the Thermochemical Platform.
- Amalgamated Research, Incorporated (ARI)[1] and the Idaho National Laboratory (INL) demonstrated that it is possible to clean-up weak acid hydrolysate and possibly eliminate over-liming and materials toxic to fermentation with a fractal based ion exchange process. ARI is now commercially marketing reduced size fractal based chromatography systems.

**Targeted Conversion Research**

- Targets for improving pretreatment options include a) understanding microfibril structure and surface cellulase-cellulose interactions; b) crystal structure of cellulolytic enzymes relative to improving performance; c) increasing thermotolerance in enzymes; d) understanding surface characteristics of biomass materials in order to design strategies for effective pretreatment and fractionation; and e) development of visual materials to allow for broader involvement by the academic and lay communities.

**Sugars Platform Analysis**

- Analysis of several biomass to ethanol processes has been conducted. The products of those analyses have included two design reports that show refined process designs, capital cost and operating cost estimates, and overall economic analyses.
- A life cycle assessment of corn stover production, conversion, and ethanol use as a fuel has been completed. The findings of the assessment highlighted the importance of soil sustainability and carbon sequestration in soil.

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[1] Amalgamated Research, Incorporated, a private research firm specializing in separations related to the upgrading of sugar-rich process streams

- Reductions in cellulase costs have been verified via the enzyme cost metric.
- Reductions in the cost of sugars and ethanol from R&D advancements are identified and reported in an annual State of Technology case.

### 3.2.3 Federal Role

#### 3.2.3.1 Element Contributions to a National Federal Need

The Sugars Platform is focused on developing technology that has a high level of technical and economic risk, is not yet commercially available, and offers significant potential rewards for the nation. Thus, the strategy for the Sugars Platform includes research activities that address the more fundamental scientific and engineering issues that face OBP, if biomass is to play a role in our long-term energy supply. By focusing on the fundamental causes of biomass recalcitrance, the development of new tools for technology development, and the development and evaluation of new process concepts, advanced R&D projects will lead to the next generation of technologies that will provide options in the development of integrated biorefineries.

#### 3.2.3.2 Complementary Federal Programs

Federal agency sugars-related feedstock and conversion research is also conducted at the Department of Agriculture, primarily through the Agricultural Research Service (ARS), the Cooperative States Research, Education and Extension Service (CSREES), and the Forest Service (FS), and under the Bioenergy Initiative. ARS conducts conversion research at its national laboratories on value-added products, sustainability issues, and switchgrass development (primarily through a national program with field management at Lincoln, NE). The CSREES funds competitive grants (the bulk of funding goes to land-grant universities) for Biobased Products and Bioprocessing and the National Research Initiative. USDA has funded the CAFI I (CSREES) and in-house bioconversion research at Peoria, IL (ARS).

Fundamental research related to Sugars Development is funded through DOE's Office of Science. Efforts in 2005 have more closely aligned the fundamental research with OBP. It is likely that a joint solicitation will be planned for FY 06 (assuming funds availability) for cellulosic ethanol utilizing the sugars platform. A joint Office of Science/EERE (OBP) workshop is also being considered. Genomes to Life programs have supported the sequencing of maize and will soon begin sequencing of switchgrass. An increased level of collaboration is expected during the MYPP out-years between the Office of Science and EERE's OBP.

### 3.2.4 Approach

#### 3.2.4.1 Core R&D Research

The Sugars Platform involves the breakdown of lignocellulosic biomass into its component sugars using a combination of chemical and biological processes. Biomass is subjected to a thermochemical process step ("pretreatment") to make the cellulose (and perhaps hemicellulose) susceptible to attack by hydrolytic enzymes; when pretreatment uses dilute acid at high temperatures, an intermediate (C5) sugar stream is produced. After pretreatment, the now reactive cellulose (and perhaps hemicellulose) undergoes enzymatic hydrolysis to produce glucose (and perhaps other biomass sugars). The sugars produced upon complete saccharification of the biomass are then converted to fuels or chemicals using appropriate chemical or biological catalysts. Process residues, composed primarily of lignin, are separated (recovered) and used either to generate heat and power or to produce other value-added fuels or chemicals products.

Lignocellulosic biomass is essentially a heterogeneous composite of interlinked hemicellulose, cellulose, and lignin polymers. Cellulose—a crystalline polymer of glucose—and hemicellulose—a non-crystalline polymer of the hexoses D-glucose, D-galactose, and D-mannose and the pentoses D-xylose and L-arabinose (and minor levels of acetic and uronic acids)—together make up the carbohydrate portion of biomass, constituting approximately two thirds of biomass on a dry weight basis. Lignin, a high-energy polymer of alkyl-linked phenolic units, constitutes the majority of the remainder. Other minor components include protein, oils, waxes and minerals.

Lignocellulosic biomass can be converted into mixed sugar solutions plus lignin-rich solid residues by the sequential use of mechanical preprocessing, storage hydrolysis, thermochemical pretreatment and enzymatic saccharification. Technical barriers impacting cost and performance currently hinder commercialization of this technology; projected operating and capital equipment costs for facilities implementing the best developed technology exceed those of current grain-based (starch) alternatives. OBP and its predecessors have historically supported fundamental and applied research and technology development targeted at producing low-cost sugars from lignocellulosic biomass with fuel ethanol as the predominant end product. Figure 8 in Section 1 shows how the Program's view of this technology has evolved into the concept of the emerging sugars-based biorefinery—a concept that is central to most of the work planned in this core R&D area.

Close interaction between the project groups is necessary to communicate plans and data. While this has been informally done, a more planned and managed interaction is warranted. Specifically, intermediate specifications and samples are needed. Demonstrating integrated process technology is a prerequisite to producing these process intermediates (e.g., sugars that are required to evaluate the product conversion technologies) and residues (e.g., residual lignaceous process solids that are needed to validate their assumed value as an energy source for producing steam, heat, and electricity, or as a substrate for gasification to produce a biomass-derived synthesis gas or pyrolysis to produce a biomass-derived high-energy liquid).

OBP uses technoeconomic analysis to judge the relative cost impacts of addressing these technical barriers for a given technology. Figure 3.2-6 is an example of such an analysis for a number of the critical barriers identified in the sugar platform based on enzymatic hydrolysis technology. In this case, analysis examined the impact of progress on the following barriers:

- FY04 State of Technology Cost: Represents the plant performance in line with what has been experimentally verified. The overall cost is dependent upon the baseline cost of a feedstock assembly system that delivers the biomass to the plant gate. $53 per dry ton is the cost of this baseline system.[2]
- Feedstock Interface: Reduce cost of feedstock from $53 to $35 per dry ton through increased efficiencies in equipment operation or increased quality of the delivered feedstock in terms of particle size, purity of delivered carbohydrate and lignin streams and in storage pretreatment benefits. Each of these cost improvements are propagated through the

[2] The cost of $0.135 per pound is based on a modification to a documented case for current ethanol cost based on best available experimental data and a feedstock cost of $53 per dry ton.

biorefining process in terms of increased ethanol production potential per dry ton of biomass.

- Pretreatment: Increase yields of hemicellulosic sugars from demonstrated level of 60%-70% to 80% with reduced pretreatment severity to avoid sugar losses.
- Enzymatic Hydrolysis: Reduce the cost of enzyme from $0.035[3] to less than $0.015 per pound of sugars.
- Target Cost: A target sugars cost that produces an ethanol cost of $1.09 per gallon, which is competitive with current starch to ethanol production costs. Additional pretreatment (90% yields) and enzyme improvements (further cost reductions) are required to achieve this market target case, reported in 2002.

As indicated in Figure 3.2-6, the cumulative effect of achieving these targets in all of the barriers provides approximately 50% savings in the cost of a mixed sugars intermediate stream relative to the experimentally verified performance of the technology in FY 2004.

A combination of successes against these specific barriers determines the performance goals for the Sugars Platform discussed in section 3.2.5.

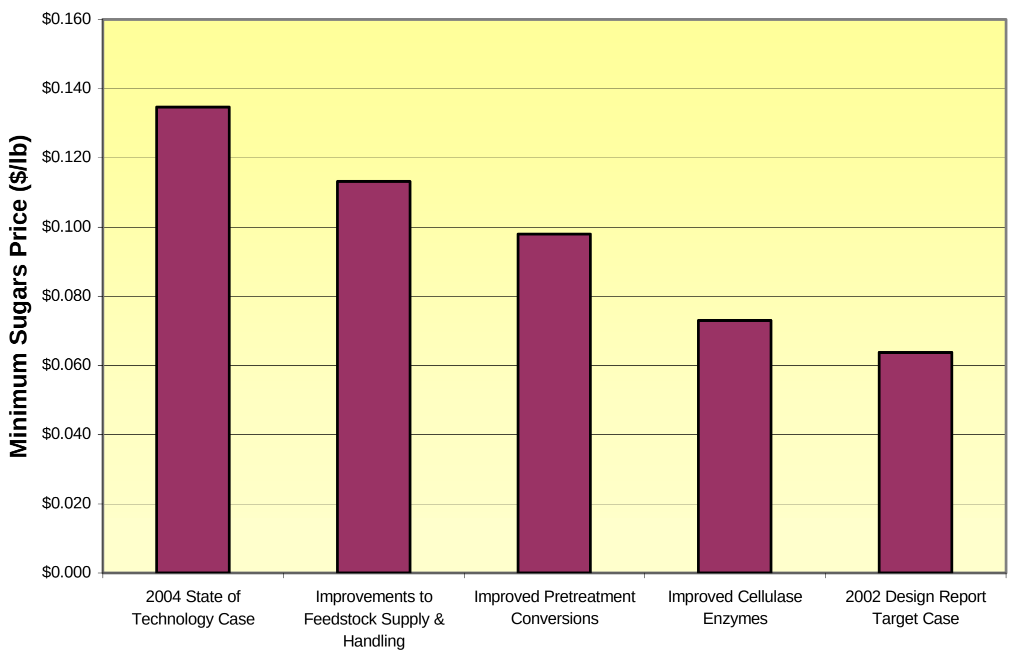


**Figure 3.2-6:** Translating Reductions in Technical Barriers to Sugar Platform Cost Savings

### 3.2.4.2 Contribution to Pathways & Program Outputs

The Sugars Platform is composed of the key research elements focused in overcoming the recalcitrance of biomass for the conversion of sugars to support the biorefinery concept. This platform directly enables the Agricultural Residues and the Perennial Crop Pathways explained in

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[3] Cost of enzyme after improvements in enzyme production process and enzyme performance available at the end of year 3 of the current industry-led enzyme improvement research subcontracts. The cost of enzymes prior to the initiation of the DOE's contracts with Genencor International and Novozymes Biotech was roughly an order of magnitude higher.

Section 1, with a focused effort and funding in support of corn stover as an agricultural residues feedstock. This platform also enables advancements in the current corn ethanol and pulp and paper industries by developing cellulose to sugar conversion technologies that can be used on captive feedstocks such as corn fiber in wet or dry mills or to extract more value from woody feedstocks in pulping mills. These opportunities to advance existing industries also serve to demonstrate the conversion technologies, thereby reducing risk. To support the coordination between the platform and pathway approach the Sugars Platform has integrated its original bioconversion of sugars projects with projects in the Feedstock Platform, and also coordinates with the Thermochemical Platform to convert lignin (see Section 3.2). The Products Platform supports the conversion of the fermentable sugars to ethanol and/or products (see Section 3.3).

While developing cost-effective pretreatment and fractionation processes is the major focus of this platform, the need to intimately interface with the feedstock supply chain to these processes is significant. Hence, the sugar's platform is cognizant of and supportive of developing the requirements for feedstock handling, assembly and delivery processes to feed the pretreatment and fractionation processes needed in biorefinery operations. Linking feedstock harvest/collection/transport/storage (i.e., feedstock assembly) and preprocessing processes with conversion processes allows evaluation of technology options and trade-offs. Feedstock-Bioconversion Interface activities will develop cost and quality specifications for feedstock assembly technologies that are compatible with biorefinery pathway technologies.

### 3.2.5 Performance Goals

The performance goals of the Sugars Platform are to increase feedstock supply to a biorefinery by being able to utilize a range of feedstocks suitable for sugars production (high carbohydrate content) at low cost (less than $35 per dry ton) of feedstock.

- Reduce the cost of producing a mixed, dilute sugar stream suitable for fermentation to ethanol, in a mature biochemical plant, from the 2002 estimated cost to $0.10/lb by 2012.
- Further reduce sugars production price to $0.064/lb (see Table 3.2-1) by 2020.

In Table 3.2-1, costs for the sugars intermediate and ethanol, a model product for sugars utilization, are shown with corresponding yields. The costs are based on a dilute acid, enzymatic hydrolysis process design.

| | 2002 State of Technology | 2004 State of Technology | 2012 Program Target[4] | Market Target[5] (2020 completion estimate) |
|---|---|---|---|---|
| **Assumed Delivered Cost of Feedstock [6] ($/dry ton)** | $53 | $53 | $45 | $35 |
| **Minimum Sugars Selling[7] Price ($/lb)** | $0.15 | $0.135 | $0.10 | $0.064 |
| **Sugars Yield (lb/dry ton)** | 1,148 | 1,089 | 1,124 | 1,285 |
| **Minimum Ethanol Selling Price ($/gal)** | $2.74 | $2.50 | $1.75 | $1.09 |
| **Ethanol Yield (gal/dry ton)** | 73 | 68 | 72 | 90 |

**Table 3.2-1:** Sugar Platform Performance Goals

The 2012 goal provided above will help enable the establishment of a biorefinery and clearly address the program performance goals reflected in the budget. However, it is assumed that a sugars selling cost of $0.10/lb will not be competitive with starch-derived sugars from the current corn to ethanol industry. Continued research and process improvements are expected to further reduce the sugars selling price, making it competitive with the sugar intermediates produced from starch.

### 3.2.6 Strategic Goals

The Sugars Platform's strategic goals in support of the EERE Strategic Goals is to develop the capability for using lignocellulosic biomass to produce inexpensive sugar streams that can be used for the production of commodity liquid fuels as well as value-added chemicals and materials..

4 **Program Target:** This is defined as the target expected to be achieved by OBP based on their understanding of the State of Technology and future funding. As program priorities and funding change, this target can either move years or be adjusted up or down.

5 **Market Target:** This target is defined as the process design and yields that will result in a market competitive product. For sugars, ethanol has historically been the model product. These yields often become R&D targets.

6 **State of Technology:** These cases represent the process understanding in a given year, and are developed from validated data at the largest scale possible and as integrated as possible (typical pilot). The yields and costs can go up or down as understanding of the process improves. For example, in 2004 the yield was reduced due to the identification of sugar degradation losses in conditioning.

7 **Minimum Selling Prices:** These values are defined as the selling price of sugars or ethanol that makes the net present value of the process equal to zero with a 10% discounted cash flow rate of return over a 20-year plant life. For sugars, which are likely to be an intermediate stream in a biorefinery, this can be thought of as an over-the-fence cost. The costs above are for a sugars feedstock suitable for fermentation processes that produce fuels or chemicals. Biocatalysts (organisms) typically have sugar concentration limits and are sensitive to certain substances, but can tolerate suspended solids and a mix of compounds. For example, the market target case predicts a mixed sugar concentration from hydrolysis of about 10% weight/volume (6.5% glucose, 3.5% xylose, small amounts of mannose/arabinose/galactose). The final sugar concentration is directly related to the solids loading in the process, which is 30% total solids in the market target case. Work to increase this level (termed process intensification) will reduce the overall cost of the sugars while increasing concentrations.

### 3.2.7 Market Challenges and Barriers

**Sm-A. Market for Hydrolyzate Sugars**

The cost of sugars from cellulosic feedstocks is currently higher than the cost of sugars from corn grain (starch). In addition, biomass hydrolyzates generally have not been available in the commercial marketplace. (There are a few notable exceptions, including xylose-containing spent sulfite liquor streams available from some pulping operations.)

Markets for most biomass extractives, for hemicellulose-derived xylose (beyond as a feedstock for production of xylitol), and for lignaceous process residues are largely non-existent. Markets for the mixed sugars and other intermediates (and new products) that will produce in a lignocellulose-based biorefinery need to be developed to reduce the market barriers and commercialization risks currently hindering technology deployment.

### 3.2.8 Technical (Non-Market) Challenges/Barriers

There is a hierarchy of technical barriers for the Sugars Platform, with each lower level targeted to a more specifically defined technology (Figure 3.2-7). At the highest and most general tier, the barrier to commercial success is conversion cost for cellulosic biomass to sugar(s). At a second level, major contributors to sugar cost are broken out at a generic level. At a third level selection of a specific technology allows greater specificity of critical barriers in terms of defined process unit operations that must perform to minimum standards and be able to be fully integrated with the other process operations to achieve the cost target.

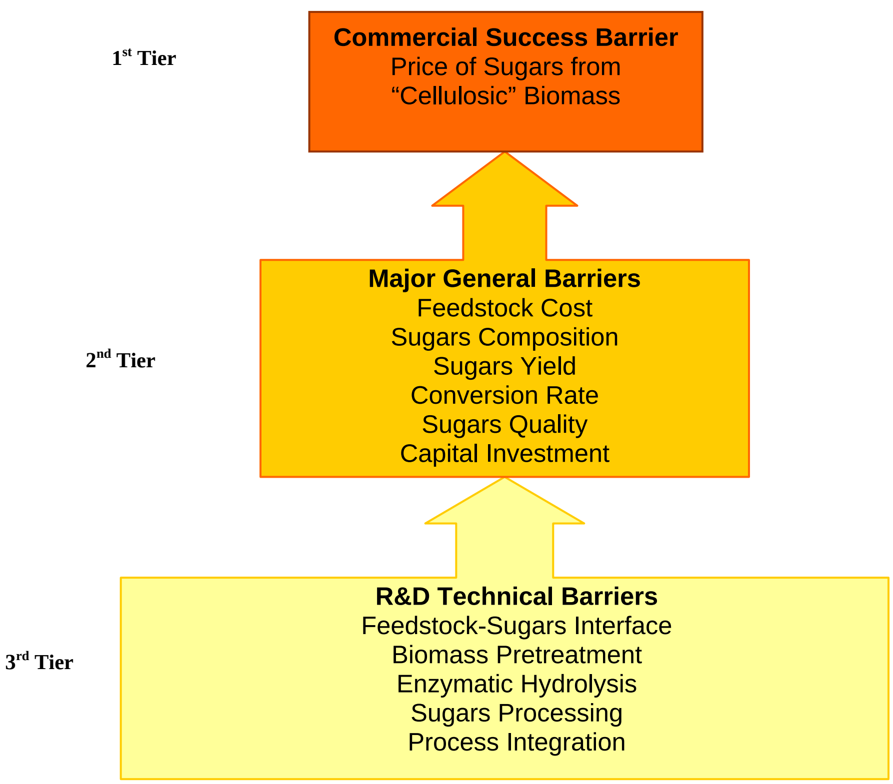


**Figure 3.2-7:** Hierarchy of Barriers for the Deployment of the Sugars Platform Affecting the Agricultural Residues Processing Pathway and the Perennial Crops Pathways

## Feedstock-Sugars Interface R&D Technical Barriers

**St-A. Biomass Fractionation.** Fractionation can be used to increase the value of the individual components in biomass prior to their subsequent conversion into products. There is a limited understanding of the chemical and mechanical routes for fractionating feedstocks into its individual components. As such, there is a need to develop a more fundamental understanding of the interactions between chemical, biological, solvation (ability to go into solution), and mechanical processes to ultimately allow biomass to be more efficiently fractionated at high yield into high purity components. Advances in understanding the core material science issues will facilitate the development of economically viable secondary processes for converting underutilized material/stream fractions into value-added products.

**St-B. Biomass Variability.** The characteristics of biomass can vary widely in terms of physical and chemical composition, size, shape, moisture content, and bulk density. These variations can make it difficult (or costly) to supply biorefineries with feedstocks of consistent, acceptable quality year-round, and also feedstock variability affects overall conversion rate and product yield of biomass conversion processes.

**St-C. Biomass Recalcitrance.** Lignocellulosic biomass feedstocks are naturally resistant to chemical and/or biological degradation. The fundamental roles of biomass structure and composition and the critical physical and chemical properties that determine the susceptibility of cellulosic substrates to hydrolysis on the recalcitrance of biomass are not well understood. This lack of understanding of the root causes of the recalcitrance of biomass limits the cost-effectiveness and efficiency of pretreatment processes.

## Bioconversion R&D

### Biomass Pretreatment

**St-D. Pretreatment Chemistry**. Thermochemical prehydrolysis of biomass, typically referred to as pretreatment, is required to open up the structure of biomass and increase its susceptibility to subsequent enzymatic hydrolysis by cellulase enzymes. The critical physical and chemical properties that determine the susceptibility of cellulosic substrates to hydrolysis and the role that lignin and other products of pretreatment chemistry play in impeding access to cellulose are not well enough understood. Continued significant cost reductions in pretreatment technologies via improved sugar yields and quality require developing a better understanding of pretreatment process chemistries, including the intrinsic kinetics of heterogeneous cellulose hydrolysis and release of glucose to the bulk medium.

**St-E. Pretreatment Costs.** Pretreatment reactors typically require expensive materials of construction to resist acid or alkali attack at elevated temperatures or prolonged times. In addition, the impact of reaction configuration and reactor design on thermochemical cellulose prehydrolysis is not well understood. Developing lower cost pretreatments depends on the ability to process the biomass in reactors designed for maximum solids levels and fabricated out of cost-effective materials.

### Enzymatic Hydrolysis

**St-F. Cellulase Enzyme Production Cost.** Cellulase enzymes remain a significant portion of the projected production cost of sugars from cellulosic biomass. Cost-effective enzyme production technologies ($/kg enzyme) for saccharification of pretreated biomass are not currently available, although significant progress has been made through concerted efforts with industrial enzyme producers.

**St-G. Cellulase Enzyme Loading.** Reducing the cost of enzymatic hydrolysis depends on identifying more efficient enzyme preparations and enzyme hydrolysis regimes that permit lower dosages (kg enzyme/kg substrate) to be used.

**St-H. Enzyme Biochemistry.** Enzymes that exhibit high thermostability and substantial resistance to sugar end-product inhibition will be essential to fully realize enzyme-based sugar platform technology. The ability to develop such enzymes and consequently very low cost enzymatic hydrolysis technology requires increasing our understanding of the fundamental mechanisms underlying the biochemistry of enzymatic cellulose hydrolysis, including the impact of biomass structure on enzymatic cellulose decrystallization. Additional efforts aimed at understanding the role of cellulases and their interaction not only with cellulose but also the process environment is needed to affect further reductions in cellulase cost through improved production.

### Process Integration

**St-I. Cleanup/Separation.** Sugar solutions resulting from thermochemical pretreatment are impure, containing a mixture of sugars and a variety of non-sugar components. Potential impurities include acetic acid liberated upon hydrolysis of hemicellulose, lignin-derived phenolics solubilized during pretreatment, inorganic acids or alkalis or other compounds introduced during pretreatment, various salts, and hexose and pentose sugar degradation or transglycosylation products. The presence of some of the non-sugar components can be inhibitory to microbial fermentation or biocatalysis or can poison chemical catalysts. Low cost purification technologies need to be developed that can remove impurities from hydrolysates.

Some processes, such as chemically catalyzed ones, to produce chemicals or fuels may require pure and/or concentrated sugar streams. While technologies exist for sugar processing, they have not been tested on the unique mix of biomass sugars. Cost effective methods for providing purified, concentrated and clean sugar feedstocks to biobased product manufacture is needed.

**St-J. Biological Process Integration.** Beyond the core saccharification steps of pretreatment and enzymatic hydrolysis, process integration remains a key technical barrier hindering development and deployment of biomass sugar platform technology. Sugar platform technology currently presents large scale-up risks because there is a dearth of high-quality performance data on integrated processes carried out at the high solids conditions required for industrial operations. The effect of feed and process variations throughout the process must be understood to ensure robust, efficient biorefineries. Process integration work is essential to characterize the complex interactions that exist between many of the processing steps, identify unrecognized separation requirements, process bottlenecks and knowledge gaps, and generate the integrated performance data necessary to develop predictive mathematical models that can be used to guide process optimization and scale-up.

**St-K. Sugars/Products/Thermochemical Processing Integration.** Integration of the entire biorefinery is the penultimate barrier and the interfaces between the platforms represent this barrier in the core R&D program. Without planned and managed integration, the complete picture of biomass conversion to fuels and chemicals will not be clear enough to attract potential developers and the risks of commercialization will be too high for financiers.

Because the sugars produced from the sugars platform technology will become the feedstock for products, it is imperative that the interface between these platforms be well coordinated. For the lignin residue, which can be considered a feedstock for syngas production and subsequent conversion to combined heat and power, fuels, or chemicals, the interface is with the thermochemical platform, which is envisioned to provide technologies to utilize the lignin in the most cost effective way for not only the sugars production, but the entire biorefinery.

### 3.2.9 Strategies for Overcoming Barriers/Challenges

### Market Barriers

#### Sm-A. Market for Hydrolyzate Sugars

Industries partnered with OBP envision a transition from intermediate feedstocks, like lactic acid, from starch sugars to biomass sugars in their production of products, like poly lactic acid (PLA), a polymer for use in disposable plastic ware. This is a good example of biobased products' ultimate road to market, however, it is likely that the cost of bio-based products will have to be lower priced and/or have better qualities than current offerings to develop market position. The exception may be companies that can transition biobased products into established contracts. A third set of products will be completely new products from biomass – these are likely to suffer the same market hurdles as those replacing established products in the open market. Regardless of the product, the conclusion for biomass feedstocks is the same – they must become a competitive and accepted feedstock. The sugar platform is focused on reducing the cost of biomass sugars, while the products platform is developing products (markets) to be made from these sugars. These efforts, combined with the companies participating in the Integrated Biorefinery projects to commercialize biobased products, will all contribute to increasing market acceptance and awareness of biomass sugars.

### Technical Barriers

#### Feedstock-Sugars Interface R&D Strategies

**St-A. Biomass Fractionation.** The Biomaterials Deconstruction and Composition Laboratory (BDCL) has been created to help understand the chemical and mechanical routes for fractionating feedstocks into its individual components. The BDCL utilizes microscopy, imaging systems, mechanical testing methods, and finite element analysis to identify how biomaterials fractionate under specific loading configurations. Through this laboratory's core R&D and underlining analysis, cross-cutting improvements can be made to feedstock harvest, collection, handling, preprocessing, transportation, and storage systems.

**St-B. Biomass Variability.** The BDCL has been created to help understand the variability in chemical and mechanical properties of biomass feedstocks. The BDCL utilizes microscopy, imaging systems, NIR analysis, and mechanical testing methods to characterize biomaterials and provide the core R&D and underlining analysis to improve feedstock harvest, collection, handling, preprocessing, transportation, and storage systems. The BDCL also collaborates with the BSCL to fully understand those biomass characteristics that jointly affect natural variability and recalcitrance.

**St-C. Biomass Recalcitrance.** The body of research in this area, which is often highly empirical in nature, has led to improvements in yield and cost of accessing the sugars. This empirical approach, however, is not good enough to meet the kind of aggressive performance requirements needed to compete with petroleum. The leap to this level of competitive technology will require delving into the fundamentals of biomass structure and its effects on chemical and biological hydrolysis and the interaction between biomass and chemical and biological catalysts.
The Biomass Surface Characterization Laboratory (BSCL) has been developed to understand the fundamentals underlying recalcitrance. In applying the BSCL tools to biomass recalcitrance, the most powerful ally we have is the basic knowledge of the molecular structure of plant cell wall polysaccharides and the ability to trace chemical changes at the micron and nanometer scale. This new asset represents a new “systematic tool box” specifically targeting acquisition of new understanding needed for biomass conversion fundamentals in all areas; feedstock, pretreatment, hydrolysis and integration. A detailed Use Plan has been developed for the BSCL.

## Bioconversion R&D

### Biomass Pretreatment

**St-D. Pretreatment Chemistry**. As part of the core technology development, different pretreatment technologies are currently being evaluated with regards to performance and cost. Pretreatment catalyst use and the requirement for any catalyst recovery and recycle are also considered in the overall costs of the pretreatment step. The range of pretreatment chemistries (i.e. acid to alkaline) is being investigated against different feedstocks to assemble a picture of the not only the range and extent of reactions, but also the details of reaction pathways. Pretreatment and enzymatic hydrolysis technologies can eventually be optimized for classes or types of feedstocks to maximize hemicellulose conversion and cellulose digestibility. Substrates that allow for enhanced enzymatic hydrolysis as a result of improved pretreatment processes can also impact the enzyme use requirements and thus the overall costs of enzymes for production of sugars.

Advanced, novel pretreatment technologies, which physically separate the three major components of biomass—cellulose, hemicellulose and lignin—may improve the economics of pretreatment, and allow different products to be made more easily. This class of pretreatment is among those being studied. Non-cellulase enzymes may increase the digestibility of lignocellulose by cellulase(s) by action before, during, or after thermochemical pretreatment, and several, including hemicellulases, are being tested coupled with pretreatments.

**St-E. Pretreatment Costs.** Pretreatment reactors that can process solids at high concentration (>30% wt/wt) with good sugar yield and quality are key to reducing pretreatment costs. Both the pretreatment and process integration tasks are working on this "process intensification" goal. In addition, coupling milder pretreatment conditions with hemicellulases and/or accessory enzyme treatments may reduce the complexity and material requirements of reactors.

### Enzymatic Hydrolysis

**St-F. Cellulase Enzyme Production Cost.** Work in the core R&D program to understand the complex relationship between cellulase action and biomass substrates will result in additional breakthroughs in enzyme design to further reduce production costs. Studies in enzyme biochemistry, discussed below, have the greatest potential to affect the production costs of cellulase enzymes by providing information to optimize enzymes for different feeds and process conditions.

**St-G. Cellulase Enzyme Loading.** Hydrolysis conditions will be developed that lower the amount of enzymes needed to saccharify the substrates and thus lower the overall costs of enzyme utilization for production of sugars. Understanding where the cellulose is located in the biomass cell wall could help to create targeted saccharification processes. Identifying pretreatment conditions that produce substrates showing enhanced enzymatic hydrolysis is another strategy to reduce enzyme loading requirements. High solids hydrolysis and the attendant physical and chemical effects will be studied to determine the limits of process intensification in relation to saccharification reactions.

**St-H. Enzyme Biochemistry.** Understanding of the fundamental mechanics of enzymatic cellulose hydrolysis will be increased to develop thermostable and inhibitor resistant enzymes. Understanding the effect of the environment on cellulase-biomass interactions (e.g. in water) through molecular modeling will provide key insights in how cellulases can be designed to work optimally in biomass processing conditions.

### Process Integration

**St-I. Cleanup/Separation.** Little core R&D is being done in this area beyond some development of hydrolyzate conditioning methods suitable to create sugar feeds for fermentation processes. Over-liming is a mature although not well understood method and sugar degradation is a drawback. Other methods including ion exchange have been developed and are useful to remove acetic acid found in inhibitory levels in woody feedstocks. To address chemical catalysis processes for fuels or chemicals, cost effective methods for sugar concentration, purification and separation need to be developed based on specifications from the Product Platform. There are several industry ready processes and methods available that should be evaluated for technical and economic feasibility, then an applied core R&D program should be developed to test the most likely processes on biomass-derived sugars. Adaptations to these commercial methods are likely to be required.

**St-J. Biological Process Integration.** The Program's effort to address the process integration barrier focuses on investigating integrated enzymatic hydrolysis-based process technology utilizing dilute acid pretreated corn stover, while incorporating the advanced, lower-cost cellulase enzymes being developed by Genencor and Novozymes (DOE cost share). Integration of biomass pretreatment and saccharification steps can improve overall efficiency and reduce cost. Investigating pretreatment and enzymatic hydrolysis technologies together with downstream synthesis identifies the issues and opportunities of integration.

Although the work will shift to advanced pretreatments and hydrolysis methods when the integrated efficacy of the current methods have been established, the outcome of the planned FY08 demonstration-focused solicitation will also play a role in determining the focus of out year integration efforts.

**St-K. Sugars/Products/Thermochemical Processing Integration.** The first strategy to overcome this barrier is in place - process design and computer modeling of integrated biorefineries. The models provide a "virtual biorefinery" that can be used to understand the impacts of changing processes in any of the 3 platforms, and provide targets to all platforms that are integrated each other. Due to the myriad number of combinations of processes in an integrated design, the idea of model products or processes have been used successfully to demonstrate the feasibility of concepts without detailing each option. Companies investing in biorefineries have used these model biorefineries as the starting point for their own process designs.

### 3.2.10 Tasks

The Table 3.2-2 translates the core R&D strategy outlined in the previous section into a working organization of focused tasks. The core R&D effort for the Sugars Platform is broken into five distinct projects. The first three tasks directly address three of the technology barriers (pretreatment, feedstock-sugars interface, and sugar processing integration). The sugars process integration task includes some limited work on the barriers related to feedstock variability and lignin utilization. The Targeted Conversion Research task addresses all of the advanced barriers related to understanding the recalcitrance of biomass and developing new concepts for processing of biomass sugars. These tasks will help enable and support the different pathways previously explained in Section 1 and 2.

**Table 3.2-2** Sugars Platform R&D Tasks

| Task | Title | Duration (years) | Barriers Addressed | Pathways Supported |
|---|---|---|---|---|
| **2.1** | Pretreatment Core R&D | 5 | St-D, St-E, St-F, St-G, St-H | Corn Wet Mill<br>Ag Residues<br>Perennial Crops<br>Pulp/Paper Mill |
| **2.2** | Feedstock-Sugars Interface | 5 | St-A, St-B, St-C | Ag Residues<br>Perennial Crops |
| **2.3** | Sugars Processing Integration | 5 | St-I, St-J, St-K | Ag Residues<br>Perennial Crops |
| **2.4** | Targeted Conversion Research | 5 | Cross-cut with all barriers | Ag Residues<br>Perennial Crops |
| **2.5** | Sugars Platform Analysis | 5 | Cross-cut with all barriers | Corn Wet Mill<br>Ag Residues<br>Perennial Crops<br>Pulp/Paper Mill |

**Task 2.1. Pretreatment Core R&D**
The Pretreatment task was merged with the Enzymatic Hydrolysis task to create the Pretreatment Core R&D task.

A key technical barrier to the commercialization of fuels and chemicals from biomass via a sugar platform route is the high cost and relative inefficiency of producing sugars from lignocellulosic biomass. Treatment of biomass with dilute acid is recognized as the most fully developed technology for the saccharification of biomass feedstocks. At lower severities the hemicelluloses can be hydrolyzed solubilizing the sugars as monomers and oligomers. At higher severities cellulose depolymerization increasingly occurs. Hemicellulose solubilization with or without partial cellulose depolymerization increases the accessibility of the remaining cellulose to enzymatic hydrolysis. A better understanding of the interaction of enzymes with biomass solids modified by dilute acid and other treatments is needed so that the rate and yields of sugars can be increased.

The pretreatment work will be leveraged to identify the opportunities for enzymatic action other than cellulases. Research will focus on development and testing of the next generation of enzymes tailored to provide high yields of sugars from corn stover feedstock, including advanced cellulase preparations resulting from the enzyme cost reduction subcontracts. These enzymes will enable the development of the first cellulosic biorefineries. The research is expected to lower costs for producing enzymes and increase the potential limits of improvement possible in enzyme performance. Research will also improve fundamental understanding of the enzymatic process through characterization of the cellulase function and cellulase-cellulose interaction.

While many attempts have been made to relate the enzymatic digestibility of pretreated substrates through measurement of properties such as cellulose crystallinity, acetyl, lignin, and hemicellulose removal, a comprehensive understanding of the substrate properties necessary for efficient enzymatic digestibility does not exist. This task will focus on increasing our understanding of the chemical and structural changes that occur in biomass during chemical depolymerization over a range of treatment chemistries and severities through theoretical, modeling and experimental studies. The knowledge base generated from this work is necessary to enable lower cost pretreatment options that are properly match to the proper feedstock types and the proper blend of enzyme activities.

Enzyme cost reduction subcontracts with industry focused on improving enzyme specific activity and reducing enzyme production cost. In mid-FY05, cost reductions of over 30-fold were realized by both companies. This task will work with the Sugar Processing Integration Project to validate industry’s cost reduction achievements under integrated high solids processing conditions. This work will be used to guide and expedite industry-led efforts to commercialize technology for enzymatic saccharification of lignocellulose in the 2010 timeframe. The resulting lower cost enzyme preparations will be utilized in a variety of core R&D activities, including studies to understand rheological property changes and resulting mixing requirement to enable practical high solids enzyme saccharification reactor systems.

**Task 2.2. Feedstock-Sugars Interface**
Establishing the value of and requirements for feedstock assembly processes to feed bioconversion processes are necessary for the development of biorefineries. The work of the feedstock-sugar interface task is a highly collaborative effort between DOE National Laboratories and USDA

Laboratories, University, and industry partners. A systems approach will integrate the minimum cost preprocessing options with the sugars biorefinery platform processes in conjunction with sophisticated computational engineering and modeling tools to provide an interactive and intuitive engineering system through which integrated feedstock-sugar processing systems can be developed and tested.

Linking feedstock harvest/collection/transport/storage (i.e., feedstock assembly) and preprocessing processes with conversion processes allows evaluation of technology options and trade-offs. Feedstock-Sugar interface activities will develop cost and quality specifications for feedstock assembly technologies that are compatible with biorefining pathway technologies. The feedstock-sugar interface task combines and focuses the R&D investment to define feedstock cost, quality assurance, and quality control requirements. Figure 3.2-8 shows where there will be direct linkages between the Feedstock and the Sugars Platform to form interactions for the Feedstock-Sugars Interface task to identify and overcome technical barriers.

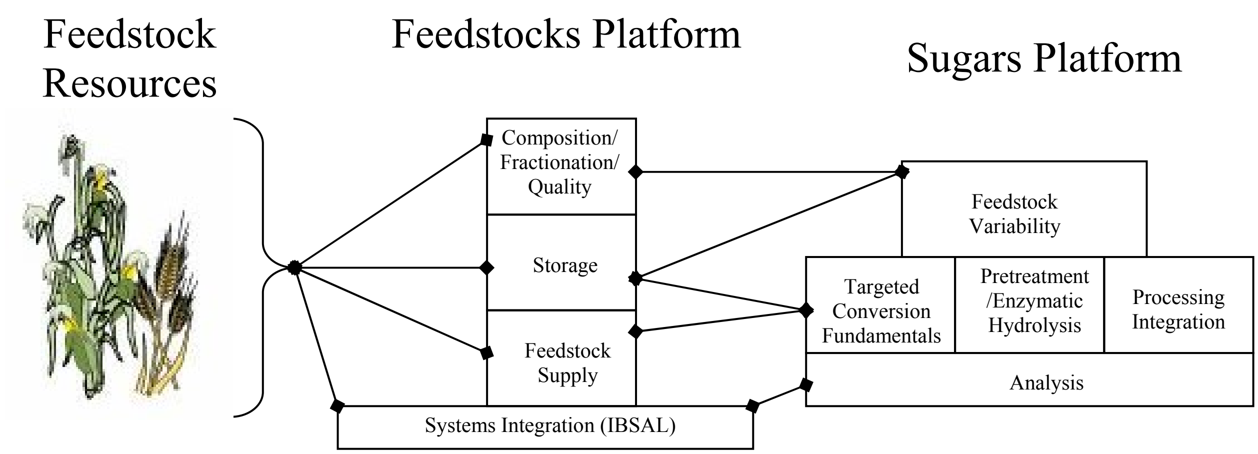


**Figure 3.2-8:** The Feedstock-Sugars interface R&D investments link feedstock resources and associate assembly / preprocessing options to biorefining pathways.

The benefit of this interface is particularly pronounced for non-traditional Agricultural Resources (i.e., lignocellulosic biomass) by:

- Defining Feedstock Requirements – Equipment manufactures, USDA, etc. continually are asking, "what are the delivery specifications/requirements for feedstocks?" These requirements are not well understood nor documented / defined, which is an objective of this task.
- Interface to near-term biorefining pathway options – Biorefining platform technologies are optimized for specific biomass resources (i.e., pretreatment conditions, enzyme cocktails, biorefining material balances between lignin and carbohydrate, etc.), and the multiplicity of feedstock resources and assembly options will be coupled to biorefinery pathway designs for near-term deployment.
- Lacking infrastructure – No proven lignocellulosic feedstock assembly infrastructure for biorefining exists. Without solid and robust feedstock interface and delivery requirements,

the diversity of infrastructure options (baling, non-bale, ground, pellets, corn/biomass combined, single-pass, etc.) are nearly as diverse as the numbers of people/institutions addressing the problem. Selection and development of the best near-term and long-term feedstock assembly options requires a strong feedstock-platform interface to make technology trade-off decisions and develop appropriately integrated technology options.

Specifically, the advanced R&D at the interface between feedstock preprocessing and sugar/thermochemical conversion will focus on identifying the fundamental properties of the feedstock structure, the mechanical and compositional variability of the feedstock components, the costs associated with the assembly/preprocessing equipment efficiencies, improved feedstock quality through preprocessing (including in-storage preprocessing), and the compositional changes and material losses resulting from dry and wet storage. These focus areas lead to the major milestone of delivering feedstock to a biorefinery at $30 per dry ton or an equivalent cost in terms of feedstock assembly/preprocessing benefits to the sugar and thermochemical processes. The achievement of this milestone is enabled because several integrated biorefinery processes and technologies (including transportation, storage, and pretreatment) rely on quantifiable improvements in feedstock assembly equipment efficiencies and feedstock characteristics/quality in terms of particle size, density, and composition. Meeting the input targets of these downstream processes and systems will help achieve the delivered feedstock cost target and reduce the risk in meeting this and other integrated biorefinery milestones.

**Task 2.3. Sugar Processing Integration**

This task provides information and materials to industry that will facilitate commercialization of enzymatic hydrolysis-based technology for sugar production from cellulosic feedstocks.

Near-term activities will focus on integrating pretreatment and enzymatic hydrolysis process technology by treating corn stover with dilute acid and the new enzymes developed by the enzyme manufacturers. The objective is to complete a limited pilot scale demonstration of integrating processing and use the performance data obtained to validate economic model assumptions and identify new or previously unrecognized barriers resulting from testing the integrated process. Longer-term work will investigate advanced pretreatment technologies and utilize other feedstocks.

**Task 2.4. Targeted Conversion Research**

The objective of R&D in this area is to develop a more fundamental understanding of the factors and causes underlying the recalcitrance of biomass to biological and chemical degradation. Embodied in this work is the development of enabling tools such as molecular modeling and more accurate chemical and structural analysis techniques for characterizing biomass at various stages during processing. The Biomass Surface Characterization Laboratory (BSCL) is a world class facility for this work.

Different lots of corn stover have been reported to perform differentially in dilute acid pretreatment. Differential performance in pretreatment suggests that a higher order level of structural variability exists among feedstock that may be largely independent of differences in bulk chemical composition. A thorough understanding of the physical, chemical and ultra-structural features of corn plants and their anatomical fractions, that affect process performance, will rationalize the development of pretreatment and saccharification processes. The Targeted Conversion Research project will develop understanding of these features as a baseline for studies in other projects. Differential performance during processing and the underlying physical, chemical and ultra-structural features may also be a function of genetic diversity among cultivars and environmental influences the plants experienced during growth, harvesting and storage.  In generating and characterizing materials in this task, a distinction between genetic and environmental factors may be revealed.  This knowledge will translate to other feedstocks, especially the similar perennial feedstocks like switchgrass.  The tools/methods will be validated in all feedstocks.

Understanding the interactions between cellulases and cellulosic substrates is critical to the development of an efficient engineered cellulase system for conversion of biomass to sugars.  The role that biomass composition and structure play in the reactivity of saccharifying enzymes will be determined.  Reciprocal examinations will determine the role of enzyme surface amino acid residues and glycosylation in the interactions of the enzymes with the heterogeneous substrates represented by pretreated lignocelluloses.  New insights gained from advanced modeling of cellulose and cellulase surfaces, and water barriers surrounding the cellulose hydrophobic surface, will direct explorations of approaches to optimize productive interactions.  The mechanism of processive (catalyzing the addition of multiple sugar residues) cellulases will be examined as a putative rate limiting operation in saccharification by fungal cellulase consortia.

**Task 2.5. Sugar Platform Analysis Support**
Analysis is performed under this task to support the ongoing research in the Sugar Platform. Analysis helps to provide direction and focus to the research by evaluating the technical, economic, and environmental aspects of biomass sugars production and conversion. This analysis also supports OBP's goals and is an integral part of the broader strategic analysis efforts of the program.

The Sugar Platform Analysis project captures the process engineering and life cycle analysis needed to direct research by translating all of the proposed and actual outputs from research into quantifiable costs and benefits for the technology. Much of the analysis work is a continuation and elaboration of past efforts to model and understand the economic factors and key uncertainties related to the sugars route to ethanol from lignocellulosic biomass.

### 3.2.11  Sugar Platform Milestones & Decision Points

**Task 2.1 Pretreatment Core R&D**
To continue advancements in this area and to make lignocellulosic sugar cost competitive with ethanol produced from starch, the pretreatment task will pursue the following critical path;

- Elucidate options in pretreatment chemistries and benchmark performance as guidance to industry development and demonstration activities.
- Coordination of the studies of pretreatment chemistries and cellulase mechanisms offer the potential to substantially reduce sugar cost.  To achieve the cellulase cost goal of $0.10/gallon ethanol (market targets case, $1.09 per gallon of ethanol), further improvements in cellulase activity must be realized.
- Development and comparison of leading biomass pretreatment technologies coupled with fermentation and enzymatic hydrolysis to gain insight that will facilitate selection and commercialization of cellulosic technologies and lead to step change cost reductions.

**Output:**

- Evaluate and compare current pretreatment options with respect to chemistry, reactor design, and pretreatment process. Select and further develop alternative pretreatment approaches that show good potential to meeting pretreatment performance and economic goals of the sugar platform.
- Ascertain the response of selected biomass feedstocks to a range of pretreatment conditions and determine their susceptibility to enzymatic saccharification.
- Further reduce cost of cellulases for the enzymatic saccharification of pretreated lignocellulosic biomass.
- Develop integrated pretreatment, fermentation, and enzymatic hydrolysis data for leading biomass pretreatment technologies on a common basis, develop models to predict the performance of each unit operation, relate performance to key features of biomass and catalysts, estimate economics on a consistent basis, and widely disseminate the results.

**Task 2.2 Feedstock-Sugars Interface**

The DOE feedstock-sugar interface R&D investment establishes the value of, and requirements for feedstock assembly and preprocessing processes to biorefining processes. The products of this task will define delivered feedstock requirements for biorefining pathways, including the following critical path:

- Developing feedstock cost and quality specifications
- Linking biorefining pathways to sustainable biomass resources, and
- Engineering feedstock assembly technologies compatible with biorefining pathway technologies.

**Output:**

- Define / document feedstock delivery and pretreatment requirements based on the best available technologies.
- Assess the multiplicity of feedstock resources / assembly option combinations for coupling to near-term biorefinery pathway technology designs.
- Selection of the best near-term and long-term feedstock assembly / preprocessing options based on feedstock and platform technology trade-off decisions.
- Develop feedstock supply assembly models and analyses necessary to optimize feedstock supply chains to biorefineries and reduce supply risks.

**Task 2.3 Sugar Processing Integration**

With the placement of Integrated Biorefinery contracts, and based on feedback from the Interim Stage Review, the Sugar Processing Integration (SPI) Task will focus on research and fundamentals as opposed to the previous concerns with defining a commercial technology. The critical path includes:

- Assess the impact of corn stover variability on process performance, advance efforts to survey new feedstocks, investigate process relevant integration issues, improve and developed new biomass compositional methods that improve mass balance closure and validate yield calculations, and develop and deploy rapid analysis methods for use by industry. Ultimately, all of these efforts also support our goal to produce process relevant streams and residues for testing and evaluation by industry.

- Continue to use dilute acid pretreatment and corn stover for the next 2-3 years.
- Incorporate advanced pretreatment technologies in integration efforts.
- Commence identification of compositional variability on an herbaceous feedstock (e.g., switchgrass).
- Validate process performance first at the bench scale (FY07) and later at the pilot scale (FY11).

**Output:**
- Characterize effect of corn stover variability on process performance
- Demonstrate high solid pretreatment and saccharification.
- Produce process relevant residues for testing.
- Demonstrate integrated pretreatment, saccharification, and fermentation at the bench and pilot scale
- Long-term plans call for incorporation of new feedstocks and technology of interest to the industry.

**Task 2.4. Targeted Conversion Research**
This task will continue the following critical path:
- A better understanding of how changes in the chemical and structural properties of hemicellulose, cellulose and lignin affect the enzymatic digestibility of biomass substrates will allow us to improve saccharification processes to decrease the cost of biomass derived sugars.
- Understanding the source of the processing variability between different lots of corn stover will potentially help to improve process yield and economics, and thus help to mitigate risk associated with commercialization of biomass conversion processes, both for stover and other feedstocks.
- Characterization of lignocellulosic biomass will be extended from compositional analysis and macrostructural classification to micro-structural and cellular characterization. Single molecule enzyme studies will allow accurate characterization of cellulase-substrate interactions.

**Outputs:**
- Study the changes in biomass caused by dilute acid and other chemical treatments.
- Using the BSCL, develop appropriate methodologies at several scales for characterization of native and pretreated lignocellulosic biomass. A user group and cadre of collaborators will be identified.
- Enhance understanding of cellulase catalytic mechanisms and mechanisms of cellulase interactions with insoluble lignocellulosic substrates.
- Characterize ultrastructural and micro-scale chemical differences between diverse varieties of corn and correlate findings with performance in model dilute acid pretreatment and saccharification reactions.

**Task 2.5. Sugar Platform Analysis Support**
The process to produce ethanol will still be used as a base case process to evaluate the economic impacts of technology developments. However, increasingly greater emphasis will be given to producing additional products from the sugar streams in addition to ethanol.

**Outputs:**
• Provide conversion process design and costs for biomass to sugar and to a model product.

- Justify and guide research within in the sugar platform. Show progress to the R&D targets.
- Provide design and cost information for sugar production to the biomass community.

| | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Corn Wet Mill Improvement Pathway | | | | | |
| Pretreatment Core R&D | | ♦1 ♦3 | | | |
| Feedstock-Sugars Interface | | | | | ♦13 ♦15 |
| Sugars Processing Integration | | | | | |
| Targeted Conversion | | | | | |
| Corn Dry Mill Improvement Pathway | | | | | |
| Pretreatment Core R&D | | | | | |
| Feedstock-Sugars Interface | | | | | ♦13 ♦15 |
| Sugars Processing Integration | | | | | |
| Targeted Conversion | | | | | |
| Agricultural Residue Processing Pathway | | | | | |
| Pretreatment Core R&D | ♦6 | | | | |
| Feedstock-Sugars Interface | ♦12 | ♦11 ♦18 | | ♦15 ♦16 ♦17 | ♦13 ♦14 |
| Sugars Processing Integration | | ♦10 | ♦8 | ♦9 | |
| Targeted Conversion | ♦6 | | | | |
| Perennial Crop Processing Pathway | | | | | |
| Pretreatment Core R&D | | | ♦6 | | |
| Feedstock-Sugars Interface | | | ♦12 ♦18 | | ♦11 ♦13 ♦14 ♦15 ♦16 ♦17 |
| Sugars Processing Integration | | | | ♦10 | ♦8 ♦9 |
| Targeted Conversion | | | ♦6 | | |

| | | | | | |
|---|---|---|---|---|---|
| **Oil Crop Processing Pathway** | | | | | |
| Pretreatment Core R&D | | | | | |
| Feedstock-Sugars Interface | | | | | |
| Sugars Processing Integration | | | | | |
| Targeted Conversion | | | | | |
| **Pulp and Paper Mill Improvement Pathway** | | | | | |
| Pretreatment Core R&D | | | ♦ 5 | | |
| Feedstock-Sugars Interface | | | | | |
| Sugars Processing Integration | | | | | |
| Targeted Conversion | | | | | |
| **Forest Products Mill Improvement Pathway** | | | | | |
| Pretreatment Core R&D | | | | | |
| Feedstock-Sugars Interface | | | | | |
| Sugars Processing Integration | | | | | |
| Targeted Conversion | | | | | |

| | Milestones |
|---|---|
| **1** | Convert residual starch to ethanol (2007) |
| **2** | Evaluate new feed product (ongoing) |
| **3** | Validate integrated process at pilot scale (2007) |
| **4** | Solubilize hemicellulose in fiber to C5 sugars (2004) |
| **5** | Meet yield target for C5 and C6 sugars without negatively impacting paper quality (FY08 for B) |
| **6** | Validate cellulase enzyme cost at the equivalent of $0.xx/lb sugar (2005) |
| **7** | Validate pretreatment technology cost at the equivalent of $0.xx/lb sugar (2005) |
| **8** | Demonstrate ability to economically satisfy internal heat and power demands |
| **9** | Capital cost limits based on least cost design basis and/or industry financing hurdle |
| **10** | Validate integrated pretreatment and enzymatic hydrolysis at pilot scale (2007) |
| **11** | Validate analysis and optimization tool to support feedstock supply chain integration |
| **12** | Identify sufficient, sustainable agricultural residue supply at $10/dry ton grower payment. |
| **13** | Resource data with national coverage for all significant existing ag. residue resources is up-to-date, documented, and readily available via the internet. |
| **14** | Develop technologies and methods to harvest and collect nationally 300 M tons/year of ag. residues with a 50% cost reduction when compared to current (2003) technologies. ($12.50/dry ton) |
| **15** | Develop and demonstrate innovative storage methods so that the impact on cost, accounting for losses, is less than 50% compared to current (2003) dry bale based systems. ($1.75/dry ton) |
| **16** | Demonstrate transportation cost reductions resulting in average transportation costs of $8/dry ton or less. |
| **17** | Demonstrate preprocessing technologies that produce agricultural residue resources with bulk and flowability properties similar to other large solid commodities so that it can be handled with traditional high-volume conveyance thus reducing cost by 50% when compared to bale-based systems. ($2.75/dry ton) |
| **18** | Develop optimized process and cost models for feedstock supply systems and validate analytically that agricultural residue feedstocks could be supplied to biorefineries at $35/dry ton. |

## 3.3 Thermochemical Platform

The Thermochemical Platform (TC Element) develops technology to thermochemically convert biomass into intermediate products that can then be used as intermediates for fuels and chemical synthesis (Figure 3.3-1). The processing technologies can be categorized as gasification, pyrolysis, or hydrothermal processing. Intermediate products include clean syngas (a mixture of primarily hydrogen and carbon monoxide), bio-oil (pyrolysis or hydrothermal), and gases rich in methane or hydrogen. These intermediate products can then be upgraded to products such as gasoline, diesel, alcohols, ethers, synthetic natural gas, or high-purity hydrogen, or may be used directly for heat and electric power generation.

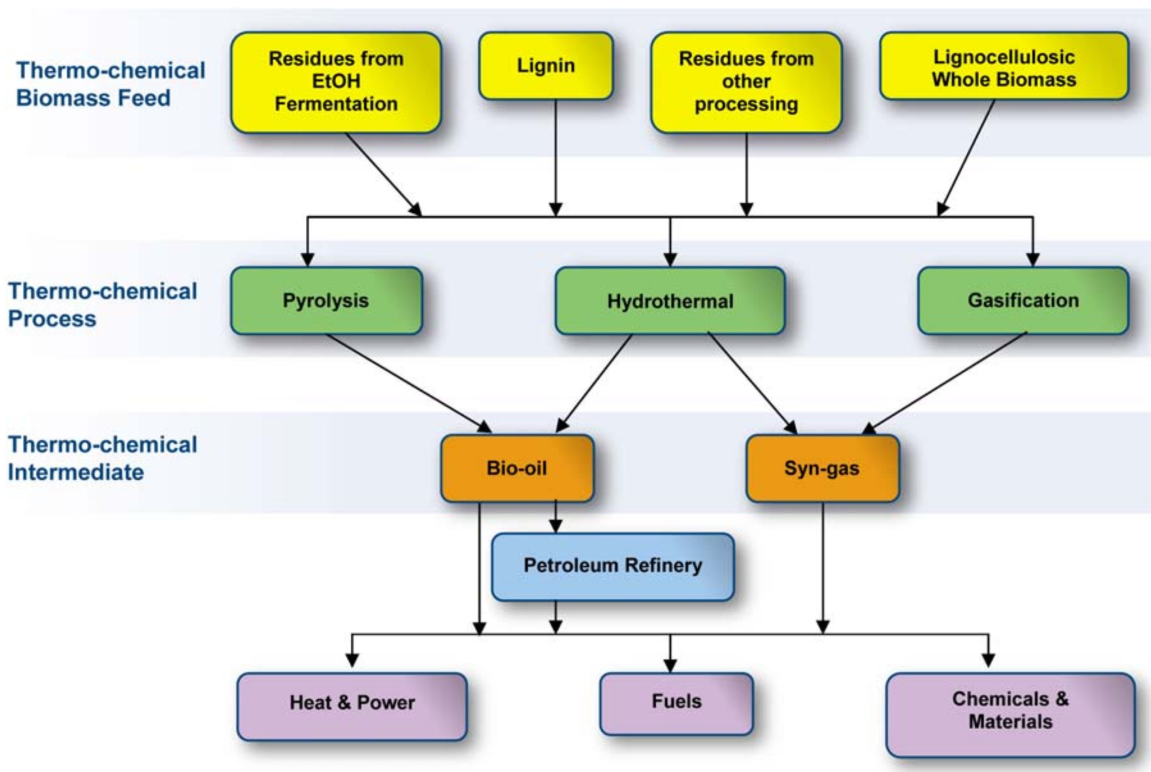


**Figure 3.3-1: Biomass Conversion to Products via Thermochemical Processes**

Thermochemical liquefaction and gasification are important in providing a source of additional value-added products for the integrated biorefinery, from not only biomass that can't be used in the sugar based biorefinery ("off-spec"), but also the lignin-rich residues from the biological-to-fuels processes (e.g. fermentation) and residues from current manufacturing processes like pulp mills. To avoid waste streams and to maximize the value, these residues, lignin, off-spec feedstocks, and other unconverted materials must be used to produce additional value-added fuels and chemicals. Development and integration of Thermochemical conversion technologies also offers the potential of more energy efficient biorefineries by allowing integration of high efficiency heat and power production systems, such as combined cycle gas turbines or fuel cells.

Thermochemical conversion provides an effective approach for producing fuels and products from a wide variety of biomass feedstocks, because it can readily convert all components of whole biomass[1], including lignin (a residue of fermentation process) and spent pulping liquors, to intermediate building blocks. Conversion of the lignin (typically 20%-30% of the biomass) to products is essential to achieve high efficiencies and added value in the biorefinery. Unlike the sugar fermentation processes, thermal processes are "omnivorous" in this regard and can convert all biomass feedstocks or residues to gas or liquid intermediates. In addition, in cases where there is low water availability, high lignin content, degradation during harvest, or diffusely distributed resource, which is a significant fraction of the available biomass resource; thermochemical conversion can provide a means to access the entire energy content of the 1.3 billion ton/year biomass resource[2].

Thermochemical conversion also provides the potential for direct substitution of biomass into the existing petroleum processing infrastructure. In gasification processes cleanup and conditioning of the raw gas results in a clean synthesis gas amenable to existing catalytic fuels synthesis processes. When perfected, liquefaction can be employed as a technology that transforms biomass into a liquid intermediate amenable to conventional petroleum processing techniques. After liquefaction, this pyrolysis bio-oil can be chemically upgraded to conventional hydrocarbon fuels using existing petroleum refinery technology. It is then possible to access and leverage the extensive infrastructure developed in the petroleum and chemicals industry to produce a wide range of liquid fuels and chemicals.

### 3.3.1 External Assessment and Element Market Overview

#### 3.3.1.1 Overview of Current and Potential Markets for the Technologies

Biomass-derived fuels and products must favorably compete against fossil-derived fuels. Technically, the systems used to thermochemcially convert biomass to a synthesis gas or bio-oil, fungible with fuel synthesis processes, are similar to those systems use for coal today. The largest market hurdles are associated with the scale-up and economics of pioneer plants, and price competition with coal-syngas and liquid products produced from stranded natural gas.

Thermochemical conversion of biomass to synthesis gas or bio-oils requires technology that is similar to that currently used in the coal and petroleum industries today. Biomass is harder to handle and feed than fossil-based feedstocks. Further, biomass feedstocks tend to be more geographically dispersed, and in much more ecologically sensitive areas than fossil resources. The synthesis gas produced has potentially higher levels of tars and particulates than its fossil counterpart feedstocks. Additionally, the size and scale of current fossil-resource-based thermochemical processing facilities are much larger than that which can be economically

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[1] For example, the Lahti circulating fluidized bed gasifier system processing a collection of biomass materials including saw dust, wood residues and recycled fuel made up of wood, paper, cardboard and a small portion of plastics achieved carbon conversion of >99.99%. Manjunath, A. et al. Foster Wheeler, “Efficient and Clean Biomass Gasification and Combustion Technologies” www.fwc.com/publications

[2] Biomass Resources: Trends And Possibilities internal OBP document

applied in a biomass conversion scenario because of the dispersed nature of the feed. More importantly, analysis has shown that thermochemical conversion of biomass for fuels production must be integrated into a larger refinery model to be economically attractive. While the program is seeking to develop a bio-refinery, integration of biomass TC intermediates into existing petroleum refineries is also an option that industry is currently considering.

**3.3.1.2 Political Environment Nuances**

DOE, in partnership with USDA, has been committed to expanding the role of biomass as an energy source for many years. Specifically, these organizations support biomass fuels and products as a way to reduce the nation's dependence on foreign oil, to offer new opportunities for economic growth in rural communities, and to foster the establishment of new domestic biorefineries throughout the U.S. The Biomass R&D Technical Advisory Committee, established by Congress in 2000 to guide federally-funded biomass R&D, has established a goal that biomass will replace 30 % of the country's petroleum consumption by 2030. More recently, the Energy Policy Act of 2005 highlights the need to move away from a petroleum-based transportation sector and toward increased use of renewable fuels such as ethanol and biodiesel, especially in the medium time range. This bill includes tax incentives and requirements for the increased production and use of renewable transportation fuels to promote these goals. In addition, the large increases in the cost of petroleum observed during the first half of 2005 are bringing a new urgency to these efforts.

**3.3.1.3 Potential Competing Technologies**

The clean syngas that could be produced from biomass using TC technologies will compete directly with coal-syngas, but having the added advantages of being domestically produced (US-based biorefineries) from a secure feedstock source (US-based biomass) and sustainable. Biomass pyrolysis oils offer the advantage of being a direct replacement for petroleum in conventional refinery operations.

Hence while the potential market is large for thermochemically derived biomass fuels and chemicals, significant technical challenges exist. These challenges are being attacked by OBP's R&D program using a detailed Work Breakdown Structure focused on eliminating technical barriers to TC technology.

**3.3.2 Internal Assessment and Program History**

**3.3.2.1 Element History**

Prior to the creation of the Biomass Program, the Thermochemical Platform (TC Element) was a program unto itself, the BioPower Program, which focused solely on the production of heat and power from biomass. Its research areas were: the combustion and gasification of biomass, the integration of combustion and gasification systems with advanced power generation (e.g. gas turbines, fuel cells, etc), and the "co-firing" of biomass with fossil fuels (coal, oil, natural gas) in both combustion and gasification systems.

The Biomass Program refocused the technology R&D efforts of the TC Element towards converting biomass to intermediates that could be utilized as a feed for fuels and chemical synthesis. This refocusing also allowed the TC Element to be closely integrated with the Sugars

Element, the Products R&D Element, and the Integrated Biorefinery Element. This has created a cohesive, unified effort to develop biomass conversion technologies, and fuels and products synthesis technologies (using TC and Sugars feeds) and integrate them into fully functioning biorefineries.

### 3.3.2.2 Element Organization and FY06 Activities

The TC Element employs rigorous analysis to focus its R&D on technical barriers that impact quality, and cost of producing syngas & bio-oils. These technical barriers form the basis of the Work Breakdown Structure described in Figure 3.3-2.

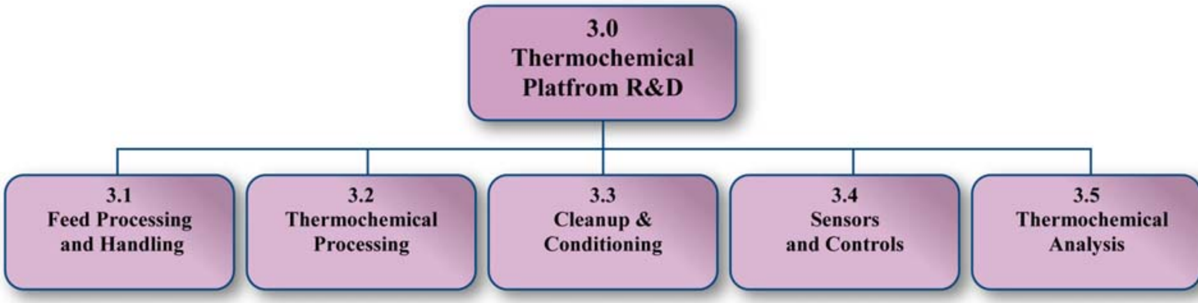


**Figure 3.3-2: Work Breakdown Structure for the Thermochemical Platform Core R&D Area**

### 3.3.2.3 Element Recent Accomplishments

A sample of recent significant accomplishments and activities within each barrier area are as follows:

**Feed Processing and Handling**

- The technology for feeding and handling wood and some agricultural residues has been developed by industry. This technology can be used by the Program.
- The Program is currently assessing the need for additional technology capable to handling slurries and other residue streams that might come from a biorefinery.

**Thermochemical Processing**

- Gasification technology applicable for spent pulping liquors produced by the Pulp and Paper industry has been developed. Two commercial-scale spent pulping liquor gasifiers are operating in the United States.
- Industrial partners are evaluating innovative gasification technology for several different biomass feedstocks.

**Cleanup and Conditioning**

- Industrial partners and national laboratories are developing and demonstrating technology for cleanup (removal of tars and other impurities) of biomass derived syngas.
- Options for removal of sulfur from syngas to levels suitable for production of liquid fuels have been identified.

**Process Controls**

- There is no work in this area, because of funding considerations.

**Integration**

- A recent report illustrates the potential for producing a number of products from biomass syngas.
- A detailed technoeconomic analysis on the production of hydrogen from biomass syngas has been completed.
- Reductions in the estimated costs of biomass syngas are detailed on an annual basis.

The conversion and clean-up technologies developed within this TC Element are closely coordinated with the Products and the Integrated Biorefineries Element so that technologies from those efforts are effectively integrated to convert the TC intermediates into fungible fuels and/or chemicals.

### 3.3.3 Element Federal Role

#### 3.3.3.1 Element Contributions to a National Federal Need

The TC Element funds R&D to develop technology that will economically convert biomass (in various forms) into synthesis gas or bio-oil that can be used as an intermediate to synthesize fuels and chemicals. By developing and implementing technology the TC Element directly helps the program complete its planned pathways, and thus its goal to reduce dependency on foreign oil. The TC Element is developing technology that has a high level of technical and economic risk, is not yet commercially available and offers significant potential rewards for the whole nation. Thus, it requires support from the Federal government to reduce the technical and commercial risks so that the benefit of reduced foreign oil imports can be realized.

The TC Element actively seeks partnerships between federal labs, universities, U.S. industry and individual states to guide and perform the R&D that will develop these technologies. Through these partnerships and based on its rigorous analysis, the TC Element has defined four primary technical barrier areas to successful technology: Feed Handling, Gasification, Gas/Oil Cleanup and Conditioning, and Systems Control.

#### 3.3.3.2 Complementary Federal Programs

The TC Element converts biomass to synthesis gas and/or bio-oils. A few other federal programs are authorized to perform R&D within the technical barrier areas defined by the TC Element, but very few provide actual funding. The DOE's Hydrogen, Fuel Cells and Infrastructure Program has funded analysis examining the conversion of biomass-derived synthesis gas and bio-oils to hydrogen, but does not currently fund R&D. DOE's Office of Fossil Energy has had their coal gasification program in place for a number of years, but has not taken an in-depth look at gasifying biomass or the barriers surrounding it. Lastly, the USDA minimally funds R&D and demonstration for biomass-gasification-to-power, only touching on all of the technical barriers defined by the TC Element. The TC Element not only compliments other federal programs, it leads the effort to develop technology for thermochemical based biomass conversion.

### 3.3.4 Element Approach

#### 3.3.4.1 Core R&D Research

The TC Element relies on analysis to guide research and determine cost, barriers and progress. This analysis function is included in the WBS, but is not a barrier. Additionally, this technoeconomic and process analysis defines the overall impact of TC conversion technologies and the benefits of specific technology sub-elements in reducing the costs of TC intermediates.

The approach utilized by the TC Element is to use its detailed WBS to focus R&D on the technical barriers that present the highest potential gain, and thus ensure that the work is organized and managed to achieve the product cost and quality goals in a timely manner. The product cost and quality goals are detailed below in "Section 3.3.5 Element Performance Goals". Managing R&D within the WBS allows the TC Element to contribute to achieving OBPs goal of developing a biorefinery.

Graphically the WBS is shown in Figure 3.3-2**,** and organizes individual projects to ensure they are clearly focused on the Biomass Program's A and B level milestones. The WBS is useful for highlighting the relationship between projects, for identifying multiple projects that are working on related milestones. Properly managed, this increases the likelihood of success for achieving the most important milestones, and for ensuring that no critical technology areas are overlooked.

The integrated biochemical/thermochemical Biorefinery, shown conceptually in Figure 3.3-3, allows the TC Element to maintain a clear focus on how the individual projects and pieces of technology need to be combined to achieve the overall goals of the Biomass Program.

The approach for the Thermochemical Element involves core research, addressing key technical barriers; industrial development and demonstration projects, addressing integration and system scale-up. National laboratories, industry, and universities perform the core technical research. The industry and university projects will be selected through solicitations targeting specific technical objectives.

Much of the supporting core research on gasification of biorefinery residues will be focused on Biorefinery integration issues. This approach focuses on the thermochemical processes that apply to the corn wet and dry mill, and agricultural residue-based pathways. In future years it focuses on advanced process ideas or technology developments that may form the basis for new R&D areas that could be integrated into the forest-based biorefineries or standalone thermochemical biorefineries. The current efforts are focused on gasification of biorefinery residues and low quality agricultural residues with the goal of having technology ready for incorporation in a biorefinery demonstration by 2008 in order to provide US industry options for their proposals to the planned FY08 Biorefinery solicitation. In later years The TC Element will pursue advanced process ideas or technology developments that may form the basis for new R&D areas, such the forest-based biorefineries or standalone thermochemical biorefineries.

#### 3.3.4.2 Element Contribution to Pathway and Program Outputs

The Integrated Biorefinery Element will utilize technologies developed in the platform research areas (e.g. TC Element) by applying them in commercial biorefineries. These industry-partnered efforts will address the critical process integration (sustainable supply, heat integration, waste minimization, etc.) issues that can be examined only in an integrated plant with specific technologies.

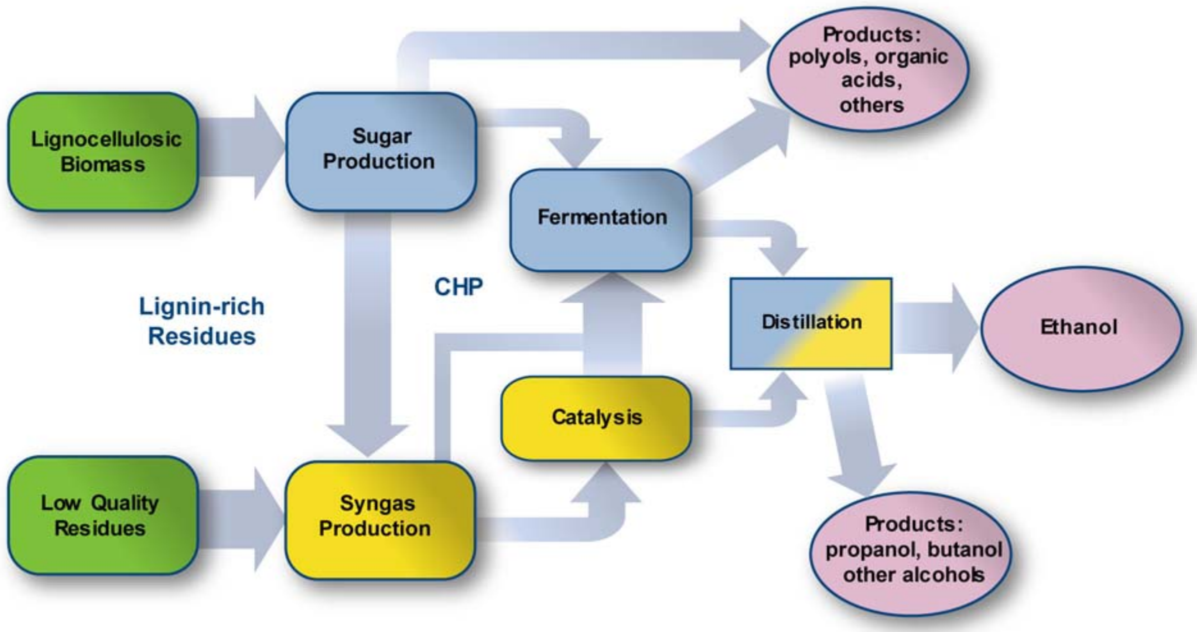


**Figure 3.3-3: Schematic of the Integrated Biochemical/Thermochemical Biorefinery**

### 3.3.5 Element Performance Goals

As mentioned above the Thermochemical Platform has organized its work to achieve cost and quality goals for the intermediates produced (syngas or bio-oils). These cost goals are defined by detailed technoeconomic analysis while the quality goals are defined by the need to couple biomass thermochemical technology with known catalytic processes used for the production of liquid fuels. In the case of biomass-derived syngas both the costs and quality goals are well defined. In the case of biomass-derived pyrolysis oils or hydrothermal products the costs and quality goals are less well known but work in the Thermochemical Platform will help defined these goals. In the case of pyrolysis oils the quality goals are tied to the presence of residual char fines remaining in the oil from the initial conversion step. These char fines directly impact the long term stability of these intermediate products.

In the case of biomass-derived syngas the product cost and quality goals are known. The goals of the program are:

- production of clean syngas at $5.0 / million Btu by 2010 and for $3.9 by 2020[3].
- production of stable bio-oil for $5.1 / million Btu by 2010 and for $4.3 by 2020[4].

[3] Spath, P. "Updated Synthesis Gas Cost Targets for FY 2005." NREL memo dated 3/8/2005.
[4] Putsche, V. and Spath, P. "Biomass Pyrolysis Cost Barriers Analysis" NREL Milestone Completion Report dated April 15, 2004, as revised by Richard Bain, 4/22/2005.

As shown in Table 3.3-1 the cost of syngas will decrease as the technology supported by the TC Element is developed and integrated within a biorefinery, or potentially petroleum refineries.

**Table 3.3-1: Future Cost of Biomass Derived Syngas**

| | | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| Syngas selling price | ($/GJ, LHV) | 6.88 | 4.98 | 4.51 | 3.84 |
| | ($/MMBtu, LHV) | 7.25 | 5.25 | 4.75 | 4.05 |

The costs of producing syngas or pyrolysis oils can be viewed in another manner. The costs of gasification and related subsystems represents over 60% of the total capital cost to produce an example product (Figure 3.3-4[5]), therefore improvements in these subsystems can have a significant impact in the cost of the final product. Thus, the cost of producing syngas is a clear target where the OBP research can make an impact. This same type of detailed analysis has also been performed for bio-oils. However, the detailed analysis for wet-gasification or hydrothermal processing has not been fully developed.

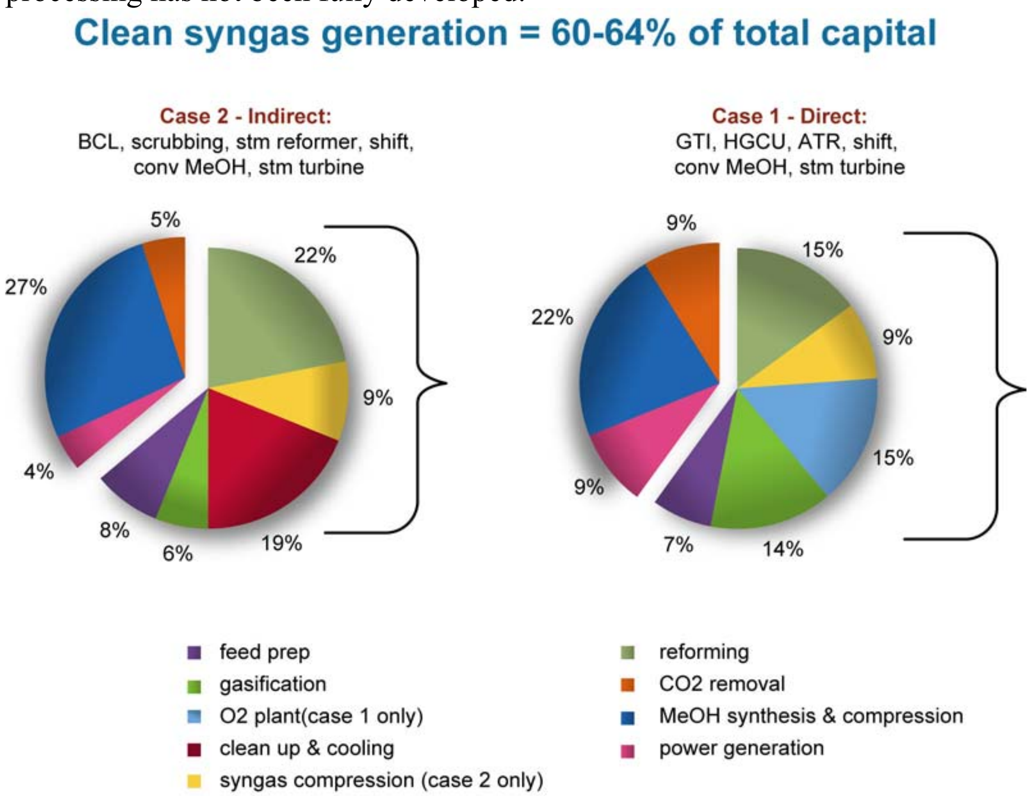


**Figure 3.3-4: Breakdown of the Costs of Producing Products from Biomass Syngas**

[5] Spath, P. L.; Dayton, D. C. (2003). Preliminary Screening -- Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas. 160 pp.; NREL Report No. TP-510-34929.

Thermochemical conversion technology development will address the impact of using the full range of biomass feedstocks including wet residues of the biochemical biorefinery and the pulp and paper industry, to lignocellulosics, such as woody biomass, forest residues, corn stover, and straw. In addition, it is important to determine the impact of scale on Biorefinery economics and to have appropriate thermochemical conversion systems available at those scales.

The Thermochemical Platform R&D efforts will ensure that the conversion technologies and the liquid and gaseous products derived from them are compatible with the production of fuels and chemicals based on technologies currently available through petroleum-based industry. This can provide near-term opportunities for biomass while also leveraging the extensive related experience of industry. In the mid- to long-term, OBP will ensure that thermochemical biomass intermediates (gases and liquids) are compatible with advanced technologies used to convert them into fuels and chemicals.

The quality goals for biomass-derived syngas are defined by the requirements for the processes that will convert the syngas into liquid fuels. In most cases these processes for converting syngas into liquid fuel products are commercial or have been demonstrated at the industrial pilot scale. Thus, the syngas quality specifications are reasonably well known. Examples of the syngas quality specifications are provided in Table 3.3-2. The specifications highlighted in Table 3.3-2 are the general targets for the biomass syngas to serve as a "drop-in" (fungible) replacement for coal or natural gas-derived syngas. The actual specification for a biorefinery will be defined by the detailed economics and the interplay between the costs of cleaning up the syngas and the costs of operating the fuels synthesis process. These targets cover a broad range of potential fuel products however, the TC Element will not meet the goals for all the fuel products in the near term.

**Table 3.3-2: Cleanup and Conditioning Specification Targets**

| Product Target | Catalyst | other , ppm | tar, ppm | particulate mg/Nm$^3$ | $H_2S$/COS mg/Nm$^3$ | metals ppm | $H_2$/CO mole ratio | Pressure psig |
|---|---|---|---|---|---|---|---|---|
| Mixed alcohols | Cu(M) | <0.01 Cl | <0.1 | <0.01 | <0.1 | <1 | 1.2 | 2000 |
| Mixed alcohols | Rh | N/A | <0.1 | <0.01 | <0.1 | <1 | 1.4 | 1000 |
| Mixed alcohols | $MoS_2$ | N/A | <0.1 | <0.01 | 500>x>50 | <1 | 1.2 | 2000 |
| MeOH/DME | CuZn | <0.01 Cl | <0.1 | <0.01 | <0.1 | <1 | 2 | 1000 |
| Fischer-Tropsch liquids | Co | N/A | <0.1 | <0.01 | <0.1 | <1 | 2 | 500 |
| Hydrogenated bio-oil | Pd, Ru, Ni | <3 P | NA | use guard bed | <2 ppm | <2 | NA | NA |
| Hydrogenated bio-oil | CoMo, NiMo | <3 P | NA | use guard bed | 500>x>50 ppm | <2 | NA | NA |

### 3.3.6 Element Strategic Goals

The TC Element has one strategic goal that supports EERE's Strategic Goal of reducing imported petroleum and developing the biobased industry. That TC strategic goal is to develop technology for producing, clean, low-cost syngas or bio-oils from biomass and biorefinery residues. Working in concert with the other OBP platforms these technologies will be integrated into a biorefinery to produce fuels, chemicals, heat and power.

### 3.3.7 Element Market Challenges and Barriers

There are a handful of market barriers related to full implementation of technologies developed within the TC Element. Most of these market barriers will be addressed by further development of the technology and industry partnerships. These market barriers are as follows:

**Tm-A. Cost of the clean syngas or bio-oil intermediate that can be converted into liquid products.** This clean biomass-derived syngas competes against syngas derived from coal or natural gas, and presently the biomass-derived syngas is not cost competitive. The currently higher cost of biomass-derived syngas is related to the lower energy density and higher feedstock costs of the biomass. However, these higher costs can often be offset by high-value marketable externalities such as a domestic source for liquid fuels, avoidance of greenhouse gas emissions, and long-term sustainability.

**Tm-B. Industry and public utilization and acceptance of biomass-derived fuels and chemicals.** This can be termed drivability and marketability. In the near term, the current higher costs of biomass-derived fuels can potentially be offset by accurately defining the marketable externalities such as a domestic source for liquid fuels, avoidance of greenhouse gas emissions, and long-term sustainability. The TC Element is actively pursuing partnerships with industries that are interested in having high-valued, thermochemically produced biomass fuels as part of its product suite.

**Tm-C. The relatively large scale and large capital costs of Thermochemical process facilities, including the cost and payback of systems.**
Thermochemical conversion processes are typically conducted in very large-scale facilities with corresponding high capital costs. This large scale leverages the economics of scale in both the initial gasification process, and also in any secondary conversion process to produce liquid products, but the high capital costs pose a significant barrier to the commercialization of Thermochemical technologies. The Thermochemical Platform is working with different partners to investigate two alternative routes for reducing capital costs. The first involves the integration of Thermochemical technologies into existing facilities. For example, two OBP cosponsored projects are developing gasification technology with the Pulp and Paper industry, and these projects leverage in-place capital and the relatively high costs of the alternative, e.g., replacing out of date black liquor recovery boilers. The Thermochemical Platform is also looking to leverage work being done by petroleum refineries who are interested in relatively small scale gasification processes for conversion of stranded natural gas resources into liquid fuels. Both of these approaches will continue to be explored.

**Tm-D. Knowledge of how to effectively integrate Thermochemical and Biochemical (Sugars) process technology in a Biorefinery configurations.**

As previously noted, the technologies developed within this TC Element are closely coordinated with the Products and the Integrated Biorefineries Element so that technologies from those efforts are effectively integrated to convert the TC intermediates into fungible fuels and/or chemicals.

This need for integration may limit the deployment of TC technology to areas where bioconversion is most promising or areas where other commercial technologies have already been deployed, i.e., pulp and paper mills. The opportunities for integration of TC and Biochemical processes include utilization of the lignin-rich fermentation residues, or raw biomass feedstocks that have relatively low amounts of fermentable sugars and other low cost biomass sources. These integration efforts are expected to increase the total amount of liquid fuels produced in the Biorefinery, and therefore improve the overall marketability of the Biorefinery. These integration efforts will also benefit from work to reduce the overall scale and capital costs of thermochemical technology.

**Tm-E. The availability of a sustainable supply of biomass feedstocks**
A large and sustainable supply of biomass is often cited as a primary reason of industry not utilizing biomass conversion technologies (including TC). As detailed in this document, the Program has ongoing efforts to address this issue.

**Tm-F. Widespread availability of personnel with knowledge of operation, maintenance of thermochemical systems.**
Thermochemical conversion systems for coal and other fossil based fuels (or residues) have been in operation for several years. However, very few biomass-based systems are in operation and some of the unique challenges associated with them can only be overcome by operational experience that comes with "time-on-line". As the TC Element develops and nurtures additional industrial partnerships this necessary pool of knowledgeable personnel will increase.

### 3.3.8 Element Technical Challenges and Barriers

Since gasification and related subsystems represents over 60% of the total capital cost to produce an example product[6], improvements in these subsystems have a significant impact on the cost of producing the final product (e.g. fuel). OBP-funded research and development are focused to make an impact on this cost. Platform and technoeconomic analyses are employed to define the cost contributions, and guide and monitor the progress of specific research projects for reducing costs.

Platform and technoeconomic analyses help determine the potential impact of the TC Element and the benefits of overcoming specific technical barriers, in addition to setting and measuring performance targets. Figure 3.3-5 is an example of how the TC element utilizes analysis to determine benefits of overcoming technical barriers[7]. The figure shows that the largest potential

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[6] Spath, P. L.; Dayton, D. C. (2003). Preliminary Screening -- Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas. 160 pp.; NREL Report No. TP-510-34929.
[7] Spath, Pamela "Updated Synthesis Gas Cost Targets for FY 2005 – Revised to include LOCAT operating cost" Technical Memorandum April 8, 2005.

reduction in syngas cost can be obtained with technology development in the Clean up and Gasification areas, while a total potential reduction of 46% can be achieved with improvements in all four barrier areas.

Although preliminary economic assessments have been completed for other TC processes, such as pyrolysis and hydrothermal processing, levels of analysis similar to those presented in Figure 3.3-5 are yet to be completed. Existing projects in FY05 should begin to address the potential economics for each of these technology areas.

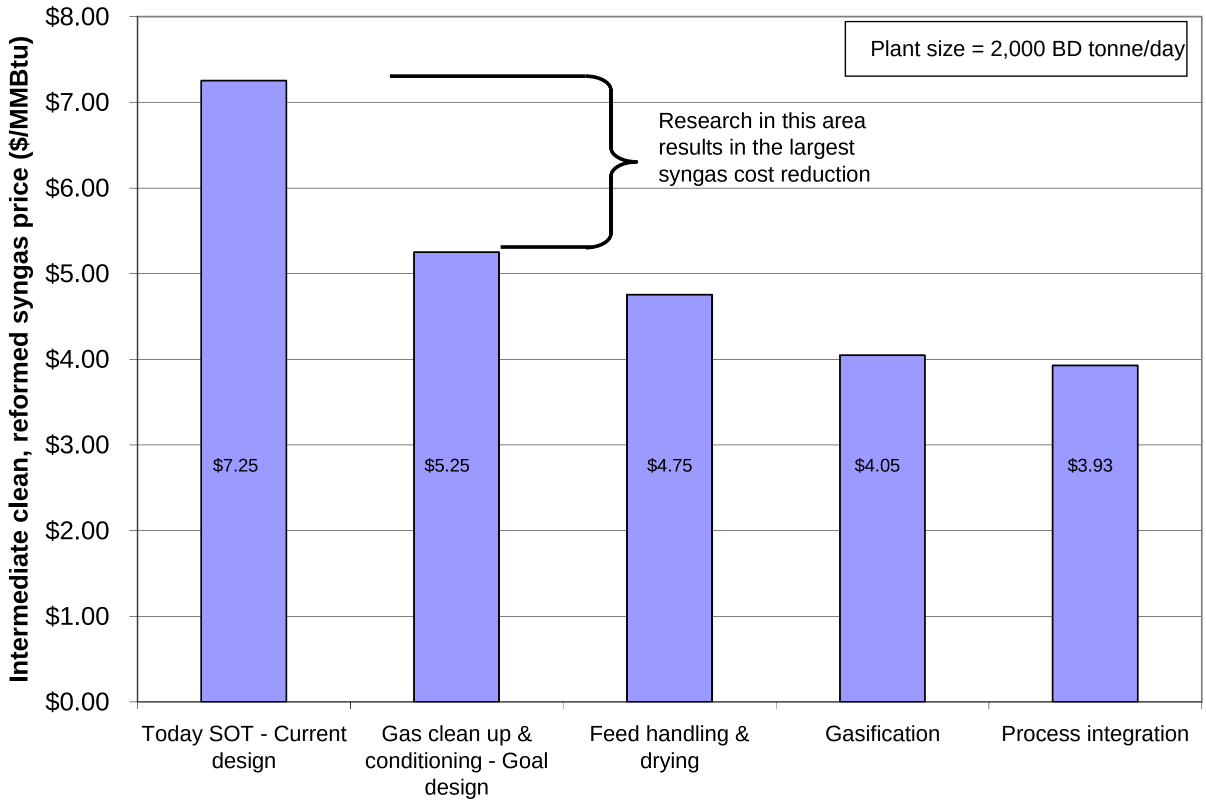


**Figure 3.3-5: Translating Barrier Reductions to Cost Impacts for Syngas Intermediate**

The TC Element uses this analysis to establish the relative priority of each of the technical barrier areas. All areas are considered necessary, but with limited resources the priority ratings provide an indication of their relative importance. The priority rankings are based several criteria including an assessment of the potential for technical success and reductions in the cost of biomass derived syngas using a combination of published reports, pilot results, and engineering experience/judgment. The first criterion is the potential impact of overcoming that barrier on the cost of processing. Secondarily, the level of development and its relation to the required commercial performance was evaluated, i.e., the more development required, the higher the priority. As an example, in the near-term case, the state of the art in gasification is relatively advanced compared to the cleanup systems that would be needed to couple with product synthesis processes. In the long-term, development of reduced cost thermochemical conversion processes provides the best opportunity for overall cost reduction. Also considered was the degree to which an area is an absolute barrier i.e. feeder development may not realize significant cost reductions, but reliable feed systems are critical to any biorefinery. In some cases the relative priority is driven by what is needed first in the development sequence for the success of a biorefinery demonstration. Although advanced sensors and controls might improve process operating and maintenance costs, a number of biomass plants currently operate with conventional instrumentation.

Over time, the relative priority of each area will change as the barriers are overcome and this research plan evolves.

As previously noted, the technologies developed within this TC Element are closely coordinated with the Products and the Integrated Biorefineries Element so that technologies from those efforts are effectively integrated to convert the TC intermediates into fungible fuels and/or chemicals.

Below are brief descriptions of each technical barrier area.

**Feed Processing and Handling**
Any process, including thermochemical technologies, requires a supply of uniform feedstock and reliable feed preparation, storage, and handling systems.

> **Tt-A. Feeding Dry Biomass.** In the near-term, there are no significant barriers to feeding and handling dry wood or agricultural residues provided they are of a relatively uniform particle size. In the longer term, there is a need for improvements in the processing and feeding of dry biomass including densification and removal of problematic chemical contaminants (e.g. alkali species).

> **Tt-B. Feeding or Drying Wet Biorefinery Streams.** There is a need to understand the costs and trade-off of drying or feeding wet biorefinery residues such as wet lignin-rich fermentation residues. Innovative dryer designs capable of utilizing low value process heat will be important improvements to the integrated biorefinery.

**Thermochemical Processing**
The technical community generally agrees that there is good understanding of global gasification and pyrolytic conversion chemistry for wood feedstocks.

> **Tt-C. Gasification of Wood, Biorefinery Residue Streams and Low Sugar Content Biomass.** There is a need to understand the fuel chemistry and physical handling properties of other biomass feedstocks, minor products and biorefinery residual solids. This includes developing an understanding of gasification chemistry for wood, spent pulping liquors and agricultural residues that are high in minerals and high-lignin feedstocks.

> **Tt-D. Wet Gasification of Biorefinery Residues.** There is a need to understand wet gasification of biorefinery residues with the inclusion of pretreatment methods for mineral and sulfur removal that will protect the processing catalyst. Technical challenges associated with hydrothermal processing of biomass include the issues associated not

only with feeding of high-pressure slurries and pressure let-down, but also defining the properties of the liquid intermediates, which are highly dependent on the feedstock composition, demonstrating the effectiveness of separation techniques, and demonstrating the subsequent processing to produce marketable products. This research has received a lower priority.

**Tt-E. Pyrolysis of Biomass.** In the longer-term, development of new methods to control the pyrolytic pathways to bio-oil intermediates in order to increase product yield and recovery is an important element for the program to include. Catalytic upgrading of pyrolysis bio-oil is included in the Products WBS, the TC Platform plan includes research on methods for improvement of the liquefaction process that lead to the formation of an improved bio-oil intermediate. These product quality improvements are important to achieving stability specifications of the resulting bio-oil and may also result in more favorable chemistry for processing in conventional petroleum refineries. This research area is not currently active because of funding limitations.

**Cleanup and Conditioning**

The raw gases from biomass gasification systems do not meet strict quality standards for downstream fuel or chemical synthesis catalysts or in most cases the less stringent standards for power technologies (CHP, fuel cells or fuel cell/turbine hybrids).

**Tt.-F. Syngas Cleanup and Conditioning.** There is a near-term need for gas cleaning and conditioning technology that can cost-effectively remove contaminants such as tar, particulates, alkali, and sulfur. The progress towards overcoming these barriers can be quantified for different target products as was shown in Table 3.3-2. These specifications are derived from a collection of knowledge from catalyst manufacturers, process licensers, and the technical literature. The entries in the table acknowledge that there is more than one catalyst to use for some of the products and these catalysts will require different levels of intermediate cleanup. The interactions between the catalysts used for gas cleanup and conditioning, and the gasification conditions and feedstock are not well understood. These interactions require careful attention to trace contaminants.

**Tt-G. Validation of Syngas Quality.** Syngas products of interest include mixed alcohol for fuels and chemicals, methanol/dimethyl ether (MeOH/DME) and hydrocarbon liquids by the Fischer-Tropsch synthesis. Each of these products has different quality specifications and this work involves validating that the syngas meets the rigorous quality specification needed for production of liquid fuels via catalytic synthesis.

**Sensors and Controls**

**Tt-H. Sensors and Controls**. Effective process control will be needed to maintain plant performance and emissions at target levels with varying load, fuel properties, and atmospheric conditions. However, since there are commercial control systems that can be used in the near-term this area was designated as low priority research, which should be included in the programs as funds are available.

### 3.3.9 Element Strategies for Overcoming Barriers/Challenges

The TC Strategy is to conduct R&D to address the Market Barriers defined in 3.3.7 and the technical barriers defined in 3.3.8.

To facilitate the development of advanced thermochemical conversion systems, OBP will conduct advanced R&D to address the technical barriers related to ensuring that the products can be reliably produced. R&D activities will be conducted in three of the four barrier areas: Feed Processing and Handling, Thermochemical Processing, Clean-up and Conditioning, plus supporting/guiding Analysis. Activities in the area of Sensors and Controls are postponed to a future time when expanded funding is available.

The TC Element utilizes Technoeconomic analysis to provide information to decision makers to direct progress towards overcoming a barrier (e.g. cost of producing biofuels and chemicals). The analyses will also evaluate major process steps and determine those areas in which technical progress will be most successful in reducing project product costs. Life-cycle analysis will be conducted to determine the cost and sustainability of Thermochemical pathways. Comparative analyses of the Thermochemical pathway, integrated with those of other platforms, will be conducted to compare the relative advantages of each.

**Feed Processing and Handling**
The TC Element will conduct R&D activities to ensure that biomass feedstocks can be effectively supplied to biomass thermochemical conversion systems. The feedstock-related activities within the Thermochemical Conversion platform will focus on handling, processing and feeding that takes place within the biorefinery plant boundaries.

The TC Element will ensure that biomass feeder systems are available and appropriate for interfacing with specific TC reactor designs. In the wider application of biomass utilization, other feedstock properties must be made compatible with the thermochemical processing technologies.

**Thermochemical Processing**
The TC Element will conduct R&D activities to ensure that appropriate biomass thermal conversion processes are available to convert a variety of biomass materials to suitable intermediates. OBP will resolve technical questions related to the operability and reliability of biomass gasification systems. The TC Element will coordinate with the Integrated Biorefinery Platform to conduct R&D necessary for integration of biomass thermal conversion processes into the Biorefinery.

The TC Element will also conduct R&D on advanced thermochemical conversion technologies for long-term applications to develop lower cost, more efficient, cleaner systems appropriate for a wide variety of biomass feedstocks. Based upon funding availability, this may include work on technologies related to the Forest Biorefinery Pathway or improved pyrolysis systems to develop new capabilities for producing higher-valued pyrolysis bio-oils and fuels or chemicals. To date, this has included evaluating the use of pyrolysis bio-oil as a petroleum refinery feedstock for the production of fuels and chemicals, which has shown great promise.

**Clean-up and Conditioning**
The key activities in the plan related to cleanup and conditioning of intermediates from thermal processing of biomass include:

- Evaluating the chemistry and kinetics of biomass gasifier tar destruction
- Examining use of catalytic reforming of tars
- Analyzing large-scale gas conditioning with catalysts
- Developing advanced systems for clean gas production through the use of membranes and circulating fluid or fixed beds of catalyst/adsorbents

The TC Element will evaluate advanced concepts for particulate and tar removal in existing test-bed facilities and will explore options for new thermal and catalytic removal and treatment technologies and materials.

In the case of pyrolysis, hot-gas cleanup prior to liquid product collection has been evaluated for particulate removal. Effective capture of biomass pyrolysis liquids from the product stream also needs to be conducted.

When hydrothermal conversion methods are used, the implicit water-based system provides a product cleaning step as part of the process. Evaluation of these byproduct waters will be investigated as related to both wet gasification and hydrothermal liquefaction. Similarly, the cleaned product gas or oil product will be analyzed in more detail to determine remaining trace components.

**Sensors and Controls**
Effective process control will be needed to maintain plant performance and emissions at target levels with varying load, fuel properties, and atmospheric conditions. However, since there are commercial control systems that can be used in the near-term this area was designated as low priority research, which should be included in the programs as funds are available.

### 3.3.10 TC Element Tasks

The WBS structure tasks for the TC Element are shown in Table 3-4. The WBS is structured so that analysis guides and evaluates the work performed (task 5), and the R&D tasks (1-4) are targeted at the barriers defined above.

The analysis involves modeling of process integration and technoeconomic analysis of TC processes. Both of these require that the ongoing research and development activities provide reliable data on the performance of the TC process of interest, and the clean-up and conditioning technology. The technoeconomic analysis and research and development activities are closely coupled to insure that the work will have an impact of the costs of the TC products.

**Table 3-4: TC WBS Elements and the Corresponding Barriers and Pathways**

| Task | Title | Pathways Enabled |
|---|---|---|
| 1 | Biomass Feed Processing and Handling | Ag Residues, Perennial Crops |

| | | |
|---|---|---|
| 2 | Thermochemical Processing | Ag Residues, Perennial Crops, Pulp and Paper, Forest Products |
| 3 | Clean-up and Conditioning | Ag Residues, Perennial Crops, Pulp and Paper, Forest Products |
| 4 | Sensors and Controls | |
| 5 | TC Platform Analysis | Ag Residues, Perennial Crops, Pulp and Paper, Forest Products |

The Biomass Feed Processing and Handling task addresses both dry and wet materials. In the case of dry wood or agricultural residues there are a number of systems that have been developed by industry that would need to be demonstrated with specific gasification or pyrolysis processes. There are also opportunities for utilization of significant amounts of biomass removed from Western forests through fire mitigation thinning operations. This would require the development of small modular systems capable of processing the biomass in the field during the thinning operations at a particular location. As the thinning location moves around a particular region the biomass conversion technology would need to move with it. Small scale systems to convert the biomass to electricity have been developed but systems to produce pyrolysis bio-oils have yet to see any development activity. This modular technology would have the potential to produce bio-oil intermediates that recent studies have shown can be substituted for petroleum feedstocks to produce liquid hydrocarbon fuels in conventional petroleum refineries. The barriers around the feeding and handling of wet materials are less clear. The first decision is to understand the technical and economic trade-off of drying the materials or feeding wet materials. This trade-off will be dominated by the overall performance of the thermochemical process, e.g., gasification, pyrolysis or hydrothermal.

The Thermochemical Processing task addresses both a technology and a cost component. The primary technology need for gasification of biorefinery residues involves a better understanding of the interaction between components such as sulfur and nitrogen species, and the minerals present in agricultural residue feedstocks. These components can influence the chemical processes taking place in the gasifier and thus influence the downstream clean-up and conditioning tasks. There is ongoing work looking that these types of interactions for corn stover and plans for work on lignin-rich residues. The work on wet gasification requires an improved understanding of the lifetime and costs of the catalysts used for wet gasification, and the overall mass and energy balances for the process when feeding biorefinery residues. This key information is currently being developed by industry/national laboratory partnerships. Much of the basic process information of biomass pyrolysis is well known and the technology has been successfully demonstrated several times. However, there are limitations with the quality and yield of the raw pyrolysis oils that, if overcome, could lead to a break-through for the technology. These break-through areas include the potential for catalytic or reactive pyrolysis where changes in the fundamental reactions or in the pyrolysis atmosphere could lead to bio-oils with improved properties. However, research and development to overcome this barrier is seen as a longer-term opportunity.

As highlighted in Figure 3.3-5 developing technology for Syngas Clean-up and Conditioning task will have a very significant impact on the cost of biomass-derived syngas. Thus, there are a number of alternative approaches being developed to meet the syngas quality specification detailed in Table 3.3-2. The clean-up and conditioning projects include catalysts for destruction of organic tars, improved catalyst support materials, sorbents for scavenging trace metals and catalysts for conversion of sulfur and nitrogen. All of these projects will demonstrate their technology with agricultural residue feedstocks. A critical component of the clean-up and conditioning work is validation of the quality of the syngas. While chemical analysis tools are effective for process development at some point the clean-up and conditioning technology must be validated with the actual catalysts that will be used for production of the liquid fuel. This validation is critical since there will be technical and economic trade-offs between syngas clean-up technology and the performance and costs of the fuel synthesis. This trade-off may indicate that improving the fuel synthesis catalysts is a better alternative than taking extreme measures to develop syngas clean-up technology.

The barriers involving improved Sensors and Controls (task 4) are important but in the near-term overcoming these barriers will not have a significant impact on the cost of syngas (see Figure 3.3-5). Process control technology will be needed to maintain plant performance and emissions at target levels with varying load, fuel properties, and atmospheric conditions. However, much of this technology can be adapted from current commercial process control systems readily available. Thus, in the near-term this area was designated as low priority research. This combined with funding limitations results in Task 4 not receiving funding in the near term.

### 3.3.11 Thermochemical C-Level Milestones ♦1

| | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Corn Wet Mill Improvement Pathway | | | | | |
| Feed Processing & Handling | | | | | |
| Thermochemical Processes | | | | | |
| Clean-up & Conditioning | | | | | |
| Sensors and Controls | | | | | |
| TC Platform Analysis | | | | | |
| Corn Dry Mill Improvement Pathway | | | | | |
| Feed Processing & Handling | | | | | |
| Thermochemical Processes | | | | | |
| Clean-up & Conditioning | | | | | |
| Sensors and Controls | | | | | |
| TC Platform Analysis | | | ♦1 | | |
| Agricultural Residue Processing Pathway | | | | | |
| Feed Processing & Handling | | ♦6 | | | |
| Thermochemical Processes | | | ♦3 | ♦7 | ♦2 ♦4 ♦5 |
| Clean-up & Conditioning | | | | | ♦8 ♦10 |
| Sensors and Controls | | | | | |
| TC Platform Analysis | | | | | ♦9 |
| Perennial Crop Processing Pathway | | | | | |
| Feed Processing & Handling | | ♦15 | | | |
| Thermochemical Processes | | | ♦12 | ♦16 | ♦11 ♦13 ♦14 |
| Clean-up & Conditioning | | | | | ♦17 ♦19 |
| Sensors and Controls | | | | | |
| TC Platform Analysis | | | | | ♦18 |

| | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Oil Crop Processing Pathway | | | | | |
| Feed Processing & Handling | | | | | |
| Thermochemical Processes | | | | | |
| Clean-up & Conditioning | | | | | |
| Sensors and Controls | | | | | |
| TC Platform Analysis | | | | | |
| Pulp and Paper Mill Improvement Pathway | | | | | |
| Feed Processing & Handling | | | ♦31 | | |
| Thermochemical Processes | | ♦37 ♦38 | ♦36 | ♦21 ♦32 | ♦20 ♦22 ♦23 ♦29 |
| Clean-up & Conditioning | | ♦35 | | ♦33 | ♦24 ♦25 ♦26 ♦27 ♦28 ♦30 ♦34 |
| Sensors and Controls | | | | | |
| TC Platform Analysis | | | | | |
| Forest Products Mill Improvement Pathway | | | | | |
| Feed Processing & Handling | | | ♦41 | | |
| Thermochemical Processes | | ♦47 ♦48 | ♦46 | ♦42 | ♦40 |
| Clean-up & Conditioning | | ♦45 | | ♦43 | ♦44 |
| Sensors and Controls | | | | | |
| TC Platform Analysis | | | | | |

| Milestones | |
|---|---|
| **1** | Investigate alternate sources for dry mill heat and power (B) (2.7) |
| **2** | Demonstrate and validate combined heat and power from lignin intermediates/residue (B) (4.10) |
| **3** | Demonstrate combined heat and power production from lignin (C) (4.10.1) |
| **4** | Validate integrated production of heat and power from lignin at pilot scale (C) (4.10.2) |
| **5** | Demonstrate and validate lignin gasification to produce syngas for $0.xx/MM Btu by 20xx (B) (4.11) |
| **6** | Validate feeder system performance (C) (4.11.1) |
| **7** | Validate gasification performance (C) (4.11.2) |
| **8** | Validate gas cleanup performance (C) (4.11.3) |
| **9** | Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount (C) (4.11.4) |
| **10** | Validate integrated gasification and gas cleanup at pilot scale (C) (4.11.5) |
| **11** | Demonstrate and validate combined heat and power from lignin intermediates/residue (B) (5.10) |
| **12** | Demonstrate combined heat and power production from lignin (C) (5.10.1) |
| **13** | Validate integrated production of heat and power from lignin at pilot scale (C) (5.10.2) |
| **14** | Demonstrate and validate lignin gasification to produce syngas for $0.xx/MM Btu by 20xx (B) (5.11) |
| **15** | Validate feeder system performance (C) (5.11.1) |
| **16** | Validate gasification performance (C) (5.11.2) |
| **17** | Validate gas cleanup performance (C) (5.11.3) |
| **18** | Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount (C) (5.11.4) |
| **19** | Validate integrated gasification and gas cleanup at pilot scale (C) (5.11.5) |
| **20** | Demonstrate and validate reliable and economic gasification of spent pulping liquor and recycle liquor causticization in a pulp mill (B) (6.1) |
| **21** | Validate reliable and economic performance of gasification of spent pulping liquor (C) (6.1.1) |
| **22** | Validate advantages of co-gasification of spent pulping liquors and other forms of biomass (woody, recycle paper streams, and bio-oil) (C) (6.1.3) |
| **23** | Validate integrated black liquor gasification and causticization process at pilot scale (C) (6.1.4) |
| **24** | Demonstrate and validate gas cleanup and process chemical recovery and recycle from spent pulping liquor syngas (B) (6.2) |
| **25** | Validate process chemical recovery from spent pulping liquor syngas (C) (6.2.1) |
| **26** | Validate gas cleanup technologies on spent pulping liquor syngas (C) (6.2.2) |
| **27** | Validate integrated chemical recovery and gas cleanup process at pilot scale (C) (6.2.3) |
| **28** | Validate integrated chemical recovery and gas cleanup process in pulp and paper mill (C) (6.2.4) |
| **29** | Demonstrate and validate cost-effective biomass gasification of wood residues and other process residues and synthesis gas cleanup in a pulp and paper mill environment (B) (6.3) |

| Milestones Continued | |
|---|---|
| **30** | Develop cost effective gasification designs for syngas production at appropriate scale (C) (6.3.1) |
| **31** | Validate feeder system performance to reliably feed solids to high pressure (30 bar) systems) (C) (6.3.2) |
| **32** | Validate forest biomass gasification performance (C) (6.3.3) |
| **33** | Validate cost-effective forest biomass syngas cleanup performance (C) (6.3.4) |
| **34** | Validate integrated biomass gasification and syngas cleanup process suitable for a pulp and paper mill at pilot scale (C) (6.3.5) |
| **35** | Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment (C) (6.5.1) |
| **36** | Demonstrate and validate bio-oil production to a stable intermediate (B) (6.9) |
| **37** | Validate woody bio-oil production (C) (6.9.1) |
| **38** | Validate woody bio-oil intermediate recovery (C) (6.9.2) |
| **39** | Demonstrate and validate cost-effective biomass gasification of wood residues and other process residues and synthesis gas cleanup in a pulp and paper mill environment (B) (7.1) |
| **40** | Develop cost effective gasification designs for syngas production at appropriate scale (C) (7.1.1) |
| **41** | Validate feeder system performance to reliably feed solids to high pressure (30 bar) systems) (C) (7.1.2) |
| **42** | Validate forest biomass gasification performance (C) (7.1.3) |
| **43** | Validate cost-effective forest biomass syngas cleanup performance (C) (7.1.4) |
| **44** | Validate integrated biomass gasification and syngas cleanup process suitable for a forest products mill at pilot scale (C) (7.1.5) |
| **45** | Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment (C) (7.3.1) |
| **46** | Validate woody bio-oil production (C) (7.4.1) |
| **47** | Validate woody bio-oil intermediate recovery (C) (7.4.2) |
| **48** | Validate integrated process at pilot scale (C) (7.4.3) |

## 3.4 Products Core R&D

The Products Platform Element envisions the use of all biomass components (i.e. cellulose, hemicellulose, and lignin) as building blocks for conversion of raw material feedstocks to useful "products". The term "products" is often synonymous with chemicals and materials, but also encompasses fuels and heat and power. The potential building blocks considered in the Products Platform Element are derived from the outputs of the Sugars and Thermochemical Platforms, along with outputs from the existing biomass industry. The basic building blocks from the grain based biomass, oleochemistry industries, and forest products industry include C5 and C6 sugars, lignin, oil, and protein. Building blocks from the Thermochemical Platform include synthesis-gas (syngas) and pyrolysis oils from the existing forest products industry.

Fuels and Chemicals/Materials have similar technical elements that need to be addressed to reduce the cost of these products. These include fermentation, organism development and chemical catalysis. In addition, regardless of the final product mix, new separation technologies offer the potential of cost reductions, by lowering capital equipment costs and providing cleaner final products. Below is a brief description of these technologies:

- **Fermentation** – Fermentation is the process by which a living cell (e.g. yeast, bacteria, fungi, etc) is able to obtain energy through the breakdown of the sugar components from biomass hydrolosate (i.e. glucose, xylose, arabinose, etc). This is a well developed and understood technology, as utilized for alcohol production from starch and glucose sugars by the current industry (i.e. corn wet and dry mills). The fermentation of cellulose based sugars, which include the xylose and arabinose sugars is not as readily understood.
- **Organism Development –** The primary need is to develop organisms (e.g. from yeast or fungus) capable of utilizing all the sugar components from a biomass hydrolysate to make value-added fuels or chemicals with minimum by-products at relevant process conditions.
- **Enzyme Development –** Novel low cost enzymes need to be developed to perform very specific reactions. The use of enzymes generally affords very high selectivity. The development of enzymes with high specific activity at low cost could have significant impact on the overall costs of producing chemicals and materials from biomass.
- **Chemical Catalysis** – The development of catalysts for converting sugars and oils into higher value products is in its infancy when compared to today's petrochemical counterparts. Fundamental research will be needed to support development of new catalysts for hydrogenation sugars and oils, as well as oxidation, dehydration, and selective bond cleavage. Catalyst selectivity and contamination are barriers to future use of syngas for products.
- **Separations** – In both chemical and biological processing, byproducts are an issue. Most fermentation products contain impurities which can lead to rapid catalyst deactivation. Improved catalyst lifetimes via purification methods will need to be developed to ensure cost-effective production of fuels and chemicals.

Heat and Power production within a biorefinery will likely utilize the feedstock, or by products of the feedstock to produce the necessary energy to run the facility. While many technology options are mature, such as boilers, and gasifiers, there are still some technical issues that need to be considered.

- **Process Integration and Effective Heat Integration/Optimized Energy Efficiency –** Successful integrated operation of biomass gasifiers, gas clean-up operations, and power production will lead to commercialization of these systems within biorefinery operations. Knowledge and understanding of these systems will also result in reliable system cost estimates, performance, and emissions information. Furthermore, since the various prime drivers have differing fuel specifications, a better understanding will be gained of the integrated process configuration options as functions of prime mover type and biorefinery scale.
- **Scalability of Current and Developing Prime Movers –** Successful demonstration of integrated systems, i.e., biomass gasifier, gas clean-up operations and power producer (prime mover), is the major technical barrier inhibiting commercialization. This barrier includes the need for reliable system cost estimates, performance, and emissions information. Furthermore, since the various prime movers have differing fuel specifications, the integrated process configuration options, as functions of prime mover type and biorefinery scale, need to be demonstrated and quantified.

### 3.4.1 External Assessment and Element Market Overview:

Recent analysis by NREL and PNNL for OBP of *Top Value Added Chemicals from Biomass, Volume 1* identified twelve building block chemicals that can be produced from sugars via biological or chemical conversions. The twelve building blocks can be subsequently converted to a number of high-value biobased chemicals or materials. Building block chemicals are molecules with multiple functional groups that possess the potential to be transformed into new families of useful molecules. The twelve sugar-based building blocks identified were: 1,4-diacids (succinic, fumaric and malic), 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol.

The final selection of 12 building blocks began with a list of more than 300 candidates. The shorter list of 30 potential candidates was selected using an iterative review process based on the petrochemical model of building blocks, chemical data, known market data, properties, performance of the potential candidates and the prior industry experience of the team at PNNL and NREL. This list of 30 was ultimately reduced to 12 by examining the potential markets for the building blocks and their derivatives and the technical complexity of the synthesis pathways. A second-tier group of building blocks was also identified as viable candidates. These include gluconic acid, lactic acid, malonic acid, propionic acid, the triacids, citric and aconitic; xylonic acid, acetoin, furfural, levoglucosan, lysine, serine and threonine.

The analysis includes a detailed description of the current and potential market, competing technologies, and barriers that need to be addressed for each of the top 12 products identified. For example:

**2,5-Furan dicarboxylic acid (FDCA)**

Dehydration of the sugars available within the biorefinery can lead to a family of products, including dehydrosugars, furans, and levulinic acid. FDCA is a member of the furan family, and is formed by an oxidative dehydration of glucose. The process has been reported to proceed using oxygen, or electrochemistry. The conversion can also be carried out by oxidation of 5-hydroxymethylfurfural, which is an intermediate in the conversion of 6-carbon sugars into levulinic acid, another member of the top 10.

FDCA has a large potential as a replacement for terephthalic acid, a widely used component in various polyesters, such as polyethylene terephthalate (PET) and polybutyleneterephthalate (PBT). PET has a market size approaching 4 billion lb/yr, and PBT is almost a billion lb/yr. The market value of PET polymers varies depending on the application, but is in the range of $1.00 – 3.00/lb for uses as films and thermoplastic engineering polymers. The versatility of FDCA is also seen in the number of derivatives available via relatively simple chemical transformations. Selective reduction can lead to partially hydrogenated products, such as 2,5 dihydroxymethylfuran, and fully hydrogenated materials, such as 2,5 bis(hydroxymethyl)tetrahydrofuran. Both of these latter materials can serve as alcohol components in the production of new polyester, and their combination with FDCA would lead to a new family of completely biomass-derived products. Extension of these concepts to the production of new nylons, either through reaction of FDCA with diamines, or through the conversion of FDCA to 2,5-bis(aminomethyl)tetrahydrofuran could address a market of almost 9 billion lb/yr, with product values between $0.85 and 2.20/lb, depending on the application. FDCA can also serve as a starting material for the production of succinic acid.

The primary technical barriers to production and use of FDCA include development of effective and selective dehydration processes for sugars. The control of sugar dehydration could be a very powerful technology, leading to a wide range of additional, inexpensive building blocks, but it is not yet well understood. Currently, dehydration processes are generally nonselective, unless, immediately upon their formation, the unstable intermediate products can be transformed to more stable materials. Necessary R&D will include development of selective dehydration systems and catalysts. FDCA formation will require development of cost effective and industrially viable oxidation technology that can operate in concert with the necessary dehydration processes.

A number of technical barriers also exist with regard to the use of FDCA (and related compounds) in the production of new polymers. Development and control of esterification reactions, and control of the reactivity of the FDCA monomer will be of great importance. Understanding the link between the discrete chemistry occurring during polymer formation, and how this chemistry is reflected in the properties of the resulting polymer will provide useful information for industrial partners seeking to convert this technology into marketplace products.

The utility of FDCA as a PET/PBT analog offers an important opportunity to address a high volume, high value chemical market. To achieve this opportunity, R&D to develop selective oxidation and dehydration technology will need to be carried out. However, the return on investment might have applicability of interest to an important segment of the chemical industry.

The *Top Value Added Chemicals from Biomass, Volume 1* also identified hydrogen and methanol as the best near-term prospects for biobased commodity chemical production because obtaining simple alcohols, aldehydes, mixed alcohols and Fischer-Tropsch liquids from biomass are not economically viable and require additional development. Therefore no further down select from syngas derived products was undertaken. This determination was based on a review of the literature and a progress review of the OBP Thermochemical Platform R&D at NREL in August 2003. The review identified gas cleanliness as a key barrier to economic production of syngas from biomass. A comprehensive report including economic analysis, technical challenges and energy impacts of syngas to liquid processes is available.

Another study, *Top Value Added Chemicals from Biomass II. Results of Screening for Potential Candidates from Biorefinery Lignin,* determined the top products to make from lignin. As with the previous report for sugars and syngas, this study identified the broad technologies that will have the greatest impact on integrating a lignin process stream into biorefinery operation. The report also identified the structures of the top lignin compounds and compound families that result from overcoming barriers associated with these technologies. The technologies and their associated products are categorized into near, mid and long term opportunities, and define a continuum of R&D activities needed to make lignin as valuable a biorefinery process stream as carbohydrates.

The compounds and their associated technologies were identified by progressively downselecting from a very large starting group of potential lignin products, using criteria of technical risk, product value, market size and risk, ability of the product to serve as a starting material for other derivatives, and whether the product could be obtained as a single material. The compounds making the final cut are a group of chemicals and chemical families that can be produced from lignin using chemical or biochemical transformations. These lignin-derived building blocks or classes of compounds also serve as starting points for the production of much larger families of chemicals within a lignocellulosic biorefinery.

**Near term opportunities for lignin**
Initial near term opportunities for lignocellulosic biorefineries use lignin as a process fuel. There are few technology barriers for this use, and R&D support will be limited to process engineering and integration analyses.

**Mid term opportunities for lignin**
Mid term opportunities and their associated technical barriers are primarily R&D activities to use lignin's polymeric nature in new high molecular weight products. This opportunity leverages existing commercial uses of high molecular weight lignins as described in Appendix 5 of the *Top Value Added Chemicals from Biomass II. Results of Screening for Potential Candidates from Biorefinery Lignin*, and will attract industrial producers interested in new market outlets for lignin. The primary technical barriers are associated with the nature of the lignin available from the sugar platform. It is anticipated that R&D studying lignin

conditioning processes will be necessary, but will lead to new high performance materials for the chemical industry.

**Long term opportunities for lignin**
The top long-term opportunities for lignin are primarily processes for converting lignin into low molecular weight compounds and compound classes. Use of lignin as a source of low molecular weight compounds would be a unique and high profile activity, changing lignin from a low value fuel into a chemical raw material with importance equal to crude oil. Technology barriers to be addressed by R&D support include selective catalytic processes for lignin conversion, bioconversion processes, oxidations, and reductions. Support of separation technology will be closely related to long-term activities, because initial results from this effort are anticipated to provide products as mixtures.

### 3.4.1.1 Current and Potential Market

Examples of existing biorefineries include forest products industry, corn wet mills, corn dry mills and some food processing industries. Wet mills extract higher value co-products than dry mills. Co-products from wet mills include corn oil, protein feed, gluten meal, germ, ethanol, fermentation derived chemical intermediates like lactates and citrates, and several grades of refined starches and corn sweeteners. In dry milling, co-products can include corn oil, ethanol, and distillers dry grain with solubles (DDGS), which is used as animal feed. Carbon dioxide is a fermentation by-product of both milling processes. Both processes can benefit from production of additional high value products to become more efficient and economically stable. The Products Element is partnering with these industries to develop the next generation of biorefinery that convert the sugars derived from a biomass feedstock to a variety of commodity products. An example of product development that can lead to new biorefineries is NatureWorks, who is developing a lactic acid intermediate chemical and polylactic acid (PLA) polymer that is produced from starch based sugars. Lactic acid is the intermediate chemical and PLA is the polymer that is used to manufacture a wide variety of commercial biobased products. The next development step would be to integrate this lactic acid chemical production with a wet or dry mill that also produces a transportation fuel like ethanol.

External factors that could affect the ability of the Products element are consumer acceptance and the cost of competing technologies. The market penetration rate of bio-based technologies is a function of technical breakthroughs, and the price trends of coal, oil and natural gas. To put it simply, in order for success, biobased products must cost the same or less and perform the same or better than their existing petroleum based counterparts.

### 3.4.1.2 Political Environmental Nuances

DOE, in partnership with USDA, has been committed to expanding the role of biomass as an energy source for many years. Specifically, these organizations support biomass fuels and products as a way to reduce the nation's dependence on foreign oil, to offer new opportunities for economic growth in rural communities, and to foster the establishment of new domestic biorefineries throughout the U.S. The Biomass R&D Technical Advisory Committee, established by Congress in 2000 to guide federally-funded biomass R&D, has established a goal that biomass will replace 30 % of the country's current petroleum consumption by 2030. More recently, the Energy Policy Act of 2005 highlights the need to move away from a petroleum-based transportation sector and toward increased use of renewable fuels such as ethanol and biodiesel, especially in the medium time range. This bill includes tax incentives and requirements for the increased production and use of renewable transportation fuels to promote these goals. In addition, the large increases in the cost of petroleum observed during the first half of 2005 are bringing a new urgency to these efforts.

**3.4.1.3 Competing Technologies**
Bioproducts, such as those described in this text compete with petroleum derived products, from gasoline and fuel additives, to polymers. The polymer market had not seen a new polymer introduced in over 40 years, which is indicative of the commercial strength of the petroleum derived materials in that market. This is changing however, with the rising cost of petroleum impacting the fuel market, as well as chemical markets such as polymers. Dow and Nature Works have each introduced a new polymer made from corn starch and are finding successful markets for the properties of these materials. Continued work on reducing the cost and characterizing the materials will allow new materials and replacement chemicals and materials to enter the market place faster.

## 3.4.2 Internal Assessment and Program History:

**3.4.2.1 Element History**
The Products Platform Element evolved from three previous Biomass related programs that conducted R&D on transportation fuels in the Office of Transportation Technologies (OTT), R&D on products and chemicals in the Office of Industrial Technologies (OIT) (now know as the Industrial Technologies Program (ITP)), and R&D on producing electric power from biomass in the Office of Power Technologies (OPT). When these separate programs were combined into the Office of the Biomass Program, the emphasis evolved to focus on core technologies that would support the growth of an integrated biorefinery industry that can process upstream outputs of heat, power, fuels, and products. A growing domestic biorefinery industry will, increase the use of sustainable renewable resources to meet the Nation's growing need for energy security, reduce U.S. dependence on foreign oil imports, provide environmental benefits versus fossil fuels, and spur rural economic development.

**3.4.2.2 Element Organization and FY06 Activities**
Activities supporting the Products Platform Element can be organized into the general work breakdown elements of fuels (transportation), chemicals and materials, and heat and power; illustrated below in Figure 3.4-1.

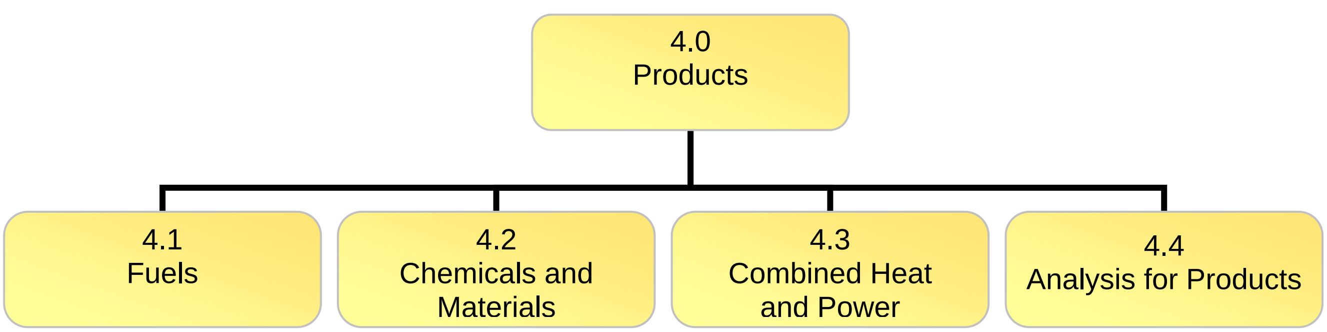


**Figure 3.4-1:** Products Platform Work Breakdown Structure

Within the Products Platform Element, about 80% of the investment is allocated to chemicals and materials distributed across sugars, thermochemical, and oils. The remaining 20% of the portfolio investment is dedicated to fuels, with the largest part of that R&D devoted to producing fuels from sugars. No core R&D is currently devoted to developing heat and power technologies; however, it is anticipated that the energy efficiency and cost savings to be gained from producing electric power and heat that can be used in the biorefinery of the future will become obvious. The program recognizes that some known energy efficiency technologies will be beneficial to combined production of fuels, chemicals and materials, heat and power.

#### 3.4.2.3 Element Recent Accomplishments

The OBP program currently employs strategic analyses to help focus the efforts as well as responses from solicitations in crafting the products portfolio. Two such strategic analyses directed towards products from biomass have been published. The first, **Top Value Added Chemicals from Biomass Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas (T. Werpy and G. Petersen)** http://www.eere.energy.gov/biomass/pdfs/35523.pdf.), was published in 2004 and contains recommendations for the top 12 and top 24 candidates for building block organic chemicals derived from sugars and the research needs associated with these candidates. The top twelve sugar-based building blocks are 1,4-diacids (succinic, fumaric and malic), 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol. The second, **Top Value Added Chemicals from Biomass Volume II. Results of Screening for Potential Candidates from Biorefinery Lignin** (Bozell, Holladay, Johnson, and White) was completed in 2005.

Some examples of significant achievements to date include:

- Successfully demonstrated technical and economic feasibility of a soy-based marine lubricant which went to commercialization.
- Metabolix's Natural Plastics win presidential green chemistry challenge award.
- A patent was filed resulting from yeast development work for new strains with multisugar fermenting capabilities
- Two patents filed for separative bioreactor wafers and applications.

### 3.4.3 Element Federal Role

#### 3.4.3.1 Element Contribution to National Need

There is still a large contingency that do not believe biobased products can be competitive with petrochemically derived products. The Federal role is to demonstrate through industrial cost shared projects, that biobased products have the similar characteristics and can be economic with their petroleum based counterparts. The successful deployment of products and the development of markets for biobased products will demonstrate the viability of this approach in the market place and bring other industry segments to the forefront of biobased product research. The long-term benefits will be that virtually all of the technologies developed for the existing biobased product industry will have value to the integrated biorefinery.

#### 3.4.3.2 Interaction with Other Federal Programs
The bioproducts effort is complimented by the efforts of USDA, which has a long history in developing new uses for agricultural feedstocks. In addition, programs that are mandated government wide, such as the Buy Bio program, which requires government purchasing of biobased products, assist in creating the necessary markets to advance the commercial production of these biobased products allowing them to attain consumer acceptance in a more time fashion.

### 3.4.4 Element Approach

The potential feedstocks considered in the Products Platform are derived from the outputs of the Sugars and Thermochemical Platforms, along with the already-existing outputs of the current biomass industry. The basic feedstocks from the Sugars Platform and existing biomass industry include C5 and C6 sugars, lignin, oil, and protein. The feedstocks from the Thermochemical Platform include syngas and pyrolysis oils. The Products Platform will provide the core technologies for creating an integrated biorefinery that processes these outputs and, in turn, slows the expenditure of nonrenewable resources and reduces our dependence on foreign oil.

This approach is best suited to meet the stated goals, as demonstrated in a recent NREL analysis. The analysis showed the value of adding products to a biorefinery producing ethanol. It revealed that as you divert more feedstock to produce value-added products, like polyols, it reduces the minimum ethanol selling price (MESP).

#### 3.4.4.1 Element Approach and Role within Program
The Products element develops core technologies for producing value-added products. The element approach is similar across the program involving the identification of barriers, conducting systematic research and development activities to overcome these barriers and establishing a prioritization of activities based on the pathways described in section 1.1. The resulting work breakdown structure described in Figure 3.4-1 illustrates the priority research areas defined for the Products Platform. It has 3 primary technical utilization elements that are intended to use outputs from existing biomass industry and the R&D platforms for sugars and thermochemical synthesis gases and fuels. The three technical utilization elements are: *Fuels*, *Chemicals and Materials*, and *Combined Heat and Power*. The fourth element is *Analysis for Products*.

#### 3.4.4.2 Element Contribution to Pathway and Program Outputs
The biorefinery of the future would use outputs from the Sugars and Thermochemical Platforms, as well as produce high-value products from currently existing biomass industry. Figure 3.4-2 illustrates how the Products Platform Element will develop technology to support growth of biorefinery industries.

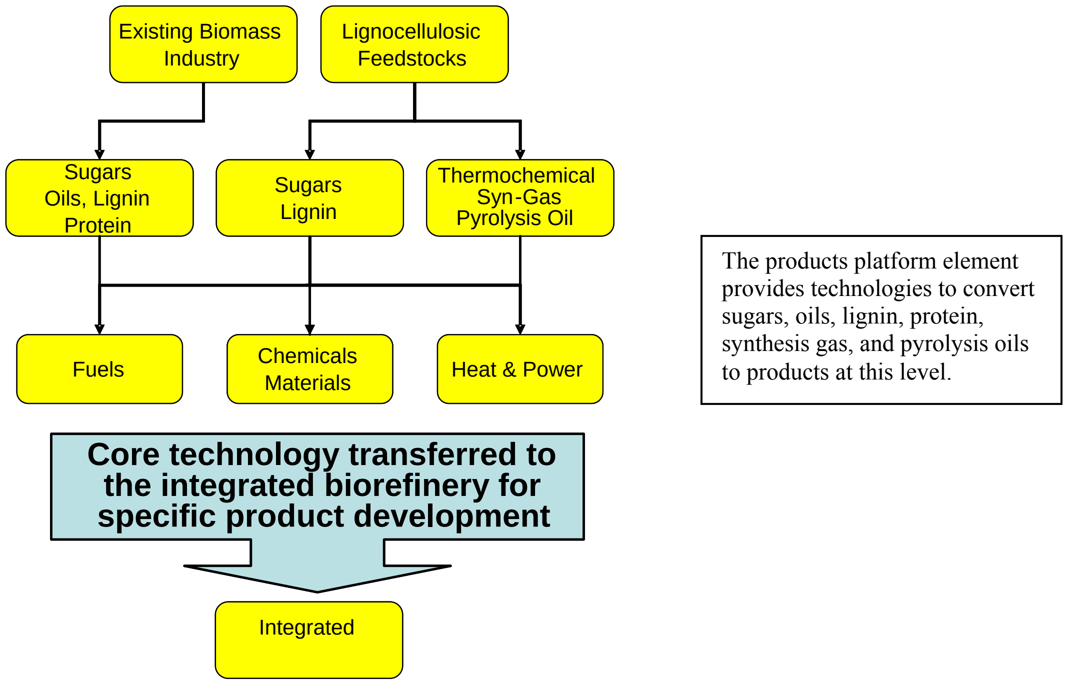


**Figure 3.4-2:** Utilization of platform outputs and transferring technology to an integrated biorefinery of the future.

### 3.4.5 Products Platform Element Performance Goals

The Products goals have been established based on specific economic targets that are called out in **Top Value Added Chemicals from Biomass Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas (T. Werpy and G. Petersen)**. The strategy of using economic targets as the measure is the only viable way to ensure that if met, commercial success will be likely. The economic targets were established based on the following three criteria:

1. Economically competitive with existing petrochemical based chemicals and materials using an average production cost for commodity chemicals of $0.40- $0.50/pound. While this is a general target it does represent the production cost of many of the chemicals identified in the "Top Ten Analysis". [1] The cost targets represent a scenario in which various combinations of fermentation, catalysis and separations could meet the overall $0.40-$0.50/pound cost goal of existing petrochemical products.
2. The economic targets can be technically achieved. For each of the cost targets established, there are examples in both commercial production and preliminary economic models that indicate these targets are achievable. For example, in the case of aerobic fermentation, citric acid would be a useful model to form the basis of the cost goal. Citric acid is the "best" commercially practiced aerobic fermentation technology and production cost is estimated to be on the order of $0.40/lb including recovery.
3. The achievement of each goal will impact multiple products in the "Top Ten" analysis not just a single product. This criterion was used to establish the basis for core technology

[1] The Top Ten Analysis (Top Value Added Chemicals from Biomass Volume 1) is a DOE published report that can be viewed or downloaded from http://www.eere.energy. gov/biomass/pdfs/35523.pdf.

development and not product specific technologies. It is important to note that super commodity chemicals were eliminated based on the assumption that they would not be able to compete with petroleum derivatives. The top 12 building block chemicals selected are listed in the report.

Early commercialization utilizing the core technologies developed under the Products Platform Element are taking place within the existing fuel ethanol industry, but will set the stage for investment in an emerging lignocellulosic biomass industry that would use lignocellulosic materials like wood, corn stover, switch grass, and wheat straw as feedstocks for making sugar that is fermentable to make fuel grade ethanol. These economic targets are also critical for identifying when DOE investment is no longer needed for the development of core technologies. The technologies developed to meet these milestones will be utilized by industry to develop specific opportunities within the biorefinery.

The performance goals for fuels are based on reducing the cost of ethanol production in both existing facilities as well as future lignocellulosic facilities. Within existing facilities this can be accomplished by utilizing the "recalcitrant" starch and utilizing all available five carbon sugars.

- The target reduction for ethanol production cost in the existing ethanol facilities is about $0.13/gallon based on an estimate of current production costs of $0.90-$1.00/gallon.
- The overall objective is to reduce ethanol costs from $2.75/ gallon to $1.75/gallon ($45/ton feedstock) in 2012. Several steps are required to achieve this reduction, one of which is the development of new strains which can utilize five carbon sugars. The target cost savings utilizing these new strains on lignocellulosics is $0.18/gallon, by 2012.

The performance goals for chemicals and materials are based on the utilization of sugar and the results of the "Top Ten Analysis" as follows:

- Develop chemical or biological transformations for the conversion of platform building blocks to secondary products, including hydrogenation, oxidation, dehydration, hydrogenolysis, and dehydroxylation at a transformation cost of between $0.03 and $0.07/pound by 2009.
- Develop separation technologies for recovering products from dilute (less than 25% product) aqueous solutions for less than $0.05/pound by 2009.
- Develop technologies that enable aerobic fermentations for the production of chemical building blocks identified in the "Top Ten" report for less than $0.35/pound from $0.10/pound sugars by 2012.
- Develop selective aqueous phase catalytic and bio-catalytic transformations of carbohydrates for the production of building blocks at less than $0.25/pound by 2012.
- Develop technologies that enable anaerobic fermentations for the production of chemical building blocks identified in the "Top Ten" report for less than $0.25/pound from $0.10/pound sugars 2015.

The performance goals for combined heat and power are to demonstrate the ability to obtain commercial CHP costs of $0.051/kWh ($5.10/1000 lb steam) for biomass and biorefinery intermediates in 2015.

The Products Platform goals will directly contribute to the program goal of synthesizing fuels and chemicals from biomass. By developing more high-value chemicals and intermediates as well as reducing the production cost of ethanol, the Products Platform directly helps the program complete its planned pathways and thus, its goal to reduce dependency on foreign oil.

### 3.4.6 Products Platform Element Strategic Goals:

The overarching goal of the Products Platform Element is to develop the core technologies required for the economical production of fuels, chemicals and materials, and heat and power utilizing intermediates from the existing biomass industry as well as the Thermochemical and Sugar Platforms. Working in concert with the other OBP platforms these technologies will be integrated into a biorefinery to produce fuels, chemicals, heat and power.

### 3.4.7 Element Market Challenges and Barriers

In working with industrial partners toward the development of products from biomass feedstocks, it has become clear that the key market barriers to deploying biobased products technology are:

Pm-A. Consumer acceptance - The product or intermediate product must be acceptable to the customer in terms of performance and characteristics.

Pm-B. Cost of competing technologies - Petroleum based chemicals and materials are already marketed and used by the industry. New products need to be able to compete with this cost, so the consumer will be willing to make a switch to the new, non petroleum based product. This incorporates the cost of infrastructure, as well as production. Therefore, it must be the delivered cost to the consumer.

Pm-C. Future energy prices - As the cost of a barrel of oil fluctuates, the market for new products will fluctuate. As oil increases, market penetration is more favorable. As oil prices decrease, then the market conditions are less favorable.

Pm-D. Policy factors – There are tax incentives and market incentives that encourage the consumer to utilize the new product. Mandated usage such as the renewable fuels standards (RFS), spur market penetration of new products.

Projects funded within the Products element are addressing these challenges by working with the end use consumers early on in the development of the technology to better understand the characteristics they are looking for in their products and to ensure that the development efforts are maximizing the potential of meeting these needs. One example is the program’s partnership with Dow Chemical Company, which is developing oil based polyols for use in foams and elastomers. They will be initiating consumer trials of the polyols with appropriate partners to assure the materials perform within the boundaries set by these partners.

### 3.4.8 Element Technical (Non-Market) Challenges/Barriers:

The Products Platform is more complex than the Sugar or Thermochemical Platforms, simply because the vast range of the outputs including fuels, chemicals and materials, and heat and power. The overall barrier to deployment within each of the major elements of the Products Platform is the inability to compete on an economic basis with petrochemicals. Specific barriers that contribute to the overarching cost barrier have been identified and are given in Figure 3.4-3. Tier 1 addresses competitiveness and costs, major components of economics and viability. Tier 2 relates to process issues involving converting raw materials into products (rate/yield/selectivity, product quality, integration into biorefinery operations, process optimization, etc.). Tier 1 and 2 barriers generally are similar across each of the Product core R&D categories. Tier 3 represents the technical components of the core R&D categories.

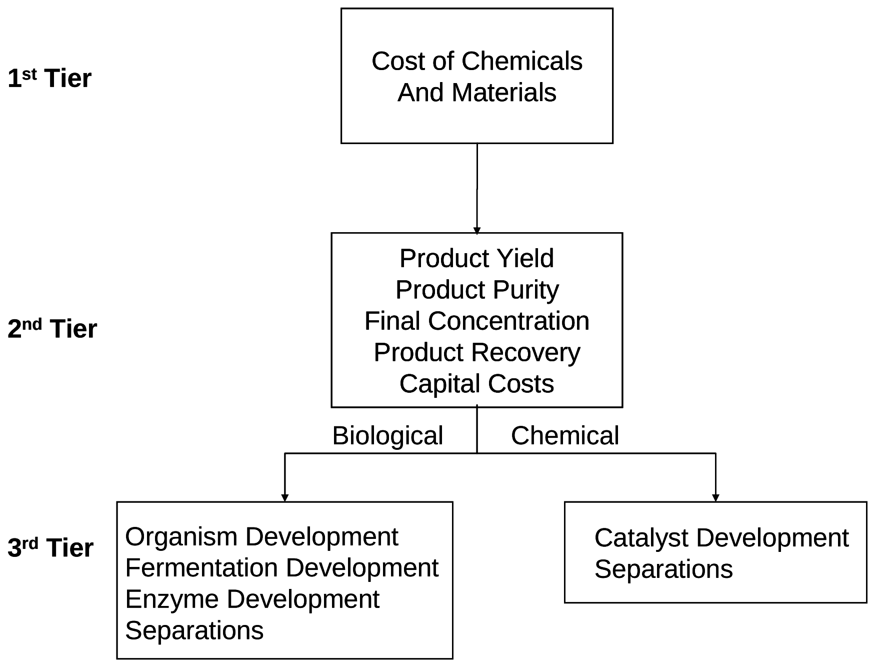


**Figure 3.4-3:** Barrier Hierarchy for Fuels/Chemicals and Materials

Within the barrier hierarchy for fuels/chemicals and materials there are several major technical elements that need to be addressed to reduce the cost. On the biological side these elements include organism development, fermentation development, enzyme development and separations. Barriers associated with the chemical conversion include catalyst development and separations.

**Detailed Description of the Barriers:**
**Pt-A. Fuels Organism Development**
Production of liquid fuels, primarily ethanol, but possibly butanol or other alcohols in the future will require significant improvements in currently existing organisms. The primary improvements are the development of organisms that are capable of utilizing all the sugar components from biomass hydrolysate. Specifically, organisms need to be capable of utilizing 5 carbon sugars, namely xylose and arabinose. The target yield is 80-90% utilization of five carbon sugars. The five carbon sugars constitute a significant portion of biomass (10-30%).

More efficient utilization of these sugars could substantially lower the overall cost of alcohol production by as much as $0.18/gallon. It would be desirable for the organisms to be capable of utilizing five carbon sugars, preferably simultaneously with six carbon sugars, derived from hydrolysate. The organisms must be robust with respect to impurities generated during hydrolysis. Impurities tend to slow fermentations or lead to incomplete utilization of sugars which can lead to the need for costly purification. The productivity of organisms utilizing five carbon sugars should be comparable to the current organisms which utilize glucose or the capital costs will be significantly higher. Current productivity targets are between 1.5 and 2.3 g/l/hr. Finally, these organisms should be comparable in product tolerance/inhibition. The organism should be able to produce alcohol at levels consistent with existing glucose fermenting organisms.

**Pt-B. Fuels Catalyst Development**
The development of robust catalysts for the upgrading of pyrolysis oil for the production of liquid transportation fuels is critical to an economically viable process. The catalysts must afford high selectivity to the desired end product and must have high conversion rates and long lifetimes. The specific targets for selectivity are currently being developed, but it is likely that at least 90% selectivity will be required to be economically viable. These catalysts must be robust with respect to the impurities of the pyrolysis oil in order to achieve reasonable catalyst lifetime that will enable viable capital costs.

**Pt-C. Chemical and Materials Organism Development:**
Economically viable fermentation for production of chemicals and materials requires significant improvements in currently existing organisms. Production rate in organism development is directly linked to the cost of capital and is one of the primary opportunities for cost reduction. Economic modeling has shown that a reasonable target for productivity is 2.0 g/l/hr or greater. This level of productivity moves the capital cost of fermentation more in line with the capital cost associated with petrochemical based processes. Product purity is critical for downstream separations. Organisms need to be developed that can provide single fermentation product of at least 95% pure as opposed to a mixture of products. Final concentration will be important in reducing separation costs. In general, a final concentration of 100 g/l will be required to be economically viable. Utilization of five carbon sugars by the organisms will be especially important for the economics of lignocellulosic derived biomass. The organisms must also be robust with respect to hydrolysate impurities. This is especially important when working from lignocellulosic biomass hydrolysate.

**Pt-D. Chemical and Materials Fermentation Development:**
The primary needs in fermentation development are in lowering the cost of capital associated with fermentations. This is particularly true in aerobic fermentations. New engineering solutions coupled with improved organisms need to be developed to lower the cost of maintaining a fully oxygen saturated fermentation system. The cost of aeration can increase fermentation costs by 40% when compared to anaerobic fermentations.

**Pt-E. Chemical and Materials Enzyme Development:**
Novel low cost enzymes need to be developed to perform very specific reactions. The use of enzymes generally affords very high selectivity. The development of enzymes with high specific

activity at low cost could have significant impact on the overall costs of producing chemicals and materials from biomass.

**Pt-F. Chemical and Materials Catalyst Development:**
The highest priority in removing barriers in catalysis is development of highly selective catalyst materials. Catalyst selectivity impacts virtually all aspects of the cost of producing chemicals and materials including capital, operating, feedstock and separations. In virtually all commercial catalytic processes, a selectivity of at least 90% is required for economic viability. Also, catalysts that are resistant to fouling from impurities in the various biomass feedstocks will directly impact catalyst lifetime. A catalyst lifetime of at least one year is typical for commercial processes. Catalyst lifetime can also be managed via low cost regeneration strategies. While regeneration is not optimal, several large scale commercial processes utilize regeneration to extend catalyst lifetime. Conversion, while important is less critical because lower conversions can be managed with recycle. Acceptable conversion levels are on the order of 60%, lower conversion tends to make recycle economically unattractive. These barriers and research needs are critical to virtually all catalytic reactions including hydrogenation, hydrogenolysis, dehydration, and oxidation.

**Pt-G. Chemical and Materials Separations:**
Separations are critical to virtually all aspects of producing chemicals and materials from biomass. Low cost purification technologies need to be developed that can remove impurities from hydrolysates and fermentation broths. Separations are also critical for final product recovery. Major areas for improvements include development of new membrane technologies and selective materials (molecular recognition). The cost of separation and purification can often be greater than the processing costs and will be a critical barrier to overcome. Separation costs should not amount to more than 10-20% of final product value.

### 3.4.9 Strategies for Overcoming Barriers and Challenges

The Products Element uses an RD&D strategy to overcome barriers identified. Appropriate research is selected through competitive funding opportunity announcements (FOA) that target applied and pre-competitive research that addresses the technology barriers and those technology areas suggested by industry to be the highest priority. The applicants are required to show a direct correlation to barriers in their proposed research plans. The lead organization in research projects needs to have the means to implement the proposed technology commercially, and often a successful partnership between Universities, National Laboratories, and industrial partners results in the highest quality research being applied to the barrier with the ability to demonstrate success.

Analysis drives the prioritization of research areas to be pursued. The “Top 10 Value Added Chemicals from Biomass" study described in 3.4.2 is a guiding analytical document for potential research partners to consider because it targets applied and pre-competitive research identified by industry as their highest priority as well as being aligned with the role of federal investments.

Expected outcomes of the research includes developing technology and tools that have broad applicability for multiple chemicals and materials, and technology that leads to implementation or use in larger, biorefinery development efforts.

**Detailed descriptions of research strategies:**

**Biochemical Catalysis (Addressing technical barriers A, C, D and E)**

- Improved microbial strains for sugars
  - Advanced metabolic engineering
  - Productivity
  - Improved oxygen efficiency in aerobic fermentations
- Conversion efficiency
  - Pentose utilization
- Hydrolysate toxicity
- Organism robustness
  - Low pH fermentation and high inhibitor tolerance
- Separation and purification of products

**Pt-A. Fuels Organism Development:**
Through interactions with industry, yeasts have been determined to be the organism of choice for near term applications, though bacterial systems have been developed that are capable of meeting the needs of multisugar fermenting to ethanol. The Products element has funded development of a multisugar fermenting yeast through industrial cost shared research, as well as taken a more fundamental approach to the barriers, by studying xylose uptake, and utilization of arabinose.

Furthermore, in research conducted outside of the program, utilizing multifermenting organisms, there is reason to believe that proprietary organisms exist that can economically ferment at least two sugars to ethanol. The program will do a field-wide survey of the need for further development of organisms, define those issues that will provide the most improvement in existing organisms and form seek to form partnerships to improve the currently available yeasts and bacteria.

**Chemical Catalysis (Addressing technical barriers B and F)**

- New catalyst systems
  - Effective catalyst design
  - Selectivity and yield
- Catalyst lifetime
- Catalysis Heterogeneous and Homogeneous
  - Selective bond breaking and bond making processes
  - Selective reductions and oxidations
  - Use of inexpensive reagents: air or oxygen
- Catalysts for aqueous systems
- Dehydrations
- Selective dehydroxylations

**Separations (Addressing technical barrier G)**

- Improved membrane separations
- Novel reactive separations

### 3.4.10 Element Tasks

Task descriptions for the Products Core R&D Platform are presented in Table 3.4-1. Each task is expected to overcome one or more of the specific barriers listed above. Each task also is expected to enable one or more pathways.

**Table 3.4-1:** Products Core R&D Tasks

| Task | Task Description | Barriers | Pathways Enabled | Duration |
|---|---|---|---|---|
| 1. | Fuels –<br>a. Biological Catalysis<br>b. Chemical Catalysis<br>c. Separations | a. P-A<br>b. P-B | a. Ag Residue<br>Perennial Crop<br>b. Oil Processing<br>Pulp and Paper<br>Forest Products | a. 60 months<br>b. 60 months |
| 2 | Chemicals and Materials –<br>a. Biological Catalysis<br>b. Chemical Catalysis<br>c. Separations | a. P-C, P-D, P-E<br>b. P-B<br>P-F | a. Wet mill<br>Dry mill<br>Ag Residue<br>Perennial Crops<br>Pulp and Paper<br>Forest Products<br>b. Wet Mill<br>Dry Mill<br>Oil Processing<br>Ag Residue | a. 24-60 months<br>b. 12-36 months |
| 3 | Combined Heat and Power | | | |

Not all barriers are being addressed fully, due to funding constraints. The chemical catalysis area is receiving more emphasis due to its near term potential to produce products commercially. This makes it attractive to industrial partners who have a shorter vision that is based primarily on profits. The Program has initiated some core R&D to address the biological barriers faced by the program through its work in fungal genomics, but yeast fundamentals are currently not being developed. Research in this area would address more fully barriers associated with sugar utilization which is of primary interest to the current ethanol industry looking at incorporating cellulosic feedstocks into their existing operations. At this point, they are planning on utilizing existing yeast technologies for the wet and dry mill pathway options, but beyond these near term options the yeast program will be inadequate to meet the need.

### 3.4.11 Milestones & Decision Points

Products research supports achievement of milestones in all identified pathways. The specific assignment of milestones to each pathway will be reevaluated after the scheduled Stage Gate Review in August 2005 when principal investigators (PIs) for each task have had an opportunity to determine appropriate placement of their project level milestones in one or more pathways.

| Tasks | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Corn Wet Mill Improvement Pathway | | | | | |
| 1 | ◊$_6$◊$_7$◊$_8$◊$_9$◊$_{10}$ | ◊$_2$◊$_3$◊$_4$◊$_7$◊$_{10}$ | ◊$_6$◊$_7$◊$_8$◊$_{12}$ | | |
| 2 | | | ◊$_{10}$ | | |
| 3 | ◊$_1$◊$_{10}$ | | | | ◊$_1$◊$_2$◊$_5$◊$_{11}$ |
| Corn Dry Mill Improvement Pathway | | | | | |
| 1 | ◊$_6$◊$_7$◊$_8$◊$_9$◊$_{10}$ | ◊$_2$◊$_3$◊$_4$◊$_7$◊$_{10}$ | ◊$_6$◊$_7$◊$_8$◊$_{12}$ | | ◊$_1$◊$_2$◊$_3$◊$_4$◊$_5$ |
| 2 | | | ◊$_{10}$ | | |
| 3 | ◊$_1$◊$_{10}$ | | | | ◊$_1$◊$_2$◊$_5$◊$_{11}$ |
| Oil Crop Processing Pathway | | | | | |
| 1 | | ◊$_2$◊$_3$◊$_4$◊$_7$◊$_{10}$ | | | |
| 2 | | | ◊$_6$◊$_7$◊$_8$◊$_{12}$ | | |
| 3 | | | ◊$_{10}$ | | ◊$_1$◊$_2$◊$_5$◊$_{11}$ |
| Agricultural Crop Processing | | | | | |
| 1 | ◊$_6$◊$_7$◊$_8$◊$_9$◊$_{10}$ | | ◊$_{12}$ | | ◊$_1$◊$_2$◊$_3$◊$_4$◊$_5$ |
| 2 | | | ◊$_{10}$ | | |
| 3 | ◊$_1$◊$_{10}$ | | | | ◊$_1$◊$_2$◊$_5$◊$_{11}$ |
| Perennial Crop Processing | | | | | |
| 1 | ◊$_6$◊$_7$◊$_8$◊$_9$◊$_{10}$ | | ◊$_{12}$ | | ◊$_1$◊$_2$◊$_3$◊$_4$◊$_5$ |
| 2 | | | ◊$_{10}$ | | |
| 3 | ◊$_1$◊$_{10}$ | | | | ◊$_1$◊$_2$◊$_5$◊$_{11}$ |
| Pulp and Paper Mill Improvement Pathway | | | | | |
| 1 | | | ◊$_6$◊$_7$◊$_8$◊$_{12}$ | | |
| 2 | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 3 | | | | | ◊$_{1}$◊$_{2}$◊$_{5}$◊$_{11}$ |
| Forest Products Mill Improvement Pathway | | | | | |
| 1 | | | ◊$_{6}$◊$_{7}$◊$_{8}$◊$_{12}$ | | |
| 2 | | | | | |
| 3 | | | | | ◊$_{1}$◊$_{2}$◊$_{5}$◊$_{11}$ |

**C&D Products Platform Element Milestones** ◊$_{1}$

**1** Develop new organisms capable of fermenting C5 sugars to products in "Top Ten" report.
**2** Organism productivity rates at 1.5-2.5 g/Lhr
**3** Yield from sugars greater that 90%
**4** Final concentration from fermentation at 100 g/l.
**5** Organisms robust with respect to impurities.
**6** New catalysts capable of converting sugars to products in the "Top Ten" analysis.
**7** Catalysts achieve selectivity of 90% or more.
**8** Catalyst lifetime of at least 1 year.
**9** Catalyst fouling minimized.
**10** New membrane technologies developed to recover products at less than 10-15% of product value.
**11** Demonstrate and validate economical conversion of mixed sugars to ethanol in a wet mill.
**12** Catalyst tolerant to temperature
**13** Demo and validate products including ethanol from lignin or biomass derived syngas
**14** Demo and validate products from new fractionation/consolidated process intermediates

## 3.5 Integrated Biorefineries

A biorefinery processes biomass into value-added product streams. In theory, anything that uses biomass and makes more than one product is a biorefinery. This very simple definition captures a wide range of existing, emerging, and advanced process concepts. Examples of existing biorefineries include corn wet mill and dry mill processors and pulp and paper mills.

The name biorefinery purposely evokes visions of today's petroleum refinery. In a modern petroleum refinery complex, the largest volume product is liquid fuel. Another segment of the refinery involves production of petrochemicals, such as olefins, for the growing polymer market. Similarly a biorefinery will seek to produce an optimum combination of fuels, power, bioproducts and heat/energy to produce the greatest financial return to the operation.

The following definition of a biorefinery was recently legislated by Congress in the 2002 Farm Bill:

> "The term 'biorefinery' means equipment and processes that—
> (A) convert biomass into fuels and chemicals; and
> (B) may produce electricity."

For the purposes of this plan, the concept of a biorefinery is expanded to embody a facility that uses biomass to make a slate of fuels and chemicals to maximize the value of the biomass, thereby maximizing the financial return to the investor. Maximizing the value derived from biomass through an optimal slate of fuels and products is the key to understanding why the biorefinery is the central strategy for the Biomass Program.

### 3.5.1 External Assessment and Element Market Overview

#### 3.5.1.1 Current Potential

Much like a petroleum refinery, the biorefinery will produce fuels as its largest volume product. The key to profitability, however, will lie in the production of a percentage of high-value chemical or material products. The biorefinery concept has already proven successful in the U.S. agricultural and food processing industries, where such facilities now produce food, feed, fiber, fuels and chemicals. Large corn wet milling plants, for example, are biorefineries that produce enzymes, lactic acid, citric acid, amino acids, and fuel grade ethanol form sugars derived from corn grain. The primary market for these products is the food and feed industries. In some facilities, heat and power are also produced to meet the energy needs of the facility.

Pulp and paper mills are another example of existing biorefineries. In these facilities wood is converted to pulp for papermaking and various byproducts are used to produce chemicals, fibers and plastics. Black liquor, a byproduct of the pulping process, is used in on-site cogeneration systems to meet a large share of electricity and steam requirements for the plants.

The future of the biorefining, and one that is going to make the biggest impact on displacing imported petroleum for the U.S., will likely require processors to utilize multiple feedstocks to produce ethanol at its maximum rate while producing by-products that have a large impact on profitability.

This integration strategy will require more research and development to allow this nascent industry to achieve its full potential. Major R&D activities supported by DOE are underway within both the agricultural processing industry as well as the chemical industry to develop new chemicals and materials from renewable feedstocks including agriculture residues as well as existing biobased feedstocks such as high fructose corn syrup. Based on a comprehensive analysis by Argonne National Laboratory[3.2], biofuels coupled with vehicle efficiency improvements could sustainably reduce our oil dependence by up to two-thirds by 2050. This would require a larger and more focused effort than we are currently devoting on research, development and demonstration. However, this conclusion is debated by many experts and the policy makers. There is not a consensus that bioenergy can improve our economy, especially in the agricultural sector. What is known is that wherever a corn wet or dry mill is built, the local economy is improved. The full impacts related to increasing starch-based ethanol while incrementally employing agricultural residues or mill by-products for added biofuels or bioproducts production have not been quantified. It is still risky and requires significant capital investments.

#### 3.5.1.2 Political Environmental Nuances

With the pending renewable fuel standards and legislation requiring biobased oxygenates, the corn and wet mill operators are eager to produce more ethanol with higher profit margins and to possibly produce profitable chemical byproducts to enhance profitability. Pulp and paper operations are looking to add value to their processing operations by developing a biorefinery model that produces pulp and fuels (some already produce biobased chemicals such as inks and resins). The oil processing industry could easily transition into a more expansive oil products and biodiesel biorefinery if increased biodiesel use is mandated. In addition, the oil processing industry could be invigorated with an infusion of new conversion technologies yielding new products such as those projects being supported by OBP today. The market for biobased products is not saturated and with fluctuating oil prices, a reliable supply of indigenously produced fuels, chemicals and materials has market potential

#### 3.5.1.3 Competing Technologies

Ultimately, biorefineries must compete, on an economic basis, with established petroleum refineries and petrochemical facilities, and their associated infrastructure.

### 3.5.2 Internal Assessment and Program History

#### 3.5.2.1 Element History

The Integrated Biorefinery Element was a natural consequence of the integration of the three Offices previously dealing with biomass conversion to fuels, power and chemicals. The previous Biofuels Program developed transportation fuels in the Office of Transportation Technologies (OTT), with a focus on ethanol facilities only. The Office of Industrial Technologies (OIT) initiated some R&D into chemicals and products in response to the chemical industries' need to

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[3.2] GM Study: Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems — A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions (May 2005), http://www.transportation.anl.gov/pdfs/TA/339.pdf be more efficient. Office of Power Technologies (OPT) had the lead in developing electric power from biomass. The integrated Office of Biomass Programs created a new vision that would focus on core technology development capable of supporting the growth of a new biomass industry, through the integrated biorefinery. This vision lead in part to the Biomass Act of 2000 which provides guidance for the creation of the industry and necessary collaboration with USDA, where the development of economic lignocellulosic energy crops is managed.

OBP's activities interface with the agricultural industry primarily at the research and development level. The focus of these activities has been on developing technologies for the production of specific product opportunities within that industry that could integrate into existing processing facilities. OBP has set a strategy to enable the production of fuels and chemicals in an integrated biorefinery utilizing existing feedstocks and over time expanding that feedstock base to include lignocellulosics. In order to meet the programmatic objectives for OBP the major transformation needed in the agricultural industry includes:

- Reducing the cost of ethanol production from feedstocks other than starch
- Enabling the production of higher valued chemicals to drive the economics of the biorefinery
- Integrating all components of a biorefinery to enable the economic production of fuels and chemicals while optimizing the internal production of heat and power

Historically, the only sustained efforts at evaluating biorefinery opportunities were started in fiscal year 2002 with the first announcement of opportunity for funding integrated biorefineries. These involved research and development to improve profitability of corn wet mills, help develop dry mills into integrated biorefineries, and assist emerging biorefineries evaluate options for full-scale integration, including the use of corn stover or other agricultural residues. In addition, joint USDA-DOE annual funding opportunity announcements have included calls for additional integrated systems, improved thermochemical processing for fuels and chemicals, and production of biobased products in support of potential biorefinery operations.

### 3.5.2.2 Element Organization and FY 2006 Activities

The Integrated Biorefineries element is organized around five key tasks, as shown in the work breakdown structure (WBS) in Figure 3.5-1.

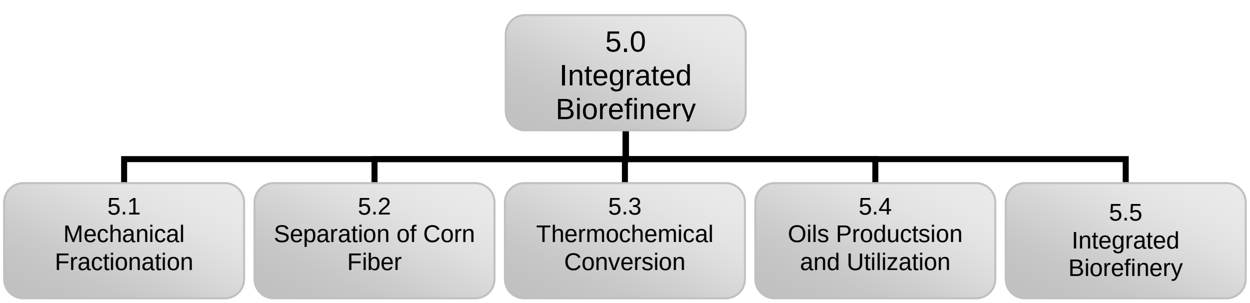



**Figure 3.5-1:** Integrated Biorefineries Work Breakdown Structure

**Element Recent Accomplishments**
In FY 2005, the program supports about $14.5 million in direct support to integrated biorefinery projects selected in 2002. Significant achievements to date include:

- Conduct a 50,000 sheet plywood and composite board production run using adhesives derived from biomass instead of wholly from petrochemicals, work started with Lousiana Pacific but completed by Weyerhaeuser;
- Development and demonstration of a new front-end pretreatment operation for a dry mill by Broin that increases the ethanol yield and produces more valuable, high protein animal feed; and
- A pilot plant demonstration by Archer Daniels Midland and the National Corn Growers Association at NREL to scale up bench results to define operating parameters involved in integrating processes into existing corn wet mills.

These successes would not have occurred without the core platform R&D (sugars, thermochemical, products, feedstocks) conducted at the DOE national laboratories or at the companies themselves both in the Biomass Program and other EERE programs. Figure 2-2 illustrates the relationship between all the program elements.

## 3.5.3 Element Federal Role

### 3.5.3.1 Element Contribution to National Need

The demonstration of the integrated biorefinery concept is the means to develop a biobased industry capable of displacing petroleum and shoring up domestic fuel supplies. The Federal role is to invest in research, development and demonstration of this first of a kind technology, and establish the scientific and technological foundation that quantifies and reduces the risks inherent in commercializing processes for producing fuels, chemicals and other materials.

Increased productivity and efficiency can be achieved through operations that lower the overall energy intensity of the biorefinery's unit operations, maximize the use of all feedstock components, byproducts and waste streams, and use economies of scale, common processing operations, materials and equipment to drive down the production costs. The federal role is a key component in helping industry assess the risks and potential for developing commercial prototypes that lead to actual commercial applications.

### 3.5.3.2 Interaction with Other Federal Programs

Currently there are no other Federal program addressing the Integrated Biorefinery.

## 3.5.4 Element Approach

### 3.5.4.1 Element Approach and Role within Program

The role of the Integrated Biorefinery Element within the Biomass Program is to support the establishment of cost-competitive integrated biorefineries through public-private partnerships. This element focuses on the validation and demonstration of integrated pilot- and demonstration-scale biorefinery systems, which is the culmination of the work being done in the program core R&D areas (feedstocks, sugars, thermochemical, and products platforms). The Integrated

Biorefinery is where the development of the platform technologies and new capabilities for products is brought together in a fully integrated operation.

### 3.5.4.2 Element Contribution to Pathway and Program Outputs

Integration of the technologies developed through the Biomass Program core R&D elements is critical to the deployment of commercially-viable integrated biorefineries, which is the ultimate measure of program success. The validation and demonstration activities of the Integrated Biorefineries Platform will ultimately contribute to all of the seven biorefinery pathways either under development or being considered by the Biomass Program. Initially, efforts will focus on the pathways that offer opportunities for improving operations of existing biomass processing facilities like corn wet and dry mills. These pathways are near term and have high cost-share industrial partners. Many of the technologies advancing through this deployment will transferable to the longer-term pathways. As research progresses and technologies advance through the program's core R&D efforts, the longer term biorefinery pathway options, such as agricultural residue processing and energy crop processing, will be demonstrated and validated through cost-share industry partnerships. While development time is longer for these options, their impact on displacing imported oil, by producing transportation biofuels and other products, is potentially significantly larger.

The objectives of the Integrated Biorefinery element reflect the major outcomes for the Biomass Program in this MYPP:

- Complete technology development necessary to enable start-up demonstration of a biorefinery producing fuels, chemicals and power by 2012 at an existing or new corn dry mill.
- Help U.S. industry establish the first large-scale sugar biorefinery based on agricultural residues by 2018
- Complete technology integration to demonstrate a minimum sugar selling price of $0.64 per pound resulting in a minimum ethanol selling price of $1.09 per gallon by 2020 from agricultural residues or dedicated perennial energy crops.
- Complete the technology integration of thermochemical processes into a sugar biorefinery to produce syngas at $3.84 per millon Btu by 2030 from lignin or wood feedstocks.

In an effort to bring the newest generation of biorefineries to fruition, a major solicitation is planned for FY 2008. This solicitation will build on the previous FY 2002 integrated biorefinery projects, the FY 2004 thermochemical projects and the FY 2005 Products solicitation. Each previous solicitation addressed key programmatic barriers, such as fiber conversion, recalcitrant starch conversion, and product development. The goal of the new FY 2008 solicitation will be demonstrating the technical feasibility and economic viability of the biorefinery concept, such as the advanced wet and dry corn mills. A successful culmination of this solicitation will result in biorefineries along the nearest term pathways to be ready for commercialization. The integrated biorefinery path and the linkage to each of the platform solicitations is shown in Figure 3.5-2.

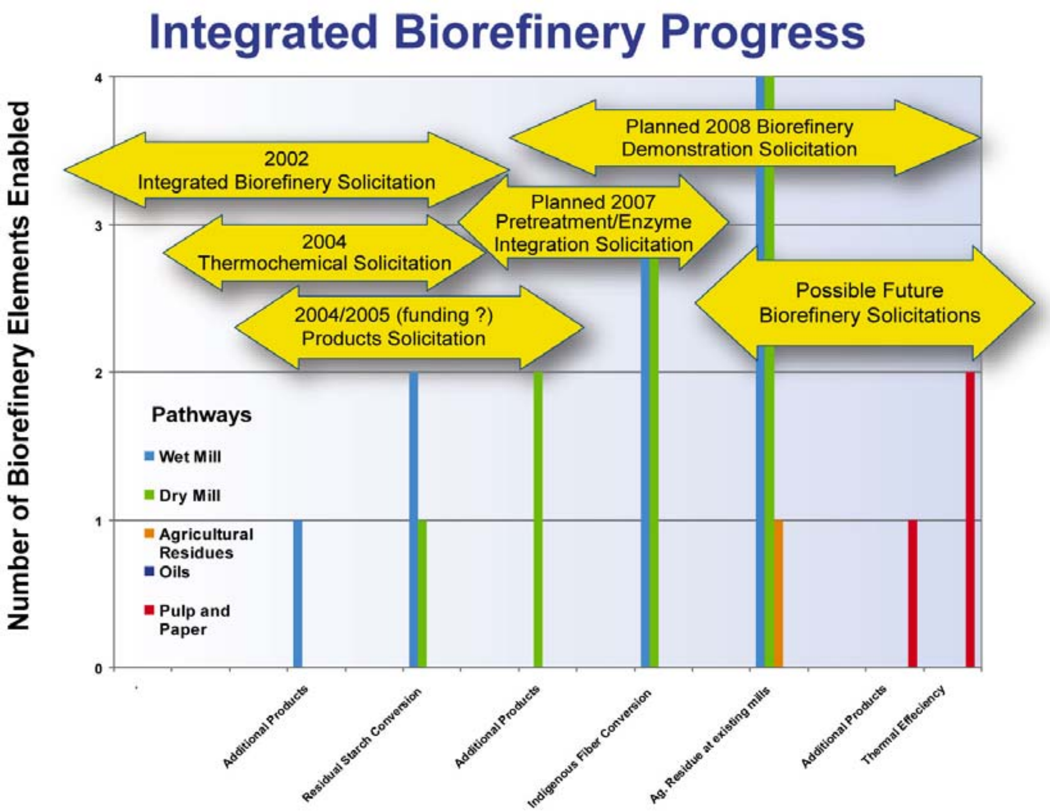



**Figure 3.5-2:** Integrated Biorefinery

### 3.5.5 Element Performance Goals

Projects within the integrated biorefinery pathways are conducted with industrial partners and thus each project may be different in terms of the feedstock, details of the processes or the suite of co-products. However, the common thrust of the Integration of the Biorefinery Technologies component is to support the integration of cellulosic conversion processes into existing starch-based ethanol plants. Some key Performance Goals include:

- Complete the fiscal year 2002 solicitation projects and demonstrate a minimum of 5 to 20 percent increase in ethanol yield from fiber conversion and recalcitrant starch by 2007
- Completion of a pilot plant project in partnership with a corn ethanol producer to convert agricultural residue to fuel grade ethanol by 2008 and demonstrate a minimum of 5 to 10 percent increase in revenues using the minimum ethanol selling price of $2.50 per gallon.
- Completion of a pilot plant to integrate one new biobased product into a corn dry mill including validation of the transformation cost between $0.03 and $0.07 per pound when integrated will demonstrate a 5 to 10 percent increase in revenues by 2009.
- Completion of a pilot plant to validate the process economics of integrating fuels, chemicals and other products into a corn dry mill by 2010 .
- Completion of a pilot plant to integrate energy crops into an advanced corn dry mill by 2012, including the demonstration of transforming carbohydrates to bioproducts at less than $0.25 per pound.
- By 2015, establish the technical and market potential, through pilot-scale testing and industry cost shared commercial demonstration, of four new value-added chemicals

and/or materials in an integrated biorefinery, for less than $0.35 per pound from sugars that cost less than $0.13 per pound.

The Integrated Biorefinery element goals will contribute directly to the program strategic goal of developing biomass and biorefinery-related technologies to the point that they are cost and performance competitive and are used by the nation's transportation, energy, chemical and power industries to meet their market objectives.

### 3.5.6 Element Strategic Goals

The strategic goal of the Integrated Biorefinery Element is to demonstrate and validate technologies at a systems level to improve corn wet mill facilities using corn grain feedstocks, dry mill facilities using corn grain (and other grains) feedstocks, natural oil processing facilities using vegetable and crop oil feedstocks, processing facilities capable of using agricultural residue and perennial crop feedstocks, and to improve forest products, pulp and paper processing facilities using wood feedstocks.

### 3.5.7 Element Market Challenges and Barriers

The commercial use of biomass technologies could vary significantly depending on a variety of external factors, including:

- Im-A. Future energy prices
- Im-B. Availability of conventional energy supplies
- Im-C. Cost or success of competing technologies
- Im-D. Labor and feedstock costs
- Im-E. Consumer preferences regarding energy sources

The primary market barriers are the lack of infrastructure to supply the biomass feedstock at lower prices; the need for an integrated production approach to realize competitive cost levels; and the lack of a framework for the monetization and reward for external benefits such as energy security and environmental improvements. The largest market hurdles are often associated with the scale-up and economics of first-of-a-kind (pioneer) plants. Commercial financing is not easily available for high risk pioneer plants.

### 3.5.8 Element Technical (Non-Market) Challenges/Barriers

Many of the technical barriers are addressed in the three Platform R&D areas. Each of these platforms builds directly off of the lessons learned and accomplishments of biofuels, biomass energy systems, feedstock and other R&D efforts supported by DOE since the 1970s.

The biorefinergy efforts will integrate the technology solutions to these barriers and then optimize the process to achieve the return-on-investment necessary for commercialization.

Technical barriers directly impacted by the objective of the Integrated Biorefinery elements that pose a challenge to developing and sustaining emerging biorefineries include:

**It-A End-to-End Process Integration -** The challenge of end-to-end, feed-to-product, process integration is crucial as it impacts both performance and profitability. The potential for success for many of the bio-chemical processes under development depends on the success of the biorefinery concept, which will be designed for efficient utilization of biorefinery residues and to reduce the production costs of range of bio-based products through co-production. Incorporation of the thermochemical gasification into the sugar biorefinery suggests needs for heat recovery and recycle from one system to the other, as well as optimization of product recovery and refining systems. These concepts are novel and the complexity of technical issues related to collecting, storing transporting, and processing the diverse feedstocks, along with the complexity of integrating several innovative process steps, entails considerable additional technical risk.

**It-B Commercial-scale Demonstration Facilities -** As with all new process technologies, demonstrating sustained integrated performance that meets technical, environmental, and safety requirements at sufficiently large scales is an essential step toward commercialization. The availability of large-scale demonstration facilities, that can test and validate new technologies and integrated systems at full scale, is critical to successful commercial deployment. Knowledge and understanding of these integrated systems will also result in improved system cost, performance, and emissions estimates, along with options for optimizing process configurations. Integrating new bioenergy processes with existing biorefineries and improving the efficiency of existing, emerging, and advanced biorefineries (e.g., integrating biomass gasification with combined cycle heat and power production) are two critical areas.

**It-C Risk of Pioneer Technology -** The probability of failure in new facilities that are based on commercially proven units is very small; however, the first biorefineries will incorporate a variety of new technologies, unproven in commercial operation. The number of process steps that are new in commercial use has been shown to be a strong predictor of performance shortfalls. Heat and mass balance equations are least likely to be known for new steps in the process, as well as for steps downstream of where the new unit/process is located. In addition, unanticipated buildup of impurities in process streams can result in abrasion and corrosion of plant equipment and deactivation of process catalysts.

**It-D Plant Economics.** The financial investment required for biorefineries will be high. Reasonable estimates of plant performance will be key to attracting investors and future market planning. Achieving design capacity as quickly as possible after start-up is critical to achieving economic viability.

**It-E Sensors and Controls -** Effective process control will be needed to maintain plant performance and emissions at target levels with varying load, feedstock and intermediate stream properties, and processing conditions. Development of new sensors and analytical instruments is needed to optimize control systems for biochemical and thermochemical systems. Existing control systems are only adequate with minimal sensor input and improved sensors are likely to require improved control systems. Some of the key barriers include the lack of real-time sensors for measuring feedstock moisture and composition, the need for on-line analysis of gas, liquid, solid and multiphase stream compositions for the monitoring of conversion processes such as pretreatment, hydrolysis, liquid conditioning, gasification, gas conditioning, gas purification processes, product synthesis, product recovery, and the lack of process control systems for reactor systems and subsystems (performance, emissions, fuel properties, etc.).

**It-F Engineering Modeling Tools.** The current level of understanding of fuels chemistry is insufficient for commercialization and process scale-up and optimization. For complete understanding of how fuel chemistry affects commercial viability, reaction chemistry, fluid mechanics, and phase behavior should be incorporated into both rigorous and engineering computational fluid dynamic models for use in design and process control. In addition, many of the initial opportunities for heat integration can be addressed with engineering modeling tools.

### 3.5.9 Element Strategies for Overcoming Barriers/Challenges

The new technologies developed under the Platform R&D plans and integrated into pilot plants will begin to give the industry experience in converting hemicellulose and cellulose to ethanol so they will be more likely to integrate biomass resources into their plants as additional capacity is needed by the market. The program strategy is encompassed in the pathway approach described generally in section 1.6 and in more detail in Figure 2-3 of Section 2.1.2.

The barriers defined in section 3.5.8 are addressed in part by progress made in all of the pathways. The Corn Grain Wet Mill and Corn/other Grain Dry Mill Pathways are nearer term than the other pathways because of the involvement of the existing industry. Barriers IB-A, IB-B, IB-C, and IB-D will be addressed to some degree in these pathways, but will require a progressing through the validation of more advanced technologies to be fully removed. Therefore, the Program strategy is to transition technology improvements through the existing industries and demonstrate agricultural residues and perennial crops in the mid to long term. These mid and long term strategies are outside the scope of the five year planning window of this document, but remain important none the less.

### 3.5.10 Element Tasks

The Integrated Biorefinery element are presented in Table 3.5-2. To complete these tasks, this element will integrate technologies from the Sugar, Thermochemical, and Products platforms, into pathways described in Section 1. The primary pathways identified and under consideration by the program include:

Agricultural Sector
1. Wet Mill Improvements
2. Dry Mill Improvements
3. Oil Processing Improvements
4. Agricultural Residue Processing
5. Perennial Crop Processing

Forest Sector

6. Pulp and Paper Mill Improvement Pathway
7. Forest Products Mill Improvement Pathway

Not all barriers are being addressed fully due to budget constraints. The program is currently focused on the corn dry and wet mill technology improvements because they have near term potential and the interest of the industry. More work is needed to further the development in the Oils, Forest, Paper and Pulp and Ag. Residue pathways. The Perennial crop pathway depends on advances in the Ag residue pathway and work at USDA not under control of the program.

**Table 3.5-2:** Integrated Biorefinery Tasks

| | Description | Barriers | Pathways Enabled | Duration |
|---|---|---|---|---|
| 1 | Mechanical Fractionation | IB-A<br>IB-B<br>IB-D | Dry Mill<br>Oil | 60 months |
| 2 | Separation of Corn Fiber | IB-A<br>IB-B | Wet Mill<br>Dry Mill<br>Oil | 24-36 months |
| 3 | Thermochemical Conversion for power, heat, and other materials | IB-A<br>IB-B<br>IB-C<br>IB-E<br>IB-F | Ag. Residue<br>Perennial Crop<br>Pulp and Paper<br>Forest Products | 60 months + |
| 4 | Oils Production and Utilization in an Existing Corn Dry or Wet Mill | IB-A<br>IB-B<br>IB-C<br>IB-D<br>IB-E<br>IB-F | Wet mill<br>Dry Mill<br>Oil | 60 months+ |
| 5 | Integrated Biorefinery Analysis | IB-C<br>IB-D<br>IB-F | All Pathways | 12-60 months |

Mechanical Fractionation

This task involves activities to separate grain and other feedstocks into their component parts for processing and conversion to reduce cost and improve yield. The use of attrition mills, roller mills, hammer mills, other grinders and filtering devices will be evaluated to reduce capital cost, and improve processing flexibility.

Separation of Corn Fiber

This task involves activities to release and concentrate corn fiber for improved conversion. It includes the use or development of improved processes and process equipment to separate, clean and concentrate fiber sources. Technologies may include wet and dry vibratory screens, filter presses, air-classification pulverizers, and chemical separation processes.

Harvest, Processing, Storage and Transportation of Feedstocks

This task involves activities to collect and separate grain and agricultural residues, woody and herbaceous materials, municipal waste and other biomass feedstocks, process in a cost-effective manner for densification and transportation to the biorefinery. Technologies may include single pass harvesters, pneumatic collection, processing and transport, slurry preparation, wet media mills, pelletizing and agglomeration, and storage.

Thermochemical Conversion for Power, Heat, and Other Materials
This task involves activities to transport, store and gasify a range of fuel types for a biorefinery. Technologies may include wet and dry feeders for handling unprocessed biomass, lignin from fiber separation, fly ash reinjection for carbon burnout, product syngas and offgas cleanup.

Pretreatment and Hydrolysis of Ag Residue in Existing Corn Dry Mill
This task is closely coupled to the Mechanical Fractionation task to provide a process that will yield the highest arabinose and xylan separation and conversion to reduce sugar losses. Technologies may include physical and chemical separation, neutralization, purification and concentration.

Oils Production and Utilization in an Existing Corn Dry or Wet Mill
This task involves activities to separate and produce a clean oil product from a range of feedstocks. This task is also closely coupled to the Mechanical Fractionation task to provide a feed that is easily handled, transported within the plant, and processed. Technologies may include additional grinding, physical and chemical separation, purification and concentration.

Integrated Biorefinery Analysis
This task involves activities to analyze the technical and economic improvements of different processes, including mass and energy balances will be developed along with capital and operating cost estimates for syngas production and sugar production. These analysis relies upon engineering feasibility studies, financial estimates, environmental assessments, and market impact evaluations.

### 3.5.11 Element Milestones & Decision Points

♦ Milestones

▼ Outputs

● Inputs

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|
| Corn Wet Mill Improvement Pathway | | | | | | | | | | |
| 1 | | | | | | | | | | |
| 2 | | ♦1 | | ♦2 | ♦3 | | ♦4 | | ♦5 | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | ♦6 | | | | | | |
| 7 | | ▼2 ▼5 | ▼3 ▼7 | ●3 | ▼8 | | ▼12 | | | |
| Corn Dry Mill Improvement Pathway | | | | | | | | | | |
| 1 | | | | ♦12 | | | | | | |
| 2 | | | ♦7 ▼4 | ♦8 ●2 | ♦10 | ●4 | ♦11 ▼3 | | | |
| 3 | | | | | | | | | | |
| 4 | | | | ●1 | ♦13 | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |
| 7 | | ▼1 ▼5 | ▼7 | ●4 | ▼8 | | ▼12 | | | |
| Agricultural Residue Pathway | | | | | | | | | | |
| 1 | | | | | | | ♦18 | | | |
| 2 | | | | | | | | | | |
| 3 | | ♦14 | | ♦15 | | | ♦16 | | | ♦17 |
| 4 | | | | | | | ♦21 | | ♦23 | ♦24 ♦28 |
| 5 | | ♦19 | ●2 | | ♦20 | | ♦21 | | ♦22 | |
| 6 | | | | | | | | | | |
| 7 | | ▼5 | ▼7 | ▼8 | ▼12 | ▼8 | ▼12 | | | ▼8 ▼12 |

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Perennial Crop Processing Pathway** | | | | | | | | | | |
| 1 | | | | | | ◆ 32 | | | ◆ 33 | |
| 2 | | | | | | | | | | |
| 3 | | | | ◆ 29 | | ◆ 30 | | ◆ 31 | | |
| 4 | | | | | | | | ● 1 | ◆ 38 | ◆ 39 |
| 5 | | | ◆ 34 | ● 4 | ◆ 34 ▼ 4 | | ● 4 | ◆ 35 ▼ 4 | | ◆ 36 |
| 6 | | | | | | | | | | |
| 7 | | | | | ▼ 2 ▼ 3 | ▼ 8 | ▼ 7 | | ▼ 8 | ▼ 1 ▼ 12 |
| **Oil Processing Improvements** | | | | | | | | | | |
| 1 | | | | | ◆ 51 | | | | | |
| 2 | | | | | | | | | | |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | ◆ 51 | | ◆ 6 | | | | ◆ 51 | | ◆ 55 |
| 7 | | ▼ 2 ▼ 5 | ▼ 3 ▼ 4 | ● 4 | ▼ 8 | ▼ 7 | ▼ 12 | | ▼ 7 ▼ 8 | ▼ 12 |

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|
| Pulp and Paper Mill Improvement Pathway | | | | | | | | | | |
| 1 | | | ● 3 | ♦ 33 | | | | | | |
| 2 | | | | | | | | | | |
| 3 | | ♦ 30 | | | | | | | | |
| 4 | | | ● 1 | ♦ 38 | | | ♦ 41 | ● 1 | | ♦ 47 |
| 5 | | ● 3 | ♦ 34 | | | | | | | |
| 6 | | | | ♦ 6 | | | | | ● 4 | ♦ 52 |
| 7 | | ▼ 2 ▼ 5 | ▼ 3 ▼ 7 | ● 3 | ▼ 8 | | ▼ 12 | ▼ 7 | ▼ 8 | ▼ 12 |
| Forest Products Mill Improvement Pathway | | | | | | | | | | |
| 1 | | ♦ 18 | | | | | | | ♦ 5 | |
| 2 | | | | | | | | | | |
| 3 | | | | ♦ 31 | | | | | | |
| 4 | | | ● 1 | ♦ 42 | | | ● 1 | ♦ 4 | ♦ 53 | ♦ 54 |
| 5 | | ♦ 48 | | ● 4 | ♦ 46 | | | ● 4 | ♦ 49 | |
| 6 | | | | ♦ 6 | | | | | | |
| 7 | | ▼ 2 ▼ 5 | ▼ 3 ▼ 7 | ● 3 | ▼ 8 | | ▼ 12 | | ▼ 7 ▼ 8 | ▼ 12 |

Milestones

1. Demonstrate and validate economical residual starch conversion in a wet mill
2. Demonstrate and validate economical fiber conversion to C5 and/or mixed C5/C6 sugars in a wet mill.
3. Demonstrate and validate economical conversion of mixed sugars to ethanol in a wet mill.
4. Demonstrate and validate economical new products from C5 or mixed C5/C6 sugars in a wet mill.
5. Demonstrate and validate economical new products from C6 sugars in a wet mill.
6. Demonstrate and validate economical new products from corn-derived oils in a wet mill.
7. Demonstrate and validate economical residual starch conversion in a dry mill.
8. Demonstrate and validate economical fiber conversion in a dry mill.
9. Demonstrate and validate economical conversion of mixed sugars to ethanol in a dry mill.
10. Demonstrate and validate economical conversion of mixed sugars to products in a dry mill.
11. Demonstrate and validate economical new products from C6 sugars in a dry mill.
12. Demonstrate and validate economical front-end fractionation processes in a dry mill.
13. Investigate alternate sources for dry mill heat and power.
14. Demonstrate and validate integrated corn stover harvesting logistics supporting a 50 million gallon per year ethanol production plant at $35 per dry ton.
15. Demonstrate and validate integrated wheat straw harvesting logistics supporting a 50 million gallon per year ethanol production plant at $35 per dry ton.
16. Demonstrate and validate integrated rice straw harvesting logistics supporting a 50 million gallon per year ethanol production plant at $30 per dry ton.
17. Demonstrate and validate feedstock flexibility and availability via blending depot or elevator.
18. Demonstrate and validate agricultural residue fractionation to produce $0.064 per pound mixed dilute sugars.
19. Demonstrate and validate ethanol from 5 biomass sugars that are economically viable.
20. Demonstrate and validate chemical building blocks, chemicals, materials from 5 biomass sugars that are economically viable.
21. Demonstrate and validate high value chemical and material products from lignin intermediates.
22. Demonstrate and validate fuel products from lignin intermediates.
23. Demonstrate and validate combined heat and power from lignin.
24. Demonstrate and validate lignin gasification to produce syngas.
25. Demonstrate and validate biomass gasification to produce syngas for $4.89 per million Btu’s.
26. Demonstrate and validate products from lignin or biomass derived syngas for $0.60 per gallon.
27. Demonstrate and validate hydrogen production from lignin or biomass derived syngas for $2.25 per kilogram.
28. Demonstrate and validate combined heat and power production from lignin or biomass derived syngas.

29. Demonstrate and validate integrated switchgrass production and harvesting logistics supporting the $35 per dry ton.
30. Demonstrate and validate integrated woody crop harvesting logistics supporting a minimum of $35 per dry ton.
31. Demonstrate and validate feedstock flexibility and availability via blending depot or elevator.
32. Demonstrate and validate switchgrass fractionation to produce dilute mixed sugars $0.064 per pound.
33. Demonstrate and validate woody crop fractionation to produce dilute mixed sugars $0.064 per pound.
34. Demonstrate and validate ethanol from 5 biomass sugars from perennial feedstocks.
35. Demonstrate and validate products from 5 biomass sugars from perennial feedstocks.
36. Demonstrate and validate high value chemical and material products from lignin intermediates.
37. Demonstrate and validate fuel products from lignin intermediates.
38. Demonstrate and validate combined heat and power from lignin intermediates.
39. Demonstrate and validate lignin gasificiation to produce syngas.
40. Demonstrate and validate biomass gasficiation to produce syngas for $4.89 per MMBtu.
41. Demonstrate and validate products from lignin or biomass derived syngas for $0.60 per gallons.
42. Demonstrate and validate hydrogen production from lignin or biomass derived syngas.
43. Demonstrate and validate reliable and economical gasification of black liquor.
44. Demonstrate and validate gas cleanup and chemical recovery from black liquor.
45. Demonstrate and validate cost-effective biomass gasification of wood residues.
46. Demonstrate and validate production of DME , FTE liquids, mixed alcohols.
47. Demonstrate and validate syngas use in a pulp mill.
48. Demonstrate and validate cost-effective extraction of C5 & C6 sugars from hemicellulose.
49. Demonstrate and validate ethanol production from extracted sugars from hemicellulose.
50. Demonstrate and validate cost-effective conversion of extracted C5 & C6 sugar to products.
51. Demonstrate and validate bio-oil production to stable intermediates.
52. Achieve cost-effective conversion bio-oil intermediate into products for pulp & paper.
53. Demonstrate and validate cost-effective biomass gasification of wood residues, syngas production in a forest products mill environment.
54. Demonstrate and validate syngas utilization in a forest products mill for CHP.
55. Achieve cost-effective converson of bio-oil intermediate into products.

Outputs

1. Output to Thermochemical Platform: Data on syngas cost to products
2. Output to Sugars Platform: Preliminary assessment of hemicellulose extraction efficiency and mixed sugar cost.
3. Output to Products Platform: Preliminary data for analytic validation
4. Output to Analysis: Preliminary data for integrated biorefinery evaluation
5. Output to Program: Input for FY 2008 solicitation

6. Output to Sugars: Complete analysis of depot concept.
7. Output to PBA: Data on integrated biorefinery for NEMS & MARKAL assessments.
8. Output to SI: Data on corn wet, dry mill economics and fiber conversion for assessments.
9. Output to Program: Data on risk assessment based on pathways.

Inputs

1. Input from Thermochemical Platform: Submit updated data on syngas costs from biomass and lignin residues.
2. Input from Integrated Biorefinery Analysis
3. Input from Sugar Analysis:
4. Input from Products Top Ten Study: Priority on chemical intermediate synthesis for biorefinery analysis.

# **Section IV:** Program Administration

## 4.1 Organizational Structure

This section contains information on how the Program is administered in an efficient manner. It includes a description of the structure of the organization, program implementation, cost management and monitoring, environmental safety and health, and communications and outreach efforts.

### 4.1.1 OBP Organization

OBP has overall authority and responsibility for managing DOE research, development, and demonstration activities relating to the use of renewable biomass for fuels, chemicals, materials, and power. OBP provides the overall strategy, policy, management, direction, and programmatic expertise necessary for a balanced program of research, development, testing, and evaluation that will catalyze the establishment of biomass technologies. Further, OBP will build its portfolio based on detailed market and technology analysis, in collaboration with leaders and technology experts from industry, academia, and the national laboratories, and in consultation with other EERE programs. The following are key characteristics of the program management and organizational approach:

- Structure that promotes clear lines of accountability and responsibility
- Cooperative partnerships to leverage OBP investment
- Program integration functions that focus on overcoming barriers to success and identifying strategies to achieve success most efficiently
- Analysis to support decision making throughout the Program
- Project Management Center for portfolio implementation and oversight to insure improved accountability and project performance
- Communication strategies and information resources that enable robust participation by all Program stakeholders

Figure 4-1 shows the organizational relationship between OBP and its technical focus areas, the DOE and EERE structures, and levels of management. OBP is one of 11 programs within EERE and under the purview of the Assistant Secretary for EERE. Overall management responsibility and authority for the Program resides with the OBP Program Manager, who reports directly to the EERE Deputy Assistant Secretary for Technology Development. All personnel within OBP report directly to the Program Manager. There are three primary levels of management for oversight and execution of the Biomass Program: Level 1 - the Headquarters Office of the Biomass Program, Level 2 - the Program Management Center, and Level 3 - the performing organizations which include the National Laboratories, private industry and academia. Each level is described below.

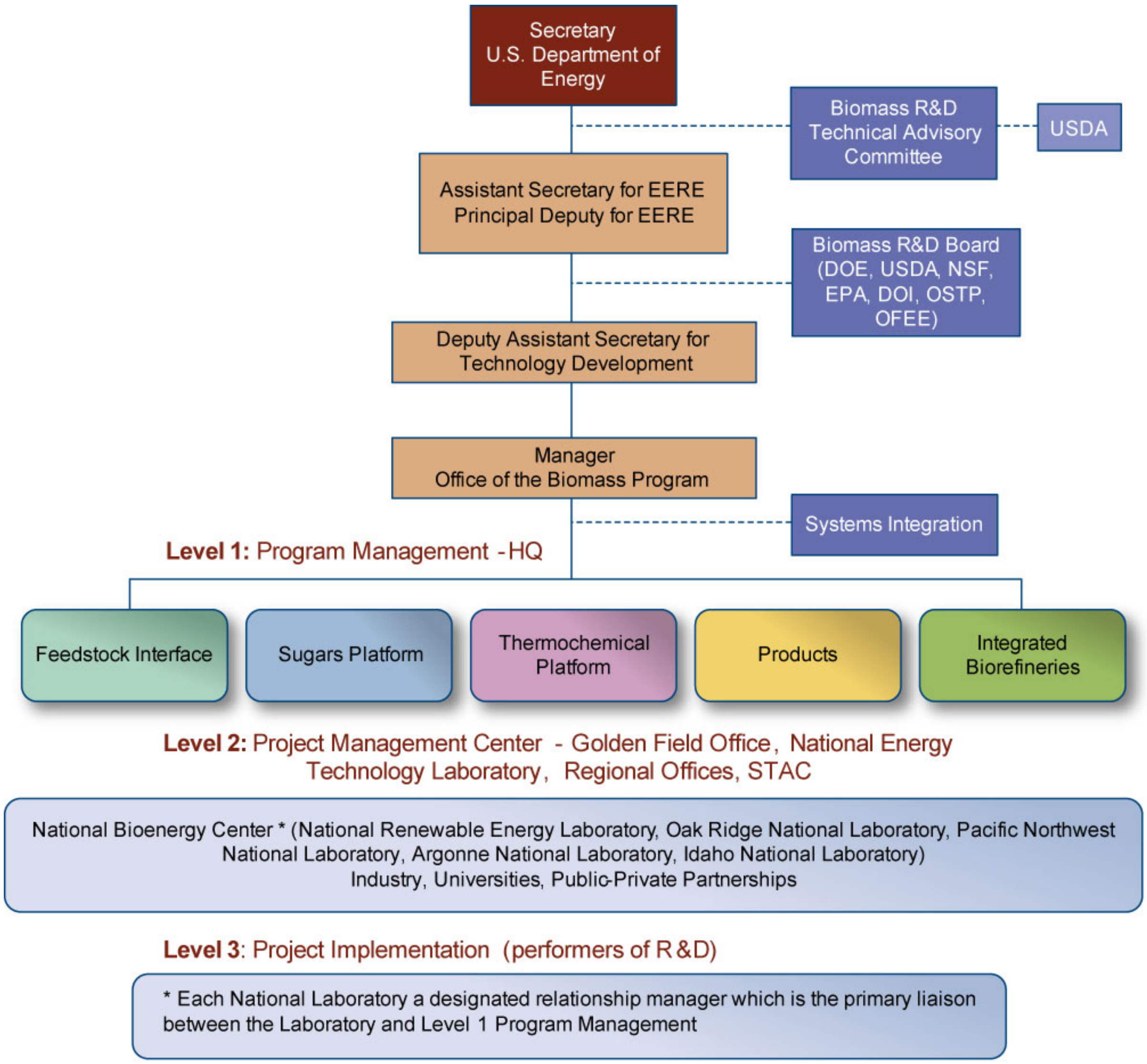



**Figure 4-1:** OBP Organizational Structure

#### 4.1.1.1 EERE/OBP Headquarters (HQ)

Program management is the responsibility of EERE/OBP HQ and includes program oversight; development, review and approval of program plans; program & technology goals development; hosting of biennial peer reviews; cultivation of interagency relations; program budget development, execution, and defense; portfolio gap identification; strategic planning; partnership development; communications and outreach; and interface with laboratory relationship managers to provide priorities and obtain programmatic laboratory feedback. There are five major program areas within HQ program management, as shown in Figure 4-1, which align with the technology R&D elements. There are also three support functions, including Systems Integration, Program Analysis, and Communications and Outreach (discussed in Section 4.5).

Systems integration provides technical support to the Program by developing and implementing a disciplined, results-driven approach to the design, development, and validation of complex systems. This ensures that requirements are identified, validated, and met, while minimizing the impact of unforeseen events and interactions on cost and schedule. DOE/EERE originally established the Systems Integration Office (SIO) at NREL to implement systems integration within DOE's Hydrogen Program. In late FY 2004, SIO's assignment was expanded to include the Biomass Program. The focus of systems integration is to understand the complex interactions between new technologies, system costs, environmental impacts, societal impacts, system trade offs, and penetration into existing systems and markets in order to help move the technologies now being developed for biomass systems from the laboratory to full-scale commercialization.

Program analysis, discussed in Section 2.3, provides the context and justification for decisions at all levels by providing quantitative metrics. Systems integration and Program analysis efforts are coordinated to ensure that the program obtains maximum value from these two functions.

#### 4.1.1.2 Project Management Center (PMC)

The focus of the PMC is to provide management support to EERE's 11 headquarters-based programs and increase value to EERE and the taxpayer through improved accountability and project performance. The PMC structure ensures the development of common, systematic business practices focused on achieving mission objectives, priority service, and accountability.

The PMC provides the Level 2 management function for the Biomass Program. The PMC provides overall execution of program plans, goals, and objectives as prescribed by Level 1 management. The functional roles of the PMC include field management of OBP research and development projects; support to preparation of the Multi-Year Program Plan (MYPP) and Annual Operating Plans (AOPs); financial and technical reporting; and assistance with partnership development. The PMC will provide coordination with NBC to provide technical resources to advance program goals and objectives, as well as oversight of laboratory projects as mutually agreed upon between OBP and the PMC. The PMC will also implement best project management practices, establish and maintain common procurement processes, develop and maintain common web-based tracking and management tools, and provide a portal to stakeholders for working with DOE.

The PMC is responsible for the field management of all OBP R&D projects, and includes staff in technical, procurement, legal, financial, and all other disciplines required for project management. The following plans and activities are employed to define and monitor technical progress, performance, and costs:

- Project Management Plans (PMP) for all major projects including detailed statement of work, milestones, deliverables, budget resources, and roles and responsibilities
- Annual Operating Plan for all projects in the portfolio, including:
    - Federal laboratory R&D projects
    - Competitively selected projects
    - Congressionally mandated projects

- Biomass Program-wide Quarterly Report, including summary of program element highlights and efficient organization for quick review of technical progress and cost status
- Monthly Financial Tracking process, maintained in a database to aggressively track, accrue, and estimate future cost profiles for every project

In addition, the PMC assists the Office of the Biomass Program in several areas of Program Management, including:

- Development of program solicitations
- Development of program performance targets, objectives and program milestones
- Maintenance and development of program budget and configuration baseline
- Assistance with Program peer reviews and project Stage Gate reviews
- Coordination with Systems Integration and Program Analysis
- Interface with laboratory relationship managers to track Core R&D progress
- Development of interagency relations; portfolio gap identification; strategic planning; and communications and outreach

#### 4.1.1.3 Project Implementation Organizations

Project implementation is conducted by recipients of competitively selected projects such as industry and academia, National Laboratories carrying out directed high-risk research, and organizations with congressionally mandated projects. These are the performers of the R&D who establish performance measures and goals commensurate with overall program goals and objectives.

All DOE National Laboratories are Federally Funded Research and Development Centers (FFRDC)[1], and as such are partners with and strategic advisors to DOE. The EERE OBP Program Manager has direct access to the DOE National Laboratory system through designated Biomass Laboratory Relationship Managers. Relationship Managers are the main liaison between OBP and the laboratories involved in the performance of R&D within the program, and ensure that the necessary resources are available at their laboratory to meet Program needs. They do not perform program management responsibilities. FFRDCs and the Relationship Managers that represent them are required to conduct business befitting their special relationship with the government; operate in the public interest with objectivity and independence; be free from organizational conflicts of interest; and provide full disclosure of its affairs to the sponsoring agency.

### 4.1.2 Coordination with other EERE Programs

Intra-agency interactions include four other EERE Office Programs: Industrial Technologies Programs (ITP), Hydrogen, Fuel Cells & Infrastructure Technologies (HFCIT), Freedom CAR & Vehicle Technologies (FC&VT), and Federal Energy Management Program (FEMP). The

[1] Federal Acquisition Regulation (FAR) 35.017 defines the role of a FFRDC as: 1) meeting some special long-term research and development need which cannot be met as effectively by existing in-house or contractor resources, and 2) enabling agencies to use private sector resources to accomplish tasks that are integral to the mission and operation of the sponsoring agency.

boundary between Biomass Program and HFCIT Program research has been established to delineate areas of responsibility within EERE. See Section 2.8 for additional details.

### 4.1.3 Interoffice Working Groups and Coordination Efforts

OBP works in conjunction with multiple offices within DOE. Currently OBP has ongoing relationships and tasks with the Office of Science (OS) and the Office of Fossil Energy (FE).

OBP is exploring potential collaboration opportunities with two programs within OS: the Energy Biosciences (EB) program and the Office of Biological and Environmental Research (OBER). The two programs respectively focus on basic science designed to comprehend biological principles and mechanisms, and fundamental development of biological and climate information and advanced technologies. The knowledge gained from these two programs can be used to design desired products while enabling the development of a predictive context for these accumulations. Bioconversion and biotechnology activities include molecular mechanisms to convert sunlight into biomass (photosynthesis research), biofuels (fundamentals of enzymes and microbial systems), and bioproducts. One potential avenue for collaboration is with OBER in Genomics, their highest priority research program, in developing high throughput, genome-scale technologies needed to understand the workings of biological, primarily microbial, systems from individual microbes to complex microbial communities.

FE and OBP both are interested in gasification; more specifically, FE is interested in coal gasification and coal-derived syngas, whereas OBP is interested in pursuing the gasification and syngas technology development with respect to biomass and associated chemicals production. Nevertheless, the physical and chemical properties of biomass are different enough to warrant an appropriate R&D plan with adequate resources.

### 4.1.4 Technology Policy Working Groups

#### 4.1.4.1 EERE Analytic Board

In March 2005, EERE created an Analytic Board with these stated purposes:

- Integrate TD and BA analysis efforts while maintaining distinctions between the two organizations where appropriate
- Provide input on EERE's analytic needs and priorities
- Develop and provide input on analysis standards
- Advance multi-year analysis planning to inform government decisions and the marketplace

The Biomass Program is represented by two full members; a HQ TD representative, a HQ BA analyst, and two supporting members; and a TD Lab analyst and a BA Lab analyst. The board is expected to meet every six months, meeting in the Fall to discuss existing analysis standards and projects recently completed or underway, and in the Spring to provide input and make recommendations on new analysis standards and the EERE analysis agenda for the upcoming fiscal year.

#### 4.1.4.2 DOE Energy and Science Risk Analysis for R&D Programs

OBP staff participate in DOE risk analysis, working as a team to develop and provide scaleable risk analysis processes and tools, with comparable methodologies at each level—project, program, portfolio, and political. The objectives of the risk analysis effort include:

- Providing Team Leaders and Project/Program Managers training and tools that can be used to identify, quantify, evaluate, manage, monitor, document, and communicate technology development risks, especially potential show-stoppers, in a systematic way. This will enable managers to better focus resources and otherwise manage risks to improve the outcomes of their projects/programs.
- Providing Portfolio Managers tools that help them more systematically balance their portfolio. This requires reasonably consistent metrics for identifying, quantifying, and evaluating risks across diverse program areas.
- Providing Political Leaders improved benefits analyses as one input for decision-making by determining more carefully the risk components and their impact on benefits, including partial success.

### 4.1.5 Interagency Coordination

#### 4.1.5.1 USDA

In carrying out the program's mission, the program has a close interagency working relationship with USDA. The Biomass Program's success is significantly dependent on the success of USDA's efforts in improving energy crops, an activity not controlled by the DOE Biomass Program. The technology base for products and energy within the USDA is provided by their Agricultural Research Service (ARS) through programs conducted at the five Regional Agricultural Utilization Laboratories and their partners. Similarly, the USDA Forest Service's Forest Products Laboratories address use and resource conservation, including forest management. Science for soil and water conservation is provided by USDA's Soil Conservation Laboratories. Other USDA offices support technology transfer and deployment. Section 4.2.3.4 describes joint funding efforts by USDA and OBP.

#### 4.1.5.2 National Science Foundation (NSF)

OBP provides limited support to NSF initiatives that contribute to OBP fundamental R&D objectives. Basic R&D related to issues, such as the recalcitrance of biomass, are cost-shared after selection by an NSF review of applications.

#### 4.1.5.3 Biomass R&D Board

The Biomass R&D Act of 2000 (Agricultural Risk Protection Act of 2000, Title III) created the Biomass R&D Board (the Board), which is responsible for coordinating biomass activities across federal agencies. With its strategic planning, this cabinet-level board seeks to guide the activities of various participating agencies in terms of federal grants, loans, and assistance and also non-R&D activities. Membership includes the following agencies:

- USDA (co-chair)
- DOE (co-chair)
- National Science Foundation (NSF)
- Environmental Protection Agency (EPA)

- Department of Interior (DOI)
- Office of Science and Technology Policy (OSTP)
- Office of the Federal Environmental Executive (OFEE)

Official functions of the Board include the following:

- Coordinating programs within and among departments and agencies of the federal government for the purpose of promoting the use of biobased industrial products by:
  - Maximizing the benefits deriving from federal grants and assistance
  - Bringing coherence to federal strategic planning
- Coordinating research and development activities relating to biobased industrial products:
  - Between USDA and DOE
  - With other departments and agencies of the federal government
- Providing recommendations to the points of contact concerning administration of the Act

#### 4.1.6 Biomass R&D Technical Advisory Committee

The Biomass Act of 2000 also created the Biomass R&D Technical Advisory Committee, an advisory group to the Secretaries of Energy and Agriculture. The Committee includes 30 industrial experts who advise DOE/OBP and USDA on technical focus and solicitation processes. The Committee also facilitates partnerships among federal and state agencies, producers, consumers, the research community, and other interested groups. The Committee created the *Vision for Bioenergy & Biobased Products in the United States* (October, 2002) and the *Roadmap for Biomass Technologies in the United States* (December, 2002). OBP has embraced the long-range goals set in the vision document:

- 10 percent of transportation fuels will be biomass-derived by 2020
- Biopower will meet 5 percent of total industrial and utility power demand in 2020
- Biomass-derived chemicals and materials will account for 18 percent of the U.S. production of targeted chemicals in 2020

The technical strategies and program goals of OBP, documented in this MYPP, were designed to help meet these targets. The Biomass R&D Initiative Web site (www.bioproducts-bioenergy.gov) provides information on Technical Advisory Committee activities.

### 4.2 Program Funding Mechanisms

#### 4.2.1 Project Funding Methods

The program funds its RD&D through two broad categories of funding mechanisms: sole-source/non-competitive awards, and awards from competitive solicitations. Non-competitive funding is only used when necessary (e.g. earmarks). In both cases, the funding vehicles used are: cooperative agreements, grants, contracts and Cooperative Research and Development Agreements (CRADA) for joint work between industry and national laboratories.

Competitive procurement is the primary mechanism for funding contractors in order to maximize return on federal investments. It is the preferred method of funding RD&D, and facilitates technology transfer because U.S. industry is directly managing these government-industry cost shared projects for their own commercial objectives and future financial gain. This approach ensures a genuine effort by U.S. industry to commercialize the technology.

Cost-shared RD&D is required by the Energy Policy Act of 1992 for awards in which the private sector participates unless specifically directed otherwise by Congressional budget language. The amount of cost-share for competitive procurements, 80:20 for government and industry for R&D and 50:50 for development and demonstration, is based on guidance in the Energy Policy Act of 1992.

DOE and other federal and state agencies negotiate interagency agreements as mechanisms to co-fund activities that are mutually beneficial to sets of stakeholders and help achieve the goals of individual agencies. Similarly, DOE and USDA laboratories have negotiated intellectual properties and joint agreements to promote interaction.

The preferred partnering mechanism between industry and DOE laboratories is the CRADA. The CRADA provides for defined intellectual property rights and patent waivers between DOE laboratories and industrial partners.

### 4.2.2 Project Selection Process

Funding priorities are defined by OBP Program management. Stakeholder input to such priorities is obtained through the portfolio decision-making process, described in Section 2.2, which includes multiple avenues, including the Biomass R&D Technical Advisory Committee and Program and project review panels. The program follows the DOE policy that all discretionary financial assistance, competitive or noncompetitive, be awarded through a merit-based selection process that explicitly considers cost-sharing (requires up to 50 percent for detailed investigation stage and potentially more for demonstration projects), technical approach, and how the proposals address national goals. Funding opportunity announcements are developed through the interaction of the OBP Program management, with the Contracts, Legal, and Project Management Offices of the PMC defining the area of research, the criteria for selection of applications, and the merit review process.

The merit review process follows a structured approach that involves independent, technically qualified reviewers who use clear and appropriate pre-defined criteria to evaluate the technical merit of applications. Recommendations for potential selections are then forwarded to the selection official in a report that also contains the reviews of all applications. The selection official then makes selections based on technical merit, budget availability and program policy factors. In addition to technical merit, EERE must assess the financial condition of proposed awardees and their ability to complete the proposed work. If risk is high, proper monitoring mechanisms and special award conditions must be included as required by 10CFR 600.114 for both competitive and earmarked awards. If it is likely that an earmarked project will not be successful or cost effective, the Assistant Secretary will determine if he should consult Congress about terminating the project.

OBP also participates in the EERE State Energy Program (SEP) and Small Business Innovative Research Program (SBIR). SEP provides support to communities and states to extend energy-efficiency technologies and practices. SBIR supports development of new technologies by small businesses through annual competitions employing a phased development approach. SEP and SBIR RD&D awards for biofuels, biopower and bioproducts serve to augment the OBP portfolio.

### 4.2.3 Partnership and Stakeholder Roles

The program utilizes a three-pronged research arm comprised of National Laboratories and universities; industry; and other federal, state and local agencies. Public-private partnerships are a key element of the program.

#### 4.2.3.1 Industry, Trade and Professional Associations

Cost-shared RD&D initiated via competitive solicitations is the preferred method of RD&D and technology transfer because U.S. industry is closely involved from a technical and planning standpoint, as well as a financial standpoint (the cost-share). This involvement usually ensures a genuine effort by U.S. industry to commercialize the technology. Partnerships with industry exist throughout the OBP portfolio, and the Integrated Biorefinery element is made up exclusively of industry-led projects.

Industry stakeholders also participate in guiding and reviewing the Program through membership on the Biomass R&D Advisory Committee, which is made up primarily of industry stakeholders, as Program peer reviewers, and as project reviewers in the stage gate management process. Industry trade associations are formally organized to provide input on key areas and gaps. For forest products, the American Forest and Paper Associations prepared the Agenda 2020 vision and technology roadmaps. The chemical industry is engaged via their Vision 2020 group and industrial roadmaps. The Biomass Interest Group, a consortium of electric utility companies and technology developers led by the Electric Power Research Institute provides a mechanism for feedback and interactions among developers and users. The Biotechnology Industry Organization (BIO) annually co-sponsors (with ACS) the "World Congress on Industrial Biotechnology and Bioprocessing" which has brought biomass, bioenergy and bioproducts to the attention of the international biotechnology community. Farm communities, their trade associations, and other interested industries are also engaged regularly.

Many professional organizations are continuing to develop and expand their biomass related activities and committees including, but not limited to, the American Institute of Chemical Engineers (AIChE), American Chemical Society (ACS), American Society for Microbiology (ASM**),** and the American Society of Agricultural and Biological Engineers (ASABE, formerly the American Society of Agricultural Engineers). OBP-sponsored researchers frequently present their technical progress and results at association technical meetings and in peer-reviewed journals and proceedings.

#### 4.2.3.2 Universities

Universities provide a vital link to fundamental science and technology expertise. They also provide the critical foundation and setting for the development of a new set of engineers and scientists skilled in the disciplines necessary to build a bioindustry. A number of universities are partners in OBP activities, and participate via the same competitive mechanisms as industrial partners.

The National Association of State Universities and Land Grant Colleges (NASULGC) has provided reviewers for merit review panels making recommendations for funding of applications. This organization has also held workshops at the National Renewable Energy Laboratory to review the ongoing work in the program. Collaborations between these institutions, largely funded under USDA programs, has allowed DOE program participants to leverage some work relevant to the program, such as work related to understanding how to fractionate lignocellulosic biomass into its components.

#### 4.2.3.3 State Partnerships

The National Biomass State and Regional Partnership is composed of the Coalition of Northeastern Governors (CONEG) Policy Research Center Inc., the Council of Great Lakes Governors (CGLG), the Southern States Energy Board (SSEB), the Western Governors' Association (WGA) and the DOE Western Regional Office. The partnership works in cooperation with OBP to achieve the following objectives:

- Facilitate closer communication and encourage greater coordination among federal, regional and state biomass and bioenergy activities;
- Provide leadership in addressing policies and technical issues in order to advance the use of biomass and utilization of biomass technologies at the highest levels of state government;
- Strengthen and maintain regional partnerships with other federal agencies, the states and stakeholders to help develop biomass as a potential and significant contribution to the Nation's energy portfolio;
- Create awareness and support among states for DOE programs such as biomass special project grants under State Energy Program (SEP) and work closely with the DOE regional offices to find the areas where biomass activities cross-cut other EERE programs.
- Provide an effective communication conduit for states and DOE to identify and address biomass issues of mutual interest; and
- Maximize use of DOE and state funding through resource sharing.

#### 4.2.3.4 Other Government Agencies

OBP has a strong partnership with the U.S. Department of Agriculture in publishing an annual Funding Opportunity Announcement (FOA) for R&D relevant to each agency specifically, but that addresses the overall area of biomass to energy, products and biorefineries. Under an official Memorandum of Understanding and Congressional Acts, EERE and the corresponding offices within USDA have acted together to provide many awards over the past three years involving industry, agriculture and forestry, small businesses, DOE, and USDA national laboratories in addressing some key issues in developing the bioindustry, producing biofuels, chemicals, power, and materials. Historically, the USDA Forest Service funded work in utilization of forest residues for production of power with DOE-sponsored technology (DOE’s National Renewable Energy Laboratory helped manage these projects). Hence, DOE and USDA were partners in addressing the needs related to suppression of forest fires. In addition and related to the topic of suppression of forest fires by eliminating forest litter, the Department of Interior's Bureau of Land Management developed GIS based inventories of biomass resources. This and other USDA resource data were used in a recent study, conducted jointly by DOE's Oak Ridge National Laboratory and USDA, to identify the biomass resource potential in the U.S.[2]

Leveraging of funds occurs through interactions with other agencies, such as the National Science Foundation, where fundamental, basic R&D related to issues such as the recalcitrance of biomass are cost-shared after selection by an NSF review of applications.

#### 4.2.3.5 International and Intergovernmental Programs

International collaboration occurs primarily through participation in International Energy Agency (IEA) activities related to biomass led by the IEA Bioenergy Committee. OBP represents the United States on the Executive Committee for IEA Bioenergy. Table x shows the IEA Bioenergy tasks currently supported by the United States. The primary value of the IEA is its information-sharing activity. Typically, the United States can access the fruits of other countries' RD&D programs long before they are distilled into reports and literature citations. Site visits provide valuable lessons learned, which rarely, if ever reach open literature. The joint activities provide an outstanding venue for discussion with foreign experts. The work program and task activities within IEA Bioenergy can be accessed at www.ieabioenergy.com/IEABioenergy.php.

**Table 4-1:** U.S.-supported IEA Bioenergy Tasks (federal organization providing support)

| | |
|---|---|
| IEA Task 30: | Short Rotation Crops for Bioenergy Systems (USDA-FS) |
| IEA Task 31: | Conventional Forestry Systems for Sustainable Production of Bioenergy (USDA-FS) |
| IEA Task 32: | Biomass Combustion and Co-Firing (DOE-OBP) |
| IEA Task 33: | Thermal Gasification of Biomass (Brigham Young University) |
| IEA Task 34: | Pyrolysis of Biomass (DOE-OBP) |
| IEA Task 35: | Technoeconomic Assessments for Bioenergy Applications (DOE-OBP) |
| IEA Task 38: | Greenhouse Gas Balances of Biomass and Bioenergy Systems (DOE-OBP) |
| IEA Task 39: | Liquid Biofuels (DOE-OBP) |

There is also a biomass-related activity under the Energy End-Use Technologies area, implementing agreement on Pulp and Paper: Annex XV - Gasification Technologies for Black Liquor and Biomass. This activity has significant U.S. involvement with funding provided by OBP.

[2] Biomass as Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-Ton Annual Supply, April 2005, DOE and USDA

## 4.3 Cost Management and Monitoring

EERE tracks costs and uncosted balances using multiple systems at Headquarters and through the Project Management Center (PMC). At the PMC, the National Energy Technology Laboratory uses the Project Management Information System (ProMIS), and the Golden Field Office uses the Project Management Database. The PMC uses these systems to transmit data to EERE through the DOE Standard Accounting and Reporting System (STARS). STARS data is accessed by EERE through the I-MANAGE Data Warehouse (IDW). Data from the IDW is pulled into a reporting and analysis application called COGNOS. Once in COGNOS, data on costs and uncosted balances are reviewed by EERE Technology Program staff.

The data on costs and uncosted balances are regularly monitored and evaluated against current performance and the program's priorities. The evaluation uses performance and program priorities data from the EERE Corporate Planning System, along with DOE financial data from the COGNOS reporting application. EERE staff consults with field project managers at the PMC and National Laboratories to track costs and uncosteds against project milestones and Program goals.

### 4.3.1 Budget and Performance Planning

The Program has established long term performance goals specific to the main biorefinery platforms, sugars and syngas, which are the basis for producing fuels, chemicals, heat and power. Technology managers use these goals as benchmarks for measuring the progress the technology must make to succeed and how well research projects contribute to realizing these goals. The program uses biorefinery pathway analysis and an assessment process to guide budget requests and funding decisions. The process consists of three steps:

- Step 1: characterize and develop a hierarchy of technical barriers to achieving the performance goals associated with successful completion of biorefinery pathways;
- Step 2: identify needed R&D, focusing on areas of possible cost reduction or performance enhancement;
- Step 3: set priorities and allocate resources to projects within expected budget.

The work breakdown structure and multi-year technical plan organize all activities according to which technical barrier each activity addresses. This focused structure facilitates priority settings for budget planning purposes. The budget and performance planning processes are integrated to reflect estimates of resources and time needed to achieve R&D breakthroughs that will lead to achieving performance targets. Projects are selected that will contribute to the program goals of decreasing the cost and increasing the performance of developing systems. The program's annual R&D solicitations are guided by the strategy described in this multi-year plan, technology roadmaps, and the Technical Advisory Committee's input.

### 4.3.2 Project Monitoring and Management

The program has identified annual performance measures that demonstrate progress toward the long term goals, including completion of bench-scale and pilot-scale tests, and mid-term cost goals for biomass sugars and syngas. Effective project monitoring and management help ensure these goals are met.

The PMC is responsible for the field management of all OBP R&D projects, reviewing and documenting its assessment of project progress and financial performance on a quarterly basis. The PMC forwards the status reports to the HQ program office for their review. Further, in FY 2005 the program instituted an internal quarterly review of all R&D tasks and grantee work with the participation of PMC and HQ program staff and National Laboratory Relationship Managers.

#### 4.3.2.1 Project Performance Monitoring

Monitoring of funded activities is accomplished through a variety of mechanisms:

- Annual Operating Plans are developed to provide details of work planned for the year and to establish measures for evaluating performance. The plan includes milestones, schedules and cost projections, and identifies specific researchers.
- Organizations conducting research submit quarterly progress reports outlining technical status, problem areas, achievements and cost issues. Site reviews are conducted as needed for technology validation, operational field measurement, assessment of obstacles, and to review the work in progress, as appropriate.
- Peer review is conducted by independent outside experts of both the Program and subprogram portfolios via stage gate processes. Projects are evaluated based on criteria consistent with EERE Peer Review Guidance and the Biomass Program Stage Gate management process. Review panels also evaluate the strengths and weaknesses of each project, and recommend additions to or deletions from the scope of work. The public peer review process is discussed in Section 2.5.
- Project management is conducted by monitoring task schedules, milestones, labor and capital requirements, and project costs over time. Incurred costs are collected at the agreement level, aggregated and provided to OBP management on a monthly and quarterly basis to support project management activities.
- Quarterly and annual assessment of program and management results based on performance through Joule (the DOE quarterly performance progress review of budget targets), R&DIC (annual internal review of performance planning and management of R&D programs against specific criteria), PMA (the Presidents Management Agenda -- annual departmental and PSO based goals whose milestones are planned, reported and reviewed quarterly) and PART (common government-wide program/OMB reviews of management and results).

#### 4.3.2.2 Project Cost Management

Through the PMC, the Program has implemented the following strategies in order to achieve greater efficiency in project cost management:

- Projects may be incrementally (partially) funded and the spending monitored so that final budget revisions can be made by July, if possible.
- An Access database is used to store and manipulate budget data. This database imports financial data from STARS and the annual spend plan, and incorporates spending forecasts from recipients. This tool allows project tracking of actual against planned spending, facilitating decisions to reduce the uncosted balances.

- Quarterly updates on spending actuals and plans are tracked in a Quarterly Financial Table completed by the recipients for all projects.
- Solicitations are made earlier in the prior fiscal year so awards can be made early in the subsequent fiscal year

The Program has implemented all EERE efficiency and cost-effectiveness measures and will implement new ones as they are finalized. EERE developed a new IT system, the Corporate Planning System, to improve program managers' access to EERE cost, obligation, and procurement data. CPS will be used to coordinate and communicate project information (e.g. cost share, type of contract) between HQ and the PMC.

## 4.4 Environmental Safety & Health

EERE is committed to successfully integrating ES&H into its activities and objectives. In its *Safety Management System Policy*, the Department has adopted an approach which requires the integration of environment, safety, and health (ES&H) into the planning, execution, and measurement of all work performed at its sites and facilities. The EERE ES&H staff advises the Assistant Secretary for EERE (ASEE) on ES&H policy; performance and resources; adherence to statutory, regulatory, and DOE requirements; the National Environmental Policy Act (NEPA); occupational safety and health; and emergency management activities. The team assists senior management in establishing EERE-wide policy, guidance, and performance expectations. It monitors EERE Headquarters and Field ES&H performance to apprise organizational performance to the ASEE, and participates in the development of EERE-wide ES&H strategic and management plans. It manages the safety and wellness and Federal Employee Occupational Safety and Health (FEOSH) programs for Headquarters Federal employees. It also serves as lead for specific ES&H functions, provides EERE-wide technical guidance and assistance as requested (e.g. preparing of ES&H/NEPA documents, implementing new ES&H requirements), and participates in Departmental committees as the EERE representative.

Each EERE program is responsible for ES&H of its workplace and workers, as well as ensuring that ES&H is fully considered and implemented in program planning, R&D, budgeting and contracting. Each program, when executing projects and acquiring items over which EERE has acquisition/procurement responsibility, addresses ES&H commensurate with the severity of the associated hazards and the potential for injury or illness, loss or damage, or environmental mishaps to private or Government resources, consistent with mission requirements and economical considerations. The scope, complexity, and level of documentation of each ES&H effort are tailored to the size, mission, hazards, and complexity of each project. The approval of specific requirements to be included in contracts is delegated to an EERE Contracting Officer, and the programs review the requirements prior to their approval and implementation.

OBP’s approach to identifying and evaluating the environmental, safety and health issues associated with its projects and technologies is composed of activities at three levels:

- Environmental analysis through life cycle assessment (LCA) to ensure that the overall new renewable technology concept envisioned would be environmentally sound.

- Stage Gate management of projects throughout the stages of technology development, including recognition of environmental, safety, health and permitting issues associated with projects.
- National Environmental Policy Act (NEPA) evaluation of all contracted RD&D projects.

### 4.4.1 Environmental Analysis

OBP uses environmental analysis to quantify the potential environmental impacts of biomass production and utilization technologies. Specifically, life cycle assessment (LCA) is used to identify and evaluate the emissions, resource consumption, and energy use of all processes required to make the overall technology function, including raw material extraction, transportation, processing, and final disposal of all products and by-products. Also known as cradle-to-grave or well-to-wheels analysis, the methodology is used to better understand the full energy and environmental impacts of existing and developing technologies, such that efforts can be focused on mitigating negative effects and developing the most sustainable systems. Numerous detailed life cycle assessments have been carried out, documented, and peer reviewed on biomass technologies, including biomass to power, biomass to ethanol, and soy biodiesel. Additional life cycle assessments will be carried out as needed to identify the important energy and environmental characteristics of new biomass-based processes. OBP also encourages its partners in industry and academia to perform LCAs on their projects.

OBP is also a co-sponsor of a fuel-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) which allows researchers, analysts and decision makers to evaluate various vehicle and fuel combinations on a full fuel-cycle basis. The model covers over thirty fuel pathways, including ethanol from corn and lignocellulosic biomass and biodiesel from soy oil, and seven different vehicle technologies.

### 4.4.2 ES&H Aspects of Stage Gate Management

As described earlier (see Section 2.5) OBP uses a Stage-Gate management process for making disciplined decisions about research and development that lead to focused development efforts. One of the seven criteria employed to evaluate projects at every stage of development is "Legal/Regulatory Compliance," which includes an evaluation of potential issues regarding wastes, emissions, safety, and permitting if the technology under development was to be commercialized. The intent is to focus efforts on the most critical and uncertain elements or characteristics of a project as early as possible in the life of a project. The expectation is that projects with significant and/or insurmountable problems are weeded out from the Program portfolio sooner rather than later, so that the "big" spending is reserved for those projects that have the greatest potential for success.

### 4.4.3 NEPA Compliance

OBP carries out a National Environmental Policy Act (NEPA) review of all contracted projects, including earmarks, within its portfolio. The purpose of these reviews is to ensure that DOE funds are only expended on projects that are conducted in an environmentally responsible manner in compliance with the NEPA of 1969 (with amendments). This review utilizes a systematic, interdisciplinary approach that requires each awardee to complete a questionnaire that answers specific ES&H questions about the project. The DOE Biomass Program Project Officer then evaluates the answers provided against the Statement of Objectives (also provided for the project) to ensure that all environmental issues for a given project are adequately addressed and documented. This evaluation is forwarded to the DOE NEPA Compliance Officer who makes the final NEPA determination. Depending on the scope of the project and potential hazards, the NEPA determination could range from a categorical exclusion to requiring a full environmental impact analysis. The vast majority of projects receive a categorical exclusion, but as projects increase in complexity or scope, environmental assessments are more frequently required. For large projects, such as those planned under the proposed FY 2008 biorefinery solicitation, an environmental impact analysis is a likely requirement.

### 4.4.4 Interagency Coordination on Biomass ES&H

One of the major environmental questions related to biomass revolves around the sustainability of new agricultural practices and crops that will be required to maximize the future biomass supply. Many of the life cycle assessments carried out by OBP, described in Section 4.4.1 above, are joint efforts with experts from USDA. For example, the recent LCA completed on corn stover to ethanol included collaborators from the UDSA's Natural Resources Conservation Service who addressed soil erosion issues, and the National Resources Ecology Laboratory who carried out complex soil carbon and nutrient modeling to determine potential impacts of different agricultural practices on soil health.

Future plans include more actively engaging the U. S. Environmental Protection Agency (U.S. EPA) and State Energy, Environmental and Natural Resources Offices to understand the specific complexities of local environmental policy and regulation that may impact biomass development and deployment efforts.

## 4.5 Communications and Outreach

### 4.5.1 Coordination with EERE's Office of Communications and Outreach

Information dissemination, communications, and outreach activities in EERE are carried out by the Office of Communication and Outreach (OCO). OCO communicates the EERE mission, program plans, accomplishments, and technology capabilities to a variety of stakeholder audiences, including Congress, the public, educational institutions, industry, and other government and non-government organizations. In addition, OCO prepares speeches and presentations by the Assistant Secretary and others when requested; manages the EERE public Web site and EERE's centralized public information clearinghouse; manages official correspondence; and coordinates reviews of EERE-related statements by other DOE offices and federal agencies.

OCO coordinates outreach and information activities across EERE, integrating communications efforts from all programs to provide a unified approach to audiences. Thus, consumers will learn about all EERE technologies that may apply to them rather than simply receiving information on only one aspect of energy efficiency or renewable energy. Such coordinated efforts are designed to target opportunities where rising prices or tight energy supplies may spur the acceptance for new technologies; remove barriers to technology acceptance and implementation; and provide accurate information regarding EERE technologies.

OBP's Communication Lead regularly interacts with EERE's OCO to provide information to be included in the overall EERE efforts and increase awareness of the Biomass Program.

### 4.5.2 OBP Communications Strategy

OBP annually develops a communications plan to guide Program specific outreach efforts and ensure effective and consistent communication of Program-specific results and other OBP activities. The goals of the Communication Plan are as follows:

- Raise public awareness of biomass benefits.
- Raise the awareness of the industrial community regarding bio-based options for energy and materials.
- Stimulate business/financial community interest in biomass to enhance financial support for R&D and technology development.
- Educate policymakers at the federal, state, and local levels about the benefits of legislating and providing incentives for biomass use.
- Educate students K-12 and baccalaureate regarding the benefits of biomass and career opportunities in bio-related fields.
- Enhance information exchange among technology developers.
- Inform consumers about bioproducts available to them now as well as in the future.

The industrial community and consumers must be aware of new technology before they can use it. Education and outreach are especially important for biomass because biomass offers significant economic and societal benefits (e.g. energy security, ambient air quality, and reduced GHG emissions) that are not fully represented in its price. Increased use of biomass relies on recognition of the external benefits associated with bio-based options and legislation (financial incentives and compliance). Both of these critical drivers hinge on successful education and outreach. Developing stronger program identification is also a major focus for OBP. OBP needs to increase awareness of its program, and what it does with external audiences.

### 4.5.3 Market Information Used in Technology Development Decisions

The biomass resource base and the existing and potential future bioindustry market segments form the basis for the biorefinery pathways that are the focus of the Program's deployment strategy. Technology development priorities and decisions in the Wet Mill, Dry Mill, Natural Oil Processing, Pulp and Paper Mill, and Forest Products Mill pathways are based on evaluation of technology options and their potential market impacts compared to the current technical status and market situation. Technology performance targets are all based on what it would take for the new technology under development to be competitive in the marketplace. Fortunately, many of these market segments are large and relatively mature with an extensive scientific, technical and economic knowledge base that the Program can build upon. The Agricultural Residue Processing and Perennial Crop Processing pathways are mid- to long-term objectives of the Program and projections of future energy markets are more appropriate for technology development decisions for those pathways.

### 4.5.4 Information Dissemination

OBP communicates technology development and other information to industry or customers through various outreach activities, including multiple Web sites. OBP's official EERE Web site (www.eere.energy.gov/biomass) provides detailed information on technology improvements, solicitations and biomass related publications on both a platform and program level. The Biomass R&D Initiative Web site (www.bioproducts-bioenergy.gov) provides information on Technical Advisory Committee activities, and a monthly biomass newsletter that highlights solicitations, publications, and legislative activities. Both sites are linked with key USDA sites and other government and private sector biomass Web resources.

In addition to the traditional communication materials, OBP sponsors technical conferences and workshops on a variety of subjects to accelerate technology development and implementation. One example is the First International Biorefinery Workshop held in July 2005 in Washington, D.C. A number of regional and state activities are also sponsored, including the National Biomass State and Regional Partnership described in Section 4.3.3.3.

### 4.5.5 Key Stakeholder Audiences

DOE/OBP identified a range of important audiences for communications efforts, each with its own needs for information, interests in biomass, and concerns. The 9 key audiences are:

- Rural/farm community

  Biomass is of critical importance to the rural and farm community because it has the potential to create new jobs, provide farmers with the option of growing alternative crops, provide farmers with alternative markets to sell their crops, and generate a new source of revenue from what once were residues.
- State, local, tribal, and regional organizations

  State, local, tribal and regional groups are key partners in achieving the goals of OBP, including national and state legislators, state energy offices, governors, local permitting offices and others. At the national level, Congress authorizes and appropriates funding for biomass research and development, and makes laws that impact the use of biomass. At the state level, legislators interpret national laws for their applicability and compliance, and may approve and advocate for biomass projects in their states. Further, state legislators can pass legislation such as tax incentives, which can help with developing markets for biobased products. Renewable energy contacts at state energy offices may use state funds to help facilitate projects and promote the use of bioenergy and biobased products. State and regional level groups can be strong advocates for biomass development, such as the Governor's Ethanol Coalition, which helps to promote ethanol production and use.
- Business/financial community

  Substantial private investment in facilities and infrastructure will be required to advance the development of biomass. Keeping the business and financial community informed of the benefits resulting from the latest developments and future activities relating to biomass is essential to win and retain financial support for R&D programs and technology deployment. In addition, efforts to partner with the agriculture industry provide opportunities to tie into existing networks and understand the perspective of the farm community.

- International community

  A strong international market for biomass fuels, chemicals, materials, and power is advantageous in several ways. It will create greater demand for the biomass technologies, products and equipment that U.S. industry produces, and it will spur greater innovation in the field. OBP will cooperate with international organizations, such as the European Commission, to encourage the growth of an international market. In addition, OBP will collaborate with foreign biomass R&D organizations, such as the International Energy Agency, and equipment developers to expand the domestic knowledge base and potentially accelerate development of the technology.

- USDA and other federal entities

  Working collaboratively with other federal agencies is a major tenet of OBP's strategy. This will allow OBP to leverage funding and avoid duplicating efforts. Currently, DOE collaborates with other federal agencies through the Biomass Research and Development Board and the Biomass Research and Development Technical Advisory Committee. These organizations are described in more detail in Sections 4.1.4.2 and 4.1.5, respectively.

- Industry

  There are several related industries that are involved in or may be influenced by biomass research and development. They include the agricultural, forestry, utilities and other power producers, corn processing, enzyme, petroleum refiners, and chemical industries. In agriculture, our primary audience is a subset that contains agricultural processors, those manufacturing closely related products, those who have agricultural residues to dispose of, and potential producers of dedicated crops. There is also great synergy with the forestry industry in that they process large quantities of biomass; their low-value materials (a by-product that cannot be utilized by the pulp and paper industries) are suitable feedstocks for biofuels; and because their infrastructure is energy intensive, many plants are already burning biomass for power. Several of the Biorefinery pathways described in detail in section 2.x are built around existing agricultural and forest industries and were developed in part to achieve strong communication, cooperation and feedback between those industries and the Program.

- Technology developers/users

  OBP can enhance the work of technology developers, including industry, National Laboratories, colleges and universities, and others, by increasing their awareness of other technologies, policies, and markets that could accelerate development of the biomass industry as a whole. Keeping technology users informed of current biomass technologies available, as well as future technologies, and getting their feedback on new developments is important in order for everyone to understand the options for new product development.

- Academia

  To encourage the growth of long-term markets, OBP will target academic institutions by working with universities, colleges, and secondary and primary schools to raise awareness of biomass products and processes. The Biomass Research and Development Act of 2000, Section 307b3, calls for training and educating future scientists, engineers, managers, and business leaders in the field of biomass processing. OBP will raise the awareness of college and university students about career opportunities in biomass related fields.

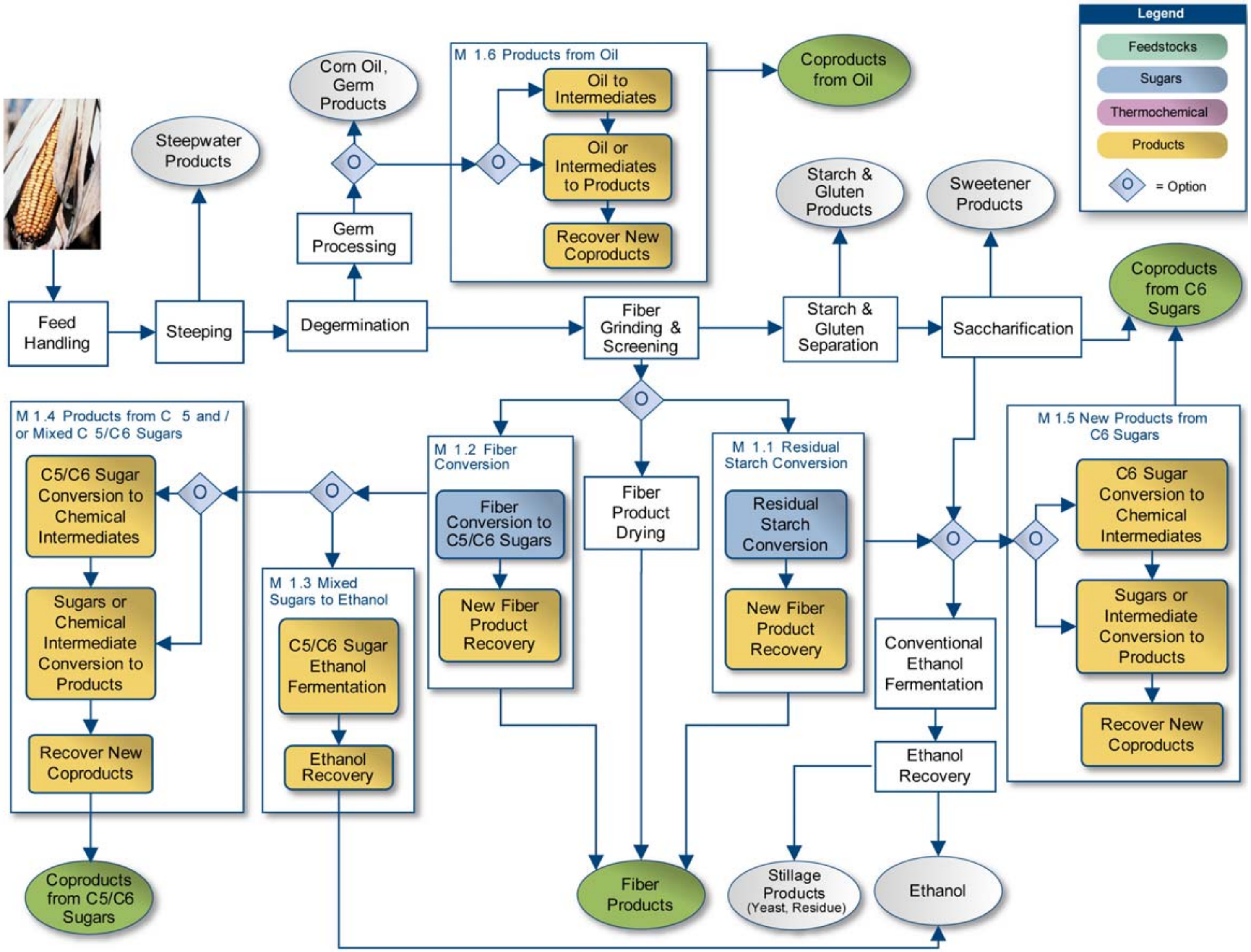
- Consumers

  Consumers need to be informed about the biomass derived products currently available and under development. This outreach is essential to creating market demand, which will exert the pull on research and investment necessary to expand the role of biomass in our economy.

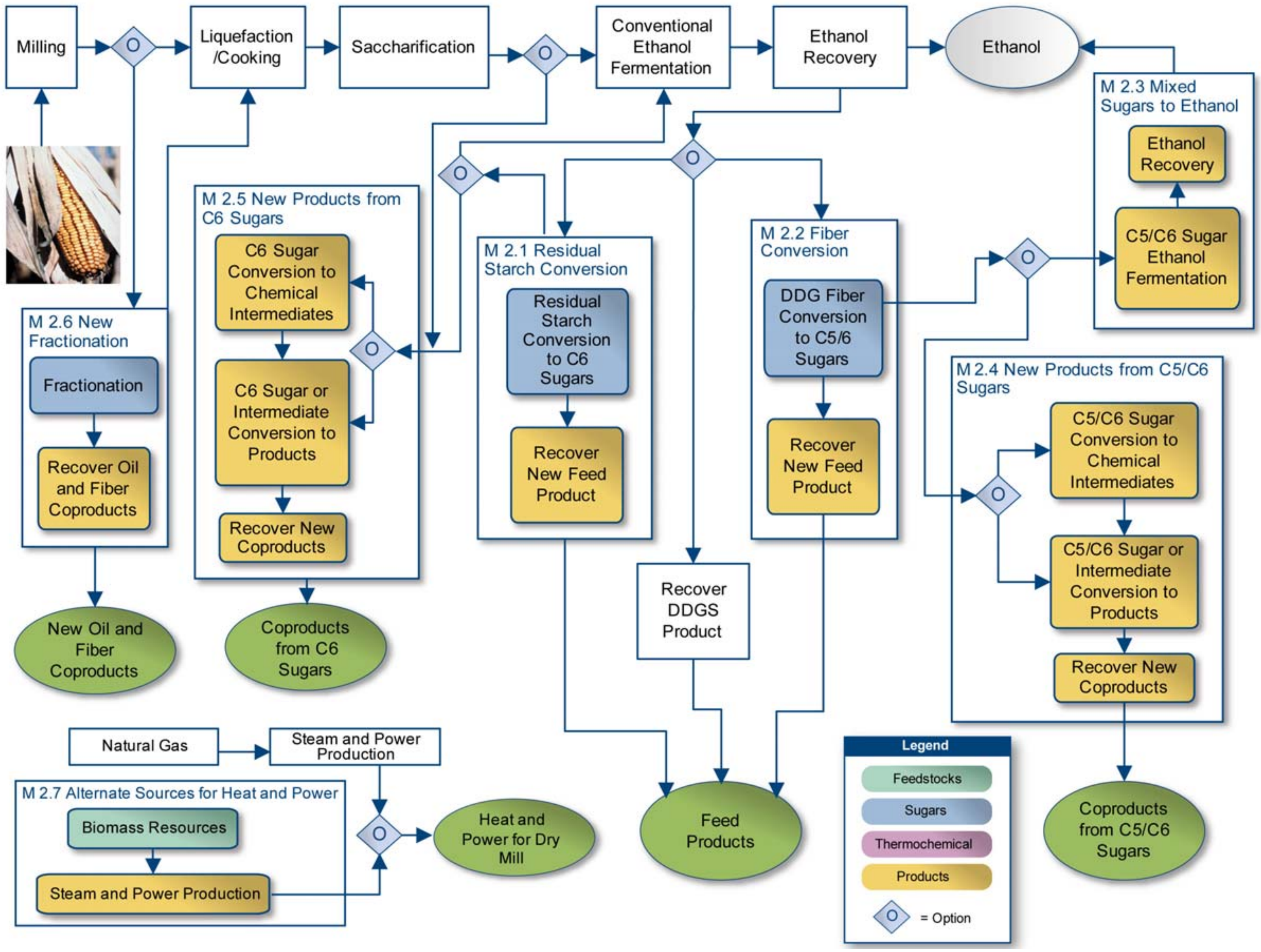
OBP reaches out to these stakeholders by providing an array of communication products, such as publications, a Web site, workshops, conferences, and educational material. All these products are designed to engage industry in developing biorefineries utilizing biomass technologies and practices, stimulate manufacturer interest in applying those technologies and practices, and encourage consumers to purchase biobased products.

# **Appendix A**: Program Pathway Diagrams

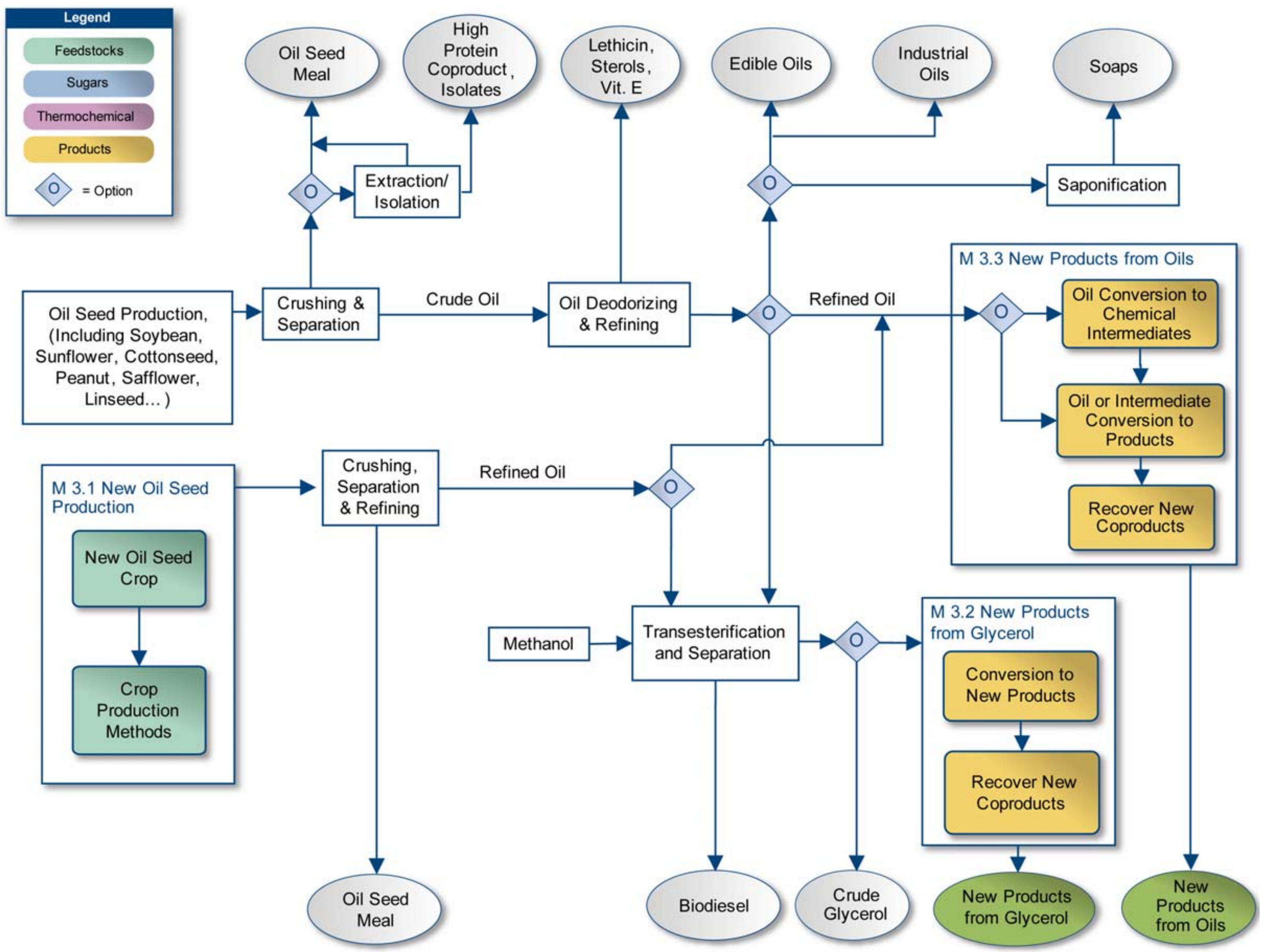
**Corn Wet Mill Improvements Pathway**



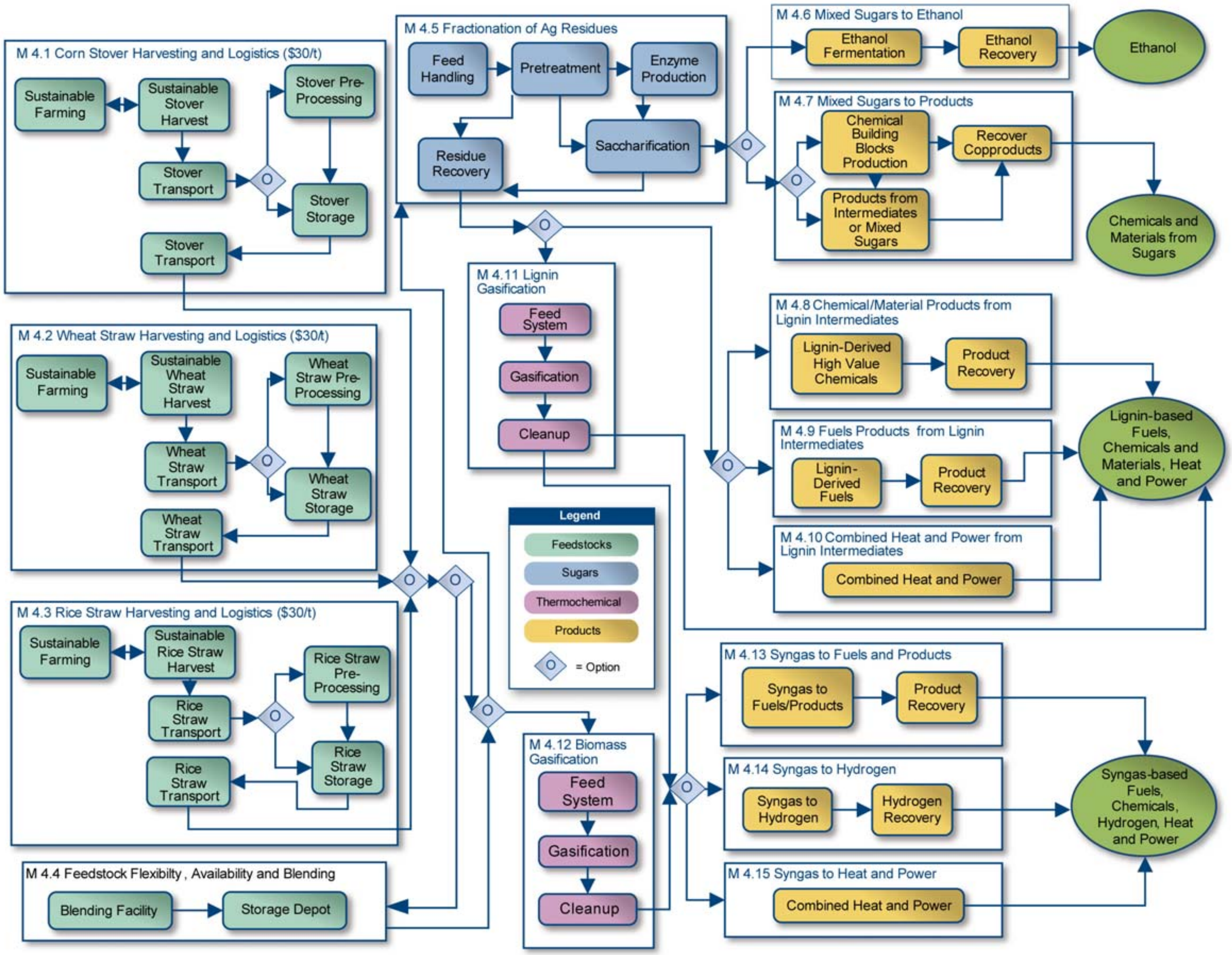
**Corn Dry Mill Improvements Pathway**



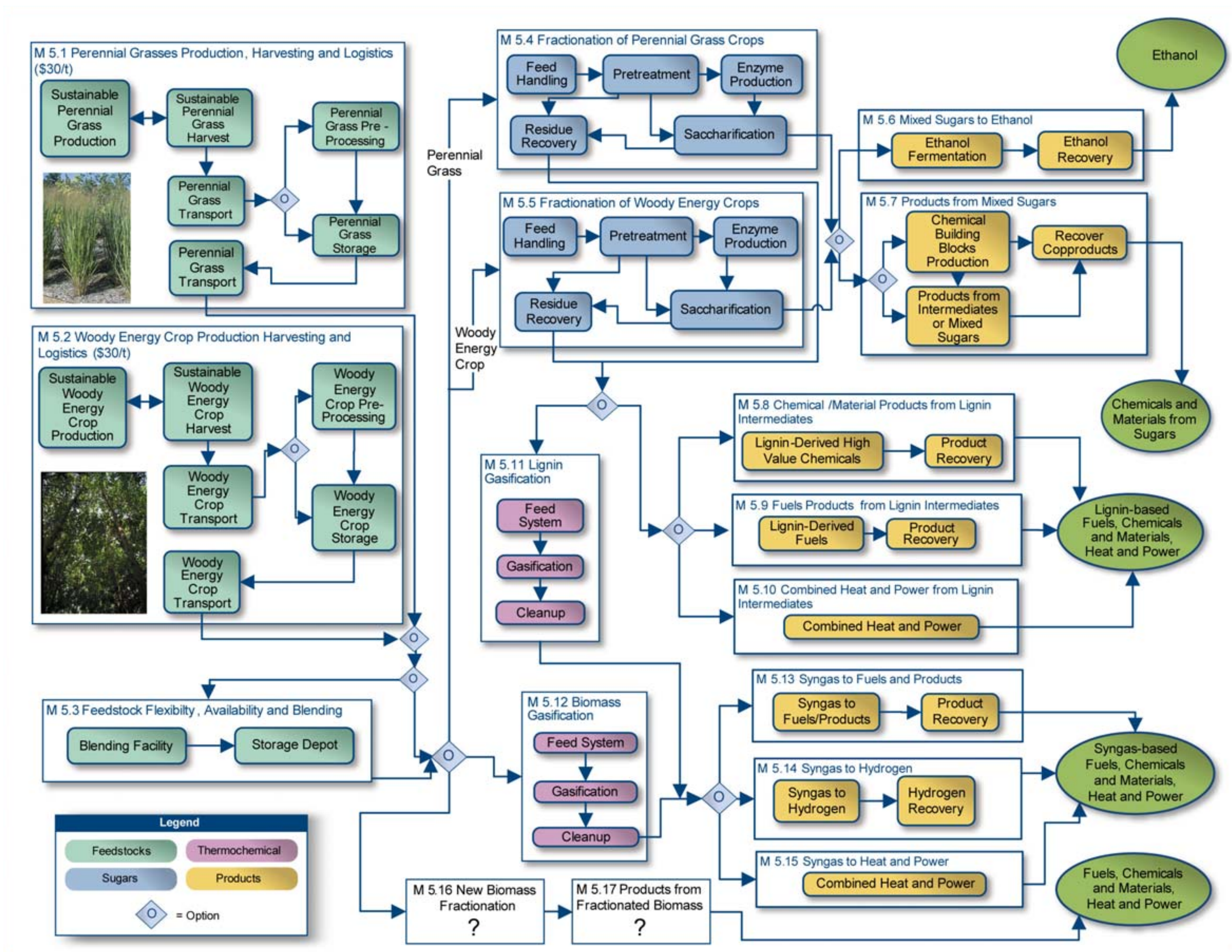
**Natural Oil Crops Improvements Pathway**



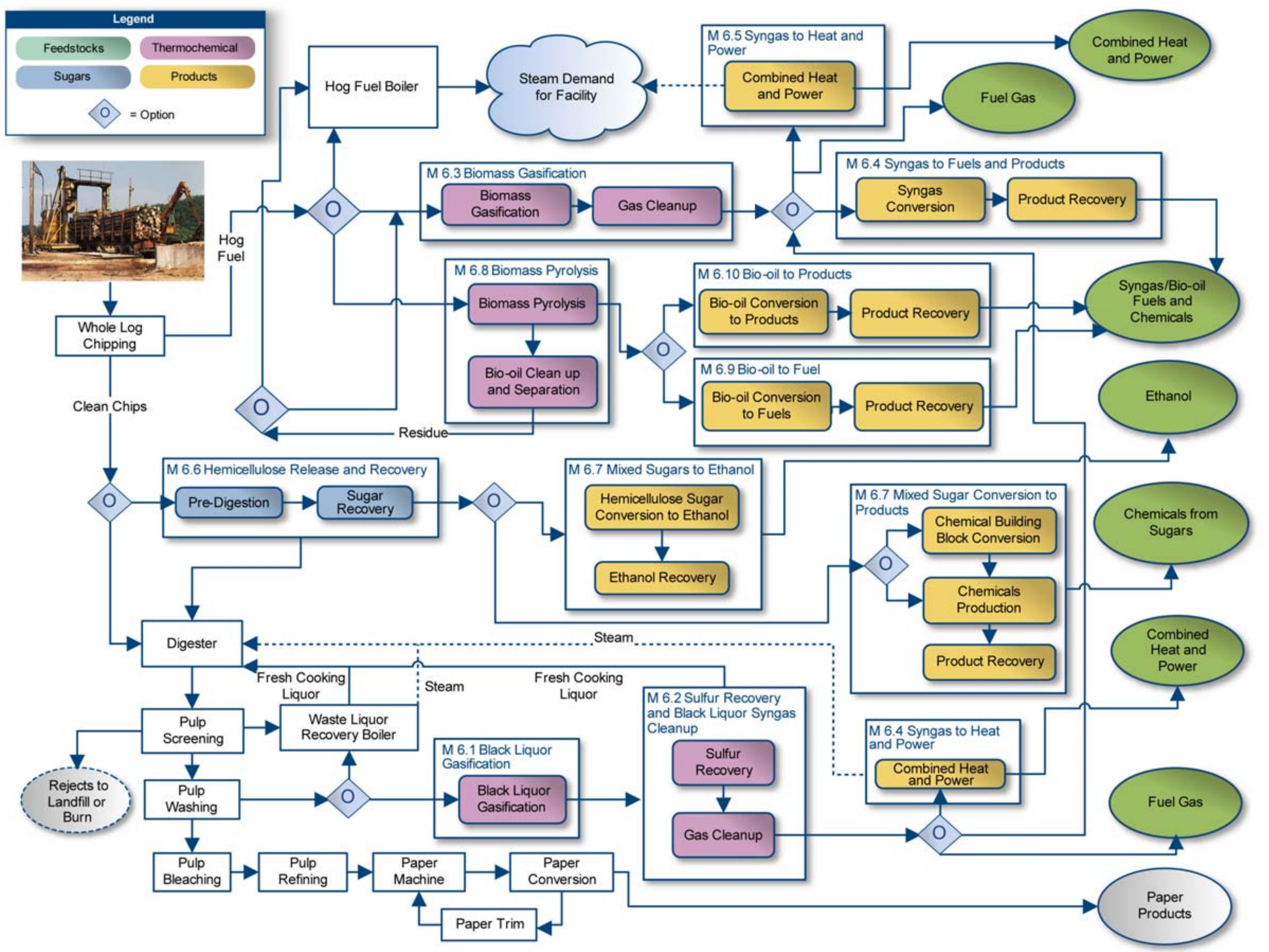
# Agricultural Residues Pathway



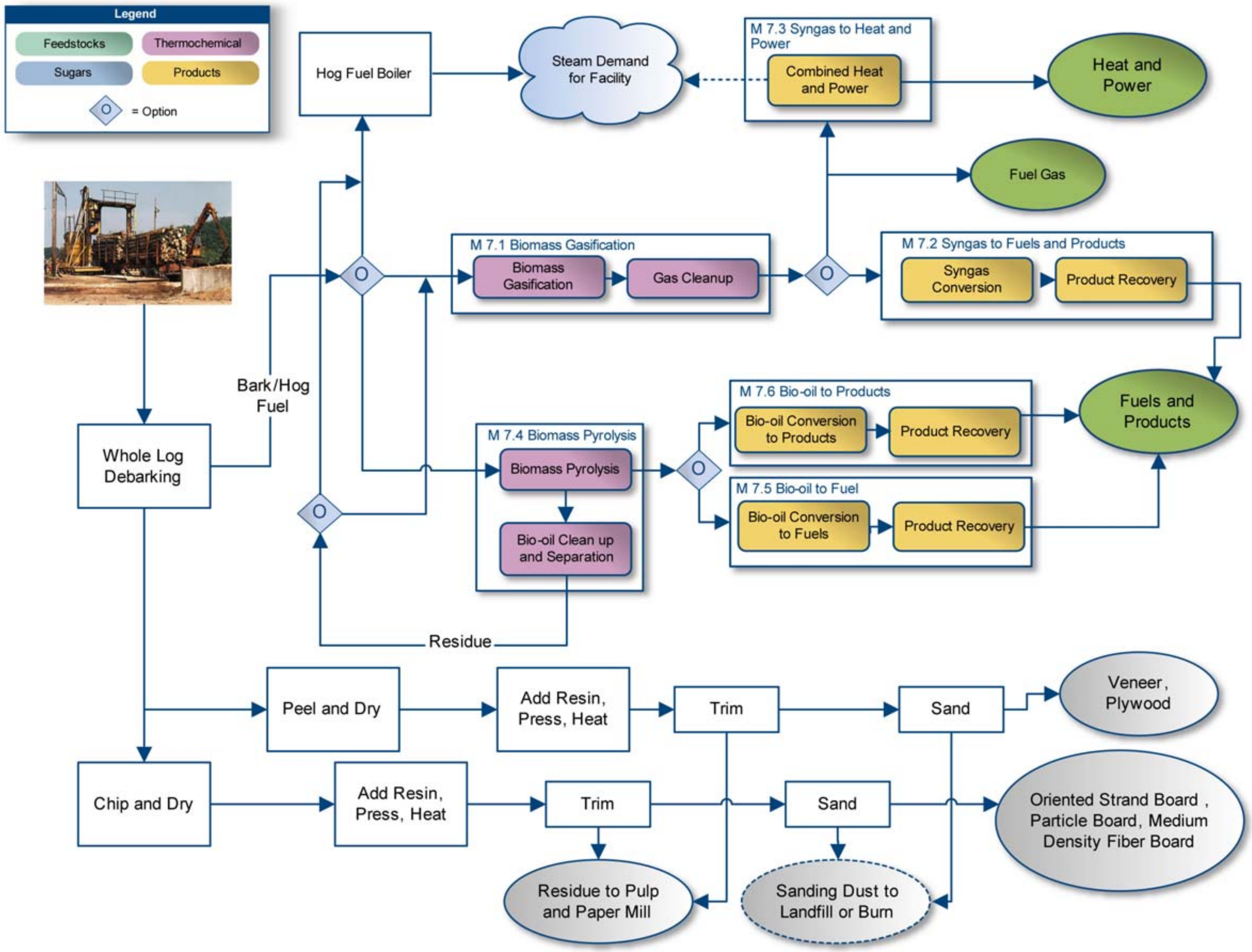
## Perennial Grasses and Woody Energy Crops Pathway



## Pulp and Paper Mill Improvements Pathway



## Forest Products Mill Improvement Pathway



# **Appendix B**: Pathway Milestones

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn Wet Mill Improvements Pathway | | | | | | | | | | | | |
| M 1.1 Demonstrate and validate economical residual starch conversion in a wet mill by 2007 | M 1.1.1 Convert residual starch in fiber stream to ethanol | | | S-1 | | | | | | | | |
| | M 1.1.2 Evaluate new feed product | | | | | | | | | | | |
| | M 1.1.3 Validate integrated process at pilot scale | | | S-3 | | | | | | | | |
| | M 1.1.4 Validate new process in wet mill | | | B-1 | | | | | | | | |
| M 1.2 Demonstrate and validate economical fiber conversion to C5 and/or mixed C5/C6 sugars in a wet mill by 2007 | M 1.2.1 Solubilize hemicellulose in fiber to C5 sugars | | | | | | | | | | | |
| | M 1.2.2 Hydrolize cellulose to C6 Sugar | | | | | | | | | | | |
| | M 1.2.3 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 1.2.4 Evaluate new feed product | | | | | | | | | | | |
| | M 1.2.5 Validate new process in wet mill | | | | | B-2 | | | | | | |
| M 1.3 Demonstrate and validate economical conversion of mixed sugars to ethanol in a wet mill by TBD | M 1.3.1 Convert released sugars to ethanol | | | | | | | | | | | |
| | M 1.3.2 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 1.3.3 Validate new process in wet mill | | | | | | B-3 | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn Wet Mill Improvements Pathway (continued) | | | | | | | | | | | | |
| M 1.4 Demonstrate and validate economical new products from C5 or mixed C5/C6 sugars in a wet mill by 2008 | M 1.4.1 Convert released C5 sugars to products | | | | | | | | | | | |
| | M 1.4.2 Convert C5 sugars to building block chemicals | | | | | | | | | | | |
| | M 1.4.3 Convert mixed sugars to products | | | | | | | | | | | |
| | M 1.4.4 Convert mixed sugars to building block chemicals | | | | | | | | | | | |
| | M 1.4.5 Convert Building block chemicals to products | | | | | | | | | | | |
| | M 1.4.6 Product separation specification | | | | | | | | | | | |
| | M 1.4.7 Demonstrate and validate economical new products from C5 sugars for a wet mill application | | | | | | | | | | | |
| | M 1.4.8 Demonstrate lab scale conversion of C5 sugars to products | | | | | | | | | | | |
| | M 1.4.9 Demonstrate and validate economical new products from mixed sugars for a wet mill application | | | | | | | | | | | |
| | M 1.4.10 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 1.4.11 Validate new process in wet mill | | | | | | | | B-4 | | | |
| M 1.5 Demonstrate and validate economical new products from C6 sugars in a wet mill by 2008 | M 1.5.1 Convert C6 sugars to products | | | | | | | | | | | |
| | M 1.5.2 Convert C6 sugars to building block chemicals | | | | | | | | | | | |
| | M 1.5.3 Convert building block chemicals to products | | | | | | | | | | | |
| | M 1.5.4 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 1.5.5 Validate new process in wet mill | | | | | | | | | | B-5 | |
| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| Corn Wet Mill Improvements Pathway (continued) | | | | | | | | | | | | |
| M 1.6 Demonstrate and validate economical new products from corn-derived oils in a wet mill by 2008 | M 1.6.1 Convert corn derived oils to products | | | | | | | | | | | |
| | M 1.6.2 Product separation specification | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M 1.6.3 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 1.6.4 Validate new process in wet mill | | | | | B-6 | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn Dry Mill Improvements Pathway | | | | | | | | | | | | |
| M 2.1 Demonstrate and validate economical residual starch conversion in a dry mill | M 2.1.1 Conversion of residual starch to glucose | | | | | | | | | | | |
| | Conversion of converted glucose to ethanol. | | | | | | | | | | | |
| | M 2.1.2 Evaluate new feed product. | | | | | | | | | | | |
| | M. 2.1.4 Validate integrated process in a dry mill. | | | | B-7 | | | | | | | |
| M 2.2 Demonstrate and validate economical fiber conversion in a dry mill. | M 2.2.1 Convert fiber to monomer sugars | | | | | | | | | | | |
| | M 2.2.2 Evaluate new feed product | | | | | | | | | | | |
| | M 2.2.3 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 2.2.4 Validate new process in dry mill | | | | | B-8 | | | | | | |
| M 2.3 Demonstrate and validate economical conversion of mixed sugars to ethanol in a dry mill. | M 2.3.2 Convert released sugars to ethanol | | | | | | | | | | | |
| | M 2.3.4 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 2.3.5 Validate new process in dry mill | | | | | | | | | | | |
| M 2.4 Demonstrate and validate economical conversion of mixed sugars to products in a dry mill. | M 2.4.1 Conversion targets from C6 sugars to building blocks | | | | | | | | | | | |
| | M 2.4.2 Conversion targets from building blocks to products | | | | | | | | | | | |
| | M 2.4.3 Product separation specification | | | | | | | | | | | |
| | M 2.4.5 Validate new process in dry mill | | | | | | B-10 | | | | | |
| M 2.5 Demonstrate and validate economical new products from C6 sugars in a dry mill | M 2.5.1 Conversion targets from C6 sugars to building blocks | | | | | | | | | | | |
| | M 2.5.2 Conversion targets from building blocks to products | | | | | | | | | | | |
| | M 2.5.3 Product separation specification | | | | | | | | | | | |
| | M 2.5.4 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 2.5.5 Validate new process in dry mill | | | | | | | | B-11 | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Corn Dry Mill Improvements Pathway (continued) | | | | | | | | | | | | |
| M 2.6 Demonstrate and validate economical front end fractionation processes in a dry mill | M 2.6.1 Derive additional value added products from front end fractionation | | | | | | | | | | | |
| | M 2.6.1.1 Mechanical Separation targets | | | | | | | | | | | |
| | M 2.6.1.2 Evaluate new feed coproducts | | | | | | | | | | | |
| | M 2.6.3 Validate integrated process | | | | | | | | | | | |
| | M 2.6.4 Validate new process in dry mill | | | | | B-12 | | | | | | |
| M 2.7 Investigate alternate sources for dry mill heat and power | M 2.7.1 Thermochemical processing of fiber stream to heat, power | | | | T-1 | | | | | | | |
| | M 2.7.2 Thermochemical processing of Residues (corn Stover) to heat, power | | | | T-1 | | | | | | | |
| | M 2.7.3 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 2.7.4 Validate new process in dry mill | | | | | | B-13 | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Natural Oils Improvements Pathway | | | | | | | | | | | | |
| M 3.1 Demonstrate and validate econmical and sustainable new oil seed crop production | M 3.1.1 ? | | | | | | | | | | | |
| M 3.2 Demonstrate and validate economical new products from glycerol in a natural oil processing mill by 200? | M 3.2.1 Convert glycerol to products | | | | | | | | | | | |
| | M 3.2.2 Recover new products | | | | | | | | | | | |
| | M3.2.3 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 3.2.4 Validate new process in natural oil processing mill | | | | | | | | | | | |
| M 3.3 Demonstrate and validate economical new products from oils in natural oil processing mill by 200? | M 3.3.1 Convert oils to products | | | | | | | | | | | |
| | M 3.3.2 Convert oils to building block chemicals | | | | | | | | | | | |
| | M 3.3.3 Convert building block chemicals to products | | | | | | | | | | | |
| | M 3.3.4 Recover new products | | | | | | | | | | | |
| | M 3.3.5 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 3.3.6 Validate integrated process in a natural oil processsing mill | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agricultural Residues Processing Pathway | | | | | | | | | | | | |
| M 4.1 Demonstrate and validate integrated corn stover harvesting logistics supporting xx tons/yr at $35/ton by ? | M 4.1.1 Demonstrate sustainable corn agronomic practices that account for corn stover harvesting | | | | | | | | | | | |
| | M 4.1.2 Demonstrate wet and dry corn stover harvesting | | | | | | | | | | | |
| | M 4.1.3 Demonstrate wet and dry corn stover storage | | | | | F-5/S-11 | | | | | | |
| | M 4.1.4 Demonstrate wet and dry corn stover transportation | | | | | F-6 | | | | | | |
| | M 4.1.5 Demonstrate wet and dry quality and quantity of corn stover available | | | | | | | | | | | |
| | M 4.1.6 Demonstrate corn stover preprocessing benefits | | | | | F-7/S-12 | | | | | | |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration | | | | | | | | | | | |
| | M 4.1.7 Validate integrated corn stover logistics at pilot scale | | | | | | | | | | | |
| | M 4.1.8 Validate integrated corn stover logistics at demonstration scale | | | B-14 | | | | | | | | |
| M 4.2 Demonsrate and validate integrated wheat straw harvesting logistics supporting xx tons/yr at $35/ton by 2030? | M 4.2.1 Demonstrate sustainable wheat agronomic practices that account for wheat straw harvesting | | | | | | | | | | | |
| | M 4.2.2 Demonstrate wet and dry wheat straw harvesting | | | | | | | | | | | |
| | M 4.2.3 Demonstrate wet and dry wheat straw storage | | | | | F-5/S-11 | | | | | | |
| | M 4.2.4 Demonstrate wet and dry wheat straw transportation | | | | | F-6 | | | | | | |
| | M 4.2.5 Demonstrate wet and dry quality and quantity of wheat straw available | | | | | | | | | | | |
| | M 4.2.6 Demonstrate wheat straw preprocessing benefits | | | | | F-7/S-12 | | | | | | |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration | | | | | | | | | | | |
| | M 4.2.7 Validate integrated wheat straw logistics at pilot scale | | | | | | | | | | | |
| | M 4.2.8 Validate integrated wheat straw logistics at demonstration scale | | | | | B-15 | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agricultural Residues Processing Pathway (continued) | | | | | | | | | | | | |
| M 4.3 Demonsrate and validate integrated rice straw harvesting logistics supporting xx tons/yr at $30/ton by 2030 | M 4.3.1 Demonstrate sustainable rice agronomic practices that account for rice straw harvesting | | | | | | | | | | | |
| | M 4.3.2 Demonstrate wet and dry rice straw harvesting | | | | | | | | | | | |
| | M 4.3.3 Demonstrate wet and dry rice straw storage | | | | | F-5/S-11 | | | | | | |
| | M 4.3.4 Demonstrate wet and dry rice straw transportation | | | | | F-6 | | | | | | |
| | M 4.3.5 Demonstrate wet and dry quality and quantity of rice straw available | | | | | | | | | | | |
| | M 4.3.6 Demonstrate rice straw preprocessing benefits | | | | | F-7/S-12 | | | | | | |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration | | | | | | | | | | | |
| | M 4.3.7 Validate integrated rice straw logistics at pilot scale | | | | | | | | | | | |
| | M 4.3.8 Validate integrated rice straw logistics at demonstration scale | | | | | | | | B-16 | | | |
| M 4.4 Feedstock Flexability and Availability via Blending Depot or Elevator | M 4.4.1 | | | | | | | | | | | |
| | M 4.4.2 | | | | | | | | | | | |
| | M 4.4.3 | | | | | | | | | | | |
| | M 4.4.4 | | | | | | | | | | | |
| | M 4.4.5 | | | | | | | | | | | |
| M 4.5 Demonstrate and validate ag residue fractionation to produce $0.064/lb (2002 $) mixed, dilute biomass sugars by 2020 (with feedstock cost $35/ton) | M 4.5.1 Validate cellulase enzyme cost at the equivalent of $0.xx/lb sugar | | | | | | | | | | | |
| | M 4.5.2 Validate pretreatment technology cost at the equivalent of $0.xx/lb sugar | | | | | | | | | | | |
| | M 4.5.3 Demonstrate ability to economically satisfy internal heat and power demands | | | | S-8 | | | | | | | |
| | M 4.5.4 Capital cost limit metric? Is it a design basis for least cost as opposed to an industry financing hurdle? | | | | | S-9 | | | | | | |
| | M 4.5.5 Validate integrated pretreatment and enzymatic hydrolysis at pilot scale | | | S-10 | | | | | | | | |
| | M 4.5.6 Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale | | | | | | | | B-18 | | | |
| | M 4.5.7 Feed flexibility | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agricultural Residues Processing Pathway (continued) | | | | | | | | | | | | |
| M 4.6 Demonstrate and validate ethanol from 5 biomass sugars that are econonomically viable (need multiple cost targets for specific products?) | M 4.6.1 Validate fermentation of all 5 sugars to produce ethanol | | | | | | | | | | | |
| | M 4.6.2 Optimize ethanol separation | | | | | | | | | | | |
| | M 4.6.3 Optimize integrated production of ethanol from sugars at pilot scale | | | | | | | | | | | |
| | M 4.6.4 Optimize integrated production of ethanol from sugars at demonstration scale | | | B-19 | | | | | | | | |
| M 4.7 Demonstrate and validate chemical building blocks, chemicals or materials from 5 biomass sugars that are econonomically viable (need multiple cost targets for specific products?) | M 4.7.1 Optimize chemical building blocks production (PLA) | | | | | | | | | | | |
| | M 4.7.2 Optimize high value chemical production | | | | | | | | | | | |
| | M 4.7.3 Optimize product separation | | | | | | | | | | | |
| | M 4.7.4 Optimize integrated production of product(s)from sugars at pilot scale | | | | | | | | | | | |
| | M 4.7.5 Optimize integrated production of product(s)from sugars at demonstration scale | | | | | | B-20 | | | | | |
| M 4.8 Demonstrate and validate high value chemical and material products from lignin intermediates | M 4.8.1 Demonstrate high value chemical/material production from lignin | | | | | | | | | | | |
| | M 4.8.2 Validate product separation | | | | | | | | | | | |
| | M 4.8.3 Validate integrated production of product(s)from lignin at pilot scale | | | | | | | | | | | |
| | M 4.8.4 Validate integrated production of product(s)from lignin at demonstration scale | | | | | | | | B-21 | | | |
| M 4.9 Demonstrate and validate fuel products from lignin intermediates | M. 4.9.1 Demonstrate direct fuel production from lignin | | | | | | | | | | | |
| | M 4.9.2 Validate fuel product separation | | | | | | | | | | | |
| | M 4.9.3 Validate integrated production of fuel(s) from lignin at pilot scale | | | | | | | | | | | |
| | M 4.9.4Validate integrated production of fuel(s) from lignin at demonstration scale | | | | | | | | | | B-22 | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agricultural Residues Processing Pathway (continued) | | | | | | | | | | | | |
| 4.10 Demonstrate and validate combined heat and power from lignin intermediates/residues | M 4.10.1 Demonstrate combined heat and power production from lignin | | | | | | T-2 | | | | | |
| | M 4.10.2 Validate integrated production of heat and power from lignin at pilot scale | | | | | | T-3 | | | | | |
| | M 4.10.3 Validate integrated production of heat and power from lignin at demonstration scale | | | | | | | | | | B-23 | |
| M 4.11 Demonstrate and validate lignin gasification to produce syngas for $0.xx/MM Btu by 20xx | M 4.11.1 Validate feeder system performance | | | T-6 | | | | | | | | |
| | M 4.11.2 Validate gasification performance | | | | | T-7 | | | | | | |
| | M 4.11.3 Validate gas cleanup performance | | | | | | T-8 | | | | | |
| | M 4.11.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount | | | | | | T-9 | | | | | |
| | M 4.11.5 Validate integrated gasification and gas cleanup at pilot scale | | | | | | T-10 | | | | | |
| | M 4.11.6 Validate integrated gasification and gas cleanupat demonstration scale | | | | | | | | | | | B-24 |
| M 4.12 Demonstrate and validate biomass gasification to produce syngas for $4.89/MM Btu by 2020 | M 4.12.1 Validate feeder systems to reliably feed solid biomass to high pressure (30 bar) systems | | | | | | | | | | | |
| | M 4.12.2 Validate gasification performance | | | | | | | | | | | |
| | M 4.12.3 Validate gas cleanup performance | | | | | | | | | | | |
| | M 4.12.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount | | | | | | | | | | | |
| | M 4.12.5 Validate integrated gasification and gas cleanup at pilot scale | | | | | | | | | | | |
| | M 4.12.6 Validate integrated gasification and gas cleanupat demonstration scale | | | | | | | | | | | |
| | M 4.12.7 Feed flexibility | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agricultural Residues Processing Pathway (continued) | | | | | | | | | | | | |
| M 4.13 Demonstrate and validate products (i.e. ethanol from mixed alcohols) from lignin or biomass derived syngas for $0.60/gal by 2025 | M 4.13.1 Demonstrate ethanol production from mixed alcohols | | | | | | | | | | | |
| | M 4.13.2 Demonstrate high value chemical/material production (C3-C5 alcohols)from syngas | | | | | | | | | | | |
| | M 4.13.3 Validate product separation | | | | | | | | | | | |
| | M 4.13.4 Validate integrated production of product(s)from syngas at pilot scale | | | | | | | | | | | |
| | M 4.13.5 Validate integrated production of product(s)from syngas at demonstration scale | | | | | | | | | | | |
| M 4.14 Demonstrate and validate hydrogen production from lignin or biomass derived syngas for $xx/kg by 2025 | M 4.14.1 Demonstrate optimized hydrogen production from syngas | | | | | | | | | | | |
| | M 4.14.2 Validate hydrogen separation/recovery | | | | | | | | | | | |
| | M 4.14.3 Validate integrated production of hydrogen from syngas at pilot scale | | | | | | | | | | | |
| | M 4.14.4 Validate integrated production of hydrogen from syngas at demonstration scale | | | | | | | | | | | |
| M 4.15 Demonstrate and validate combined heat and power production from lignin or biomass derived syngas for by 2025 | M 4.15.1 Demonstrate combined heat and power production from syngas | | | | | | | | | | | |
| | M 4.15.2 Validate integrated production of heat and power from syngas at pilot scale | | | | | | | | | | | |
| | M 4.15.3 Validate integrated production of heat and power from syngas at demonstration scale | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perennial Agricultural Crops Pathway | | | | | | | | | | | | |
| M 5.1 Demonsrate and validate integrated switchgrass production and harvesting logistics supporting xx tons/yr at $35/ton by 2030? | M 5.1.1 Demonstrate sustainable switchgrass agronomic practices | | | | | | | | | | | |
| | M 5.1.2 Demonstrate wet and dry switchgrass harvesting | | | | | | | | | | | |
| | M 5.1.3 Demonstrate wet and dry switchgrass storage | | | | | | F-5/S-11 | | | | | |
| | M 5.1.4 Demonstrate wet and dry switchgrass transportation | | | | | | F-6 | | | | | |
| | M 5.1.5 Demonstrate quality and quantity of switchgrass available | | | | | | | | | | | |
| | M 5.1.6 Demonstrate switchgrass prepprocessing benefits | | | | | | F-7/S-12 | | | | | |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration | | | | | | | | | | | |
| | M 5.1.7 Validate integrated switchgrass logistics at pilot scale | | | | | | | | | | | |
| | M 5.1.8 Validate integrated switchgrass logistics at demonstration scale | | | | | B-29 | | | | | | |
| M 5.2 Demonsrate and validate integrated woody crop harvesting logistics supporting xx tons/yr at xx/ton by 20xx? | M 5.2.1 Demonstrate sustainable woody crop agronomic practices | | | | | | | | | | | |
| | M 5.2.2 Demonstrate woody crop harvesting | | | | | | | | | | | |
| | M 5.2.3 Demonstrate woody crop storage | | | | | | F-5/S-11 | | | | | |
| | M 5.2.4 Demonstrate woody crop transportation | | | | | | F-6 | | | | | |
| | M 5.2.5 Demonstrate quality and quantity of woody crops available | | | | | | | | | | | |
| | M 5.2.6 Demonstrate woody crop preprocessing benefits | | | | | | F-7/S-12 | | | | | |
| | New: Validate analysis and optimization tool to support feedstock supply chain integration | | | | | | | | | | | |
| | M 5.2.7 Validate integrated woody crop logistics at pilot scale | | | | | | | | | | | |
| | M 5.2.8 Validate integrated woody crop logistics at demonstration scale | | | | | | | B-30 | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perennial Agricultural Crops Pathway (continued) | | | | | | | | | | | | |
| M 5.3 Feedstock Flexability and Availability via Blending Depot or Elevator | M 5.3.1 | | | | | | | | | | | |
| | M 5.3.2 | | | | | | | | | | | |
| | M 5.3.3 | | | | | | | | | | | |
| | M 5.3.4 | | | | | | | | | | | |
| | M 5.3.5 | | | | | B-31? | | | | B-31? | | |
| M 5. 4 Demonstrate and validate switchgrass fractionation to produce $0.064/lb (2002$) dilute, mixed biomass sugars by 2020 | M 5.4.1 Validate cellulase enzyme cost at the equivlent of $0.xx/lb sugar | | | | | | | | | | | |
| | M 5.4.2 Validate pretreatment technology cost at the equivalent of $0.xx/lb sugar | | | | | | | | | | | |
| | M 5.4.3 Demonstrate ability to economically satisfy internal heat and power demands | | | | S-8 | | | | | | | |
| | M 5.4.4 Capital cost limit metric? Is it a design basis for least cost as opposed to an industry financing hurdle? | | | | | | S-9 | | | | | |
| | M 5.4.5 Validate integrated pretreatment and enzymatic hydrolysis at pilot scale | | | | | S-10 | | | | | | |
| | M 5.4.6 Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale | | | | | | | B-32 | | | | |
| | M 5.4.7 Feedstock flexibility | | | | | | | | | | | |
| M 5.5 Demonstrate and validate woody crop fractionation to produce $0.064/lb (2002 $) mixed, dilute biomass sugars by 2020 (with feedstock cost $35/ton) | M 5.5.1 Validate cellulase enzyme cost at the equivlent of $0.xx/lb sugar | | | | | | | | | | | |
| | M 5.5.2 Validate pretreatment technology cost at the equivalent of $0.xx/lb sugar | | | | | | | | | | | |
| | M 5.5.3 Demonstrate ability to economically satisfy internal heat and power demands | | | | | | | | | | | |
| | M 5.5.4 Capital cost limit metric? Is it a design basis for least cost as opposed to an industry financing hurdle? | | | | | | | | | | | |
| | M 5.5.5 Validate integrated pretreatment and enzymatic hydrolysis at pilot scale | | | | | | | | | | | |
| | M 5.5.6 Validate integrated pretreatment and enzymatic hydrolysis at demonstration scale | | | | | B-33? | | | | | B-33? | |
| | M 5.5.7 Feed flexibility | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perennial Agricultural Crops Pathway (continued) | | | | | | | | | | | | |
| M 5.6 Demonstrate and validate ethanol from 5 biomass sugars - similar to ag residues with different biorefining opportunities | M 5.6.1 Validate ethanol production | | | | | | | | | | | |
| | M 5.6.2 Validate ethanol separation/recovery | | | | | | | | | | | |
| | M 5.6.3 Validate integrated production of product(s)from sugars at pilot scale | | | | | | | | | | | |
| | M 5.6.4 Validate integrated production of product(s)from sugars at demonstration scale | | | | B-34 | | | | | | | |
| M 5.7 Demonstrate and validate products from 5 biomass sugars (need multiple cost targets for specific products?) - similar to ag residues with different biorefining opportunities | M 5.7.1 Validate chemical building blocks production | | | | | | | | | | | |
| | M 5.7.2 Validate high value chemical production | | | | | | | | | | | |
| | M 5.7.3 Validate product separation | | | | | | | | | | | |
| | M 5.7.4 Validate integrated production of product(s)from sugars at pilot scale | | | | | | | | | | | |
| | M 5.7.5 Validate integrated production of product(s)from sugars at demonstration scale | | | | | | | | | B-35 | | |
| M 5.8 Demonstrate and validate high value chemical and material products from lignin intermediates | M 5.8.1 Demonstrate high value chemical/material production from lignin | | | | | | | | | | | |
| | M 5.8.2 Validate product separation | | | | | | | | | | | |
| | M 5.8.3 Validate integrated production of product(s)from lignin at pilot scale | | | | | | | | | | | |
| | M 5.8.4 Validate integrated production of product(s)from lignin at demonstration scale | | | | | | | | | | | B-36 |
| M 5.9 Demonstrate and validate fuel products from lignin intermediates | M 5.9.1 Demonstrate direct fuel production from lignin | | | | | | | | | | | |
| | M 5.9.2 Validate fuel product separation | | | | | | | | | | | |
| | M 5.9.3 Validate integrated production of fuel(s)from lignin at pilot scale | | | | | | | | | | | |
| | M 5.9.4 Validate integrated production of fuels(s)from lignin at demonstration scale | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perennial Agricultural Crops Pathway (continued) | | | | | | | | | | | | |
| M 5.10 Demonstrate and validate combined heat and power from lignin intermediates/residues | M 5.10.1 Demonstrate combined heat and power production from lignin | | | | T-12 | | | | | | | |
| | M 5.10.2 Validate integrated production of heat and power from lignin at pilot scale | | | | T-13 | | | | | | | |
| | M 5.10.3 Validate integrated production of heat and power from lignin at demonstration scale | | | | | B-38? | | | | | B-38? | |
| M 5.11 Demonstrate and validate lignin gasification to produce syngas for $0.xx/MM Btu by 20xx | M 5.11.1 Validate feeder system performance | | | T-15 | | | | | | | | |
| | M 5.11.2 Validate gasification performance | | | | | T-16 | | | | | | |
| | M 5.11.3 Validate gas cleanup performance | | | | | | T-17 | | | | | |
| | M 5.11.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount | | | | | | T-18 | | | | | |
| | M 5.11.5 Validate integrated gasification and gas cleanup at pilot scale | | | | | | T-19 | | | | | |
| | M 5.11.6 Validate integrated gasification and gas cleanup at demonstration scale | | | | | | | | | | | B-39 |
| M 5.12 Demonstrate and validate biomass gasification to produce syngas for $4.89/MM Btu by 2020 | M 5.12.1 Validate feeder systems to reliably feed solid biomass to high pressure (30 bar) systems | | | | | | | | | | | |
| | M 5.12.2 Validate gasification performance | | | | | | | | | | | |
| | M 5.12.3 Validate gas cleanup performance | | | | | | | | | | | |
| | M 5.12.4 Validate capital costs - ROI hurdle rate versus cost magnitude hurdle amount | | | | | | | | | | | |
| | M 5.12.5 Validate integrated gasification and gas cleanup at pilot scale | | | | | | | | | | | |
| | M 5.12.6 Validate integrated gasification and gas cleanup at demonstration scale | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perennial Agricultural Crops Pathway (continued) | | | | | | | | | | | | |
| M 5.13 Demonstrate and validate products (i.e. ethanol from mixed alcohols) from lignin or biomass derived syngas for $0.60/gal by 2025 | M 5.13.1 Demonstrate ethanol production from mixed alcohols | | | | | | | | | | | |
| | M 5.13.2 Demonstrate high value chemical/material production (C3-C5 alcohols)from syngas | | | | | | | | | | | |
| | M 5.13.3 Validate product separation | | | | | | | | | | | |
| | M 5.13.4 Validate integrated production of product(s)from syngas at pilot scale | | | | | | | | | | | |
| | M 5.13.5 Validate integrated production of product(s)from syngas at demonstration scale | | | | | | | | B-41 | | | |
| M 5.14 Demon-strate and validate hydrogen production from lignin or biomass derived syngas for $xx/kg by 2025 | M 5.14.1 Demonstrate optimized hydrogen production from syngas | | | | | | | | | | | |
| | M 5.14.2 Validate hydrogen separation/recovery | | | | | | | | | | | |
| | M 5.14.3 Validate integrated production of hydrogen from syngas at pilot scale | | | | | | | | | | | |
| | M 5.14.4 Validate integrated production of hydrogen from syngas at demonstration scale | | | | | B-42 | | | | | | |
| M 5.15 Demon-strate and validate combined heat and power production from lignin or biomass derived syngas for by 2025 | M 5.15.1 Demonstrate combined heat and power production from syngas | | | | | | | | | | | |
| | M 5.15.2 Validate integrated production of heat and power from syngas at pilot scale | | | | | | | | | | | |
| | M 5.15.3 Validate integrated production of heat and power from syngas at demonstration scale | | | | | | | | | | | |
| M 5.16 Demonstrate and validate new fractionation process to produce intermediates/building blocks to compete with sugar, lignin and/or syngas intermediates/building blocks | M 5.16.1 ? | | | | | | | | | | | |
| | M5.16.2 ? | | | | | | | | | | | |
| | M 5.16.3 ? | | | | | | | | | | | |
| | M 5.16.4? | | | | | | | | | | | |
| | M 5.16.5 Validate integrated new fractionation process at pilot scale | | | | | | | | | | | |
| | M 5.16.6 Validate integrated new fractionation process at demonstration scale | | | | | | | | | | | |
| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| Perennial Agricultural Crops Pathway (continued) | | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M 5.17 Demonstrate and validate products from new fractionation/consolidated process intermediates | M 5.17.1 ? | | | | | | | | | | | |
| | M5.17.2 ? | | | | | | | | | | | |
| | M 5.17.3 ? | | | | | | | | | | | |
| | M 5.17.4? | | | | | | | | | | | |
| | M 5.17.5 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 5.17.6 Validate integrated process at demonstration scale | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | | | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pulp and Paper Mill Improvements Pathway | | | | | | | | | | | | |
| M 6 .1 Demonstrate and validate reliable and economic gasification of spent pulping liquor and recycle liquor causticization in a pulp mill | M 6.1.1 Validate reliable and economic performance of gasification of spent pulping liquor | | | | | T-21 | | | | | | |
| | M 6.1.2 Validate cost effective causticization and return Na based pulping chemicals | | | | | | | | | | | |
| | M 6.1.3 Validate advantages of co-gasification of spent pulping liquors and other forms of biomass (woody, recycle paper streams, and bio-oil) | | | | | | T-22 | | | | | |
| | M 6.1.4 Validate integrated black liquor gasification and causticization process at pilot scale | | | | | | T-24 | | | | | |
| | M 6.1.5 Validate integrated black liquor gasification and causticization process in pulp and paper mill | | | | | | | | | | | |
| M 6.2 Demonstate and validate gas cleanup and process chemical recovery and recycle from spent pulping liquor syngas | M 6.2.1 Validate process chemical recovery from spent pulping liquor syngas | | | | | | T-25 | | | | | |
| | M 6.2.2 Validategas cleanup technologies on spent pulping liquor syngas | | | | | | T-26 | | | | | |
| | M 6.2.3 Validate integrated chemical recovery and gas cleanup process at pilot scale | | | | | | T-27 | | | | | |
| | M 6.2.4 Validate integrated chemical recovery and gas cleanup process in pulp and paper mill | | | | | | T-28 | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | | | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pulp and Paper Mill Improvements Pathway (continued) | | | | | | | | | | | | |
| M 6.3 Demonstrate and validate cost-effective biomass gasification of wood residues and other process residues and synthesis gas cleanup in a pulp and paper mill environment | M 6.3.1 Develop cost effective gasification designs for syngas production at appropriate scale | | | | | | T-30 | | | | | |
| | M 6.3.2 Validate feeder system perfomance to reliably feed solids to high pressure (30 bar) systems) | | | | T-31 | | | | | | | |
| | M 6.3.3 Validate gasification performance | | | | | T-32 | | | | | | |
| | M 6.3.4 Validate cost-effective gas cleanup performance | | | | | T-33 | | | | | | |
| | M 6.3.5 Validate integrated biomass gasification and syngas cleanup process suitable for a pulp and paper mill at pilot scale | | | | | | T-34 | | | | | |
| | M 6.3.6 Validate integrated biomass gasification and syngas cleanup process in pulp and paper mill | | | T-35 | | | | | | | | |
| M 6.4 Demonstrate and validate production of DME/mixed alcohols/FT liquids or other products from syngas in a pulp mill at a price competive with current comercial practice | M 6.4.1 Identify economically viable product(s) from syngas (evaluate technologies for mixed alcohols, DME and FTL) | | | | | | | | | | | |
| | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | | | 2015 |
| | M 6.4.2 Produce mixed alcohols from syngas | | | | | | | | | | | |
| | M 6.4.3 Produce DME from syngas as a LPG substitute | | | | | | | | | | | |
| | M 6.4.4 Produce FTL from biomass syngas | | | | | | | | | | | |
| | M 6.4.5 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 6.4.6 Validate new process in pulp and paper mill | | | | | | B-46 | | | | | |
| M 6.5 Demonstrate and validate syngas utilization in a pulp mill for CHP and direct fuel gas including clean cold gas | M 6.5.1 Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment | | | | | | | | | | | |
| | M 6.5.2 Validate CHP from syngas and/or direct use of sygas in process equipment | | | | | | | | | | | |
| | M 6.5.3 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 6.5.4 Validate new process in pulp and paper mill | | | | | | | | | | | B-47 |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | | | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pulp and Paper Mill Improvements Pathway (continued) | | | | | | | | | | | | |
| M 6.6 Demonstrate and validate cost-effective extraction of C5 and C6 sugars from hemicellulose upstream of the pulp digestor in a pulp mill without negatively impacting paper quality | M 6.6.1 Meet yield target for C5 and C6 sugars without negatively impacting paper quality | | | | S-5 | | | | | | | |
| | M 6.6.2 Meet sugar upgrading requirements | | | | | | | | | | | |
| | M 6.6.3 Meet targets for recovery of other intermediates | | | | | | | | | | | |
| | M 6.6.4 Validate integrated sugar extraction process at pilot scale | | | | | | | | | | | |
| | M 6.6.5 Validate sugar extraction process in pulp and paper mill | | | | | | | | | | | |
| M 6.7 Demonstrate and validate ethanol production from sugar extract | M 6.7.1 Validate fermentation of all sugars in the extract to ethanol | | | | | | | | | | | |
| | M 6.7.2 Validate ethanol separation | | | | | | | | | | | |
| | M 6.7.3 Validate integrated prodcution of ethanol from extracted sugars at pilot scale | | | | | | | | | | | |
| | M 6.7.4 Validate integrated prodcution of ethanol from extracted sugars in pulp and paper mill | | | | | | | | | | B-49 | |
| M 6.8 Demonstrate and validate cost-effective conversion of extracted C5 and C6 sugars to products | M 6.8.1 Validate chemical building blocks production | | | | | | | | | | | |
| | M 6.8.2 Validate high value chemical production | | | | | | | | | | | |
| | M 6.8.3 Validate product separation | | | | | | | | | | | |
| | M 6.8.4 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 6.8.5 Demonstrate and validate new process in pulp and paper mill | | | | | | | | | | | |
| M 6.9 Demonstrate and validate bio-oil production to a stable intermediate | M 6.9.1 Validate bio-oil production | | | T-37 | | | | | | | | |
| | M 6.9.2 Validate bio-oil inermediate recovery | | | T-38 | | | | | | | | |
| | M 6.9.3 Develop and test field prototypes for pyrolysis | | | | | | | | | | | |
| | M 6.9.4 Demonstrate and validate new process in pulp and paper mill | | | | | | B-51? | | | B-51? | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | | | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pulp and Paper Mill Improvements Pathway (continued) | | | | | | | | | | | | |
| M 6.10 Achieve cost-effective conversion bio-oil intermediate into product(s) in a pulp and paper mill | M 6.10.1 Validate production of products from bio-oil | | | | | | | | | | | |
| | M 6.10.2 Validate bio-oil product(s) recovery | | | | | | | | | | | |
| | M 6.10.3 Validate integrated process for producing bio-oil product at pilot scale | | | | | | | | | | | B-52 |
| | M 6.10.4 Validate integrated process in a pulp and paper mill | | | | | | | | | | | |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Forest Products Improvements Pathway | | | | | | | | | | | | |
| M 7.1 Demonstrate and validate cost-effective biomass gasification of wood residues and other process residues and synthesis gas cleanup in a forest products mill environment | M 7.1.1 Develop cost effective gasification designs for syngas production at appropriate scale | | | | | | T-40 | | | | | |
| | M 7.1.2 Validate feeder system perfomance to reliably feed solids to high pressure (30 bar) systems) | | | | T-41 | | | | | | | |
| | M 7.1.3 Validate gasification performance | | | | | T-42 | | | | | | |
| | M 7.1.4 Validate cost-effective gas cleanup performance | | | | | T-43 | | | | | | |
| | M 7.1.5 Validate integrated biomass gasification and syngas cleanup process suitable for a forest products mill at pilot scale | | | | | | T-44 | | | | | |
| | M 7.1.6 Validate integrated biomass gasification and syngas cleanup process in foest products mill | | | | | | | | | | B-53 | |
| M 7.2 Demonstrate and validate production mixed alcohols/DME/FT liquids or other products from syngas in a forest products mill at a price competive with current comercial practice | M 7.2.1 Identify economically viable product(s) from syngas (evaluate technologies for mixed alcohols, DME and FTL) | | | | | | | | | | | |
| | M 7.2.2 Produce mixed alcohols from syngas | | | | | | | | | | | |
| | M 7.2.3 Produce DME from syngas as a LPG substitute | | | | | | | | | | | |
| | M 7.2.4 Produce FTL from biomass syngas | | | | | | | | | | | |
| | M 7.2.5 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 7.2.6 Validate new process in a forest products mill | | | | | | | | | | | |
| M 7.3 Demonstrate and validate syngas utilization in a forest products mill for CHP and direct fuel gas including clean cold gas | M 7.3.1 Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment | | | T-45 | | | | | | | | |
| | M 7.3.2 Validate CHP from syngas and/or direct use of sygas in process equipment | | | | | | | | | | | |
| | M 7.3.3 Validate integrated process at pilot scale | | | | | | | | | | | |
| | M 7.3.4 Validate new process in a forest products mill | | | | | | | | | | | B-54 |

| B Milestones | C Milestones | Current Program Focus (yes/no) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Forest Products Improvements Pathway (continued) | | | | | | | | | | | | |
| M 7.4 Demonstrate and validate bio-oil production to a stable intermediate | M 7.4.1 Validate bio-oil production | | | | T-46 | | | | | | | |
| | M 7.4.2 Validate bio-oil inermediate recovery | | | T-47 | | | | | | | | |
| | M 7.4.3 Validate integrated process for producing bio-oil at pilot scale (prototypes) | | | T-48 | | | | | | | | |
| | M 7.4.4 Demonstrate and validate new process in a forest products mill | | | | | | | | | | | |
| M 7.5 Achieve cost-effective conversion bio-oil intermediate into product(s) in a forest products mill | M 7.5.1 Validate production of products from bio-oil | | | | | | | | | | | |
| | M 7.5.2 Validate bio-oil product(s) recovery | | | | | | | | | | | |
| | M 7.5.3 Validate integrated process for producing bio-oil product at pilot scale | | | | | | | | | | | |
| | M 7.5.4 Validate integrated process in a forest products mill | | | | | | | | | | | B-55 |

# **Appendix C**: Resource Allocation Plan

**FY 2007 Financial Information and Outyear Planning**

| WBS | Title | FY 2005 | FY 2006 | FY 2007 | FY 2008 | FY 2009 | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Biomass Feedstock Interface R&D | 1,984 | 1,000 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Sugar Platform Core R&D | 8,999 | 10,384 | 8,830 | 8,675 | 8,500 | 8,500 | 8,500 | 8,500 |
| 3 | Thermochemical Platform Core R&D | 7,090 | 5,492 | 7,189 | 6,522 | 6,000 | 6,000 | 6,000 | 6,000 |
| 4 | Products Core R&D | 6,051 | 7,764 | 2,721 | 1,740 | 5,000 | 5,000 | 5,000 | 5,000 |
| 5 | Integrated Biorefineries | 14,516 | 5,999 | 15,291 | 56,828 | 50,000 | 50,000 | 50,000 | 50,000 |
| 6 | Program Management | 8,471 | 9,402 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 |
| | Total | 47,111 | 40,041 | 44,031 | 83,765 | 79,500 | 79,500 | 79,500 | 79,500 |

**Program Priorities**

To reduce our dependence on foreign oil by 25 percent or more, EERE will accelerate RD&D aimed at bringing to the market domestically produced bio-based transportation fuels, power, and products (i.e. chemicals and materials). Through public/private partnerships, DOE will significantly reduce technological and financial risks, and institutional barriers associated with next-generation technologies. This investment will greatly help the Nation meet the goal of reducing its dependence on foreign oil.

The program's strategy focuses on enabling biorefineries that can use a variety of feedstocks, and produce transportation fuels and high-value co-products that are regionally marketable while expanding the Nation's biomass supply potential in diverse regions. Pathways, all based on different agriculture and forest resources, now form the strategic basis for R&D to enable biorefineries.

Specifically,

- Under Feedstock Development and Infrastructure, funding ramp-up through FY 2011 will help establish and expand work at regional feedstock development centers. These centers are necessary because of the diversity of regional feedstocks in terms of growth requirements, climatic differences, and infrastructure needs.

- Pathway Research and Development ramps up through FY 2009 to convert the wide range of regional feedstocks that, when converted to intermediate products, enable the integrated biorefinery.

- Utilization of Platform Outputs is the major thrust of the program. Accelerated funding through 2011 will allow for the validations of pathways at an industrial scale. Products development, to enable a slate of high valued bio-based products, is integral to an integrated biorefinery. These validations are required by industry and the investment community to consider commercial financing of first-of-a kind facilities.

**Human Resources**

OBP is led by the program manager, a technology coordinator, and two technology team leads -- one for Platforms R&D and one for Products (within the context of integrated biorefineries). This group makes up the senior management team. Senior technology scientists and engineers support feedstock interface, platform development, products, and integrated biorefinery activities at the Program level. A systems integrator is the conduit between the field and headquarters management activities. At the DOE Golden Field Office, the Project Management Center is responsible for project management and national laboratory task oversight. Core technology development is conducted through National Laboratories with primary responsibility at the National Renewable Energy Laboratory. Staff levels are sufficient to meet management responsibilities through careful orchestration of program and project level roles and responsibilities. If some of the new authorities authorized under the Energy Policy Act of 2005, such as loan guarantees, the present mix of human resources need to be augmented.

# **Appendix D**: Glossary

**Baseline.** The starting point from which gains are measured and targets are set. The baseline year shows actual program performance or prior condition for the given measure in a specified prior year.

**Biodiesel.** A biodegradable transportation fuel for use in diesel engines that is produced through the transesterfication of organically- derived oils or fats. It may be used either as a replacement for or as a component of diesel fuel.

**Biofuels.** Biomass converted to liquid or gaseous fuels such as ethanol, methanol, methane, and hydrogen.

**Biomass.** An energy resource derived from organic matter. These include:

- any organic material grown for the purpose of being converted to energy
- any organic byproduct of agriculture (including wastes from food production and processing) that can be converted into energy
- any waste material that can be converted to energy, including mill residues, precommercial thinnings, wood waste materials, and municipal solid waste.

**By-product.** Material, other than the principal product, generated as a consequence of an industrial process or as a breakdown product in a living system.

**Cellulose.** A carbohydrate that is the principal component of wood. It is made of linked glucose molecules that strengthens the cell walls of most plants.

**Cellulosic Biomass Ethanol.** Ethanol derived from any lignocellulosic or hemicellulosic matter that is available on a renewable or recurring basis.

**Catalyst.** A substance that increases the rate of a chemical reaction, without being consumed or produced by the reaction. Enzymes are catalysts for many biochemical reactions.

**Decision Point.** A clearly defined point during the performance of an activity where a decision can be made to go on to the next phase, to stop, change direction, or re-focus the activity. Decision points include the identification of circumstances under which the program should end (see "End Point"). A decision point can also be a termination point if the decision is made to prematurely end the activity because milestones have not been reached, or cannot be reached with knowledge that is available or reasonably anticipated (see "Termination Point"). **(***Related Concepts*: Off-ramp; Exit strategy; go/no-go decision point; critical path milestone).

**Efficiency Measure:** A description of the level at which programs are executed or activities are implemented to achieve results, while avoiding wasting resources, effort, time, and/or money. Program efficiency can be defined simply as the ratio of the outcome or output to the input of any program.

**End Point**. *(Synonyms and Related Concepts.* "Completion Milestone"). The *planned* conclusion of an R&D or deployment activity program that reflects the intended successful achievement of a desired goal.

**Enzyme.** A protein or protein-based molecule that speeds up chemical reactions occurring in living things. Enzymes act as catalysts for a single reaction, converting a specific set of reactants into specific products.

**Ethanol.** ($CH_3CH_2OH$) A colorless, flammable liquid produced by fermentation of sugars. Ethanol is used as a fuel oxygenate. Ethanol is the alcohol found in alcoholic beverages.

**Evaluation, Program.** Systematic studies conducted periodically or on an ad hoc basis to assess how well a program is working. They help managers determine if timely adjustments are needed in program design to improve the rate, or quality, of achievement relative to the committed resources.

**External Factor.** A factor that may enhance or nullify underlying program assumptions and thus the likelihood of goal achievement. Goal achievement may also be predicated on certain conditions (events) not happening. They are introduced by external forces or parties, and are not of the agency's own making. The factors may be economic, demographic, social, or environmental, and they may remain stable, change within predicted rates, or vary to an unexpected degree.

**Ermentation.** A biochemical reaction that breaks down complex organic molecules (such as carbohydrates) into simpler materials (such as ethanol, carbon dioxide, and water). Bacteria or yeasts can ferment sugars to ethanol.

**Fossil Fuel.** A carbon or hydrocarbon fuel formed in the ground from the remains of dead plants and animals. It takes millions of years to form fossil fuels. Oil, natural gas, and coal are fossil fuels.

**Graduation Criteria.** Clearly defined (and almost always quantitative) thresholds of key performance indicators that, when reached, would allow further development and commercialization to be turned over to the private sector under expected future market and policy conditions.

**Input.** Resources required to produce outputs and outcomes.

**Lignocellulosic Feedstock.** The term ''lignocellulosic feedstock'' means any portion of a plant or coproduct from conversion, including crops, trees, forest residues, and agricultural residues not specifically grown for food, including from barley grain, grapeseed, rice bran, rice hulls, rice straw, soybean matter, and sugarcane bagasse.

**Logic Model.** A tool to describe the linkages among program resources, activities, outputs, customers reached, and short, intermediate and longer term outcomes.
Specific logic model terms are:

- Resources or Inputs include human and financial resources as well as other inputs required to support the program such as partnerships. Information on customer needs is an essential resource to the program.
- Activities include all those action steps necessary to produce program outputs.
- Outputs are the products, goods and services provided to the program's direct customers or program participants.
- Customers receive the program outputs and react in ways that lead to outcomes.
- Outcomes are changes or benefits resulting from activities and outputs. Programs typically have multiple, sequential outcomes, sometimes called the program's outcome structure. First, there are "short term outcomes", those changes or benefits that are most closely associated with or "caused" by the program's outputs. Second, there are "intermediate outcomes," those changes that result from an application of the short term outcomes. "Longer term outcomes" or program impacts, follow from the benefits accrued though the intermediate outcomes.
- "Outcomes" are typically multiple and sequential (sometimes called the program's outcome structure). There are "short-term outcomes" representing changes or benefits directly associated with, or "caused," by the program's outputs. There are "intermediate outcomes" that are changes resulting from the short-term outcomes, and "ultimate" outcomes that occur in the more distant future. In some discussions of logic models, intermediate outcomes are referred to as "mid-term" outcomes, and ultimate outcomes are called "long-term outcomes."
- Key contextual factors are external to the program and not under its control that could influence its success either positively or negatively. Antecedent variables are those the program starts out with, such as client characteristics. Mediating factors are those influences that emerge as the program unfolds, such as new competing programs.

**Long term. (see "Short" and "Intermediate" term)**

| | |
|---|---|
| **Short term** | 3 years or less |
| **Intermediate term** | 4-10 years |
| **Long term** | 10 years or more |

**Market Failures or Barriers.** Deficiencies that obstruct or impede the development of or entry of technologies or practices into the market or prevent efficient operation of the market.

| Market Barriers and Failures | Description and Examples |
|---|---|
| Deficiencies in information / awareness | Lack of consistent, accurate, unbiased information on the performance, benefits, and costs of different energy technologies and services. End users and decision-makers have limited awareness of efficiency/ renewable options and benefits and costs. Current tax provisions or other subsidies favor other technologies or practices. Principal/Agent issues (information asymmetry) may arise when knowledge of all of the costs and benefits is not fully shared between facilitators or delegated managers and the ultimate customer/decision- |

| | |
|---|---|
| | maker (e.g., relationship between builders and buyers). |
| Policy, regulation | Potentially incompatible policies, regulations, or codes & standards |
| Cost and Financing | Limited access to capital (e.g., low-income households, small businesses). Purchasers are more concerned with low first-cost than with life-cycle cost. Financing instruments available do not provide credit for the savings that the buyer will realize. |
| Technical capacity and knowledge | Limited knowledge and capacity of service providers, project developers, users, and decision-makers – For example, insufficient skills or experience with 'systems (optimization)" and how to specify, design whole systems or applications for end-users. Limited experience with transactions and processes necessary to successfully procure and implement a technology or service. |
| Risk Aversion | Some potential buyers or users of improved technology and practices may give greater weight in their decision-making to the "downside risk" of a technology failure than they give to the upside benefits of a technology success. |
| Market fragmentation and undeveloped market structures | Market fragmentation arises when market agents and investors make decisions in one market segment without adequately interacting with others from the other market segments. (e.g., the fragmentation that characterizes the U.S. building industry where developers, designers, builders, utilities, engineers, and occupants pursue objectives which often are at cross-purposes.) Undeveloped market structures include lack of infrastructure to support technology use as has been the case for alternative fueled vehicles which require significant fueling infrastructure). |
| Misplaced or Displaced Incentives | The person or organization who would make the decision about adopting a particular technology or practice is different from the one who would derive economic benefits. A classic example is a landlord who makes building investments and a tenant who pays all of his own utilities. |
| Externalities | Price signals don't reflect costs – e.g., don't account for many environmental costs, or are not time-differentiated. |
| Public Goods | The social benefits cannot be appropriated by any one company to a sufficient degree to justify the required investment. |
| Market Power | When firms have market power they tend to cut back production in order to drive up prices and increase profits – e.g., product supply decisions made by a few powerful equipment manufacturers. |

**Metric.** Unit of measurement used to assess an input, milestone, output or outcome measure. Metrics may be quantitative such "dollars per gallon" or qualitative such as "completed/not completed."

**Milestone.** A measurable, discrete event or accomplishment marking identifiable and measurable progress toward a desired result. Milestones are further characterized as annual performance, critical path, or completion milestones.

- **Annual milestone.** A performance milestone that marks progress toward an outcome on a fiscal-year basis.
- **Critical path milestone.** A performance milestone that must be completed on schedule for an output to be produced on schedule
- **Completion milestone.** The final performance milestone marking a completion decision-point or the achievement of a final output.

**Mission Statement.** The charter of the program and provides the basis for all subsequent planning activity. Program performance goals flow up into the program's mission.

**Municipal Solid Waste (MSW).** Any organic matter, including sewage, industrial, and commercial wastes, from municipal waste collection systems. Municipal waste does not include agricultural and wood wastes or residues.

**Outcomes.** Results that are *external* to the program but that are of direct importance to the intended beneficiary and that contribute to the achievement of the program's vision. Outcomes are also useful trend indicators for the program to determine whether or not it is on course to reach its vision endstate. Programs are expected to monitor outcomes, even though they are not ultimately responsible for their accomplishment.

**Outputs.** Anticipated measurable results from *internal* program activities for which the program may be held accountable. Programs are expected to measure outputs on a regular basis.

**Oxygenate.** An oxygenate is a compound which contains oxygen in its molecular structure. Ethanol and biodiesel act as oxygenates when they are blended with conventional fuels. Oxygenated fuel improves combustion efficiency and reduces tailpipe emissions of CO.

**Peer Review.** A rigorous, formal, and documented evaluation process using objective criteria and qualified and independent reviewers to make a judgment of the technical/ scientific/business merit, the actual or anticipated results, and the productivity and management effectiveness of programs and/or projects.

**Performance Goal.** A tangible, measurable target against which actual achievement can be measured, such as a quantitative amount, value or rate. A performance goal must contain a date. Performance goals are output-oriented while program strategic goals are outcome-oriented.

**Performance Measure.** A general term for any indicator, statistic or metric used to gauge program performance.

**Petroleum.** Any petroleum-based substance comprising a complex blend of hydrocarbons derived from crude oil through the process of separation, conversion, upgrading, and finishing, including motor fuel, jet oil, lubricants, petroleum solvents, and used oil.

**Program.** a centrally managed set of activities directed toward a common purpose or goal in support of an assigned mission area. Generally, a program is the highest level of work breakdown structure within a specific mission area.

**Program Assessment.** A determination, through objective measurement and systematic analysis, of the manner and extent to which Federal programs achieve intended objectives.

**Project.** The lowest level of the work breakdown structure. It is an executable element of a program, normally with a discrete start and end point, as well as a scope, schedule and budget. A single project has a program lead, may have multiple phases that cover more than one year, has a project manager and may include multiple awards in support of its objective. For monitoring and assuring progress, interim and final milestones are instituted as a integral part of the project management process.

**Strategic Goal.** Program goals that aim to achieve the program's vision. Strategic goals are outcome oriented and broader than performance goals and contain elements that are beyond the program's control. They may contribute significantly toward achieving the endstate described in the vision, and are the accumulated program outcomes. As opposed to performance goals, which are output-oriented and more near-term, strategic goals are outcome-oriented and can be longer-term. These measures should be monitored by the program, but not necessarily measured. Program outcome goals should relate to and in the aggregate be sufficient to influence the strategic goals or objectives

**Sub-Program.** Has the same characteristics of a program (but represents one additional level of division). It is the second level of the work breakdown structure.

**Target.** Quantifiable or otherwise measurable characteristic that tells how well a program must accomplish a performance measure. Targets must be *ambitious* (i.e., set at a level that promotes continued improvement) and *achievable* given program characteristics.