Printed and Flexible Electronics
Market Expectations for 2013-2020

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Yole Developpement is a market, technology and strategy consulting company, founded in 1998. We operate in the following areas:

- Power Electronics
- Advanced Packaging
- MEMS & image sensors
- Photovoltaic
- Microfluidic & Med Tech
- Equipment and materials
- HB LED, LED & LD

Our expertise is based on research done by our in-house analysts, conducting open-ended interviews with most industry players.

- 30+ full time analysts with technical and marketing degrees
- Primary research including over 3,500 interviews per year
Some applications are likely to happen while some others are more technological-push (e.g. what will be the lifetime of a bendable screens, the washing resistance of a smart clothes integrating electronics?).

Table below shows the ranking of the different applications:

<table>
<thead>
<tr>
<th>FUNCTIONS</th>
<th>CONFORMABLE</th>
<th>BENDABLE</th>
<th>&quot;UNUSED&quot; FLEXIBILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SENSING</td>
<td>Touch Screens</td>
<td>Smart clothes</td>
<td>Sensors (gas, image)</td>
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<td>DISPLAYING</td>
<td>Smartphones/tablets screens</td>
<td>e-readers, smart clothes</td>
<td>e-readers</td>
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<td>LIGHTING</td>
<td>Automotive / Luxury OLEDs lighting</td>
<td>Organic PV</td>
<td>General OLED lighting</td>
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<td>ENERGY GENERATION</td>
<td>Organic PV</td>
<td>Smart clothes</td>
<td>Organic PV</td>
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<tr>
<td>SUBTRATES</td>
<td>Smart IDs, thin film batteries</td>
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<td>Smart IDs, thin film batteries</td>
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In the next years, the number of applications using printing processes for Flexible Electronics will grow.

**2013**

Flexible Electronics
Application enabling / Function enabling

- Flexible PV
- Electronic Paper

**The Printed/non-Printed Frontier**

**2020+**

Flexible Electronics
Application enabling / Function enabling

- Flexible PV
- Conformable OLED Lighting
- Small OLED Displays
- Electronic Paper
- Large OLED Displays
- Sensors
- Systems on foil
- OLED general Lighting

**The Printed/non-Printed Frontier**
Market drivers for flexible and printed electronics are different, even though manufacturing processes and end applications share similarities.

Main market drivers for flexible electronics are:

- The possibility to add new functionalities:
  - Conformability for OLED lighting (for the automotive industry), for OPV (energy harvesting)
  - Robustness for small OLED displays (for smartphones & tablets)
- The possibility to create new applications: Wearable electronics.
- Flexible electronics is NOT meant to be low-cost, and usually uses expensive processes (MOCVD, evaporation).

The main market driver for printed electronics is:

- Cost reduction thanks to high volume (Roll-to-roll) manufacturing OR to the fewer use of expensive manufacturing processes (MOCVD, evaporation):
  - Potentially lower cost OLED TVs can be built if solution based manufacturing is mastered, potentially low cost OPV can appear if technical challenges are leveraged.
Example of sensing application: ISORG

- ISORG is a pioneering company in Organic and Printed Electronics devices for large-area photonics and image sensors with a technology revolutionizing the industry.
- ISORG converts plastic and glass surfaces into smart surfaces & offers a new generation of high performance opto-electronic sensors with 3D product integration capability recognizing any shapes and form factors.
Flexible & Printed Applications Market for the Different Functions (in US$M)

- Displays will account for the largest market.

Flexible Applications based on PE Technologies Forecast 2012-2020 in US$M

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<table>
<thead>
<tr>
<th>Year</th>
<th>Substrates</th>
<th>Energy generation</th>
<th>Lighting</th>
<th>Displaying</th>
<th>Sensing</th>
<th>CAGR</th>
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Printed & Flexible devices could represent large part of the total market by 2020 because of the large displays applications.
Applications and Market Segments of OLED Displays

- Display
  - Smartphone
  - Monitor
  - Netbook
  - TV
  - Camera & Camcorder
  - Media player
  - Game console
  - Outdoor Display

- Signs

- Automotive Lighting
  - Interior
  - Exterior

- General Lighting
  - Residential
  - Commercial
  - Offices
  - Architectural
  - Decorative
  - Specialty

- Other
  - Bio-Sensors
  - Toys & Clothes
  - ..
  - Others

OLED Displays
OLED Displays

- OLED displays are divided into two main categories:
  - Small displays (for mobile phone & tablet/laptop application)
  - Large displays (for TV applications)
- Those two categories have different technology roadmaps and different market drivers.
- Main drivers include new features for small display (linked to flexibility) and lower cost for large displays (linked to printability)

![Acceptable OLED Panel Costs Diagram]
Small OLED displays - market drivers

- There are three drivers for the development of flexible and at longer term printed small OLED displays:
  - Robustness linked to flexibility:
    - No rigid and fragile glass encapsulation
    - Possibility to use soft materials such as polymers
  - New features linked to flexibility:
    - Curved smartphone like the one presented by Samsung at CES 2013.
  - At longer term: low cost linked to the development of printed OLED displays
    - This will be enabled by research on large printed OLED displays for TV application
    - This will be a killer driver for OLED displays as they could reach lower costs than LCD

Source: Samsung
The flexible display allows for the display of information on the trench while the phone is in stand-by mode
The main technical challenge at short term lies in finding a good barrier technology: encapsulation materials are not so good on flexible substrates. Current solutions are:

- Flexible glass
- Polymers and active materials
- Multi-layer technology alternating polymers and getters

Flexible glass is very expensive and fragile, and polymers still face reliability issues. The current solution is multi-layer technology, but it is still expensive and has a very slow manufacturing process (the panel has to enter the evaporation chamber 6 times).

Active barrier materials for both oxygen and water should not reach the market before at least 2016.
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OLED for Lighting
OLED panel acceptable cost

- OLED lighting can be divided into two major parts: luxury & design lighting (luxury luminaires or automotive lighting) and general lighting.
- Flexible OLED lighting will typically focus luxury & design lighting cost is less important than esthetic features.
- Printed OLED with potential low price will focus general lighting where cost is a strong driver.
OLED Lighting Panels - Not Adapted for Retrofits

- As an OLED is area light device, the upgrade of OLEDs in existing luminaires would be difficult and many OLED advantages would be lost by a such approach.

- Therefore, OLEDs general lighting market development will be driven almost exclusively by new lighting installations.

Contrary to other lighting products including inorganic LEDs, planar OLED panels are not adapted for luminaire retrofit.
In 2012, there was a factor of 70 between OLEDs (~352 $/klm) and LEDs (~5 $/klm) at the cost level... This should be reduced to a factor of 16 by 2020 (OLED at ~13 $/klm vs. LED at ~0.8 $/klm).
Main Tools/Materials Challenges

INKS
- Viscosity
- Surface tension
- Localization
- Solvent evaporation

SUBSTRATE
- Wettability
- Surface state
- Thermal behavior

TOOLS
- Alignment
- Throughput
- Handling
- Drying
Printed Electronics: materials issues

- **Material** issues are: reliability, stability over time, and light conversion efficiency
  - Impacts peOLED displays and Lighting and peSolar
  - Material system integration together from different vendors

- **Substrates** are an often underplayed and underestimated barrier to successful flexible electronics implementation.
  - Substrates reliability, stability barriers to outside effects, impacts all areas
Substrates & ITO Issues

• While much development is being done in conversion inks, substrates are also a key issue

• Will the industry be able to use substrate barrier materials from the food packaging or other industries?
  – Food industry has been fighting moisture, oxygen and flexibility issues for a long time
  – DuPont Teijin Films is developing PET films and Amcor Flexibles are investigating opportunities in substrates barrier films for printed electronics and pESolar

• ITO is currently used in solar and displays as a conducting substrate
  – Transparent but brittle and is high cost because Indium is a rare metal
  – Opposite to needs of market for flexible and low cost
  – PEDOT:PSS substrates are very inexpensive plastics (used in soda bottle materials) but lose electrical properties quickly

• The hunt is on to find an ITO replacement that has optical, electrical and physical properties
  – Much research is being done employing PEDOT with nanotechnologies
  – Layering nanotechnology on top of conventional subs
  – Copper nanowires; Carbon nano tubes
Conductive and Emissive Inks for OLEDs

- The development of organic-based inks has been the key enabler for OLEDs and other types of displays (ElectroPhoretic, ElectroWetting, etc)

- OLED Inks have been under development since first discovery ~1989
  - CDT (UK + Cambridge U) developed large molecule inks
  - UDT (USA + Princeton U) developed small molecule inks

- Economics and new inks enabling industry to move from vacuum processing to printing

- Ink life times, color stability (blue) has been the most difficult issues. Solved only recently

- Inks are extremely expensive at ~$1,000/gram
Main Material Supplier Map
Yole Activities in a Nutshell

MEDIA
- News feed
- Magazines
- Webcasts

REPORTS
- Market & technology
- Patent Analysis
- Reverse costing report

CONSULTING
- Market research
- Technology & Strategy
- Patent Analysis

YOLE FINANCE
- M&A
- Due Diligence
- Fund raising services