Anaerobic biotechnology is viewed as a sustainable alternative to aerobic biotechnology for municipal wastewater treatment. However, past examples of anaerobic treatment in temperate climates have either not been able to meet strict low organic effluent concentrations or have experienced process failure due to biomass washout resulting from operating at low temperature and short hydraulic residence time. Recently, the anaerobic membrane bioreactor (AnMBR) has been shown to achieve low organic concentrations in effluent and maintain a stable anaerobic biomass. However, shortcomings have included high energy demands for membrane operation and poor understanding of microbial community structures present within AnMBRs.

This dissertation describes efforts to improve AnMBRs by developing a low energy membrane operation strategy and explores the microbial relationships responsible for organic removal. Two AnMBR configurations were operated at 10 and 25°C, and achieved over 94% organic removal with average permeate five-day biochemical oxygen demand (BOD$_5$) concentrations remaining at 10 mg/L or less while treating either synthetic or real primary effluent municipal wastewater. The AnMBRs used tubular membranes that were operated at crossflow velocities (CFV) ranging from 0.018 to 0.3 m/s, which is far below the typical CFV range of 2 to 5 m/s. Use of fluidized granular activated carbon (GAC) within tubular membranes at very low CFV extended membrane run time between cleanings by 55 to 120% and resulted in energy demands of 0.05 to 0.13 kWh/m$^3$, representing a 98% energy savings compared to historical energy requirements.

Illumina sequencing and statistical techniques were used to characterize the microbial consortia within each AnMBR. Results indicated a large portion of the microbial communities were composed of only 5 out of over 700 uniquely identified operational taxonomic units. Additionally, unique microbial community structures were observed in each bioreactor during synthetic wastewater operation, ostensibly due to selective pressures including bioreactor/biofilm configuration and temperature. A significant shift in all AnMBR microbial populations was observed when switching from synthetic to real wastewater, suggesting continual bioreactor seeding with the influent wastewater microbial consortia impacted bioreactor community structure. Sequencing and results of activity assays indicated that hydrogenotrophic methanogenesis emerged as the dominant pathway in each AnMBR.