Energy efficiency and sustainability are major factors towards mitigating the depletion of fossil fuel reserves and the environmental impact of their consumption. Tight integration is a key enabler towards achieving these goals, both in existing chemical plants, but also in emerging technologies for power generation and for production of fuels and chemicals from renewable resources. The first part of the talk will focus on the dynamics and control of tightly integrated process networks. The efficient transient operation of such networks is essential, as the current economic environment dictates frequent changes in operating states and a tight coordination between the optimization and supervisory control levels. Recent results will be discussed which establish that tight integration, achieved through large material and/or energy recycle, leads to multi-time-scale dynamics, with individual units evolving in a fast time scale with weak connections, which become significant over slower time scales giving rise to a slow evolution of the entire process network. A model reduction framework will be described which enables obtaining a hierarchy of low-order nonlinear models valid in the different time scales. The analysis lends itself naturally to a hierarchical control framework which allows for the development of robust nonlinear supervisory control strategies for effective network transitions. The efficacy of the proposed hierarchical controller design framework will be illustrated through case studies on reaction-separation networks, reactor – heat exchanger networks, heat integrated and thermally coupled distillation columns, and hybrid power production systems based on high-temperature fuel cells.

The second part of the talk will focus on the emerging concept of biorefinery, which aims at the production of fuels and chemicals from renewable resources (biomass). Although considerable emphasis has been given so far to the “upstream” conversion of biomass to intermediate platforms (sugars or syngas), progress in “downstream” conversion to chemicals and intermediates is still lagging. Due to the oxygen present in biomass and the diversity of raw materials derived from biomass, the necessary downstream reaction and separation processes are different from existing ones based on fossil fuels. Furthermore, there is limited data available on physical properties of such molecules, and on their full array of chemical transformations, and their kinetics and thermodynamics. These challenges lead to several emerging opportunities for systems research that can have a major impact on the realization of the ambitious concept of an integrated biorefinery. The talk will highlight such opportunities and will discuss recent results on: i) the elucidation of the chemical transformations involved in biomass conversion, and ii) the design and optimization of novel reaction-separation processes for biomass-based chemical synthesis.