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Sustainable Harvest for Food and Fuel

Preliminary Food & Fuel Gap Analysis Report

Ray Grosshans
Kevin M. Kostelnik
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Idaho National Laboratory
Idaho Falls, Idaho 83415

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INTRODUCTION

To promote economic growth and energy security, and to protect the environment, the U.S. is pursuing a national strategy of energy independence and climatic protection in which domestic renewable carbon-neutral biofuels displace 30 percent of U.S. oil consumption by the mid-21st century. Such fuels, including ethanol and biodiesel, will be produced from biological feed stocks (biomass).

The availability of this billion-ton biomass will hinge on the application of modern scientific and engineering tools to create a highly-integrated biofuel production system. Efforts are underway to identify and develop energy crops, ranging from agricultural residues to genetically engineered perennials; to develop biology-based processing methods; and, to develop large-scale biorefineries to economically convert biomass into fuels.

In addition to advancing the biomass-to-biofuel research and development agenda, policy makers are concurrently defining the correct mix of governmental supports and regulations. Given the volumes of biomass and fuels that must flow to successfully enact a national biomass strategy, policies must encourage large-scale markets to form and expand around a tightly integrated system of farmers, fuel producers and transporters, and markets over the course of decades. In formulating such policies, policy makers must address the complex interactions of social, technical, economic, and environmental factors that bound energy production and use.

The Idaho National Laboratory (INL) is a science-based, applied engineering national laboratory dedicated to supporting the U.S. Department of Energy (DOE). The INL Bioenergy Program supports the DOE and the U.S. Department of Agriculture. Key multidisciplinary INL capabilities are being leveraged to address major science and technology needs associated with the cost-effective utilization of biomass. INL's whole crop utilization (WCU) vision is focused on the use of the entire crop, including both the grain and traditionally discarded plant biomass to produce food, feed, fiber, energy, and value-added products.

DOE PROGRAM GOALS

The Energy Policy Act of 2005 legislation revised the national energy objectives and goals (2005). Included within this legislation was reauthorization of the Agricultural Biomass Research and Development Program and amendments to the Biomass Research and Development Act of 2000 (2005, , 2000). Specific goals of this legislation include:

a. Increase the energy security of the United States,
b. Create jobs and enhance the economic development of the rural economy,
c. Enhance the environment and public health, and
d. Diversify markets for raw agricultural and forestry products.

The production and conversion of biomass-based resources is therefore expected not only to reduce dependence on foreign oil but also to support the growth of agriculture, forestry, and rural economies as well as to supplant petrochemical feed stocks used by major domestic industries to produce other fuels, chemicals, and industrial products.

Authorizing legislation details additional considerations that seek to minimize potential economic shocks while maximizing domestic benefits. Considerations should be given to:

1. Create continuously expanding opportunities for participants in existing biofuels production by seeking synergies and continuity with current technologies and practices, such as the use of dried distillers grains as a bridge feedstock;
2. Maximize the environmental, economic, and social benefits of production of bio-based fuels and bio-based products analysis and other means; and
3. Assess the potential of Federal land and land management programs as feedstock resources for bio-based fuels and bio-based products, consistent with the integrity of soil and water resources and with other environmental considerations.

This concern, to rapidly expand biomass production and conversion without wrecking the economy or the environment resonates with multiple constituencies.

The DOE Office of Energy Efficiency and Renewable Energy's Office of the Biomass Program (OBP) has implemented the Biofuels Initiative, with the goal of reducing U.S. dependence on foreign oil. OBP has established the following programmatic targets in support of these policy goals:

1. Make cellulosic ethanol (or ethanol from non-grain biomass resources) cost competitive with gasoline by 2012 (Collins, 2007).

2. Replace 30 percent of current levels of gasoline consumption with biofuels by 2030 (30x30), which equals 60 billion gallons of ethanol production (Perlack et al., 2005, Hettenhaus, 2006).

SUSTAINABLE HARVEST FOR FOOD AND FUEL PROJECT

Scope

This “Sustainable Harvest for Food and Fuel” project supports the DOE Program Goals by investigating the potential impacts and the long-term sustainability of projected biomass harvests as they relate to both food and fuel applications.

This project will model the potential consequences associated with the national biomass strategy in terms of agricultural/forestry economics, environmental quality, food and fuel sufficiency, and community viability. The principles of sustainability will be applied to better understand the projected harvests of biomass for food and fuel and a set of sustainable harvest indicators will be developed to guide policy and strategic direction as well as monitor performance.

By helping to ensure that the biomass harvest remains sustainable both in terms of food and fuel, the “Sustainable Harvest for Food and Fuel” model will help evaluate regional economic growth, the long-term protection of our environmental and natural resources, and also safeguard the safety, health, and the quality of life for current and future generations.

Purpose of this Report

Phase 1 of the “Sustainable Harvest for Food and Fuel” project will result in the development of an integrated “Food and Fuel Framework”. This systems-level interdisciplinary framework will integrate pertinent resource data and existing component-level models.

This report is the initial deliverable supporting the development of the “Food and Fuel Framework”. This report summarizes the following primary activities:

1. Summarize relevant literature, system models and applicable data sources as they relate to the sustainable food and fuel harvest questions,
2. Identify a series of preliminary sustainability indicators for potential use in measuring economic, environmental, and social outcomes,
3. Present an initial Food and Fuel Framework in terms of a Causal Loop Diagram, and
4. Identify data gaps and a proposed path forward for filling those gaps.

LITERATURE REVIEW SUMMARY

The terms “sustainable” and “sustainability” embody efforts to balance today’s resource requirements with future demands. For example, agriculture is considered “sustainable” when sum agricultural inputs – natural resources, energy, chemicals, labor and so on – meet current demand for food, fuel, and fiber without environmental consequences that would cause future shortfalls. In terms of meeting the DOE 30x30 goals, the sustainability concern is whether or not the U.S. agricultural system can produce sufficient feedstocks for biofuel production while continuing to meet the food price expectations of American consumers without causing environmental degradation that would threaten to curtail the production of both food and fuel.

The ability to assess U.S. agricultural sustainability depends on the ability to identify key cause-and-effect relationships between agricultural practices such as crop rotations, fertilizer applications and water use; environmental impacts and economic considerations. The challenge, of course, is identifying the proper measures of sustainability and then understanding what these measures mean over time so that they can be used by practitioners and policy makers.

The following sections summarize previous work that identifies and characterizes sustainability measures, or so-called “sustainability indictors,” and that examines the interplay between indicators over time through modeling.

Determining Indicators of Sustainability

There is no shortage of agricultural data nor is there a shortage of economic data that show how burgeoning ethanol production effects farm commodity markets. Counter-cyclical corn price spikes, for example, illustrate how ethanol producers’ corn purchases drive up corn prices. Meanwhile, the increased availability of distiller’s dry grain (DDG), a livestock feed supplement, is threatening to supplant soy bean demand in animal feed markets. More subtly, inequalities in the taxing of gasoline and ethanol affect the share of motor fuel taxes transferred to U.S. Highway Trust funds. This reduces the revenues available to state and transportation department and creates “adverse incentives” (Ferris and Joshi, 2004). In each case, the unintended consequences that stem from a rapid increase in ethanol production undermine the willingness of affected constituencies to support the DOE 30x30 goals.

Under present circumstances, an obvious mitigation strategy that addresses both food and feed market volatility and adverse tax consequences is to simply grow more corn while adjusting the tax code. No doubt, from such a simplistic approach other unintended and adverse consequences will flow. Resulting market distortions will further undermine progress towards the DOE 30x30 goals, and, such intensive mono-cropping is likely to yield negative environmental consequences.

A more complex strategy that includes the devising, modeling, and monitoring of sustainability indicators is more promising in terms of achieving long term goals. According to Zander and Kachele (1999), agricultural sustainability can be assessed through models that incorporate a “combination of economic and ecological objectives” (Zander and Kachele, 1999). Efforts to develop such a strategy have been underway – mainly outside the U.S. – for about 20 years. In fact, a 1987 report issued by the World Commission on Environment and Development is frequently described as introducing sustainability concepts to the international community (Ediger et al., 2007, Dalgaard et al., 2006).

Sustainability indicators per se have been addressed from a variety of perspectives. Some researchers have focused on individual factors or on regional sustainability issues. For example, the importance of carbon dynamics in modeling the sustainability of crop land (Evrendilek and Wali, 2001) and the effects of prescribed burning and harvesting on forest recovery and sustainability (Garten, 2006) have both been addressed in regional U.S. studies. The role of forests in carbon management scenarios at the global level is explored with a “Forest Identity” index (Kauppi et al., 2006). Also, the role of geology as a critical factor in the “genesis of biophysical resources” and as a sustainability indicator of agriculture has been studied (Bakri, 2001). Another study focused on harvesting rates and logging selectivity as indicators that might determine whether or not rain forests are sustainably utilized (Osho, 1995).

Others have suggested a role for complex quantitative approaches to sustainability, including the potential contributions of fuzzy set theory (Cornelissen et al., 2001) and functional differential equations (Garcia, 2001). Another study predicts tropical palm tree harvest consequences by applying structured population models to tree density and harvest timing (Freckleton et al., 2003). Other technical concerns include IT applications for the integrated modeling of a sustainable regional agricultural development strategy (Kurlavicius and Christauskas, 2004).

Other studies have focused more broadly. For example, Sands and Podmore (2000) looked at the effects of erosion on farm productivity in order to provide a “quantitative measure of sustainability from an environmental perspective” (Sands and Podmore, 2000). Their work compared different crop management systems and demonstrated “clear differences” regarding the environmental sustainability of these systems. Another study used quantitative indicators, including livestock numbers, income, labor hours, area under cultivation and soil chemical balances, to compare four different agricultural policy scenarios and the resultant trade-offs (Lehtonen et al., 2005). Interestingly, one energy policy paper proposes a “Fossil Fuel Sustainability Index” in order to guide the efficient management of fossil fuel resources. Not surprisingly, according to these authors, over reliance on oil is an “incompetent” policy to be mitigated by increased emphasis on domestic resources including renewables, coal, and nuclear (Ediger et al., 2007).

Other broadly focused studies account for the interacting effects of multiple indicators. For example, Ross (2002) estimated energy, carbon and economic budgets for grain biofuel feedstocks including wheat grain and corn grain, and for the corresponding cellulosic feedstocks wheat straw, and switch grass (Ross, 2002). This study also included calculated estimates of the combined carbon emissions from crop production, fermentation, cellulose digestion and the distribution of ethanol products. In an even broader approach, Yamamoto (2003) created a “global land use and energy model” to examine several energy production scenarios (Yamamoto, 2003). This study includes 11 regions, encompassing the world, and 14 types of renewable energy sources in a time frame that stretches to 2060.

In one interesting case, researchers substitute known causes and effects of land degradation, or threats to sustainability, for sustainability indicators in a “Threat Identification Model” (TIM) (Smith et al., 2000). In this study, TIM is linked to a Geographic Information System (GIS) in order to map known “constraints to agriculture” to particular sites and to known land-management options. According to the authors, this strategy enables the “ex ante assessment of agricultural land management sustainability.”

An international effort to define sustainability indicators is presently underway on behalf of the International Energy Agency (IEA) which acts as energy policy advisor to its 27 member countries. The IEA effort is aimed at creating a commodity market for bio-energy by developing a third-party certification program to ensure the sustainability of global biofuel production. A draft report prepared for this effort outlines sustainability indicators that appear in both governmental and non-governmental sources (Jungingera et al., 2007). These include:

- GHG emissions
- Economic prosperity
- Social conditions
- Biodiversity
- Use of agrochemicals
- Soil quality
- Emissions to air
- Institutional, governance
- Competition food, energy
- Working conditions
- Origin of biomass
- Waste
- Farming practices
- Water quality and quantity
- Use of GMOs
- Energy balance

Underlying the concern to identify sustainability indicators is discussion of the utility of such indicators. By and large, most studies concur on the importance of framing agricultural sustainability issues in terms of the cause-and-effect relationship between agricultural production systems and environmental health (Weersink et al., 2004). Or as Belcher et al. (2004) put it, in order to determine the economic and environmental sustainability of a system, one must understand and monitor the “biophysical constraints” that limit technical, agronomical and economic vitality (Belcher et al., 2004). Pannell (2003), however, notes that the value of indicators will “vary by issue, by indicator, by region and by farm” and makes the common sense observation that for indicators to have enduring value, they must yield results that make significant differences to individual farmers as they pursue their individual objectives (Pannell, 2003). Pannell also notes that over time, in many cases, the value of monitoring sustainability indicators will fade as sustainable practices become integrated into agriculture. Nevertheless, the sense of the literature is that "sustainable agricultural systems should be productive, stable in the face of natural fluctuations in environmental and social conditions, resilient to sudden changes and provide equitable access to the means of production" (Stevenson and Lee, 2001).

A second underlying sustainability-indicator concern is the question of stakeholder "buy in." The risk is that when stakeholders don't buy in, they push back. Even in cases where a publicly acknowledged positive outcome is at stake, stakeholders battle renewable energy infrastructure projects to a standstill based on negative perceptions. Oftentimes this phenomenon is termed "not-in-my-backyard" or "NIMBY" to characterize how citizens would welcome wind farms or ethanol plants – but not near where they live.

Several studies examine just how indicators are developed and their perceived value based on who participates in the indicator identification and definition process. For example, Zander and Kachele (1999) argue that in order to make sustainability decisions, "land users require both an economic framework and compelling institutional (governmental) communications: possibilities and limitations, relationships and interdependencies must be explicit" (Zander and Kachele, 1999). Other work shows the value of attending to both "stakeholders' experience and style of reasoning" as well as other cultural factors (Schreider and Mostovaia, 2001). In fact, some suggest that the quality of sustainability decisions improve when decision-making processes include multiple constituencies. For example, Carolan (2006) examines how expert knowledge is co-produced in agriculture by local and non-local experts for the benefit of both (Carolan, 2006). And another study suggests that the exchange of information between the public and technical experts increases the technical competency of decision making (Steelman and Ascher, 1997).

According to Alberts (2006), in the case of sustainability indicators, what is desirable are "socially robust decisions" based on "socially robust knowledge;" that is, knowledge validated by stakeholders (Alberts, 2007). Alberts suggests that effective stakeholder decisions attend to five social goals:

- Incorporating public values into decision
- Improving the substantive quality of decision
- Resolving conflict among competing interests
- Building trust in institutions
- Educating and informing the public

Alberts cautions, however, that in some cases, the productivity of engaging citizens in policy making to avoid the "NIMBY" phenomenon is questionable. Consensus-driven compromises may weaken policy therefore consulting technical experts may be more useful.

Importance of Modeling Sustainability for Policy Purposes

Sustainable agriculture provides food, fiber, and fuel while protecting environmental systems in an economic framework that is profitable for farmers. Experience to date with ethanol production and how it distorts agricultural markets underscores the potential of sustainability concerns to undermine the DOE 30x30 goals: Can the U.S. agricultural system produce sufficient feedstocks for biofuel production and meet the food price expectations of American consumers without causing environmental degradation that would curtail the production of both food and fuel?

Computer-based modeling tools that support agricultural decision making are widely used. Such models have become increasingly popular with policymakers who are obliged to assess social, political, and economic decisions in light of the publics' growing interest in a more sustainable agriculture and in the mitigation of the potential consequences of global climate change. Indeed, this twin sustainment concern focuses public attention on both science and government and how one influences the other in the formulation of policy. In response, efforts to assess the sustainability of agricultural systems against a wide range of scenarios in a publicly transparent manner have emerged, mainly within the last decade.

For example, Stevenson and Howard (2001) present a model that combines scientific and political approaches "to meet the multiple objectives of involving people, maintaining scientific integrity and providing guidance for policymakers and practitioners alike" (Stevenson and Lee, 2001). One study illustrates the convenience of using trade-off curves to summarizing information for policymakers and to "form the basis for conceptualizing and empirically modeling issues regarding sustainability (Weersink et al., 2004). Another argues that models must bring together economics, ecology, physics and other disciplines "to raise awareness of the environmental dimensions of agriculture as well as the agriculture-environment interactions" (Dalgaard et al., 2006). Some studies stress the development of modeling tools that are readily accessible to both policymakers and the public. Concern for "increased public involvement and sustainability decisions that are technically sound" led one team to call for "an easy-to-use decision-support tool that allows users to analyze potential future outcomes from a sustainability perspective" (Sharma et al., 2006).

PRELIMINARY SUSTAINABILITY INDICATORS

Sustainability is an interdisciplinary process that integrates economic development, social values, and environmental health considerations. Sustainability strives to meet the needs of the present without compromising the ability of future generations to meet their own needs (UN, 1987). Key to the sustainability concept is acknowledging that human beings, and their associated influences, are intimately linked to the natural environment.

Additional issues remain with regard to the amount and type of resources to use or leave for future generations (McIntosh and Edwards-Jones, 2000). By classifying existing resources into categories of natural capital, human-made capital and human capital several authors have attempted to define systems and policies in terms of "weak" versus "strong" sustainability (Pearce et al., 1989, McIntosh and Edwards-Jones, 2000, Turner, 1992). Weak sustainability implies that one form of capital can be substituted for another, while by contrast strong sustainability suggests that natural capital must be maintained because it can not be replaced by other human capital.

Sustainability indicators are the language through which the Sustainable Harvest Food and Fuel model communicates. These indicators include measures of economic outcomes, environmental outcomes, and social outcomes (Heller and Keoleian, 2002, Stevenson and Lee, 2001, Heller and Keoleian, 2000). Sustainable harvest indicators are tools useful for delineating potential consequences as the biomass strategy unfolds in terms of agricultural/forestry profitability, environmental quality, food and fuel sufficiency, and community viability. In turn, these sustainability indicators may be used to guide best management practices at the regional and local levels.

Sustainability issues and externalities such as Market Size, Energy Conversion Technology, Natural Resources, Socio-political Concerns, Financing, Production and Environmental Impacts are all important conditions within the context of sustainable harvest. The importance of these issues and externalities relates to influences they represent with regard to key variables within a dynamic system. Table 1 provides a summary of the currently identified Sustainability Issues and Externalities and their associated Influences. A list of potential Indicators that appear useful for monitoring and measuring these influences is also presented. Finally, this Table identifies potentially relevant data sources and existing models. These data sources and models are being evaluated further to determine their applicability to the sustainable harvest question.

Table 1. List of Preliminary Sustainable Harvest Indicators and potential sources of Data/Models.

Sustainability Issues & Externalities	**Major Considerations & Influences**	**Potential Indicators**	**Potentially Relevant Data/Models**
Market Size	Population Growth Fuel Demand ETOH % Consumption Export/Imports FFV availability Substitutions for other petrochemicals	Census data Consumption rates Rate of fuel switching	U.S. Census DOE EIA AEO SAGE USDA ERS
	Energy Demand Growth	Consumption projections	DOE EIA
Conversion Technology	Technological Advancements	Conversion Efficiency Rate of energy crop utilization	30x30 workshop & Biological Barriers projections
	Energy Potential	BTUs biofuel vs. oil # of integrated refineries	
Natural Resources	Water Demands Water for food demand	Water use/ BTU produced	IMPACT-WATER
	Land Resources	Land-use rates Rate of agricultural land conversion Quality of land used	AGMOD NREL BSM POLYSYS
	Nutrients, Soil Health	Soil Balance (generation vs. depletion) Nutrient loading (external fertilizer)	Cbudget POLYSYS
Socio-political concerns	Rural economic development	Return on Investment Employment growth (jobs in energy sector) Farm wage vs. other CRP vs. bio-cropping	DOL BLS USDA
	Stakeholder concerns: -Economic security -Incentives equity -Energy security -Conservation -Climate change	Market penetration (Biofuel, FFV) Degree of Industrial Consolidation Other bio-product acceptance vs. cost Conservation rates NIMBY/downwinder pushback	SAGE
	Taxes/Tax Credits	Production Tax credit permanence Investment Tax Credit permanence Carbon Tax, when and how much Bio-incentives	IRS US legislation

	National Security	Imports/Exports Negative consequences of US market on developing countries	USDA ERS
Financial Investment	Rate of biofuel R&D	Investor responsiveness Oil prices	NREL BSM SAGE POLYSYS
	Capital Investment	Investor response	NREL BSM
Feedstock production Food commodity production	Market demand Policy incentives ROI	ROI/acre Agricultural input cost: -Land, Chemicals, Energy, Equipment Commodity prices and market volatility	Argonne WtW INL Feedstock FAPSIM ORIBAS POLYSYS IMPLAN NREL BSM POLYSYS
Biomass supply logistics	Feedstock assembly Field to bio-refinery Field to vehicle		INL Feedstock IBSAL NREL BSM POLYSYS
Environmental Impacts	Waste Management	Waste/by-products generated per unit of production Off-site pollutants released	EIO-LCA PNNL MiniCAM
Climate Change	CO2 Emissions	Emission rates Atmospheric CO2 levels	Argonne WtW NOAA CMDL
	Ecological Impacts	Wildlife impacts Invasive Plants	NWF, WWF

CAUSAL LOOP DIAGRAMS

Description

Causal loop diagrams (CLDs) have been shown to be an important tool for representing the feedback structure of complex systems and a means of illustrating how variables within a system are interrelated (Pegasus, 2007, Sterman, 2000). CLDs are excellent for:

1. Quickly capturing an hypotheses about the causes of dynamics,
2. Eliciting and capturing the mental models of individuals or teams, and
3. Communicating the important feedbacks you believe are responsible for a problem.

A causal loop diagram consists of variables (things that change over time), connected by arrows denoting the causal influences among the variables, as well as important feedback loops. Each causal link is assigned a polarity, either positive (+) or negative (-) that indicates how the dependent variable changes when the independent variable changes.

A positive link means that if the cause changes then the effect changes in the same direction (increase or decrease) beyond what it would otherwise have been. A negative link means that if the cause changes, then the effect changes in the opposite direction (Pegasus, 2007).

Causal influences and variables form loops within a CLD. These loops are identified as either reinforcing" (positive) or "balancing" (negative) feedback loops. As the label suggests, positive loops indicate a growth while negative loops suggest equilibrium within the relationships. A fast way to tell if a loop is positive or negative is to count the number of negative links in the loop. If the number of negative links is even, the loop is positive; if the number is odd, the loop is negative.

Furthermore, important variables within CLDs are often highlighted within boxes. These variables are indicator variables that are sensitive to the health of the system. Indicator variables can be used to detect changes in system behavior early on.

Preliminary Food and Fuel Framework Causal Loop Diagram

The preliminary Food and Fuel Framework, in the form of a causal loop diagram, is illustrated in Figure 1. This figure captures several key variables and shows how those variables function within the complex fuel-feed system. In the "Biofuel Loop", as biofuel production increases it drives the price for biofuel down, subsequently increasing the potential market size which in turn converts more people to biofuel use. Increased use then drives up the biofuel demand which increases capacity utilization and likewise increases biofuel production. The overall loop is a positive loop which means without restrictions from other loops this loop would produce continuous unrestricted growth (collapse).

As in all systems in nature, nothing can continue to grow forever; something will always step in to restrict the growth. In the biofuel case, there are several loops that can restrict the growth. One restrictive loop is the biomass feedstock loop. As demand for biofuel increases this increases the demand for biomass. This in turn increases the attractiveness of biomass crops which will increase the production of biomass feedstocks which will increase biomass production which will then decrease the price for biomass which will then decrease the attractiveness of biomass production. This balancing loop will limit the growth of biofuel production but in addition will cause ripple affects in the "Food Stock" loop.

Figure 1 shows how each component affects the entire system. What is not captured in the diagram is which loop/s is/are dominating as the system moves through time. Anytime the system shows growths the positive loops are dominating. When the system remains stagnant the negative loops are dominating the system behavior. As a system moves through time different loops will dominate at different times. As this shift in loop dominance occurs the system will display different behavior (i.e., growth, oscillation, collapse). A causal loop diagram will illuminate the connections between system components but to understand loop dominance and system behavior it is necessary to move to the next stage of system thinking/system dynamics which is to develop a model that captures the causality displayed in the causal loop diagram in a simulation environment. With a full dynamic system model it is possible to understand under what circumstances which loops will become dominant and thereby understand the behavior of the system. Once you understand how and why the system is responding to different influences it is possible to start to develop policies that will emphasize the desired behavior while minimizing or restricting unwanted behavior.

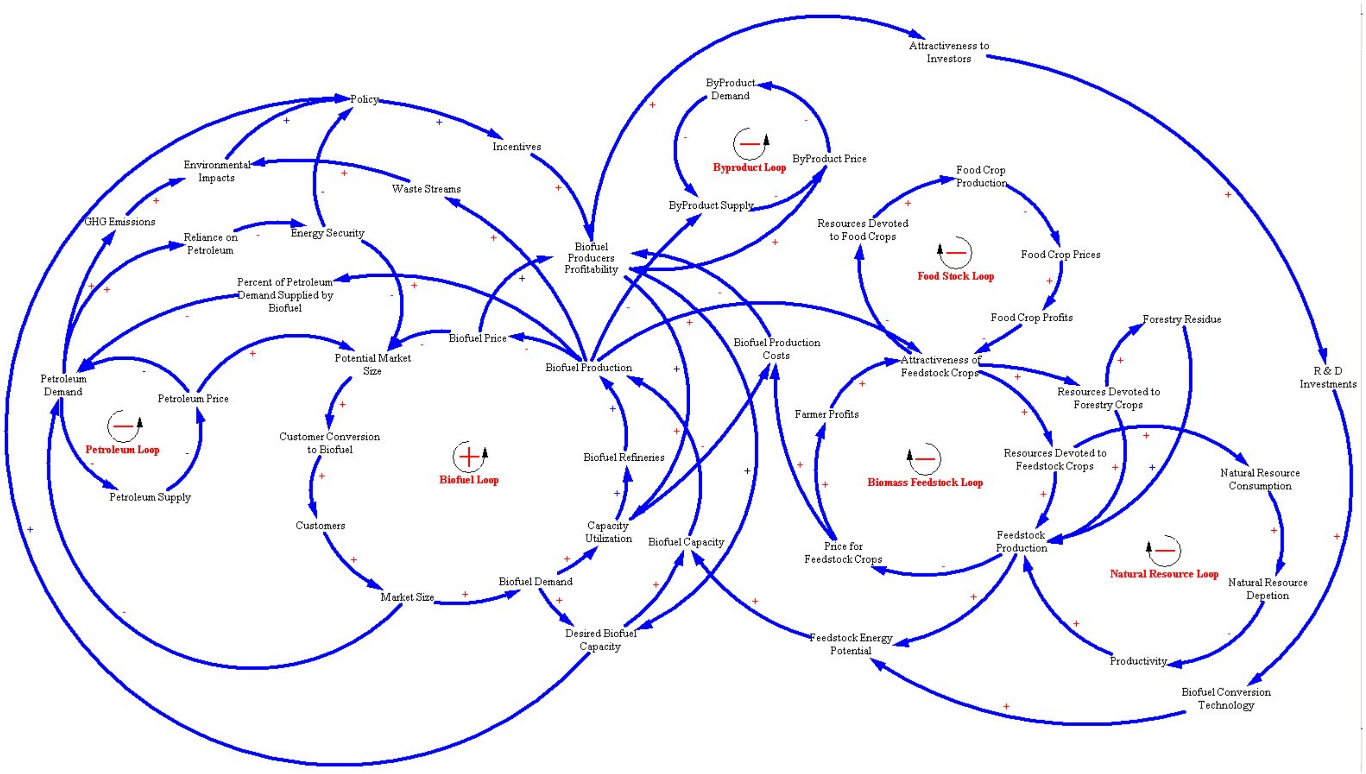

Figure 1. Preliminary Food and Fuel Framework Causal Loop Diagram.

PRELIMINARY DATA/MODEL GAP ANALYSIS

A vast array of models exist that can support the DOE in pursuing its 30x30 goals. As Table 2 shows, over 20 models address various issues associated with biofuel production. Most of the models focus on particular areas or topics. There are some models, however, that attempt to address the entire biofuel system. These models offer the best opportunities to understand the biofuel system. Nevertheless, many of the less ambitious modeling efforts also yield useful data in support of the food versus fuel question.

For example, some econometric models focus on linear relationships between various parameters. These models do a relatively good job as long as relationships are somewhat linear in nature and assumptions don't stray too far from assumed nominal values. Some of the models were developed in Microsoft Excel. These models tend to be data intensive and limited in scope. These types of models can be very helpful in establishing functional relationships between various parameters. Although it is possible to do some time simulations with Excel models it is not the most efficient or effective platform for such analyses.

Other models are written in high-level programming languages. These models can be very powerful but have several drawbacks. First, programming time can be very extensive. The models are not very accessible (a researcher cannot look under the hood very easily). Updating and modifying the models is not a trivial task. Again, there are better tools available for doing dynamic simulations.

Preferred models are those developed with computer-based dynamic simulation modeling software. System Dynamics is a computer-aided approach to evaluating the interrelationships of components and activities within complex systems. The key aspect of System Dynamics is the utilization of feedback principles in the analysis of complex systems. A System Dynamics computer model consists of interacting feedback loops forming the complex structure and mathematical equations and decision rules defining the behavior in a complex system. The NREL Biofuel Scenario Model (BSM) and the Biodiesel Industry Growth Simulator (BIGS) both use Stella which is a system-dynamics modeling software package, for their modeling platform. The INL has been involved is several projects where we have successfully used System Dynamics to address modeling dynamic complex systems.

In reviewing the models available, the BSM was found to have many positive attributes that complement the objectives of this project. This model is a dynamic simulation model that has already undergone a significant level of development as well as stakeholder review and validation. We have reviewed the model and available documentation and identified several areas that would need to be added or enhanced to support the goals of this project. These include:

1) Environmental Component (Climate Change, CO_2, Waste Streams, and Water Resources)
2) Sustainability Indicators (Soil Health, Air Quality, Investments)
3) Stakeholder Concerns (Energy Security, Conservation, Alternative Feedstocks)

Table 2. Summary of identified and potentially relevant Models.

Index	Model Name	Developer	Model Platform	Notes
1	INL Feedstock Model	Idaho National Laboratory	Excel	This model is a detailed cost model analysis based on crop type and various technologies
2	POLYSYS	University of Tennessee	Modular Simulation Model	14 crops 5 livestock @ regional level with national demand/price model
3	Watersim	International Water Management Institute/International Commission of Irrigation and Drainage IWMI/ICID		Global water, food, environment
4	IMPACT-WATER	International Food Policy Research Institute (IFPRI)	GAMS	Global food supply, demand, trade, prices and security, water
5	Cbudget	Evrendilek and Wali	STELLA	C as sustainability indicator
6	FAPRI	Iowa State University		Econometric projections of US agriculture and international markets
7	FAPSIM	US Department of Agriculture	Econometric Model	Econometric model of US agriculture
8	ORIBAS	Oak Ridge National Laboratory	GIS-based Model	Delivered costs of biomass to hypothetical ethanol plants
9	AGMOD	Michigan State University	Micro-TSP	Econometric model of US agriculture with data since 1960
10	EIO-LCA	Carnegie Mellon University		Economy-wide environmental impacts estimated for changes in 491 economic sectors.
11	AMIGA	Hansen, Argonne		Characterizes energy efficiencies, energy markets, demand and policy
12	SAGE	US Department of Energy	GAMS	Varying oil price cases & impacts on energy use and energy supply outside of the United States
13	GREET	Argonne National Laboratory	Excel	Life-cycle of fuels and vehicles
14	MiniCAM	Pacific Northwest National Laboratory		Calculate greenhouse gas emissions, impacts on climate, and costs of mitigation
15	EPPA-ROIL	Massachusetts Institute of Technology		Analyzing interactions between the oil market and the world economy, and for assessing economic effects of the transition from conventional oil to unconventional sources.
16	Wells to Wheels (WtW)	Argonne National Laboratory	Excel	Environmental impacts of vehicle technologies using different fuels
17	IMPLAN	University of Tennessee		IMPLAN contains state level input-output models that provide an accounting of each state's economy
18	USDA Suite	US Department of Agriculture		CENTURY, soil organics; RUSL, soil erosion; etc.
19	IBSAL	Oak Ridge National Laboratory		Delivered costs of biomass to ethanol plants
20	BSM	National Renewable Energy Laboratory, Idaho National Laboratory		Biomass scenario model

SUMMARY AND PATH FORWARD

This report summarizes the results of the “Sustainable Harvest for Food and Fuel” Phase 1 activities to date. Included is a preliminary analysis of the literature, system models, and data sources relevant to questions concerning the sustainability of efforts to meet the DOE 30x30 goal. This analysis suggests that certain sustainability indicators can be identified and modeled to provide insights on whether or not the DOE biofuels initiative is sustainable in terms of both food and fuel. These sustainability indicators, shown in Table 1, are multi-variable composites. For example, the composite indicator “Socio-political concerns” represents how the public is influenced by such issues as economic, energy, national security, the adverse environmental effects of pollution, and so on.

Also, after reviewing existing agronomic, econometric, and biofuel process models and determining what each provides to the food vs. fuel issue, an initial Food and Fuel Framework was developed. The Framework is presented above in the form of a causal loop diagram (CLD), see Figure 1. The causal loops it portrays represent a unique strategy as the CLD begins to integrate information flows between existing models and data sources to provide sustainable harvest indicators. The upper left quadrant of the CLD, for example, shows how environmental impacts and energy security and fuel prices drive sociopolitical concerns that translate through political processes into incentives that in turn drive “Biofuel Producers Profitability” that in turn increases “Attractiveness to Investors.” This Framework illustrates what the literature review highlights: Positive stakeholder engagement is crucial in the success of large-scale infrastructure projects

For the past 30 years, the public’s interest in alternative fuels has waxed and waned proportionately with prices at the gas pump. Financial support for alternative fuels R&D programs has likewise varied. Accordingly, beyond technical concerns, the success of a program at the scale and scope of the biofuels initiative ultimately depends on the ability of the DOE to gain and focus the attention of the public in support of the DOE 30 X 30 goals. Experience to date suggests that nothing will distract the public’s attention faster than rapidly increasing food prices.

In its next steps, the “Sustainable Harvest for Food and Fuel” team will proceed to refine and validate the sustainability indicators and the CLD. Through CAES, the research team will engage with its INL and university partners, NREL counterparts, as well as with selected model authors and data providers identified in Table 1. The Phase 1 goal is to complete and validate the Food and Fuel Framework and to communicate the purpose and utility of the framework to stakeholders.

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APPENDIX A - DEFINITIONS

Biodiesel	A fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751 (NBB, 2007).
Bioenergy	Energy produced from biofuels.
Biofuel	Fuel, such as fuel wood, charcoal, bio-ethanol, biodiesel, biogas, or biohydrogen, produced directly or indirectly from biomass.
Biomass	All living plant matter as well as organic wastes derived from plants, humans, marine life and animals. Trees, grasses, animal dung as well as sewage, garbage, wood construction residues, and other components of municipal solid waste are all examples of biomass (Tester et al., 2005). Material of biological origin (excluding material embedded in geological formations and transformed to fossil), such as agricultural and forestry crops, by-products, waste, manure or microbial biomass (Fresco, 2006).
Biomass Categories	Fuel Crops (switchgrass, sugarcane, etc.), Agro Wastes (waste associated with farming and processing of crops [straw, stover, etc.]), Fuelwoods (firewood, charcoal, forestry residues), and Animal Wastes (manure) (Wei et al., 1997). Water-based biomass is a fifth category although it is currently excluded from this study.
Causal Loop Diagrams	A systems thinking tool that illustrates how variables in a complex system are interrelated. These closed loop illustrations depict cause-and-effect linkages (Pegasus, 2007).
Cellulosic Ethanol	The conversion of plant cellulose to fermentable sugars from which ethanol is produced.
Renewable Energy	Energy flows that is replenished by natural processes (Boyle et al., 2003).
Sustainability	An interdisciplinary planning process that integrates economic development, social well being, and environmental health into planning and decision making.
Sustainability Indicator Criteria	Validity, applicability, availability

Sustainability Indicators	A set of attributes or numeric measures that embody a particular aspect of the system (Duncombe-Wall et al., 1999).
Sustainable	Meeting the needs of the present without compromising the ability of future generations.
Systems Dynamics	A field of study and methodology for constructing simulation models to better understand the structure and relationships in complex system (Pegasus, 2007).
Water-based Biomass	Aquatic plants such as algae, seaweed, or other plants intensively grown in areas of the sea or inland waters (Shepard and Shepard, 2003).