This work is motivated by the need for tighter integration of industrial processes in an attempt to improve process sustainability. To this end, this work considers an interesting case study around which different systematic approaches are used or developed to achieve the above goal. The thesis is concerned with the understanding of an integrated bioreactor and electrically driven membrane separation processes for lactic acid fermentation. This is achieved through a model based investigation of the individual units and the integrated system. Development of system understanding is the key to reveal how the system should be designed and operated in accordance with different production goals. The selected case includes a fermenter and a two stage membrane separation. In the first membrane stage the lactate is exchanged by hydroxide by means of anion exchange membranes, in a process referred to as Reverse Electro-Enhanced Dialysis (REED). Unconsumed substrate and biomass are effectively recycled to the fermenter. In the second membrane separation stage, the lactate is recovered and concentrated as lactic acid using Electrodialysis with bipolar membranes (EDBM), while sodium hydroxide is regenerated and recirculated. The novelty of the process relies in the specialized design and operation of the Reverse Electro-Enhanced Dialysis module. The REED design allows removal of the lactate from the fermentation broth and simultaneously facilitates pH control in the fermenter using hydroxide. Additionally, the periodic operation of the REED mitigates the adverse influence of the formation of a fouling layer at the membrane surface. A first principles dynamic model is derived for the REED module to describe the transport of multiple ions through ion exchange membranes and adjacent boundary layers in a dialytic module. The unknown model parameters are regressed from experimental data for Donnan Dialysis recovery of different monoprotic carboxylic acids. Static simulation results agree with previously qualitative predictions of concentration profiles during Donnan Dialysis separation. Further static simulations under current load conditions are used to evaluate the influence of imposing an external electrical potential gradient on the ion fluxes and concentration profiles. Results demonstrate the development of asymmetric concentration profiles, the potential ion fluxes enhancement and the limiting current density constraint. Through dynamic simulations, the system behavior is investigated under current reversal conditions. Several phenomena are predicted such as preferable ion transport at the interfaces, transient flux inversion and accumulation/depletion of ions within the membranes. The combination of those phenomena can explain the loss of current efficiency, which has been experimentally demonstrated. Diverse numerical issues are encountered during the different type of simulations, and solutions are proposed. A bioreactor model with unstructured kinetics is proposed which is suitable for integration with the Reverse Electro-Enhanced Dialysis process. An identifiable set of parameters are estimated from experimental data. The identifiability analysis is supported by mathematical and statistical tools. In order to investigate the operability of the REED module, a methodology for control structure design is extended to handle periodically operated systems. As case study, the pH regulation of the outlet stream of the membrane unit is addressed. Based upon the goal driven analysis, a non conventional input resetting control structure is designed. The control performance is evaluated through a set point tracking test. Satisfactory results are obtained regulating the pH and managing the input constraints. The design and operability of the integrated bioreactor and REED module are investigated using the developed models and control structure. The study involves two different case studies: continuous lactic acid production and batch production of a starter culture. Substantial improvements are predicted in productivity and substrate utilization, while design and operability limitations are discussed. The investigated integrated system is a clear example where a model based approach, supported by experimental evidence, can bring improvements in the system understanding, and therefore promote the development of goal driven process design and the process control discipline.