Towards Green Electronics in Europe

Strategic Research Agenda
Organic & Large Area Electronics

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1.0 Executive Summary

Organic and Large Area Electronics (**OLAE**) has a huge potential to give answers to many questions in our society on the future of energy, environment, information and communication, mobility, health and others. OLAE covers 5 important topics which have all a similar disruptive technology in common:

- Lighting
- Organic Photovoltaics
- Displays
- Electronics
- Integrated Smart Systems

For these 5 topics so far several technology platforms and organisations are involved:

- Photonics 21
- OE-A (Organic Electronics Association)
- EPoSS (European Technology Platform on Smart System Integration)
- OPERA (Organic/Plastic Electronics Research Alliance)

Organic and Large Area Electronics has a large market potential of up to US$ 300 Billion in 2027 according to IDTechEx a leading research company. As we address 4 important application areas and industries (lighting, photovoltaics, displays and electronics) we have to coordinate and focus on a European as well as national level the resources in industry and academia. In addition OLAE will have significant impact on additional large markets such as printing and packaging, health care and chemical industry. The diversity of the applications requires a clustered approach with one roadmap. Therefore, as an industry-led initiative, around 70 companies and institutes from 15 European countries contributed in the 5 topic areas to the preparation of the first OLAE Strategic Research Agenda TOWARDS A GREEN ELECTRONICS IN EUROPE, which was prepared from February to September 2009.

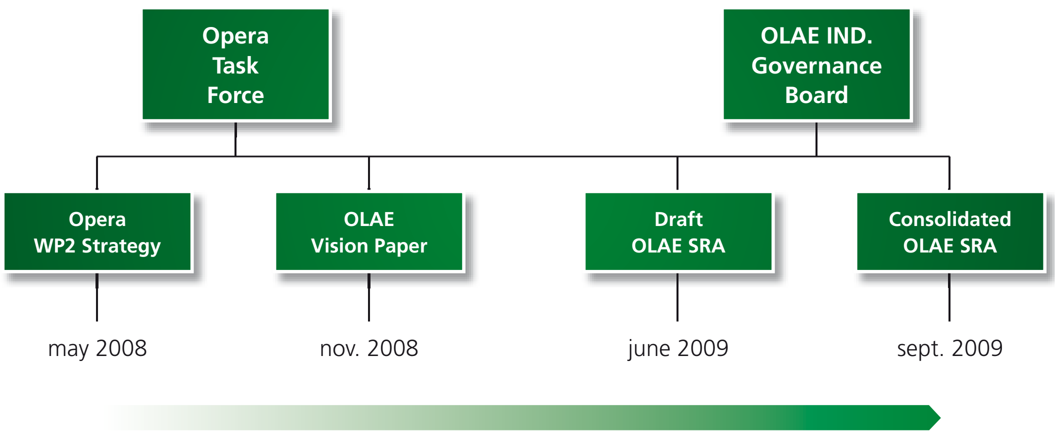
In view of the complexity of the area, the synergies between the topics and the economic and the societal impact a coordinated European funding is suggested with an R&D budget of more than EUR 500 Mio. for 2011 to 2015. With this increased funding Europe has a good chance to keep leading positions in the value chain.

November 2009.

2.0 Introduction and vision

This document is the final version of a Strategic Research Agenda (SRA) for the area of Organic and Large Area Electronics (OLAE). The purpose of this document is to outline the research objectives for this emerging field of technology in the short (2009-2011), the mid (2011-2015) and long term (2015-2020), to identify the importance and impact for Europe in terms of the potentialities for new to be created business value and employment, and the impact of the technology on society at large and the contributions to its sustainability. Core objective of setting the SRA is aimed at paving the way for securing Europe's scientific, technological and economic leadership in OLAE in the long term.

Milestones to an OLAE SRA



OPERA Strategic Task Force. The fundament of this SRA was laid as part of the work program of the FP7 OPERA project, to define a coherent strategy for the future of OLAE in Europe. A task force was established in May 2008 in order to draft a vision paper on the objectives and challenges anticipated. The task force, composed of members of the OPERA consortium, and complemented by a representative of Merck KGaA, presented this Vision Paper to the Commission in Brussels on November 18, 2008.

OPERA OLAE Vision Paper. The joint effort of the Vision Paper Task Force reached the following key recommendations:

Why Organic and Large Area (OLAE) business and why in Europe?

- OLAE will create a global market of more than 100 Billion EUR in the mid- to long-term future
- OLAE is a disruptive technology that will enable next-generation information technology, energy, healthcare, entertainment, and advertising industry solutions to meet large end-user markets demand in Europe in the future
- OLAE provides significant societal benefits such as more effective usage of materi-

als and energy and added functionality of products. It will enable new cost-effective products for healthcare and wellness, in particular for changing demographics
- OLAE will change the way we live, consume, work, and play!
- Europe possesses a full set of excellent technical competences for realising these opportunities. If Europe maintains and further expands its present competitive edge, it can be the leading global region in this field.

Which position in OLAE can and should Europe have reached in 2015 - 2020?
- European players are global leaders in the OLAE markets with a combined market share of over 50%
- A significant part of the value created along the value chain is generated in Europe, including materials, equipment, components, products, up to media and content
- Europe is the leading R&D and innovation powerhouse in OLAE
- Europe plays a major role in defining standards and visions in this field

What needs to be done to reach these visions?
- Establish a strong and focused European Platform on OLAE and actively link with EC programs that represent application areas for this technology
- Develop a coherent strategic research agenda, including roadmaps, to coordinate EC and national research (i.e. a consolidated Strategic Research Agenda)
- Establish specific measures, e.g. pilot production centres, to close the gap between R&D and products. (Follow the "clustered approach" as outlined in par. 2.3 below)
- Nurture the emergence of an European OLAE industry, for example through new approaches to create lead markets, such as the Lead Market Initiatives (LMI)
- Increase the funding budget in proportion to the huge expected markets and establish new ways to access venture capital
- Develop an approach for cooperation in and beyond Europe
- Take measures to early establish standards for new products (Follow the "clustered approach as outlined in par 2.3 below)
- Establish new training schemes which fit to the interdisciplinary nature of the OLAE field and which range from basic science through engineering and business planning

At the meeting with the Commission of 18 11 08 the need was jointly expressed to align the work of the Vision Paper Task Force with comparable efforts and initiatives taken by the Organic Electronics Association (OE-A) and established European Technology Platforms (ETP's) with objectives and working programs adjacent to the OLAE field, such as Photonics21 platform on photonics and EPoSS on integrated smart systems.

In this context the white paper on "Organic Electronics Recommendations for the advancement of organic electronics on a National and International level", published by the OE-A, February 2008 is of importance mentioning, proposing a clustered, industry guided approach for the funding of OLAE [10]

The leading market research company IDTechEx forecasts a market size by 2027 of US$ 330 Billion for the sector as a whole, a volume comparable to that of the traditional CMOS based electronics sector of 2009 in terms of size and importance. It is expected that the size of logic and memory devices will grow disproportionally and will by 2027 constitute a market volume of US$ 115 Billion.

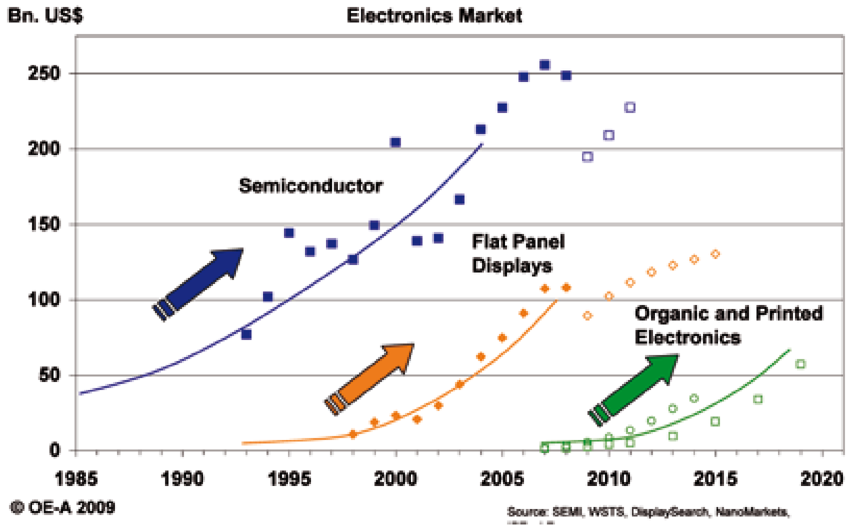


Figure NN: The worldwide sales of organic and printed electronics is expected to grow to almost 60 billion US$ by 2019. The Market development of semiconductors and Flat Panel Displays are shown for comparison (Data: WSTS, Display-Search, SIA von Custer, NanoMarkets, IDTechEx; Graph OE-A).

OLAE Industrial Governance Board. At the meeting of 18 11 08 it was also decided to continue the work of the OPERA taskforce in the OLAE Industrial Governance Board and to seek for support and endorsement of the Vision Paper among the growing community of OLAE stakeholders in Europe, particularly among the industry. This has led to the involvement of between 60-70 industry representatives and representatives of the major European research institutes and academia, who have given valuable input to the work of the Board in the respective OLAE topic areas. A full list of contributors is given in the acknowledgement, par 5.0 at the very end of this document. These contributions have considerably endorsed the work of the board and should be considered as the pre-cursor to an anticipated European OLAE platform.

It was decided to continue the preparations for developing an SRA and an Implementation Plan together with representative organizations and individual industry representatives to become the "OLAE Industry Governance Board". Preparations were started for a first meeting in Brussels, 10 02 09. The board would be supported by the Photonics21, EPoSS, the OE-A and OPERA and chaired by Prof. Karl Leo of the TUD/IAPP.

In his presentation at the meeting of 10 02 09 Mr. Thierry Van der Pyl of the Commission focused on the following topics:

- The current EU ICT R&D funding;
- The scattered OLAE R&D facilities, industrial players and low collaboration among industrialists;
- The importance of a common OLAE Strategic Research Agenda.

It was proposed by the new chairman of the meeting, Dr. Thomas Geelhaar of Merck KGaA, and accepted by a majority of the attendees to continue the work and to request input, involvement, and support of the external parties presented, e.g. ETP Photonics21, ETP EpoSS and from the OE-A. Purpose would be to contribute to drafting a first version of an OLAE SRA.

The parties and attendees present were asked to volunteer for taking up responsibility for specific OLAE topic areas with the following outcome:

- Lighting, Photonics21, Dr. Bruno Smets,

Philips Lighting BV
- Displays, Mr. Martin Jackson, Plastic Logic Ltd
- Photovoltaics, Dr. Andreas Rueckemann, Heliatek GmbH
- Electronics, Mr. Wolfgang Mildner, PolyIC GmbH
- Integrated Systems, EpoSS, Dr. Nello Li Pira, Centro Ricerche Fiat S.p.A.

Draft version & consolidated version OLAE SRA. In order to prepare for a first version of the OLAE SRA, to be presented to the Commission in Brussels on the 15 06 09 the OLAE Industrial Governance Board representatives met in Frankfurt on two occasions (24 03 09 and 08 05 09). By then the agenda for the respective topic areas was discussed and finalized.

At the meeting with the Commission in Brussels of 15 06 09 it was decided to prepare for and to present a "consolidated version of the OLAE" on 18 09 09, which would once again review the necessities of continued EU public funded research, and to highlight the socio-economic impact of the technology for future value creation, employment and the benefits for the European consumer community, from the constituent topic area within the OLAE field. A final version of the OLAE SRA will demand consultation of the European stakeholder community at large. This will be done online at the respective websites of the OLAE Industrial Governance Board Members in the period September 18 – October 18, 2009.

2.1 Objectives of the SRA

By drafting and implementing the SRA, the participants in the Governance Board aim to achieving a European scientific, technological and economic leadership in OLAE in the long term, establishing and reconfirming Europe's leadership in this important emerging knowledge-based sector. To this end the following objectives will be pursued:

- Establish strategic links among mainly SME based OLAE industries as well as towards key user industries (OEM) and to align common R&D efforts accordingly;
- Ensure that knowledge generated throgh research is transformed into leading-edge technologies and processes, and ultimately into marketable products and services, which are competitive on a global scale;
- Define medium to long-term research and technological development objectives and lay down KPIs for achieving them;
- Provide for the necessary research environment capable of accelerating OLAE research, enhancing cooperation, increasing public and private R&D investments and ensuring the mobilisation of critical mass of resources.

The OLAE Industrial Governance Board is convinced that an independent platform, representing all major European stakeholders will be an essential and powerful tool to further strengthen and expand our strong position in this emerging technology and business area. Such a platform will also help the European Commission and EU member states to coordinate the strategic activities in the field and to ensure that research and infrastructure investments are utilized in the most effective way to help the European economy and employment in its global competition.

2.2 Organic & Large Area Electronics – a key technology based on multi-disciplinarity

Organic semiconductors and other low-temperature process able materials represent a new class of functional materials. Combined with novel manufacturing approaches, they enable many new applications, summarized as Organic and Large-Area Electronics (OLAE). According to recent market research studies, products based on organic semiconductors will have an annual value of several hundred billion in the next decades. Products in this field which are already commercially available such as flat-panel displays based on organic light-emitting diodes (OLED) will achieve a global market size of approx. € 1.4 Bn by 2015

(Source: DisplaySearch). The equivalent global market size for OLED lighting is to reach € 4 Bn by 2015 (Source: Photonics21, WG4). Devices based on these new materials and processes will be ubiquitous in our everyday life.

The markets will be driven by the promise of low cost, high volume, high throughput production of electrical and electronic components or devices in lightweight, small, thin and flexible form factors that will in turn facilitate the creation of new markets. For instance, low-cost organic solar cells have the potential to drive the cost of photovoltaics down to levels which are not achievable with classical solar cells, organic light emitting diodes will revolutionize lighting and reduce the CO2 output, and intelligent devices based on organic and printed circuits, sensors, energy sources etc. will allow new approaches in logistics and consumer packaging. New flexible displays with extremely low energy consumption can be used everywhere and anytime. This promising perspective, however, demands a continued effort in developing new and more advanced formulations of materials and related processing technologies.

In a knowledge-based economy, the future of the emerging European organic and large area electronics sector will increasingly depend on the industry's ability to innovate. To achieve such an innovation process, a close collaboration between universities, research institutes, industry and the funding bodies is most important. As Thomas Friedman expressed in his best selling publication "The world is flat", of 2005 "the country that endows its people with the know-how and tools to create new enterprises is the one that will thrive down the road".

Creativity and ingenuity from individuals drives and fuels innovation, along with an appropriate and responsive eco-system and public support measures to support it. Innovations in electronics, information technology and media has brought many achievements, but particularly contributing to higher comfort levels in peoples personal live.

Organic and Large Area Electronics, with its highly multidisciplinary character, create opportunities for truly disruptive manufacturing concepts, innovations and applications. From incandescent or fluorescent lights to SSL, LED and OLED will be existing next to each other and not phase out each other. Similarly, the steps in electronics from vacuum tubes to transistor to integrated circuits are followed by a step of at least equal impact, towards printed electronics, underlining the importance of this new technology paradigm. The forces that drive OLAE technology differ strongly from those of existing electronics, as represented by other technology platforms (EPOSS, ENIAC, Photonics21, etc.), which justifies and requires the creation of a new, dedicated platform.

OLAE technologies make use of a wide variety of materials and their combinations; organic semiconductors, low-temperature solution- and vacuum-process able organic, inorganic and hybrid materials, biomaterials and bioactive materials, small-particle and nano-particle materials, etc. Substrates like plastic, steel, paper and textile are used. Manufacturing involves many processes from other domains than traditional electronics manufacturing: roll-to-roll printing, evaporation, laser processing and other low-temperature processes. All these aim at cost-efficient high-throughput manufacturing on large areas. Processing methods often are combined and customised. On device level for example, basic passive and active electronic components, OLEDs, solar cells, batteries and sensors may be manufactured as functional component foils, rolls or sheets. Lamination and interconnection of such functional foils and films create flexible OLED lighting, autonomous flexible energy sources, disposable point-of-care diagnostics, flexible large area sensors, etc. OLAE manufacturing concepts may also be integrated into existing manufacturing lines to embed added value functionality into for example product packages and printed media.

2.3 OLAE's impact on Europe's future and economic welfare

This new manufacturing landscape creates opportunities for new kinds of industrial players, in addition to the existing electronics industry value chain, to join the OLAE community building the future technology backbone of European excellence and business creation. Such new players will not only be active on the application level but also on materials, components, machinery, instrumentation and automation, e.g. composing a complete new value chain. So building the European OLAE community will be building a complete new value chain.

OLAE SWOT for Europe. The European Commission has drafted a SWOT diagram (See below) for the OLAE of technology area, this SWOT makes it immediately apparent that the Strength (S) and Opportunities (O) of Europe are considered to be located in the pole position it has created in developing new and advanced materials in combination with the processing equivalents. It anticipates great opportunities to capitalize on the outlined basic and applied research connected to the interplay, and the opportunity of launching products and solutions making use of the huge size of the European consumer markets.

With respect to the weaknesses (W) and threats (T), specifically socio-economic factors and challenges are at play. Although the effects of the OLAE technology on the European industry more in particular and the European society at large are subject of this SRA, the execution of strategies, measures and policies to counter these effects are not considered to be falling within the scope of the SRA, but should be dealt with in an "OLAE Implementation Plan" following on the Vision Paper and the SRA.

OPERA Stakeholders Survey. The findings of the European Commission are reconfirmed by a survey executed in the period of March - November 2008, as part of work package 1 of the ICT FP7 OPERA project among major European OLAE stakeholders. This has resulted in valuable input received from 142 respondents (45% industry, 23% research institutes, 25% universities, 7% others). The main conclusions

OLAE SWOT for Europe

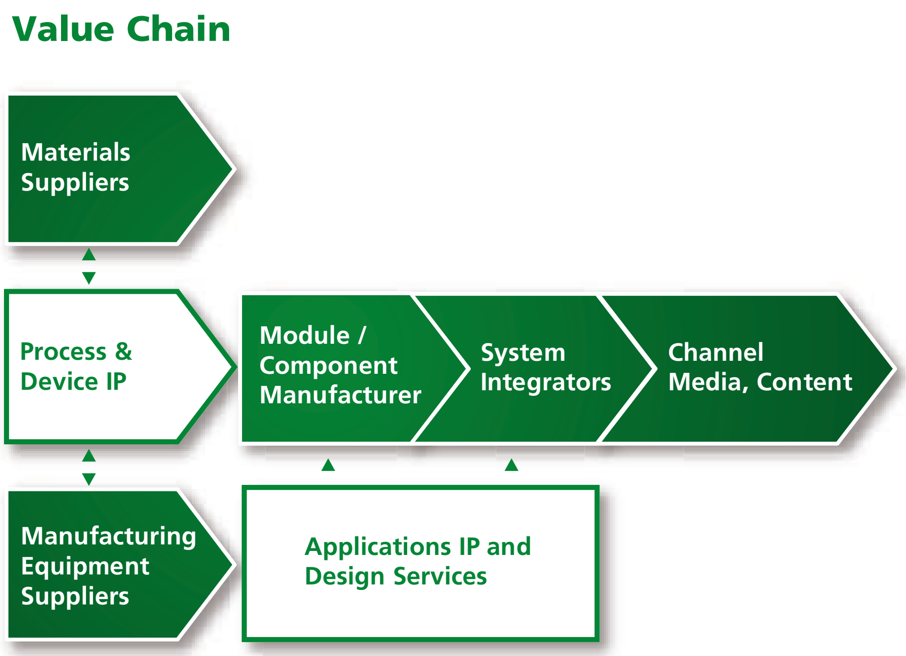
S ▸ Already in possession of materials and production machinery ▸ Huge European market	W ▸ Lack of start-ups and entrepeneurs with clear view from research to manufacturing ▸ Committed giants are needed
O ▸ Formidable research on OLEDs, printed RFIDs and transistors. ▸ Field of applications steadily growing	T ▸ European market will be taken over by foreign manufacturers ▸ External companies will benefit from the research and investment done in Europe

and recommendations from this survey are the following:

- There is a broadly observable perception that Europe is leading in OLAE technology; with almost each and every respondent thinking with high regards of themselves as contributing to this leading position. On the other hand there is a cry for collaboration, which means that stakeholders see a lot of hurdles in the way to success, which they cannot overcome on their own. Shared facilities (e.g. clean rooms) and services (sponsored education & training) should be developed in order to create a support structure.
- The OLAE area is still in an embryonic stage of growth with a strong demand with all players for a closer collaboration between the stakeholders in Europe. Public funded research projects should be more oriented and supportive for commercialization;
- A strong demand for information and a demand to be informed can be perceived and a strong interest to have contacts with peers to discuss issues of common interest. This calls for more, but perhaps more specific and tuned networking events;
- Stakeholders are very much open for consultation in the future.

It is obvious from this survey that serious collaborative effort is needed to keep Europe in the leading position in OLAE. In the following, we discuss the components of the OLAE to point out where the challenges lie.

The value chain for OLAE starts with materials. The development of in particular organic active materials has turned out to be a challenge, since there is no systematic understanding of the relation between a molecular structure and the solid-state electronic properties of an organic material yet. Nevertheless, the level of R&D on organic materials is very high in Europe and companies like Merck, Novaled, CDT, AGFA, H.C.Starck, Evonik and BASF are leading materials suppliers in the various OLAE markets. As the chemical industry is and must remain strong in Europe, it is of strategic importance that Europe stays the global leader in materials for OLAE.



Schematics of the Organics Value Chain

As a consequence one of the focal points of future European efforts on OLAE should be on maintaining and strengthening Europe's position in material science & technology, and more particular in the development of a new class of solution based ink formulations, with conductive and semi-conductive properties, enabling new and more advanced and more efficient applications, interfacing with processing technology.

As indicated, there are challenging problems to be solved in order to reach the objective keeping Europe the global leader in OLAE materials: materials development and optimisation does need a close collaboration between materials, process, and device developers and partners further down the OLAE value chain. Thus, a strong OLAE materials industry cannot do anything without comparable strengths in device and system manufacturing in Europe. Furthermore, it is important to note that OLAE is based on many more materials than just organics, e.g. electrodes, substrates, and encapsulation materials. Issues like ITO replacement have an importance even beyond OLAE.

Or as quoted from the OE-A White Paper "Organic Electronics":

"A common feature of all future generations of different products is that the complexity and overall size of the logic circuits is increasing. In certain cases, the applications include millions of transistors, other combine various different electronic devices like circuit, power supply, sensors, displays and switches. The large area up to the square meter results in additional challenges. A number of "red brick walls" in material development are identified which need long-term strategies, funding and new partnerships along the OLAE value chain in order to be overcome.

In the next step of the value chain, device design, Europe is currently also global leader: Both in organic LED and solar cells, current record values are held by European groups. In transistors and other circuit development, Europe is leading as well. Again, the challenge is to defend and extend this position. In particular, this requires a joint effort of university labs and industry to quickly transfer new basic developments to product.

Major breakthroughs in the following areas are absolutely necessary:

- Resolution, registration and process stability of the patterning processes;
- Charge carrier mobility and electrical mobility of the semi-conductor and conducting materials;
- Circuit design including CMOS like transistor architecture.

These challenges cannot be treated in separate ways since they depend on each other. Resolution and registration accuracy differ for the various patterning techniques and even within a technique largely depend on the throughput of printing speed. The process stability depends on tolerable deviation, the circuit design and the materials that are used [8][10].

When it comes to manufacturing, the picture is less rosy: Although European toolmakers have made significant innovations like inline coating, novel printing techniques, and OVPD, the actual organic device manufacturing (being only in displays) is 100% Asian. To keep the full value chain in Europe, it is therefore of utmost importance that for the future products, manufacturing is established in Europe.

Topic areas in OLAE. With respect to the 5 topic areas elaborated in this SRA, there are at least three areas where European industry is leading in the world: OLED lighting, organic photovoltaics and in organic electronics. For the additional 2 selected topic areas, e.g. displays and Integrated Smart Systems, Europe has to reconfirm its position in displays and reverse the trend of the technology drain to countries such as Taiwan, and Korea. For the integrated Smart systems, the challenge will be to generate a cross-fertilization effect from all the other topic areas into a new class of applications and products non-existent so far.

A clustered approach. In order to confirm our position in OLED's for lighting, in organic photovoltaic and in organic electronics and in order to regain strong positions in displays and integrated systems, certain crucial conditions need to be assured. The following clustered approach is suggested, to coordinate the efforts and to secure the collaboration and commitment of specific industries:

- From the materials industry, with a new class of soluble functional materials in high quality, suitable and performant for electronics, scaled up to be used in production;
- From the processing equipment industry, to produce electronics on a large scale and yield, with appropriate quality control methods
- From circuit development, including modelling and simulation to allow functional circuits based on the materials.

The targets are connected and only reachable in synchronized activities. Therefore the efforts should be taken in clustered approaches and not as single tasks. Material researchers need to collaborate with design and process experts. Detailed requirements are elaborated in the OE-A whitepaper [8] [10].

Application research. As some of the application fields are new, customers and end-users need to be integrated to see first applications in Europe. Therefore support from end-users to apply the technology in its young immature stage is crucial for faster business and market development in Europe.

Economic potential and impact on the economy (quoted from the White Paper "Organic Electronics" of the OE-A, page 8) "Through its very broad range of applications, organic electronics will influence many established industries and revolutionize existing value chains. This provides the different production bases within Europe with excellent opportunities, based on existing technological know-how in the production of electronics, to once again join the global leaders and thus secure existing jobs and create new ones. Widening the range of products opens up new growth opportunities for established sectors such as the printing and packaging industry.

Organic electronics stimulates industrial development in all industries participating. As explained above, the great potential of the applications is that new fields of electronics can be opened up in addition to the existing fields of application for classical silicon-based electronics. Additional jobs will thus be created in the industries participating. This will happen regionally and be concentrated in particular in those areas where these electronic components are developed and manufactured. It is easy to image that other industries along the value-added chain will likewise profit:

- **Chemical industry** (new materials for mass-produced low-end electronics, new applications for existing materials);
- **Mechanical engineering** (specific machines, further development of existing machines);
- **Printing industry** (further development of existing printed products and the development of new printed products, adaptation and integration);
- **Electrical engineering** (diverse, from the development of new systems to accompanying the application);
- **Packaging and consumer goods industry** (intelligent packaging, new electronic based products);
- **Systems engineering** (design concept, development and linking of complex systems).

Companies and industries who become involved in this new technology at an early stage will internationally have knowledge, and thus time, head start will profit economically [10]. Strong synergy, leverage and cross-over effects can be obtained from a close collaboration between previously mentioned disciplines and industries adopting OLAE technologies in consumables with high visibility such as the Agrofood Industry, and the Fashion/Textile Industry.

Apart from the opportunities for the emerging organic electronics industry which are already capitalized by a new class of European start-ups, acceleration trends in globalization of industries (such as in electronics, automotive, etc) in combination with global technology trends in information technology, would necessitate to have a look at existing European industries which are at risk:

- **Electronics Industry.**
  Major changes within the end-market Electronic Manufacturing Services (EMS) industry, over the last decade have brought about giants (such as Hon Hai Precision, Flextronics, Jabil, Sanmina-SCI, Celestica and Elcoteq), dominating mid/high volume-low mix markets such as of consumer electronics, industrial, communications, automotive and others. These giants, all non-European, currently take up about 58.5% share of the total electronics market of roughly USD 250 Bn. These giants are expected to grow and to face out or smaller mid-size players, particularly in Europe (IDC and Riverwood Solutions expect 11 European EMS companies to go in insolvency in 2009, mainly in Germany and the UK, but also in Eastern European member states). These EMS companies incorporate assets, which could of great value to the emerging organic electronic field, if and when transitory strategies for safeguarding these companies are in place.

  The semiconductor industry in Europe includes a few world champions such as ASML, Global Foundries (AMD successor)STM, Soitec and Siltronic and several hundreds of innovative SME's, with a production in Europe of € 9 Billion, employing 105.000 people (most very highly skilled). Microelectronics are at the heart of solutions in industries where Europe is still leading such as in automotive, aerospace, communications, industrial machinery, medical equipment and to a lesser extend in consumer electronics. But more and more European companies are choosing to outsource (to EMS) device manufacturing to other regions mainly Asia. However, without major semiconductor manufacturing in Europe, know-ledge based activities, including R&D, will relocate to other regions. [Source: SEMI Europe "A sectoral policy for the European semiconductor industry", 2009].

- **Printing Industry.**
  Another example is the European printing industry. Accounting for a total European market value of € 149 Bn in 2008, including packaging (Source : "European top-line market value", Pira International 2009), with over 90.000 companies and 700.000 employees in the printing sector alone, the sector's main concerns seems to be with the delocalization of print towards China (Sources : "The Printing Industry – China and the EU, Intergraf, International Confederation for printing & allied industries, 2006, "Competitiveness of the European Graphic Industry, Ernst & Young 2007). Additionally the sector could be confronted with a severe risk, once society would massively start to switch to virtual books, newspapers and magazines. It seems that the European printing equipment industry by now has become well aware of that trend, but the end-user industry (the publishers and print-houses) to a much lesser extent. Also in this case transitory strategies should be in place and stakeholders involved in this mature sector of industry, in order to prevent a massive shake out of business and employment in the mid to long-term future.

Impact in Specific OLAE topic Areas
What is the potential for European stakeholders in the selected SRA topic areas, in terms of market position to be gained and of the socio-economic impact in terms of value and employment to be created:

- **Lighting.**
  It is very likely that OLED lighting is the

next considerable market which OLAE can enter. The very first products have just been launched by European companies, Osram and Philips. OLED lighting seems to be a promising market since, even more than for displays, organics have unique selling points: there is no other highly efficient area light source with good colour rendering, high brightness and long lifetime. Therefore, it can be expected that OLED lighting will secure a sizable part of the US$50 billion lighting market, if very low production costs can be achieved.

Europe is very well positioned in the OLED lighting field since two of the three globally largest lighting companies (Philips and Osram) are headquartered in Europe and since the European work on white OLED is in the fore. Additionally there is the lighting luminaires industry, a rather segmented market. Here design is very important, again addressing one of Europe's strong points. There is literally thousands of SME lighting manufacturers in Europe, and it is of utmost importance to make OLED accessible to them as early as possible to enable them to take the global lead in bringing novel luminaires to the market.

Then, looking beyond existing lighting applications, low-cost OLAE manufacturing technologies and concepts enable OLED signage and lighting to penetrate completely new low-end application areas like product packaging, posters, disposable sensors, etc.

- **Organic Photovoltaics.**

Organic Photovoltaics is, in terms of commercial applications, still emerging. Currently, the first dye-sensitized flexible solar cells are delivered to customers. However, the market potential for photovoltaics in general is extraordinary. Notwithstanding a temporary dip due to the economic crisis, it is virtually guaranteed that the photovoltaics market, currently about 10 billion US$, will grow by a factor of 10 in the next 10-15 years, continuing to grow at a high rate after that. In particular, the growth rate of thin film solar cells is 100 % annually. A major challenge is the cost of manufacturing. The key question is whether Organic Photovoltaics can capture a major share of the market. Given that established technologies achieve module efficiencies of >15% and lifetimes of >30 years, the entrance barriers for organic solar cells are high. Organic Photovoltaics however allows for disruptively cost-effective high-throughput roll-to-roll manufacturing on large areas. It also promises a very positive ecological profile due to its short energy pay-back time and minimal toxical impact (mainly depending on choice of substrate). Thus, OPV does not (yet) represent a guaranteed road to success, but a promising technology option which Europe cannot afford to miss. Europe is positioned very well in the Organic Photovoltaics R&D and also in other photovoltaics technologies that actually will support the emergence of Organic Photovoltaics by dual use of e.g. electrode and encapsulation technologies.

Additionally, OLAE will provide the energy management systems for a wireless ICT society: Smart labels, smart and interactive packaging, autonomous sensors etc. are requiring low-cost, thin, flexible energy sources and storage.

A number of start-up companies and large enterprises have started R&D efforts directed towards manufacturing of (flexible) OPV. Heliatek with his partner IAPP are world leaders in OPV efficiency with recently reported 6.07% certified efficiency. Several European companies are involved in producing and selling photoactive materials and ink formulations for OPV including BASF, Ciba, HC Starck, Merck and Solvay. Today, no consolidated information is available about the number of employees that work on organic PV in Europe. We can guess that the largest fraction is working in R&D and a smaller one in industry, commercialization and consultancy. At this stage, no reliable estimate can be given of impact on economy and jobs. Given Europe's existing strong position in academic research, in materials development and manufacturing, in production equipment (printing, vacuum deposition), combined with the presence of major (non-organic) PV manufacturers, Europe is well positioned to capture a key role in the emerging OPV industry.

- **Displays.**
It is not hard to predict that the display market, being around 100 billion US$ today, will continue to grow, having the focus upon larger and higher-resolution displays for TV, multimedia, computer and portable applications. Flexible displays will clearly gain a larger share in future.

Currently, fabrication of displays themselves has no significant economic importance in Europe. However, European companies play a major role in the value chain of display manufacturing, as illustrated by the globally dominant position of Merck as material supplier in the liquid crystal business. Thus, it makes sense to continue the successful European R&D on OLED for displays. One particular aspect which might offer opportunities for European companies is the fact that the current trend towards even larger TV displays is leading to a huge increase of power consumption in the average household. To stop this trend, it will be of utmost importance to significantly reduce the power consumption of flat-panel displays. Here is a chance to leverage the European leadership in high-power efficiency OLED.

Previously many people believed that OLED displays would open a "second chance" for the fabrication of displays themselves in Europe. This did not work out. In hindsight, the key reason seems to be that critical steps of the technology (the backplane) were controlled by the LCD industry and became a sustaining technology for current manufacturers, which was not clear at the beginning. Only in specific markets, Europe was able to enter the market again. For OLED on CMOS based micro-displays, two of three players in the world (MED and Microoled) are located in Europe. Besides that, advanced R&D on OLED microdisplays is performed in Europe in partnership with leading European CMOS silicon foundries, which combined effort, allow for taking world-leadership in this field.

However, we believe that flexible displays and microdisplays are definite opportunities for Europe. Here, new technologies like organic transistors and new manufacturing approaches like printing will make the field much more diverse. In both areas, Europe is leading, and actually the first fabrication of flexible electronic paper devices is done in the EC by Polymer Vision, Plastic Logic and Acreo. It is of key importance that these European activities stay at the leading edge.

- **Organic Electronics**
Perhaps the largest expectations of OLAE address the field of organic and printed electronics, involving applications in which organic logic and memory will be used. This is also visible in the market prognosis discussed above in which logic and memory and OLED jointly have the largest share. The key point supporting these expectations is that OLAE makes "ubiquitous electronics" possible, i.e. electronics on any package, on clothing, etc. Market forecasts now even start to recognize Disposable Electronics as a future business area: low-cost RFIDs, e-paper, games and gadgets, etc. The OE-A roadmap and several market forecasts expect a stepwise penetration of RFID and smart labels into consumer goods within 10 years, capturing very high volumes with low-cost solutions. High-speed deposition and structuring manufacturing concepts (e.g. printing) are promising disruptive developments in manufacturing, providing opportunities to use organic/inorganic/bio materials as embedded electronics in products. Assets of Europe are the globally leading level of R&D and leading positions in materials,

process development and production of organic and printed electronics devices. R&D for organic and printed electronics is a collaborative approach. Improvements will lead to advances in technology and design or in better, improved processing capabilities (See par 3.4 on Electronics). Organic and printed electronics will enable new applications and markets for electronics. They will also change, save or even revolutionize existing industries. The impact of these changes will be huge, either in business models, job qualifications and new jobs created, and would create to off-set losses in existing mature industries, such as in CMOS electronics, printing, textiles, and others.

- **Integrated Smart Systems.**
As the population in Europe and in many other industrial countries ages, biosensors for health care close to the patient (at the point-of-care), especially involving biomolecular diagnostics, become essential for improving the quality of life of patients and reducing the costs for health care systems. Rapid and portable home diagnostic tests are required in order to assist elderly and people with prolonged illnesses to live home. Moreover, current diagnostic tools are largely inadequate for meeting health needs in developing countries. Practical low-cost technologies for monitoring treatment efficacies do not yet exist. Point-of-care and home diagnostics are expected to dominate the biosensor markets, followed by security and biodefence applications. Forecasts expect a market size of 10 billion USD in 2013 and an annual growth rate of more than 10%. Printing based manufacturing concepts will enable low-cost printed diagnostic systems. In such devices, nanobiomaterials, microfluidics and sensing components will be integrated. Applications will range from simple disposable sensors to complete lab-on-chip analysis systems, all under a cost-efficient manufacturing paradigm. A further extension may involve integration of functions in everyday hygiene products such as bioactive papers.
OLAE technologies will also allow new distributed sensing concepts and applications in large and economically valuable objects such as technical infrastructure, homes and utilitarian buildings. For instance, moisture and corrosion problems may be monitored inside structures, sensor carpets will support safety applications and assist disabled persons, strain and failure measurements will prevent unexpected failure of bridges, building support structures, wind mill blades, etc. On a smaller scale, body sensor networks will be enabled by OLAE.

Moreover, heterogeneous integration of OLED with mature processes (e.g., silicon CMOS) allows embedding an on-chip light source for optical sensors (finger-print, fluorescence, color) for disposable sensors in medicine, biotechnology and security

The application of OLAE technologies to displays, lighting, electronics and photovoltaics as we know and understand them today, as described in the previous paragraphs, will yield an extremely valuable set of technical capabilities in Europe. These capabilities will also expand existing industry boundaries: e.g. beyond what lighting is today, opening up opportunities for novel products in areas previously less associated with electronics, such as smart packaging, disposable electronics, hybrid media, etc. While it is difficult to predict which products will occur and be the most successful, it is beyond doubt that there will be many products un-conceived yet which will open attractive markets. Many of these may initially be realized with relatively simple OLAE manufacturing capabilities, in which a lower performance electronic component adds new functionality to items. These may significantly increase the value of existing printed products and open up fully new product areas. Such novel products can provide significant new business opportunities for current SMEs.

OLAE and the benefits for the consumer. By taking into account what OLAE could contribute to the benefit of the consumer, it should be clear that there is no such notion as THE consumer whatsoever. We have to define more specifically what groups will be affected, and what applications and form factors will be adopted to the greater benefit of the consumer groups involved. And secondly that consumer behaviour is not driven by technology at all, but only by the benefits created and enabled by such technology.

In order for OLAE technology to be successful, there should be clear value-proposition options offered by OLAE included in the proposed new class of products, which will lead to market penetration and substitution of existing "dumb" products and product packages. This can particularly be anticipated in the area of fast moving consumer goods (FMCG), where OLAE can be expected to create a serious "demand pull" effect. Although it is not the main focus of the OLAE SRA to extend too much on the benefits for the "consumer", it should be kept in mind that these benefits are and should be the main drivers for the success of OLAE adoption.

For that reason, trends and driving forces behind the adoption of the OLAE technology are considered here in brief, but should be of main focus and objective in the OLAE Implementation Plan to follow. Worth mentioning in this respect is the recent published report by Faraday* (www.faradaykowledge.com) on "Plastic Electronics and the FMCG Consumer", commissioned by the Materials Knowledge Transfer network in the UK.

This report shows how OLAE is likely to affect sellers of consumer products and the people who buy them – the consumers themselves. While it may be possible for brand owners to use OLAE technology in consumer products and packages in new and exciting ways, its use must be incorporated into design processes that are user-led to ensure value is added to the brand and not taken from it. Maybe even more important is the role OLAE will play in creating a society that is online all the time. Once this always-on society has become a reality, traditional product marketing will probably have had its day. The report is arguing that "a brand owner's ability to market their own products will be severely diminished unless relationships with consumers deepen considerably. And if that wasn't bad enough, there may not be a great deal of time left to start thinking about these issues".

Consumers tend to be better informed about product propositions offered, due to the time connected to the internet and the way "peer reviews" influence their buying behaviour. This is considered to be the beginning of the "recommendation society", a social landscape in which consumers purchase products based almost entirely on the recommendations of other users. In this always-on society, the users market the products, not the product or the brand owners. This could mean the end of product-marketing as we know it today, mainly based on advertising that is focused entirely on getting the consumer to purchase the product. In contrast, online peer reviews are based on the user's experience of interacting with the product, an interaction that will change considerably in ways we do not yet understand if OLAE is used to add electronic or communications functions to these products. Findings in this respect are supported by the outcome of the `Fifth Annual Report on the State of Communications in the UK", by regulator Ofcom (august 2008).

Organic and Large Area Electronics based on low cost processing, enabling information technology at the product level (with access by on-line media), could anticipate this trend and would considerably enhance and influence the buying behaviour of consumers. By itself it would contribute to the value propositions of many products and applications, and more in particular of the fast moving consumer goods (FCMG). It will be the pre-cursor to a world of ambient intelligence in which people are surrounded with electronic enabled environments that are sensitive and responsive to people, and additionally to a world where the Internet will reach out into the real world of physical objects. Technologies like RFID, short-range wireless communications, real-time localization and sensor networks are now becoming increasingly common, bringing the Internet of Things into commercial use. They foreshadow an exciting future that closely interlinks the physical world and cyberspace - a development that is not only relevant to researchers, but to corporations and individuals alike

2.4 Value creation: Establishing an OLAE manufacturing base in Europe

Currently, the OLAE products which are mass manufactured are mainly OLED displays. Here, with the exception of Micro-emissive Displays as a niche manufacturer, all devices are produced with vacuum techniques. Other mass products or mass-printed sensors for single use glucose test-strips for bio-medical applications, printed batteries as well as several passive components like antenna's, resistors, etc.

European companies have brought forward some novel ideas like inline manufacturing (Applied Materials) and organic vapour phase deposition (Aixtron). Companies like Solar Coating Machinery, RK Print and OTB have realized tools at the forefront of technology. Since tool makers need the feedback from manufacturing, the importance of controlling the full value chain in Europe is once more emphasized. Fortunately, European manufacturers are very strong in printing technology, with leaders like MANRoland, Heidelberger, and KBA. Moreover, Europe holds a strong position in CMOS manufacturing (ST, NXP, Infineon, XFAB), particularly in integrating sensors, analogue devices, MEMS and OLED. It can be expected that much of this knowledge can be leveraged for OLAE applications.

Establishing a manufacturing base for OLAE in Europe requires the development of a shared strategic vision of all major OLAE stakeholders involved, whether from industry, research and public authorities. This should be considered as one of the main objectives of an "OLAE Implementation Plan", that should be compiled as a third step and direct follow-up of the "OLAE Vision Paper" (Nov. 2008) and "OLAE Strategic Research Agenda" (Sept 2009).

In this respect suggestions and recommendations are laid down in the "White Paper- Organic Electronics", of the OE-A (Update Feb 2008), and quoted from par. 6.5 pp 18-20, which should be considered as of high value for the whole technology area of OLAE [10]:

Structure recommendations for Organic Electronics Centres. Becoming involved in the emerging technology of organic electronics means taking considerable risks and making advance contributions to R&D. The key here is, through suitable development programs, to lower the threshold at which companies will come on board and thus to create the basis for sustainable jobs in a key technology.

Due to the complexity of the subject, the setting up of centres for organic electronics is particularly promising. These centres, hereafter called "clusters", should be industry driven and consist of a well balanced combination of companies, research institutes and universities specialised in several key fields in the value chain from material to components, production to application and which reflect the variety of the future fields of application for organic electronics.
The criteria for setting up and promoting the clusters should be:

- Bringing together companies, research institutes, and universities;
- Interdisciplinary networking over several stages in the value chain;
- Focus on industrializing the technology;
- Application oriented, but also promotion of essential basic subjects;
- Promising organizational structure and
- Setting of verifiable aims, milestone principle.

Funding period for organic electronics centres. In accordance with the current state of technology, the funding period for the clusters should be designed to begin in 2009, but be long-term funded (roadmap 2020 + extensions). The budget for the cluster should include a fixed percentage for temporary participants in the project (around 25-30%) and clear mechanisms should be defined for sorting out less successful projects and replacing them by new projects."

Coordination of clusters. The Coordinated Action FP7 OPERA Project (FP7.ICT.2007.3.2-215150) in its work package 2 on "Strategy" is focusing on coordinating the emergence and further development of pre-mentioned OLAE technology clusters. OPERA has currently 8 technology cluster location partners as consortium members (Cambridge, Dresden, Eindhoven, Oulu, Basel, Heidelberg, Lyon/Oyonnax, Thessaloniki) and PEF (Coordinator) and the OE-A as a member of the Steering Committee. An assessment process is foreseen within the framework of OPERA in order to define the comparative strength of each cluster and to coordinate between the cluster sites in terms suggested in the OE-A White Paper for the period Q4 2009 and Q1+Q2 2010:

- To give an overview of the state of technology and industry;
- Formulation of the economic and technological aims;
- Evaluation of current activities;
- Positioning and assessment of new activities;
- Classification and assessment of the international position of the individual clusters

An "OLAE Implementation Plan", which could be anticipated after EU evaluation and endorsement of the OLAE Vision Paper and OLAE Strategic Research Agenda, could lay down the fundaments for using the "cluster" setting as a core instrument to establish a solid and competitive base for OLAE manufacturing in Europe. It should be clear that the number of OLAE clusters mentioned previously does not include all prevalent in Europe. There are several more such as the OLAE cluster emerging in the North-East of England (PEtec], the cluster around the University of Lynkoping in Sweden, Aachen area and the University of Barcelona in Spain, and a few others.

The validity of the OLAE "eco-systems" created at the cluster-locations could also be deployed to safeguard and secure economic value and employment, related to industry sectors (which share part of the technology base with OLAE) in or about to be in their reconversion phase, such as the European electronic manufacturing services industry and the European printing industry, referred to in par. 2.3 of this introduction. The clusters could offer infrastructure and support services to these industries, in order to prevent divestitures and loss of employment. Researching these opportunities would or could be part of the OLAE Implementation Plan.

2.5 The greening of electronics: OLAE contributions to lower the CO2 footprint

As seen from an ecological point of view, OLAE is promising ecological benefits in several ways. The first way concerns functional advantages. OLAE devices contribute to reduction of energy consumption (e.g. OLED lighting, as compared to conventional lighting technologies), lowering the CO2 footprint. And OPV will be a major technology option for affordable green generation of energy, specifically when available areas are large and low-cost; large-area manufacturing can make the difference.
Manufacturing: The second aspect concerns the energy invested in manufacturing of OLAE devices. Typically, extremely thin layers of functional layers are used and most deposition processes must run at modest temperatures because of the organic materials used. Thus, the energy invested in manufacturing of OLAE devices is much lower than in their "conventional" counterparts. To illustrate this, OPV on plastic substrate is seen as the PV technology

promising the shortest energy pay-back time of all.
The third ecological benefit relates to the low toxic impact of OLAE devices. As the functional layers used are very thin and often organic, the toxic impact mainly consists of the impact of the substrate, which in itself can be very low if well chosen.
A careful approach is required when applying OLAE technology to create disposable devices in areas where nowadays no active functionality is used (e.g. on food and pharma packaging). Here, research and design choices will have to be supported by ecological analyses to avoid negative ecological impacts.

The organic and large area electronics technology is to be considered as in potential inherently green. Because the developments of the devices are based on the use of thin film technology (TFT) in combination with high volume roll-to-roll processing technologies, the result is:

- A reduction in the use and consumption of materials, and the use of toxic materials compared to traditional processes in CMOS technology;
- The omission of multi-masking and multi-stepping processing technology, with the avoidance of intermediate curing and etching processes such as in traditional CMOS technology;
- The development of devices based on low-power consumption.

OLAE can significantly reduce the cycle times and cost structures of the semiconductor industry due to the use of high-volume commercial manufacturing such as roll-to-roll printing. Currently, printing of both organic and inorganic semiconductors is taking place using techniques such as inkjet, lithography, and gravure, while flexographic and screen printing are likely to feature in the future mix of low-cost manufacturing techniques. Eventually, the expensive R&D cycles in complementary metal oxide semiconductor (CMOS) wafer based systems will give way to simplified materials processing and large area electronics manufacturing. This is due to the elimination of lithographic masks and economic custom design for small orders and low-volume production.

However, despite the huge strides made in technology development, OLAE components have still a way to go before they can be manufactured using conventional presses. Products are likely to be in liquid or semi-liquid form, covering the substrate in patterned layers. Reduction in the cost and weight of the products can be achieved only if electronics circuitries are printed on thin substrates (TFT), allowing them to have ubiquitous application in displays, sensors, lighting, and communication devices. Large Area Low-cost Manufacturing using printing to have a major impact on inorganic silicon based electronics
while there has been tremendous progress in the development of organic conductive/semiconductive/di-electric chemistries, products, and processes, the focus needs to shift to developing printable logic and complementary circuits similar to those of CMOS wafer-based systems, which were originally meant to be replaced. With the discovery of conductive polymers, the electrical functionalities of conductive and semi-conductive polymers and monomers are being utilized for the direct printing of electronic features, especially for low-resolution circuits and low cost microelectronics products.

Low-cost manufacturing, especially printing, seems to be the appropriate technology in cases where conventional components cannot be incorporated in the silicon chip due to their size and it would not be feasible to increase chip sizes. When the technology matures, the cost of these printed circuits may only be 1 percent of the cost of silicon chips on flexible substrates, leading to high throughputs for the printing of large area electronics. "Large area low-cost manufacturing using printing is expected to revolutionize the market for

inorganic silicon-based electronics because unlike silicon and other III-V compound-based electronics, printing techniques do not rely on high-volume production to drive down the costs of electronics manufacturing," says the analyst. However, there is definitely a trade-off between the high volumes that can be achieved using standard printing presses and the limited resolution of these techniques with regard to silicon microelectronic fabrication. Therefore, silicon technology is likely to continue to dominate applications that require fast switching and complex processing, whereas the lower cost/area ratio of printed electronics is expected to be more suitable for less sophisticated applications.
Mass-printing technologies will have a large impact on OLAE. The biggest potential lies in organic or combined organic/inorganic structures because they often promise the lowest costs, allied to the fastest printing technology, such as gravure employing water-based inks, with low temperature curing. Other printing techniques such as ink-jet have become a popular choice, because of its tolerance of uneven substrates and its instant reprogramming. The silicon chip has little to offer beyond logic, memory and a few small sensors because it is only economical when small. By contrast co-deposition of different devices using printed electronics can exploit the fact that it is economical with a large footprint. For example actuators, batteries, powerful capacitors and resistors, photovoltaics and a considerable choice of wide area sensors that will be co-deposited without the need for conventional unreliable and expensive interconnects required when connecting silicon chips.

All previously mentioned manufacturing processes are still under development and in time to take care of life-cycle analysis of the products, and the recyclability of all OLAE components. Unlike silicon technology whose manufacturing paradigms and component materials are sometimes untouchable. This is because the semiconductor industry emerged 50 years, and belongs to the legacy of the 20th century. OLAE manufacturing technologies green added-value, and will contribute to greening the 21st century.

Solvents. Major challenges can be expected to arise when we try to move from the current level of technology of solution-based lexaan and hexaan processing to completely redundant, and recyclable and environmentally sustainable processing. For example, research efforts have been considerably in the past to get away from fluor (hydrofluor ethers) based solvents into the direction of a.o. aliphatic solvents, ionic liquids and super heated water.
Additionally worth mentioning are initial concepts developed within the framework of the ESMA, the Association of European Manufacturers of machinery and consumables for the specialist printing industry (www.esma.com), but further R&D efforts should be taken. As stated by the ESMA "There is from the industry and market an absolute desire to develop inks without any VOC's (volatile organic components). Alternative solutions have been tested, but do not give the same desirable levels of conductivity. Printed electronics should raise its benefits for inks in durability and recyclability in comparison to traditional CMOS based electronics. New ink developments should support these facts and be available before legislation makes changes to the requirements of conductive inks".

Substrates. Another topic is the current use of environmentally unfriendly and non-degradable substrates in the thin film devices such as PET and PEN. Efforts should be made to develop different types of flexible substrates that are bio-degradable and better recyclable, such as polylactic acid (PLA) based substrates. Where recyclability is expected to have the largest impact.

These are among the many research issues to be solved in order to be able to classify OLAE technology as a real green technology for the future. It is suggested to include these "greening" in the "OLAE Implementation Plan", following the SRA.

3.0 OLAE topic tasks and research priorities

Inspection of OLED Lighting panels during pre-pilot production in Aachen
Courtesy: Philips Lighting

3.1 Lighting

Abstract & Summary

One of the major applications for organic large area electronics is Organic LEDs for general lighting. The global general lighting market is a Euro 60 Billion market, which consists of lamps, electronics, controls and luminaire systems. Europe is still in the lead for this market, with over 150.000 employees in several thousands of companies working on lamps, materials, production equipment, designs, and lighting fixtures.

In the next decade we will see a massive transformation of the lighting industry towards energy efficient Solid State Lighting (SSL). This change will have great impact on the current lighting market and business models, and is comparable with the change from vacuum radio tubes to the transistor or from CRT picture tubes to LCD. This technology platform transformation will offer many opportunities for new players to enter the lighting domain.

The lighting market today demands higher energy efficiency and longer lifetime on component level as well as system solution approaches for intelligent light control, to compensate decrease in energy security and reduce into CO2 emission worldwide. SSL offers many solutions to the above problems in the future. Classical lamp components will be replaced by solid state lighting system solutions, delivering light only when it is needed. The long lifetimes of SSL will diminish over time the traditional lamp-replacement market, and will change the importance of well designed luminaires. And organic area lights will migrate in total new applications where today none of the existing lighting solutions is apparent.

Together with LEDs, OLEDs are currently entering the lighting market as novel light source and alternative to existing lamps. To develop the OLED lighting market, massive investments in research and development is required. For the next five years the R&D focus will be on small and medium sized tiles to reach high efficacy and luminance levels with appropriate color quality on rigid substrates, including transparency. Due to its very specific form factors (compactness, lifetime, robustness, flexibility, transparency and color changing) OLEDs create totally new application fields for lighting (e.g. ambience creation, light embedded in all kind of products like furniture, staircases, walls, floors, curtains,….). Beyond 2014 the R&D for OLED lighting needs to focus on low cost area approaches (for both R2R and glass). This will enable to OLED technology to migrate into the general lighting market.

As OLED are area lights, it should be noted here that OLEDs are a different types of light sources, which combines the lamp and fixture trough its specific form factor. In order to spread the usage of OLED lighting, close co-operation with the large number of European luminaire manufactures as well as acceptance by end-users and is essential for the overall success of this lighting revolution.

OLED lighting market predictions

The market for OLED lighting started in 2008 with the introduction of the first European OLED designer lamp (by OSRAM and Ingo Maurer).

The first OLED desk lamp "Early Future" Courtesy: Ingo Maurer

Since then, smaller quantities of OLED tiles have been sampled for demonstration and application studies (mainly Philips), targeting lighting products for the near future. From the reactions to these early feeds, market expectations for this new light source are positive but also very high.

Market studies predict a strong OLED lighting market growth for the next years towards a Euro 4 Billion market in 2015, or about 5% of the total lighting market. This 5% level in market penetration is presently reached by inorganic LEDs and is generally considered as the point of no return for market acceptance. This requires besides massive R&D effort also strong investment in up scaling in production platforms (which are still under development) as well as in marketing and sales, which are currently taking place. It is expected that larger quantities of lighting products will be commercialized in 2010, targeting demonstrations and smaller high end markets which less price sensitive. From this point the OLED lighting market will gradually develop towards usage as general illumination, with stronger growth once the efficacy and cost levels are comparable with other (LED's or fluorescent based) luminaires.

Several development iteration cycles have to be passed to reduce the area costs of OLED lighting without sacrificing the design appeal and the performance for general lighting applications. Lighting history has shown us that such transition will take much time, and that several lamp types will co-exist for some decades. But given the momentum with the phase out of less efficient lamps, such as incandescent and high pressure mercury lamps in Europe, this transition time could be much shortened. This offers a very good opportunity to strengthen the large European lighting Industry.

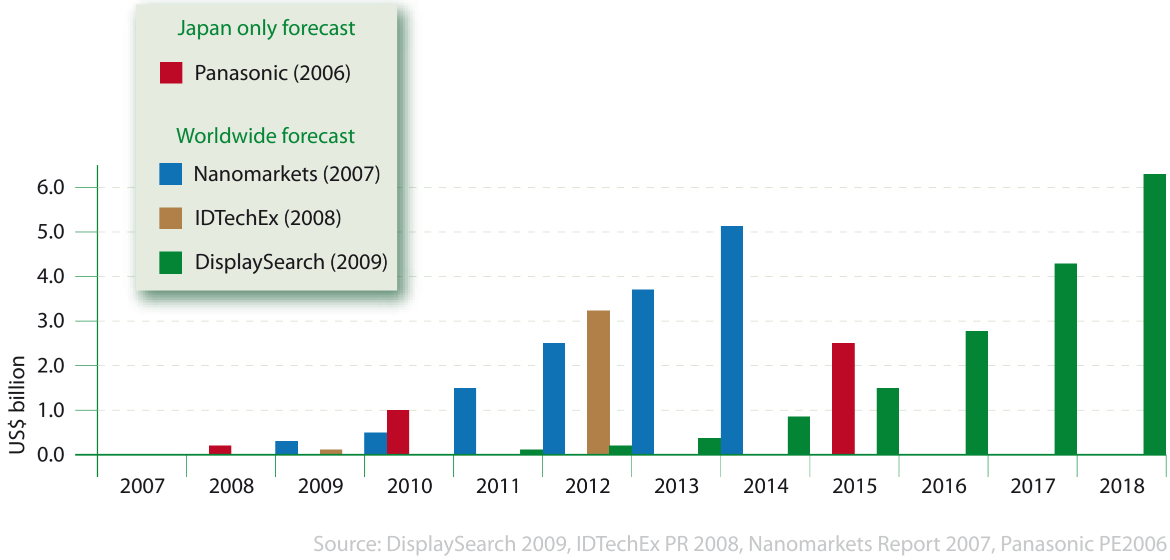


Figure 1: Overview of OLED lighting market predictions from several market research companies. Note that some predictions also include luminaires. (Source: Cintelliq, 2009, http://www.cintelliq.com/)

However, with the imminent threat of diffusion this technology to the Far East, it might be of importance to couple the transition from incandescent lighting to new technologies, in Europe effected by law, to the support of technological development of new lighting technologies (among which OLED lighting), through directed programs of technology purchase. This may be where bids for supply of lighting to state/ European facilities are connected to the technology profile. Yes, this is one of the forms of etatism, and has been a very important form in Sweden, where much of the telecommunications industry grew under such technology purchase forms.

Focus Areas/R&D Priorities
Europe is able to address the whole OLED lighting value chain: from materials-technologies, through equipment development, OLED panel manufacturing, electronics and assembly, towards luminaire design and all integration aspects. Already a lot of project and results have been preformed the last decade. One of the main results of former or running projects is that today the efficiency, lifetime, brightness & large active areas are very contradictory and even confusing. Through this research it was possible to demonstrate single record values in efficiency, brightness or lifetime, and thus to demonstrate the potential of the OLED technology. However, the challenge now is to combine all these unique properties and explore devices with high quality and high flux, as well as high efficiency at lifetime higher than 5,000 hours lifetime and also at moderate costs. Only if the R&D effort will be successful in combining all these superior properties in one device the OLED will be ready for market launch.

To advance the development of the European OLED lighting industry, three top R&D fields are selected:

Priority 1: High quality white light devices for general lighting based on OLED technology
Priority should be given to maximizing the external quantum efficiency, reliability and lifetime of OLEDs (beyond > 100lumen/Watt at >10,000 hours lifetime) at higher brightness levels (5000 cd/m^2) through stack development and testing procedures, as well to developing integral solutions for OLED at luminaire system level, such as OLED tiling concepts, concepts for efficient and integrated driver electronics, or cost-effective and reliable encapsulation enabling 10-15 years shelf life. Practical simulation tools with good predicting power for optical and electrical OLED stack simulation are necessary to lower the enormous stack development efforts.

On the longer run, projects are needed which target the development of flexible, conformable and transparent devices, including suitable materials (substrates, barrier layers) and cost effective processing.
For the purpose of fast market acceptance, all aspects of light quality (high CRI, angle dependency, differential aging and colourbinning) demonstration and user acceptance studies should be an integral part of all projects. Special attention should be paid to early standardization of OLED metrics, devices and electric drivers, so that interoperability problems can be solved in an early market phase.

In a later stage, the design of luminaires offering illumination beyond the present state-of-the-art should be addressed. Only in this way the full potential of OLED lighting can be exploited.

Priority 2: Novel materials for highly efficient, low cost and innovative OLED solutions
This involves projects targeting breakthrough materials such as highly efficient (especially deep-blue) emitters, charge transport and injection materials, and materials special suited for high speed solution processing, or materials optimized for high temperature vapor phase deposition, with the reasoning of shortening throughput times. Also materials with higher conductivity that enable thicker layers

and therefore more robust OLED designs are desired.

New, predictive quantitative analysis methods for materials properties are needed, supporting the screening of novel OLED materials.
Further interest is in low-cost thin film encapsulation of OLEDs, enabling very high shelf-life and application robustness, and supporting low cost and flexible substrates.
As a next stage, the development of OLED materials stable in ambient air conditions would mean a breakthrough because it making the need for encapsulation obsolete. It is expected however, that these materials will have lower efficiency than state-of-art-materials.

Special attention should be given to cost effective alternatives for (printable) ITO, transparent electrode materials and to low-cost bendable substrates.

Priority 3: Novel, very low cost production processes for OLEDs,

Priority should be given to all research and developments that will bring gas-phase deposition for OLEDs below < 100 €/m², and integrate lamination or printing processes for (parts of) OLED panels. Special focus should be put to R2R production aspects for manufacturing, as well as process and know-how development for large scale industrialized production, such as modelling and control systems for fabrication. The interaction between processing and integration aspects in its final applications needs to be investigated.

Socio-economic impact and relevance for the EU

Solid-state light sources, i.e. LED and OLED, may in the future outperform almost all other light sources in terms of efficiency and thus provide a saving potential of about 50% of the electrical energy. If the SSL technology is combined with intelligent light management systems, which will control the light output according to ambient lighting conditions and/or people's presence, another 20% can be saved. Therefore efficient lighting is one of the quickest roads to energy and CO_2 reduction, and represents also huge cost savings.
The lighting industry is a rather large industry in Europe. It employs over 150.000 people in Europe, and generates annually 20 Billion Euro turnover. Besides the lamp components, Europe is very well represented in the global luminaire market, of which 60% of the light fixtures industry is European based. The lighting industry has links to several other optical

Research Topic	Technical Objectives	Short term	Mid term	Long term
OLED Materials	‣ Highly efficient emitter materials and materials for charge transport and injection; Materials suitable for high process operation temperatures ‣ Improved electrode materials ‣ Encapsulation enabling high shelf-life time; better packaging materials for perfect light out-coupling ‣ Material screening	‣ Suitable for gas phase processing ‣ Printed ITO ‣ Stable under ambient conditions ‣ Analytical tool development	‣ Suitable for solution processing ‣ Suitable for high speed deposition ‣ ITO alternatives ‣ Also stable under high temperature conditions (e.g. automotive) ‣ Analytical tool	‣ Air stable and materials with high conductivity (R&D) High temperature stable materials (automotive) ‣ >20 years stable for fixed integration (e.g. in architecture)
OLED Devices with combined performance properties	‣ Device efficiency ‣ Reliability (at higher temperature, less differential ageing) ‣ Less short circuits ‣ High operating and shelf life-time ‣ High quality white (CRI, Color over angle, homogeneity) ‣ Transparent devices ‣ Conformal/flexible devices ‣ Drivers (high efficient, new concepts (integrated design, miniaturized) ‣ Simulation tools for modelling devices	‣ >100 lm/W (in R&D) ‣ 25°C ‣ Stack development ‣ >10 y / >5 y T_{50} ‣ >80 CRI ‣ 60-70% ‣ rigid ‣ Miniaturized high efficient ‣ Tool development	‣ >100 lm/W (in production) @ high lifetime & high lumen ‣ 50°C ‣ Stack development ‣ >15 y/ > 10 y T_{20} ‣ >90 CRI ‣ 75% ‣ conformal ‣ Integrated design ‣ advanced tools	‣ >120 lm/W (in production) ‣ 80°C ‣ > 20 y/ > 15 y ‣ > 95 CRI ‣ >80% ‣ Also flexible ‣ Organic drivers ‣ Advanced tools with good predictive power

Research Topic	Technical Objectives	Short term	Mid term	Long term
OLED luminaires	‣ High system efficiency ‣ Tiling concepts ‣ Luminaire design ‣ Acceptance studies (well-being)	‣ Connecting ‣ Simulation studies	‣ Seamless ‣ Demonstration studies	
OLED Standardization	‣ Standardization of OLED devices and drivers	‣ Measurement metrics	‣ Standardization	
OLED Production	‣ Novel low cost & high throughput production processes ‣ OLED technologies development ‣ Equipment development, in line diagnostics & up-scaling ‣ Cost decrease	‣ Low-cost vacuum deposition ‣ CVD OVPD ‣ Development for production ‣ Decrease	‣ Fabrication via laminating or printing ‣ Also laminating & printing options ‣ Development for mass production ‣ < 100 €/m²	‣ R2R manufacturing ‣ Also R2R ‣ < 70 €/m²

technologies and a good existing network with universities and R&D institutions.

Synergies

OLED have strong synergetic effects with many other organic electronic domains: several technologies are based on similar materials and processes. OLED lighting materials and encapsulation solutions can be shared with e.g. the displays and signage domain. Even if the materials itself may not be able to be shared, development results (know-how, class of materials) can definitely benefit from each other. Especial OLED and OPV have very similar requirements concerning the basis technology and the price level requirements. Furthermore, equipment development could be at least partially shared. The methods and processes of R2R processing for OLED, OPV and thin film batteries show substantial overlap. A European clustered approach for the development of R2R processing and equipment is therefore highly recommended, and will help to speed up development. Most of the involved players have already such a synergistic view, thus the synergy exploitation at a European level can be secured.

R&D budget requested 2011 – 2013 and 2014 – 2015

Europe is in an excellent starting position to build the OLED industry on its large existing lighting industry base. High investments in research and development are needed to develop a large scale and global spanning OLED lighting industry. But as this OLED lighting market is still in its very initial phase, these R&D investments are needed without direct return on investment over existing products.

In the previous period the overall research effort in this area in the EU is estimated to be around 300 M Euro, of which 200 M Euro was funded by public authorities at a European, national or regional level. Main focus was to develop the first generation of OLEDs and the development of novel materials and deposition processes, which showed the potential of OLEDs for lighting.

Priority aspects	Period 2011- 2013 (FP7)	Period 2014-2015
Device related R&D	55	10
Novel materials	25	20
Low cost processing	25	25
System integration aspects & luminaires	15	25
Total funding level in € Mio	€120	€ 80

In the coming five years it is estimated that a research & development effort amounting to 900 M Euro will be needed from all stakeholders in order to maintain our lead over other parts of the world. The funding by public authorities at European, national and regional level is expected to reach a level of 500 Meuro.

Over time, the focus of the activities will shift from basic research on materials and the understanding of the principles towards the development of application knowledge and overall system aspects. At the same time, new basic research should be done for future generations of OLED lighting, with higher efficacies and longer lifetime and lower costs.

For the remaining calls in FP7, period 2011-2013, it is advised to devote most of the funding to device and material aspects, weather for the period 2014-2015 (within the FP8 framework) the advice is to direct more funding more towards system aspects and luminaires:

3.2 Organic Photovoltaics

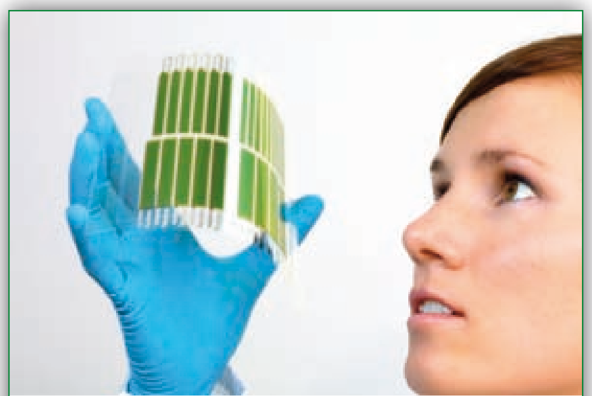
Abstract/Summary

Organic photovoltaics addresses a high mid-term market potential (about €7bn in 2023*) and a key societal issue of Europe. Affordable green energy, especial photovoltaics, is a must-have for achieving the ambitious goals of Europe, namely a fraction of 20% renewable energies by 2020 and an increasing autonomy from energy imports. With estimated production costs of **40 Cent/Wp** in 2020, OPV has the clear potential to become an important affordable green energy.

The main advantages of organic solar cells are low production costs, light weight, homogeneous transparency and flexibility. Further advantages are the use of abundantly available, non-toxic materials and scalable clean production processes with low material and energy consumption, which lead to short energy payback time.

Therefore, organic photovoltaics pave the way to a large mid-term market **independent of subsidies**. OPV will allow for new system-integration and large-area applications, and in long-term perspective, it creates a unique chance to significantly contribute to worldwide CO_2-reduction.

Today, organic photovoltaics are still in an early stage – no (substantial) revenues yet - and so far, there are only few industrial players worldwide (e.g. Japan with Sony and the US companies Konarka, Solarmer, Plextronics and GlobalPhotonics). Europe as a location of industry and business has a very good starting position, combining leading R&D, promising start-ups, and a strong industry background, especially in chemistry and engineering. It is important to reinforce this leadership to transform the R&D activities into future green energy mass production, market shares, jobs and quality of life in Europe.



Courtesy: Heliatek GmbH

Market

Today, Europe is the worldwide leading market for photovoltaic applications with a market value of around €10 billion**. Also, in Europe and especially in Germany are the leading module-producers for Silicon Gen1 photovoltaics (Q-Cells). The PV industry is furthermore one of the industries with the highest growth rates at all. Due to the expected yet higher growth rates of the PV markets in the other countries (USA, China, ...) the market share of Europe will change from 73% in 2007 to around 30% in 2020 with an expected value of around €40 billion**. So also on the long term scale, Europe

*source: ID Tech Ex report 2008 "Printed and Thin Film Photovoltaics and Batteries"
**source: Solar Generation V - 2008, EPIA European Photovoltaic Industry Association

will be a very important PV market and Europe should concentrate to keep its leadership as production-place.

Very strong increase of thin film photovoltaics
"IDTechEx find that the market for thin film photovoltaics beyond thin film silicon technologies will reach at least $3 billion in 2012 after a slow ramp up and grow rapidly after that to $8 billion in 2014. The global solar energy market is expected to reach $34 billion in 2010 and $100 billion in 2050 and most of that latter figure is expected to be achieved by non-silicon photovoltaics."
ID Tech Ex 2008 "Printed and Thin Film Photovoltaics and Batteries"
Also the bank Sarasin & Cie AG predicts a market share of 23% of thin film modules until 2012 (study "Solarenergie 2008").

Advantages of Organic Photovoltaics
Organic PV cells can be processed using large area evaporation or continuous printing processes, as opposed to batch-processes used in conventional PV so far. The possibility of using flexible plastic substrates in an easily scalable, high-throughput, high speed, low temperature "roll-to-roll" process will reduce the production costs of OPV to a point **significantly** below inorganic thin-film technologies, namely < **40Cent/Wp in 2020**.

Although organic solar cells in mid-term will be not as efficient as their inorganic counterparts, their other characteristics - flexibility, homogeneous transparency, light weight, low cost - still make them very attractive for applications which are less suitable for conventional PV. OPV modules can be embedded more readily in other products, from fabrics to plastics to building-integrated systems and roofing. Further, they are ideal for small, low-power projects and can also be scaled to large area applications.

A lot of research and development work both from companies as well as leading research institutes and universities is focused on organic photovoltaics in order to face the challenges that hinder today's commercialization of the technology. These challenges include the much desired increase in efficiency, in order to be able to reach the efficiency levels of competitive thin film technologies, as well as the long term stability and the production technologies.

In 2007 the Federal Ministry of Education and Research of Germany has started a research initiative for organic photovoltaics together with the companies Bosch, BASF, Merck and Schott: the initiative has a volume of €360 million.

OPV market potential

Consistently, all market studies predict a strong increase of thin film photovoltaics in the next 10 years and moreover. The following figure shows a forecast for the different thin film technologies:

All thin film technologies have the potential to reach (and overcome) levels exceeding today's c-Si PV market. Organic photovoltaics will play a minor role till 2013 due to its by then lower performance (efficiency, lifetime) and the lack of large-area production technology experiences. In this time, the OPV market will be a niche market (small, low-power projects). As soon as OPV will reach similar performance values as the other thin-film photovoltaics (10% module efficiency, 20 years lifetime, <1 €/Wp), OPV will enter the markets of large-area applications and building-integrated systems. Especially for building-integrated systems, the fact, that OPV can form uniform semi-transparent areas will be a strong competitive advantage. Also design aspects due tu the fact that OPV cells are dye-base and usually not black are highly welcomed by designers and architects. Therefore, from 2015 on OPV will gain significant market shares. After 2015, the other advantages of OPV, namely the lower price, lower weight and flexibility, will become fundamental so that OPV has the potential to become the leading thin-film PV technology after 2020. From Figure 2 one can interpolate a worldwide OPV market potential of about €600 million in 2015 and about €3.4 billion in 2020 (sum of small-molecule, polymer and DSSC). For Europe one can estimate around the half of the values given above.

In Summary, OPV will go the way from niche markets to large-area mass-applications, if - and this point is essential - if the targets of 10%

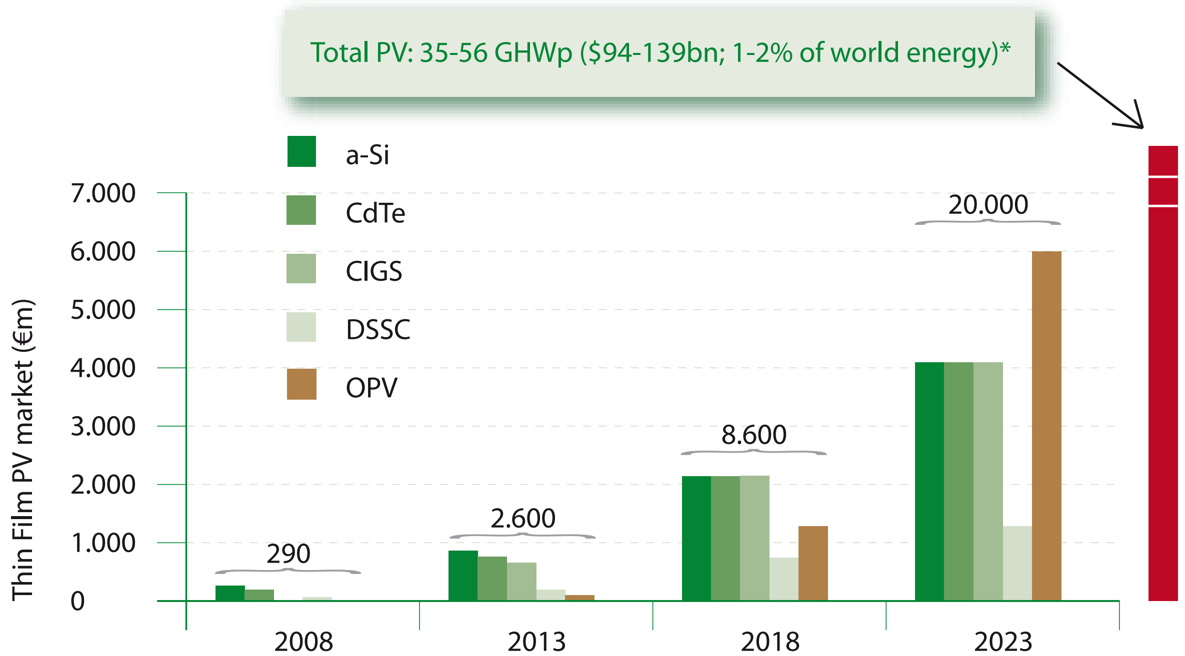


Figure 2: Forecast for the thin film PV market: here, OPV stands for small-molecule and polymer solar cells, while DSSC cells are indicated independently. Data sources: IDTechEx report 2008 "Printed and Thin Film Photovoltaics and Batteries"; assuming Euro/USD 1.40; and EPIA study 2008 "Solar Generation V", value for 2020.

module efficiency and 20 years lifetime will be reached. However, experts agree that these targets are realistic and the industries and the research institutes have clear R&D roadmaps to reach these values.

Focus

A SRA for OPV needs to include all parts of the OPV value chain: material providers (e.g. BASF, Merck, Solvay), equipment providers (von Ardenne, Roth & Rau, FHR, Coatema, Solarcoating…) and the OPV cell/module producers (Konarka, G24I, heliatek, Solarmer). An international cooperation is absolutely mandatory to bring together the leading players in every field and to keep the leading position of Europe. Furthermore, even being an SRA with industry focus, due to the early stage, an SRA for OPV is valid only if also research institutions are integrated.

It will be very important for the movement of research to industry and the commercial success of OPV that in the SRA the development of the production technology starts directly: efficiency and production technology must be developed simultaneously and in close interaction.

The following overview *(figure 3)* shows the short, medium and long term targets for the focus parameters efficiency, lifetime and manufacturing:

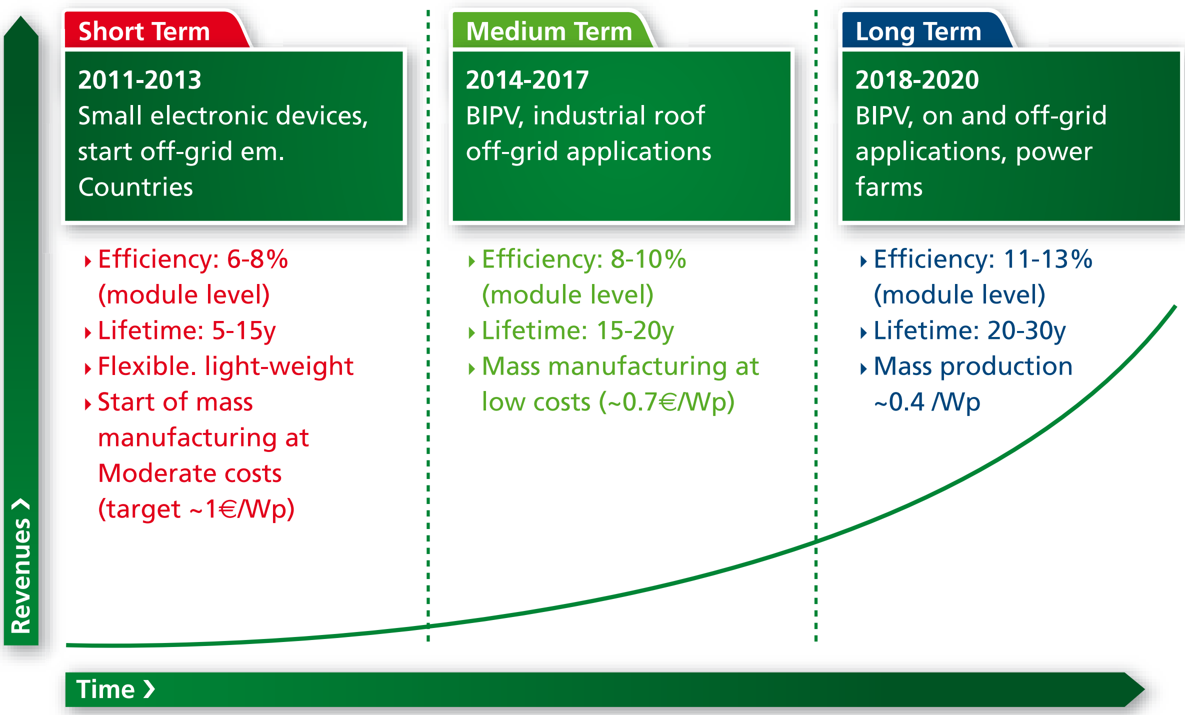


Figure 3: Overview SRA organic photovoltaics

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R&D Priorities
The suggested priority R&D points of EU projects are the following:

2011-2013:
A) Projects dedicated to OPV in the core area of OPV:
- photoactive materials with optimized transport and absorption properties
- control and long-term stability of nanomorphology
- infra-red absorbers (up to ~900 nm), tandem-cells
- Development of low-temperature solution- and vacuum-processable photoactive hybrid organic-inorganic materials
- Develop of wet processable inorganic materials and organometallic precursors (e.g. CIGS, amorphous Si…)
- Develop of photo chemically and oxidatively stable organic materials
- "new organic dyes for wide-light absorption" for DSSC: morphology of metal oxide; replacement liquid electrolyte
- specific production technologies

B) Projects regarding production technologies for OPV, with synergies to OLED production:
- thin film encapsulation with ultra-barriers and lamination technique for barrier foils
- stable, flexible electrodes and interfaces
- homogeneous and fast large area deposition (evaporation or printing)
- transparent conductors to replace ITO (other TCOs, highly conductive polymers, CNTs…)
- roll-to-roll production technology
- selective structuring
- Development of new deposition and patterning techniques for the manufacturing of hybrid devices (DSSC, organic-, inorganic soluble inorganic…)
- Development of specific characterization techniques dedicated to the control of large scale fabrication

2014-2015:
A) Projects dedicated to OPV in the core area of OPV:
- Scale up of the above materials synthesis for large scale production
- photoactive materials with optimized transport and absorption properties
- control and long-term stability of nanomorphology
- infra-red absorbers (up to ~1000 nm), tandem-cells
- DSC: morphology of metal oxide; replacement liquid electrolyte
- light-trapping structures
- specific production technologies

B) Projects regarding production technologies for OPV, with synergies to OLED production:
- Implementation of the above techniques for large scale production
- Implementation of the above specific characterization techniques
- thin film encapsulation with ultra-barriers and lamination technique for barrier foils
- stable, flexible electrodes and interfaces
- homogeneous and fast large area deposition (evaporation or printing)
- transparent conductors to replace ITO (other TCOs, highly conductive polymers, CNTs…)
- roll-to-roll production technology, insitu process control
- selective structuring

The aim of the above given R&D points is that they shall be handled by European projects. The contribution of common European R&D activities bringing together the leading companies, institutes and universities are necessary to reach these ambitious goals and go the way from lab to fab.

Tables for short-/mid-/long-term objectives

A) Short Term

Technical Objectives	Research Topic	Application	Synergies	Socio-economic relevance
Short Term (1-3 Years / 2011 - 2013)				
Efficiency: 8-10% (cell level) 6-8% (module level)	‣ Material: - Transp. -Prop. - Energy levels. ‣ Control of Nanomorphol. ‣ DSC: morphology of metal oxide; replacemant liquid electrolyte ‣ IR-Absorber (<900nm) ‣ Tandem-Cells ‣ Simulation Loss-Mech.	‣ Small electronic devices, Non-residential applica-tions, ‣ prepare for BIPV / off grid em. Countries / industrial roof	‣ OLED-lighting ‣ TF-PV ‣ TF-Batteries	‣ CO2-reduction (OPV has low energy pay-back-time!) ‣ **Clean production technology based on abundantly available materials** ‣ **Reduce dependence on energy imports** ‣ Decentralized energy production ➔ smart grid required ‣ Energy "prosumer" with increased awareness for energy consumption ‣ Sustainable technology for export to emerging and developing countries
Lifetime: 5-15y	‣ TF Encapsulation/sealing (WVTR 10^{-3}-10^{-5} g/m^2d) ‣ stable morphology ‣ Photochemically stable materials ‣ stable electrodes and interfaces			
Modules and large-area R2R-Production technology: Start of production at mod-erate costs <1€/Wp	‣ Homogeneous Large Area Deposition (Evaporation- or Printing; on glass or flexible substrates) ‣ Structuring (Laser or printing) ‣ Try to replace ITO (highly conductive polymers, CNTs…) ‣ Printed top electrode			

B) Mid Term

Technical Objectives	Research Topic	Application	Synergies	Socio-economic relevance
Mid Term (4-7 Years / 2014 - 2017)				
Efficiency: 10-12% (cell level) 8-10% (module level)	‣ Material: Transp. -Prop. ‣ Control of Nanomorphol. ‣ DSC: morphology of metal oxide; replacemant liquid electrolyte ‣ IR-Absorber (~1000nm) ‣ Tandem-Cells ‣ Light-Trapping	‣ BIPV ‣ industrial roof ‣ Off grid applications in emerging and developing countries	‣ OLED-lighting ‣ TF-PV ‣ TF-Batteries	‣ CO2-reduction (OPV has low energy pay-back-time!) ‣ **Clean production technology based on abundantly available materials** ‣ **Reduce dependence on energy imports** ‣ Decentralized energy production ➔ smart grid required ‣ Energy "prosumer" with increased awareness for energy consumption ‣ Sustainable technology for export to emerging and developing countries
Lifetime: 15-20y	‣ TF Encapsulation/sealing (WVTR 10^{-4}-10^{-5} g/m^{2}d) ‣ stable morphology ‣ Lifetime analysis and spectroscopical and chemical analysis of degradation ‣ Photochemically stable materials ‣ stable electrodes and interfaces			
Modules and large-area R2R-Production technology: Start of mass manufacturing at moderate costs (<0.7€/)	‣ Homogeneous and fast Large Area Deposition (Evaporation or Printing) ‣ Replace ITO (highly conductive polymers, CNTs…) ‣ insitu Prozess-Control			

C) Long Term

Technical Objectives	Research Topic	Application	Synergies	Socio-economic relevance
Long Term (8-10 Years / 2018 - 2020)				
Efficiency: 13-15% (cell level) 11-13% (module level)	▸ Material: Transp. -Prop. ▸ Control of Nanomorphol. ▸ DSC: morphology of metal oxide; replacemant liquid electrolyte ▸ Tandem-Cells ▸ Antireflection-Layer ▸ Electrode Optimisation	▸ BIPV ▸ industrial roof ▸ Off grid applications in emerging and develop-ing countries	▸ OLED-lighting ▸ TF-PV ▸ TF-Batteries	▸ CO2-reduction (OPV has low energy pay-back-time!) ▸ **Clean production technology based on abundantly available materials** ▸ **Reduce dependence on energy imports** ▸ Decentralized energy production ➔ smart grid required ▸ Energy "prosumer" with increased awareness for energy consumption ▸ Sustainable technology for export to emerging and developing countries
Lifetime: 20-30y	▸ TF Encapsulation/sealing (WVTR 10^{-3}-10^{-5} g/m²d) ▸ stable morphology ▸ Photochemically stable materials ▸ stable electrodes and interfaces			
Modules and large-area R2R-Production technology: Mass production at ~0.4€/Wp	▸ Homogeneous Large Area Deposition (Evaporation- or Printing) ▸ Structuring (Laser or printing) ▸ Replace ITO (highly con-ductive polymers, CNTs…) ▸ In-situ Prozess-Control			

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SOCIAL/ECONOMICAL IMPACT AND RELEVANCE FOR EU

"*By 2030, following the Solar Generation Advanced Scenario* (remark: 280 GWp annual installed capacity), *it is estimated that 10 million full-time jobs would have been created by the development of solar power around the world. Over half of those would be in the installation and marketing of systems.*
By 2030, according to the Solar Generation Advanced Scenario, solar PV would have reduced annual global CO2 emissions by just over 1.6 billion tonnes. This reduction is equivalent to the output from 450 coal-fired power plants (average size 750 MW)." Source: Solar Generation V - 2008, EPIA

Up to now, for organic photovoltaics there are no calculations concerning jobs and CO_2 reduction. Taking the above calculations for PV and assuming a share of 6% for OPV on the total PV worldwide in 2023 one obtains for OPV:

- 45,000 full-time jobs and
- a CO_2 reduction of 13 million tons

Worldwide in 2023. For the calculation of the number of jobs we assumed that for the production and installation of the same capacity (Wp) OPV requires only one half compared to conventional PV. For Europe one can estimate around half of the values given above.
Concerning the energy payback-time, today one can also only make a rough estimation: Due to the easy and low-temperature production processes and the simple installations (e.g. fixing a foil on a flat roof) the energy-payback-time will be significantly lower compared to conventional PV (which is today around 2 years in Europe).
Further important socio-economic effects of OPV are the clean production technology based on abundantly available materials, a reduced dependency on energy imports and a decentralized energy production. Especially the last point is very important as the energy "prosumer" (private household that both produces and consumes energy) have a strong increased awareness for energy consumption.

Furthermore, OPV is a sustainable technology for export to emerging and developing countries. An affordable green energy source is one of the basic necessities of these countries.

Synergies
There exist important synergies with the other organic electronic technologies, such as organic light emitting diodes (OLED) and thin film batteries (TFB). The different technologies are based on similar or even the same materials and processes (including production and encapsulation). Especially the emerging technology of OLED for lighting and OPV have very similar requirements concerning both technology and cost.

Concerning the basic parameters of the organic stack (efficiency and lifetime), the OLED technology is 2-3 years ahead of OPV. However, so far for both technologies there exists no production technology on flexible substrates: this includes mainly the durable foil with barrier layer and contact layer, the roll-to-roll equipment, the structuring and the thin-film encapsulation. Therefore, it is very reasonable that these missing technologies are developed common and in cooperation for OLED lighting and OPV. Additionally, OPV and OFETs have several common aspects (e.g. materials, encapsulation, and production on foils).

Synergy Matrix						
	Charge Transport materials and doping	Transparant contact materials	Structuring (printing, shadow masks, laser scribing)	Encapsulation	Optical and electrical simulation	Production process
OLED displays	• •	•		•	•	•
OLED for lighting	• •	• •	•	• •	•	• •
OPV		• •	• •	• •	(•)	•
Thin film batteries				•		

Figure 4: Synergy Matrix of different organic electronic technologies

R&D budget requested 2011 – 2013 and 2014 – 2015
The overall research effort for OPV in the EU in 2008 is estimated to be around **€ 60m**, including industry financing and funding by public authorities at a European, national and regional level.

Budget 2011 - 2013:
The requested EU budget for 2011 -2013 is **€ 54m** (€ 18m p.a.).
(materials €24m, devices € 15m, processing € 15m)

Budget 2014 - 2015:
The requested EU budget for 2014 -2015 is **€46 m** (€ 23m p.a.).
(materials € 16m, devices € 10m, processing €20m)

Total R&D budget for 2011 -2015: € 100m

3.3 Displays

Summary

Europe presently holds a strong position in the research and development of organic large area displays, with expertise in top Universities, start-ups and large companies. Two types of organic large area display technology are being developed: emissive (OLED) and reflective. Beside that OLED-on-CMOS micro-displays are another promising topic. These technologies will enable new products and markets, due to their novel properties and performance, and provide a huge opportunity for Europe to benefit across the value chain.

The commercialisation of organic displays is underway, with sub-5" OLED displays for mobile devices growing at 37% annually since 2006[1]. The majority of these displays are manufactured in Korea, primarily sourcing from Asian supply chains with organic materials from Asia and the US. However large area organic displays are not destined to be manufactured or have their supply chains based primarily in Asia, as organic front and backplane technologies are being developed globally and a number of manufacturing and technology challenges prevent small organic displays from easily scaling. In contrast for OLED-on-CMOS micro-displays, where the full supply chain is based in Europe already.

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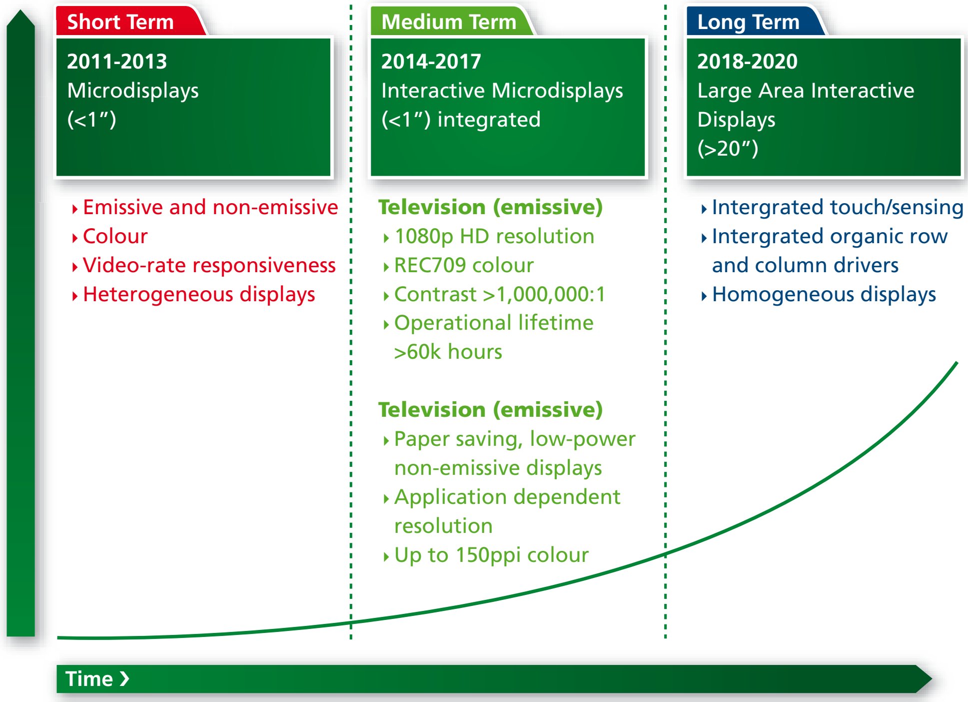
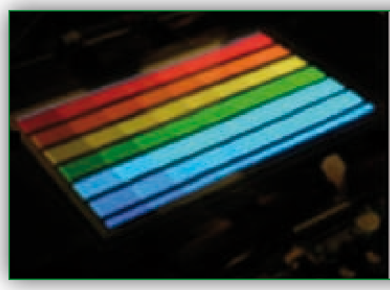
With national governments developing significant investment schemes for maintaining or enhancing their position in the emerging organic displays and electronics markets, Europe must act strongly and strategically to ensure that its curren position is not eroded. Acting together, European governments and industry have the opportunity to highlight current eaknesses in the native supply chain and make strategic invstments to ensure the developent of a robus valuechan



Market

The overall flat panel display market will continue to be > €100 billion industry and remain stable beyond 2015[1], despite the global downturn in economy and decrease in pricing. During this time period the OLED market will increase rapidly as technology matures and manufacturing costs are reduced. CAGR of 140% will mean the OLED TV market alone will reach > €1.4 billion by 2015 and > €7.5 billion by 2020.



OLED display

Courtesy: Cambridge Display Technology Ltd

The initial key drivers for this growth are the advantage of low power consumption and ability to produce lightweight and thin displays (reduced number of layers and components compared to LCD) of high quality. In the longer term, as flexible film, organic transistor and sensor technologies become more advanced, new markets for flexible all organic interactive displays based will be generated from 2017 onwards.

There is already a rapidly growing market for reflective displays (presently on glass substrates); sales of E-readers (e-paper) that use electrophoretic front planes (on glass backplanes) are growing at a very high rate even in the present economic climate. Today over 1 million E Ink (electrophoretic) E-readers are in use [4] and CAGR of 105% is predicted for

Example product concept for a reflective organic E-reader

Courtesy: Plastic Logic Ltd

E Readers over the next 4 years [5] Forecasts (Displaybank [6]) of the e-paper display total market are $2.1 billion by 2015, rising to $7 billion by 2020. With suitable funding in place, Europe has the capability to create significant value and jobs from this technology.

The main drivers for large area reflective display market are:

- Ultra-low power displays that can be comfortably read in all lighting conditions (e.g. sunlight-readable)
- Thin, lightweight displays which are ultimately robust, flexible or conformable.
- A technology that reduces the use of paper for newspapers, books, printouts.

Focus

Europe has a long tradition for innovation and production and development of materials, processes and manufacturing equipment. Many of the major breakthroughs in field of displays have been produced in Europe for both LCD and the new organic based technologies. In the field of LCD, although fabrication has moved to low cost centres outside Europe, companies such as Merck remain as global leaders for providing LCD materials. In the area of organic displays, Europe has the opportunity to build upon the existing expertise and capture significant revenue from the value chain for displays. Micro-emissive displays are still a concept with great market potential. Best practice case is the US company eMagin, which was able to develop and to launch products for the consumer market based on back-up orders from the US government. Micro Emissive Displays, a company based in Dresden, which developed a superior technology to eMagin, by contrast is ailing, because European authorities [whether at EU, national or regional level] maintain no facilities and support schemes to finance the up-scaling process from pilot to full-scale production.

Strengths • High level of innovation • World renown Universities and institutes • Global presence in materials and processes – including printing technologies	**Weaknesses** • Current lack of display manufacturing base • No strong brand for displays
Opportunities • R&D development and IPR based revenue • Supplier of materials to global market • Low cost manufacturing in Eastern Europe • New markets and application that cannot be achieved by LCD on glass	**Threats** • Without funding competition from Far East and US will erode Europe's strong position • Incumbent technologies (TFT-LCD) with significant finance will improve to compete with organic technologies

SWOT table for display market in Europe

The short term focus for emissive displays will be materials and process development (especially microdisplays), utilising inorganic backplanes sourced mainly from the Far East or CMOS backplanes from Europe to develop the technology base for production. As the organic backplane technology matures and suitable flexible materials and processing come on-line (supported by the organic electronics and integrated smart systems SRAs), opportunities will arise for initial production in Europe (for example Plastic Logic plant in Dresden for e-Reader production). In the longer term production will move to the most cost-effective locations, with Eastern Europe having an opportunity to capture significant market for all organic displays. Regardless of location, Europe can continue to capture global revenue by retaining supplies of materials and components as well as continuing to innovate and capture IPR.

Europe has a number of strengths in the area of organic displays and these can be leveraged in the short to medium term to develop a valuable display related industry in Europe. The funding and collaboration in Europe will be required to fend off competition and convert current technology leadership into revenue throughout the value chain for displays. The table below is a SWOT analysis highlighting the key factors for EU based organic display development.

Europe has strong position in the development of (amongst others) OLED materials, OLED process optimization and production equipment for organic devices. Although large area display manufacture is dominated by the Far East, and Small companies formed in Europe through venture capital have, in the majority of cases, been acquired by large companies outside Europe particularly in the Far East. These domains represent for Europe a substantial part of the value chain and represent also a substantial part of the IP.

In order to keep these parts of the organic display value chain in Europe, Europe needs continued support towards new display: materials, technologies and processes, comprising the full display process for innovative displays concepts. This is the only route enabling the continued IP generation in the display domain and only in this way; Europe can keep the parts of the value chain in which it has a strong position in Europe. Moreover, this will foster new innovative display concepts and new dedicated display products in, for example, hand-held, signage, packaging and clothing-based applications.

R&D Priorities

The main challenges for the R+D of reflective displays are based around improving the display performance, and increasing the level of system integration, thereby capturing more of the value chain in Europe. Specifically the major challenges are:

- Research and development of colour reflective displays,
- Research on high-efficiency flexible OLED.
- Research and development of video-rate performance front planes and backplanes.
- Development of backplane and display models to aid design.
- Research and development of integrated gate drivers (route to homogeneous system integration).
- Building a roadmap to the next level of integration.

A major strength of European R&D has been the ability for innovation that has led to significant contributions to the development of OLED technology. Materials development by companies such as CDT, Merck, BASF and Novaled has led the industry, with companies Aixtron and Leybold building process technologies and equipment which is supported by a diverse range of Universities and research institutes such as VTT, Fraunhofer Institute, Durham University. Support of these activities and increased coordination between companies and research institutes can be the impetus to build significant presence in the value chain, even with final volume production in the short term based in the Far East on inorganic backplanes. In the longer term, as more components transitions to low temperature and organic processes, opportunities will arise for low cost manufacturing basis to be developed in Europe.

Strategic Research Agenda Overview (short-, mid-and long- term)

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Short Term (1-3 Years / 2011 - 2013)				
Conformable substrates	▸ Robustness ▸ Bend radius ▸ Water/gas permeability of 10^{-4} gms/m^2/day at large area without defects ▸ Investigate storage lifetime with encapsulated foil substrates ▸ Cost	▸ Light weight display products with acceptable operating lifetime, e.g. Low power eReaders and netbooks, and Light weight, robust emissive displays	▸ Substrates for Large Area Electronics, including lighting, displays, energy and other printed electronics.	▸ REACH compliance and reduction of environmental contaminants ▸ Jobs creation ▸ Low power electronics ▸ Paper-saving technology
Backplane integration and development	▸ Average mobility (+/- X) ▸ Lifetime ▸ Operating voltage ▸ Operating current ▸ Resolution (transistor density) ▸ DV_t ▸ Solution processability ▸ Temperature stability ▸ Design rules ▸ Manufacturability ▸ Chemical stability ▸ OLEC-on-CMOS, photosensor integration	▸ Light weight, low power displays. ▸ Increasing yield, enabling higher resolution for colour displays at low cost: capital cost and materials cost. ▸ Small form-factor microdisplays	▸ Synergies with other large area / printed electronics applications and systems. ▸ Synergy with ISS	▸ Increases market share, enables new factories in Europe with low infrastructure requirements.

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Short Term (1-3 Years / 2011 - 2013)				
Frontplane Integration	**Non-emissive:** ▸ Improve contrast reflectance ▸ Improve switching speed ▸ Lower voltage ▸ Drive scheme development ▸ Video capability **Emissive (OLED):** ▸ Low cost planarization ▸ Conformable encapsulation ▸ Conformable transparent cathode (for top emission and transparent OLED) ▸ Conformable reflective anode ▸ High efficiency and lifetime ▸ Low drive voltage ▸ Solution processable and hybrid (solution/vacuum) OLED stacks ▸ White OLED and color filter development for niche applications ▸ OLED on CMOS, high brightness	▸ Develop display products that approach paper-like quality. ▸ Robust lightweight colour displays for mobile applications. ▸ Low power, high definition, video-capable and high contrast displays for small televisions and niche applications (such as automotive, avionic). ▸ Small form factor microdisplays, "sensor-embedded displays"	▸ Synergies with complex flexible electronics. ▸ Synergies with new mobile product concepts. ▸ Conformable lighting and energy applications.	▸ Reduced paper usage in magazine, journal and newspaper applications. ▸ Readable in normal lighting conditions, lower manufacturing and recycling costs.
Image and signal processing	▸ Optimising display performance using standardized signal inputs ▸ For OLED: low voltage pixel drive (PWM)	▸ Improved visual and video image quality ▸ OLED displays ▸ Bi-directional displays embedded camera, "capture user's eye"		▸ Better displays ▸ Less power consumption
Metrology/Design for Manufacturing	▸ Inline defect visualization ▸ Inline defect repair ▸ Begin predictive device and circuit models ▸ In line process control	**For Displays:** ▸ Improved yield and process control.	▸ Synergy with other large area / printed electronics applications and systems	▸ Decreased waste through increased yields and lower product costs.

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Mid Term (4 – 7 years / 2014 - 2017)				
Conformable/flexible substrates	‣ Robustness ‣ Bend radius ‣ Water/gas permeability of 10^{-6} gms/m²/day ‣ Getter inside encapsulation for longer storage time ‣ Cost	‣ Light weight display products with acceptable operating lifetime, e.g. HDTV and other high resolution displays i.e. signage	‣ Substrates for Large Area Electronics, including lighting, displays, energy and other printed electronics.	‣ Lower distribution, installation and operating costs. ‣ New application environments.
Backplane integration and development	‣ Aging performance compensation ‣ Multi-layer routing ‣ Multi-layer architectures ‣ Improvements to allow larger area displays (see short term objectives) ‣ Sensor based vision-interactive displays	‣ Backplane electronics for television and display applications: eReaders and signage ‣ Small form-factor microdisplays	‣ Support for other printed electronics applications and systems.	
Frontplane integration	‣ Increased speed ‣ Decreased complexity ‣ Wider colour depth and gamut	‣ Backplane electronics for television and display applications: eReaders and signage ‣ Small form-factor microdisplays, "microprojection"	‣ Conformable lighting and energy applications.	‣ Rich user experience at affordable prices
Metrology/Design for Manufacturing	‣ Yield compensation techniques ‣ Yield optimization techniques ‣ Process, device and circuit models to aid rapid system design and implementation ‣ OLED-on-CMOS "ultra high-brightness, high temperature"	‣ Improved yield and process control. ‣ Broaden access to plastic electronics	‣ Synergy with other large area / printed electronics applications and systems.	‣ Decreased waste through increased yields and lower product costs. ‣ Creation of local infrastructure companies for metrology, manufacturing equipment, system software and specialist analysis

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Mid Term (4 – 7 years / 2014 - 2017)				
Image and signal processing	‣ Mapping old media characteristics to new front plane/display technologies. ‣ Improved performance and lifetime (as via low voltage driving) ‣ Capture image on display device	‣ Content re-use. ‣ Conforming to pre-existing content standards ‣ Scene camera in micro-displays	‣ Synergies with local infrastructure providers	‣ Maintains availability of traditional media ‣ Additional product opportunities in adjacent spaces, e.g. semiconductor chipsets
Interactive technology evaluation (sensing, touch screen)	‣ Review available touch sensor techniques. ‣ Confirm compatibility with current manufacturing techniques. ‣ Evaluate key metrics, e.g. reliability and durability	‣ Gather basic data for long term integration goal ‣ See-through video/data eye-glasses, gesture based microprotection ‣ Microprotection based configurable instrumentation	‣ Support for integrated systems.	‣ Improved/new user interfaces for changing needs of society
High density integrated logic circuitry	‣ Review application, e.g. drivers, needs for integration ‣ Evaluate compatibility with current manufacturing processes ‣ Evaluate key metrics, e.g. speed, density, voltage switching, reliability and lifetime ‣ Evaluate memory storage possibilities	‣ For organic backplane display technologies: Gather basic data for long term integration goal	‣ Support for other printed electronics applications and systems.	‣ Better independence of supply chain, higher margins

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Long Term (8 – 10 years / 2018 - 2020)				
Interactive technology integration (sensing, touch function) and remote data input interface	‣ Integrated display/touch solutions for HDTV and display applications. ‣ See-through augmented-reality	‣ New products	‣ Synergies with integrated systems	‣ Improved/new user interfaces for changing needs of society
Row and column driver integration	‣ Integrated system solutions for HDTV and display applications.	‣ New products	‣ Synergies with integrated systems	‣ Greater value generation in Europe ‣ Generating greater margin with reduced supply chain dependence
Metrology/Design for Manufacture	‣ Fully automated in-line quality control, test and repair ‣ Modelling for device and circuit design	‣ New equipment and software systems	‣ Synergies with electronics and other integrated systems.	‣ Reduced wastage
Manufacturing processes	‣ Minimize WIP through balanced line design. ‣ Reduced handling through e.g. roll to roll processing. ‣ Flexible manufacturing techniques for rapidly reconfigurable production lines.	‣ New equipment and software systems	‣ Support for other printed electronics applications and systems.	‣ Production on demand using local infrastructure.

Socio-economic benefits and relevance for EU
There is an opportunity for Europe to benefit from a large portion of the value chain for these new markets, and capitalize on lessons learned from Europe's missed opportunity in exploiting liquid crystal display technology (LCD). In the early 90's the EC funded a set of R+D projects for the development of LCD technology. These involved large industrial companies (Philips, Sagem, Thales), and began at a point where AMLCD technology was already industrialized in Asia.

Today, Europe has an opportunity to benefit from the new technology of organic displays, by providing funding to Start-ups and Universities/Research Centres, as well as larger companies, and by funding the technology development before it becomes industrialized elsewhere (such as Asia). There is no reason why Europe cannot extract value across more of the value chain, including developing significant manufacturing capability, and associated jobs. Moreover, the nature of the organic display technology means that development will be towards increased system integration (integrated drivers, touch screens etc), meaning even greater margins and jobs for Europe, and a more independent supply chain.
Reflective displays can reduce the usage of paper, since they are an excellent substitute for magazines, newspapers and other printed media. Reflective displays have very low power consumption due to absence of power-hungry backlighting, and can be bi-stable, allowing ultra-low power consumption.
Emissive displays have a distinct advantage in that light is only generated when required.

LCD displays use a white backlight which is filtered to obtain the required colour and brightness, thereby throwing away a significant portion of the generated light. As number of displays increases globally, the pressure to reduce power consumption becomes more important, especially for larger area displays where OLEDs will be more desirable from both consumer and environmental viewpoints.
Estimates regarding the power efficiency of large OLED displays range from 70% less that of a conventional LCD display to 30% less of more recent LCD displays with local backlight dimming [7]

OLED versus LCD power efficiency demonstration by CMEL at FPD 2007

Present manufacturing processes for conventional LCD production are based around multiple subtractive patterning steps, which inherently produce large quantities of waste solvents and materials. In contrast, many patterning steps being developed for organic display manufacture are additive (such as printing techniques), and therefore have higher materials utilization and produce lower levels of waste.

Finally, the various advantages of organic displays (including novel design features such as flexibility and conformability) offer the opportunity of entirely new markets. As the inherent advantages of additive manufacturing develop, the anticipated lower manufacturing costs will also support the diversification of displays in a variety of new markets.

Synergies

To seize these opportunities it will be critical to develop and maintain synergies with the other strands of plastic electronics, including flexible substrates, organic transistors, organic sensors and integration of these components.

For emissive and reflective displays, there are synergies across the areas of plastic electronics manufacture, in developing larger area, low temperature processes for depositing thin films and patterned layers. As displays move to increased levels of system integration (for example, integrated row and column drivers, and

	Synergies with other strands of plastic electronics			
	Lighting	Electronics	Integrated smart systems	Photovoltaics
Large area Substrates	✔	✔		✔
Backplane Integration		✔	✔	
Frontplane Integration	✔	✔		✔
Metrology / Design for Manufacturing	✔	✔	✔	
Interactive Technology		✔	✔	
Integrated logic circuitry		✔	✔	
Manufacturing Processes	✔	✔	✔	✔

Table of synergies between the displays SRA and the other plastic electronics SRAs integrated touch screen technology), a strong synergy between integrated smart systems, and electronics is vital. Similarly for metrology and design for manufacturing, where components and metrology tools developed will be required across the electronics, ISS, and reflective displays areas.

R&D Budget

The total R&D spend for organic displays (OLED and reflective displays and backplanes) in 2009 in the EU is estimated to be €101M. In order for Europe to secure a significant portion of the value chain for organic displays, including capturing manufacturing capability, additional funding is required to accelerate progress.

TOTAL R&D budget request for 2011-2015: €100M (€20M pa)

The requested budget for 2011-2015 represents approximately 20% of the estimated annual R&D spend in Europe for organic displays. The budget should be used to ensure a valuable organic display-related industry can be built up in Europe, by speeding up the development of this technology area to provide manufacturing within Europe, to extract significant value from the hugely growing market.

	Requested R&D budget Breakdown	
	Budget 2011-2013	Budget 2014-2015
Backplane R&D • Materials • Devices • Architectures	€ 20.7M	€ 19.4M
Frontplane R&D • Materials (OLED, Electrophoretic, Electrochromic, LCD) • Backplane Integration • Process	€ 28.8M	€ 18M
Displays R&D • Metrology • Reliability • Qualification (Performance)	€ 7.5M	€ 5.6M
TOTAL	€ 57M	€ 43M

3.4 Electronics

Abstract/Summary

Printing of electronics offers great opportunities with a revolutionary approach:
Enabling ultra low cost electronics with the help of highly efficient mass production (i.e. roll-to-roll) methods [8, 9, 10]

- Thin, light-weight and flexible, conformablesubstrates
- Low-Cost
- Electronics functions distributed over large area devices
- Everywhere available (easy to integrate)
- Disposable/save for the environment

Courtesy: PolyIC GmbH

Roll-to-roll printed electronics

Products

Although Printed Electronics is a general definition, the key areas for product development, could be differentiated in three main segments[2]:

- Basic Components,
  like transistors, resistors, capacitors to implement circuits and logic
- Printed RFID
  Example of a an circuit/logic combined with an antenna
- Printed Memory
  Components to store and retrieve data
  Complexity and performance of the corresponding products will be increased over time to access new applications fields.

Applications

Basic technology development in this direction will open a lot of applications for this new kind of electronics, examples are:

- **Item level identification**
  (e.g. for printed RFID and memory)
  Trillions of barcodes are used on today products. The vision of –not only- the consumer industry is to have a unique identifier for each product which is machine readable without line of sight. The technology is already existent on the market – RFID (Radio Frequency Identification). But standard silicon electronics cannot supply solutions (tags and integration methods into products) at a price level to allow this vision to come true.
  Printed RFID will enable true item level identification for the EPC™ (Electronic Product Code).

Item-level-tagging for consumer-goods

Courtesy: PolyIC GmbH

- **Electronic brand protection**
  (e.g. for printed RFID and memory)
  Counterfeit products are a threat to brand owners in several industries (consumer, sports goods, pharmaceutical to industry products). The possible damage caused is from missed business opportunities, over warranty issues to health risks in the case of false drugs. Electronic security measures are – easy to integrate, hard to simulate and simple to check and will be a milestone in the fight against counterfeits.

[2] The term "electronics" is used for these devices in this document. For other devices like sensors, batteries etc please see the chapter integrated smart systems (ISS).

- **Smart packaging** (for all products)
  Intelligent packaging, a sensor integrated with logic in a milk carton indicating its freshness, Gaming and interactive information are just a few examples of future possibilities enabled if these functions will be affordable for brand owners and producers. They will enable new markets as they will enhance customer attractiveness.

Game Cards with built-in memory

Courtesy: Thin Film Electronics AB

And many others. Further Applications and Scenarios are described in the OPERA Vision Paper.

Printed Electronics is not substituting conventional electronics; it will open new markets for low-cost electronics in applications with no electronics today.

Definition

	Basic Components	Printed RFID	Printed Memory
Product description	**Basic Components /Circuits** Transistors, Resistors, capacitors, etc.	1-4 bit ROM 4-8 bit ROM 16-32 bit ROM 32-64 bit ROM **96/128 bit ROM** **EPC (Electronic Product Code)**	**WORM** Write Once Read Many **NVRAM** Non volatile RAM
Market	- Basic Logic to drive various applications - Logic for Sensors/Actuators - Driving circuits for sensor or memory arrays - Backplane for Displays	Brand Protection Ticketing automation internal logistics Supply chain automation	Toys Brand Protection Identification Storage devices Advanced Gaming Multimedia

Figure n: Definition of electronic devices, products and corresponding markets.

Market
The market for organic and printed electronics is in a very early phase, first products like printed batteries and Sensors entered the market. On a ten year timescale a huge growth of the market is predicted by market analysts to approx. 9 bn Euro (2019), mainly driven by logic and memory.

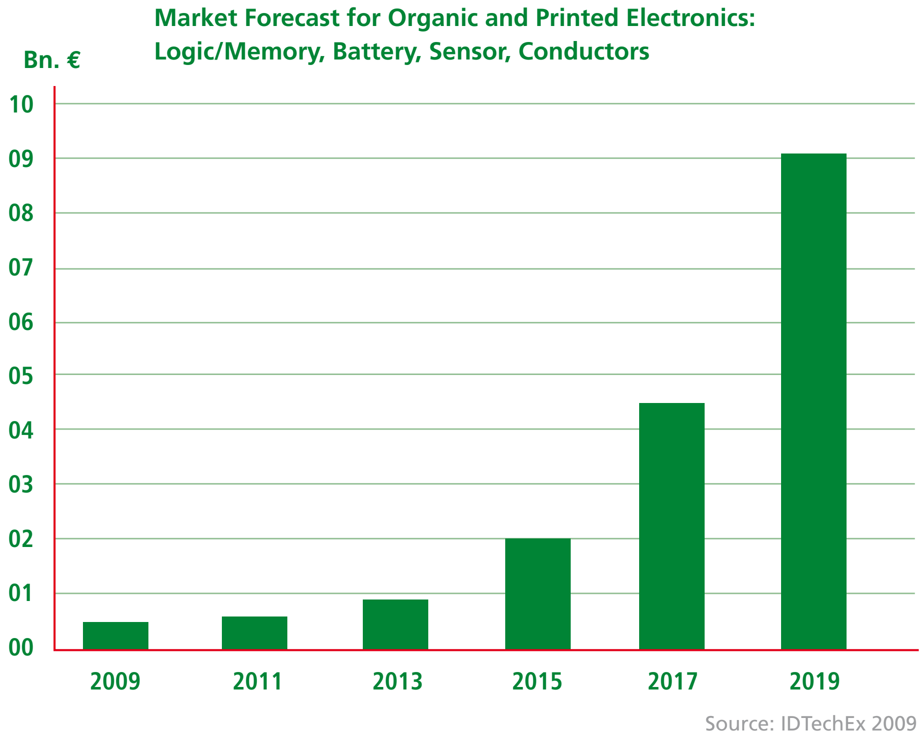


Figure n5: Market Forecast for Organic and Printed Electronics: Logic/Memory, Battery, Sensors, Conductors (ink only), other, (not included: Displays, OTFT backplanes, OPV, Lighting) [Source: IDTechEx 2009, currency exchange rate 1€= 1,4 US$].

Neither the magnitude nor the timeframe for this extrapolated market potential can be accurately predicted. All the market researchers however forecast growth momentum on a similar scale.

Focus
Technological breakthroughs are necessary in several technology areas in order to enable more complicated and higher performing applications and devices.

Therefore research and development should focus on the following aspects:

- **Improved materials**
  New Materials are a key enabler for this technology. Soluble semiconducting materials enabled new production technologies for electronics like large area printing processes or digital printing (e.g. digital inkjet, screen, gravure…). Therefore the future development of better performing materials, which allow efficient production of better products is key for the future development.
  - Highly conductive materials;
  - Reliable Material for passive devices (capacitor, resistor) over a wide range of frequency
  - High mobility and/or stability semiconductors;
  - High purity dielectrics.
  - Interface adaptation materials
  - Orthogonal solvents
  - Ink formulation to ensure limited coffee stain effect upon printing

Low cost, large area processes

One promise of the technology is the potential to produce at ultra low cost. Printing processes have been developed to provide a very efficient way for production. But the methods are still mostly optimized to provide visual products. Functional printing requires new processes, adaptations to current processes or development to improve and optimize current technologies: Others processes than printing have as well shown some compatibility with high throughput large area and flexible substrate (such as R2R photolithography, atmospheric evaporation, laser patterning…) and will need also some development effort to fulfill the requirement for a cost efficient production of large area electronics:

- high throughput processes with small feature sizes and high overlay accuracy;
- novel (self aligned) process options;
- large area uniformity and quality control;
- Scaling down of channel length and thickness of dielectric.
- high density interconnection and BEOL (Back End Of Line) process solution
- Substrate handling
- Hybrid approaches and novel batch processes

Design/technology

New Materials and new process require new methods to define and develop electronic circuits. Although transistors and other basic components have been built successfully already, the development of more complex logic and adapted logic is a key requirement. Design changes caused by new materials, CMOS type logic are additional important aspects of R&D in this space. Development of methodology and tools to characterize the reliability of the circuits and devices are needed.

- robust uni-polar design logic;
- CMOS-like design rules;
- Compact modeling, device physics.
- Aging of the devices upon electrical, environmental, mechanical stresses

Equipment

Device specific process requirements and adapted processes require new developments for production and quality control equipment. Specific developments need to be done in the functional quality control development.

- large area uniformity control
- in-line inspection
- functional high speed test

There is also a need to implement pilot lines integrating all the different steps needed to produce circuits: Cleaning steps, layer deposition & patterning, via opening, layer passivation, interconnection, encapsulation, in line with the process control equipments.

Europe has a leading position in the technology development. Distributed efforts exist in several centers of excellence in Europe. Industry activities have been started but need to grow in the future to reflect the business potential. A stronger coordinated approach will help to secure EU's competitive advantage for the future. Investment in industry-driven infrastructure focused in production, quality control could speed up manufacturing efforts. Support for first of its kind applications could support market development and deployment of this industry.

Currently activities are intensified on a worldwide base for technology development and R&D for printed Electronics. Especially Asia is focusing its Roll-to-Roll Printing activities in programs in Taiwan and even with greater impact in South Korea. Although these programs are visible to the western world, and collaboration is a target communicated, the speed of progressing in these countries puts pressure on and will challenge Europe's leading position.

R&D priorities
R&D for printed Electronics is a collaborative approach. Improvements in materials will lead to advances in technology and design or in better, improved processing capabilities. So the priorities are clustered as it is also the work which is necessary.

- **Priority 1 (Short term)**
  - mobility of semiconductor > 0.1 cm2/Vs FET
  - Resolution: (minimum feature size and overlay)
  - Large Number of transistors
  - Lower Drive voltage
  - Higher Circuit frequency 1kHz
  - P+N type semiconductor common process
  - Establish CMOS like Design Kit (design rules + modeling)

- **Priority 2 (Mid/Long term)**
  - FET-mobility of semiconductor
  - >1 cm2/Vs with spread lower than 0.05 cm2/Vs
  - Vt control (<0.2V)
  - Resolution < 10 µm: (minimum feature size and overlay)
  - Number of transistors ~1000
  - Drive voltage (< 10V)
  - Circuit frequency (> 1 kHz):
  - Circuit design tools CMOS: Digital and Analog

For details see tables Chapter 6.

Short/mid/long-term objectives (tables)

General comment
The specific technology targets are classified in short, mid, and long term targets, they are derived from the OE-A Funding White Paper [10], OE-A Roadmap White Paper (May 2008) [8], and will be updated with the corresponding next version. The tables only discuss the main aspects and headlines, a detailed description of the technology targets can be also be found in the OE-A White Papers [8, 10, 10].

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Short Term (1-3 Years / 2011 – 2013)				
Improved materials ▸ Highly conductive materials ▸ High mobility and/or stability semiconductors; ▸ High purity dielectrics **Low cost, large are processes** ▸ High throughput printing with small features and high overlay accuracy ▸ Novel (self aligned) process options ▸ Large area uniformity and quality control ▸ Scaling channel length and thickness dielectric **Design/technology** ▸ Robust unipolar design logic ▸ CMOS-like design rules ▸ Compact modelling, device physics **Equipment** ▸ large area uniformity and control ▸ in-line inspection **Detailed description could be found in Roadmap OE-A Vers. 05.2008**	▸ FET-mobility of semiconductor > 0.1 cm2/Vs ▸ Resolution: (minimum feature size and overlay) ▸ Large Number of transistors ▸ Lower Drive voltage ▸ Higher Circuit frequency 1kHz P+N type semiconductors Memories ▸ WORM Memory (Write once, read many) ▸ NV RAM non volatile RAM	**Basic Components/ Circuits** Transistors, Resistors, capacitors, memories etc. **Printed RFID** 1-4 bit ROM for brand protection 4-8bit ROM for ticketing **Printed Memories** for ID, Toy applications **New Markets by LowCost Products based on R2R Production** Low-Cost Electronics will open new Applications in new markets, Markets , where the use of electronics was desired but unthinkable due to the product and integration aspects Scaling up Production will support **this development to reach high market penetration**	Smart Systems Backplanes for Displays	**Market trends and impact** Printed electronics and printed RFID will enable new applications and markets for electronics ▸ Enhancing the Barcode with a unique identifier ▸ Enable Electronics applications in industries (e.g. Printing and Packaging) ▸ Media (like the print media) will be connected to IT in areas where there was no connection (Mobile Phone with Newspaper , Mobile Phone to package) ▸ Every object could be identified and interact with humans and other objects ▸ Brand protection and the fight against counterfeits will be strengthened **Production impact** The technology also promises the environmental safe and reduced use of resources **Impact to industries:** Retail, Food&Beverage, (new Packaging and IT concepts Supply chain automation, New customer interaction) Packaging Industries New packaging concepts integration features like RFID for identification IT industries Massive data increase requires new data management concepts , if every product will be identified

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Mid Term (4 – 7 years / 2014 – 2017)				
Improved materials ‣ conductors ‣ high mobility and/or stability semi-conductors (p+n); ‣ high purity, high-k dielectrics ‣ interlayer dielectrics **Low cost, large area processes** ‣ high throughput printing with small features and high overlay accuracy ‣ novel (self aligned) process options ‣ large area uniformity and control ‣ scaling channel length and thickness dielectric **Design/technology** ‣ robust unipolar design logic ‣ CMOS circuit design rules ‣ Compact modelling, device physics **Equipment** ‣ large area uniformity and control ‣ in-line inspection **Detailed description could be found in Roadmap OE-A Vers. 05.2008**	‣ FET-mobility of semiconductor > 1 cm2/Vs with spread lower than 0.05 cm2/Vs ‣ Vt control (<0.2V) ‣ Resolution < 10 µm: (minimum feature size and overlay) ‣ Number of transistors ~1000 ‣ Drive voltage (< 10V) ‣ Circuit frequency (> 1 kHz): ‣ Circuit design tools	**Basic Components/ Circuits** Transistors, Resistors, capacitors memories etc, integrated with small memory arrays Printed Memories 16-32 bit ROM automation 32-64 bit ROM internal logistics 96bit WORM general logistics for automation, internal Logistics Digital processing blocks on foil that reduce system complexity (for example to reduce I/O): such as display line drivers	Smart Systems Backplanes for Displays	**Market trends and impact** Printed electronics and printed RFID will enable new applications and markets for electronics ‣ Enhancing the Barcode with a unique identifier ‣ Enable Electronics applications in industries (e.g. Printing and Packaging) ‣ Media (like the print media) will be connected to IT in areas where there was no connection (Mobile Phone with Newspaper, Mobile Phone to package) ‣ Every object could be identified and interact with humans and other objects ‣ Brand protection and the fight against counterfeits will be strengthened **Production impact** The technology also promises the environmental safe and reduced use of resources **Impact to industries:** Retail, Food&Beverage, (new Packaging and IT concepts Supply chain automation, New customer interaction) Packaging Industries New packaging concepts integration features like RFID for identification IT industries Massive data increase requires new data management concepts , if every product will be identified

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Long Term (8 – 10 years / 2018 - 2020)				
Improved materials ‣ conductors ‣ high mobility and/or stability semi-conductors; ‣ high purity dielectrics **Low cost, large area processes** ‣ high throughput printing with small features and high overlay accuracy ‣ vertical transistor ‣ large area uniformity and control ‣ scaling channel length and thickness dielectric **Design/technology** ‣ defect tolerant design ‣ robust CMOS design logic ‣ Compact modelling, device physics **Equipment** ‣ On the fly adaptive patterning ‣ in-line quality control **Detailed description could be found in Roadmap OE-A Vers. 05.2008**	‣ FET-mobility of semiconductor > 2 cm2/Vs with spread lower than 0.05 cm2/Vs ‣ Vt (<0.1V) ‣ Resolution < 2 µm: (minimum feature size and overlay) ‣ Number of transistors >1000 ‣ Drive voltage (< 5V) ‣ Circuit frequency (> 100 kHz): ‣ Circuit design tools ‣ Transistor-based sensors.	Basic Components/ Circuits Transistors, Resistors, capacitors, memories etc., integrated with other active electronic elements such as active memories and sensors. Printed RFID EPC (U)HF retail item level retail logistics printed large NVRAM memories Backplanes for (pressure, light, gas)sensor readout electronics: AD converters More complex digital circuits such as ALU, microprocessor, peripheral display circuits Analogue building blocks (operational amplifiers, Low Noise Amplifiers (LNAs), filtering stages, comparators, etc.) and mixed signal systems (like A/D Converter for a flexible temperature sensor	Smart Systems Backplanes for Displays In addition: Any other form of (micro-)electronics	**Market trends and impact** Printed electronics and printed RFID will enable new applications and markets for electronics ‣ Enhancing the Barcode with a unique identifier ‣ Enable Electronics applications in industries (e.g. Printing and Packaging) ‣ Media (like the print media) will be connected to IT in areas where there was no connection (Mobile Phone with Newspaper , Mobile Phone to package) ‣ Every object could be identified and interact with humans and other objects ‣ Brand protection and the fight against counterfeits will be strengthened **Production impact** The technology also promises the environmental safe and reduced use of resources **Impact to industries:** Retail, Food&Beverage, (new Packaging and IT concepts Supply chain automation, New customer interaction) Packaging Industries New packaging concepts integration features like RFID for identification IT industries Massive data increase requires new data management concepts , if every product will be identified

Social & Economical Impact and Relevance for EU

Market trends and impact

Printed electronics and printed RFID will enable new applications and markets for electronics; they will also change or even revolutionize industries. The impact of these changes is huge, either to business models, job qualifications and new jobs created. Some examples for changed paradigms:

- Enhancing the Barcode with a unique identifier enable electronics applications in industries (e.g. Printing and Packaging) which had no or few contact to electronics and IT before;
- Media (like the print media) will be connected to IT in areas where there was no connection (Mobile Phone with Newspaper, Mobile Phone to packages)
  This will allow new transparency and new business models for these industries;
- Every object could be identified and interact with humans and other objects;
- Electronic features could be used to protect brands and help to fight against counterfeits.

Impact to Production

The technology also promises the environmental safe and reduced use of resources, as it's not using clean room environment for production. Evaluating the "green" advantage of this production technology to conventional production should be compared as soon first upscale production facilities are available

Impact to Industries:

Printed electronics will have an impact to many industries. Given the vision of the electronic product code EPC™ all consumer industries (e.g. **food, beverage, sports and apparel industries**) are affected. It will change the supply chain and logistic handling as well as the handling and management of the goods in the stores. But also enabling industries like the **printing and packaging industry** has to prepare to incorporate new functionalities into their products. The **IT industry** has to handle the massive increased data amount and has to find and develop new strategies for data management.

Impact to Jobs:

New Jobs are created in several industries as they are described in "impact for industries" fulfilling the new business opportunities. The Jobs created or the changes in existing industries require new qualifications for the new production methods and product capabilities. The new products are often used as integrated features in current products (RFID as an extension to barcode), so the production will happen in Europe and the jobs created are not moved away easily to Far East, as it has happened in the past.

Synergies

Printed Electronics is an enabling technology also for other applications. So synergies exist in several aspects:

Application:

Logic circuits are a requirement and a building block for integrated smart systems.
Backplanes for displays consist of a uniform matrix of transistors.

Production/Process:

Production and process know-how is synergetic to all areas of OLAE: Know-how and Competence (Modeling and Simulation, Specific Equipment, Quality Control) for efficient Roll-to-roll production.

Materials:

The used materials (semiconductors, dielectrics, conductors) to produce transistors and other components could be used for other applications as well.

	Materials	Process	Application	
Lighting	✔	✔		
OPV		✔		
Displays	✔	✔	✔	(O-TFT Backplane)
ISS	✔	✔	✔	

Large area distributed electronics is totally transverse to the other topics, the impact of the research and development will address in the future all the market segments of OLAE. As exposed, different processes schemes (Roll-to-Roll, Foil-to-Foil, substrates carriers) will need to be developed to address the different level of complexity of these markets segments (unipolar / CMOS like process and design, low / high complexity Digital circuits, Analogue circuit).

R&D Budget requested

Electronics represents the basic components, processes and materials for many devices. In order to secure Europe's position in the field the funding volume of EU-programs for electronics in the timeframe 2011-2015 should be in the order of 40 Mio. Euro.
For 2011-13, (FP7) approx. 24 Mio. Euro (8 Mio. Euro p.a.) for Priority 1 targets and for the first years of the Framework 8 program (2014-15) additional 16 Mio. Euro (8 Mio. Euro p.a.) for priority 2 (mid/long term targets).

The budget should be used to speed up the current European efforts to bring this technology **faster into production and to the market**, keeping and support Europe's leading position in this field. To coordinate the budget use with other regional European activities the result of the current projects for coordinated actions (e.g. PolyMAP, PolyNET) should be used. A SWOT analysis of the regional competence should lead to a special support to regional centers by supporting local competencies and centers and exchange local competencies on European level.

Target of this process is to mature the technology by speeding up and making strong activities even better and more competitive.

3.5 Integrated Smart Systems (ISS)

Abstract/Summary

Organic printed electronic and optoelectronic components, multidisciplinary sensors, displays, energy sources and storage, smart lightings are examples of building blocks for integration of smart systems and devices. Integrated Smart Systems (ISS) provide novel enabling functionalities and as such are currently a driving force behind disruptive product innovation. Technology and component development of other 4 focus areas is very synergetic and supports ISS developments. The heterogeneous integration of multidisciplinary functionalities into single devices (ISS) promises to open a variety of totally new value propositions. The new products like disposable diagnostics, smart lighting, interactive packaging, large area sensors, that did not exist before in the market, will satisfy demands in terms of comfort, safety, style and usability. ISS developments and innovations will be decisive for solving some big challenges of society, such as wellness and healthcare of aging population, sustainable energy, safety and security, pollution and environmental problems, entertainment etc… The primary ISS application areas proposed are: Diagnostic systems, large area sensors, intelligent smart lighting and optical systems, and Smart packaging and objects.
Today, European industry still occupies a leading position in the manufacturing of ISS and products incorporating such technologies. Nevertheless, although the EU is the worldwide technology leader (leading institutes, large industries, and SMEs), it is facing significant threats from the low-wage countries (China and Asian countries), due to the high costs and long development costs. That is why it is more important than ever to rapidly adapt to the new markets by developing high-quality and low-cost products with a reduced time to

market, to counter international competition. Keeping up with the pace of technological development on a global scale - particularly against the backdrop of a growing economic crisis- requires a drastic increase in investment in ISS research, not least to counterbalance the losses experienced in other key technology sectors.
The total market potential of ISS is difficult to assess, because of the expected market penetration from niches to higher volume markets, but there will be emerging potential

- to capture a remarkable share of the existing and growing 10B€ Point-of-care diagnostics markets
- to be a key technology for added value and interactivity in consumer goods packaging (packaging markets 400B€)
- to be the enabler for large area sensing applications in valuable large size objects like buildings, bridges, windmills, airplanes, automobiles, etc…
- to produce innovative components for transport markets (automotive, airplanes) such as large area sensors, smart lighting, autonomous electronics…

Then the improvement of ISS is therefore crucial for the competitiveness of European Countries, supporting emerging industry sectors with great socio-economic benefits (increasing employments, power consumption reduction, etc…), expanding economy stability and creating new job opportunities.

Market Data

ISS represents radically new products that did not exist before in the market. The new products are based on combination of several functions, merging together printed electronics, lighting, sensing, display, energy storage and harvesting.

For that reason the total market value of ISS is difficult to assess with accuracy as it is a technology enabling competitive system products, and in several areas it is perceived as a disruptive technology in the sense that it will break traditional product/technology paradigms and will create a new technological competency base. The world market value in 2009 for microsystems ranges from 52 billion USD to 95 billion USD for the total microsystems supply chain. The leverage effect of Smart Systems can be illustrated by the price of inkjet cartridges which is of the order of 20-40 USD while the price of the corresponding printer is 100-300 USD. A better view of the impact of Smart Integrated Systems can be derived from a top-down approach for an entire application area such as automotive value chain where the value of ISS is estimated to amount to 45 billion USD.

Although there is tremendous potential for these products, high volume sales of printed systems will initially mostly occur in the retail and supply chain management industries. It will take at least until 2010 for the full scale commercialization of printed organic batteries, photovoltaic panels, flexible and active displays, as well as some logic components. The commercial successes of other innovative products are harder to predict because they will largely depend on the availability of e-content providers and customer adoption. Although volume penetration of printed systems (principally printed electronics) is expected to occur in 2010, the Organic Electronics OE and PE Polymer Electronics demands will explode to a market worth hundreds of billions of dollars over 2018 (*source ID-techEX*). But the demand for this technology is likely to come from new markets unforeseeable with silicon technology and for some years will not offer the resolution required to fabricate computer CPU's and large capacity memory chips, although this is feasible with the use of nanoimprint lithography.

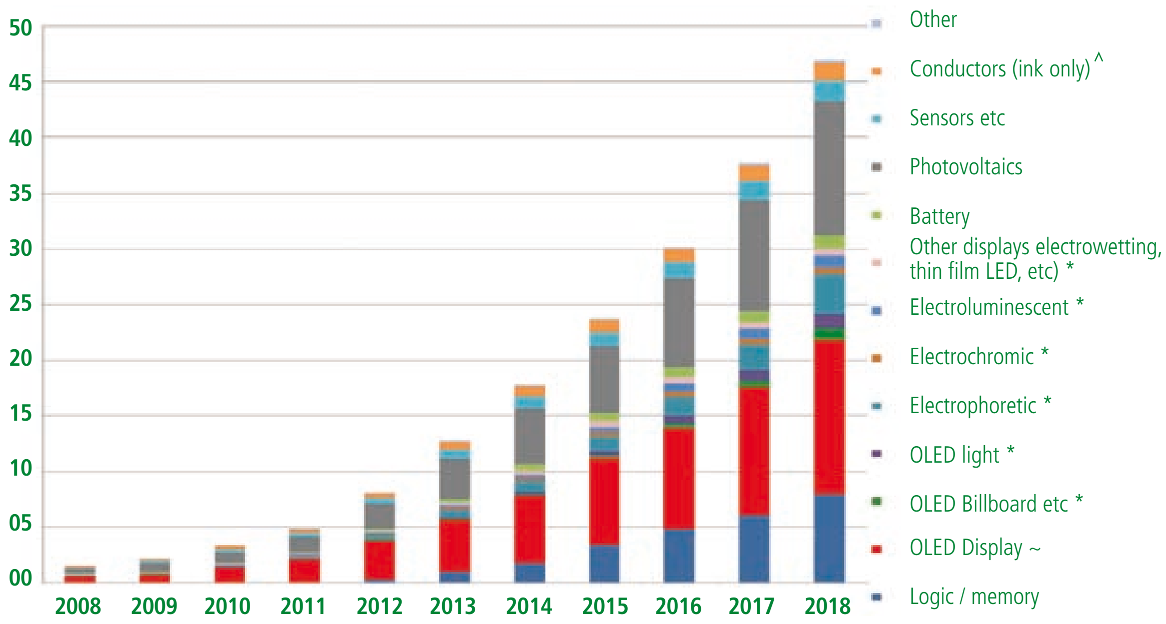


Figure 6: Global market for organic and printed electronics – ID-techEX

Considering global market for organic and printed electronics, ISS could cover all sectors including several functions such as battery, photovoltaic, display, printable materials, electronics, packaging… The markets for individual component categories are expected to grow rapidly (see Figure 6).

Components combined to form ISS, are expected to bring about new business expansion possibilities e.g. to the diagnostics and well-being markets. Further it will allow cost savings in health care. Kalorama (2008) estimated the global In-Vitro Diagnostics (IVD) in 2007 to have been 42 Billion USD with the Point-of-Care (POC) sector at about 6 Billion USD and decentralized glucose monitoring at 10 to 11 Billion USD. The global self monitoring blood glucose market is forecast to grow annually at a rate of 10.8% for the next seven years to reach $19.7 billion in 2015 from which the disposable test strips will account 91% (GlobalData 2009). "Diagnostic tests account for only less than 2 % of government healthcare expenditures worldwide, yet their finding influence 60-70% of healthcare decisions" (Clinica 2008).

By 2020, ISS applications could reduce global emissions by 23%,with an equivalent of 9.2 Gt CO2e3 by providing smart solutions for energy management and distribution, smart control of electrical drives, and optimization of logistic or energy-efficient facility management. This figure is equivalent to a market value of 65 to 70 billion EUR worldwide.

The worldwide market for Monitoring & Control (M&C) products and Solutions, one of the most important fields of ISS, containing solutions for environment, critical infrastructures, manufacturing and process industry, buildings & homes, household appliances, vehicles, logistics & transport or power grids, is around 188 billion Euros. This value represents 8% of total ICT expenditures worldwide. And - it is identical with the whole semiconductor industry world revenues and approximately twice that of the world mobile phone manufacturers' revenues. The larger sub markets of integration, installation & training services, control hardware and maintenance represent together over 100 billion Euros. Currently Europe represents 32 % of the world total market value.

The M&C market for vehicles alone, comprising OEMs' costs for internally produced vehicle

embedded solutions, e.g. ABS braking, air conditioning, airbags, automatic transmissions, adaptive suspension, engine control, etc., represents a total of approximately 17Bn € (in 2007). Because of demands induced by global issues as CO2 emissions reduction, hybrid motorization, electrical and smart vehicles, and traffic management, an annual growth rate of to 5% during the next decade is expected. Smart systems integration will be the all-dominant enabler for pre-crash systems and predictive driver assistance features to reach the goal of the Road Safety Action Plan to halve the number of traffic deaths by 2020.
Taking into account all organic and printed electronics the overall market of ISS will cover these outcomes. Furthermore the global market will be oriented to the implementation of the manufacturing processes for yield rise, efficiency optimization and new function integration. Such leverage means that ISS technology will be underpinning sales volumes of several hundred billion € per year, comparable with the situation as for microelectronics about 20 to 30 years ago.

Focus Area for ISS

The ability to miniaturize and integrate intelligence and new functionalities into conventional and new components and materials as well as totally new applications and products is a key element for improving the quality of life, for implementing the concept of ambient intelligence and for extending this concept towards 'ambient assisted living' in general. The convergence of existing processes and components to continuous integrated technology (e.g. technologies based on roll-to-roll (R2R) production concepts) will allow the production of really autonomous multifunctional foils (e.g. ISS), disposable products or functionality embedding into products with high industrial and social impact.

Large Area Mass Production Processes are the key to enable the production of large-area low-cost electronics systems. As a consequence, these production processes should not be restricted to one industrial answer, being the Roll-to-Roll printed solutions (as appears now from the document). Many institutes and industries have shown that Sheet-to-Sheet and Carrier based processes are also efficient production schemes for large area flexible high throughput processing which lead to more complex designs with high production yield, a key parameter for production cost. Furthermore, even though printing techniques are very promising, one should not restrict the OLAE only to such processes. High-throughput photolithography, laser ablation, evaporation and other techniques show potential results for OLAE and are already used in other mature industries (PCB, displays). Furthermore these technologies have been applied to OLAE during the last years and within EC PF6 and PF7 projects proofing very well their suitability for organic electronics and ISS fabrication.
Therefore we need to consider a technology platform where different fabrication modes are available and can be adapted to the need of the different R&D disciplines and the later applications. Important is to ensure the comparability of such different technology of fabrication modes by integrating them in a platform with combined bench-marking as this is proposed in several European Projects. The question whether roll-to-roll or fast sheets is furthermore not really applicable, because it is in the most situations and for the most applications always the question when to cut the basic substrate rolls into sheets for further processing. The point always depends on the needed performance, the target cost of the application and on the production volume planned.

Organic and printed electronics systems have already been introduced on the market with some pioneer applications such as talking pizza boxes or aerosols and medication tools. The key enabling technologies are about to reduce costs of electronics suitable around 99%. Consequently, many leading brand owners is recently adopting the new paper thin electron-

ics on their high volume packaging, providing a host of consumer benefits. This is mainly about modern merchandising - progressing way beyond static print - and dramatically better consumer propositions.
In short term objectives for ISS development will focus on the availability of existing components, improving R2R processes enabling integration and processability of heterogeneous functionalities in one single device or simple system. Medium and long term objectives will lead to really autarkic devices combining high complexity in a single autonomous device through continuous production process integration. The last goal will be manufacturing of multifunctional 3D objects starting from single plastic foils by the combination of R2R and injection moulding approaches.
The ISS can be exemplified in four main categories, depending on the primary application and the dominant market:

- Diagnostic systems: Home care and point-of-care diagnostics, Environmental diagnostics, Medical diagnostics, Hygiene and safety diagnostics, Therapeutic and drug delivery systems, Printed batteries and supercaps, Disposable diagnostics and indicators (food, hygiene, cosmetics)

- Large area sensors: Automotive and aerospace (gases, pressure, thermal, fire sensors, driving status monitoring, exhaust gases/temperature sensors), Network sensing system, Fire sensing, Buildings & civil structures (structural health monitoring, moisture), Security

- Intelligent Smart Lighting and Optical Systems: Intelligent lighting, Sign-boards, Road-signs, Info-panels, Labels, Logos, integrated energy sources and storage Products, Automotive and aerospace lighting (courtesy, security lighting…),
- Smart packaging and objects: Smart cards, Tickets, Toys/Game boards, Intelligent surfaces, Consumer goods packaging, electrochromic TFT, HMI, Printed (bio) fuel cells

These applications are expected to have great potential in several markets such as medical, automotive, aerospace, building and civil infrastructure, army, food, packaging, entertainment, agricultural, security etc… These applications require a better deal of materials, components, processability of organic matter. (see figure 7).

R&D priorities

The development of such ISS devices for overall different market fields will require a successful finalization of the knowledge and investment arising both from national/public institutes and private leading industries. To achieve manufacturing of functional innovative ISS a strong innovation with a solid orientation on customers' needs, market requirements, and societal demands is requested. In order to achieve above aims, the main targets in short-medium-long terms may be formulated as follows:

- **Priority 1 (Short term)**
  - Materials for integration of intelligent new functionalities with enhanced physical/chemical stability
  - Integration of organic and hybrid electronic/functional systems based on separate existing components (e.g. power source, circuits, sensors etc.)
  - cost efficient and large area manufacturing
  - Advanced process control and on-line quality inspection
  - Functional system modelling

- **Priority 2 (Mid/Long term)**
  - Product line integrated OLAE manufacturing concepts
  - Disposable/recyclable printed electronics
  - Data processing and communication
  - High speed processes for hybrid electronics assembly and integration
  - Production and Integration on single foil
  - Environmentally friendly and high performance materials

For details see tables in Chapter 5.

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	Diagnostic Systems	Large Area Sensors	Intelligent Smart Lighting and Optical Systems	Smart packaging and objects
Product description	‣ Home care and point-of-care diagnostics ‣ Medical diagnostics ‣ Hygiene and safety diagnostics ‣ Therapeutic and drug delivery systems ‣ Printed batteries and supercapacitors	‣ Driving status monitoring ‣ Pressure/exhaust gases/temperature sensors ‣ Network sensing system ‣ Fire sensing ‣ Structural health monitoring ‣ Printed batteries and supercapacitors	‣ Intelligent lighting ‣ Sign-boards ‣ Road-signs ‣ Labels ‣ Logos ‣ Flexible OPV and printed photovoltaic in ISS	‣ Smart cards ‣ Tickets ‣ Toys/Gameboards ‣ Intelligent surfaces (electrochromic TFT) ‣ HMI ‣ Printed (bio) fuel cells
Market	‣ Medical ‣ Home ‣ Hygiene ‣ Environmental ‣ Food	‣ Automotive ‣ Army ‣ Aerospace ‣ Buildings & civil structures ‣ Agricultural ‣ Security ‣ Food	‣ Automotive ‣ Army ‣ Aerospace ‣ Consumer goods packaging ‣ Buildings & civil structures (roads, airports…)	‣ Games/Toys ‣ Automotive ‣ Consumer goods packaging

Figure 7: ISS main devices and applications

Tables

Following tables will summarised the main topics within ISS area for short, medium and long terms.

- Short Term (1-3 years -2011/2013)
- Medium Term (4-7 years -2014/2017)
- Long Term (8-12 years -2018/2023)

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Short Term (1-3 Years / 2011 – 2013)				
Summary of relevant ISS targets				
‣ New sensing, biocompatible and multifunctional materials ‣ Conformable/flexible substrates ‣ Integration of organic and hybrid electronic/functional systems based on existing components ‣ Cost-efficient manufacturing ‣ Multidisciplinary education and training ‣ Functional systems modelling	‣ Low-temperature processable, thermally/chemically stable materials ‣ Foil based label manufacturing and integration concepts and platforms ‣ Product line integrated OLAE manufacturing concepts ‣ Bio-indicator & sensor devices and concepts ‣ Integration of energy + processing + interfaces ‣ Hybrid electronics assembly & integration ‣ Processing on large areas ‣ Foil based label manufacturing	‣ **Diagnostics systems** ‣ **Large area sensors** ‣ **Energy sources and storage** ‣ **Intelligent lighting** ‣ **Smart packaging & objects**	‣ Applying OLAE components for ISS applications; OLED, OPV, displays, electronics	‣ New products for well-being, safety and convenience ‣ New opportunities for European electronics, diagnostics, packaging, automotive industries, … ‣ Job opportunities ‣ Reduced power consumption ‣ Reduced material consumption
‣ Specific applications/devices				
‣ Biocompatible printable materials ‣ Manufacturing processes ‣ Detection methods ‣ Multidisciplinary components integration	‣ Bio-indicator & sensors devices and concepts ‣ Sensing platforms (& systems)	**Diagnostics systems** ‣ Disposable Diagnostics for wellness, healthcare, environmental ‣ Indicators, simple hygiene & diagnostics products	‣ Simple displays and electronics ‣ Printing based R2R processing	‣ Robust, low-cost and easy to use diagnostics for ageing population ‣ Added value products for safety, hygiene and wellness ‣ Diagnostics for underdeveloped areas
‣ Sensing materials and devices ‣ Sensor arrays and systems processing on large areas	‣ hybrid electronics assembly & integration ‣ Large area, multielement read-out ‣ High sensitivity ‣ High selectivity ‣ Communication concept and sensor networks ‣ Large number of sensors on single foil	**Large area sensors** ‣ User interfaces ‣ Structural health monitoring ‣ Buildings; moisture, fire,… ‣ Driving status monitoring ‣ Exhaust gases control	‣ Printed electronics components applicability	‣ New large area sensing opportunities for valuable large size 'objects' for health and safety ‣ Automotive/aerospace sensors for safety and pollutants reduction
‣ Energy sources, storage & management ‣ Integration of organic and hybrid electronic systems ‣ User interface concepts	‣ Integration of energy storage/ source into novel products ‣ Power source and storage for standalone operations ‣ Foil based label manufacturing ‣ Product line integrated manufacturing	**Energy Sources and Storage** ‣ Flexible, thin foil batteries ‣ Printed Fuel Cells ‣ Printed supercapacitors ‣ Autonomous energy foils	‣ Electronics for 'brains', driving, control and interconnections ‣ Flexible OPV for energy	‣ Consumer added value
‣ Integration of organic and hybrid electronics/functional systems ‣ Materials with high thermal/mechanical stability ‣ Multidisciplinary components integration ‣ Solution manufacturability	‣ Hybrid electronics assembly ‣ High efficiency and lifetime ‣ Integration of OLED, OSCs and sensors on single foil ‣ Integration of inorganic EL devices (AC/DC converter)	**Intelligent lighting modules** ‣ Sign-boards ‣ Labels ‣ Road-signs ‣ Logos ‣ Autonomous courtesy lighting	‣ Flexible display (Organic and Inorganic) ‣ LEDs	‣ Reduced power consumption ‣ Consumer added value ‣ Increase safety/wellbeing (elderly people)
‣ Integration of organic and hybrid electronic/functional systems ‣ Multifunctional materials ‣ Energy sources, storage & management ‣ User interface concepts ‣ Cost-efficient manufacturing	‣ Electrochromic TFT ‣ Integration of communication with other functionalities ‣ Mechanical/chemical stability ‣ Foil based label manufacturing ‣ Product line integrated manufacturing ‣ Integration of energy + processing + interfaces ‣ Device and system performance; energy supply functional complexity, communication with existing ICT infra, lifetime, reliability & packaging ‣ Power and functionality for standalone operation	**Smart packaging and objects** ‣ Smart cards ‣ Intelligent surfaces (electrochromic…) ‣ Toys/gameboards ‣ HMI	‣ Simple flexible displays ‣ Flexible OPV for energy ‣ OLED/LED for signage ‣ Electronics for 'brains' and communication ‣ Flexible batteries	‣ Consumer added value ‣ New products with novel functionalities

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Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Medium Term (4-7 Years / 2014 – 2017)				
Summary of relevant ISS targets				
‣ Integration of heterogeneuos technologies ‣ Equipment development and assembly ‣ Processing on large areas ‣ Development of multi-functionalities ‣ New biocompatible and multi-functional materials ‣ Process inspection, control and machinery ‣ Integration of organic and hybrid electronic/functional systems ‣ Functional systems modelling	‣ Product line integrated OLAE manufacturing concepts ‣ Disposable/recyclable printed electronics ‣ Organic data processing and communication for sensor applications ‣ Printed sensor systems ‣ Printed power supply and harvesting ‣ Hybrids systems with high efficiency and lifetime ‣ Multifunctional materials ‣ High performance components ‣ Green energy sources	‣ **Process machinery development** ‣ **Low-Medium complexity devices by hybrid components integration**	‣ Integration of OLAE components for ISS applications ‣ Converging R2R technologies	‣ New products for well-being, safety and convenience ‣ New opportunities for European electronics, diagnostics, packaging, automotive industries ‣ Job opportunities
‣ Specific applications/devices				
‣ Processing on large areas ‣ Integration of heterogeneous technologies ‣ On-line quality inspection ‣ Advanced Process control ‣ Cost-efficient processing on large areas	‣ High speed processes for hybrid electronics assembly & integration ‣ High throughput ‣ High Resolution ‣ Continuous process ‣ In line process control ‣ In-situ monitoring /defect repair ‣ Sensor integrated into products on it's manufacturing ‣ Environmental safe technologies ‣ Environmentally friendly materials	**Process machinery development** ‣ R2R platform with integration of printing techniques ‣ Encapsulation processes	‣ Printing based R2R processing	‣ Converging technology for autarkic devices ‣ Reduced power consumption
‣ New OLAE-based components and device concepts ‣ Hybrid Integration ‣ Multidisciplinary components integration ‣ Functional systems modelling	‣ Integration of OLED, OSCs, batteries and sensors on single foil ‣ Standalone printed electronic circuits ‣ Predictive device and circuit models ‣ Imaging sensor systems ‣ Biological receptor integration ‣ Simulation to allow several functions	**Low-Medium complexity devices by hybrid components integration** ‣ Diagnostics systems ‣ Array of sensors ‣ Printed batteries, PV cells ‣ Lighting and signalling ‣ Smart systems and packaging	‣ Flexible components (Organic and Inorganic SC, displays, lighting, batteries, sensors…)	‣ Autarkic devices with novel functionalities

Research Topic	Technical Objectives	Application	Synergies	Socio-economic relevance
Long Term (8-12 Years / 2018 – 2023)				
Relevant ISS targets				
‣ Integration of heterogeneuos technologies for high complexity integration ‣ High performance OLAE components, devices and systems in single step process ‣ Large areas products ‣ Organic/inorganic materials combinations	‣ Product line integrated OLAE manufacturing concepts ‣ 3D objectives combination with other manufacturing processes (i.e. injection moulding) ‣ All-printed intelligent systems ‣ Completely Independent integrated OLAE modules ‣ Technologies for high resolution and high packaging density	‣ **Completely independent integrated system: single foil or 3D objective**		‣ New opportunities for European electronics, diagnostics, packaging, automotive industries ‣ New products for well-being, safety and convenience

Social and economic impact

Electronics, display, energy will be manufacturing fields upon which nanotechnology will have the most sustained, significant impact, as so much of the technology development in this area is scaling to (or is already at) nanometre length scales. The ICT sector in the European Countries represents 5.6% of EU GDP (670 Billion Euro) and 5.3% of total employment in 2007. 50% of the EU productivity growth (1.1% between 2000-2004), comes from ICT and 25% of research expenditure (2002-2003). This share of European employment equates to about 13 million jobs.

In this scenario ISS represent radically new solution in terms of innovative products for customers and modern manufacturing processes. The development of novel ISS related to disruptive manufacturing techniques could contribute largely to sustainable growth in Europe and could grow to become a large dynamic industry. The main applications are included in several markets in which EU is worldwide leaders or is growing fast. The market sectors are automotive, aerospace, security, portable equipments for infotainment and entertainment, toys, PC, e-cards, e-papers, displays, lighting, security, food, packaging, etc… The opening-up of new market sectors is expected to significantly increase the employment opportunities in existing European companies and promoting the birth of new high-tech companies. Firstly sure advantage will be for tier-one industries. Furthermore new market sector will provide a network for both SMEs and large scale producers and a source for the development, establishment and further enhancement of SMEs throughout at once. Considerable employment opportunities may arise with the introduction in the market of developed new products and optimized production line.

Improvement of quality of life and safety such as enhancement of vision, driving comfort, reducing the occurrence of accidents and increasing safety of life are expected by ISS development and application. For example electronic packaging, so called "e-packaging" addresses the need for elderly people to create very low cost self diagnosis and treatment using disposable packages or for brands to reconnect with the customer or face oblivion from copying. Particularly e-packaging addresses the fact that one third of us have difficulty reading ever smaller instructions. The increase of age leads to an increase of magnification need for view capacity. As the population ages, intelligent and high bright signals, displays for e-books and e-newspapers with electronic capabilities to provide larger print, changing or vibrating textures to signal something using the sense of touch, easier portability and more intuitive human interfaces will extend the time in which elderly remain involved with the society. As recognised within the EU, the ageing of Europe's population will be a crucial challenge for the 21st century

Wider benefits are also expected to arise from ISS production in terms of contribution towards science and engineering education and other type of learning and self-instructions. The main EU academic institutes will enhance their technical and academic level by organization of specific lectures, courses of industrial stages, improving educational degree of younger generations.

Synergies

Under the current vision, the ISS will have a fundamental impact on worldwide society offering new opportunities for modern life. The development of such multidisciplinary devices will be made possible by exchanging information and work in synergy with all other R&D topics areas. Integration of organic, printed large area electronics components within single backplane will result from a synergic merge of today's developed systems. Such synergies will be derived from the various scenarios and development paths and specific technologies will serve multiple purposes.

Every OLAE topics areas sustain the development of potential building blocks for ISS production. Work in synergy with each other OLAE topics will increase the quality and functionalities of single devices. Particularly materials, processes and components development are the three thematic of major interest. Regarding materials, OLED, OPV and OTFT materials, for printing and roll-to-roll processing are of major relevance. Then a successful integration of the roll-to-roll processes and productions leads to the development of suitable and reliable components useful for each single topics and for the overall integration. Above all production and development aspects such as modelling, simulation, testing and quality control are very synergetic with all others.

	Materials	Processes	Components
Lighting	✔	✔	✔✔
OPV	✔	✔	✔✔
Displays	✔	✔	✔✔
Electronics	✔✔	✔✔	✔✔

SYNERGY MATRIX

R&D Budget for next 5 years

The EU demands input about the relevance of the R&D anticipated in a specific topic area. Integrated Smart Systems represent radically new market in worldwide scenario, holding a promise for future businesses, emerging markets and new employment in Europe. The estimated budget for 2009 is approximately 30M€ with increase roughly of 2.5-5 M€ per year. With the main priorities of developing new sensing, biocompatible and multifunctional materials, of modelling multifunctional systems, of integrating hybrid electronics and finally of improving the cost-efficient manufacturing, all EU efforts should be concentrated to reinforce existing R&D centres, where technical design integration and processing is already condensed (e.g. Finland- VTT, Netherlands-Holst, Germany Dresden- Plastic Logic, Sweden - Acreo/Linköping, etc….). All R&D plans will be addressed to have common synergies and convergences. R&D EU requested support is 90 M€ for 5 years 2011 - 2015.

Two budget figures are reported: one short term 2011 - 2013 which is in line with the R&D focus short term (Chapter 4) and one for 2014 - 2015 which is in line with the mid/long term focus.

- **Budget 2011 -2013**: The requested EU budget for 2011-2013 is 45 M€. Diagnostic systems 15M€, Large area sensors 10M€ , Intelligent lighting 10M€, Smart packaging & objects 10M€)
- **Budget 2014 -2015**: The requested EU budget for 2014-2015 is 45 M€. Diagnostic systems 12M€, Large area sensors 9M€, Intelligent lighting 10M€, Smart packaging & objects 9M€.

4.0 Key Recommendations and SRA Implementations

4.1 Motivation

Organic electronics is a disruptive technology which is in an early stage and has a huge potential for lighting, organic photovoltaics, displays, electronics and integrated smart systems. The applications are in early stage of development and now the main challenge is the transition from 9 laboratory prototype to production. In order to achieve this goal we need to join forces from academia, start-up's and industry along the value-chain from materials, equipment, devices to application.

OLAE technologies make use of a wide variety of materials and their combinations; organic semiconductors, low-temperature solution- and vacuum-processable organic, inorganic and hybrid materials, biomaterials and bioactive materials, small-particle and nano-particle materials, etc. Substrates like plastic, steel, paper and textile are used. Manufacturing involves many processes from other domains than "traditional" electronics manufacturing: roll-to-roll printing, evaporation, laser processing and other low-temperature processes. All these aim at cost-efficient high-throughput manufacturing on large areas. Processing methods often are combined and customised. On device level for example, basic passive and active electronic components, OLEDs, solar cells, batteries and sensors may be manufactured as functional component foils, rolls or sheets. Lamination and interconnection of such functional foils and films create flexible OLED lighting, autonomous flexible energy sources, disposable point-of-care diagnostics, flexible large area sensors, etc. OLAE manufacturing concepts may also be integrated into existing manufacturing lines to embed added value functionality into for example product packages and printed media.

This new manufacturing landscape creates opportunities for new kinds of industrial players, in addition to the existing electronics industry value chain, to join the OLAE community building the future technology backbone of European excellence and business creation. Such new players will not only be active on the application level but also on materials, components, machinery, instrumentation and automation.

4.2 Concrete proposals

Clustered approach with pilot production centres to close the gap between R&D and products

The gap from research to product is the most difficult one to bridge for OLAE products, and worldwide competition in getting new products to the market is intense:

Particularly in Asia, there are many companies with vertically and horizontally integrated businesses which are willing to carry R&D to products even if this is a time-consuming and expensive process.

Again in Asia, the public is rather open to gadgets which demonstrate a new technology, even if parameters like lifetime are not fully satisfying. European companies generally tend to stay away from such products.

In the US, financing opportunities for new companies are more abundantly available, in particular when the product phase is reached and substantial resources are needed to get the product on the market.

It must therefore be a key element of the European strategy on OLAE to undertake all possible measures to support bridging the gap from research to product. Possible measures are:

Establish pilot productions centres where R&D institutions and companies can test their technologies and test early markets. Here we can learn from the CMOS world, in which many SME's only were able to pick up manufacturing of custom-specific microelectronic products by using pilot production facilities established with government help.

Establish application oriented transfer projects which can, with little bureaucratic effort, be applied for when successful R&D projects indicate that a technology is ready for implementation in first products. Such transfer projects should result in limited series of demonstrators. The realization of these should be fully eligible for funding.

Identify the gaps that need to be turned on to get products realized. It is necessary to offer not only technology, but to have a holistic look: the investment community, designers, and business people need to be brought together. For this, specific funding measures are needed.

Since many innovations are put forward by SME's, it is important to stimulate the foundation of new companies. We suggest establishing a seed and early phase (3-5 years) funding tool for new start-ups.

Nurture the emergence of a European OLAE industry, for example through new approaches to create lead markets

For many new products, it is difficult to enter the market and build up experience with such products without "launching customers" which take a risk and accept initial disadvantages such as higher costs. Governmental support to establish new products will be helpful, by leveraging the procurements of governments for that purpose. An example would be that governments planning for a significant new building require that novel technologies with societal benefits like low energy consuming OLED lighting are used and ask European companies to provide these products. Using this governmental entry market, companies can then proceed to address other markets.

Another approach is to lower the barriers for early product adoption by funding and supporting applications which are "first of its kind". Application projects with pilot customers and suppliers of new technology should be supported to carry a part of the risk in this early phase. The experience and successful application of the new technology can later be used to address mass markets autonomously.

Finally, it is of equal importance to remove ineffective regulatory obstacles to OLAE products commercialisation, for example a consideration of the directive on Batteries and Accumulators and Waste Batteries 2006/66/EC which hinders printed eco-designed power sources.

4.3 Coordination topics

Establish OLAE Platform together with all stakeholders

The OLAE Industrial Governance Board has to coordinate all OLAE stakeholders:

- Industry, start-up's and Academia in the OLAE topic areas Lighting, Organic Photovoltaic, Display, Electronics and Integrated Smart Systems
- Existing Technology Platforms and projects (Photonics21, EPoSS and opera) and organisations (oe-a)
- European OLAE activities and bodies
- National OLAE activities and bodies
- Cross-functional OLAE coordination topics (education/training, standardisation and SME funding)

Coordinate existing OLAE networks and platforms

There are already existing OLAE networks and platforms like the Organic Electronics Association (OE-A) and the Plastic Electronics Foundation. The OE-A, a membership organisation, is currently evolving into a world-wide network of players in the field, both industrial and academic. The international association OE-A currently develops a regional organizational structure including a chapter focussed on Europe. OE-A can provide valuable input on strategy and priorities to the OLAE platform. The Plastic Electronics Foundation (PEF) focuses on European interests with a strong R&D component and organizes activities and measures that are supportive to the OLAE field. PEF can support in defining European interests and priorities.

Technology platforms like Photonics21 and EPoSS are also covering the topic areas Lighting and Integrated Smart Systems.

All these networks and platforms were now involved in the preparation of the Strategic Research Agenda for Organic and Large Area Electronics.

OLAE is a base technology with a wide variety of application fields. It has relations and synergies with different existing Technology Platforms. Therefore - as soon as OLAE has reached maturity - it should be established as an own Technology Platform to give OLAE appropriate visibility.

Coordinate EC and national research programmes

Another important issue is coordinating EC and national R&D funding. To enhance and maximise synergies within this area and its funding, we propose the following measures:

Coordinate the national funding programmes, according to the strengths and activities of the stakeholders in the different EU countries.
Install an era-NET plus activity within the funding programmes with common calls, to combine the strengths in European and national OLAE programs. Preparations for this are now made in Polymap.

Quickly implement the road mapping results in the funding programmes and calls.

Revise the effectiveness of existing funding schemes. Specifically, the OLAE community asks for schemes that facilitate a good mix between large (IP-type) projects and smaller and shorter projects.

Implement new funding instruments to support close interactions between academia and industry. This instrument should serve to build up and support centres of excellence as competitive clusters in the EU

Adjust the budget for calls according to the expression of interest of the stakeholders and maintain a pace of no less than yearly calls to meet the dynamic developments in the field

Develop an approach for cooperation in and beyond Europe

It is important that European networking activities are well connected to similar undertakings in other relevant regions of the world. First steps are taken by largely industry-driven associations like the OE-A. However, it is important to also establish such connections for more basic R&D oriented entities like universities, among others to make sure that the basic R&D work funded by the EC is of globally distinctive level.
Secondly it is important to realize that many markets for potential OLAE products are difficult to only approach from the EC. Opportunities to establish collaborative projects beyond the EC, particularly R&D on the level of full solutions and on systems integration, will keep Europe in the position of intellectual ownership and business leader at the same time, and it will avoid IPR sales or either total licensing.
There is already a large interest of international partners, e.g. from Taiwan, Korea, Singapore and Russia to collaborate with EC partners. We propose to establish an effort similar to Era-Net plus to allow a close collaboration with these partners.

One aspect to be addressed when linking national and EC R&D funding is the timing of programmes: It will be a large improvement if project proposals can be submitted anytime (or on much more frequent calls) addressing any topic within the OLAE field. The rapid progress in a new field like OLAE makes it difficult to align more infrequent calls on specific subthemes to the actual progress. Also, a relaxation of the rules concerning the minimum number of European countries involved would be helpful to arrive at consortia that are optimal from a technical and business creation viewpoint.

Take measures to early establish standards for new products

Another major roadblock for establishing OLAE products is the lack of standards, as is common in emerging technology areas. It is therefore important that work on standardization involves all key partners. The OLAE platform could drive such activities from a European point of view, in close collaboration with international networks like the OE-A.

Establish new training schemes which fit to the interdisciplinary nature of the OLAE field

The field of OLAE is a perfect example of a highly interdisciplinary topic area: scientific as well as technological ranging from chemistry and physics to engineering. To train suitable personnel for this field, boundaries between these fields must be overcome and new training schemes must be established providing people the broad qualification needed to successfully work in this field.

A first step would be to support the creating of new degree courses at individual universities. However, a probably better approach would be to coordinate these measures between the different higher education partners. Research institutes and industry may be included to offer practical training modules. Such an approach, coordinated by the OLAE platform, can offer a much broader and more complete approach than those possible by a single partner alone.

It is important that these new training schemes do cover the full value chain on the training side. They should not only cover basic science and engineering training, but also business planning, educating and training people capable to bring new products from development onto production and to a commercial success.

4.4 Required Funding

Increase the funding budget in proportion to the huge expected markets and establish new ways to access capital

As argued in the first section, there is a tremendous economic potential (300 Billion US$ in 2027) in OLAE. EC and national governments have funded this field in the past with significant amounts, but we believe that the level of funding must be significantly increased to match the future importance of the field. As stated above, the expected markets for OLAE are larger than the total present microelectronic market, and there is good reason to believe that Europe will catch a larger share of the world market for OLAE products than for microelectronics if there is ample funding. Therefore, the scale of OLAE funding should take the microelectronics funding as reference and should grow dramatically.

Secondly we propose that new ways to access venture capital for European start-up companies are established. The European venture capital market is less developed than e.g. the US venture capital market, making it more difficult for start-ups to obtain capital. This being a general shortcoming in Europe, in the OLAE field the urgency to take countermeasures is specifically high because of the high degree of innovation of start-ups in this field. We recommend to establish better access to private VC funds by establishing a credit guarantee system, for instance by the European Investment Bank. Additionally, new approaches must be developed to create a sound capital basis for young companies which are already in the transition to production.

Mio. EUR	FP 7 2011-2013	FP 8 2014-2015	Total
Lighting	120	80	200
OPV	54	46	100
Displays	57	43	100
Electronics	24	16	40
Integrated Smart Systems	45	45	90
OLAE	**300**	**230**	**530**

This *table summarizes the proposed budgets for each topic area in FP 7 (2011 – 2013) and FP 8 (2014 – 2015) for the next 5 years.*

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