**Agrivoltaic Architecture: Energy Pods, Green Weave, & Light Meander** *Designing for Light and the Environment at the Nexus of Energy, Food, and Water*

# Narrative and Environmental Impact Statement

Agrivoltaic Architecture intertwines **contemporary building-integrated agrivoltaics, advanced material-conscious computational design and digital fabrication, and playful community-building architectures** to create a series of **environmentally sensitive dynamic waypoint prototypes** within the otherworldly landscape of Fly Ranch: Village Pavilions (Energy Pods), Agrivoltaic Surface Farming (Green Weave), and Canopy Light Networks (Light Meander). Agrivoltaic Architecture embraces holistically the sustainable initiatives proposed by LAGI & Burning Man at Fly Ranch and Black Rock–High Rock NCA, Nevada.

**Beauty is an essential part of nature, and in many scenarios outweighs strict efficiency.** Beginning with biological adaptations including heliotropic mechanisms in sunflowers and the light-scattering structures in Lithops plants, non-conventional configurations of PV panels combined with agriculture, explore designing with light and energy while investigating maximized energy conversion efficiency. Agrivoltaic Architecture innovates the design and engineering of Building Integrated Photovoltaics (BIPV) through computational design and 3D printing for highly customized non- standard filters and panels that result in site-specific non-mechanical tracking solar collection systems. **By leveraging the beauty and performance of nature’s toolkit, Agrivoltaic Architecture demonstrates an adaptable system through 3 linked prototypes (Energy Pods, Green Weave, & Light Meander) with low greenhouse gas emissions (GHG)**, showcasing the potential of sustainable design for a resilient land use model to provide an **integrated approach to food, water, energy, and shelter**.

## TECHNOLOGY

Our design strategy for Argrivoltaic Architecture considers efficiency of site-specific agrivoltaics, material consumption in fabrication, and the aggregation and optimization of building components to form pavilion, farming, and wayfinding typologies integrated in the Fly Ranch context. **This multi-program system for agrivoltaics and solar power generation offers creative design solutions to prevalent engineering problems present in current solar technologies.** With the implementation of agrivoltaic systems, spatial competition between food production and solar collection is alleviated and has been shown to increase land productivity by 60-70%1. Integrating PV systems and infrastructure in the early phases of design, this proposal aims to inspire widespread integration of sustainability, technology, design, and aesthetics. The majority of ubiquitous BIPV and building-applied photovoltaic (BAPV) technologies forego the opportunity to **utilize PV cells as a compelling design element**. This project innovates the design and engineering of PV cells through advancements in computation and 3D printing for highly customized bio-inspired filters and panel assemblies that leverage the **phenomena, beauty, and performance of light absorption for energy generation.**

**The arrangement of PV cells and light filters create an ideal ecosystem to grow crops native to the Fly Ranch environment** in partial shade leading to an increased CO2 uptake, high production yields and better water-usage efficiency. At the same time, the lower amount of transpirational water loss result in the PV panels in an agrivoltaic system being cooler during the day, which increases renewable energy production, lower LCAs and prolongs the retention times of water within the soil. To overcome some of the inefficiencies inherent in traditional static PV arrangements, we develop three design methods based on fundamental operations of photosynthesis - heliotropism (orientation), light scattering (filters), and cellular morphological responses (module shape) to varied radiant exposure. Nontraditional photovoltaic cells designed to transform light into electricity, significantly reducing GHG emissions.

With innovative computational design tools, we are able to design and engineer PV arrays which respond more systematically to light and dynamic contexts. Most contemporary sustainable approaches to reduce CO2 emissions offer technological solutions through sanctioned rating systems such as LEED. While these measures adequately address resource consumption in buildings, they do not address the systemic ecology of the built environment over the long term or the role of aesthetics in exciting the general public about the importance of employing sustainable building materials and practices in our private and public domains.

## ACTIVITIES

Agrivoltaic Architecture poses not a singular pavilion, but a scalable modular system that can be contextualized, aggregated and transformed in multiple ways to respond to functional urgencies and design priorities of varied contexts. In one organization as Village Pavilions known as Energy Pods, the system can be assembled as a series of inhabitable shelters, **an Eden where energy collected supports users’ overnight sojourn through stored power and greenhouse farming for local food production through agrivoltaics.** As Green Weave, it accommodates agrivoltaic farming, the co- development of land for both solar photovoltaic power and agriculture2, where the system energy is stored in batteries. Lastly, as Light Meander, the system can become a desert waypoint offering shelter and power needs between sites of interest, a wayfinding device and light network at night, or even backyard canopy where the system could be connected to the grid and aid domestic energy demands.

## MATERIALS, DIMENSIONS, & COST ESTIMATE

The Energy Pods, Green Weave, and Light Meander that compose Agrivoltaic Architecture consist of cradle-to-cradle materials, including a bottom HDPE waffle grid, a hexagonal grid shell, and a top cell array, with intermediate elements including aluminum pipes, 3D printed nodes and dichroic film filters mounted on plexiglass. The HDPE frame makes up for the structural skeleton and ground connection of the system with varied configurations based on type (Energy Pod, Green Weave, Light Meander). This grid shell supports the PV cell system on its exterior and hosts another layer of hexagonal dichroic coated plexiglass elements. These exhibit **atmospheric light diffusion** and create a changing and colorful light experience for pavilion inhabitants. The proposed Energy Pod prototype is 130 square feet (12 square meters), 9 feet 10 inches (3 meters) by 15 feet 3 inches (4.65 meters) and contains approximately 500 PV cells and three 1.2kWh EnergyCell 106RE batteries, which will operate at 12v, 100AH over 20 hours.

Based upon recent proof-of-concept models, prototypes, and research, we estimate a total maximum order of magnitude cost of $30,000 to fabricate and construct an Energy Pod prototype at Fly Ranch. A rough breakdown of this estimate includes the following: material costs $20,000, fabrication and transport fees $6,500, and $3,500 for equipment, including $1,100 for three Energy Cell batteries and $900 for PV cells.

## OUTPUTS & INPUTS

In total, the sum of all systems can accommodate thousands of PV cells and support 300 hectares of agriculture. The Energy Pod module, our proposed prototype, contains 498 PV cells in 125 panels and supports approximately 1 acre of agriculture. Module output for one 4-cell grouping at maximum power point (mpp) is recorded, after lab measurement of an early model prototype, as follows: the voltage at maximum power point is measured at 2V, the current at 2.07 A, and the power at 4.12 W. Therefore, average daily energy output for a desert-climate for each system application is measured at 3.42 kWh, with a module efficiency of 17%.

The installation will require minimal maintenance over its lifetime. All materials are durable and of an outdoor grade quality. These materials should be able to withstand the seasonal temperature changes of Fly Ranch as well as other typical outdoor environmental events. We suggest cleaning the Energy Pods semiannually to remove dust and particulates that have collected on the project. All materials can be safely cleaned using a non-toxic surface cleaning solution and a damp wrap or towel. The Green Weave will be largely self-sufficient, in part due to the farming of native plants and self-sufficiency of the solar collection system.

## PROTOTYPE DEVELOPMENT

Early prototyping is essential to test the integrity within the assembly system and to cross-reference energy yield with the projected efficiency calculation of the photovoltaic system. Initial studies, system testing, and physical mockups have provided proof of concept for our proposal and we are well prepared to construct and assemble a full prototype. Components will be prefabricated to be transported and assembled on site. CNC-machining produces the ribs and connection slots while 3D-printed joints allow for nonstandard orientations, clusters of modules and panels, and waterproofing for PV wiring and diodes. PV cells are prefabricated and produced offsite, encapsulated and encased in digitally fabricated acrylic sheet material, and organized by cell family and shipped to the site for the construction and installation of the Energy Pod pavilion. Each panel will be wired offsite and connected in series as the pavilion is erected on site at Fly Ranch.

## CONCLUSION

With its potential for diverse applications integrating technology, environment and community, as Energy Pods, Green Weave, and Light Meander, Agrivoltaic Architecture will inspire community, play and wonder at Fly Ranch. This proposal will be an immersive, socially and environmentally responsive habitat, offering creative design advancements in solar technology and agrivoltaic systems. Through an integration of sustainability, technology, design, and aesthetics, Agrivoltaic Architecture embraces local ecologies and invites meaningful creative thought truly emblematic of Burning Man’s sustainable initiatives at Black Rock–High Rock NCA and Fly Ranch.

# Environmental Impact Statement

Like the sunflower, non-conventional configurations maximize energy conversion and efficiency in photovoltaic elements. Optimization of structure, wiring and componentry additionally reduces material usage and cost. Clad in photovoltaic elements, the structure is made from recycled and recyclable materials, including HDPE, up-cycled scrap aluminum and wiring, dichroic film and altuglas made of bioplastic, and 3D-printed nodes composed of PETG filament created from recycled bottles with the intention of cradle-to-cradle assembly and disassembly. These nodes are essential in not only providing connection between the pavilion’s structural and photovoltaic elements, but also hosting and waterproofing PV wiring paths, connectors and diodes. All PV cells are standardized to create 20 unique cell families for manufacturing ease.

PV cells capture light, creating a partially-shaded area and energy storage in the proposed farming environments. The interior of the agrivoltaic system hosts shade plants taking full advantage of sunlight. While solar cells capture a portion of the sunlight, uncaptured light filters through gaps between cells, providing light for native crops for food production for visitors and residents.

While operation of Photovoltaic systems (PV) has negligible greenhouse emission gases (GHG) compared to fossil fuels, fabrication of solar panels does not. However, a horizontal 1-axis tracking can improve environmental profiles of PV systems by approximately 10%3. The GHG for the entire lifecycle of PV power production for two of our module prototype systems, one installed in the South West & one in the North East was calculated following the parametric modeling proposed. The model contemplates two types of silicon products, single crystalline (sc-Si) and multicrystalline (mc-Si) with a 17% and 16% efficiency respectively, a cell temperature of 25 °C and degradation rate of 0.7%/yr, shown in the table below. Values are compared to the GHG emission from combined cycle natural gas and supercritical coal power. The proposed approach for Agrivoltaic Architecture tracks the sun without having to add the 50% more structural metal and 30% more copper cable per module, decreasing significantly carbon intensity by 15% for an installation in the southwest. The carbon intensity for our 17% efficient single crystalline Silicon (sc-Si) installation in a desert-climate location is based on average daily insolation of 7.35 kWh/m2/day.

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| --- | --- | --- | --- |
| Power (kWh) | GHG Solar (kg CO2 – e) | GHG Combined Cycle (kg CO2 – e) | GHG Supercritical Coal (kg CO2 – e) |
| 3.44 | 0.133 | 1.68 | 3.32 |

## ENERGY GENERATION, STORAGE & OUTPUT

**Energy Pod System**

498 Cells in 125 Modules

Module Output at maximum power point (mpp) measured in the lab Voltage @ mpp = 2V

Current @ mpp = 2.07 A Power @ mpp = 4.12 W

Average daily Energy Output for AZ insolation = 3.43 kWh Module Efficiency = 17%

## Powering Your Energy Pod with Sunlight

Solar energy gathered during the day is stored and emitted during the night in the form of light energy.

Three 1.2kWh EnergyCell 106RE Nano-Carbon VRLA-AGM

Operates at 12V, 100AH, (100Ah @ 20hr)