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Implementing Systems Engineering in the U.S. Department of Energy Office of the Biomass Program

Preprint

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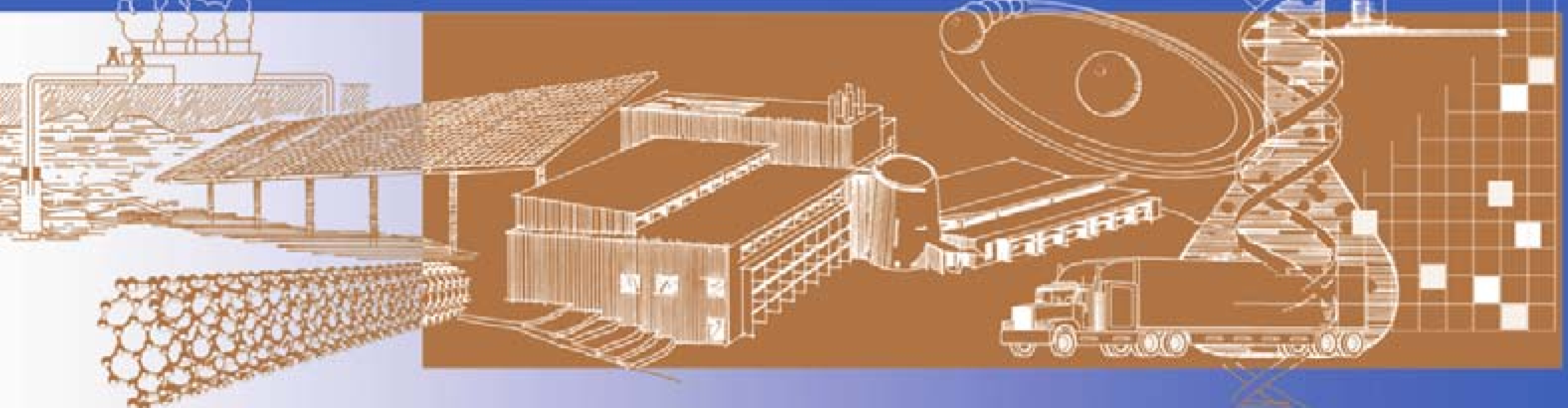

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Implementing Systems Engineering in the U.S. Department of Energy Office of the Biomass Program

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Abstract – The DOE Biomass Program is tackling the challenge of advancing biomass energy technologies and systems from concept to commercial adoption with a goal of enabling the production and use of biofuels to help reduce future U.S. oil consumption. The complexity of the biomass-to-biofuels system of systems and the combined dynamics of the existing agriculture, forestry, energy and transportation markets within which it operates pose challenges for reaching consensus on both a concept of operations and preferred strategies for transitioning to a significantly larger biofuels industry that is secure, reliable, environmentally responsible, and supportive of a thriving economy. To ensure that the program is focused on the activities critical to achieving its goal, the program is implementing systems engineering processes, practices, and tools to guide informed decision-making.

Key Words: Biofuels, biomass, bioenergy, biorefinery, cellulosic ethanol, biomass-to-biofuels supply chain, energy system dynamics modeling, stage gate management.

1 Background

The increased reliance on imported petroleum sources of energy threatens the U. S. national security, economy, and future competitiveness. Biomass is the only domestic, sustainable, and renewable primary energy resource that can provide liquid transportation fuels. Biomass resources include crops such as corn and soybeans, agricultural and forest residues such as corn stover (stalks and leaves that remain after the corn grain is harvested), wheat straw and forest thinnings. Also included are non-edible perennial crops such as switchgrass and poplar, which can be grown as energy crops. It is estimated that the United States has the potential to produce over 1.3 billion tons of biomass annually [1]—more than enough to replace about 60 percent of current U.S. gasoline consumption—sustainably, and without impacting food, feed, and fiber uses.

In his 2006 State of the Union Address, President Bush highlighted the role of biomass in reducing the nation's future demand for oil and refined gasoline and diesel fuels. The President's near-term goal for biomass is "to foster the breakthrough technologies needed to make cellulosic ethanol cost-competitive by 2012, enabling greater use of this alternative fuel to help reduce future U.S. oil consumption". The President continued to provide leadership towards US energy independence in his 2007 State of the Union Address when he asked Congress and America's scientists, farmers, industry leaders and entrepreneurs to join him in pursuing the goal of reducing U.S gasoline usage by twenty percent in the next 10 years. To support this goal the President proposed increasing the supply of renewable and alternative fuels by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels in 2017. This level is nearly five times the 2012 target for biofuels now in law. To support this effort the FY07 budget provided for the U.S. Department of Energy (DOE) Biomass Program was more than doubled to a total of more than $200 million. The Program has set a longer term target to enable the production of enough biofuels by 2030 to replace 30% of current gasoline consumption.

2 DOE Biomass Program

The Biomass Program has overall responsibility for managing DOE research, development, demonstration and deployment (RDD&D) activities relating to the use of renewable biomass for fuels, chemicals, and power production. 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, chemical and power industries to meet their market objectives.

Biomass research has been a cornerstone of DOE's renewable energy RDD&D efforts over the last 25 years. Today, the unprecedented national visibility of cellulosic ethanol, in particular, and biofuels, in general, as viable alternatives to conventional transportation fuels puts the Biomass Program under greater pressure to produce measurable results than at any other time in its history. The monetary requirements for deployment will dwarf what has been spent on research, even over the last 25 years. The risks are high and the resources are limited. As the program moves forward with the deployment of full-scale biofuels systems, increasingly larger sums of government money will be spent on research and large-scale technology demonstrations. The Biomass Program has an obligation to make sure the money is spent properly on the right projects and that the projects are conducted in the best possible manner.

2.1 Role of Systems Engineering in the Biomass Program

The Biomass Systems Integration Office (SIO) was established in 2004 to implement the systems engineering processes, practices, and tools that will enable the program to meet the challenges of aligning RDD&D efforts with the program's strategic goals and directing funding to the efforts that offer the most promise. As the technical arm of the Biomass Program management structure, SIO is tasked with (1) establishing, validating, and maintaining the integrated baseline as biomass technologies and systems are advanced from concept to commercial adoption, (2) providing consistent results of analyses to support programmatic decisions, and (3) verifying that technology and system designs meet program requirements. This paper will describe aspects of SIO work in these three areas.

2.2 Biofuels Concept of Operation

At the highest level the overall biofuels energy system can best be described as a system of systems arranged according to the five major elements of the biomass-to-biofuels supply chain - from the farmer's field to the consumer's vehicle. Brief functional descriptions and the required 2030 annual capacities of these systems are provided in Table 1.

Because of the wide diversity of biomass feedstocks, conversion technologies, and potential products, technical elements can be combined in a multitude of bi-refinery configurations. The capture this complexity the program has created a second tier to the biofuels concept of operations defined by seven primary biorefinery pathways, described in Table 2. These pathways guide RDD&D efforts and help to identify key interfaces that will enable the establishment of commercially viable integrated biorefineries. The pathways are: corn wet mills, corn dry grind mills, natural oil processing mills, agricultural residue processing, energy crop processing, forest products mills, and forest residue processing. These technology pathways are linked to the U.S. biomass resource base, existing segments of today's biomass industry when possible, and future biomass industry market segments where envisioned. Each pathway represents a generic set of potential biorefinery configurations for a specific biomass resource base. Within each pathway there are multiple viable alternative routes to biofuels production. This pathway framework was designed to help:

- Recognize the diversity of feedstocks and their specific associated issues.
- Strengthen the interfaces between the biomass production and conversion elements of the overall supply chain.
- Identify the complete set of technologies required by a biorefinery and the interfaces between the individual technology parts, especially those from fundamentally different areas.
- Clarify how new technologies could fit into the existing bioindustry market segments.
- Existing bioindustry market segments understand each other and identify current and future synergies.
- Envision the transition from today's bioindustry to the future.
- Support creation of detailed RDD&D plans and progress tracking by giving technical context to performance metrics and cost targets,

The performance and cost targets specified for each of the seven resource-based pathways, along with the strategic goals and barriers identified in the program's multiyear plan [2] form the basis of the Biomass Program's technical baseline.

Table 1: Major Systems within the Biomass-to-Biofuels Supply Chain

Supply Chain Systems	Functional Descriptions	Annual Capacities in 2030
Feedstock Production	Produce large, sustainable supplies of regionally available biomass	600 million tons
Feedstock Transport	Implement biomass feedstock infrastructure, equipment and systems including harvesting, collection, storage, preprocessing, and transportation operations	600 million tons and 30 billion ton-miles of transport
Conversion to Fuel	Deploy cost-effective biomass-to-biofuels conversion facilities that meet all safety and environmental standards	48 billion gallons of biofuels (gge*)
Fuel Transport	Implement biofuels distribution infrastructure including storage, blending, transportation, and dispensing operations	48 billion gallons of biofuels (gge*)
Fuel Use	Deploy publicly available biofuels and biofuels-compatible vehicles with same performance as vehicle operating on petroleum fuels	230 million biofuel compatible vehicles consuming 48 billion gallons of biofuels (gge*)

gge = gasoline gallon equivalent . A unit of measure used to express the energy content of alternative fuels that have different energy densities on a common volumetric basis .

Table 2: Biorefinery Pathways -the Second Level of the Biofuels Concept of Operations

General Resource Category	Specific Biomass Feedstocks	Biorefinery Pathway	Biofuel Product
Starch	Corn	Corn Wet Mill Improvements	Ethanol
	Corn	Corn Dry Grind Mill Improvements	
Natural Oils	Soybeans, Waste Fats and Grease	Natural Oil Processing Mill Improvements	Biodiesel
Ligno-cellulose (plant material composed of cellulose, lignin and hemi-cellulose)	Corn Stover, Cereal Straw, Bagasse	Agricultural Residue Processing	Ethanol, Other Alcohols, Renewable Diesel, Renewable Gasoline, Other Fuels
	Switchgrass, Hybrid Poplar Trees, Willow, Energy Cane	Energy Crop Processing	
	Pulpwood	Forest Products Mill Improvements	
	Forest thinnings, logging residues	Forest Residue Processing	

2.3 Biomass Program Integrated Baseline

The DOE Biomass Program is organized around a RDD&D based work breakdown structure (WBS) and the biorefinery pathways. This organization is designed to integrate the technology advancements from the RDD&D efforts into complete biorefinery systems.

The Biomass Program WBS comprises five technology elements described below. The Program uses this WBS to manage more than 150 projects conducted at universities, national laboratories, and in partnership with industry across the country. Detailed information on each of these projects forms the programmatic baseline.

- **Feedstock R&D**. Development of new sustainable agricultural and feedstock infrastructure technologies and methods that will be required to supply lignocellulsic feedstocks to future large-scale biorefineries.
- **Biochemical Conversion R&D**. Fundamental and applied research and technology development for producing low-cost sugars from lignocellulosic biomass.
- **Thermochemical Conversion R&D**. Fundamental and applied research and technology development for cost-effective, efficient thermochemical technologies for producing intermediate products (e.g., syngas, pyrolysis oil) from lignocellulosic biomass and biomass-derived biorefinery residues.
- **Products R&D**. Investigation, evaluation, and demonstration of cost-effective fuels—as well as co-product, chemical, material, and heat and power production from process residues and intermediates— to improve overall biorefinery plant economics.
- **Integrated Biorefineries Demonstration and Deployment**. Pilot- and demonstration-scale evaluation of cost- and performance-competitive integrated biorefinery technologies through public–private partnerships. Also includes funding for pioneer commercial scale biorefineries.

The pathway framework for biorefinery deployment provides the management structure and processes for integrating advanced technologies being developed by the R&D elements to achieve the program mission. The WBS-pathway matrix links the WBS project information (scope of work, schedule, and cost) with the pathways (system configuration, performance, and characteristics) and forms the basis of the Biomass Program's integrated baseline.

The SIO uses CORE, a computer-assisted systems engineering support tool, to organize, coordinate, and document the integrated baseline development efforts. It captures the complete set of requirements, functions, strategies, technologies, inputs, and outputs in a central repository. The CORE software provides the Biomass Program management with the necessary requirements for traceability to establish a defensible basis for budget estimates and technical decisions. The software has been customized to allow viewing program organization and efforts from a variety of perspectives through automatic generation of standard reports, tables, and diagrams. Also, as shown in Figure 1, custom scripts have been developed to import and export data and information through Microsoft Office products—Microsoft Word, Microsoft Excel, and Microsoft Project—which streamlines the production of program-specific periodic standardized reports and schedules. This capability is proving to be a key element of enabling the diverse set of program participants to share and evaluate needs, priorities, plans and progress. As the systems engineering management approach continues to mature, the more advanced capabilities of the CORE software will be implemented.

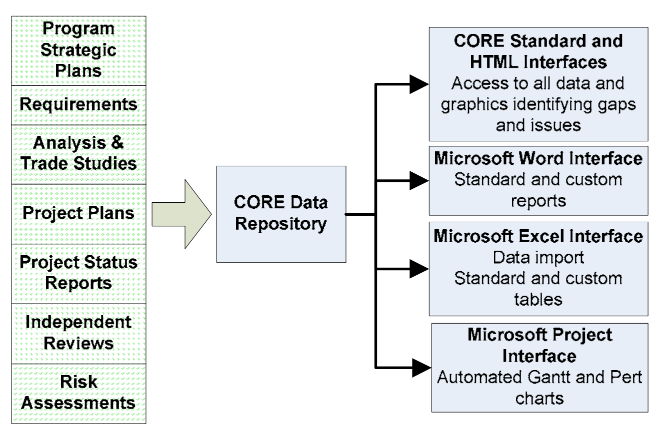

Figure 1: CORE Software Use in the Program

3 Bioindustry Transition Scenario Analysis

The Biomass Program uses a variety of analytical methodologies and tools to guide its RDD&D efforts. Bioindustry transition analysis is carried out with the commercially available dynamic systems model STELLA and 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 bio-based future?
  - What are the interactions between these technologies and other established technologies?
  - What are the scenarios for biomass use in transportation, power, and chemical markets?
  - What market penetration pathways are likely?
- Determine what can be done to accelerate biofuels 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?

As shown in Figure 2, the model is organized around the biomass-to-biofuels supply chain, starting with 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. The build up of the infrastructure 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.

An example of a portion of the model output is presented in Figure 3 which shows the modeled ethanol demand and supply between 2000 and 2030. The four lines on the chart show U.S. ethanol demand, total ethanol supply, and the breakdown of the total ethanol supply between lignocellulose-derived ethanol and corn-derived ethanol. According to this particular scenario corn ethanol is expected to reach a maximum supply level of about 12 billion gallons and lignocellulosic ethanol is expected to enter the market around 2015 and ramp up to a capacity of about 48 billion gallons by 2030. 60 billion gallons of ethanol is equivalent to approximately 48 billion gallons of gasoline when adjusted for the lower ethanol energy density.

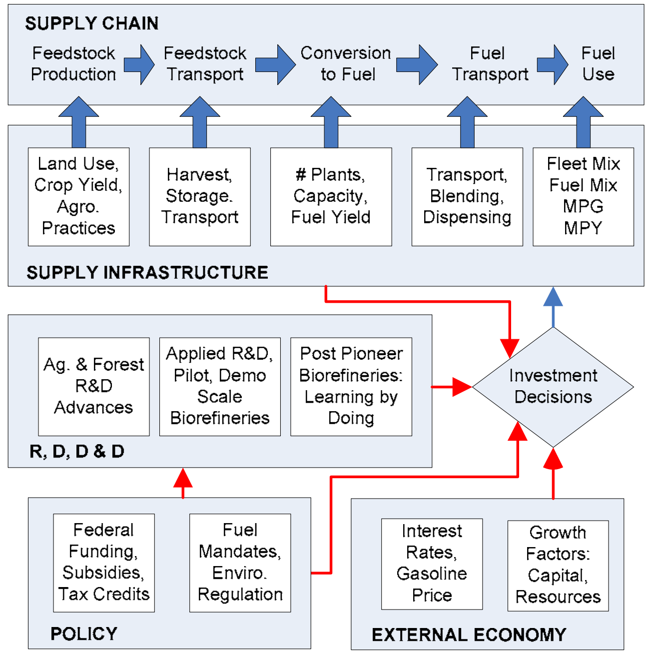

Figure 2: Bioindustry Transition Scenario Model Structure

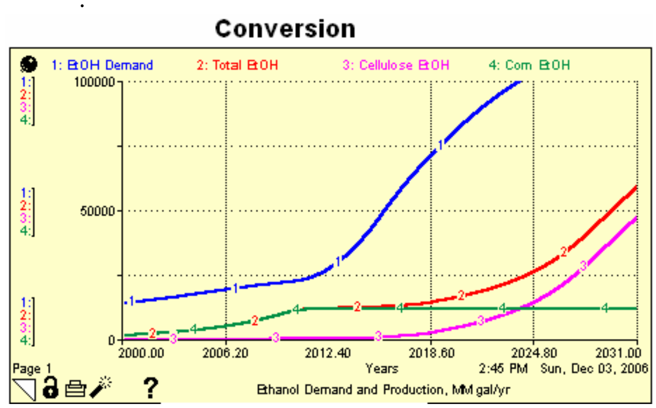

Figure 3: Bioindustry Transition Scenario Analysis Results

4 Stage Gate Management

Stage gate management is a common systems engineering based process for making disciplined decisions that lead to focused process and product development efforts. Focusing the RDD&D efforts of the Biomass Program is particularly challenging because of the number and diversity of Program participants as well as the broad scope in terms of technology as well as stages of development. Specifically, the Biomass Program uses stage gate management to:

- Guide decisions on which projects to include in the Program's portfolio,
- Align 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 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. As shown in Figure 4 [3], 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 more fundamental, pre-competitive scientific projects that are critical to developing the technical underpinnings of the emerging industry and resolving scientific barriers to progress as they are identified.

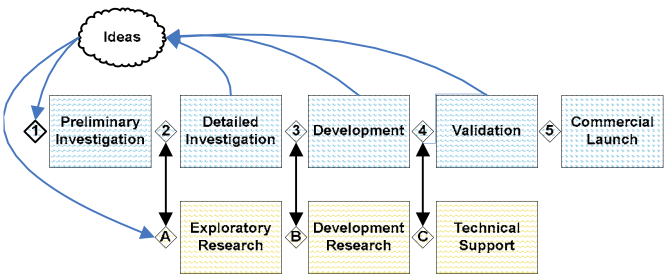

Figure 4: Stage Gate Management in the Biomass Program

The purpose of each gate is two fold. First the project must demonstrate that it met the objectives identified in the previous stage plan and that it satisfies the criteria for the current gate. A set of seven types of criteria have been developed against which a project is judged at each gate including:

- Strategic fit,
- Market/customer
- Technical feasibility and risks,
- Competitive advantage
- Legal and regulatory compliance
- Critical success factors and showstoppers
- Plan to proceed

The second half of the gate review involves the plan to proceed. If the decision is made that project "passes" the gate, then a 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. Once the plan is accepted, the project can move to the next stage. Since the stakes get higher with each stage, the decision process becomes more complex and demanding as a project proceeds along this development path. 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. Projects on the research track have generally had gate reviews that included external reviewers with meetings open to the public. Gate reviews provide critical information that enables key decisions in a number of areas, all of which are difficult: project selection and prioritization, resource allocation across projects, and implementation of the business strategy.

5 Summary

The DOE Biomass Program is taking on the challenge of advancing biomass technologies and systems from concept to commercial adoption. To ensure that the program is focused on the activities critical to achieving this goal, the program is implementing systems engineering processes, practices, and tools to guide informed decision-making. The SIO is working with DOE program managers to establish, validate, and maintain the integrated baseline based on the biomass-to-biofuels supply chain and biorefinery pathways. CORE software is used to organize, coordinate, and document the integrated baseline in a central repository. A systems dynamics model is being developed with STELLA software to create and evaluate possible bioindustry transition scenarios. The model is organized around the biofuels supply chain and includes interactions between technology, investment, policy, and the larger energy markets. Stage gate management is employed not only as critical review process but also to align the RDD&D activities of numerous diverse participants and activities with the Program's goals and objectives.

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