Lessons Learnt Report: Market & Technology Analysis for Organic Photovoltaics

Project Name: New Materials and Architectures for Organic Solar Cells - beyond the S-Q limit

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	QLD

Key learning

Full commercialisation of organic photovoltaics (OPV) is hindered by scaling issues – by 2018 modules must demonstrate proven efficiencies of > 8%, lifetimes in excess of 10 years and must be manufactured at a cost of < $0.5/watt if OPV is to be competitive with existing and other emerging PV technologies.

State-of-the-art: The total global cumulative installed capacity of PV now exceeds 100GW and will grow exponentially to 2020 and beyond. Manufacturing costs for traditional thin film and c-Si PV modules are now < $1.00/watt. Organic solar cells have recently achieved efficiencies at the lab-scale of 10% (solution processed) and 12% (vacuum evaporated). The best minimodules based upon serially connected thin strip junctions lie in the 5-9% range. We expect to see lab-scale cells at 13-15% within the next 2 years but mini-and-sub-module efficiencies will only improve when a number of key technical challenges are overcome. Module-level efficiencies must reach at least 8% at pilot-manufacturing scale by 2015.

The key players: With the demise of Konarka in 2012, the leading OPV manufacturer is Heliatek in Germany with their multi-junction *p-i-n* vacuum evaporated technology. Toshiba and Mitsubishi in Japan have invested heavily and may well emerge as the first-to manufacturing if their impressive laboratory-scale cell efficiencies can be translated to the module level. Research activity in organic solar cells has exploded in the past 5 years and this activity is supported by a “cottage industry” of photoactive and ancillary component suppliers. The big chemical companies (BASF and MERCK) continue to have a strong presence particularly in materials development and should not be discounted. Konarka, Plextronics and Princeton dominate the historical device, process and materials IP landscape although we should see new patents on (for example) narrow optical gap photoactive polymers flowing through from companies such as Solamer in 2014-2015.

Cost considerations and targets: The EU Roadmap establishes a cost target for OPV modules of $0.5/watt at ~ 2020 with a Global Production Capacity of 60GW. In reality, we believe that an OPV module must be produced for < $0.20/watt by 2018, and that the Global Production Capacity will be far less than 60GW (Figure 1). Based upon a ~ 2.6GW Installed Capacity (1.1GW Production Capacity) by 2020, the OPV market revenue is predicted to be a modest USD$650M, derived mainly from on-plastic modules with three main applications: DC portable power (63%); Building Integrated PV (35%); and conventional power (2%).

Implications for future projects

Our analysis of the market opportunities and technology status has identified a small number of high priority areas for short-to-medium term research and development in organic photovoltaics, namely:

i) the development of large area, monolithic submodule architectures to reduce cost and manufacturing complexity;

ii) the replacement of costly components such as the current transparent conducting electrode materials (indium tin oxide) with lower cost alternatives;

iii) the creation of new low-cost barrier materials to improve module lifetime; and

iv) the development of "thick junction" cells to reduce defect density and improve manufacturing yield. These are the necessary elements of an organic photovoltaics "Technology Roadmap" going forward.

Knowledge gap

Technical & cost challenges to be overcome: Achieving $0.50/watt will be a significant challenge for OPV. The primary cost drivers at the module level are: substrates (19%); metal electrodes and interconnects (27%); and barrier materials /encapsulants (29%). Cheaper, more effective alternative to those currently available must be found. Simplified architectures with optimal geometric fill factors will also reduce manufacturing and materials costs. These cost imperatives are aligned with the key technical challenges that the field needs to address:

a. *Reduction of the transparent conducting electrode (TCE) sheet resistance will allow larger monolithic active areas* – this will reduce manufacturing complexity versus the current serially connected thin strip architectures, allow greater current-voltage module flexibility, reduce the amount of interconnection metal, and improve yield because processes such as laser scribing will not be required.

b. *Decrease the defect density in larger area (> 5 cm x 5 cm) monolithic organic solar cell sub-modules* – Organic solar cells are thin film structures with the junction often < 200 nm. For solution processing, this is a major issue causing an exponential scaling of defect density with area and a loss of fill factor because of shorting. This is also true to a somewhat lesser extent for vacuum evaporated systems. New junction materials with better electrical properties (higher mobilities and lower bimolecular recombination coefficients) will allow thicker junctions to be created whilst maintaining fill factor. Hence, larger monolithic active areas can be manufactured with dramatically lower defect densities. For solution-processed devices, junction thicknesses of 400 – 500 nm would be ideal and not dramatically impact cost.

c. *Improved light harvesting* – multiple junctions extend the absorption range of a solar cell for more efficient light harvesting. However, multiple junctions are more complex and expensive to manufacture and an alternative strategy would be to extend the range of single junctions using concepts such as complementary absorbing acceptor-donor pairs.

d. *Module lifetime& power electronics* – Organic semiconductors are susceptible to moisture and oxygen and for long term stability organic photovoltaic modules must be encapsulated. This is a tractable engineering challenge which has been solved in other organic optoelectronic arenas. The EU Roadmap targets a 5-7 year in-field module lifetime by ~ 2020. This will likely not be good enough and 10 years minimum by 2018 is an absolute imperative if organic photovoltaic modules are to move into mainstream power production in applications such as BIPV. AC integration of organic photovoltaic technology is also central to its commercial expansion. This will require new inverter and power electronics not only to connect to the conventional grid, but also to fully utilize some unique benefits of organic photovoltaics such as exceptional low light performance and increase yield as the cells gets hotter.

Background

Objectives or project requirements

Organic solar cells have been demonstrated at the lab-scale to have efficiencies > 12%. However, these efficiencies have yet to be translated to the “mini-module” or “full-module” scale. We have undertaken a detailed analysis of the market opportunities, and technological and manufacturing status. This analysis has been used to benchmark and prioritize the outcomes from our Research Project “*New Materials and Architectures for Organic Solar Cells - beyond the S-Q limit*” and develop a strategic plan for organic photovoltaics research within the Australian Centre for Advanced Photovoltaics (ACAP).

Supporting information

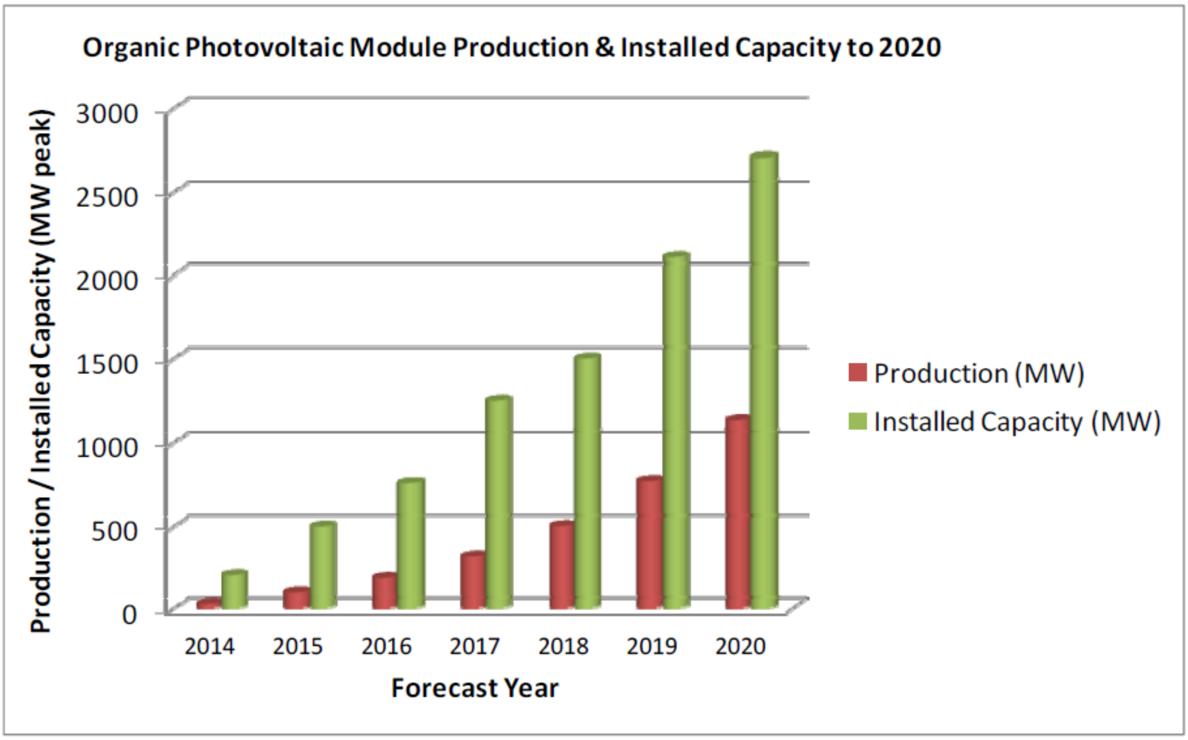

Figure 1: Forecast Production Capacity and Installed Capacity for OPV Modules out to 2020. [Data source and adapted from: “Recent OPV Technology and Market Forecast (2009-2020)”, SNR Research, (2013).]