Regional Optimization of Biofuel Supply Chains

In this project, we will deliver advanced decision tools and systems analysis to inform the investment, policy making, and market transformation critical to achieving the nation's biofuel targets. The evolution, economic feasibility, and environmental sustainability of biofuel supply chains will be highly dependent on geographic region. The planned optimization studies will provide regionally-based insight into transition pathways and consequent energy, economic, environmental, and social impacts of biomass production and conversion. Armed with this insight, we can identify viable strategies for expanding biofuel production to benefit regional economies while minimizing negative impacts on the environment including land, water, and energy use. Our studies will provide a deeper understanding of the risks, uncertainties, potential disruptive consequences, and value capture within regional biofuel supply chains.

Project Scope:

We are developing comprehensive modeling frameworks for regional biomass-to-biofuel supply chains that integrate decision-making across multiple temporal and spatial scales. The models encompass the complex interactions between various biomass sources, supply and demand, diverse conversion technologies, energy yield, carbon implication, geographical diversity, social impact, market adoption, economics, and policy. We are pursuing two parallel approaches:

1) Simulation-based multi-agent framework incorporating models of disaggregated decision making, conversion technologies and processes, logistics, behavioral economics, public policy, and life cycle cost, environmental, and social impacts.

2) Computational modeling and optimization framework based on multi-scale and multi-objective mathematical programming techniques and systems analysis methods such as process design and synthesis, superstructure optimization, logistics planning, environmental management, and geographic information systems (Figure 1).

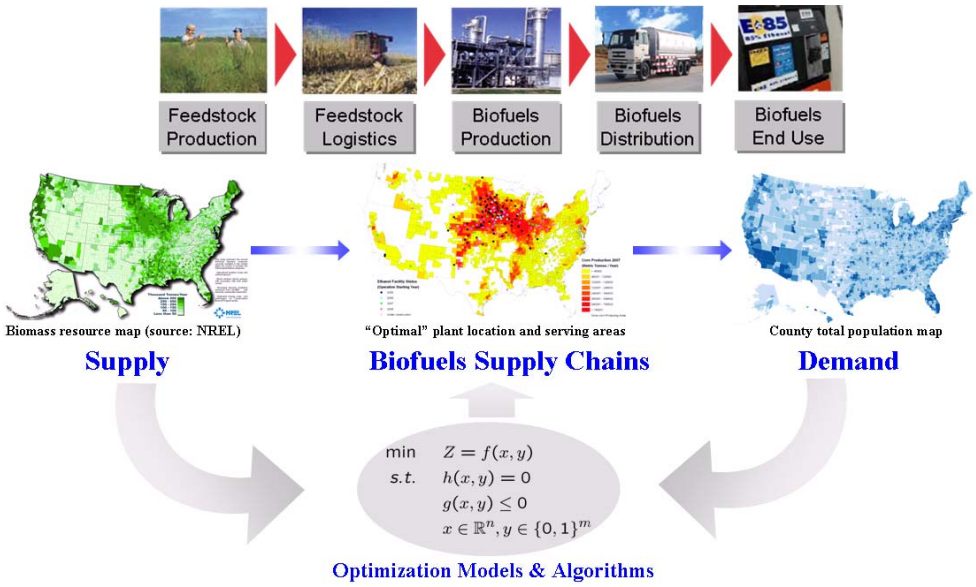

Fig. 1 Integrate computational modeling and optimization with geographic information system for systems analysis and integrated management of biofuel supply chains

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1) Multi-scale modeling and optimization: The comprehensive modeling of the entire biofuel supply chain needs to integrate the design, planning, scheduling, and inventory control decisions using mathematical models with integer variables and nonlinear terms. The multi-scale and multi-site nature of this problem requires effective temporal and spatial integration across geographically distributed facilities and over time horizons spanning from days to years. An important challenge that has not been addressed is to integrate the detailed production process model of biorefineries into the supply chain model. We pioneer the simultaneous optimal design of the biofuel supply chain and the corresponding biorefineries processes, and coordinate the complex conversion pathways and technology selection problems of biorefineries (Figure 2) with the multi-scale temporal and spatial decisions of biofuel supply chains.

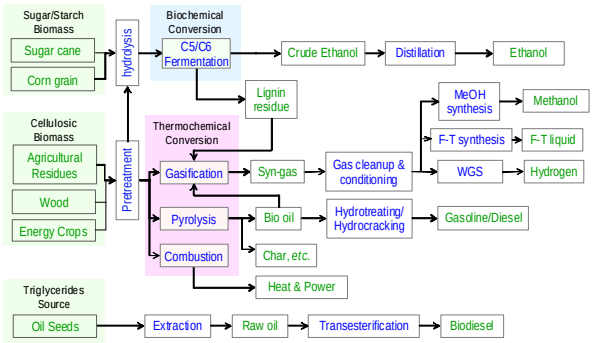

Fig. 2 Pathways in biorefineries.

2) Multi-objective optimization: In order to integrate sustainability management into the planning and management of biofuel supply chains, we develop an optimization framework that includes multiple objectives to simultaneously account for economic, environmental, and social performances. We pursue a state-of-the-art multi-objective optimization scheme to systematically assess and improve the supply chains' overall performance. Specifically, we develop systems models that consider various impacts, and incorporate them into the design and operation of biofuel supply chains to evaluate the design alternatives and operation activities from economic, environmental, and social perspectives. In addition, combining optimization techniques with life cycle assessments (LCA) principles enables the automatic assessment and generation of alternative decisions with significant economic, environmental and social benefits (Figure 3).

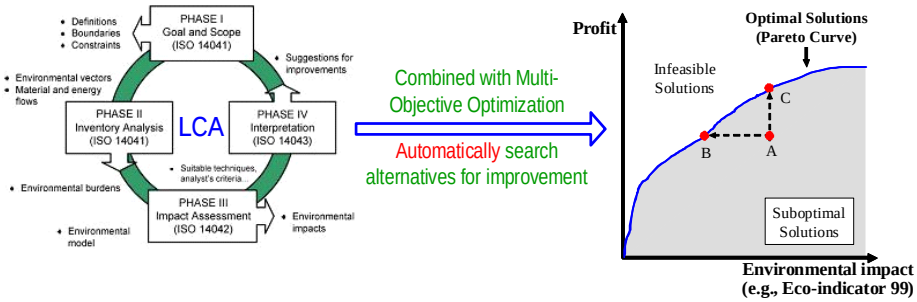

Fig. 3 Integrate LCA with multi-objective optimization

3) Risk analysis and uncertainty quantification: Uncertainties in the design and operations of biofuel supply chains arise from various sources, such as climate change, fuel price, demand fluctuation, and policy. The quantitative understanding of uncertainty is essential when predictions are to be used in decision-making. We will pursue novel optimization paradigms to address the decision-making under uncertainty. Both stochastic programming and chance constraint approach are employed. To explicitly consider the risks included in the system, we quantitatively assess and manage the risks via a multi-objective optimization scheme to simultaneously minimize the risks and maximize the supply chain performances.

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