IMPACT OF EMERGING PV TECHNOLOGIES ON SSP VIABILITY

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Objectives

- Two Emerging Technologies
  - Quantum Dots and Perovskite PV
  - Impact on SSP
    - Efficiency
    - Specific Power
    - Environmental Stability
- Terrestrial Comparison

Introduction

- Global energy demand continues to rise
- A push is being made for renewable sources
- Solar is abundant
- Hydro: currently the only stable renewable energy source
- To remain competitive, a 24 hr renewable source needs to be developed [1]

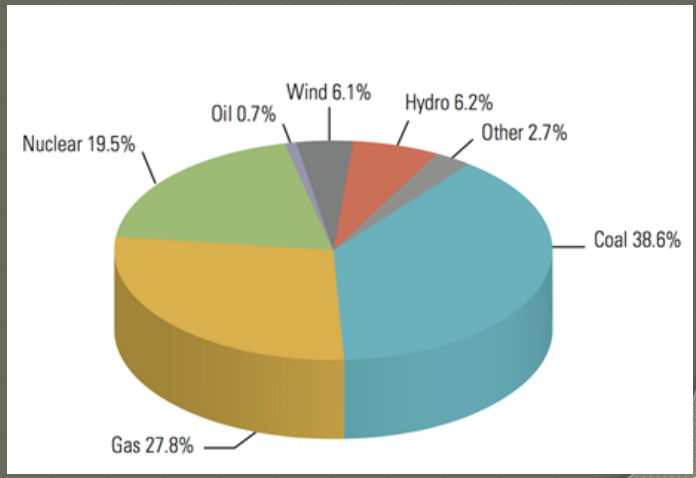


Image Credit: EIA – 2014 U.S. Power Generation Sources

Introduction

- SSP supplies 24hr power to the grid
- Technology to realize SSP system exists
- Current costs do not justify SSP
- Research in emerging PV is investigated
  - Improving efficiency
  - Reducing system mass
  - SSP environment stability

Perovskite and Quantum Dots

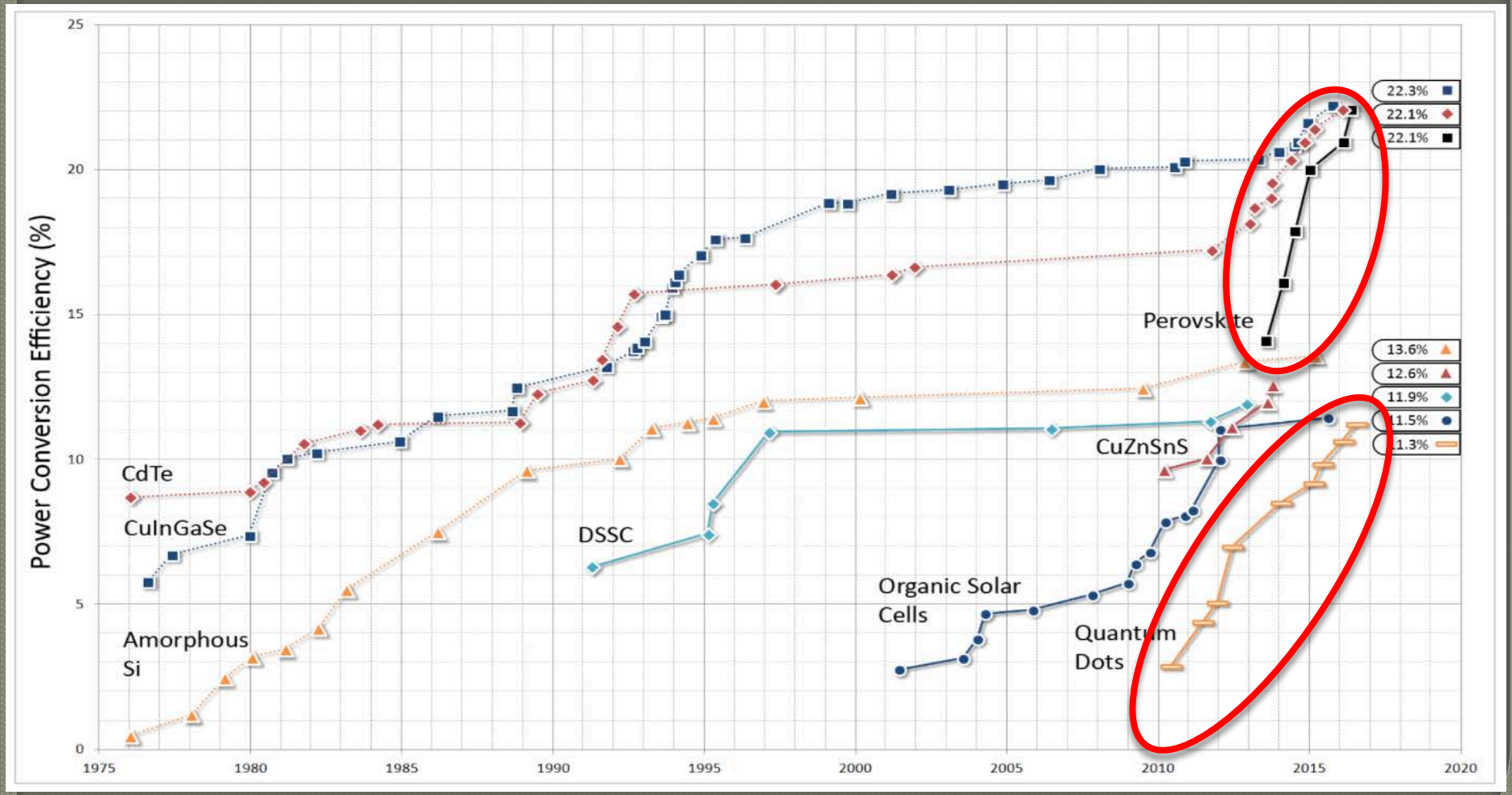
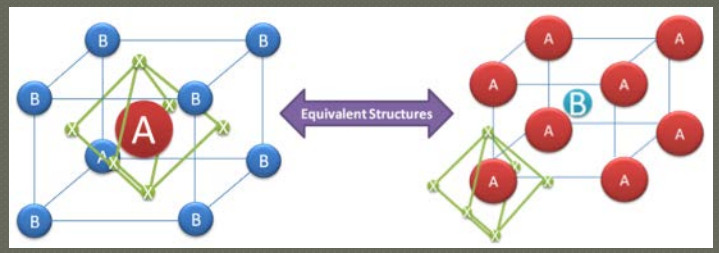


Image Credit: https://www.ossila.com/pages/perovskites-and-perovskite-solar-cells-an-introduction

Perovskite

- First perovskite solar cell created in 2013
- Theoretical efficiency: ~31%[2]
  - Record efficiency: 22% [3]
  - Shockley-Quiesser limit (single junction): 33%
- Advantages: (compared to currently available products)
  - Less expensive
  - Easier to manufacture
  - Lighter
- Disadvantages:
  - Organic compound sublimation at relatively low temperatures[4]
    - 185°C or 234°C
  - Moisture sensitive



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Quantum Dots

- Nano crystal semiconductor “artificial atom”
- “tune-able” bandgap
  - Larger spectrum capture
- First QD solar cell created in 2010
- Multiple electrons per incident photon
- Theoretical efficiency: ~63% [5]
  - Record efficiency: 12% [6]

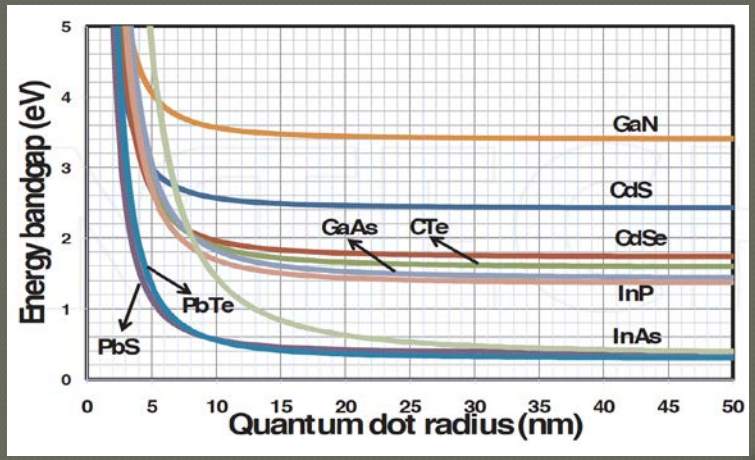

Image credit: Khalil Ebrahim Jasim: Intech 2015 CH.11, Quantum Dot Solar Cells

Impact on SSP

- Metrics:
  - Conversion efficiency
  - Specific power
  - Environmental stability
- Terrestrial comparison

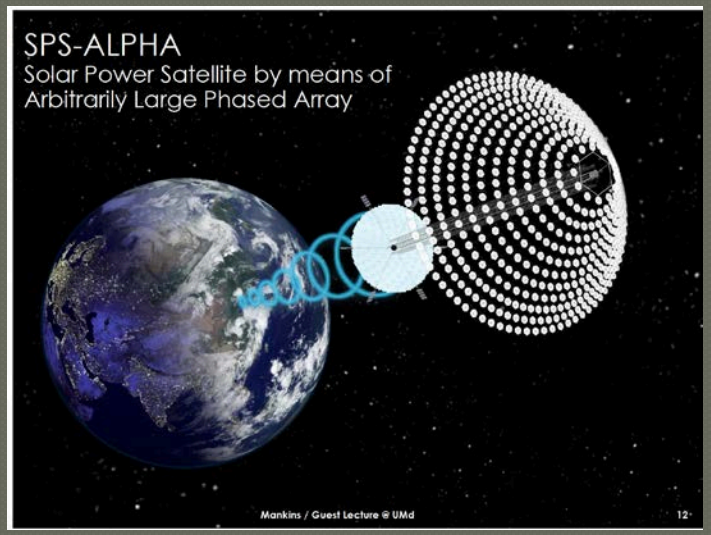

Image credit: John Mankins, SSP Lecture @UMD-Jaffe 28FEB17 V1,
PV Magazine November 2016

Efficiency

- SPS-ALPHA concept estimates 45% solar conversion efficiency[7]
- AzurSpace CPV cells conversion efficiencies [8]:
  - 250 suns 42.1%
  - 500 suns 42.0%
  - 1000 suns 40.3%
- Current record efficiencies:
  - Quantum dots: ~12%
  - Perovskites: ~22%

Specific Power

- AzurSpace[9]:
  - 80μm thick triple junction GaInP/GaAs/Ge
  - 29.5% conversion efficiency
  - 0.806 W/g
- Perovskite [10]:
  - 3μm thick
  - 12% conversion efficiency
  - 23 W/g

Specific Power

- SPS-ALPHA specifications [7]:
  - 550 W/m^2 PV output at 45% conversion efficiency
  - 1.7km PV diameter
  - 2.26km^2 PV Area
  - 1.25GW PV output

	Thickness (μm)	g/W	Mass/1.25GW (kg)	Equivalent Area (1.25GW)	Cost to LEO ($2500/kg)[11]
AzurSpace (29.5%)	80	1.24	1.55E6	3.1 km^2	3.875 B
Perovskite (12%)	3	0.043	5.424E4	7.62 km^2	0.136 B

Environment

- Little research available WRT temperature and radiation
- Concentration increases surface temperature
- Increased temperature decreases efficiency
  - Sublimation issue with perovskites
- Generally, radiation causes efficiency decline
  - Ionization
  - Atomic displacement

Terrestrial Comparison

- 2017 Dubai solar farm contract <$.03/kWh [12]
- Terrestrial requires massive storage
- Storage costs > $250/kWh
- $4.8 trillion for storage to supply 2GW for 12 hours of dark

	Today	2020	2025
Energy Storage Cost ($/kWh)	250	200	160
Storage needed for 12hr night (GWh)	24	24	24
Energy Cost ($/kWh) (10000 cycles)	0.025	0.02	0.016
Upfront costs (billions)	6000	4800	3840

Conclusion

- Global power needed will increase
- Increased PV efficiency and system mass reduction are vital to feasibility
- Reduce carbon emission
- Market products will improve research results

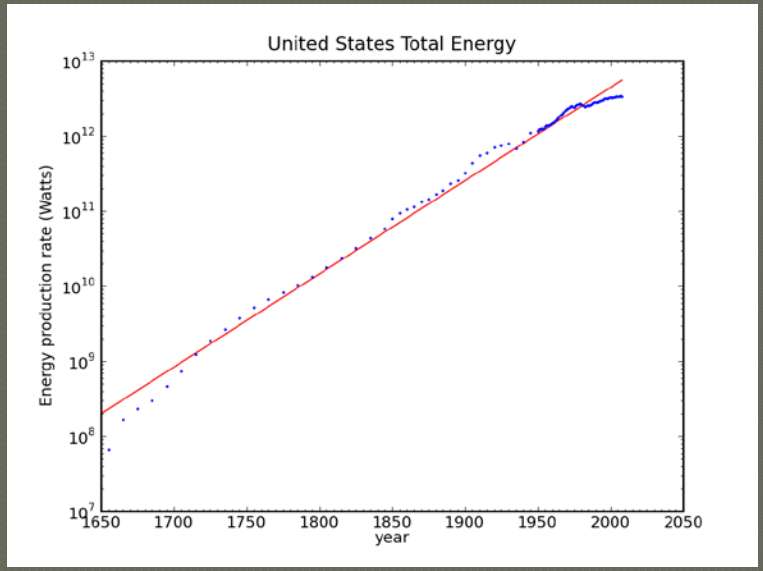

Image Credit: Do the Math: Galactic-Scale Energy

Further Research

- SSP environment stability
  - Radiation
  - Concentration/Temperature
  - Vacuum
- Manufacturing cost analysis
- Increasing efficiency
- Increasing perovskite stability
- Etc.

Questions

References

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- [11] Capabilities and Services 2017 http://www.spacex.com/about/capabilities
- [12] Sam Pothecary; Solar record-breakers *PV magazine* November 2016

Backup Slides

- SPS-ALPHA
  - 1367 W/m^2 x 45% = 550 W/m^2
  - 1.7km diameter -> 2.26km^2 area
  - 550 W/m^2 x 2.26km^2 = 1.25 GW

Backup Slides

- Specific power calculations
  - AzurSpace
  - 1367 W/m^2 x 29.5% = 403.265 W/m^2 output
  - Converted to W/cm^2 / density ($50mg/cm^2$)
    - $=8.0653 \times 10^{-4}$ W/mg
  - Convert to g/W = 1.2406 g/W
- For output of 1.25GW:
  - $1/403.254\ W/m^2 = 9.98 \times 10^{-4}\ m^2/W$
  - x 1.25GW = 3.099 km^2
  - Diameter = 1.99km

Backup Slides

- Perovskite
  - Paper reported 23 W/g = 0.0434 g/W
- For output of 1.25 GW
  - 1367 W/m^2 x 12% = 164.04 W/m^2
  - = 6.096 m^2/W
  - x 1.25 GW = 7.62km^2
  - Diameter = 3.11 km