BY **MIKE WOOD**

Green as grass

LAST ISSUE I WROTE ABOUT THE COLOR BLUE. Just blue. Nothing else. I hadn't intended to continue that theme, but a recent paper in the journal *Science* took my eye just as the *Protocol* deadline loomed near. So, this issue you are getting green. Just green. Nothing else. Well, actually that isn't true, what you will be getting is the absence of green, in particular why plants absorb every other color and reflect green.

The answer you know already is, of course, that plants look green because chlorophyll, the chemical pigment that helps plants convert sunlight to usable energy, appears green because it absorbs red and blue light energy. But doesn't that seem backward? If you were asked to design a system to capture energy from sunlight, wouldn't your first choice for the wavelength to use be the most abundant

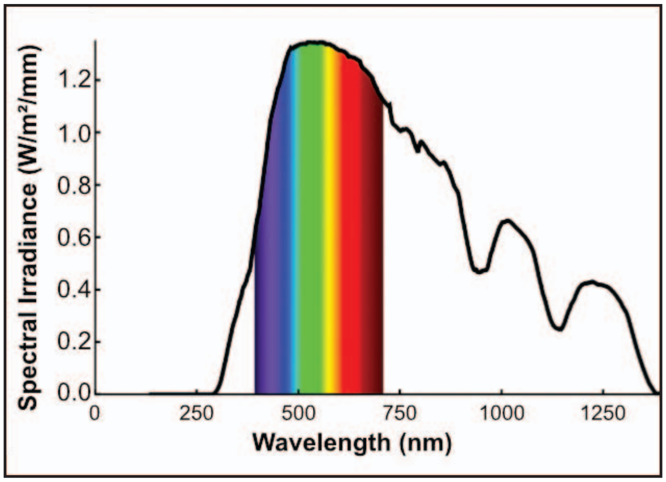

Figure 1 – Sunlight Irradiance

wavelength right in the middle of the range? **Figure 1** shows a portion of the solar irradiance spectrum on the earth's surface and the energy peaks right in the middle of the green.

> **"If you were asked to design a system to capture energy from sunlight, wouldn't your first choice for the wavelength to use be the most abundant wavelength right in the middle of the range?"**

If the pigments in the photosynthesis mechanism absorbed green, which is what you might expect to maximize efficacy, then they would reflect red and blue and appear magenta. So why have billions of years of evolution produced a system that does the exact opposite? It seems counter intuitive. **Figure 2** shows the absorption spectra for chlorophyll a and chlorophyll b, both have two peaks, one in the red and one in the blue, and both reflect just about all light between 500 and 600 nm which is cyan to amber, centered on green.

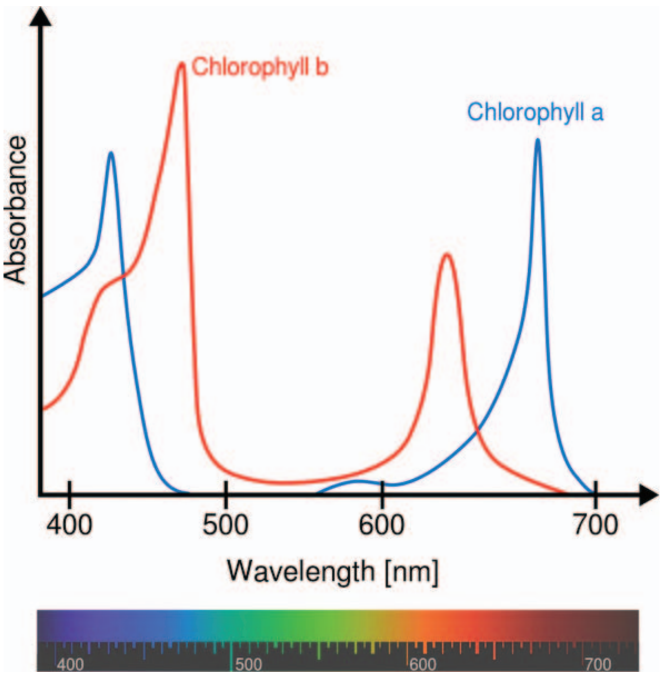

Figure 2 – Absorption Spectra for Chlorophyll

It's long been known that this is a form of protection. Chlorophyll (particularly chlorophyll a which is the major light absorbing pigment) is quite a sensitive molecule and can be easily damaged or destroyed by too much energy. If the chlorophyll gets damaged, then the light energy can pass into the rest of the plant and damage other tissues, including low level cell damage of DNA. Too much light energy is dangerous for a plant as they have very limited mechanisms for getting rid of unwanted heat. Plants use differing densities of chlorophyll in leaves that see more or less energy, you'll see leaves at the tops of trees are paler than those at the base for example. Some plants can angle their leaves to collect more or less light. However, on the whole these mechanisms are limited. A plant can't move around and hide in the shade or dig a cool burrow. Plants have also evolved repair mechanisms for DNA and other tissues that are damaged by excess energy, but these mechanisms are hungry and require even more energy. They are short term solutions at best.

Nathaniel Gabor a physicist at the University of California, Riverside, Richard Cogdell at the University of Glasgow, and others have been studying this problem and have built a model to explain why photosynthesis avoids green light. Their team recognized that another concern in photosynthesis is the problem of noise on the input. What do I mean by noise? Light energy isn't stable, as clouds pass across the sun, or other plants blow in the wind casting shadows, the light level on any particular leaf is constantly changing, at a flickering rate that's too fast for any of the protection and adjustment mechanisms to cope. What would be perfect for a plant would be constant light level that the photosynthesis system could be tuned to. In practice, that light level, and thus energy level, is constantly changing forcing the plant's systems to chase it around. Too few photons can cause an energy shortage, while too much energy causes free radicals and overcharging effects that damage tissues.

Better than trying to get rid of excess energy is to evolve a system where that excess energy doesn't build up in the first place. One solution for this is to use light at the ends of the spectrum, red and blue, which are much lower in intensity and that, over the eons, have proven to be safe areas, much less prone to dangerous cell destroying energy levels.

This has been the understanding for some time, but, until now, nobody had modeled a system which predicted the actual best wavelengths to use. Yes, we now know that it's red and blue, but why both, and which red and blue? Which wavelengths offer the best compromise between energy availability, stability, and protection from excess? Gabor and Cogdell's team developed a model for the light-harvesting systems of plants and applied it to the solar spectrum measured below a canopy of leaves. Their work made it clear why what seems to be the obvious solution of collecting the maximum energy from green light, just doesn't work for plants. Using green might be highly efficient but would be detrimental for plants because, as the sunlight flickered through the clouds and tree cover, the noise from the input signal would fluctuate too wildly for the photochemical system to regulate the energy flow. Instead for a steady energy output at safe levels the chlorophyll pigments have to be finely tuned in a very specific manner. The pigments need to absorb light at similar wavelengths to reduce the internal noise. But they also need to absorb light at different rates to buffer against the external noise caused by swings in light intensity. To use the analogy of an electrical system, to smooth the input from a noisy signal you need to avoid the peaks and use both slow and fast charging of capacitors to flatten the peaks and fill in the valleys. Their model predicted that the best light for the pigments to absorb was in the steepest parts of the intensity curve for the solar spectrum. That is at the red and blue ends of the spectrum.

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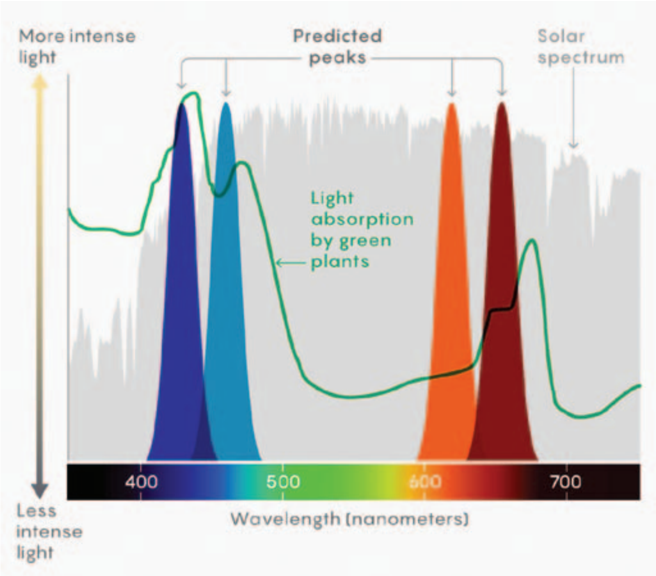

Figure 3 – Model vs. Reality

Figure 4 – Purple Bacteria

Figure 3 shows the output from the team's model compared with the actual curves of chlorophyll a and b. The dark green curve shows the actual absorption by plants, and the four peaks show the models prediction. The match is excellent, within 5%, for both chlorophyll types.

The team went on to apply the predictive model to other environments, such as that under a forest canopy or under water in the ocean and was again able to successfully match their model with evolutionary reality. In particular they were able to predict why purple bacteria, common in ponds, are a reddish color. **Figure 4** shows an example, the water in the pond looks reddish because of the purple bacteria that have their own photosynthetic chemicals to extract energy from sunlight. In this case, the light under the tree canopy is muted and has most energy at the red end of the spectrum.

In the end the researchers were surprised by how general and simple their model is. "Nature will always surprise you," Gabor said. "Something that seems so complicated and complex might operate based on a few basic rules. We applied the model to organisms in different photosynthetic niches and continue to reproduce accurate absorption spectra. In biology, there are exceptions to every rule, so much so that finding a rule is usually very difficult. Surprisingly, we seem to have found one of the rules of photosynthetic life."

Apparently, it ***is*** easy to be green. ■

Mike Wood runs Mike Wood Consulting LLC, which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and Intellectual Property. A 40-year veteran of the entertainment technology industry, Mike is a past President of ESTA and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.

Reference:

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