UNLOCKING THE SECRETS OF PLANT SKELETONS

In humans and other mammals, it is our bones that give form to our bodies and enable our muscles to exert force. Insects have a hard exoskeleton for the same reason. But plants—from flowers to trees—are different. Their structure comes from bundles of cellulose biomolecules that form microfibers, which combined with other materials including lignin make up the walls of plant cells. These walls are so strong that they essentially act as a skeleton. Indeed, cellulose-rich cell walls enable a slender stalk of corn to grow 6 or 8 feet tall and a giant Sequoia to tower more than 300 feet, dwarfing any other life form. Cellulose is the most abundant (and arguably the most important) long-chain biomolecule on earth.

About the image: Giant trees of Sequoia National Park *(mkldesigns / Shutterstock)*

A successful thick crop of sweet corn stands in a tall, straight, dense row and will soon be harvested for market.
(Eric Buermeye / Shutterstock)

Until recently, however, cellulose—both its structure and how plants make it—was a mystery. That's why the U.S. Department of Energy's Office of Science funded an Energy Frontier Research Center (EFRC) to explore the topic and its implications for advanced plant-based materials and biofuels. The Center for Lignocellulose Structure and Formation included a dozen principal investigators spread across a number of universities, including physicists and engineers as well as plant biologists.

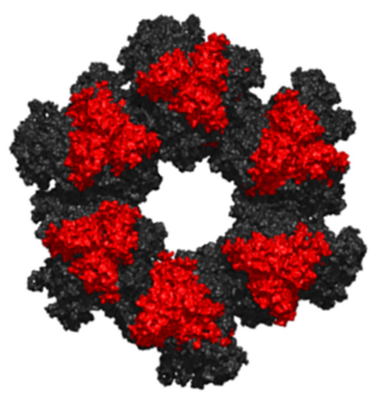
The cross-disciplinary research effort pursued several related problems. Plants take carbon dioxide from the air and transform it into sugar, but how do they convert sugar into a long-chain molecule called a polymer? A computer model of plant enzymes involved in cellulose synthesis showed a strong similarity with the structure of a previously identified cellulose-forming protein in a bacterium. Further laboratory and computational testing led to insights into both the structure of cellulose-forming enzymes and how they catalyze microfiber-formation in living plants.

A second mystery was the actual structure of cellulose in plant walls. Plant biologists knew that the fibers they could see under a microscope were made of many individual polymer strands, but the individual strands were too small (less than a nanometer in width) to count accurately. A full-scale effort with different forms of imaging, computational analysis, and biochemical experiments finally established that each cellulose microfiber has 18 polymer chains, tightly bonded to each other to give added rigidity, enabling a crystalline-like character and behavior. The research also provided insights into how the fibers grow within a plant, including understanding the behavior of a group of enzymes that act as a microfiber-spinning machine, directing the clustering of the 18 polymer chains (see image).

With the secrets of plant skeletons in hand, the scientists then tried to replicate the process in the laboratory. In a remarkable breakthrough, they were able to synthesize cellulose polymer chains and see microfiber formation in a test tube. This research opens the door to engineering modified fibers—either in plants or as an industrial process—for specific applications. For example, it now seems possible to grow plants with thicker cell walls, creating a richer source of fiber for biofuels. It may also be possible to make cellulose that is easier to degrade and digest for biofuels or animal feed, or to develop novel nano-cellulosic materials with new physical properties.

Research is also continuing into lignocellulose, the plant cell wall material that makes wood so strong. New types of cell walls in wood and other plant fiber cells may one day support innovations in structural materials and renewable resources for the pulp, paper, and textile industries.

Mankind has bred plants to improve food supplies for millennia. Only now, however—thanks in part to the EFRC program—have we understood critical parts of their biology sufficiently to imagine using plants in dramatically new ways.



This rosette-like formation of plant proteins—grouped as six units, each with three enzymes—is what catalyzes the formation of 18 cellulose polymer strands that together create the microfibers that give plant cell walls the strength to serve as the skeleton for every plant. Understanding how this fiber-spinning mechanism works within plants is not only an important advance in basic science, but also opens the door to an array of practical applications. *(Under the Creative Commons License, this image is an excerpt of Figure 5 in www.nature.com/articles/srep28696.)*

Center for Lignocellulose Structure and Formation (CLSF)
Winner — Scientific Ideas Award
www.science.osti.gov/bes/efrc/Centers/CLSF