Research in my group is on systems engineering and process control; it brings together modeling, mathematical analysis, control theory, optimization and computation, in order to understand the structure and improve the operation of chemical, biological and energy systems.

Dynamics and control of complex process networks
Sustainable designs of process plants rely on tight integration through material and energy recycle. Process integration can lead to significant reduction in capital and operating costs, but also to intricate network-level dynamics due to the feedback interactions induced by recycles. We are pursuing the development of hierarchical and distributed control approaches to controlling such dynamics. One line of research focuses on networks with large rates of material and/or energy recovery and recycle, compared to input/output flows. We have shown that such networks exhibit dynamics over multiple time scales, and have proposed the use of singular perturbations for deriving reduced order models in each time scale. This multi-time-scale analysis lends itself naturally to a hierarchical control framework, whereby network-level control objectives can be effectively addressed at a slow, supervisory level. Another line of research addresses generic networks with no material or energy flow segregation. Distributed control, in which coordinated controllers tackle operational objectives of different sections of the plant, is a natural approach for such systems. A key underlying problem is the optimal decomposition of the integrated system into the distributed control architecture. A new approach to this problem inspired from network science is currently pursued. It relies on identifying “communities” of system variables whose members interact strongly among them, yet are weakly coupled to the rest of the network members. A modularity measure defined on suitable graphs is used to quantify strength of interactions;
maximization of modularity leads to optimal decompositions. Such decompositions have been shown to lead to significant reduction in the computational cost of distributed optimization-based control while retaining satisfactory performance compared to centralized control.

Distributed, sustainable production of power, fuels and chemicals
Our group has recently pioneered the development and application of systems engineering tools for designing and operating sustainable fuel, chemical and power production systems.

We have developed RING, an automated tool (available as open source) for elucidating the complex chemistry involved in biomass conversion. RING relies on cheminformatics and graph theoretic algorithms, for reaction network generation in a wide variety of chemistries. It has been expanded to allow on-the-fly thermochemistry calculations and kinetic modeling, and is already used by several experimental groups working on biomass conversion. Building on RING, we have developed a multi-scale systems engineering framework for biomass conversion processes, which encompasses chemistry elucidation, simultaneous product design and chemistry selection, process design, and supply chain optimization to determine optimal facility locations, technologies and capacities.

On a different front, microgrids are autonomous power systems, which use distributed generation and storage units and allow for high penetration of renewable power. We are developing (i) a comprehensive framework for the optimal design of such systems taking into account location, load and public policy incentives; and (ii) scheduling and supervisory control algorithms based on deterministic or stochastic weather and load forecasts. This research has brought forth powerful analogies between operations in process systems and power systems, along with exciting opportunities for process systems engineering research in this new application domain.

Other recent research in our group has advanced the application of systems engineering and control to other key energy and sustainability problems, e.g. the optimal operation of outdoor microalgae cultivation facilities, the pre-combustion CO2 capture in IGCC power plants via membrane reactors, the design and operation of synergistic systems for producing power and chemicals, and the nonlinear control of co-fired power plants for wide ranging operation.

Other efforts in my group revolve around the application of systems approaches to the analysis and simulation of complex biological networks that determine cell metabolism and gene regulation; the modeling, analysis and control of energy production systems; and the control of advanced materials processing operations.

Selected Publications


