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INKJET PRINTING OF SOLUTION-PRODUCED SOLAR ENERGY COATINGS FOR A RANGE OF APPLICATIONS

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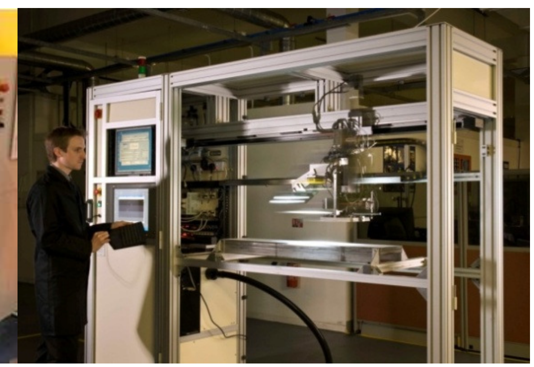
THE QUEEN'S AWARDS FOR ENTERPRISE 2010

Outline

1. Introduction
2. Solar energy coatings
3. Inkjet versus other manufacturing techniques
4. Applications
5. Outlook

Xennia helps customers lower operating costs, increase productivity and simplify mass customised production by revolutionising manufacturing processes



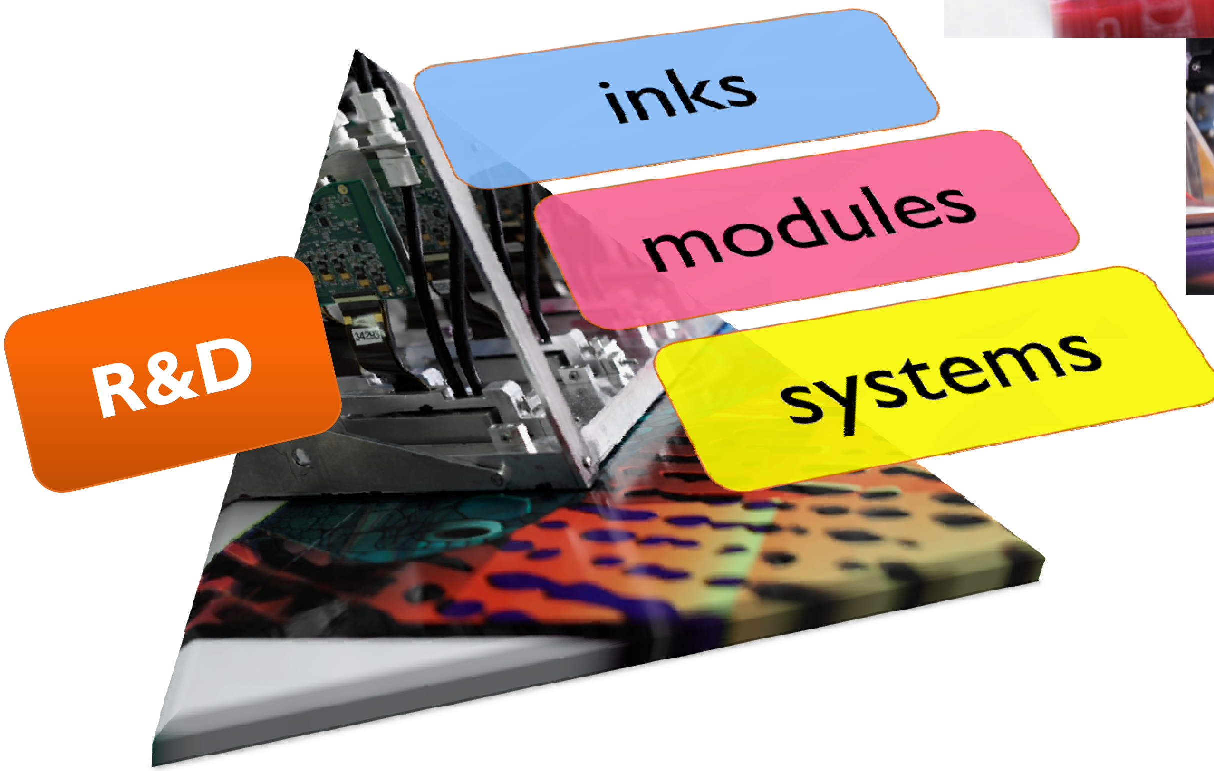
www.xennia.com

Background

- Xennia is the world's leading industrial inkjet solutions provider
- 14 year history, over 300 customer development programmes
- World class reputation underpinned by a strong IP portfolio
- Unique expertise in inkjet chemistry with strong engineering capability
- Headquartered in UK, offices in US and China

- Offering reliable inkjet process solutions:
  - Inkjet modules and inks for OEM partners with market access
  - Printing systems and inks for end users

Proposition



From inkjet ideas to production reality

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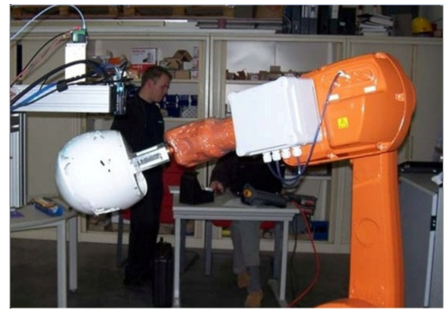
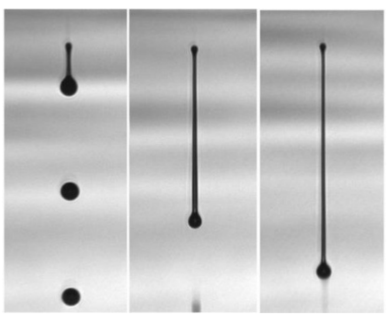
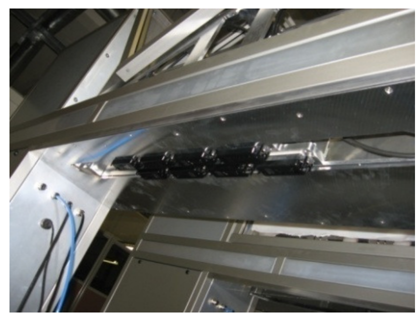


ink formulation & test | **evaluation tools** | **system design** | **production solutions**





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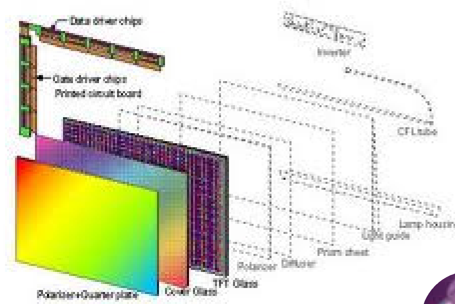
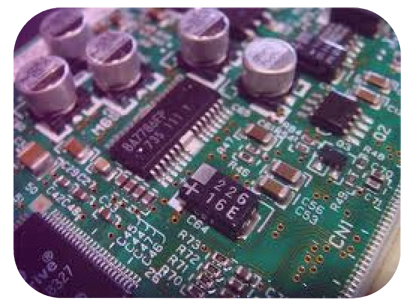
Inkjet to coat, process and manufacture

- Use inkjet to:
  - Coat
  - Create manufacturing processes
  - Manufacture products
- Inkjet printing difficult materials
  - Pigments (including inorganic), phosphors, metals
  - Polymers
  - Functional materials
- Key inkjet ink technologies
  - Pigment and polymer dispersion
  - Solvent based and UV cure chemistries



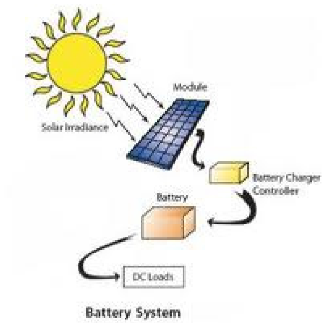


Solar energy coatings

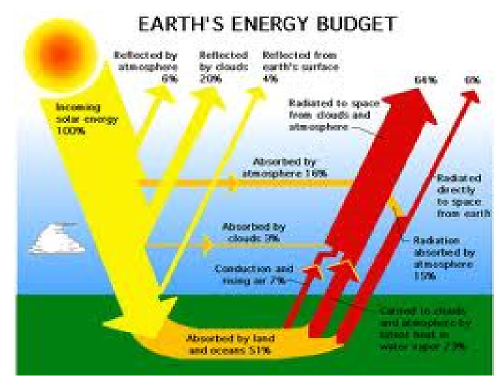
Renewable energy

- Concerns about
  - Sustainability
  - Global warming
  - Pollution
- Lead to increasing trend for clean, renewable energy
  - Solar photovoltaic
  - Solar thermal
  - Wind
  - Tidal
  - Geothermal
- Solar photovoltaic and wind have greatest potential
  - Renewable energy proportion still very low (0.8% in 2002)

Solar energy generation



- Huge potential for energy generation
  - 840 W/m^2 reaches Earth's surface during daylight
  - e.g. 1600 TW strikes continental USA
  - All electricity needs met with 10% efficient devices covering 2% of area
  - (Interstate highways currently cover 1.5% of area)



- Solar energy harvesting
  - Thermal – heat from sun heats water
    - Used for hot water and swimming pools
  - Photovoltaic – energy from sun used to generate electricity
    - **Can be used for any purpose**

Solar photovoltaics

- Types of photovoltaic (PV) (solar cells) available
- Conventional (inorganic)
  - 1st generation – crystalline Si
  - 2nd gen – poly-Si, a-Si, CdTe or CIGS
  - Input energy creates electron-hole pairs
    - Separated by internal field
  - Generates photocurrent
- Organic (small molecule or polymer)
  - Heterojunction design incorporates:
    - Electron transport layer (ETL) and hole transport layer (HTL)
  - Input energy creates excitons
    - ETL/HTL interface drives dissociation into electrons and holes
  - 'Standard' materials P3HT and C_{60} derivatives

OPV schematic

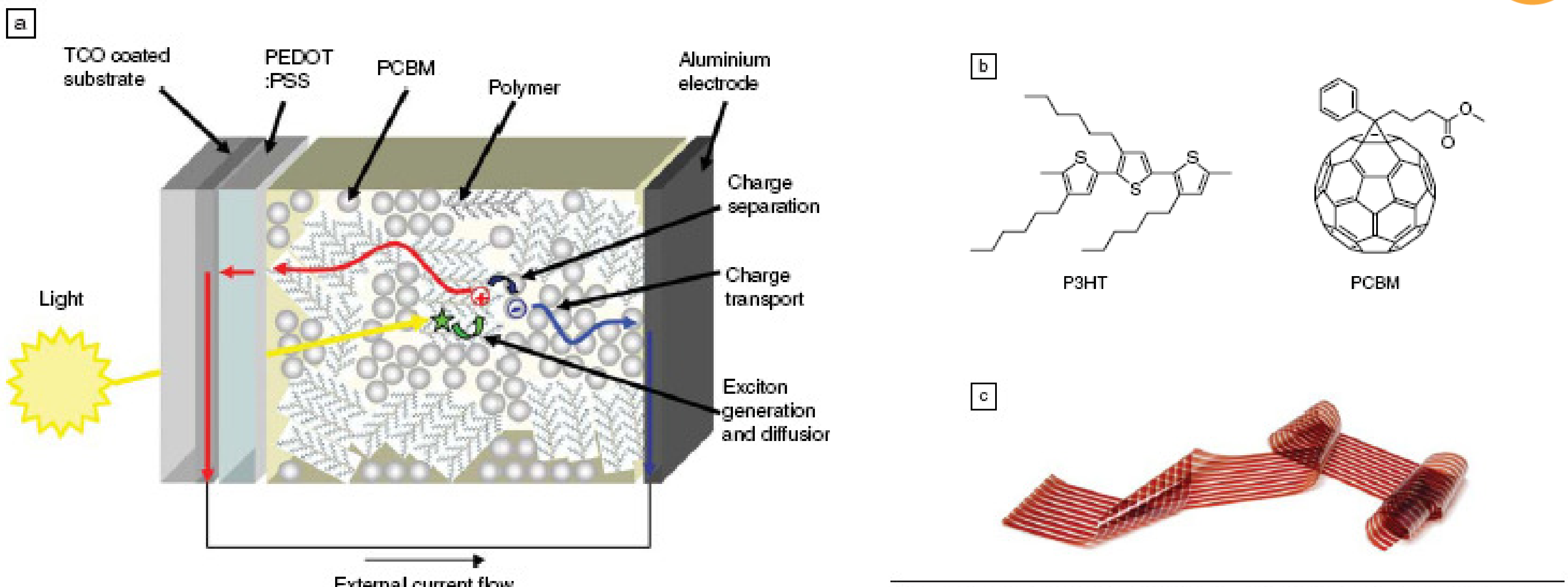


Figure 1. (a) Schematic layout of the function of a typical organic solar cell. (b) Chemical structures of typical donors and acceptors. (c) Photograph of reel-to-reel-fabricated organic solar cells. The active layer of the solar cells is a P3HT/PCBM blend. *Note:* P3HT is poly(3-hexylthiophene), PCBM is [6,6]-phenyl-C61-butyric acid methyl ester, PEDOT is poly(3,4-ethylenedioxythiophene), PSS is poly(4-styrenesulfonate), and TCO is transparent conductive oxide.

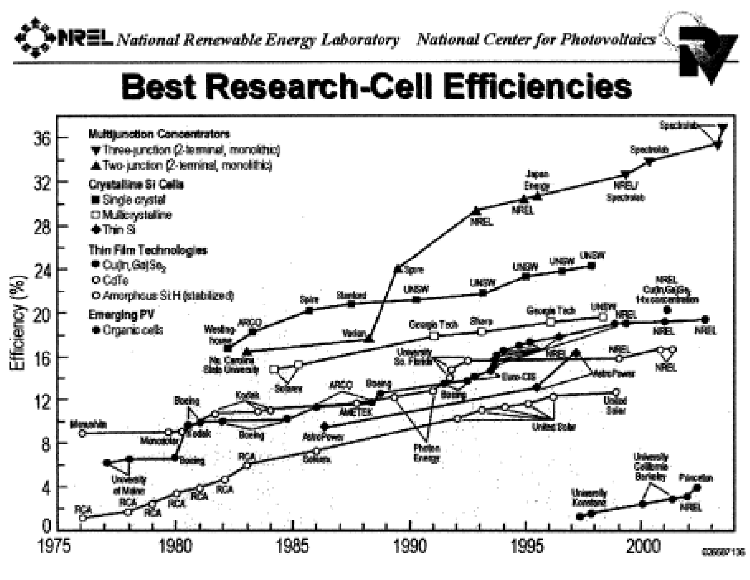
- P3HT bandgap 1.9 eV
- PCBM LUMO-P3HT HOMO separation ~ 1eV
- Carrier mobilities 10^{-4} cm^2/Vs

Device efficiencies >4%

Christoph Brabec and James Durrant, Solution-Processed Organic Solar Cells, MRS Bulletin, 33, 670 (2008)

Solar photovoltaics

- Key figures of merit for PV
- Efficiency
  - Percentage of incident energy converted into electrical energy
  - Includes collection efficiency as well as conversion efficiency
- Cost
  - Measured in $ (or €)/W_p
  - Current typical cost 2-8$/$W_p$
  - **Need to reduce significantly**
- Lifetime
  - Minimum 3-5 years
  - Desirable 20-25 years



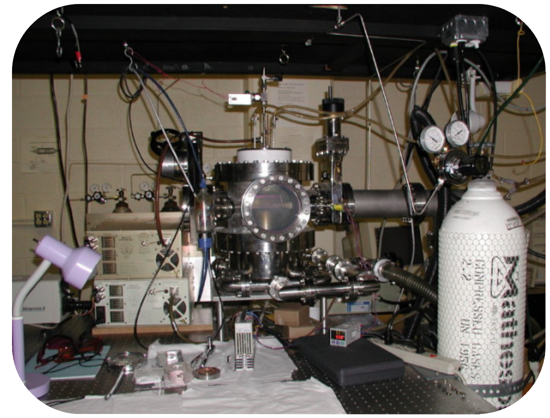
Key cost drivers

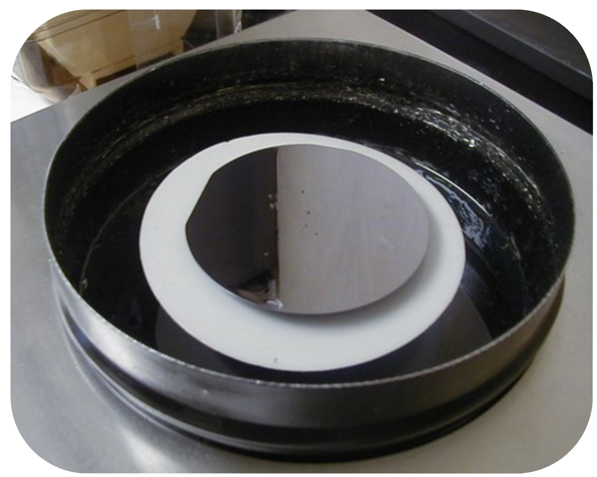
- Key to reducing cost of PV
  - Lower cost materials
  - Lower cost manufacturing
    - Continuous
    - Additive (no waste)
    - Flexible

Inkjet versus other manufacturing techniques

Manufacturing techniques

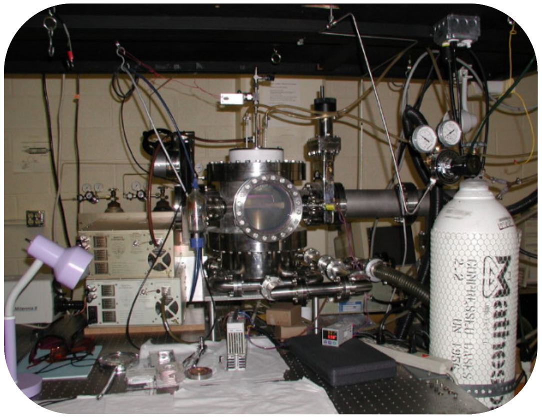
- Traditional semiconductor techniques
  - Thermal/electron beam evaporation
  - CVD/MOCVD etc
- Other coating techniques
  - Spin coating
  - Spray coating
- Printing
  - Flexo/gravure printing
  - Screen printing
  - Inkjet printing





Traditional techniques

- Thermal/electron beam evaporation
  - Material is heated and evaporates
  - Deposits onto substrate and layer grows
- CVD/MOCVD
  - Material made into volatile compound
  - Compound decomposes to deposit material
- Spin coating
  - Material in solution spun on flat surface
  - Uniform coating with evaporation of solvent
- Spray coating
  - Solution sprayed on surface
  - Solvent evaporates



Technology comparison

Technology	Applicability	Scalability	Productivity	Materials Wastage	Film quality	Process type	Multiple layers?
Thermal evaporation (vacuum)	Inorganic/ small molecule	Low	Low (batch)	Moderate	High	Subtractive	Yes but slow
CVD (low pressure)	Inorganic/ small molecule	Low	Low (batch)	Moderate	High	Subtractive	Yes but slow
Spin-coating	Polymer/small molecule	Low	Low (batch)	Poor	Medium	Subtractive	Yes but slow
Spray-coating or doctor blade	Polymer/small molecule	High	High	Poor	Low	Subtractive	Yes
Screen or gravure printing	Inorganic/ polymer/small molecule	Medium	Very high	Moderate	Medium	Additive	Yes but damage?
Inkjet printing	Inorganic/ polymer/small molecule	High	High	Good	Medium	Additive	Yes

Gas phase versus solution phase deposition

Inkjet versus other techniques

Strengths	Weaknesses
Non-vacuum Highly scalable Compatible with continuous/reel-to-reel process on flexible substrates Compatible with multi-layer printing Additive process	Film quality not as good as TE/EB/CVD
Opportunities	**Threats**
Creation of a low-cost organic PV solution	

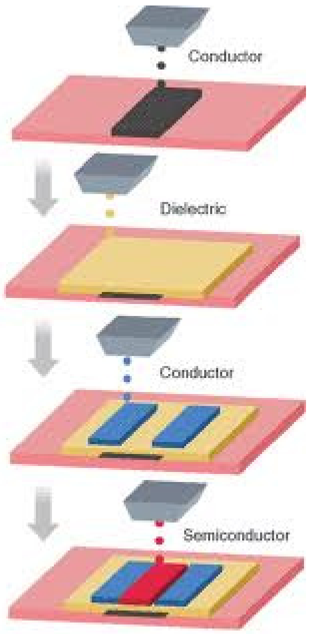
Inkjet deposition of coatings

- Production inkjet coating deposition requires
  - High throughput
  - High reliability → high productivity
  - Excellent ink chemistry
    - Functional performance
    - Reliable printing
  - Costs must make sense for application

Low cost manufacturing

- **Inkjet has the potential to allow low cost manufacturing of PV**
- Can create a new market dynamic for solar energy production

- Need to deposit
  - PV materials
  - Contacts



Applications

Applications for low cost PV

- Low cost, flexible PV allows
  - Lower cost of ‘conventional’ power generation PV
  - Easier installation
  - Return on investment reasonable for mass market

- Enable new applications not currently possible/significant
  - Power generation for mobile devices
  - Power generation for signage
  - Power generation in clothing

Applications example

- Sestar Technologies LLC
- SolarTurf™
  - PV incorporated into synthetic grass
  - Light absorbing layer can be coloured
  - Absorbing grass is green!
  - Make compatible with existing consumer products

- Allows power generation from existing areas
  - Lower cost of lighting public and private areas

Applications example

- Sestar Technologies LLC
- SolarFabrics™
  - PV incorporated into clothing
  - Military and civilian
  - Absorbing materials in all colours
- Allows power generation from clothing
  - Powering phones, radios, iPods, GPS
  - Powering active camouflage

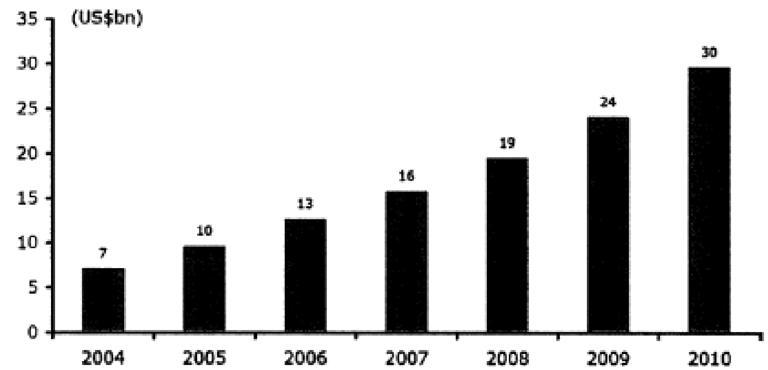
Applications example

- Sestar Technologies LLC
- SolarFabrics™
  - PV incorporated into tents, awnings, etc
  - Multiple colours
- Allows power generation to campsites, homes and buildings
  - Powering portable devices
  - Lower cost of lighting public and private areas

Outlook

Market size

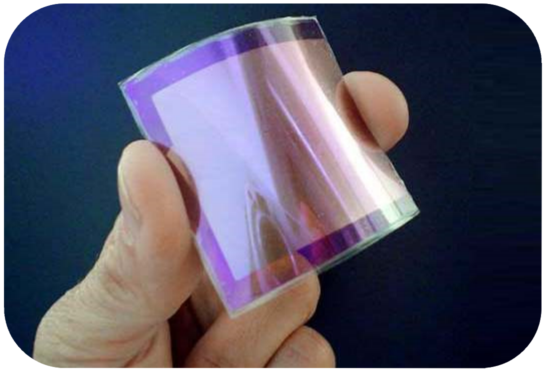
- Photovoltaic market growing significantly
  - 20-25% per annum
  - $30Bn industry generating 32GW
  - Faster introduction impeded by costs
- Impact from
  - Subsidies
  - Regulations (e.g. specified renewables percentage)
  - Emissions taxes



- **Low cost solutions have massive potential**

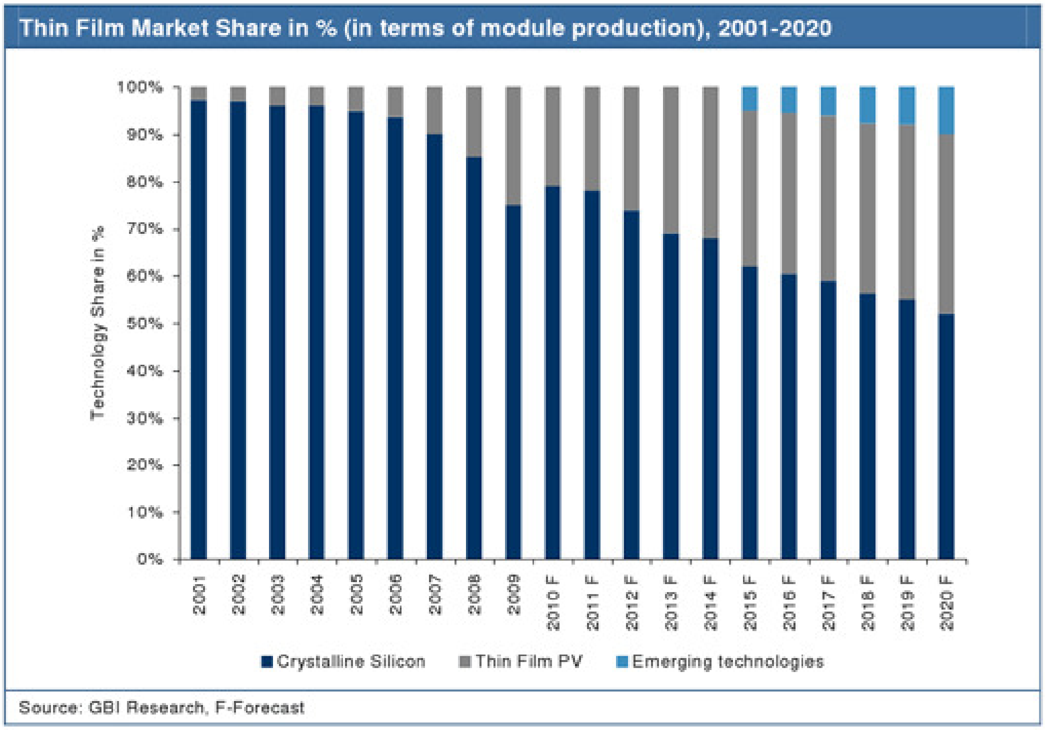
Outlook

- Potential
  - **Solar power generation everywhere!**
  - Based on low cost production



- Challenges
  - Increase efficiency
    - OPV ~$^1/_3$ efficiency of conventional
  - Increase stability
    - OPV relatively unstable

Outlook



- Thin film (2nd gen) market share in the global solar PV market
  - Grew from 2.8% in 2001 to 25% in 2009
  - Set to increase its share to ~38% by 2020
- Impact of lower cost technologies already clear
- Significant share from emerging technologies expected 2015

Source: GBI research, F-Forecast

Outlook

- **Inkjet deposition ready to replace conventional techniques**
- 2008: First organic solar cell fabricated with inkjet
- Commercialised inkjet PV production in 2009
  - Report 1.5m wide, 40m/min

- Inkjet printed electronics expected to grow
  - €62M in 2008
  - €3,079 in 2013

Source: Plus Plastic Electronics, Pira International

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FROM INKJET IDEAS TO PRODUCTION REALITY