Engineering biological modules

This group of projects is centered around cyanobacteria, photosynthetic organisms formerly known as “blue-green algae.”

We seek to understand the fundamentals of how energy capture and conversion work in this single-cell organism and apply that knowledge to engineer improvements in productivity.

Our approach embodies an iterative process of *learn, design, build, test, and learn*, applying the principles of engineering to biology.

The challenge: applying an engineering perspective to photosynthesis

We are addressing key questions in photosynthetic energy capture and storage from a **unique perspective, using concepts borrowed from engineering, particularly modularity**.

Modules are semi-autonomous functional units that work together in the context of larger systems. Some of the hallmark features of modularity include division of labor and the requirement for communication among modules in order for synergistic, complex functions to emerge.

Modules can be found across the scale of biological organization, including genes and operons, protein domains, metabolic pathways, organelles, and specialized cells.

Photosynthesis in cyanobacteria can be seen as an integration of functional modules. For example, the two major processes of photosynthesis are the so-called light-dependent reactions – which capture 'raw' sunlight energy – and the Calvin Cycle – which captures carbon dioxide from the atmosphere to convert the captured light into usable forms of energy.

From a modularity perspective, the light harvesting complexes and the Calvin Cycle can be studied as separate yet interrelated modules.

Our approach: understanding how biological modules function as the foundation for designing new ones

By virtue of their potential for “plug and play” into new contexts, modules can be viewed as units of both evolution and engineering. Our overall aim is to gain a fundamental mechanistic understanding of the structure and function of photosynthetic modules involved in both light harvesting and CO2 fixation.

Our project focuses on structure/function studies that will ultimately allow us to repurpose natural building blocks, such as protein domains and compartments, into designed modules for the building of new biological parts and devices to improve photosynthetic productivity in cyanobacteria and plants.

We are emphasizing **research on the features and interconnectivity of two modules in cyanobacteria**:

* Light harvesting and the **carboxysome**: Carboxysomes are specialized compartments for carbon fixation in cyanobacteria. Despite considerable progress in understanding the structure, function and assembly of carboxysomes, their regulatory connections with other photosynthetic modules, including light reactions, are poorly understood.
* The light-responsive protein, the **Orange Carotenoid Protein (OCP)**: The OCP is a modular protein that controls photosynthetic efficiency by attaching to the light harvesting antenna. The OCP senses and responds to changes in light quality and intensity in order to protect the cell from damage.

The research subprojects, below, aim to fundamentally understand the structure and function of these two modules, reveal how they communicate, and then use the knowledge to engineer and recombine modules to improve photosynthesis, create new renewable energy sources, or devise new compounds for medical or industrial uses.

We currently study these modules from three angles:

1. We want to understand the relationship between light perception and carbon fixation within cyanobacteria, focusing on the carboxysome (*Ducat, Kerfeld, Montgomery, and Sharkey labs*).
2. This project builds on the first by using that knowledge to design and construct new types of compartments and scaffolds for metabolic engineering (*Ducat and Kerfeld labs*).
3. We want to draw on our understanding of the OCP to repurpose it as a light-responsive protein that can be used to connect or activate engineered modules for specific applications (*Kerfeld and Montgomery labs*).