A European strategy for Organic and Large Area Electronics (OLAE)

Vision paper

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Introduction to this paper

This paper serves as input to the Horizon2020 priority setting process. The field of Organic and Large Area Electronics (OLAE) is a technology area with business potential in many application domains. It has received support in earlier EU framework programs. Its potential to create business in Europe justifies further EU support. Priorities related to the OLAE field are now included in various parts of the Horizon2020 programming. It is important however to maintain an overall vision on this field and to ensure that the major synergies between the different OLAE research, development and innovation activities are guarded.

1. OLAE and Europe's position

Organic and large area electronics (OLAE) is an emerging technology with potential for disruption, based on organic and oxide semiconducting materials instead of ‘conventional’ silicon semiconductors. In contrast to traditional (further miniaturising) semiconductor electronics, it is well suited for applications that need large areas and/or flexibility like paper and plastic. It is made of widely available, cheaper and less toxic material than traditional electronics. It is made by a scalable manufacturing technology, often using additive methods (such as printing) on flexible substrates (such as paper, plastic films or metal foils). It has the potential of creating new manufacturing sites in Europe. It is also a key technology helping to have a greener and environmental friendly society not only with the products made by it but also with the manufacturing.

In 2011, the global market of OLAE-based products was €2 billion. This is projected to reach €50 to €70 billion \(^1\) by 2020. The breakthrough of OLED displays has happened in 2012 (with small displays for smartphones, to be followed by large displays for TV). Europe is already in a strong position in several key areas of the value chain (materials, organic lighting, sensors and manufacturing equipment).

OLAE-based products are generally thin, lightweight, energy-efficient, robust and flexible. Examples of high volume applications are organic light-emitting diodes (OLED) for both rigid and rollable displays, OLED for lighting and organic photovoltaics (OPV). Also more broadly, embedded components with intelligence (technically reflected by transistors, logic and other components) are needed for smart, interactive objects and systems.

OLAE not only allows innovations in existing consumer (handheld) or automotive products because of form factor benefits and/or user interface improvements, but also it has the potential to provide new products not feasible with traditional electronics. Examples include standalone solutions for a broad range of niche markets by integrating OLAE based displays, sensors, solar cells and lighting with computing and communication functions realized by traditional electronics. Other examples are portable health monitoring systems for patients/elderly persons, lab-on-

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\(^1\) According to different market sources the forecasts for 2020 are $35 billion (IDTechEx) or $120 billion (FlexTech). NanoMarkets estimate that the OLED luminaire market will reach $6.4 billion by 2017 and they believe the market of OPV has the potential to grow over $700 million by 2019 with a make or break scenario in next two years. Yole Développement has a very restricted definition of printed electronics requiring some kind of printing (thus excluding vacuum processing) and a semiconductor effect and is thereby having very low estimates of $2 billion for 2015.
a-chip devices and off-grid solar powered systems. All these new solutions open up huge opportunities for SMEs.

OLAE is able to trigger innovation in traditional industries like the paper and plastic industry (with smart packages, RFID tags and anti-counterfeiting solutions), the printing industry (with Flexible Printed Circuits including sensors and human interfaces for automotive, home appliances, industry and consumer electronics), the glass and building industry (with smart windows and building integrated photovoltaics, BIPV) and the advertisement industry (with large area reflective displays replacing paper advertisements in bus stops or in side-road advertisement panels).

A distinct advantage of OLAE based products is that they are more robust and less fragile than glass based ones. However, as some materials are extremely sensitive to water, their encapsulation is challenging especially if long lifetimes (more than 10 years) are needed and if they are intended for outdoor use.

The following observations can be made regarding the (European) OLAE technology sector:

- **Europe has strong research** in OLAE with world leading research organisations, many companies\(^2\) and national and regional innovation clusters. The European stakeholders are organised around the Photonics21 European Technology Platform and the Organic Electronics Association, OE-A.

- **The market** for OLAE based products is fragmented; it is mainly driven by technology advances rather than by applications and needs more products providing solutions to end-users. Europe has market leaders in materials and equipment. With very few exceptions, there is a need for a stronger engagement from the large European materials companies and stronger links with applications, end-user industries and system integrators.

- **The technology** is mature enough for OTFT based backplanes and in general for OLED displays\(^3\). The success of OLED displays will stimulate the introduction of OLED lighting. Moreover, some sensors are already manufactured at large volume by printing companies. The efficiency of OPV technology has improved a lot in the last year and hero cells in the research labs are now above 10% conversion efficiency. Several (more than 3) years of research are needed for raising the performance of organic transistors and the complexity of circuits based on these transistors and their interconnections with sensors to a suitable level for applications. Thin-film oxide transistors, also solution processable, are providing interesting application perspectives.

- **Production pilots**: OSRAM (Regensburg), Philips (Aachen), Plastic Logic and Heliatek (Dresden) have recently made significant investments (in the order of tens to hundreds of million Euros) for manufacturing plants of OLEDs,

\(^2\) According IDTechEx Europe has 1050 organisations versus 975 organisations in North America and 825 organisations in East Asia involved in OLAE. Many large companies are involved in East Asia, many start-ups are involved in North America and Europe has many large and small companies involved, but few start-ups.

\(^3\) Plastic Logic is now supplying to OEMs fully industrialised plastic OTFT backplane technology consisting of a few millions of transistors.
electronic paper displays and OPV solar cells. Others are already manufacturing Flexible Printed Circuits and membrane switches, meanwhile integrating new printed functionalities. Several leading research centres in the OLAE domain have a pilot production line and are attracting customers to build further excellence in certain applications.
2. Building blocks of a European Research & Innovation strategy in OLAE

A European strategy is required in OLAE in order to enable the emergence and wide market deployment of this disruptive technology, with Europe taking a leading market position. The strategy should build along two major axes: (i) accelerate the innovation capacity of the European OLAE industry (in particular SMEs) as well as the route to industrial manufacturing of OLAE products; and (ii) further develop advanced OLAE technologies, notably the increase of the device performance and complexity and the move to smart interactive systems.

The strategy should build on the main strengths of Europe: leadership in materials and production equipment and world leading research centres with strong clusters and pilot production lines (see the SWOT analysis in the appendix).

It should involve a broad range of stakeholders including industry, research & academia, end-users, regional and national clusters and public authorities. It should be based on an excellent cooperation of these stakeholders along the research and innovation value chain, from materials through equipment and devices, to manufacturing and to products and services, and from advanced RTD to pilot lines and to the market.

The strategy could be based on the following three development axes:

1) Getting more application-driven and providing solutions to end-users;

2) Accelerating and improving success along the route to manufacturing (process robustness improvement enabling transfer from lab to fab) with the aim of extending existing or creating new manufacturing sites in Europe; and

3) Increasing the device performance of components and the level of integration and complexity towards systems.

These three axes are further presented below.

2.1. Getting more application-driven and providing solutions to end-users

There is a high market potential of standalone systems in many application domains and niches and this creates in particular a lot of opportunities for start-ups and SMEs. Customised solutions to end-users can be offered when hybrid integration is available allowing combining conventional microelectronics with OLAE components and devices. As this market by its nature is fragmented, grouping such customised solutions for certain applications on one manufacturing platform will create critical volume\(^4\). However, SMEs need on the one hand to work closely together with product developers to help them design and create new products and on the other hand, to have easy access to the technology, with the necessary support (see point 4 below, under research and innovation).

New solutions based on concrete business cases may emerge by combining different approaches and implementations: combining and interfacing different design and life styles, different components, different technologies and different manufacturing

\(^4\) Adopting a hybrid integration strategy and opening up many niche markets is better for Europe, than directly targeting high volume applications like OLED displays and competing head-to-head with East Asia.
processes or adapting production capabilities. Such solutions could be prototyped and/or produced in small quantities by either using existing pilot OLAE manufacturing capabilities or by integrating wide area electronics into existing (microelectronics and printing) production lines.

Developing such innovative solutions requires bringing together the different stakeholders along the value chain. Adequate collaboration mechanisms are essential here to put in place, such as open innovation, complemented with financing of feasibility studies, trials and demonstration actions. For example, smart windows (with controlled transparency), large area sensors and Building Integrated Photovoltaics (BIPV) will bring stakeholders from the building, automotive, train and aeronautics industry together with OLED lighting and OPV companies\(^5\) and flexible/printed circuits industries (like APEM, Bosch, IEE, Plastic Electronic, PolyIC, Pragmatic Printing, ST Microelectronics, Wurth...). Brand owners in cosmetics and in the pharmaceutical/food industry (like L’Oréal, Nestlé, Unilever) need to be made aware of existing OLAE product possibilities so that they can enter into joint innovation with the paper and plastic manufacturers to enable “smart packaging”. Such demonstration actions can also elucidate the areas where standardisation or regulation would be needed. Furthermore, innovation in this area can be accelerated by pre-commercial procurement.

2.2. From lab to fab

The aim is to extend existing or establish new industry-driven open-access pilot production facilities, in which industry and research institutes jointly develop innovative (sheet-to-sheet and/or roll-to-roll) production platforms, targeting certain (families of) applications relevant to societal challenges and economic needs. The creation of such pilot manufacturing platforms is addressing the “valley of death” by bridging the gap between research prototypes and industrial production, ultimately leading to higher volume for cost-effective production. Pilot production lines, currently installed at research centres, and regional clusters are instrumental for the lab to fab route.

The main goals for pilot production lines in OLAE are:

- Bringing together actors along the value chain so that they can define key performance production parameters, run experiments to further improve manufacturing processes (e.g., tolerances, production stability, yield, reliability, etc.) or explore the design and development of new manufacturing processes;
- Defining widely-accepted standard manufacturing process methodologies for a broad range of applications of OLAE;
- Stimulating use of and cooperation amongst pilot lines, from supply (technology push) but also from application (market pull), to generate business cases of OLAE and to create business eco-systems along the value chain.

OLAE has the potential of cost efficient manufacturing. Cost will be decisive when replacing or improving existing products, in particular those in cost sensitive consumer markets. Significant further markets for OLAE will come from disruptive

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\(^5\) The bowling pin strategy as explained in the book "Crossing the Chasm" of Geoffrey Moore has been applied here. Hitting the front pin in bowling can lead to a strike. Therefore it is important to choose well the front market with leverage potential towards neighbour markets. Examples are smart windows (with OLED lighting) and BIPV (with OPV).
innovations not feasible with existing technologies. Such innovations will therefore be less cost sensitive. These disruptive applications enabled by OLAE (in cases when large area and flexibility do not only provide manufacturing advantages but also end-user benefits) are best addressed as a priority to launch first industrial products. In the long term, cost will further reduce as volume goes up, allowing to address more cost sensitive markets. Note that the smart packaging market is more cost sensitive than the medical market.

2.3. Increasing performance, integration and complexity
Research advances are needed at device level to have more efficient and stable materials, better lifetimes, higher mobility and conductivity, more uniformity and better encapsulation. Increasing the level of integration and complexity and going towards more application-driven systems will be addressed with hybrid integration platforms as explained before.

Fully printable autonomous devices can be expected by 2020. The autonomous devices offered earlier will not be fully printed, but will combine different manufacturing steps (from vacuum deposition to printing under ambient temperature conditions). Several core functionalities must be integrated in such devices: batteries/photovoltaics, sensors/input, computing and control, displays/output and other interfaces. The necessary support (like libraries, simulation and layout tools) for designing such hybrid devices is presently not available and more research is needed to manufacture such devices. Roll-to-roll manufacturing processes have the greatest potential for low cost at mass quantities, while sheet-to-sheet processes could be more suitable for moderate to large volumes and for customised products.
3. Research and Innovation in Horizon 2020
To ensure industrial leadership in OLAE in Horizon 2020, the following measures are being considered:

i. **Roadmap based research on OLAE technologies:** roadmap based research will be undertaken to drive technological development and innovation in strategic areas where Europe is strong and is able to further lead the strategic area. The aim is maintaining Europe's leadership in OLAE research and technology. Input is coming from the Photonics21 and OE-A stakeholders, in close cooperation with other related communities. Focus will be on key areas like OLED lighting, OPV, organic and oxide transistors and hybrid integration with other functionalities (chips, sensors, actuators, energy) on flexible substrates. Also research actions on CAD tool development and standardization of design styles/rules will be needed, as well as design for recyclability.

Strategic application areas include healthcare, lighting, advertisement, paper, building, aerospace, automotive and sensing. Healthcare, user interfaces and building could be the first ones to address as they can help to build the ecosystem around. Expanding from healthcare into food safety & security and well-being can be done in a later step, as these markets will be more cost sensitive.

ii. **OLAE manufacturing platforms** aimed at (i) getting more application-driven and providing innovative solutions to end-users; and (ii) accelerating the route from "lab to fab" for crossing the valley of death.

One focus of support should be to use existing pilot production facilities, in which industry, in particular SMEs, together with research institutes, system integrators and end-user companies can jointly design and develop innovative products and production processes driven by concrete business cases. Strong focus should be given on projects to increase process manufacturing readiness levels to support technology transfer and industrialization. This type of research, dedicated to continuous improvement of parameters such as performance, reliability, manufacturability and cost, has been undervalued in Europe and in its framework programs, favouring research aimed at ‘invention’. A change of approach is needed here.

A second focus should be to promote further integration of OLAE technologies with existing microelectronics infrastructures, and/or support the creation of new OLAE manufacturing sites in Europe. What is at stake here is the ability to test and run enough experiments of manufacturing processes to prepare their industrial up-scaling at TRL levels 7 or higher.

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6 See the Photonics21 Strategic Multiannual Roadmap (strategic research and innovation agenda) developed for Horizon 2020 - [http://www.photonics21.org/](http://www.photonics21.org/)

7 OLED displays are not directly focussed on, because OLED displays are mainly manufactured in East Asia and Europe would need to catch up in this area to become a leader. However some research on OLED displays could be included provided the research focus is on integration with OLED lighting, OPV or other parts of a standalone system or the research focus is clearly differentiated from the main display market (such as OLED micro-displays).

8 Note that the bowling pin strategy is again applied here.
Currently each pilot line customizes its technical options, prohibiting economies of scale. Research is needed to define and select suitable manufacturing options with the right balance between performance and volume. A set of manufacturing platforms suitable for a family of applications needs to be defined and developed. The establishment of a number of manufacturing platforms will also help overall as more companies (and especially SMEs) will be able to adopt OLAE, commercialise it and compete globally.

iii. Demonstration actions: Pilot production and demonstration of the feasibility and performance of advanced OLAE products in a number of large area applications. Examples include: smart windows and other smart surfaces with OLED lighting and OPV that would help create an eco-system around the value chain with the glass, building or automotive industry; large area colour reflective panels for the advertisement industry; large area sensor diagnostics and their interfaces for health monitoring and ambient intelligence applications.

iv. Access to technology and actions for innovative SMEs: A large proportion of innovations with OLAE comes or will come from SMEs. These however often lack risk money to commercialise the research.

One focus of support should be access to finance for SMEs to better attract sufficient capital and management support for seeding and growing innovative business ideas.

Another focus should be access to technology providing feasibility and prototype development, in particular for innovative SMEs. Europe has world-class research institutes that could provide SMEs access to best expertise and technology specialists. They can offer dedicated solutions, access to the latest cutting-edge technologies, a complete one-stop-shop solution with supply chain ‘from material to systems’, and access to small scale pilot manufacturing. An example of such an action is the FP7 project ‘COLAE’.

v. Collaboration among and with innovation clusters in OLAE: Developing clusters further and with their respective regional industry and public authorities and stimulating inter-cluster collaboration activities will help further alignment of priorities enabling smart specialization and growth in European regions. The existing Europractice initiative could be used as a model to create a Europractice dedicated to Flexible Electronics (or Systems On Foil).

vi. Inducement prizes: Inducement prizes are quite effective in advancing the technology and can mobilize resources far above the prize value itself. Such prizes could be used to for instance produce for a targeted application (e.g. health monitoring) a multifunctional device on a plastic flexible substrate incorporating printed sensors, printed battery or OPV, display, computing processor and memory.

vii. Forster the involvement of new industrial actors to adopt OLAE solutions and further networking, outreach, training and education: networking of OLAE

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9 The suitable manufacturing options should be made in function of the material and application. For example the suitable options for automotive, medical and hand held consumer devices will likely be different.

10 Pre-competitive procurement actions could also be considered when the technology is mature enough.
stakeholders and other relevant communities (e.g., electronics but also industrial or professional users) to reinforce the value chain and to define key performance parameters in production processes; standardisation activities; "OLAE and people" (outreach actions for promoting OLAE to young people, entrepreneurs and the general public); and, promoting further skills development, training and education, given that OLAE is highly interdisciplinary.

4. Impact

In 2011, OLAE already was a €2 billion business sector, with high growth potential in key market areas (e.g. displays, lighting, photovoltaics, medical, automotive, etc.). However, European industry is facing fierce competition from other regions of the world, in particular from East Asia (already dominating the OLED displays industry and now strongly investing in flexible printed circuits), where substantial financial resources are being invested.

OLAE is able to contribute to addressing several grand societal challenges identified by the Europe 2020 strategy: climate action, resources efficiency and raw materials (by renewable energy with OPV, energy savings in buildings with OLED lighting, resource efficiency with additive manufacturing and use of less scarce and more disposable materials), smart, green and integrated transport (by lighter weight components and systems), health, demographic change and wellbeing (by comfortable, unobtrusive health monitoring devices allowing elderly to live at home longer and allowing earlier release of patients from hospitals) and food security, sustainable agriculture, marine and maritime research and the bio-economy (by widely applicable low-cost but advanced detection and more sophisticated surveillance technology).

Overall, the potential impact that OLAE can make covers many application sectors.
5. Monitoring

Manufacturing has to be matched with sufficiently mature applications. The impact on industrial leadership and the market share of each OLAE electronics sector will be measured (by growth potential and by the European market share of each sector). Also the structuring (with extension towards end-users) and networking of the community will be monitored. Indicators are the participation across the value chain, the involvement of new actors and the degree of consultation within the stakeholder group for OLAE.

A measure for the research excellence is the number of peer-reviewed research papers published of advanced or new OLAE devices and their manufacturing technologies. The number of registered patents and licenses as well as the number of start-up and spin-off companies created, the number of OLAE-based products launched by existing industry, the size of capital investments and the additional jobs (in existing or new firms) that are created will be measures for the impact of OLAE.
### OLAE SWOT Analysis

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<th><strong>STRENGTHS</strong></th>
<th><strong>WEAKNESSES</strong></th>
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<tr>
<td>S1 Technology leadership in materials, printing technology and production equipment</td>
<td>W1 Fragmented and uncoordinated development strategy, particularly for development along the value chain</td>
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<td>S2 State-of-the-art research on OPV, OLED, smart systems and sensors, etc.</td>
<td>W2 Lack of demonstration and commercialization actions to accelerate transfer from lab to market</td>
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<tr>
<td>S3 World leading R&amp;D activities in major EU countries: DE, UK, FR, NL, SE, FI.</td>
<td>W3 Lack of standards</td>
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<td>S4 Disruptive technology with wide range of potential and disruptive applications</td>
<td>W4 Lack of risk taking in Europe (low number of start-ups &amp; Entrepreneurs)</td>
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<tr>
<td>S5 Strong clusters around leading research centres with pre-industrial technology platforms</td>
<td>W5 Lack of dedicated interdisciplinary training</td>
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<td>S6 Pilot manufacturing plants for OLED, OTFT and OPV</td>
<td>W6 More technology push than market pull</td>
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<td>W7 Lack of public support for research dedicated to increase process Manufacturing Readiness Level.</td>
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<td>W9 Lack of involvement of classical electronics and industrial integrators</td>
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<tr>
<th><strong>OPPORTUNITIES</strong></th>
<th><strong>THREATS</strong></th>
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<tr>
<td>O1 Many opportunities for spin-offs and growth of SMEs</td>
<td>T1 Off-shore manufacture (PVs and Displays are manufactured predominantly in East Asia)</td>
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<tr>
<td>O2 Pilot manufacturing lines and regional clusters in Europe available to accelerate take-up &amp; innovation by end-users</td>
<td>T2 Increasing competition, especially from Asia</td>
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<td>O3 Emerging markets with application fields growing, in particular in niche and fragmented markets with SMEs</td>
<td>T3 Massive investments to improve competitiveness</td>
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<tr>
<td>O4 Demands for greener technology and carbon neutral energy generation (building industry, automotive)</td>
<td>T4 Lack of Venture Funds and Bank Loans to support Innovation-To-Market process.</td>
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<tr>
<td>O5 Cross fertilisation with materials, photonics, nano-electronics and manufacturing</td>
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