

Noblis Corporate Energy Initiative

Tools for modeling, simulating, and assessing energy supply-chain scenarios can help those who must manage the transition to a more sustainable energy future.

Achieving a secure and sustainable energy future will require traversing a rich set of interconnected technological, economic, political, and regulatory challenges. Production technologies, demand economics, and environmental and climate impacts are all related on a global scale and will continue to change over time. As the sidebar “Energy Security as a System of Systems” on p. 7 of this issue describes, the complexity of energy security might well demand a system-of-systems engineering approach that accounts for the full array of energy choices, in terms of consumption, innovation, economics, and, environmental sustainability. Clearly, managing the transition to a more sustainable energy future will require methods that let decision makers understand both the near- and far-term implications of choosing an alternative.

Goals and first steps

The Noblis Corporate Energy Initiative, launched in January 2007, focuses on developing tools that will inform decisions with supply-chain modeling and simulation, providing a way for policy decision makers to explore a range of alternatives and scenarios.

With the president’s goal of producing 35 billion gallons of biofuels by 2017,¹ decisions must be made about land and feedstock availability, technology maturity, optimal process mix, and infrastructure readiness. These in turn give rise to a complex community of aspects—greenhouse gases, water requirements, soil erosion, food prices, availability, and stable pricing—

all of which calibrate the performance and impact of candidate alternative fuel cycles. Modeling is a first step in exploring these interactions.

Supply-chain focus

In designing the Noblis initiative, our goal was to break down these questions, starting with the decision makers’ initial concerns. We wanted a model flexible enough to accommodate agricultural policies that alter planting patterns or transportation research that changes traffic operations or subsidies that influence new plant placements and schedules or communications enterprises that shift fuel use patterns, and so on—all concerns that should drive simulation. Our mission was to give those who must navigate their organizations through this transition a method for evaluating the obvious and not-so-obvious consequences of available alternatives.

For that reason, we chose to focus the initiative on supply-chain analysis. Our initial thrust has been on modeling scenarios relating to the penetration of biofuels into the national energy supply, particularly in the context of transportation. According to the Energy Information Administration (EIA), the transportation sector consumes 28 percent of all energy used in the United States, and consumption is growing 1.2 percent annually.² In 2006, 96 percent of the sector’s energy came from petroleum sources—68 percent of all petroleum used nationally. Moreover, since 1996, net imports of petroleum have increasingly exceeded domestic production.

Many experts recognize the potential of augmenting the energy supply with liquid fuels from renewable energy resources.

Not only would this move the world toward sustainable energy, but it would also reduce greenhouse gas emissions relative to fossil fuels. However, as reported in other articles in this issue, interested groups quickly generate competing headlines around narrow aspects of these complex issues. Hence, it is easy to become overwhelmed by the streams of responses pro and con quoting government and industry sources. A supply-chain or systems approach offers a comprehensive, more balanced way of viewing these pros and cons.

Modeling the supply-chain dynamics, from resource to end use, lets us see complex interactions among the production stages and evaluate alternatives in concert.

Modeling and simulation

At the heart of the Noblis initiative is the mission of providing a supply-chain analysis tool. To that end and with our initial focus in mind, we built a tool that models the system dynamics in the production supply-chain of three major biofuels—corn ethanol, cellulosic alcohol, and biodiesel. The idea is to simulate the influence of technical and engineering factors as well as the environmental, economic, infrastructure, and resource availability impacts associated with the chosen approach. In essence, the tool lets decision makers explore the implications of the policy, performance, and demand what-ifs associated with a particular alternative. The many interdependent, sometimes time-delayed, relationships among the components and modules give

the tool its dynamic characteristic.

As the sidebar “Modeling System Dynamics” describes, system dynamics lets analysts evaluate a wide variety of technical, economic, and policy changes and impacts that occur under changing conditions and inputs. As such, it is a good fit with the kind of exploration typical of alternatives assessment. In essence, system dynamics models various flows, for example, the flow of petroleum from the ground through refinement and then through various distribution channels. Model complexity is added as various parameters interconnect and provide feedback among the various flows. Supply-chain scenarios are modeled as a set of appropriate flows for each alternative. For example, a supply-chain scenario for biodiesel might include the agricultural feed-stock flow, the diesel production flow, and the flow of carbon emissions into the environment. Noblis chose ISEE Systems’ Stella/iThink modeling package, which provides the system dynamics modeling platform, as well as a graphical user interface, which allows quick modeling and provides an intuitive way to report results.

We created system dynamics models for the three biofuel technologies’ supply chains—from feed stock or resource through processing to distribution and end use. Asking critical questions, we developed the feed-stock and processing technology modules and built supply-chain production components that correspond to four stages: resource and production, infrastructure and environmental impacts; costs; transportation and end use; and impacts from technology improvement. Figure 1 shows a simplified example of the flows comprising one supply-chain scenario for biodiesel production.

Preliminary findings

The models produced for the three biofuels have already helped Noblis collect insights into issues surrounding these alternatives. As the ensuing description makes clear, there is no silver-bullet technology; rather, there is only the best choice for a particular context. With the models, it is possible to obtain quantitative responses to important policy questions and thus make an informed choice that anticipates many of the associated complex interactions.

The sidebar “Questions Worth Exploring” gives a sampling of the kinds of questions that the model might answer.

Corn ethanol

Using corn for ethanol production competes with its use for food and animal feed,

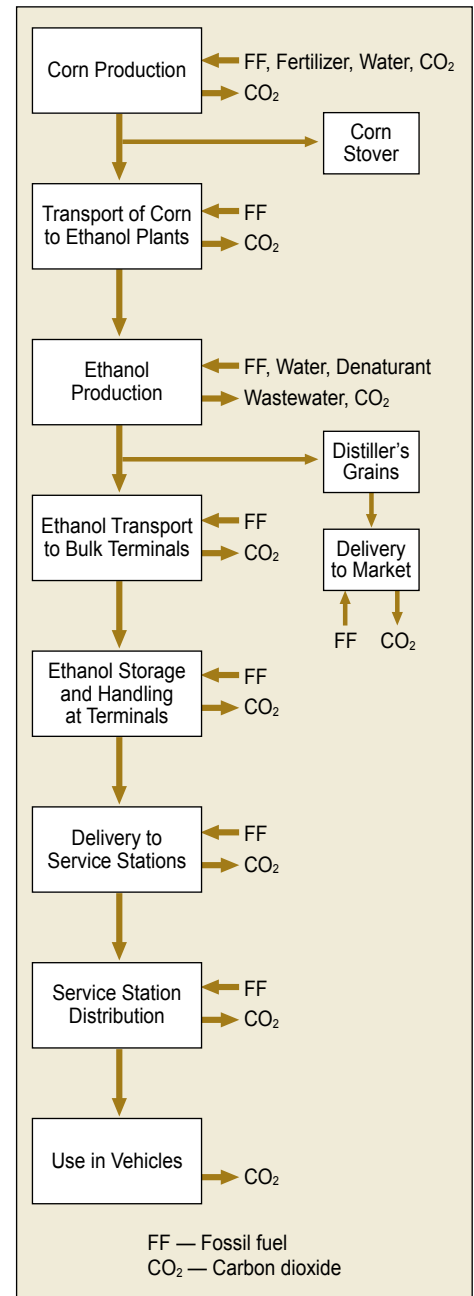


Figure 1. Model for biodiesel production generated using the Stella/iThink system dynamics modeling package. The Noblis tool is based on the modeling of supply-chain flows, which allows policy decision makers to assess the impacts associated with a particular energy alternative.

which could raise grain prices. The technology is mature, already capable of large-scale commercial production, and processing yields distiller's grain, a commercially viable byproduct. The transportation and distribution step is where corn ethanol faces challenges. It cannot be transported through the existing pipeline structure, and large-volume shipping must be by rail. However, corn ethanol is a flammable material and shipping large volumes of such a hazardous material in that manner presents safety hazards. Also, the rail infrastructure would need to be upgraded to serve many plants that are not located on the lines of the major railroads. If volume increases, it is not clear that rail transport would be the most efficient distribution method. In the end-use supply-chain stage, corn ethanol has several disadvantages relative to gasoline. For one, it produces less energy—it takes 1.5 gallons of corn ethanol to yield the energy of one gallon of gasoline. Another disadvantage is that the current vehicle fleet can use an ethanol-gasoline mix of about 10 percent ethanol. A mix with 85 percent ethanol would require replacing the entire fleet. Even with that, the entire U.S. corn production at the current level would replace about 25 percent of the gasoline now consumed.

The last disadvantage is production cost: Corn ethanol needs the current subsidy to compete with gasoline.

Cellulosic alcohol

Cellulosic alcohol's primary advantage is that it comes from a variety of feed stock not used as food and often perennial, such as switch grass, wood (either clear cut or slash removal), corn stover, and other cellulosic biomass. In addition, the entire plant is usable, not just the grain, as in corn ethanol. Thus, theoretically, an acre of biomass or other crops could produce more gallons of ethanol than an acre of corn.

The processing technology is still maturing, with several small-scale plants and only one large-scale demonstration plant producing one million gallons per year. On the upside, existing processes can yield several commercially viable products such as a variety of alcohols, including ethanol and butanol, and convert the lignin, which could be used to generate power. Any power generation would be from renewal sources and could displace fossil-fuel

Questions Worth Exploring

The Noblis model lets analysts explore policy-driven questions in three influential categories:

The president's goal ...

- Can we produce 15 billion gallons per year (gal/yr) of ethanol from corn by 2017?
- Could we produce 30 billion gal/yr of ethanol from multiple sources by 2017?
- How soon could we reach 30 billion gal/yr from corn?
- When could we produce 15 billion gal/yr from cellulosic ethanol?

Externalities associated with using this much corn ...

- How much corn will be available for other uses if we produce 15 billion gal/yr of ethanol from corn ... How much for 30 billion gal/yr?
- How much distillers' dried grains will be produced under these levels of ethanol production?
- What will be the consumptive use of water when producing these levels of corn ethanol?
- What is the net emission of greenhouse gases from these levels of corn ethanol production for use with gasoline? How does this compare with using gasoline alone?

Demand throughout the supply-chain ...

- How might continuing increases in corn yield rate impact the supply chain?
- How many processing plants will we need by when? How might their cost impact bio-fuel price?
- How long would it take to create a market for 30 billion gal/yr of ethanol with current types of vehicles?
- How long would it take to reach 30 billion gal/yr of demand if the vehicle fleet transitioned to vehicles that run on 85 percent ethanol (E85)?

power creating a greenhouse gas credit.

A major disadvantage is that these cellulosic processes require more and larger equipment and are therefore more capital intensive. Relative to corn ethanol, the conversion of the cellulose is more complex, and the resulting products streams are more diluted, requiring more intensive processing. Current technologies have yields of about a third of the theoretical,

so there is sufficient incentive to develop new and better enzymes for the fermentation processing.

The amount of land required for biomass is significant on the basis of current technology's fermentation and biomass-per-acre yields. For example, 15 billion gallons would require about 41 million acres—approximately the size of Ohio. At present, no infrastructure exists that can cultivate, harvest, or distribute switch grass, wood slash from forests or other possible feedstocks. This industry would have to be developed concurrently with the construction of cellulosic ethanol plants.

Distribution and end use have the same disadvantages as those for corn ethanol, except for butanol, which can be transported through existing pipelines rather than by segregated or unit train.

Biodiesel

Although biodiesel fuel comes from many available types of oil seed crops, including soybeans, these crops are also used for food and chemical production. Consequently, soybean prices could increase dramatically, and price swings in feed-stock commodities could destabilize the biodiesel market. Moreover, the energy stored in the fuel is less than the total energy to produce, manufacture, transport, and distribute it.

In processing, the biodiesel alternative seems promising. The technology is mature, since it involves only a relatively simple catalyst reaction of oil feed stock with methanol. The United States already has many small-scale production facilities, and the process yields several commercially viable byproducts, including glycerin and livestock feed. Relative to petrodiesel production, biofuels processing produces 56 to 66 percent fewer greenhouse gas emissions, but biodiesel costs more to produce.

In distribution, biodiesel fuel also has advantages. It can use the current transportation and distribution infrastructure, and does not require storage tank or pipeline cleaning.

In end use, biodiesel has 12 to 15 percent less energy per gallon than petrodiesel, but it is easier to ignite (higher cetane number) and is a better lubricant. Current diesel engines can use a bio-petrodiesel mix of up to 20 percent biodiesel. Modifying the fuel injector design would make it possible to

use 100 percent biodiesel fuel. However, the supply obstacle remains. Using the entire U.S. annual soybean crop at the current production level would replace only 15 percent of the current petrodiesel demand.

Comparing fuels

Table 1, which compares issues and impacts associated with ethanol from corn and cellulose, and biodiesel, is an example of the comparative output the model can provide. The table shows at a glance that corn ethanol, although the most mature technology, has significant transportation and distribution issues as well as only modest results in end-use energy savings and in the reduction of greenhouse gas emissions. Cellulosic alcohol represents potentially the best alternative for alcohol production because it is useful as a variety of feed stock. However, it is not yet ready

for large-scale use. Biodiesel, a relatively mature technology, also comes from a variety of feed stock, and it is compatible with the distribution infrastructure in place. It also has no end-use challenges. Unfortunately, the feed stock that yields biodiesel fuel also serves as food and raw material for chemical products.

Reaching established goals





The baseline model reflects President Bush’s goal in the *2007 State of the Union Address*, which is to make 35 billion gallons per year of biofuels by 2017. Allocated production targets are 15 billion gallons of corn ethanol, five billion gallons of biodiesel, and 15 billion gallons of cellulosic alcohol.

Our preliminary modeling focused on corn ethanol and biodiesel technologies,

since cellulosic technology has a less mature process and production chain. Meeting the corn ethanol production target is feasible as long as the production capacity becomes available. The goal is reachable within the current U.S. land and agricultural resources, but a critical factor will be the availability and adaptability of the distribution infrastructure. The downside will be the competition with soybeans and other crops for land resources, and the diversion of corn from export and animal feed will significantly impact food prices. Finally, corn ethanol will need subsidies to compete with gasoline and other biofuel technologies.

Meeting the biodiesel goal does not seem as optimistic. Even if the entire annual U.S. soybean production projected for 2017 was converted, it would not be enough to meet the five billion gallon goal. In fact,

Table 1. Issues and questions in a comparative assessment of three biofuels. The Noblis model has four main supply-chain steps. Preliminary runs indicate the range of questions and issues that will be critical to decisions surrounding each type of biofuel in each step.

Supply Chain Element	Ethanol		Biodiesel
	Corn	Cellulose	
Feed Stock (Resource) 	Crop planting practices Crop lands competition Effects on food, animal feed, and export quantity Effects on food and animal feed prices Effects on global commodities market Environmental effects	Creation of switchgrass farming industry Creation of wood slash harvesting industry Harvesting and infrastructure development Availability of sufficient acreage Crop lands competition Environmental effects	Alternatives to soybean feed stock development Crop planting practices Crop lands competition Effects on food, animal feed, and export quantity Effects on food prices Effect on global commodities market
Processing 	Effects on water resources Effects on market for distiller’s grain byproducts	Effects on water demand Energy conversion efficiency Displacement of fossil fuels in electric power generation Credit for carbon dioxide sequestration Energy-intensive product purification Overall yield Capital investment requirements Engineering and construction limitations	Effects on glycerin byproduct market Effects on soybean mash byproduct market Location of production facilities—feed stock- or end-user oriented
Transportation/Distribution 	Shipping infrastructure requirements Receiving infrastructure requirements End-use infrastructure requirements Rail shipping concerns (similar to gasoline)	Shipping infrastructure requirements Receiving infrastructure requirements End-use infrastructure requirements	No issues —biodiesel can use existing petrodiesel infrastructure
Use/Overall Impacts 	Energy density relative to gasoline Vehicle design requirements Vehicle fleet effects Greenhouse gas emissions vs. alternatives Effects on water resources Subsidies and costs vs. alternatives	Energy density relative to gasoline Vehicle design requirements Vehicle fleet effects Greenhouse gas emissions vs. alternatives Effects on water resources Subsidies and costs vs. alternatives	Energy density relative to petrodiesel Vehicle design requirements for 100 percent biodiesel use Vehicle fleet effects Greenhouse gas emissions vs. alternatives Effects on water resources Subsidies and costs vs. alternatives

Modeling System Dynamics

System dynamics, created in the early 1960s by Jay Forrester then of the Massachusetts Institute of Technology, is a formal approach to modeling complex systems that describes, models, and simulates the causal structure of systems. As its name implies, system dynamics focuses on the dynamic behavior of systems—how system variables interact and consequently change their values over time. From its beginnings, system dynamics used computer simulations to test, refine, and more fully understand the implications of the system descriptions it produced.

Over the past four decades, system dynamics has been used to model an extremely wide range of systems and problems. In May 2001, however, Forrester expressed an interesting view:

The most important use of system dynamics should be for the design of policies, that is, the rules that should govern decisions. ... A system dynamics model should first show how past policies created the current difficulties. Then, one experiments in the model with alternative policies in search of a better-behaved system.—Ventana Systems Forum; <http://www.ventanasystems.co.uk/forum/viewthread.php?fid=28&tid=1667&action=printable>.

Thus, system dynamics is appropriately used to identify policies that have caused major system problems and to experiment with variations in an

attempt to arrive at alternative policies that could yield significant improvements. Sensitivity analyses using system dynamics models are particularly helpful in comparing policies and their impacts over time. In sensitivity analyses, analysts compare how key results vary with incremental changes in input parameters.

Noblis uses Stella/iThink software to construct system dynamics models. The software has a graphical user interface with four building blocks:

- **Stocks** are state variables whose values change over time.
- **Flows** change the amount (values) of stocks.
- **Converters** are used for constants and computed values.
- **Connectors** are directed arrows into flows or converters indicating which variables are used in the simulation equations.

Figure A portrays a small subset of the system dynamics model developed for the Noblis energy initiative. From a mathematical perspective, the model is built as a set of difference equations that the system dynamics tools efficiently solve through a numerical analysis engine. From a user perspective, the model is built through the graphical user interface and then solved for each time increment by the Stella/iThink software.

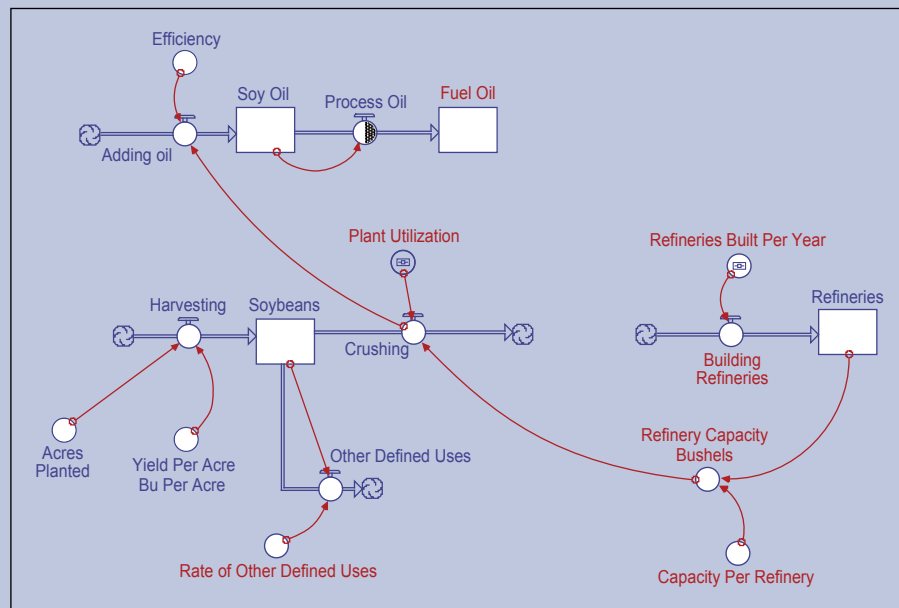


Figure A. Subset of the system dynamics model for soybean production representing three flows (red): growing and producing soybeans, refining fuel oil from processed soybeans, and building refineries. These flows are interconnected—for example, the flow of building refineries controls the amount of refined product that can flow—which means that analysts are more likely to discover subtle interrelationships among the flows.

for the last two years, the U.S. soybean acreage has declined, most likely because of the shift to corn for ethanol production. As described earlier, assuming appropriate growth and process plant use, the entire annual soybean crop would replace only 15 percent of the petroleum demand.

A larger issue ripe for future research is how to use the 30 billion gallons of ethanol that would be produced. The current gasoline use in the United States is approximately 150 billion gallons per year. With the limit of 10 percent ethanol in gasoline, only 15 billion gallons of ethanol would be required. Ethanol is an oxygenate that is not required in all gasoline supplies around the United States today. The 15 billion remaining gallons of ethanol would have to be consumed in further development of E85 as an alternative fuel in “flex-fuel” vehicles, or greater quantities of ethanol must be blended into the gasoline.

The Noblis Corporate Energy Initiative has started with detailed supply-chain mappings of three major biofuel technologies. By integrating the supply-chain models, it will be possible to explore dynamic scenarios involving the *combined* production of biodiesel, corn ethanol, and cellulosic alcohol. Many, many private and public model representations of these and numerous other fuel production supply-chains exist. In fact, Noblis has developed its own specialized modeling capability for coal-based gas and liquid fuel processes, and has plans to combine these capabilities with the tools from this initiative to explore the production of liquids from coal and biomass. The focus with this effort is to learn how to bridge from the critical high-level questions haunting decision makers to a measure of the practical impacts on feedstock, transportation, production, and end use. ❖

References

1. *2007 State of the Union Address*; <http://www.whitehouse.gov/news/releases/2007/01/20070123-2.html>.
2. *Annual Energy Review 2006*, Energy Information Administration, U.S. Department of Energy, 2007; <http://www.eia.doe.gov/aer/>.

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