The PETAL Concept

How can we generate power with the efficiency of tree growth?

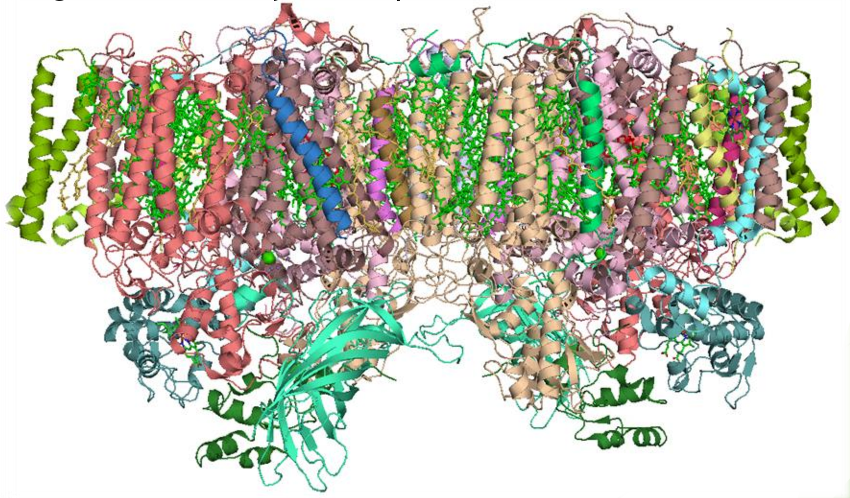
Photosynthesis operates at nearly 99% efficiency for photon capture to harvest light for tree growth. How do we take advantage of this light harvest for light energy.

The PETAL Concept
Hacking photosynthesis!

- What if we can hack photosynthesis?
- Trees use photosynthesis to capture photon energy and convert it to sugar.
- What if, instead of sugar, we harvest the electrons before the chemistry conversion begins …
- The sun provides an Ultraviolet measure of 100mW/ cm^2 .
- What if we could create a system to harness this power

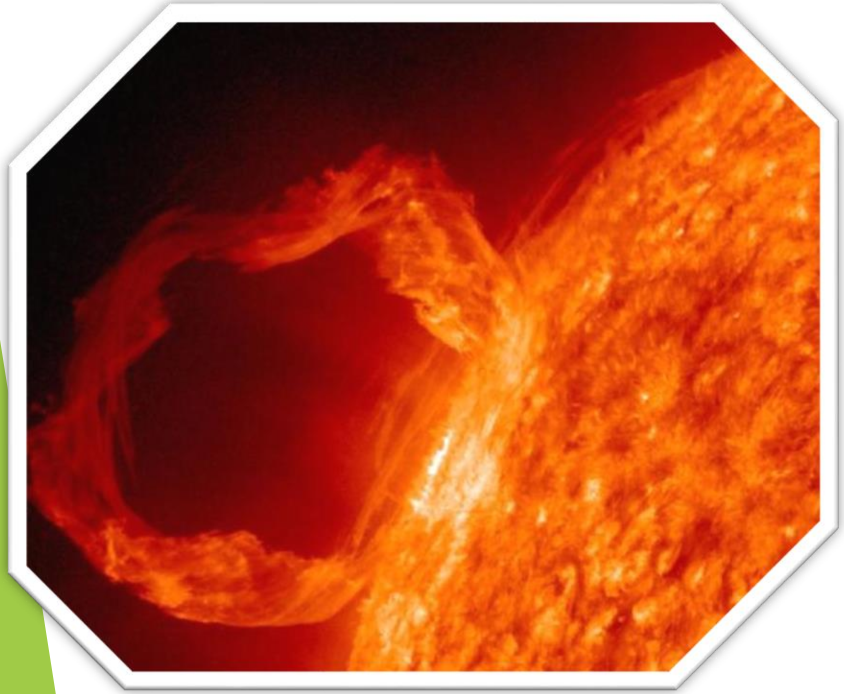
  that is 50% efficient? Or better?

Figure 1: Photosystem II protein.



The PETAL Concept
What do we hack and what do we get?

Sunlight + photosynthetic proteins+ Nano tubes + water = "Nano Power"



Steps to proof of principal:

- Purify Photosystem II (PSII) protein from plants.
- Attach the protein to a Carbon Nanotube (CNT).
- Attach the Carbon Nanotube (CNT) to a collective substrate.

- Three Possible Application
  - Nano-scale – power source for nano-bots.
  - Micro-scale – power skin for small UAV to provide 2w level power for radio, level flight and recharging.
  - Industrial – football field-sized flexible substrate rolled into a tree-sized column (theoretical yield of 1 Mw) for deplorable base power source.

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Why we believe it is possible and has a high probability of success.

- Virginia Commonwealth University (VCU) preformed a bench-scale (2cm x 2cm) experiment which yielded 20.44 (±1.58) μA/cm2 power flow for ECSquared in 2017.
- ECSquared Patent issued – (2018)
- ECSquared currently exploring partnerships to continue benchtop research.

Figure 2: 2cm x 2cm test slide from VCU experiment

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Scaling up

- Objectives
  - Leaf-sized – 5 cm^2 (power membrane)
  - Wearable membrane – 20 cm^2 (2w to 5w to power Land Fighter’s radio, in continuous receive mode and burst transmission mode)
  - UAV (Unmanned Aerial Vehicle) – 100 cm^2 (100w power for level flight and sensors)
- INTIAL TARGET: SCALABLE BIOSOLAR POWER MEMBRANE (SBPM)
  - Sunrise to sunset (2w continuous)
  - Conformal skin (wattage based on size of application)
- LONG TERM TARGET: CONFORMAL SCALABLE BIOSOLAR DENSE SURFACE (CSBDS)

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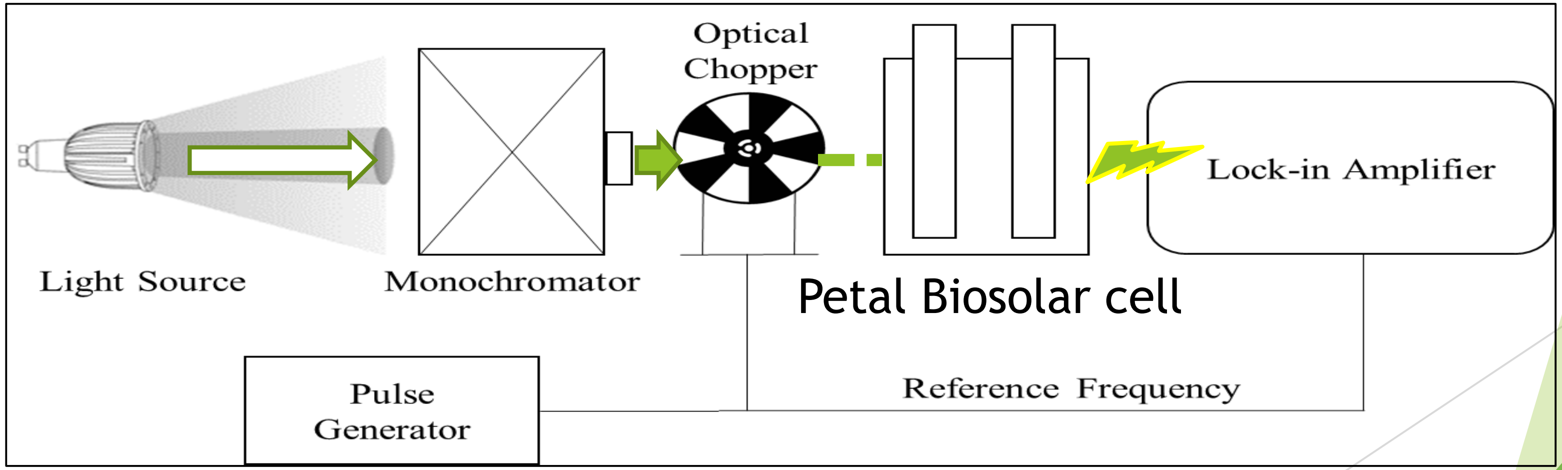
Where do we go from here?

- Wearable membrane
  - Discover scalability (increase and decrease from 2cm x 2cm)
  - Discover light intensity ranges (dusk/dawn to full sun)
  - Discover deployability and skin conformity
  - Discover activity level durations

Figure 3: VCU test bed schematic



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Research plan for initial SBPM

(SCALABLE BIOSOLAR POWER MEMBRANE)

- This plan will require and more robust research partner. University of Delaware
- Create initial 5cm^2 carbon Nano tube scaffold (CNTS) and circuit (CNTS-C).
- Purify the Photosystem II (PSII) protein.
- Orient the CNTS along 3 axes (3D) and attach PSII Protein to the CNTS-C
- Insulate the assembly, add water, and seal the SBPM.
- Attributes of the SBPM:
  - Self-contained
  - Flexible
  - Linkable
  - Sustainable power feed for a measurable usable power level
- Brassboard/benchtop SBPM research goals:
  - CNTS-C loaded with PSII protein, water, sunlight
  - Expected by products: molecular oxygen and power
  - Measure power output and efficiency
  - Consumables external to the membrane
  - Initial target: define power output levels and degradation curve of consumables
  - Light intensity level required for initiation, sustainment and termination

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Technical Challenges & Questions

- Technical Questions
  - How to purify the PSII Protein?
  - How to attach/orient the PSII Protein along Carbon Nanotube Scaffolding (CNTS)?
  - Antenna proteins inclusion
  - How to design a Carbon Nanotube Scaffolding-Circuit (CNTS-C)?
  - How to print/build the CNTS?
  - What are suitable skin/membrane materials?
  - How to replace the protein and which proteins to replace?
- Additional Questions (to be answered after seedling success)
  - How can the skin/membrane be manufactured and stored in the 'off' state prior to use?
  - Can spent PSII protein be stripped and replaced with new, active PSII protein to achieve a renewable platform?
  - Can we power a small UAV (Unmanned Aerial Vehicle) along a level flight path? Time? Distance?
  - Can we solve a 24-hour/7-day hybrid power equation for a usable UAV payload?
  - How far past the 24-hour/7-day can we push the performance envelope before failure?

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Key players

- ECSquared – Concept originator, patent holder as System Integrator
- University of Delaware (UD), Dr. Robert Opila as PI
- Virginia Commonwealth University (VCU) Dr. Stephen Fong as PI
- Peer Review team

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Research Team Qualifications

- University of Delaware
  - Robert Oplia, PhD - Opila group has the ability to perform detailed surface chemical reactions and characterization, as well as study spectroscopically the lifetime of the excited electrons and, separately, the degree of bandbending due to adsorption, and the amount of charge trapped on the surface. The Group also has the ability to perform detailed density functional theory calculations.
  - **Meixi Chen, PhD** - She has been working on developing hybrid solar cells for 6 years with a specialization in semiconductor physics and chemistry, defects, organic and thin films on Si wafer interface reactions. She is proficient with various advanced semiconductor materials, CNT material and organic charge transferring materials, as well as solar device fabrication and characterization.
  - **Shuang Liu, PhD** – She is an associate scientist working on biomaterials design for tissue engineering applications. Her expertise in applying various bioconjugation chemistry to materials design and synthesis, including natural biopolymers, synthetic polymers, peptides and proteins etc., as well as molecular, protein activity and materials property level characterization using various instruments.

- ECSquared –
  - Edward Crowder – Owner of the Patent and veteran of biotechnical project development and project management.