Display Technologies

OLEDS :
Opportunities for European industry opened by their disruptive potential

from
OLEDS and Electronic Paper, Final Report, for IPTS and DG Enterprise

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Context of the study

The Institute for Prospective Technological Studies, commissioned this report as part of its COMPLETE (Competitiveness by Leveraging Emerging Technologies Economically) study on behalf of DG Enterprise to assess whether:

- New display technologies - specifically OLEDs and ePaper - will disrupt the current market in displays
- They will substitute for existing technologies
- They enable new applications and new market segments
- Europe’s future competitive position will be affected, and
- If new opportunities, how well placed are EU firms to take advantage?
Displays are an increasingly important segment of the ICT industry

• Global display industry has grown dramatically, to over €100 billion, as cathode ray tube (CRT) has been replaced by flat panel displays (FPDs) based predominantly on LCD technology.

• Development of FPDs has enabled new product segments - dominant growth categories today in consumer electronic devices - laptop computers and mobile handsets.

• Geo-politically the industry dominated by Asian suppliers, for the current leading technology, thin film liquid crystal displays, TFT LCD.

• But 2 new technologies may be on the verge of breaking into the displays market – organic light emitting diodes (OLEDs) and electronic paper (e-paper).
OLED Routemap – estimated development to 2025 for OLEDs, technology & applications

The three Epochs are general indicators and so overlap

<table>
<thead>
<tr>
<th>Level of acceptance</th>
<th>2010-2015</th>
<th>2012-2020</th>
<th>2016-2025</th>
</tr>
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<tbody>
<tr>
<td>Lowest cost commodity</td>
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<tr>
<td>Major growth; Competes with other technologies</td>
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OLEDs enter application market

Technical advance in volume production

Indoor environments typically

- Mobile phones
- Specialist lighting
- Large outdoor ads
- Laptop PC

Any environment

- Adverts & public space indoor signage
- Avionics instruments
- Cars
- Medical scanning / instruments
- Wearable devices and apparel
- Industrial displays - large panoramic & small machine
- TVs
- E-readers
- TV wall

Household lighting

Avionics passenger entertainment

OLED wallpaper

SCF

2010-2015

2012-2020

2016-2025
Success for OLEDs depends on two key technical advances

1 operating lifetime - based on stability of each colour, ie of the basic polymer technology

2 production process - develop for larger screen sizes, with consistent high quality at low cost, eg roll-to-roll mode, by using low cost printing and room temperature processes, such as inkjet printing- a combination could take unit costs per FPD below those of TFT-LCD.

To displace TFT-LCD may well require further incremental progress in production techniques for consistent high yield and high quality at lower cost.

Contrasting comments from market players on future development path for OLEDs, vs TFT-LCD:

• Sony - produces both types and has to defend its large revenue stream in LCD.

• Has publicly positioned OLEDs as the display technology for entirely new device.

• Positions LCD as larger sizes of TVs, also becoming both thinner and lighter

• Executive President of Sony TV Business Group - production of large TVs using OLEDs is currently difficult (has 11 inch OLED production model Jan 2008) and shown 27inch (Aug. ‘08)

• However also noted that commercialisation of OLEDs must be carried out without delay - next generation of displays for colour, contrast and thinness (down to 3mm)

• Sharp, in contrast, publicly holds the position that LCD is not yet a mature technology and that it will be another decade before it is threatened by OLEDs. OLEDs may be successful for very short-life screens only, in rapid product cycle appliances – eg MP3 and MP4 players (cheap/disposable).
Why OLEDs might be disruptive - For reasons of technology

Technical limits –for TFT-LCD and plasma:-

• Limits in brilliance, resolution and colour ranges

• Power requirements difficult to reduce further - need backlight

• Weights difficult to reduce further

• Production facilities - semiconductor clean-rooms

• Sizes constrained by technologies, especially yield with scale

• The mainstream technologies in LCD and plasma not yet flexible - however new LCD technologies, eg cholesteric LCD, by Fujitsu for e-paper, gives flexible displays

OLEDs substitute directly for LCD so quite disruptive to current industry as :-

• Based on plastic technologies of polymers- low temperature production, not high vacuum conditions

• Can scale up production quickly in theory - lower cost processes - inkjet printing or spin coating - lower capex

• Unit prices of OLED displays may eventually perhaps be 10-20% LCD or plasma

• Claims more colours, brightness, contrast & less motion blur than LCD, especially against cheaper LCD

• Flexible display - widens applications base

• Power and luminescent efficiency higher

• More sustainable technology – (A) both in energy required to manufacture and to operate (no backlight) so smaller battery needed - less recharging

  (B) For recycling, glass may be absent, while polymers can be recycled or broken down, so advanced over LCD. Biodegradable properties possible by adding triggers (thermal, chemical, light, radio frequencies) for reprocessing/unwinding polymers

• Display weight lower – and depth thinner (3 mm)

• Size impacts of LCD on production yields could have less effect, especially on a roll-to-roll type production line, for better yield
The disruptive potential of OLEDs: the key types of impacts

Disruption comes as OLEDs act as a replacement technology for:
- LCD screens
- Plasma screens
- Others

Disrupts

Industry structure
- Value chain
- Clusters
- Consortia

Disrupts

Industry Players

Extensions of current types of applications:
- Mobile handsets
- TVs
- Laptops
- Small screens
- FMCG & industrial

Disrupts

Types of auxiliary technologies:
- Backplanes with organic transistors, power supplies etc
However OLED replacement being delayed by offset factors

• Industry trend is to replace the base technology slowly, in order to recoup current LCD capital investments

• In absence of a ‘badly behaved’ large competitor, or pressures from a major customer, such as the mobile handset suppliers – deliberate is a tardiness significant factor

• The lifetime of OLEDs is currently significantly less than LCDs. In May 2008, the first mass production OLED TV on sale, Sony’s XEL-1 was reported in a 1000 hour test by DisplaySearch to have aged twice as fast as claimed by Sony. Service life on average usage was projected to be reduced from 10 years to 5 years

• However the same research noted that other OLED displays, -eg Samsung small OLED display for mobile phones, last far longer than Sony’s OLED screen.

• A specific version of the above problem is perfection of individual colour lifetimes –eg blue

• Problems in practice with OLEDs in everyday use- water resistance and oxidising

• Problems in perfecting the production techniques for high yield and low unit cost - OLED TVs, today, v. expensive, eg Jan. 2008, $2500 for Sony XEL-1 with only 11 inch display

• Problems in scaling OLED FPDs beyond small screen sizes

• WOLED for lighting – problems of power supply (needs DC), fitting/plug and display area (usually rectangular flat panels) make replacement for domestic light fitting and bulbs a problem – really for a specialised architect’s market today

• To resolve these issues much industry and academic effort is under way.
When could a discontinuity due to OLEDs occur?

• Sharp, Toshiba and Matsushita Panasonic LCD suppliers do not expect large OLED TV displays until the second half of the next decade, ie not before 2015.

• Views of OLED producers in Europe is a much sooner date for take-off – certainly major steps in 2009 and marketed products in 2010, especially for 2-5 inch screens for mobile handsets, the largest market by far in unit terms.

• OLED technology is advancing:

1000 hour test of % OLED luminescence decay shows 400-500% improvements in 4yrs

<table>
<thead>
<tr>
<th>Colour luminescence degrade test over 1000 hours</th>
<th>Red, % of start luminescence</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004, Kodak small on-camera OLED screen</td>
<td>62%</td>
<td>69%</td>
<td>38%</td>
</tr>
<tr>
<td>2008, Sony TV XEL-1</td>
<td>93%</td>
<td>92%</td>
<td>88%</td>
</tr>
<tr>
<td>Improvement over 3.5 years</td>
<td>540%</td>
<td>388%</td>
<td>517%</td>
</tr>
</tbody>
</table>

Source: DisplaySearch, May 2008

Point of discontinuity for OLEDs could be in 3 to 5 years time for 2 reasons:

• Time to solve the many technical problems of OLEDs
• Current investments in plant for rival technologies (LCD) written off - so major players will let a new technology enter.
The basic OLED Value Chain – 6 stages

1 Basic R&D with IPR licensing

- IPR for:
  - Technology
  - Manufacturing
  - Components

- OLED FPD screen assembly by device manufacturer or third party

- Integration of screen in manufacture of:
  - TV
  - Mobile handset
  - Laptop PC
  - PC Monitor
  - Consumer goods
  - Industrial goods

- Glass/plastic sheet
  - Backplane substrate
  - Front plane film
  - Colour filter
  - Driver circuits
  - Video-processor
  - Video RAM

- FPD Screen production in volume

- OED/OEM product device manufacture, integrating the FPD

- Brand management
  - Marketing & promotion
  - Channel management
  - Logistics
  - Pricing
  - Retail/direct networks

- Return & recycling
  - Collection
  - Refurbishment
  - Dismantling
  - Recycling components
  - Recycling materials
  - Bio-decay

Key production technology is roll-to-roll printing with inkjet
Marginal value of the value chain elements

<table>
<thead>
<tr>
<th>Link in value chain</th>
<th>R&amp;D (IPR)</th>
<th>Materials</th>
<th>Production equipment</th>
<th>Components</th>
<th>OLED film &amp; FPD production</th>
<th>Device/product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margin</td>
<td>Hi</td>
<td>Hi</td>
<td>Lo</td>
<td>Hi, 45%</td>
<td>Hi/Med, 20%+</td>
<td>Consumer market margins*</td>
</tr>
<tr>
<td>Player example</td>
<td>UDC, CDT</td>
<td>UDC, CDT, Merck, 3M, Sumitomo</td>
<td>ULVAC</td>
<td>Maekawa, Japan</td>
<td>Samsung, Sony</td>
<td>Samsung, Matsushita</td>
</tr>
</tbody>
</table>

Sources: SCF industry research

Perhaps surprisingly:-

- Materials and components have higher margins than the production equipment or the finished products – display screens and complete devices
- Being early on in the value chain may be advantageous.
Clusters - TFT-LCD industry today is an Asian Industry

Sources: DisplaySearch, David Hsieh 2005, Flat panel display Market outlook
OLED production industry structure at initial stages today– trading consortia and technology partnerships – expect change

End product design

OLED film manufacture

Display Screen fab (OEM/branded)

Branded product manufacture

Materials supply

OLED R&D and IPR
### OLED value chain – EU players’ have both strong and weak links

<table>
<thead>
<tr>
<th>Link in OLED value chain</th>
<th>Strength of presence of EU industry</th>
</tr>
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<tbody>
<tr>
<td>Original IPR for devices and for manufacturing processes + material supply/ verification</td>
<td>HIGH – Innovation by the EU in OLED technology is strong and growing in the basic OLED mechanisms, manufacturing and materials</td>
</tr>
<tr>
<td>Bulk materials for manufacture and glass</td>
<td>HIGH / Medium – Strong as EU has leading special organic compounds suppliers but also other global suppliers are present</td>
</tr>
<tr>
<td>Components – driver circuits, packaging, etc</td>
<td>WEAK – Few players and weak presence</td>
</tr>
<tr>
<td>Process equipment</td>
<td>MEDIUM – Some strong players but major competition from Asia and USA</td>
</tr>
<tr>
<td>OEM OLED FPD screen manufacturer &amp; resellers</td>
<td>WEAK – Not at levels of Asia, Taiwan for instance</td>
</tr>
<tr>
<td>Branded application device or/and FPD screen manufacturer with retail device sales</td>
<td>WEAK – Not at manufacturing levels of Korea (Samsung) or Japan (Sony)</td>
</tr>
<tr>
<td>OLED lighting branded suppliers and R&amp;D</td>
<td>MEDIUM – But future of segment uncertain</td>
</tr>
</tbody>
</table>
Competitive global comparison for production of OLEDs
– multi-dimensional mapping on cross-regional parameters

Size reflects capability in manufacturing complete OLED screens and devices (Low/medium/high)

Industrial capability for manufacturing OLED film

Production of materials for manufacturing

Capability in IPR – R&D, patents, process knowledge

Korea

Japan

USA

EU

Taiwan

China

Low

Med

Hi
Competitive global comparison of industrial infrastructure for OLED products
– multi-dimensional mapping on cross-regional parameters

Size reflects strength in white label engineering and manufacturing complete OLED screens and devices (Low/medium/high)

Strength of industrial ecosystem for mass-produced electronic components required, manufacturing equipment, etc

Strength in moving technology from innovation to mass production

Own-brand strength in main global markets for devices with OLED screens
SWOT analysis of the EU position for OLEDs

• Competitive behaviour of major players, both globally and in the EU market often centred on 2 opposing tenets – obtaining a first mover position while guarding existing market positions for consumer electronics and ICT goods - eg - Sony & Samsung- OLED players with both strategies

• Use of IPR protection important but impacts are likely to be mitigated through cross-licensing agreements,

• NOT necessary to have all the IPR & patent protection for complete manufacture, but to have SOME IPR resources in order to trade to get the full set required.

• For original technology IPR, materials and processes, Europe has a strong position through players like CDT (although owned by Sumitomo Chemical), Merck, BASF, etc as well as centres of research in Cambridge, Dresden and the Netherlands.

• In the value chain segments where it competes, the EU has a good probability of export market success.

• For OLEDS - Technical problems ensure there is great space for improvement in 2 key areas – fundamental technology, especially polymer chemistry and volume processing techniques- to solve colour and aging problems.

• However bringing these innovations to market is possibly difficult for the EU- may be large Asian suppliers, although the advances in volume processes such as printing are likely to be incorporated into the manufacturing equipment produced in the EU.
### SWOT analysis – summary of positioning of the EU in OLEDs

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
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<tbody>
<tr>
<td>• Capability for innovation</td>
<td></td>
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<tr>
<td>• Production of base materials for OLED manufacture</td>
<td></td>
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<tr>
<td>• Process equipment manufacture</td>
<td></td>
</tr>
<tr>
<td>• Lack of industrial productive capacity or eco-system to support low-cost volume production</td>
<td></td>
</tr>
<tr>
<td>• Capability to bring innovations to market - ie probability of export market success</td>
<td></td>
</tr>
<tr>
<td>• Lack of branded consumer goods suppliers apart from mobile handsets - eg Nokia</td>
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<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Possible renaissance in manufacturing at low-cost, perhaps in Eastern Europe</td>
<td></td>
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<tr>
<td>• Use of IPR - with mitigations through agreements</td>
<td></td>
</tr>
<tr>
<td>• Expansion in base materials supply and process equipment manufacture for low temperatures</td>
<td></td>
</tr>
<tr>
<td>• Older technologies - TFT-LCDs which improve technically - become cheaper, flexible, lower power demands and better colour/contrast, scale up larger, etc, make existing (LCD) players far stronger</td>
<td></td>
</tr>
<tr>
<td>• Strong competitive position and behaviour of current major players both globally and in the EU market make market entry difficult or increasingly impossible</td>
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Points in the OLED value chain for entry by European suppliers

For OLED value chain – 3 three discrete segments where discontinuity may offer EU players an opportunity to play significant part in the displays sector:-

• **Original R&D and IPR** for devices and for the manufacturing process and material supply
  - Innovation by the EU in OLED technology is strong and growing in the basic OLED mechanisms, manufacturing and materials

• **Bulk materials for manufacture and glass**: EU potentially strong – has leading special organic compounds suppliers - but other global suppliers also present

• **Process equipment**: some strong EU players but major competition from Asia and USA

BUT are EU suppliers of a critical mass to change the balance of industrial power in the display segment:-

• EU has fairly restricted access to finished goods production cycle, especially TVs and laptops, ie screen dimensions of over 10 inches - seems remote

• Only in smaller screen sizes for mobile handsets could there perhaps be a possibility of entry by EU display screen suppliers.
European strengths to play on

Foundations of future EU industrial strength in displays:-

• EU R&D - public and private

• EU industrial organisation – clusters building (Dresden, Cambridge, Netherlands) but weaker eco-systems in components that USA or Asia

• Very small firms in leading technology but large firms in materials and medium level in equipment for production lines – so need to support the small firm more for the transition from conception to larger scale industrialisation

• Regional development strengths – the Dresden syndrome

• Promise of Eastern and Central Europe as new hi-tech manufacturing centre – need to build eco-systems for components – chance now as transport/ labour costs rising in Asia

BUT are the current industrial structures in LCD being challenged as a cartel? – Sharp, LG Display and Chunghwa found plead guilty in NOV 2008 to conspiring on LCD price fixing and pay $585 Million in fines?

EU competition authorities have also opened investigation of the LCD market.
Could this become a discontinuity opportunity for Europe?

• Pragmatic strategy for EU entry may as a competing participant in certain segments, supplying some elements of the production chain to other players who perform final assembly rather than being a dominant player, end to end.

• Such a strategy gives reasonable credence to the notion of a potentially disruptive phase with several avenues for market entry into the supply chain, although today's players in Japan, USA, Taiwan, and China will be there tomorrow:

<table>
<thead>
<tr>
<th>Market entry method</th>
<th>Degree of EU strength</th>
<th>Value of strength factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create new players, for new technologies, with an evolved industry structure</td>
<td>HIGH in certain value chain links - especially R&amp;D, materials, production processes</td>
<td>High, despite the display value chain being close to the LCD/ semiconductor model today</td>
</tr>
<tr>
<td>IPR - Ownership and control</td>
<td>MEDIUM - EU has gained more expertise in applying IPR to production.</td>
<td>Low - value is in local skills acquired, not necessarily pure ownership of IPR. Relevant IPR is fairly globally owned so ownership may be useful for trading IPR</td>
</tr>
<tr>
<td>Competences and skills</td>
<td>HIGH in some key segments - materials, printing, production equipment, original R&amp;D and end-product design</td>
<td>High - possibly the key parameter for creation of industry in the EU</td>
</tr>
<tr>
<td>Industrial ecosystem or clusters with ‘mini value-chain’</td>
<td>LOW From original R&amp;D, EU has built some eco-systems in materials, print production processes, the manufacturing equipment to end-product design</td>
<td>Medium - for the segments in which the EU may concentrate but not as crucial as for final assembly</td>
</tr>
</tbody>
</table>
Policy Pointers to enhance the opportunity for Europe

• Large EC Framework programmes of little help and less appropriate for SMEs and start-ups – replace with more appropriate programme

• Moving from prototypes to full production is the big challenge and risk for the SME, where they need most help – not available as EU level

• Support for clusters in low cost electronics manufacturing – probably in Eastern Europe – could provided the ecosystem needed for a new display industry