Perovskites Dec 2014

HEJC

Agenda

Current PV Pricing

Appeal of Thin Films

Tandem Economics

State of Perovskite Research

PV Pricing 1 - Addressable Market

Status of major factors affecting PV addressable market for a given cost:

- Lending markets

Low rates, confidence building for higher leverage ratios and debt tenors for solar projects. Some regions like India and Turkey still have high rates.

- Existing electricity prices

Still well below 2008 levels in US due to natural gas. Globally, thermal coal prices have declined throughout 2014.

- Subsidies and tax laws

Several instances of imminent subsidy reductions.

- Available sunlight

No change

PV Pricing 2 - Recent Quotes

Recently, Acwa Power bid 5.98 c / kWh for a solar project in Dubai.

According to news reports this is unsubsidized. I am not familiar with expected returns, lending terms, or tax treatments.

SEIA.org has utility scale systems in the US priced as low as \$1.55 / W_{DC} .

There is wide variability here (i.e. tracking), but this is considerably down from \$2.90 and \$2.14 / W_{DC} in Q1 2012 and Q1 2013, respectively.

Standard silicon module prices are now \$0.62 / W_{DC} with mixed profitability among suppliers.

PV Pricing 3 - Imminent Industry

Several upcoming silicon heterojunction products:

First Solar-TetraSun and SolarCity-Silevo.

Panasonic currently selling 19.4% efficiency modules and, separately, has achieved over 25% efficient cells.

Cost appeal is no diffusion which is high temperature and slow, and fewer patterning steps. Should be easier to replace silver as metal touches TCO.

<u>Commercial standards are becoming ever more rigorous rendering all but the best research ideas uncompetitive.</u>

Thin Films 1 - Big Picture

Thin Film Module - A piece of glass with ~2 microns of several materials "sprayed" on in seconds. Comparable time and labor is spent packaging in cardboard for shipping as in their construction.

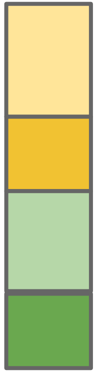
Silicon Module - Slowly purified bulk silicon from one vendor is sliced with losses then sold to another vendor who then performs a dozen, often slow, semiconductor process steps to make cells which are packaged with internal wiring, a protective plastic sheet…

But somehow the silicon module ecosystem has optimized itself to dominate the market!

Thin Films 2 - Competitiveness

To date, thin-films and silicon have competed as silicon has earned an efficiency premium for its higher costs, per area or watt.

Both at the module and cell level, there is a price multiplier for higher efficiency.



Non-module costs fixed per area	e.g. labor, land
Non-module costs scaling with power	e.g. inverter
Module costs fixed per area	e.g. glass, encapsulant
Cells	

Thin Films 3 - Example

Suppose the previous system could sell for $X and produced Y watts.

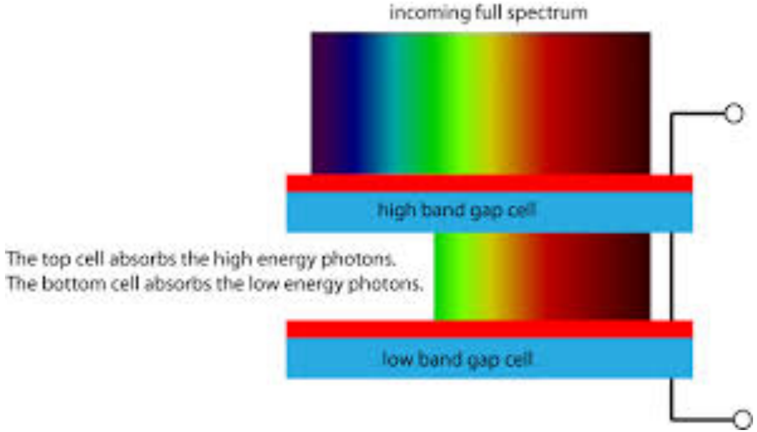
If the cells were replaced and allowed the system to generate 1.01Y watts, the system would now be worth $1.01X. But the fixed per area costs don't change.

Let's say the non-module power-scaling costs were 20% of the initial system. For 1.01Y watts, this adds $0.002X to initial costs.

Let's say the cell costs were 25% of the initial system. They capture the remaining $0.008X of system price for a value increase of 3.2% for each 1% output improvement.

Tandem Economics 1 - Idea

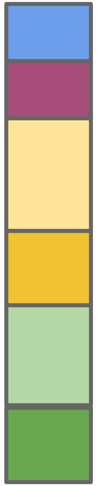
Efficiency may be increased by earning a higher voltage for higher energy light.



This comes at the expense of less current, and per the diode equation, less voltage from the bottom cell. Each cell's solo efficiency in full sunlight is no longer relevant; only the combination of the two matters.

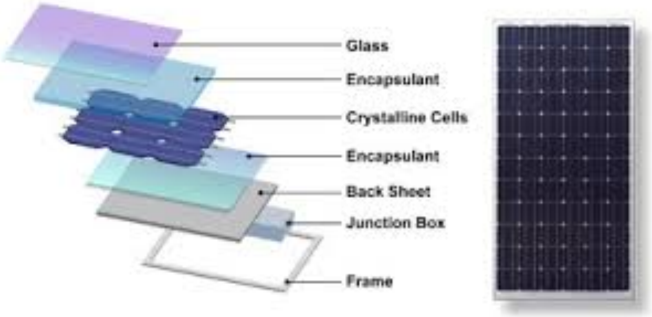
Tandem Economics 2 - Cost

The combined efficiency needs to compensate for the incremental cost. Given that glass is already part of standard silicon cells, an additional thin-film cell can be added at a modest fraction of total system cost.



Cost of thin-film top cell and module modifications.

Prior module and system costs.



Perovskites 1 - Good News

The royal flush of ideal photovoltaic characteristics:

- High efficiency over 20%
- Low cost materials, typically PbI_2 and CH_3NH_3I
- Simple processing, either evaporating or spinning the two together
- Possible match with silicon for tandem cells
- Various layouts possible
- Relatively tolerant of defects

Physically, perovskites demonstrate high light absorption (i.e. thinner permits less distance for charge carriers to travel) and reasonable mobilities for both electrons and holes.

Perovskites 2 - Bad News

Lifetime - Tends to break down with moisture, UV light, and heat. Low temperature creation brings low temperature destruction. Can product be sealed well? Is a UV filter expensive and transparent in the visible range?

Other Instabilities - Hysteresis effects in voltage-current curves suggest uncontrolled atomic movement. Halide blending is not giving expected results, possibly due to separation of various halide phases.

Lead - Comparable performance is not yet being achieved with Sn^{2+}. Given the water solubility of MAPI, this may be a future concern. Positive terminal materials may be expensive.

Perovskite 3 - Current Work

Even the effective founder of perovskite solar cells does not expect a commercial product before 2017.

Isolate concerns. Can surfaces and contacts be coated to block moisture for 20+ years? Is heat stability only a problem in mixed-halide recipes?

General scale-up concerns. Optics, tooling, optimization, etc.

Entirely new compounds? “Perovskite” is only a shape, apparently a shape that can lead to favorable semiconductor metrics. What else can be formed?