Solar Power for Indoor Systems

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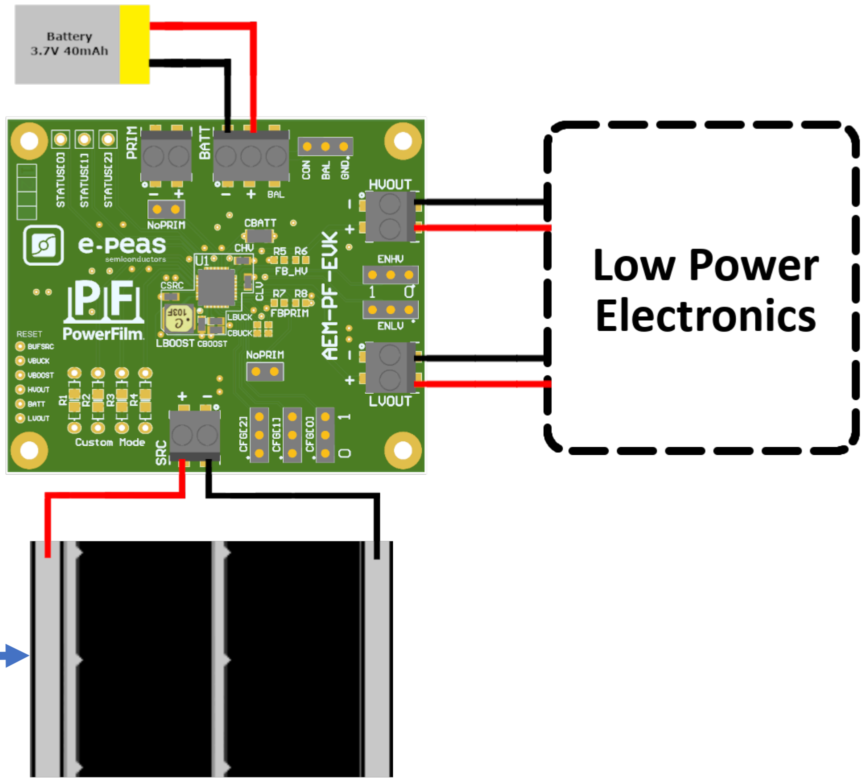
Components of an EH System

Storage Element

Charge Controller or EH PMIC

Transducer (TEG, Piezo, RF, Solar)



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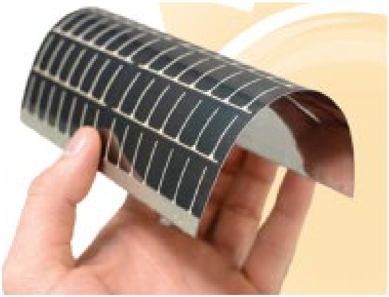
Choosing the Right Solar for an EH System



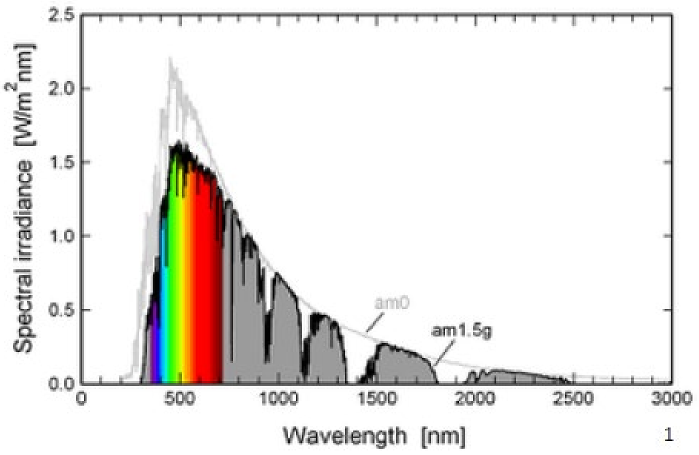
What's commercially available?

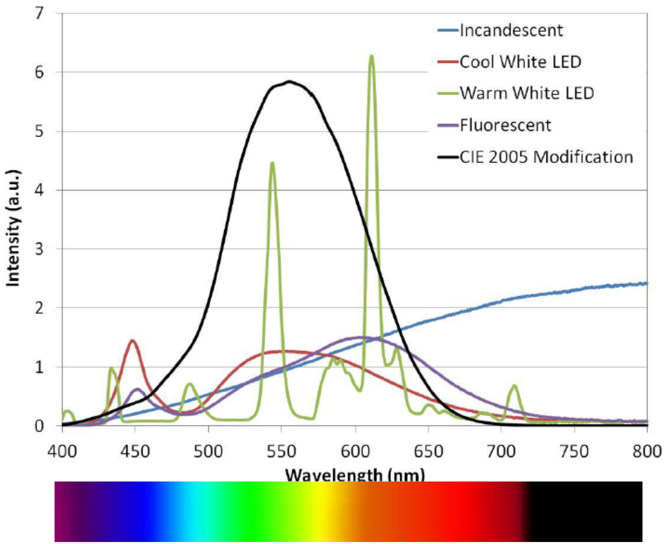
How does it work?

SOLAR

Light Energy Spectrum

Solar efficiencies quoted under light spectrum of AM1.5 at 1000W/m^2 and 25˚C

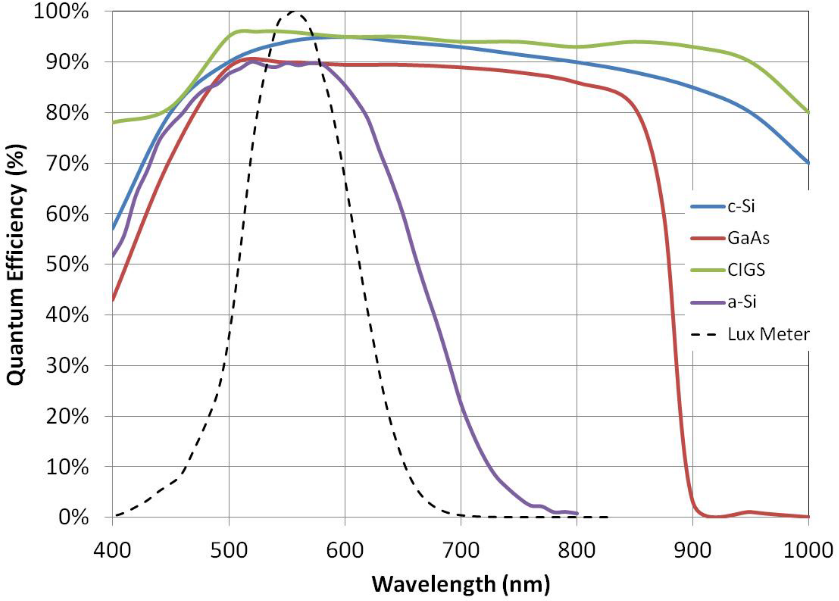


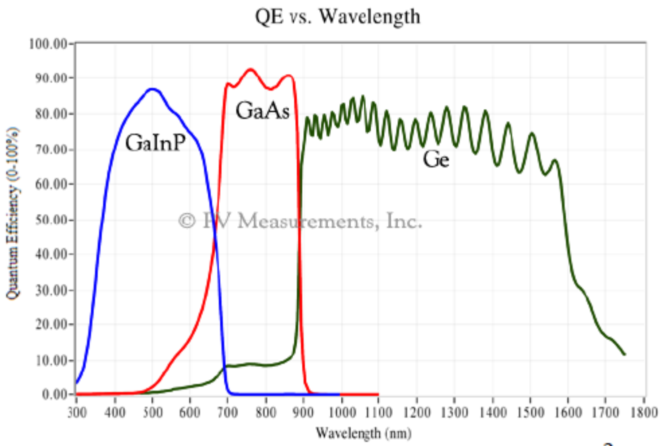


Spectrum of energy efficient light sources limited to visual range

Quantum Efficiency

Parameter that describes a solar cell's absorption efficiency at each wavelength





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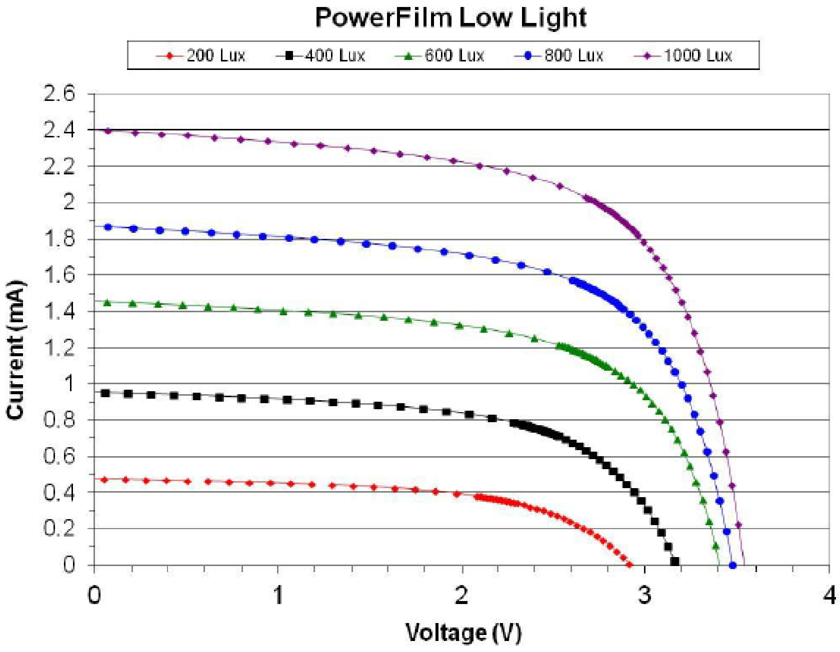
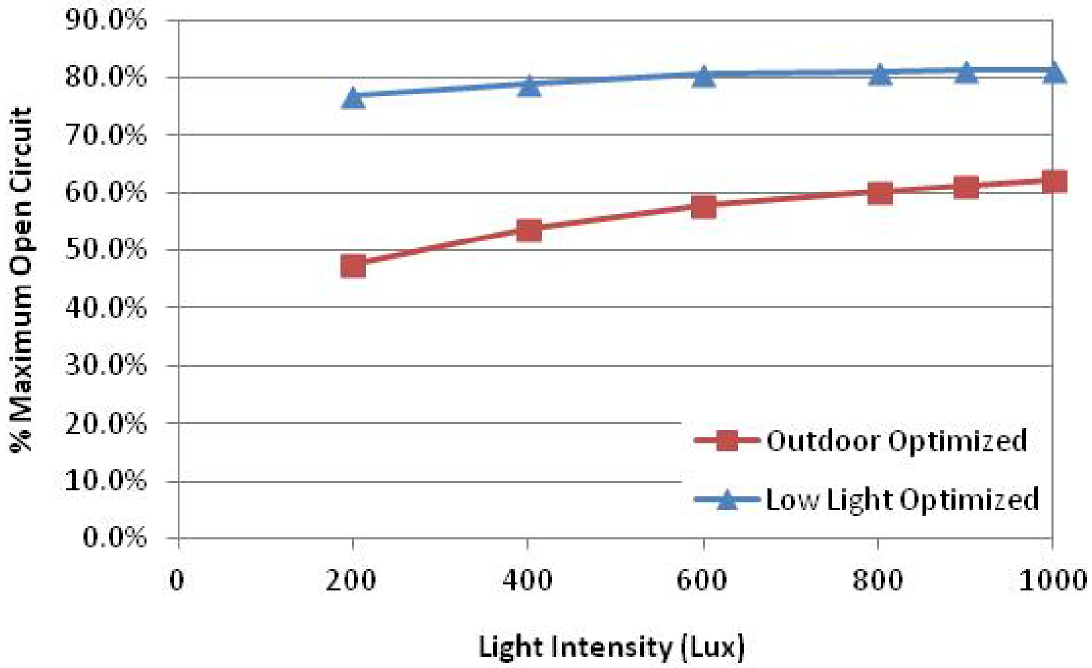
Cell matching will limit indoor performance of multi-junction cells

Solar Cell - IV Curve

- Solar cells are diodes
- Collected power depends on resistance across cell
- Current changes proportional to light intensity
- Voltage depends on a cell's shunt resistance



Solar Voc vs Light Intensity



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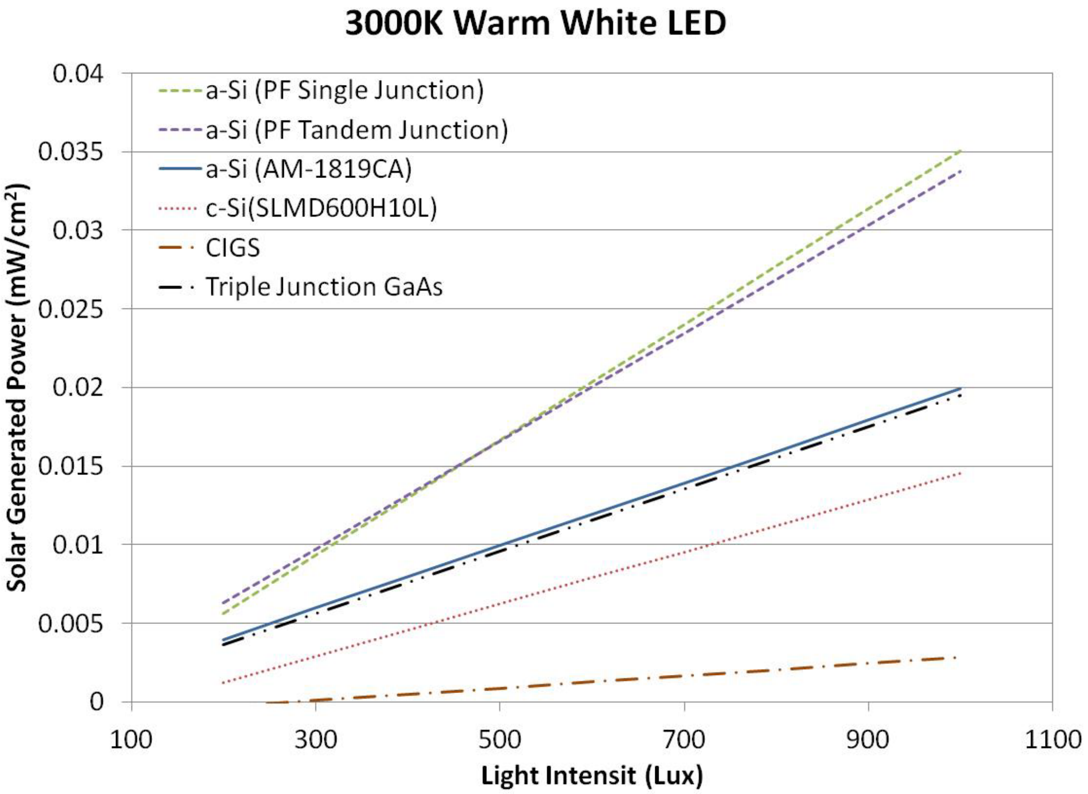
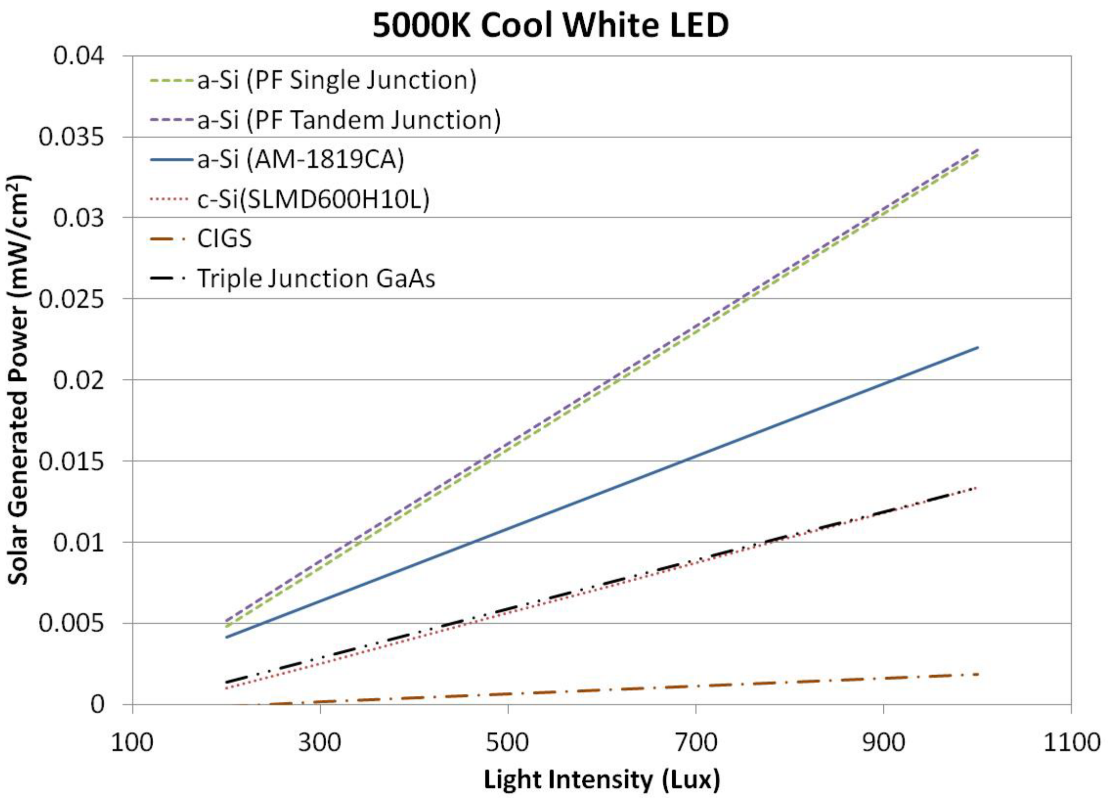
Energy Harvesting Solar Power Sources

	a-Si	c-Si	GaAs	CIGS
Weight	Light	Moderate	Light to Moderate	Light to Moderate
Area	Moderate	Low	Very Low	Moderate
Indoor Performance	High	Low to Moderate	Low to High	Very Low
Durability	Excellent	Poor	Good	Moderate
Flexibility/Conformability	Excellent	Poor	Poor to Good	Good
Thickness	Thin	Thick	Thin to Thick	Thin to Thick
Cost	Moderate	Low	High	Moderate
Shade Tolerance	Excellent	Poor	Poor	Poor to Moderate
Manufacturing	Moderate	Moderate to Complex	Complex	Moderate

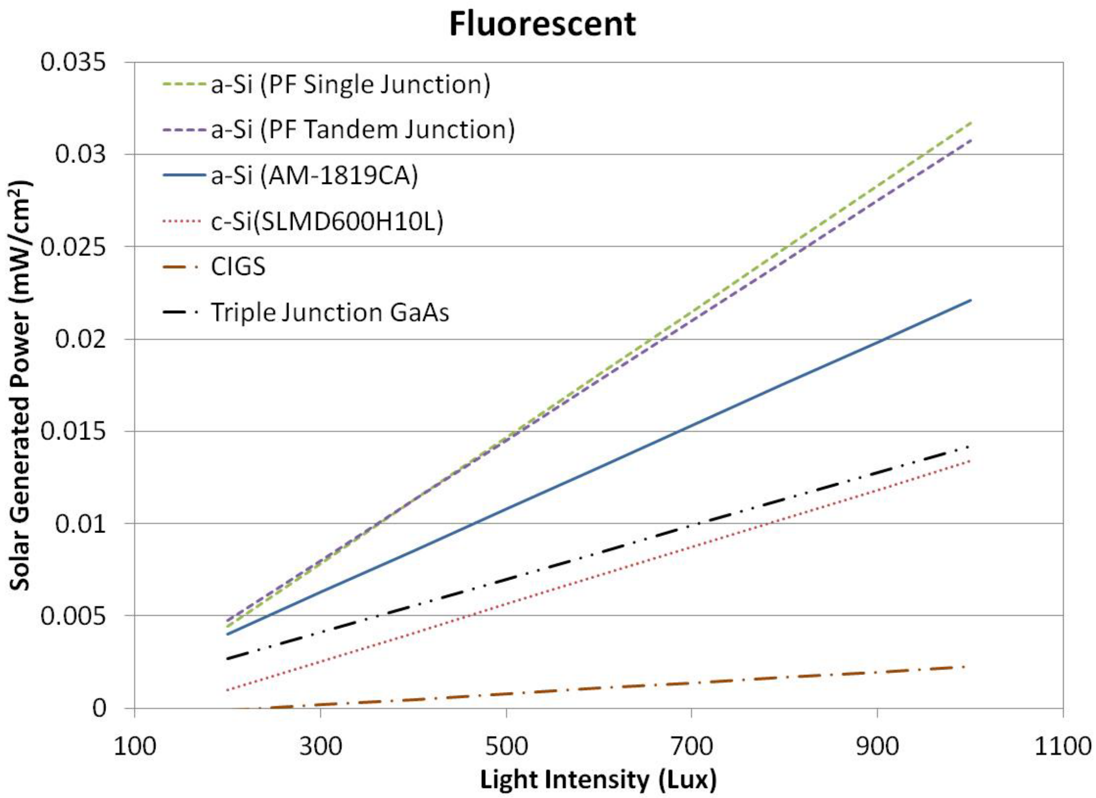
Light Source 3000K LED



Light Source 5000K LED



Light Source Fluorescent



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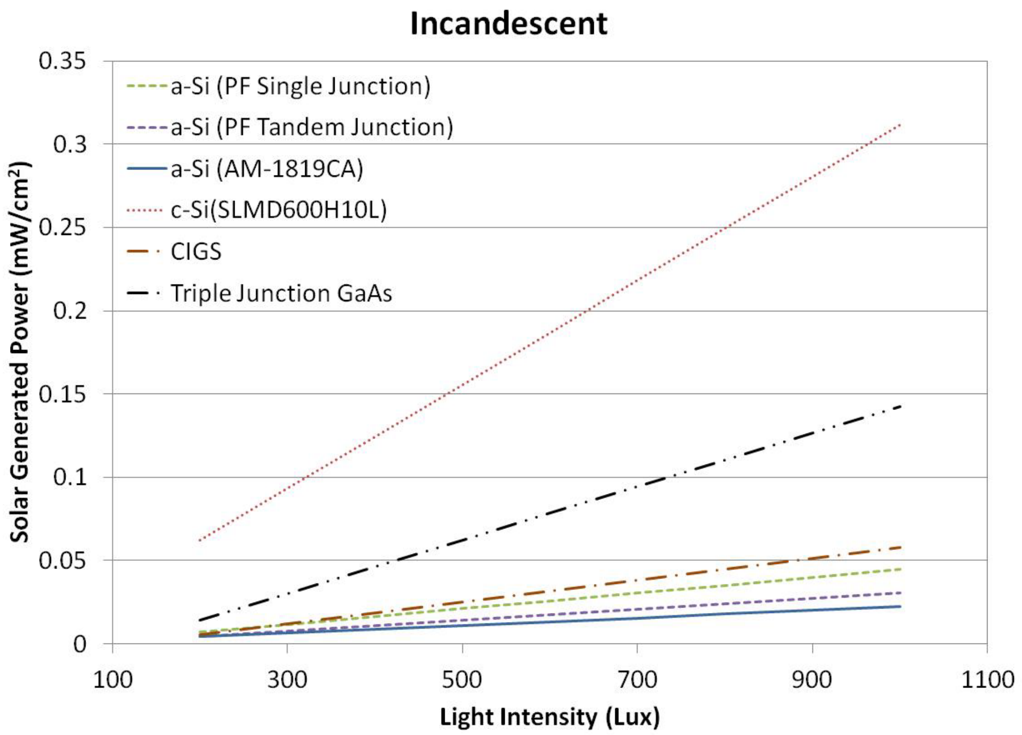
Light Source Incandescent



Selection Criteria

- Rated efficiency has no correlation with indoor performance – Quantum efficiency and leakage do
- Light source spectrum has a major impact
- a-Si collects the most power in energy efficient indoor lighting

Technology	Rated Efficiency %	Current Density (mA/cm^2) at 1000Lux		
		Fluorescent	LED	Incandescent
CIGS	8.5%	0.002	0.003	0.058
Si	18.0%	0.013	0.015	0.310
a-Si	6.0%	0.032	0.035	0.045
Triple Junction GaAs	30.0%	0.014	0.020	0.142

Estimating Solar Requirements

- Energy harvester efficiency (90%, high solar voltage improves EH IC efficiency)
- Desired days to recharge from worst case given by safety factor (5 days)
- Illumination (12 hours/day)

$$\text{Solar Generation Capability} = \left[\frac{\frac{\text{Capacity Required}}{\text{Days to Recharge}} + \text{Daily Power Consumption}}{\text{Illumination Time}}\right]$$

- Illumination Intensity – PowerFilm a-Si Solar Module LL2.4-75-200, 0.29mW @ 200Lux, 1.91mW @ 1000Lux

Daily Power Consumption (mWh)	Capacity Required (mWh)	Days to Fully Recharge	Illumination Time (hours/day)	Solar Generation Capability (mW)
	15.7	5	12	0.44
1.57	[redacted]		12	0.15
	69	5	12	1.92
6.9	[redacted]		12	0.64
Charger efficiency is 90%				

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OPV Considerations

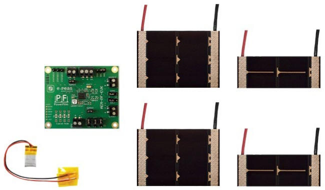
- Organic Solar Modules or Organic Photovoltaics (OPV) Considerations
- High temperature degradation.
  - High temperatures ($T \gg 300$ K), mechanical stress, or contact with water can, in principle be overcome by engineering solutions like encapsulation or active cooling(13)
- UV Degradation;
  - UV light is well known to cause degradation in OSCs, photodegradation is typically studied with UV cutoff filters, which have a typical cutoff wavelength of around 380 nm. Using a cutoff filter leads to lower light-harvesting potential of the OSCs and hence a loss in maximum current and performance of the devices.
- Moisture/Humidity Degradation;
  - There are no significant changes in the *J*–*V* characteristics of unencapsulated P3HT:PCBM cells using PMA as HTL during the course of 4 h in damp heat (85 °C/85% RH), while PEDOT:PSS-based devices are completely nonfunctional after such treatment.(14)
  - With regard to the thermal stability, the state-of-the-art device based on a PBDBT:ITIC blend with an initial 11.2% PCE achieved a T_{80} lifetime of >250 h after heating at 100 °C in a nitrogen-filled glove box (26).
- Light induced Degradation;
  - Samples that were illuminated with green light degraded linearly with *SE**h*, reducing their PCE by ≈15% within 100 *SE**h*, the samples degraded with blue light were suffering from a burn-in-like degradation behavior, in the beginning, reducing PCE by ≈50% within 100 *SE**h* (13)
- Encapsulation Solutions;
  - Glass-encapsulated annealed OPVs show good environmental stability with 4.8% loss in efficiency after 4,736 h and an estimated T_{80} lifetime (80% of the initial power conversion efficiency) of over 20,750 h in the dark under ambient condition and T_{80} lifetime of 1,050 h at 85 °C and 30% relative humidity.

Conclusions

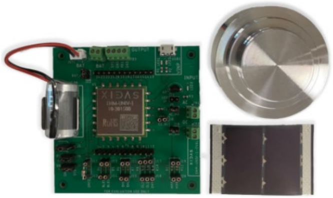
- Solar enables self sustaining sensors indoors and outside
- Rated solar efficiency has no correlation with indoor or low light intensity performance
- a-Si excels at producing power indoors
- a-Si has proven history of endurance in the field
- CIGS low performance/lack of availability
- GaAs can perform indoors, look for Single Junction devices
- OPV's are still in development
- The devil is in the details!

Getting Started

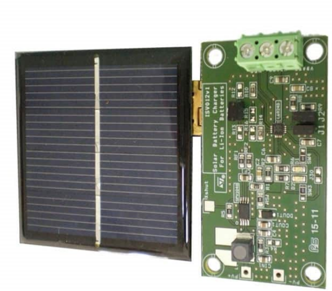
Development kits are a great way to start and available with many different harvesters and radios



AEM10941 – EPeas[7]

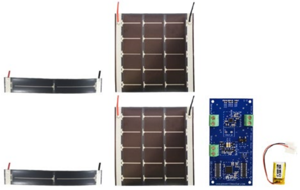


EMH-UNIV-1 – Xidas[8]

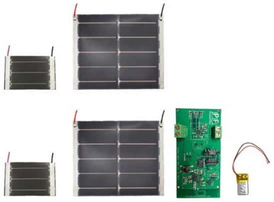


SPV1040 – STMicro[9]

MAX20361 – Maxim[14]



BQ25570 – TI and nRF52832 – Nordic[11]



BQ25570 & CC2650 – TI[12]

ADP5091 – Analog Devices[13]

Questions??

Do you have systems that you'd like to optimize and power via energy harvesting? PowerFilm can help! We would love to hear about your application and help make your vision a reality. Visit us at **Booth 962** or contact us www.powerfilmsolar.com

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