Agrivoltaic innovations: Co-locating food production, water harvesting, & solar renewable energy generation for the cooling of urban heat islands

- How to maximize desert crop yields, water savings, and energy generation under rapid climate change. Gary Paul Nabhan, with Greg Barron-Gafford et al of the University of Arizona’s Water-Food-Energy Nexus interdisciplinary team
We are all aware that global climate change will affect our food security, but how can we dampen the causal factors &

**Our Coming Food Crisis**

Op-Ed Contributor
by Gary Paul Nabhan
• July 21, 2013

- TUCSON, Ariz. — THIS summer the tiny town of Furnace Creek, Calif., may once again grace the nation’s front pages. Situated in Death Valley, it last made news in 1913, when it set the new record for the world’s hottest recorded temperature, at 134 °F degrees (56.6 °C). With the heat wave currently blanketing the Western states, and given that the mercury there has already reached 130 degrees, the news media is awash in speculation that Furnace Creek could soon break its own mark.

- The real problem isn’t simply spiking temperatures, but a new reality in which long stretches of triple-digit days are common — threatening not only the lives of the millions of people, but affecting the productivity of the very crops that provide our food security as well.
Beirut, just like my home in Tucson, Arizona, USA is an urban heat island where ambient temperatures have been rising even faster than the global average. What can these metro areas learn from one another that can enhance our food security in the face of climate change?
How can we use principles from the **desert ecology of “nurse plants”** for **biomimicry design** of food & energy systems? We want crops to have “**sheltering canopies**” to protect their yields & harvesters from severe **heat & drought** related stresses!
In Tucson USA’s Desert Laboratory & Biosphere Two, we are designing new agricultural systems based on insights from 100+ years of desert ecology research.
We know desert legume trees provide the following ecosystem services:

1. **Soil stabilization** & colonizing opportunities for vascular-arboreal mycorrhizae that understory plants require for recruitment & establishment

2. **Buffering from extreme hot & cold** temperatures & catastrophic freezes or droughts

3. **Buffering from hard rains** & improved moisture-holding capacity

4. Positive (& some negative) **ecological interactions** among understory plants & their nurse tree

Protection from browsing & damage by large animals
How can agrivoltaics do the same?

agrivoltaics = agriculture + photovoltaics

- We are investigating the potential for reintroducing vegetation into the typical PV power plant installation in drylands. Why??
- We think that this novel approach may lead to reduced urban heat islands, increased renewable energy production, increased food production, and enhanced water use efficiencies!
Is agri-voltaic food systems research a bridge between controlled environment & natural systems agriculture?

- **AVFS can draw upon existing solar photovoltaic arrays** already built & financed *(3500 in Metro Tucson alone)* as the **primary infrastructures for food production** rather than building **controlled environments** from scratch at higher costs.

- **They can reduce the urban heat island effects** that are exacerbated by the hard, highly reflective surfaces of these arrays, providing green absorptive cover around & under them.

- **They can put glazing, shade cloth, netting or other kinds of walls on the sides below the pv collectors** to create buffered, semi-controlled environments that reduce insect infestations & other biotic intrusions.

- They can still **grow plants in the (native) soil**, thereby enhancing the terroir of edible products.
Comparing a natural desert habitats to PV installations

A transition from (A) desert’s carbon, water, & energy flux dynamics affects the types of ecosystem services.

Within deserts, vegetation reduces heat gain and storage (down-facing orange arrows), by both shading the soil & transpiring, as absorbed energy is released in the transition of water-to-water vapor to the atmosphere (open arrows).

These latent energy fluxes are significantly reduced in typical PV installations (B), leading to greater soil heat storage and re-emission in the form of sensible heat (solid red arrows). (C) A novel ecosystem approach of a water-sensitive reintroduction of vegetation could yield multiple ecosystem services. Anthropogenically generated sensible heat flux from PV panels = dark brown arrows, & energy transferred to electricity = purple checkered arrows.
& if we recruit teams of renewable energy engineers, ecologists, hyrologists, agronomists & nutritional scientists to redesign photovoltaic arrays to foster urban agriculture, we can create abundance in cities by

- harvesting water off the solar collectors & funnel into storage tanks for later use or into micro-olla irrigation systems.
- buffering crops from both hot & cold extremes, including catastrophic freezes.
- expanding the cover of tree canopies, providing some ecosystem services that fully-controlled environments cannot offer.
- providing greater comfort to casual laborers harvesting crops during summer months
- providing fresh, high nutritious food crops to urban dwellers that are grown with a few kilometers of where they live & eat
What is Natural Systems Agriculture & How is it Different?

“Natural Systems Agriculture explores multi-strata mixed cropping systems based on processes found in native ecosystems, using “nature as measure or model.” The Land Institute has specifically attempted biomimicry of the natural grassland ecosystem of tall grass prairies. Critical elements of an agricultural system based on natural processes are perenniality, high biodiversity, provision of ecosystem services. It may also include integration of beneficial insects, microbes and (marketable) herbivores. Native ecosystems harbor multiple strata including a great diversity of mostly perennial plants and historically included mixed herds of herbivores. These are important features to consider use in the bottom-up bio-design of any food-producing systems that ecologically mimic natural systems...”

GP Nabhan (2014) Growing Food in a Hotter Drier Land
Origins of agri-voltaic food production systems & their relevance to solving multiple problems at once: URBAN HEAT ISLAND EFFECTS, GLOBAL CHANGE, ETC

- Farmers & scientists have long pondered the best ways to utilize sunlight to grow food & produce fuel while reducing (or generating on the same site) the inputs to do so.

- For millennia, the answer was easy: we used solar energy to grow plants that we could eat. Then, in the 1970s, the answer became more complex as fields of photovoltaic panels (PVPs) began popping up all over the planet, sometimes on former farmland. In the 1990s, farmers began growing food crops for fuels such as corn-based ethanol. The problem is that the food-fuel equation has become a zero-sum game.

- That led French agricultural scientist Christian Dupraz to ponder whether both food and fuel production could be successfully combined on one plot of land.
### Ecological Comparison of Controlled Environment vs. Natural Systems Agriculture—GPN & GB-G

<table>
<thead>
<tr>
<th></th>
<th>Controlled Environments</th>
<th>Natural Systems Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fit crops to environment or environment to crops?</strong></td>
<td>Environment controlled to foster rapid growth of select plants</td>
<td>Plant ecotypes selected to fit the ambient environment rather than remake it</td>
</tr>
<tr>
<td><strong>Degree of environmental control</strong></td>
<td>Tight temperature &amp; radiation controls</td>
<td>Poor temperature &amp; radiation controls but greater reliance through crop adaptation &amp; participatory breeding</td>
</tr>
<tr>
<td><strong>Crop product yield per area</strong></td>
<td>Intensive: high yield of product/ha</td>
<td>Extensive: lower yield of product/ha</td>
</tr>
<tr>
<td><strong>Vegetative biomass per area</strong></td>
<td>Low standing (esp. root) biomass, usually one strata</td>
<td>High standing (esp. root) biomass, usually multiple strata</td>
</tr>
<tr>
<td><strong>Embedded energy</strong></td>
<td>High embedded energy costs</td>
<td>Low embedded energy costs</td>
</tr>
<tr>
<td><strong>Embedded water</strong></td>
<td>Water efficient but high embedded water in product</td>
<td>Water efficient but low embedded water in product</td>
</tr>
<tr>
<td><strong>Pest and disease control</strong></td>
<td>Precise control of pests &amp; diseases by IPM or chemicals</td>
<td>Diffuse control of pests &amp; diseases by high diversity/spatial heterogeneity/avoidance/allelopathics</td>
</tr>
</tbody>
</table>

|                                | Controlled Environments                                                                 | Natural Systems Agriculture                                      |
| **Annual vs. perennial focus**  | Typically focused on annuals/short-lived perennials, few tolerated animals (beneficial insects) | Focused on perennial plants, sometimes with understory annuals & their favored herbivores |
| **Nutrient delivery**            | Precise nutrient delivery but little use of N-fixing bacteria or mycorrhizal associations | Diffuse nutrient delivery but high n-fixing bacteria & mycorrhizal associations |
| **Terroir/taste of place**       | Virtually no terroir effects                                                           | Place-based terroir optimized                                    |
| **Capital costs**                | High capital cost for construction, reliable return on investment                       | Lower capital costs to begin, less reliable return on investment  |
| **Labor costs**                  | Lower costs due to easy access of harvestable product?                                 | Lower cost per hectare?                                         |
| **Transferability**              | Mobile; independence for spatial constraints                                            | Place-dependent and constrained                                  |
| **Diversity of products & ecosystem services** | Low biodiversity, no provision of ecosystem services                                  | High biodiversity, high provision of ecosystem services          |
Why do current solar pv arrays create negative side effects while providing local renewable energy production?

- Larger solar installations create a heat island effect, & that is bad for the PV panels because when they get too hot, they become less efficient.

- There two ways for the excess sun energy that is not converted into electricity to leave the area: sensible heat (the energy you can feel) & latent heat loss (the energy used to convert liquid water to water vapor).

Latent heat = associated with phase changes of water vapor (mostly vaporization and condensation)
Sensible heat = energy transferred that affects the temperature of the atmosphere
Biosphere 2 Agrivoltaics Research Site: Our Pilot Project
Why might agrivoltaics benefit renewable energy production?

- We are trying to **increase the latent heat loss** from plants so that there is less **sensible heat loss**.

- Can such a simple concept potentially have a big impact?

Latent heat = associated with phase changes of water vapor (mostly vaporization and condensation)
Sensible heat = energy transferred that affects the temperature of the atmosphere
Plant cover in & around solar pv arrays cools micro-climate & reduces urban heat island effects
How might agrivoltaics benefit food plant production?

By reducing heat & water stress, & damaging radiation that also increase vulnerability to insect pests/vectors & viral diseases.
Biosphere 2 Agrivoltaics Research Site’s Tests of Three Crops
How might agrivoltaics reduce occupation hazards from heat stress for farmworkers?

- Kjellstrom et al (2016) in Annual Review of Public Health predict that by 2100, 30-40% of annual daylight hours will be too hot for harvesters to work in open sunlight, generating a 20% loss in global gross (agricultural) product.

- Petitt et al (2013) in PLOs One reported elevated risk of death due to heat-related illness --- particularly immigrant & refugee farmworkers & food service workers laboring outdoors, with heat-caused death rates rising higher for farmworkers than other occupations over the period of 2002-2009 in US deserts.

- Can harvesting in agrivoltaic shade reduce these health risks?
Goal: That food production reduces rather than exacerbates global climatic changes through a broader suite of ecosystem services...
An ideal science-technology-engineering-math (STEM) experience now in four public schools & Biosphere II Science Camps in Tucson!
Potential goals for AUB WERFA team if you consider implementing one on campus

1. Create an outdoor WERFA “STEM” teaching lab on AUB campus where students can or at AREC field stations in split-plot designs

2. Engage engineering students in solar pv array redesign with solar-tracking panels & better water-harvesting mechanisms, working with math & physics students to create optimal crop production conditions for each season

3. Engage agriculture students in selecting the best culinary herb crops for growing in these systems & comparing their yields per month in & out of shade

4. Engage health students in measuring harvesters’ heat stress symptoms when working in solar pv array shade & in open environments