

Industry Session 5: Energy Harvesting



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Indoor Energy Harvesting with Photovoltaics

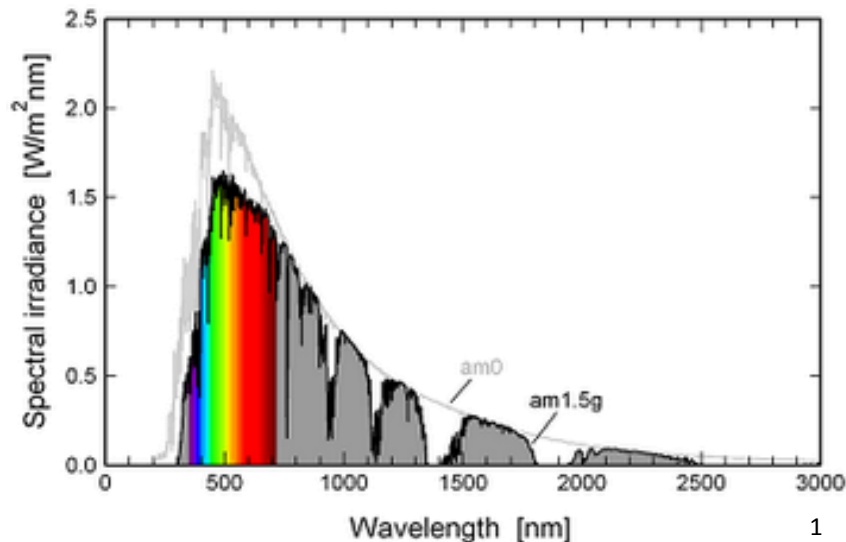
Presented By:
Dan Stieler, PhD
President

March 6, 2018

Innovative Energy Solutions

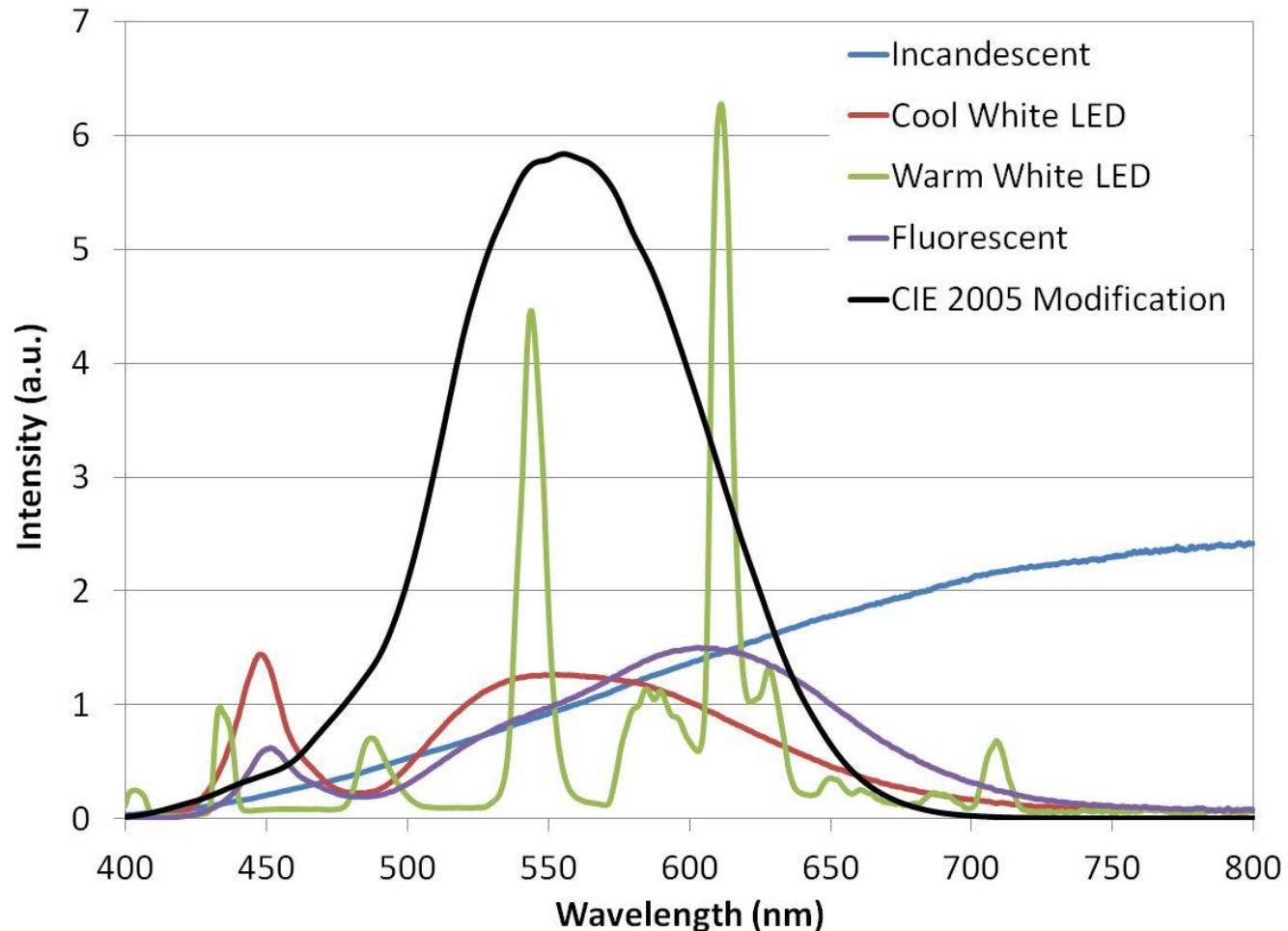
Is the efficiency the same indoors and outdoors? - No

- Efficiency is typically quoted for panels under a light spectrum of AM1.5 at 1000W/m² illumination and 25°C
- Indoor light sources have a much more narrow spectrum
- Poor cell matching in high efficiency multi-junction cells limits output
- Low intensity of indoor lighting increases impact of parasitic leakage



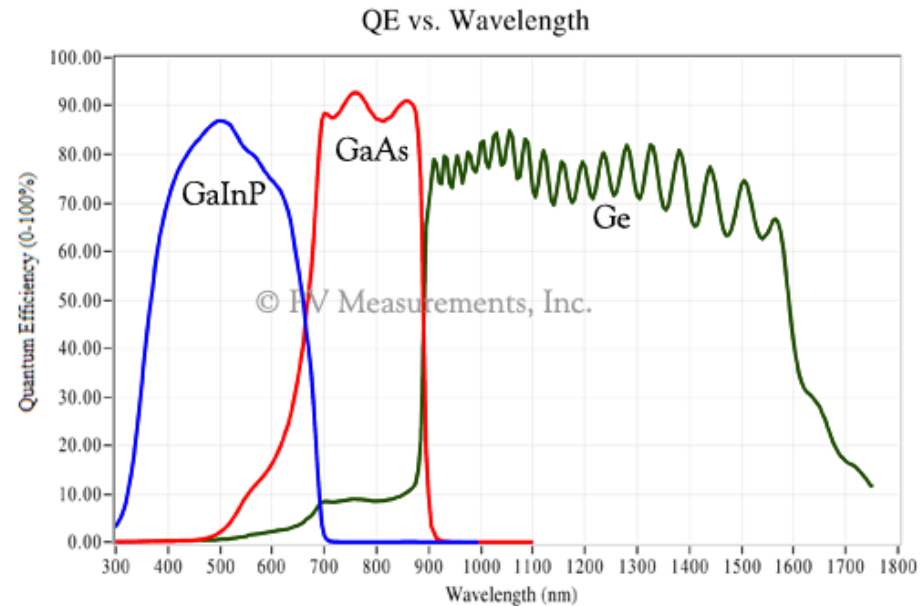
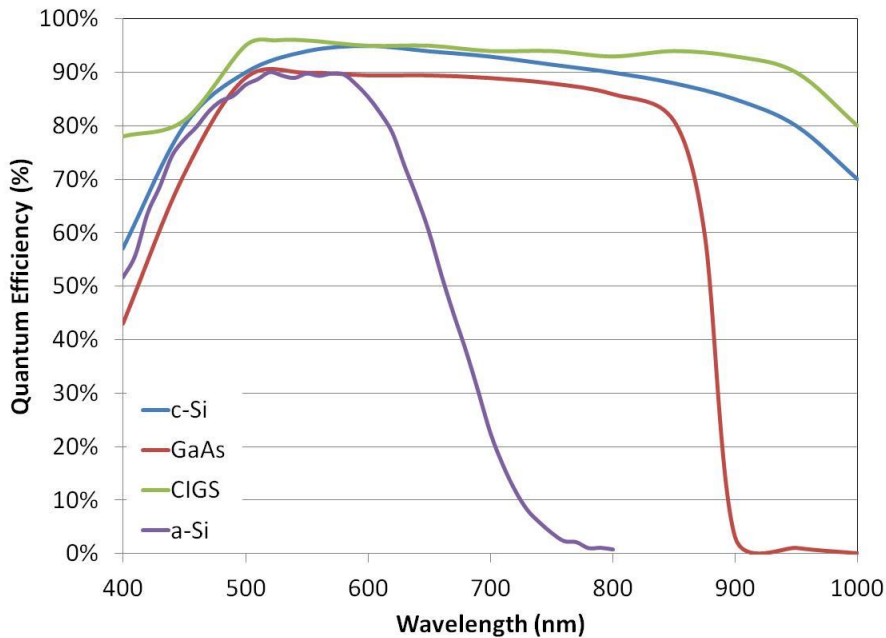
Spectra of Indoor Light Sources

- Lux Measurement
 - Set by International Commission on Illumination (CIE)
 - Based on perception of human eye, not solar cell
 - CIE 2005 Modification is most recent
 - Direct sunlight is ~100,000 lux



What is quantum efficiency?

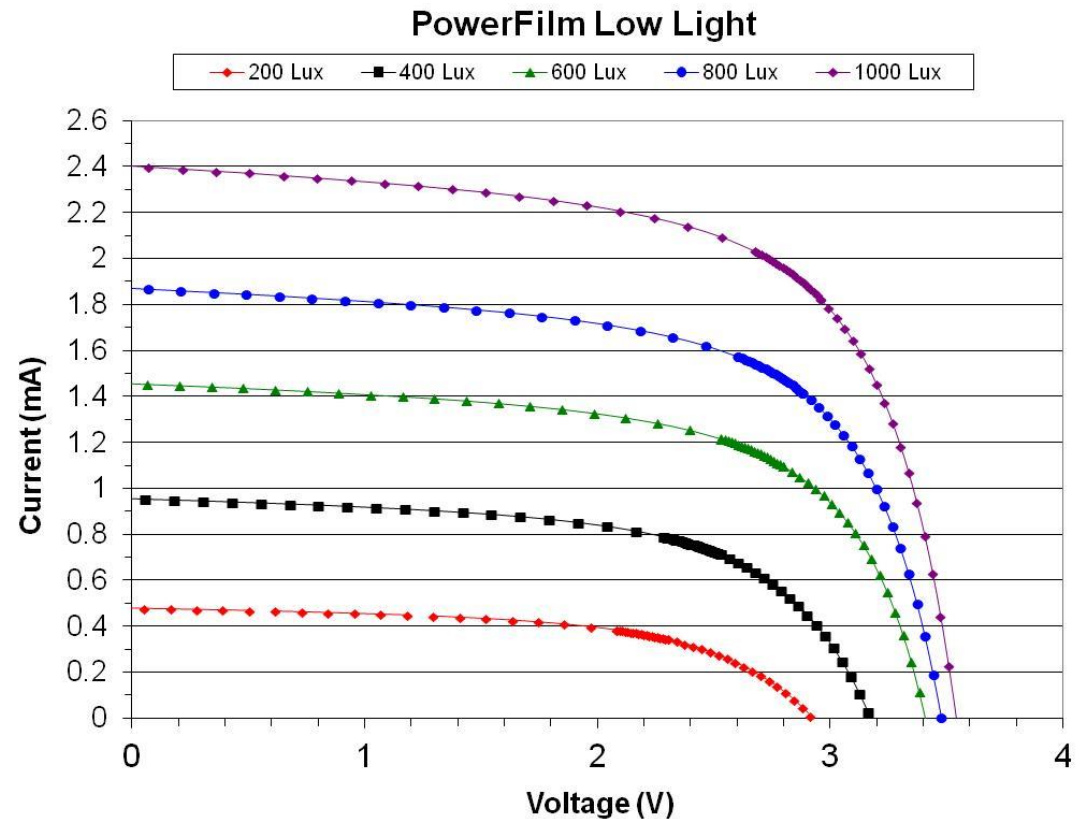
- Ratio of carriers collected at a specific wavelength or energy to incident photons.



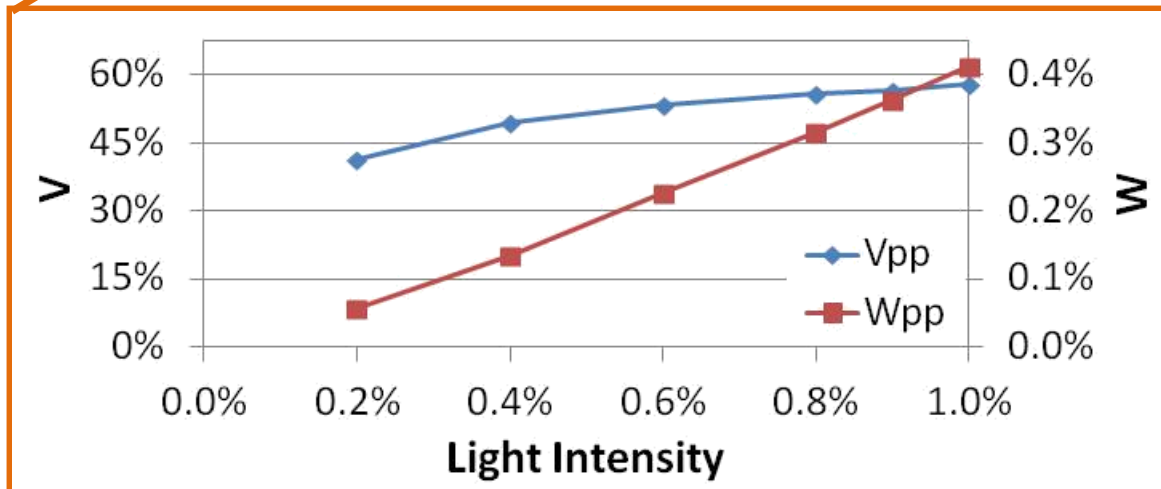
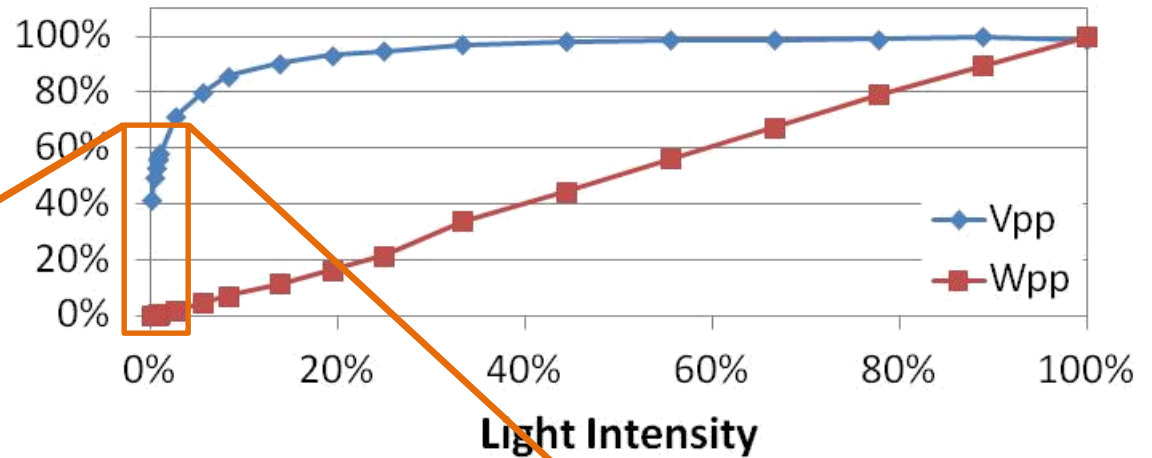
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Solar Cell IV Curve

- Current changes proportionally with light intensity
- Voltage only slightly decreases until <10% light intensity

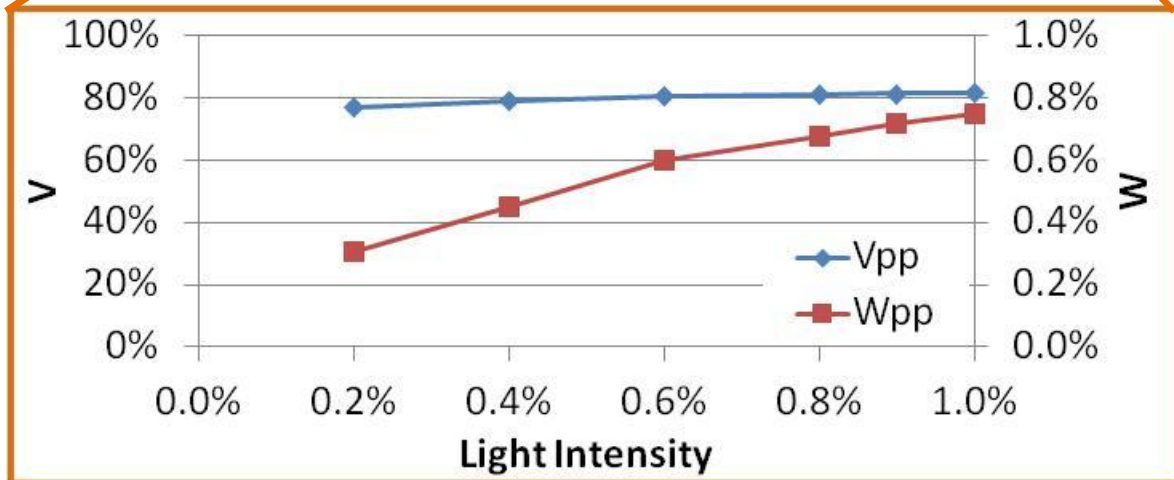
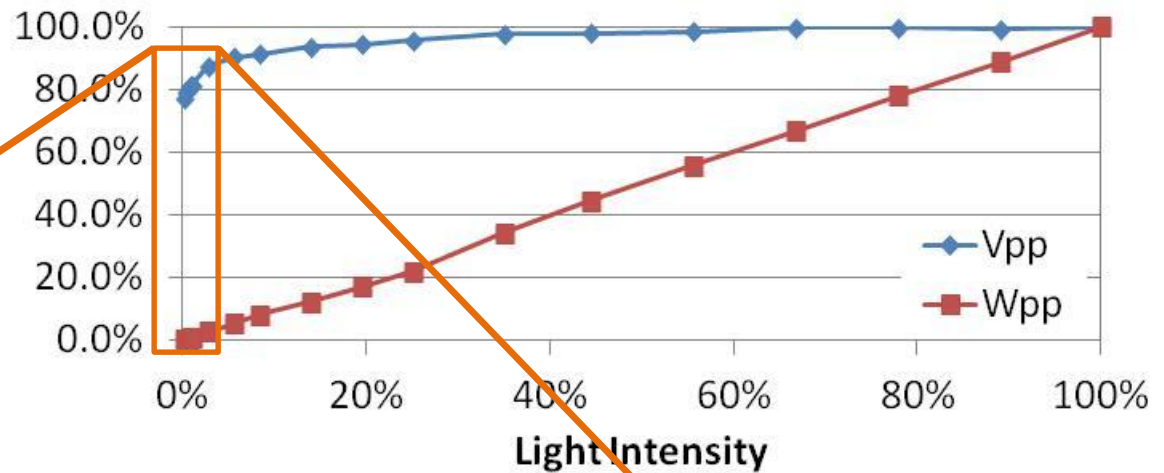


How will a solar cell respond in low light conditions?



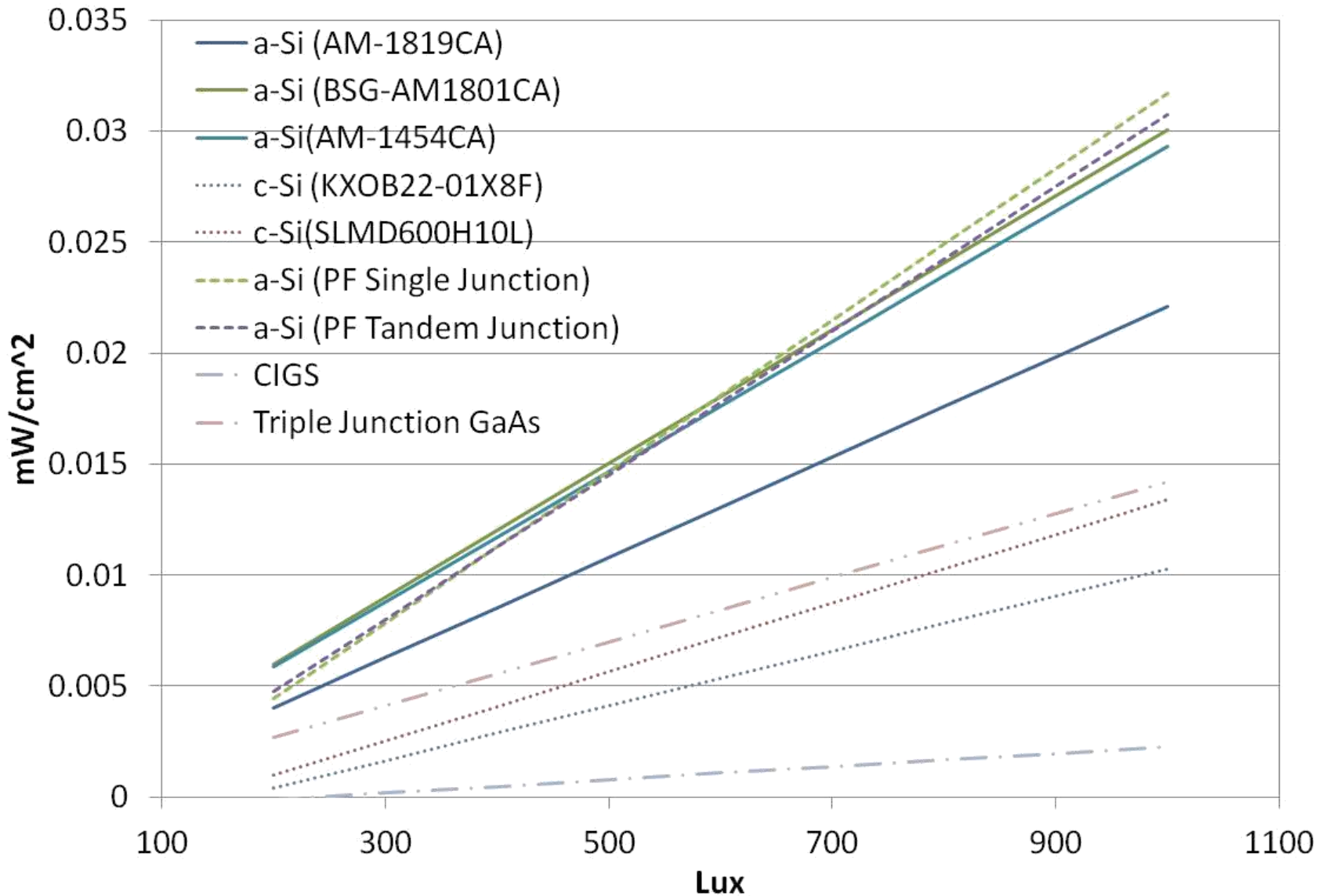
**Note that V_{pp} and W_{pp} are on different axes in zoomed plot for clarity

How will a low light optimized cell respond?

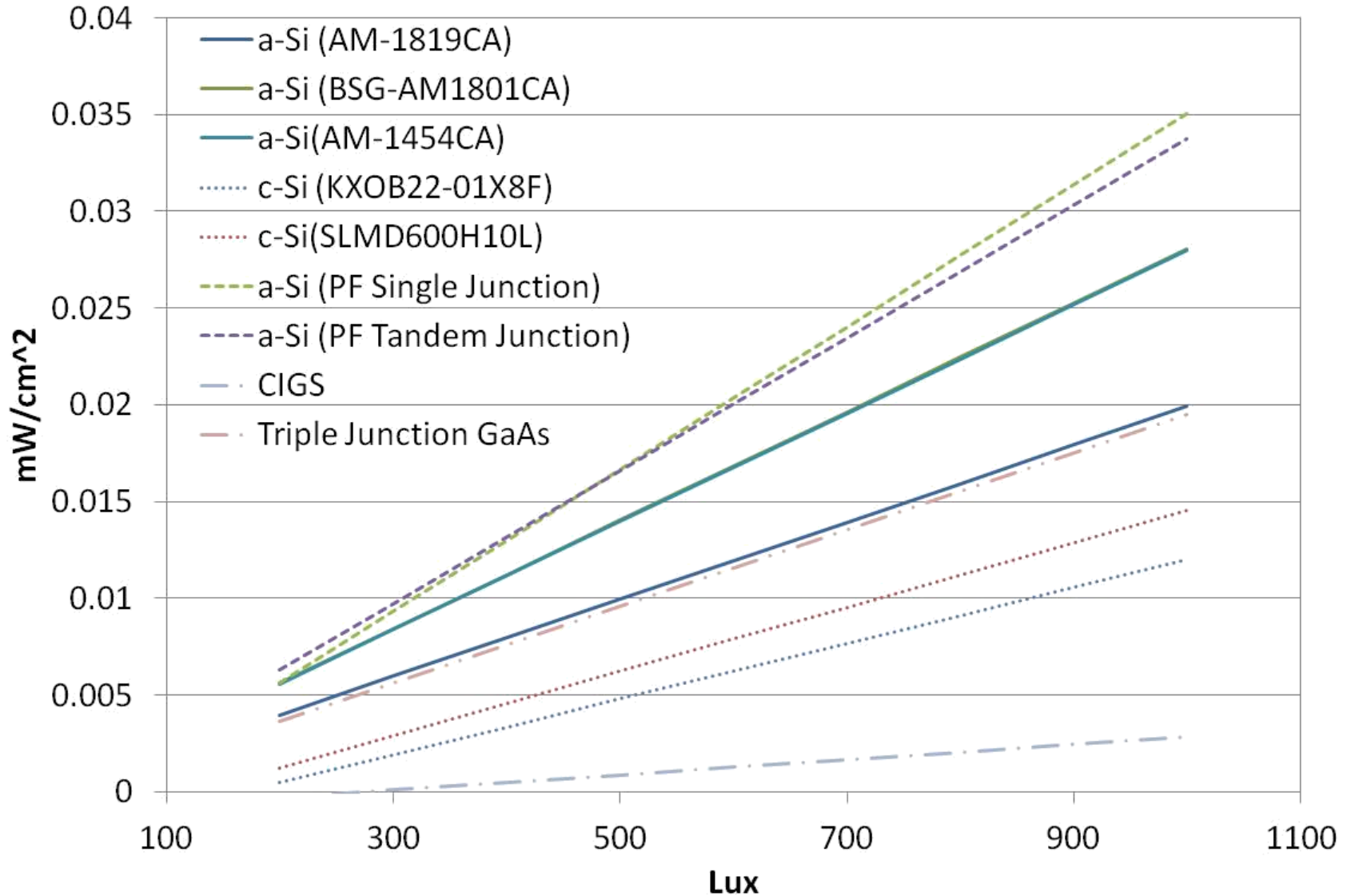


**Note that V_{pp} and W_{pp} are on different axes in zoomed plot for clarity

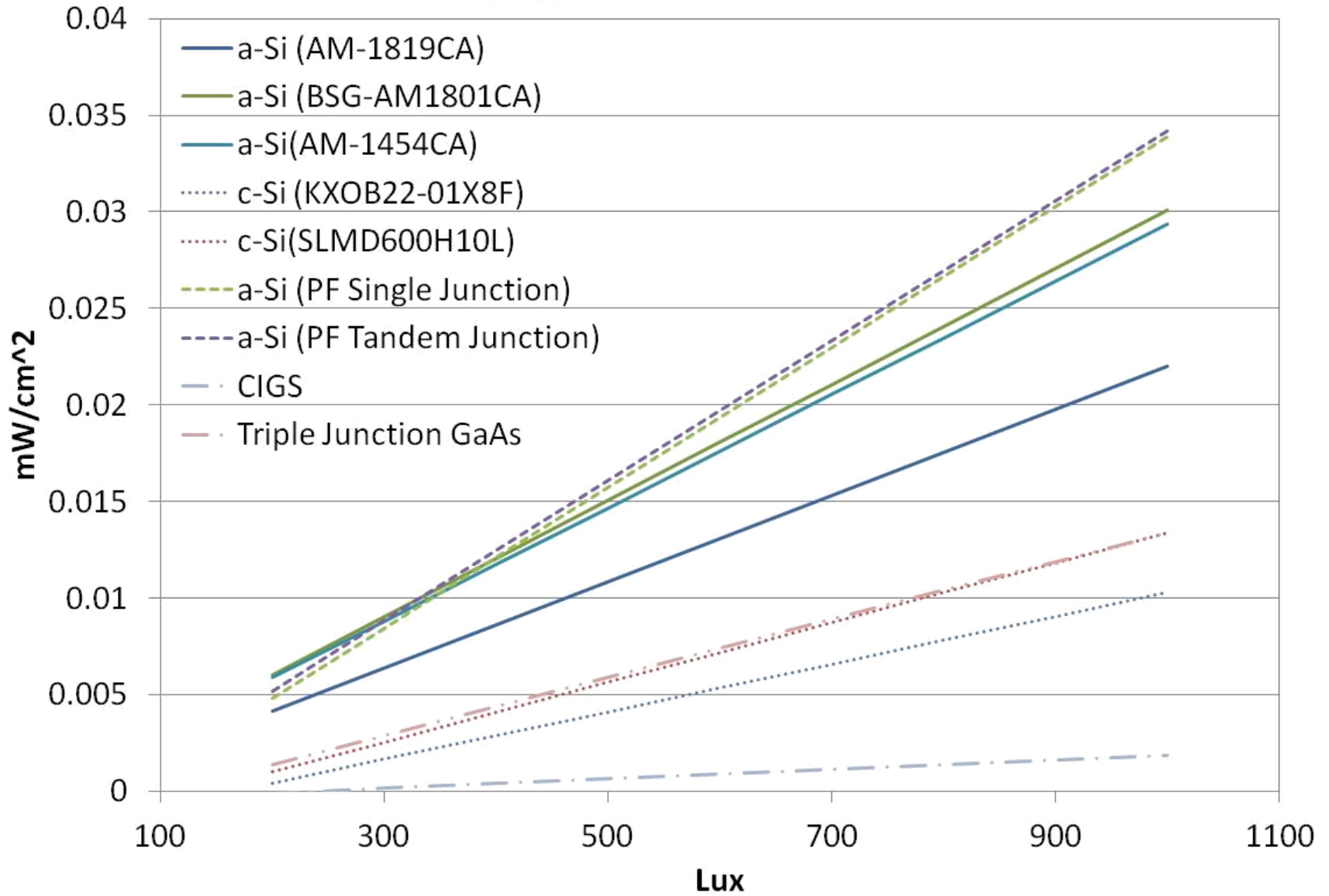
Fluorescent



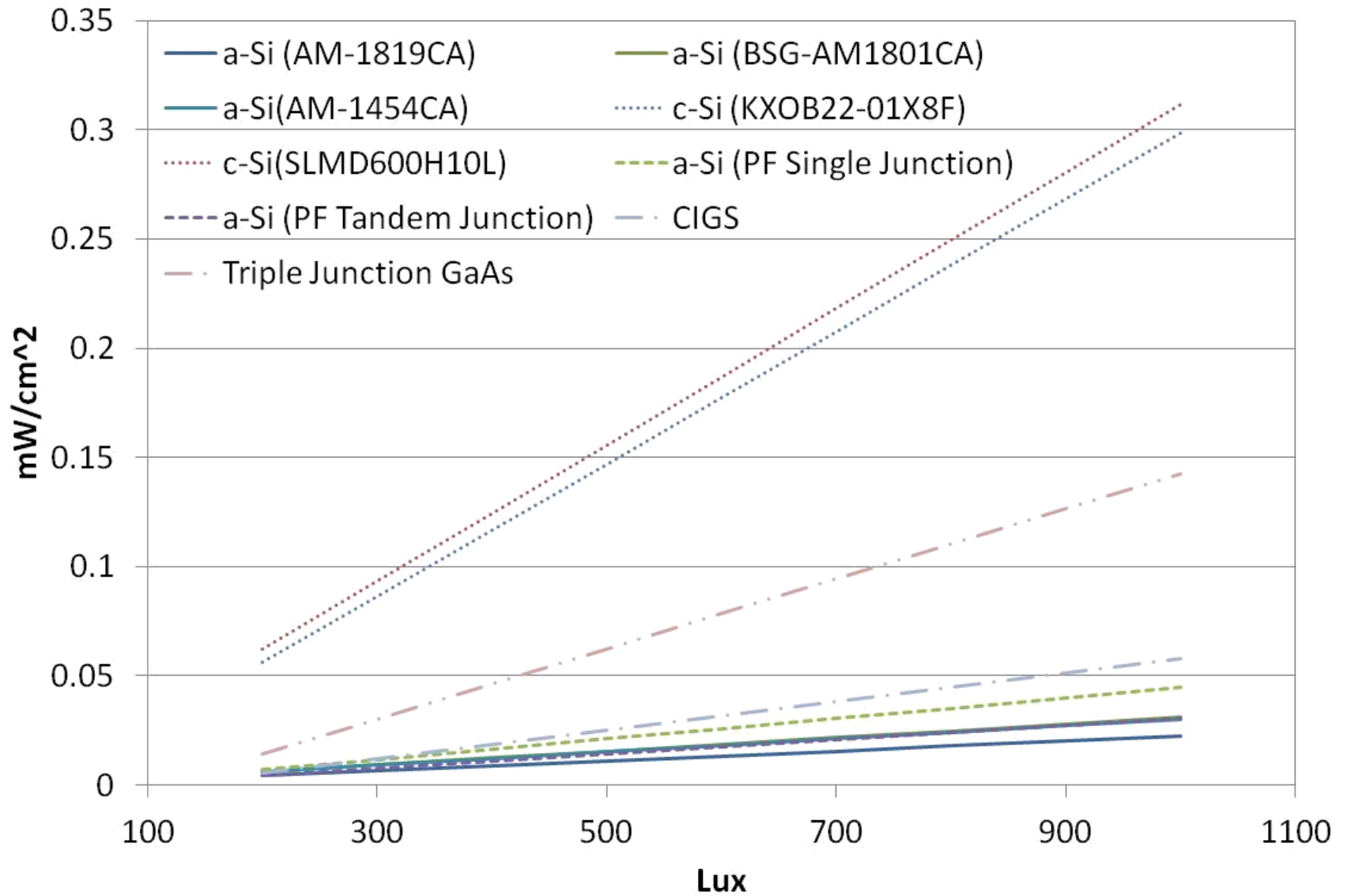
3000K Warm White LED



5000K Cool White LED



Incandescent



Illumination/Power Production

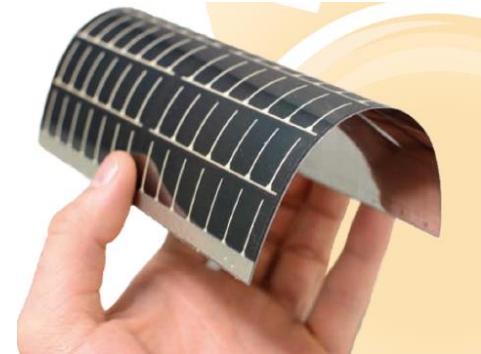
Lux	Area	Solar Power Produced ($\mu\text{W}/\text{cm}^2$)	
		LED/Fluorescent (a-Si)	Incandescent (c-Si)
150-200	Auditorium, Dining Area, Warehouse	4	50
200	Corridors, Lobbies, Tunnels, Stairwells, Bathrooms, Locker Rooms, Utility Rooms, Maintenance Shop, Loading Docks	6	60
300	Conference Rooms	10	95
500	Workstation, Library, Training Rooms, Kitchens, Physical Fitness, Child Care, Structured Parking Entrance	17	160
750	Mechanical Workshop, Supermarket	26	240
1000	Drawing Area, Detailed Mechanical, Operation Theater	35	310

Outdoor Environments	
Lux	Area
107,527	Direct Sunlight
1,000-10,000	Overcast
10	Twilight
0.1	Full Moon
0.0001	Overcast Night

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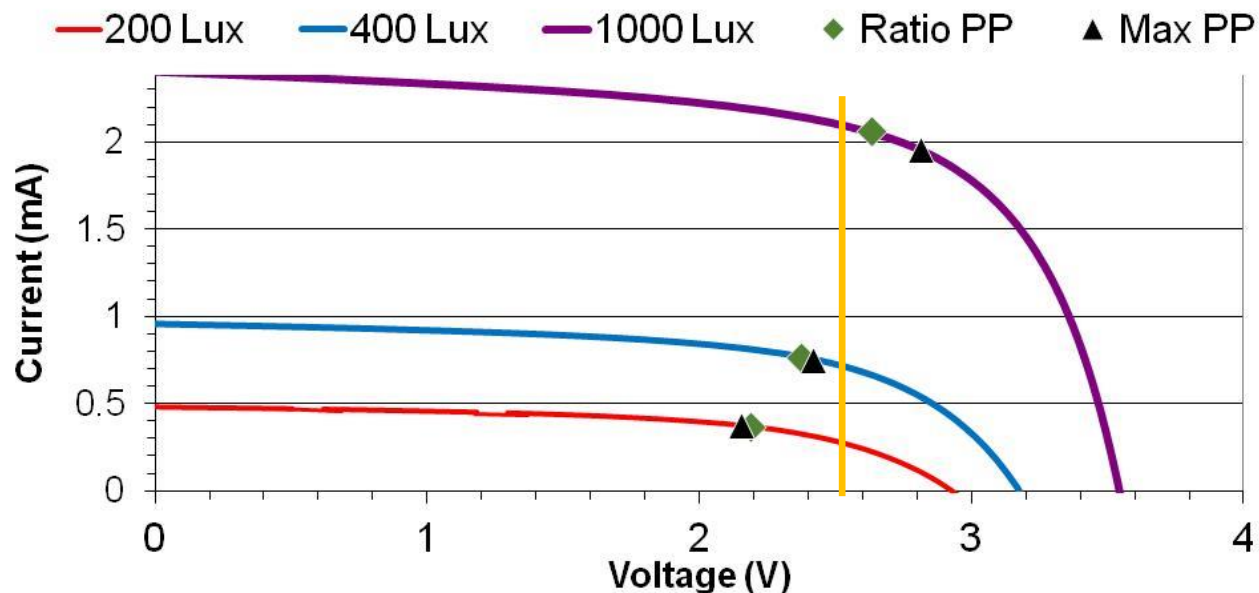
Solar Technology Considerations

- Flexibility
- Durability - Impact
- Weight (W/Kg)
- Ease of product integration (Back contact, solder or spot weld, conformable, single or multi piece)
- Anticipated light source/level
- Voltage requirements
- Environmental factors (moisture, humidity, temperature, UV, temperature cycling)



Features of Energy Harvester ICs

- Controllable input impedance for max power collection
 - Fixed set point
 - Ratio power point
 - Maximum power point



- Integrated battery charging for various battery types: Li-Ion, Li Vanadium Pentoxide, Solid State (Enerchip)
- Switcher shutdown for reduced RF interference
- Integrated solid state battery
- Under/over voltage protection for battery
- Very low voltage power collection – as low as 80mV
- Collect very low input powers – as low as 1 μ A
- Power down and power good output signals
- Power point tracking – Fixed, Ratio, MPPT

- Integrated comparator
- Primary battery backup
- Super cap balancer
- Dual energy harvest inputs
- Regulated outputs
- Efficiency
- Price
- Table of available solar compatible energy harvest ICs in Appendix A

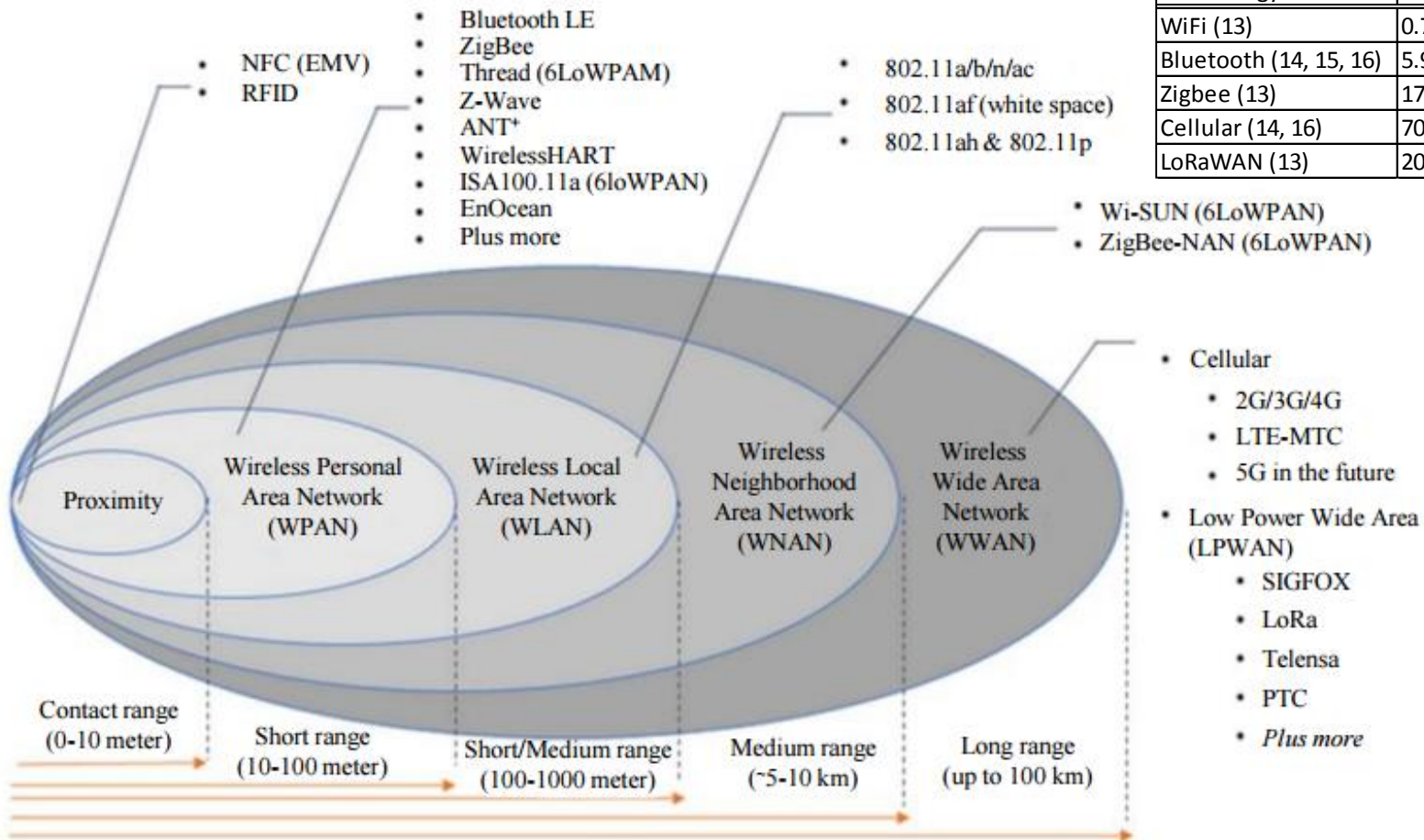


Power Consumption Considerations

- Factors that determine power consumption
 - Sleep power
 - IC sleep power
 - Parasitic power loss – High Impedance dividers and Low voltages
 - Transmit/Receive power
 - Communication interval
 - Time to connect
 - Bandwidth
 - Storage element self discharge
 - Storage elements need to be able to support peak transmit currents
 - Larger storage elements will have larger absolute self discharge

Power Consumption/Range of Wireless Technologies

Technology	Transmit Current (mA)
WiFi (13)	0.76 - 250
Bluetooth (14, 15, 16)	5.9-18
Zigbee (13)	17.6 - 40
Cellular (14, 16)	700-2500
LoRaWAN (13)	20-41

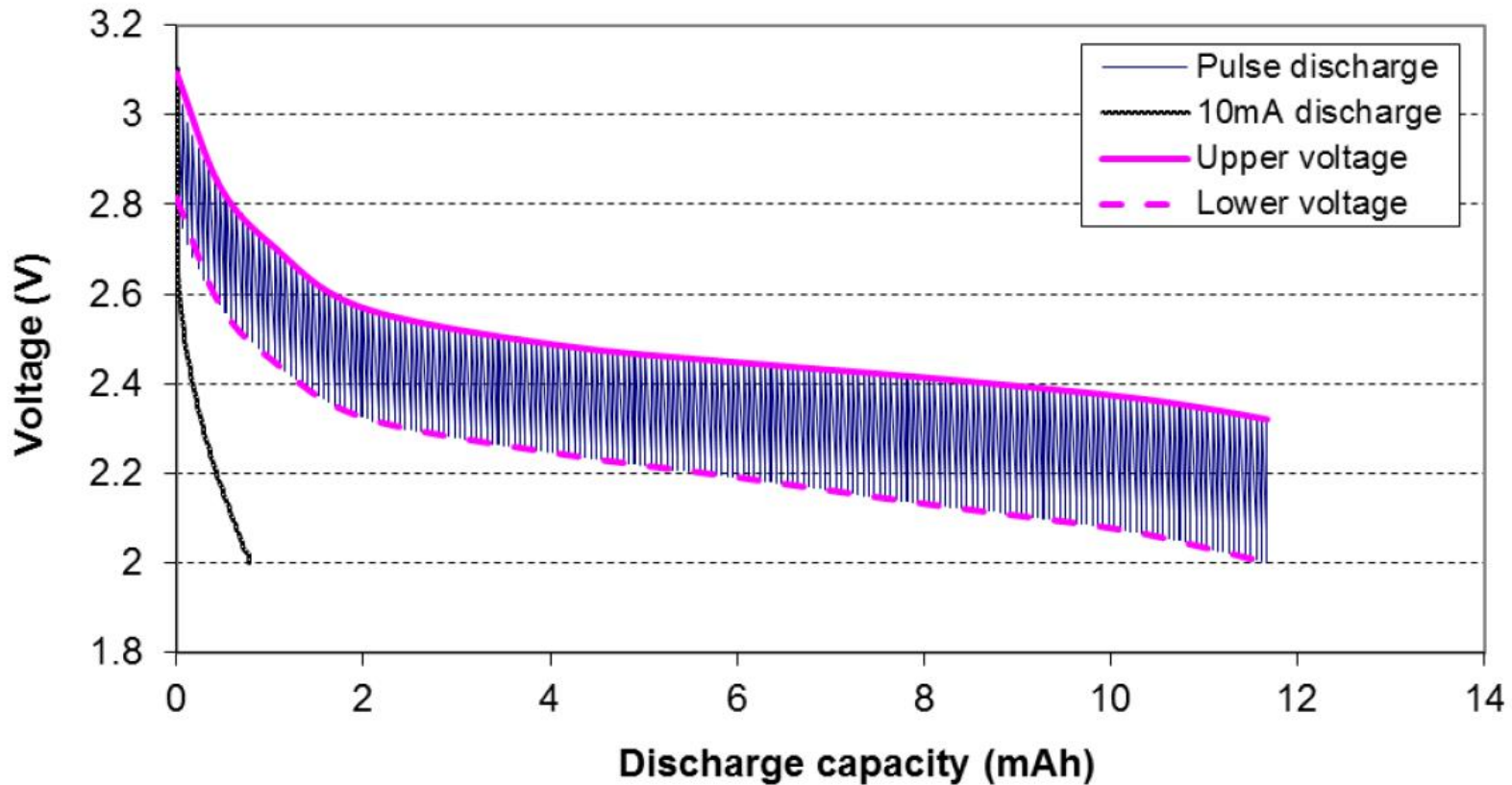


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Storage Element Tips

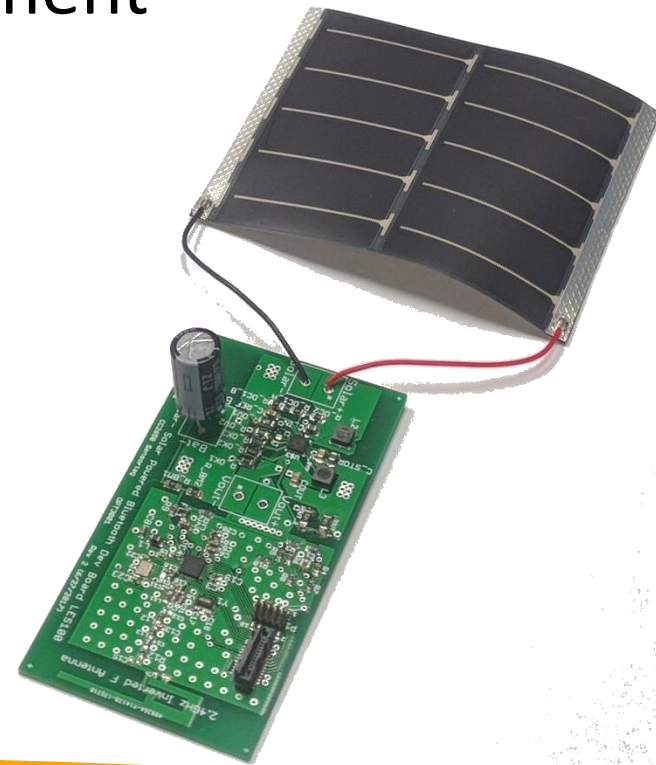
- Peak current consumption is critical to sizing storage elements
- Add tank capacitor in parallel with storage element
- Vet batteries in relevant scenario – Typically pulse Discharge
- Vet batteries for a given vendor not just battery type

Battery Capacity vs Discharge Rate



Example: Solar Powered BT Sensor

- PowerFilm LL2.4-75-200
 - produces a minimum of 0.29mW at 200 Lux
- 1800uF capacitor as storage element
- BQ25570 energy harvester
- CC2650 BT radio
 - Peak transmit current is 9.1mA
 - External Lux meter
- Sustained operation at 200 lux illumination with 1210ms connection interval (~60uA average current consumption)



Conclusions

- Efficiency of solar outdoors is not the same as indoors, parasitic loss more important
- Understand the available illumination in the operating environment to ensure appropriate amount of solar
- Choose a energy harvest IC specifically designed for solar to harvest maximum amount of power
- Know your average and peak power consumption in order to size storage element and solar panel

Questions



References

1. [https://www2.pvlighthouse.com.au/resources/courses/altermatt/The%20Solar%20Spectrum/The%20global%20standard%20spectrum%20\(AM1-5g\).aspx](https://www2.pvlighthouse.com.au/resources/courses/altermatt/The%20Solar%20Spectrum/The%20global%20standard%20spectrum%20(AM1-5g).aspx)
2. <http://www.pvmeasurements.com/Products/Discontinued-Products/qex7-solar-cell-spectral-response-quantum-efficiency-ipce-measurement-system.html>
3. https://www.noao.edu/education/QLTkit/ACTIVITY_Documents/Safety/LightLevels_outdoor+indoor.pdf
4. Mahmoud, M.S. and Mohamad, A.A.H. (2016) A Study of Efficient Power Consumption Wireless Communication Techniques/Modules for Internet of Things (IoT) Applications. Advances in Internet of Things, 6, 19-29.
5. Particle. Whitepaper, "Power Management for IoT Devices". (2017). <https://www.particle.io/white-papers/power-management-for-iot-devices?sent=true&submissionGuid=5f28f939-95a3-439b-ab68-c1677f6d80da>
6. CC2640 Datasheet
7. CC2541 Datasheet

Appendix A

Part Number	Manufacturer	Volume Price (USD)	Features						Cold Start (mV)	Low Voltage (mV)	Max Voltage (V)	Min Power (mW)	Max Power (mW)
			Topology	Power Point Tracking	Primary Cell Backup	Regulated Output	Low Battery Disconnect	Other					
ADP5090	Analog Devices	\$2.81	Boost	Ratio	Y	N	Y	Switcher Enable	380	80	3.3	0.016	200
ADP5091	Analog Devices	\$3.52	Boost	Ratio	Y	Y	Y	Switcher Enable	380	80	3.3	0.006	600
ADP5092	Analog Devices	\$3.52	Boost	Ratio	Y	Y	Y	Switcher Enable	380	80	3.3	0.006	600
BQ25504	Texas Instruments	\$2.36	Boost	Ratio	N	N	Y		330	80	5.5	0.015	400
BQ25505	Texas Instruments	\$2.70	Boost	Ratio	Y	N	Y		330	100	5.5	0.015	510
BQ25570	Texas Instruments	\$3.60	Boost	Ratio	N	Y	Y		330	100	5.5	0.015	510
LTC3105	Linear Technology	\$3.45	Boost	Fixed	N	Y	N	Switcher Enable	250	225	5	0.016	300
LTC3106	Linear Technology	\$3.70	Buck/Boost	Fixed	Y	Y	Y		850	250	5	0.012	540

Part Number	Manufacturer	Volume Price (USD)	Features						Cold Start (mV)	Low Voltage (mV)	Max Voltage (V)	Min Power (mW)	Max Power (mW)
			Topology	Power Point Tracking	Primary Cell Backup	Regulated Output	Low Battery Disconnect	Other					
LTC3331	Linear Technology	\$4.49	Buck/Boost	Fixed	N	Y	Y	Super cap balancer, dual input	1800	1800	5.5 Buck/Boost, 19V Buck	0.002	250
LTC3588	Linear Technology	\$3.75	Buck	None	Y	Y	N		2700	2700	20	0.006	360
MAS6011	Micro Analog System		Buck	None	N	N	N	Low battery and power down outputs	2000	2000	5.5	-	-
MAX17710	Maxim Integrated	\$7.50	Boost	None	N	Y	Y	Thinergy battery compatible	750	750	6	0.001	100
MB39C811	Cypress Semiconductor Corp	\$3.37	Buck	Fixed	N	Y	N		450	450	24	0.010	410
MB39C831	Cypress Semiconductor Corp	\$2.30	Boost	Ratio	N	T	N		350	300	4.75	0.010	265
S6AE101A	Cypress Semiconductor Corp	\$2.53	Buck	None	Y	Y	N		2000	2000	5.5	0.001	-

Part Number	Manufacturer	Volume Price (USD)	Features						Cold Start (mV)	Low Voltage (mV)	Max Voltage (V)	Min Power (mW)	Max Power (mW)
			Topology	Power Point Tracking	Primary Cell Backup	Regulated Output	Low Battery Disconnect	Other					
S6AE102A	Cypress Semiconductor Corp	\$3.38	Buck	None	Y	Y	N		2000	2000	5.5	0.001	-
S6AE103A	Cypress Semiconductor Corp	\$3.38	Buck	None	Y	Y	N	Comparator	2000	2000	5.5	0.001	-
SPV1040	STMicroelectronics	\$1.59	Boost	MPPT	N	N	N	Switcher Enable	450	240	5.5	-	3000
SPV1050	STMicroelectronics	\$1.53	Buck/Boost	Ratio	N	Y	Y	Switcher Enable	550	750	18	0.010	400