Final Report: EnerTree

Team 3

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Trees perform photosynthesis everyday - some through their leaves and others, such as the palo verde tree, through their bark. Just as a tree carries out generating energy, our team wanted to replicate that behavior into creating a solar panel. Furthermore, we wanted the solar panel to be able to withstand harsh weather environments, like pine needles do, and we wanted it to be portable. We designed the dowels of the solar panel to be presented in a Fibonacci spiral to help embrace how these spirals are so evident in nature. We also made the dowels have the ability to raise up and down together to promote portability. The final design has 1 center piece of pine wood, 5 retractable dowels, 1 string intertwined between all the dowels to assist in raising up and down, and the ability to produce only 7% fewer kiloWatt hours on a clear, sunny day than a flat solar panel with the same surface area.

To begin the design process, our team started with a collection of 25 unique organisms that were chosen based on our respective interests. To narrow down our organisms, we looked for similar behaviors or processes between each of them using a Functional Matrix, where we researched unique adaptations of each organism and potential applications (see Figure 1).

	Shirali Desai					Teagan Groh			
Species	Flying Squirrel	Sugar Glider	Flying Snake	Tree Squirrel	Frog	Venus Fly Trap	Pine Cones/Needles	Palo Verde Tree	Saguaro Cactus
Movement	Gliding movement	Gliding movement	Gliding movement	Swiftly climbing trees	Shock absorber type movemenet	very quick convex to concave leaf shape change	——	——	——
Research focus	Flying squirrels are able to use their body to glide	Flying squirrels are able to use their body to glide	Flying snakes are able to use aerodynamics to glide	Climbing ability	Sticky tongue and adhesive saliva	rapid shape change to catch bugs but still photosynthesize	pine needle shape efficiency	photosynthetic bark (and needle leaves wooo) - basically an inverted tree	spine/needle shape efficiency
Adhesion	Uses paws to latch onto trees	Uses paws to latch onto trees	Snakes will dangle on branch in J shape before gliding	Soft pads underneath paws assist in climbing	Tongue allows frog to capture insect, and then the saliva keeps the insect in contact with tongue	stays closed based on hair and deformation sensors in leaf	——	——	——
Structural Composition	Skin between hind leg and front leg; flat tail helps balance; Patagium (area of skin) helps squirrel steer away from predators	Fold of skin from wrists to their sides helps with gliding	Tubular shape of body helps generate a force of lift. When snake turns at particular angle, added boost of lift. The snake's body has circular cross sections that go into a flat profile	Hind legs are longer than fore limbs; ankles rotate 180 degrees, causing hind legs to point backward and grip tree	Viscoelastic tongue and non-Newtonian saliva; tongue acts like a shock absorber; saliva spread over tongue and allows for attachment/swallowation	Elongated cells in the leaves dehydrate, changing the shape from convex to concave, and the momentum of the shape change brings the leaves all the way closed	Cylindrical needles can photosynthesize at any angle, arranged in a way that promotes snow and water to roll off the leaves to prevent weighing down; also spaced out so strong winds don't knock down the tree	Instead of photosynthetic leaves, this tree has photosynthetic bark to minimize water loss	Contain water in their centers and the stems/bodies are photosynthetic while spines serve as protection and photosynthesis waste (water, CO2) emitters; can grow very tall and live hundreds of years
Signaling/Coloration	——	Scent gland on male's head is used to mark territory	——	——	——	Hairs have a mechanical disturbance threshhold that when reached triggers the shape change; further similar signaling determines if the leaves stay shut or not	——	chlorophyll makes the whole tree green!	——
KOANS	Mechanics: gliding swiftly	Mechanics: gliding swiftly	Mechanics: gliding; stealthy; efficient	Mechanics: stealthy and efficient	Materials: lightweight and strong	Mechanics: moving without muscles	small needles but good at photosynthesizing (small but efficient?)	maximized potosynthesis but minimal water loss	photosynthesis with minimal water loss
Similar to Other Organisms	Flying snakes, sugar gliders	Flying squirrels, flying snakes	Flying squirrels, sugar gliders	Chipmunks, flying squirrels, other squirrels	Lizard, toad	beech tree leaves; plant tendrils	most evergreen trees	succulents and cacti	succulents, other cacti, palo verde tree
Protective Devices	Big eyes allow for vision at night to evade predators	Big eyes allow for vision at night to evade predators	Fangs	Large incisors for gnawking; large eyes to see from trees; can descend head first down a tree to evade predators	Frogs can capture insect in less than 0.7 seconds and carry 1.4 times its weight	can digest insects without a stomach	needles are coarse and waxy (not very tasty) and seeds are protected in pine cones until they are ready for release	instead of leaves, it has spines (like a cactus) that have very small stomata; it is also woody, not waxy	it has spines instead of leaves and a waxy outer layer that isn't tasty
Potential Applications	Parachute like object that needs to glide down to Earth	Parachute like object that needs to glide down to Earth	Flexible that can use lift and its own weight to transport things at different levels.	An attaching object that can scale a tree up and down in order to obtain information about the tree	A sticky subtance that can clean windows; a product that has reversible adhesives that stick at a high speed	hydraulic powered muscles/shape change and sensors	cylindrical solar panels arranged for high-altitude optimization, or areas with harsh weather	creating materials that are solar-charged without explicitly solar panels; renovated solar panel efficiency, using solar panels for the bodies of structures instead of just panels/rooftops	use spines in water collection practices; tall cylindrical solar panels

		Vamsi Choday					Grace Oberst	
Species	Beech Leaves	PufferFish	Porcupine Fish	Cane Toad	Puff Adder	Greyhound	Desert Ants	Monarch Butterfly
Movement	ordered folding and unfolding via Miura-Ori origami pattern	Awkward/slow swimming & body inflation	Awkward/slow swimming & body inflation	——	Caterpillar-like locomotion & body inflation	Fast locomotion especially around corners	Perform "learning dances" to orient themselves to stay on track as they navigate	——
Research focus	ordered folding of leaves	Skin expands/gets thinner but retains structural rigidity	Spines lay flat to conserve hydrodynamics, become erect when animal is puffed up	Females inflate bodies to fend off predators and sexual select males.	Entire body inflates to intimidate predators and make it more difficult for them to swallow puff adders	Greyhounds are able to run very quickly around corners	Navigation through desert using the position of the sun & geomagnetic field of the earth	circadian clock located inside the antennae combined w/sun's position in the sky aids butterfly migration
Adhesion	——	——	——	Puffed-up stomach decreases the ability for males to attach/adhere to the females.	——	Lower center of gravity = better around traction corners	——	——
Structural Composition	Leaves can fold up into very space-efficient shapes and expand to several times their width due to linearly repeated Miura-Ori folds in the leaves	Unidirectionally oriented collagen fibers in ventral layer. Orthogonally oriented collagen fibers in dorsal layer. Each with varying young's modulus to allow for rigidity and expansion	Unidirectionally oriented collagen fibers in ventral layer. Orthogonally oriented collagen fibers in dorsal layer. Each with varying young's modulus to allow for rigidity and expansion. Spines attached to medial layer, and become erect when medial layer is under tension during inflation	Rapidly inhale air into buccal cavity and expand the cavity	During exhalation phase of making the hissing sound, pressure buildup in the mouth pushes on a diaphragm that makes the body inflate/puff-up	Forelimbs dominated by bone, tendon, and high pennate muscles which act as a passive spring. Hips dominated by muscles, and power locomotion. Hips are non-weight bearing allowing for greater power output	Covered in tiny triangular hairs that facilitate regulation of body temperature - keep body significantly cooler by reflecting visible light and getting rid of excess heat through black-body radiation	Wings composed of thin layers of chitin; female bodies lighter in proportion to wing size than males + more resistant to tears - more successful during migration
Signaling/Coloration	changes in weather/season induce changes in leaf water pressure, which signals leaf shape changes	When puffed up it is a signal to other puffer fish of potential danger	When puffed up it is a signal to other porcupine fish of potential danger	When female cane toads are puffed-up and there is still a male attached, other males see this as a signal that the female does not want to mate with the attached toad and will try to usurp.	Emit a very loud and high pitched sound to intimidate predators and warn other puff adders of potential danger. Use tongue to attract amphibian prey.	——	——	Communicate availability of food through interactions; ants that find food enter and leave the nest quickly, and their high speeds translate over to other ants who are now more likely to leave the nest to get food
KOANS	compact, but large surface area	Bad swimmer but can escape faster predators	Bad swimmer but can escape faster predators	Weaker than males but can remove them from amplexus.	Slow moving but fastest striking snake	Faster around corners than in a straight line	Physiology - temperature cooling	Physiology - internal circadian clock
Similar to Other Organisms	mimosa plant	Porcupine fish, Balloon fish, & Globe fish	Puffer fish, Balloon fish, & Globe fish	Toads, Frogs, & Lizards	Vipers & Legless Lizards	Saluki & Afgan Hounds	All navigate using light from the sun or geomagnetic field of the Earth	
Protective Devices	climate sensors protect leaves from opening in inopportune conditions	Toxic poison & puffed up body	Toxic poison, puffed up body, & out-ward radiating spines	Puffed-up body & toxins in parotoid glands	High pitch sound and puffed up body	——	——	Toxic to birds and other predators; orange coloration warns such predators not to eat them
Potential Applications	Miura-Ori can be used in solar panels that change shape though the day; product packaging that is robust but space efficient; honestly almost anything that can benefit from conditional changes in shape and dimension	Improve cardiac stint deployment using puffer fish skin inspired balloons	Flood control sheet with spines/flaps that can be "activated/raised" using an actuation system to redirect water	Better designed airbag that can be reused after deployment	Drain snake to clear clogs where a balloon at the end is inflated to fill in the space of the drain and push down obstructions. Hissing sounds/vibrations used to help break up obstructions	Car/Dune Buggy suspension that better manages weight distribution around corners to minimize energy loss	Desert robot navigates without GPS using light sensing; materials that are cooling/heat-resist ant using desing of desert ant hairs	Architecture where the amount of light/heat passing through windows is controlled; window could be transparent to certain colors of light; powerful solar cells based off the butterfly wing

				Mary Mulcahy				
Species	Bats	Dung Beetles	Fiddler Crabs	Dog	Deinonychus	White pelican	Squid	Polychaete worms
Movement	——	Roll their balls of dung in a straight line and circumvent obstacles	Have one claw significantly bigger than the other to scare away attackers/attract mate using waving	——	Leaping, tight gripping with claws, flying behavior	Flying and diving into water to hunt	——	Tentacle used for feeding and picking up exogenous materials to attach to tube
Research focus	internal magnetic compass set by the polarized refraction of the sun - migration across the ocean	Perform a dance on top of their ball to record mental picture of position of the Sun, Moon, stars and can see polarized light - navigation through	Have polarization contrast against the mudflat which can be minimized to avoid confrontation with other crabs or be enhanced to send signals	Canines have a very strong and sensitive sense of smell	Deinonychus engaged in pack hunting behavior	Pelicans have a pouch like beak to scoop up fish	Cephlapods have very developed camoflauge mechanism	Produce strong protective tube around their body
Adhesion	——	——	——	——	——	——	——	"Glue" on tube made of phosphate, Ca, & Mg rich proteins
Structural Composition	Flexible wing structure similar to a human arm; thumb extends out of the wing as a small claw that helps the bat to climb; great maneuverability for diving throug the air	Spurs on back used to help roll the balls of dung, strong front legs for digging, long flight wings to allow traveling for several miles to look for dung	Males have one claw much larger than the other; purple, blue, or grey carapace	300 million olfactory receptors, divided nasal cavity, secondary olfactory system with vomeronasal organ	Unusually large second claw with very sharp talongs, organized flying between organisms, communicated with noises and chemical signals	Expandable gular skin on mandible part of beak that is usually folded up but can expand to hold 3 gallons when hunting to scoop up fish and water	Iridphore cells in skin with diff. reflective indexes reflect polarized light. Different colored chormatopore cells change size to change skin color	Tube made of fine threads of chitin, polysaccharides, & calcium carbonate & covered in exogenous materials
Signaling/Coloration	Release chemicals from scent glands on wings to attract females for mating	Communicate through high pitched chirps and screeches; different sounds for mating, marking territory, alerting danger, etc	cuticle of the crab changes color/pattern to signal to other crabs about mating status/stress/diet/access to ground water	Vomeronasal organ has seperate sensory neurons to detect pheramones from other canines	Groups of deinonychus grouped up to attack a much dangerous, much larger predator. Jump on predator, pin it down with cumulative weight, and hold it down with sharp claws	Coordinated pack hunting through squawks and chemical signals to other pelicans	Selective relection of polarized light allows them to communicate with one another to coordinate defensive behaviors	——
KOANS	Physiology	Physiology	Sensing - communication through polarization	Compact but complex	Aggressive and dangerous but organized and cooperative hunting	Large and spacious but compact. Big beak but doesn't impede flight	Colorful but hard to see	Tough and flexible
Similar to Other Organisms			Similar to squid which also uses polarization for communication	Cats, bears, mongoose	Komodo dragon, crocodile, velociraptor, Human and wolf (pack hunting)	Cormorant, snow goose, wood stork	Chameleon, octopus, cuttlefish, mantis shrimp	Armadillo, turtle,mollusk
Protective Devices	Safety in numbers; great ability to detect potential enemies and avoid them	Hornlike structure on head used for fighting other ants; strong front legs also help defense	Wave their big claw to appear strong to other crabs; can reduce brightness of appearance to blend in better and avoid confrontation	Good sense of smell allows it to detect and avoid predators better	Sharp claws, saw like jaw, flying. Coordination of these between animals could be used for protection against predators via attacks	——	Concealed communication btwn cephlapods for group defensive behavorior bc non-cephlapods can't see the polarized light they use to communicate with eachother	Tube protects from predators and harsh environmental conditions
Potential Applications	bio-inspired drones, driverless cars, assistive devices for the blind	night vision of dung beetles inspired high-quality video shooting in low light situations	innovations with polarization vision	Artificial dog nose to sniff out land mines, cancers, diseases	Better communication and coordination methods between humans when engaging in group behaviors or hunting	New stretchy, strong material	Better camoflauge for soldiers	New biomimetic materials (new cement, water-borne adhesive, bone glue)

Figure 1. Our team's functional matrix.

Through this method, we narrowed down to the palo verde trees, pine cones/needles, pufferfish, and the white pelican. The palo verde trees and pine cones/needles both produce energy whereas the pufferfish and white pelican both maintain flexibility while having a structured shape. These findings inspired us to look into producing an EnerTree solar panel, an origami tent solar panel, or a kelp inspired solar panel. After prototyping these three devices, we evaluated them in a Pugh Matrix (see Figure 2), and the EnerTree was selected as the design our team wanted to move forward with.

Criteria	Baseline=On house solar panel	Origami Tent	EnerTree	Kelp solar panels
Weight	2-4 lb/sq ft	-1	-1	1
Price	$250	-1	1	1
Energy Capacity	6 kW	0	2	0
Power rating	320 watts	1	-1	-1
Weather resistance	Withstand 1 inch hail falling at 50 mph, winds up to 140 mph	1	2	1
Size	65" x 39"	0	1	-1
Total:		0	4	1

Figure 2. Pugh matrix for our device

Through this thorough design process, each member of our team was able to gain insights about the unique biological gifts of more than twenty-five organisms, as well as insights about how to conduct comprehensive analysis techniques, such as the Pugh Matrix and four box method, to determine the best design concept. Finally, our team was able to gain valuable insight on the proper way to amalgamate the unique design perspectives of several different people into one all-inclusive final design.

The EnerTree design can replicate the way the palo verde tree generates solar energy through its bark, how the pine needles can efficiently produce energy by facing many different directions at once and withstand harsh weather, and how the pufferfish and white pelican promote flexibility and strength. The key linchpin of the design is producing energy, and if the solar panel cannot produce the energy like the trees and needles, then our device would not qualify as a bio inspired design. Our prototype has dowels that replicate the behavior of the pine needles since they are able to move up and down. While our design is not actually able to produce energy as it is merely a prototype, we do think it is an efficient way to improve solar panels - especially after executing copious calculations - so we do think it would be neat to show in a gallery.

Our final prototype is inspired primarily by the pine tree, since we found that specifically for our solar panel design, it was more effective to hone in on a specific concept of an organism. However, some aspects of our design are more broadly inspired, such as arranging the branches as a Fibonacci spiral, which is a common design found in many trees and other plants to maximize area for photosynthesis. A particularly important aspect we wanted to replicate from the pine tree, though, was its unique adaptations to living in environments with more extreme weather patterns.


Figure 3. Pine needle clusters

The pine tree is easily able to survive in places with heavy snowfall because of the shape of the pine needles, which allows precipitation to roll off, and the clusters of needles (Figure 3) which shed snow instead of breaking under the weight of snow build-up. Furthermore, while strong winds are able to travel more easily around the needles rather than flat leaves, preventing the tree from being knocked over. Even though individual needles have a small surface area, the bundles of needles maximize sunlight capture and are particularly efficient at high altitudes where there is a lot of reflected light during the winter. We wanted one of the functions of our solar panels to be that they could be distributed in disaster zones and be able to perform in suboptimal weather, so in modeling after the design of the pine needles, we are able to create a more resilient solar panel design.

When we settled on the idea of a plant-inspired solar panel, we came up with a range of different sketches to explore all of the possible designs we could think of, including a series of sketches that eventually became the EnerTree (see Figure 4). Some of the other ideas we entertained but did not ultimately select, such as a tree-like structure with the solar panels on the trunk, solar panel buoys modeled after the puffer fish, a pine cone-shaped solar panel that revolves to keep facing the sun, and a kelp-like structure that could float in a body of water and absorb radiation from the sun.

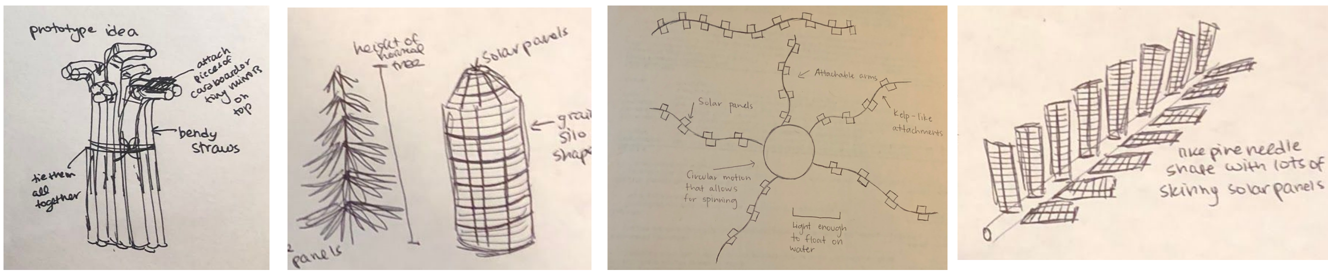

Figure 4. Prototype ideation sketches

Having a lot of different sketches and possible design solutions helped us to ensure that EnerTree was the best design. After deciding to move forward with the EnerTree design, we iteratively prototyped a portable, cylindrical device that would eventually be covered on all sides with solar panels. Our first iteration of this prototype explored the idea of a sturdy base with different attachable elements to the arms (Figure 5). Our second iteration of the EnerTree prototype introduced the idea of retractable dowels to add portability and resiliency to the structure (Figure 6). Our final prototype also incorporated this retractable dowel element, but was closer to what the actual device would look like so as it could be used for preliminary testing (Figure 7).

Figure 5. Prototype 1

Figure 6. Prototype 2

Figure 7. Prototype 3

We believe the design of cylindrical solar panels modeled after pine needles is viable because cylindrical solar panels have already been developed in the past. The original cylindrical solar panel design failed because originally, they were mounted onto rooftops just like flat solar panels, which meant that they were not installed to utilize the full potential of the solar panels' ability to absorb solar radiation from all angles, and thus the performance was far lower than the creators were expecting. However, if the cylindrical solar panels are part of a pine tree structure, then the shape is maximized, especially in snowy areas where the underneath of the panels would be subject to reflected light from the ground. Translating the single solar panels to our design would be an achievable process.

In the process of creating our prototype, we took advantage of the wide variety of skills that our team possessed. We utilized the mechanical engineering expertise of our team to model, construct, and add dynamic movement to our prototype. The team took advantage of the biological/biomedical engineering knowledge to analyse and apply the biologically inspired component of our design. The industrial engineering know-how of our group allowed us to apply optimization principles and engineering methods to the design of our prototype, which allowed us to design and create our device in the most efficient way possible. Finally, we were able to use the environmental engineering insight of our team to identify our design's applications in the real world, such as in harsh weather conditions and in disaster zone environments.

Our specific prototype is exclusively testable for size and portability concerns, but does not have the ability to be tested for energy conversion efficiency. However, our team does have a plan to test our prototype to obtain objective data. For our testing plan going forward, our team will conduct a series of light tests and measure the surface area of our prototype that is exposed to light at several different light angles, and along with the knowledge of the specific photovoltaic output of the type of solar panels that will comprise our device, we will calculate the amount of energy converted by our device at each light level. After evaluating the viability of the results of this test, the next step of our testing plan would be to create another prototype that had the flexible cylindrical solar panels covering the surfaces of the prototype, and then conduct similar light tests and compare the results to a typical photovoltaic cell, so as to truly validate the energy conversion efficiency of our design.

The viability of our prototype has been assessed through energy output prediction calculations. We utilized the equation for finding the solar PV energy output of a photovoltaic system and calculated the energy output of our solar array in different environments (see Figure 8). We then compared this value to the calculated output of a flat solar panel with the same surface area (Figure 9). We used surface irradiance data from NASA's Climatology Database to determine the daily change in sunlight intensity in Atlanta, GA. Under normal, sunny conditions, EnerTree is predicted to make only 7% less energy than a standard solar panel. In snowy conditions, EnerTree is capable of generating energy where flat panels can not.

Radiance for Surface * Surface Area			
Morning (~6am-10am)			
1/4 Direct Sun	0.00327841	kW-hr/day h	DNR MAX
1/2 Indirect Sun	0.00313867	kW-hr/day	DIFF MAX
1/4 Shade	0.00095665	kW-hr/day	DIFF MIN
Total Surface Radiance:	0.00737373	kW-hr/day	
Midday (~10am-2pm)			
1/4 Direct Sun	0.00327841	kW-hr/day	DNR MAX
1/2 Indirect Sun	0.00313867	kW-hr/day	DIFF MAX
1/4 Shade	0.00095665	kW-hr/day	DIFF MIN
Total Surface Radiance:	0.00737373	kW-hr/day	
Evening (~2pm-6pm)			
1/4 Direct Sun	0.00327841	kW-hr/day	DNR MAX
1/2 Indirect Sun	0.00313867	kW-hr/day	DIFF MAX
1/4 Shade	0.00095665	kW-hr/day	DIFF MIN
Total Surface Radiance:	0.00737373	kW-hr/day	
ALL TOTAL:	0.02212120		
Solar Energy Output (kWh/day)			
A*H =	0.02212120		
r =	0.17		
Pr =	0.75		
Energy	0.03384544	kWh/day	

Figure 8. EnerTree energy calculation

Calculation of the solar PV energy ouput of a photovoltaic system

Yelow cell = enter your own data
Green cell = result (do not change the value)
White cell = calculated value (do not change the value)

Global formula : E = A * r * H * PR

E = Energy (kWh)	2811	kWh/an
A = Total solar panel Area (m²)	20	m²
r = solar panel yield (%)	15%	
H = Annual average irradiation on tilted panels (shadings not included)*	1250	kWh/m².an
PR = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)	0.75	
Total power of the system	3.0	kWp

Losses details (depend of site, technology, and sizing of the system)

- Inverter losses (6% to 15 %)	8%
- Température losses (5% to 15%)	8%
- DC cables losses (1 to 3 %)	2%
- AC cables losses (1 to 3 %)	2%
- Shadings 0 % to 40% (depends of site)	3%
- Losses weak irradiation 3% yo 7%	3%
- Losses due to dust, snow... (2%)	2%
- Other Losses	0%

Figure 9. Standard solar panel energy

However, these calculations are only predictions. We would have to do proper light-shadow testing to determine the true daily energy output of the solar arrays. Due to the technical aspect of working with solar panels, our prototypes were not operable and modeled the shape changes in the array more so than the actual functionality. As a result, there could be electrical and material problems with our design that we did not have the knowledge to predict or experiment with during the class. Further testing and prototyping with actual solar panels would be needed to verify the absolute viability of our design before it could be applied to real scenarios.

We have demonstrated an elementary understanding of the natural systems that were used as inspiration for the EnerTree, however, given the vast complexities of each organism, we believe that we will never ever be able to completely understand the natural systems referenced in our work. We have drawn inspiration from a multitude of organisms for the final prototype, but we primarily focused on the morphology of certain natural systems without delving too deeply into the mechanistic attributes of the organisms. Morphology alone was enough for us to develop a solid foundation for a product idea and prototype. With more time and resources, we will be able to develop a thorough understanding of our organisms' and natural systems' attributes, and subsequently create more advanced iterations of the EnerTree. For example, further research into plants who have found ways to optimize photosynthetic energy storage can help us design the circuitry to improve energy retention efficiency.

Through this design process, our team learned how inspirations from nature can be used to develop new products and/or elevate existing technologies. Unlike other design courses that our team members have been exposed to, the BioInspired methodology used in this course forced us to seek out applications or issues that could benefit from our product. This required us to think in a new manner and approach design from a new perspective. As a team, we were able to look at 25 organisms, isolate interesting functions and attributes from each, and uses a series of unique tools to brainstorm potential solutions. With a 4.5-billion-year head start when compared to mankind, nature has already developed solutions and clever mechanisms to address large problems. We simply utilized this fact to expedite the research and development of the EnerTree, a Bio-Inspired approach to revolutionize the morphology and deployment of solar panels.

To maximize energy production during the day while also retaining the benefits of round panels, we could modify the branches to be more almond-shaped. That way the panels can still produce energy on their undersides during snowy weather and also expose a larger percent of their surface area to the sun when it is clear. To further increase energy output, it would be useful to program or design the solar array so the branches can be raised at a specific degree to the horizon that allows maximal irradiance absorption. Such a degree can be easily found for any location on the NASA Climatology Database (see Figure 10)

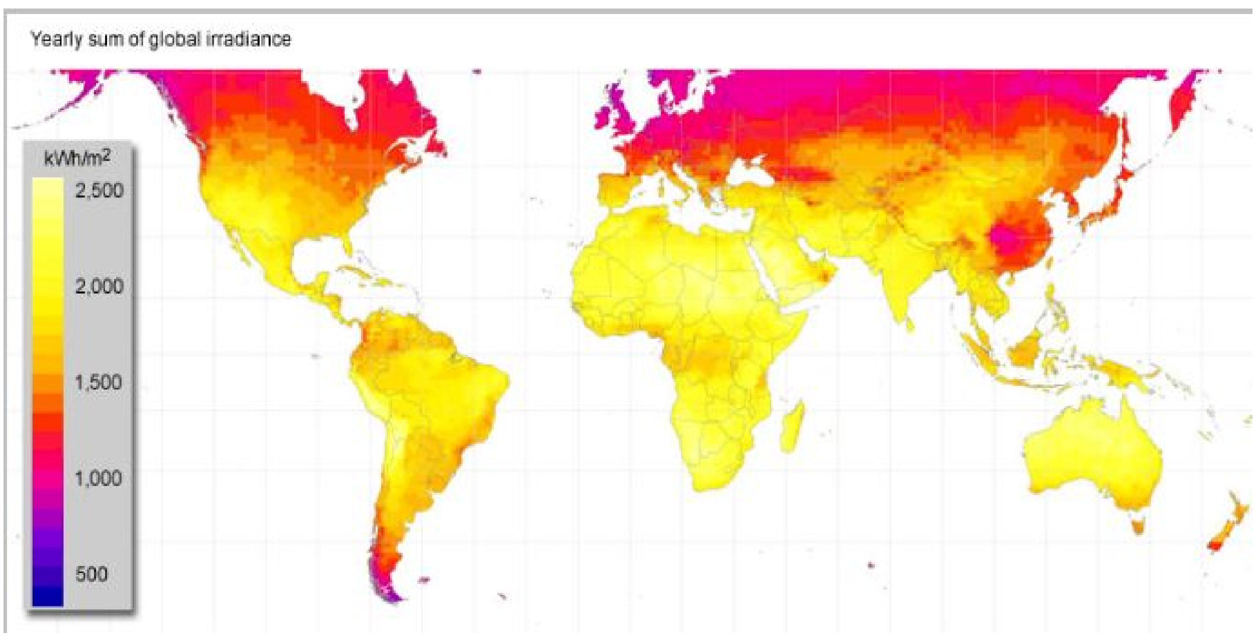

Figure 10. NASA Climatology Database radiance graph

More improvements would be evident as we transitioned to working with real solar panels. Aspects such as electrical efficiency, deployment, stabilization, and weather resistance would all be more easily hashed out with further prototyping and field testing. It would also be beneficial to determine what surface area to size ratio is most efficient for our solar array.