Marine eukaryotic phytoplankton produce organic matter that is depleted in $^{13}$C relative to ambient dissolved carbon dioxide. This photosynthetic carbon isotope fractionation ($\varepsilon_P$) is recorded in marine sediments and used to resolve changes in the global carbon cycle, including variations in atmospheric CO$_2$ levels. These applications rely on a coherent understanding of the environmental and physiological controls on $\varepsilon_P$. I performed CO$_2$ and growth rate ($\mu$) manipulation experiments with modern phytoplankton in chemostat cultures to address outstanding questions regarding the mechanistic underpinning of $\varepsilon_P$, and to evaluate the potential for new paleobarometry ($p$CO$_2$) proxies derived from algal biomass. In this talk, I will discuss experiments characterizing the stable carbon isotope ratios of coccolith-associated polysaccharides (CAPs) and other cellular constituents (bulk biomass, coccolith calcite, and alkenones) of *Emiliania huxleyi*. CAPs are involved in regulating calcification and have been recovered from sediments dating back ~180 Ma. It has been proposed that the carbon isotopic contents of CAPs may be used in combination with other proxies to reconstruct ancient atmospheric $p$CO$_2$ levels. I will also discuss chemostat culture experiments with the dinoflagellate *Alexandrium tamarense*, which uses an unusual form of the carbon-fixing enzyme RubisCO (Form II). Based on the surprising outcome of this study and other support from the literature, I will propose a revised framework for interpreting $\varepsilon_P$. The results of this work imply that the kinetics, intrinsic discrimination, and taxonomy of RubisCO may be largely irrelevant to the expression of $\varepsilon_P$ under growth conditions of low nutrients and high photosynthetic activity, *e.g.*, in the ocean gyres or away from coastal upwelling zones.