Project acronym	**PolyNet**
Project full title	*NoE PolyNet - Network of Excellence for the Exploitation of Organic and Large Area Electronics*
Grant Agreement no.	FP7 GA 214006

White Paper on PolyNet Critical Research Issues

Responsible for this whitepaper	Isak Engquist / isak.engquist@itn.liu.se / Linköping University
Version	1.1

Introduction

One of the main objectives of the NoE PolyNet is to network European research resources to enable high quality collaborative research within the field of organic and large-area electronics. To aid in achieving this, one of the tasks of PolyNet is to find critical research issues as a base for research cooperations within the field of OLAE. This should help bringing the community forward towards successful products.

Within PolyNet, critical research issues (CRIs) are defined as follows:

> *Critical Research Issues are research topics that are of importance and benefit to the European OLAE research community, and/or the European industry, not only to your own organisation. The CRI should address a high priority knowledge gap towards industrial use of organic and large area electronics.*

The CRIs reflect the collective view of the NoE PolyNet on where research efforts are in demand in order to strengthen the European position in the field of OLAE. Thus, in addition to the internal purpose of the CRIs, we expect there to be a general interest in these issues.

CRI selection process

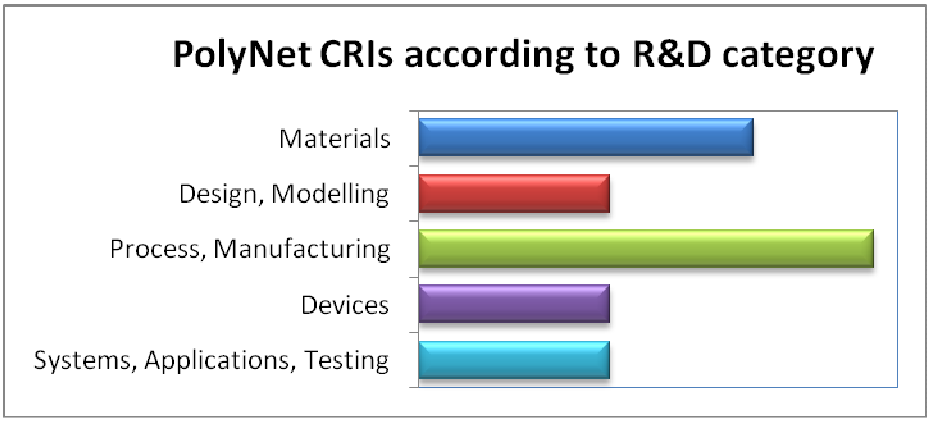
All 16 research partners in PolyNet have submitted their suggestions for CRIs, according to the definition in the previous section. A variety of information sources were used as input to find possible CRI candidates, including previous PolyNet work on CRIs and on gaps in knowledge and expertise, OE-A reports, industrial service needs, and each partners own areas of expertise. The resulting list was processed to remove duplicates and to rephrase near-duplicates into a common wording. This resulted in a list of totally 41 candidates.

Using a web-based voting tool, all PolyNet partners classified the CRI candidates as “very important”, “important”, “not so important”, or “unimportant”. Numerical averages were calculated, resulting in a ranked CRI list. Almost all candidates were ranked above average (with “average” taken to be between “not so important” and “important”), which is not surprising considering that all issues were initially suggested because of their importance.

The detailed order of the ranked list is of course of less importance, given the close separation in rank between neighbouring issues. Still, it can generally be said that if a CRI has received a high position in the ranking, it is considered by the PolyNet members to be of higher priority than the issues at the bottom of the list.

CRIs in PolyNet

The CRIs can be categorized into the five R&D categories that are used within PolyNet, resulting in the distribution seen below. As seen in the figure, the CRIs span all the 5 R&D categories, with some preference towards issues related to materials and processing.



Further analysis of the CRIs reveals that they can be grouped into six subject areas, based upon the R&D categories but also taking into account the actual subjects addressed by the individual CRIs. These subject areas are given below, together with the related CRIs. The CRIs have been sorted according to the ranking procedure, so that the highest ranking CRI for each subject area is placed at the top, and so on in relative order of importance.

New or improved materials

- Encapsulation / passivation materials
- New high-conductivity materials – printable and air-stable
- New high-mobility semiconductor materials – printable, air-stable, especially n-type
- Materials with multiple functionalities
- Semiconductor materials with self-organisation ability
- New high-k dielectric materials with good compatibility towards other materials
- Cost-optimised substrates with adequate smoothness and purity for the application
- New materials for OLEDs, e.g. organometallic fluorophores

Materials properties and understanding

- Better comprehension on the mechanism of charge injection
- Physical modelling of organic transistors and diodes
- Extensive materials characterisation
- Standardisation of measurement methods for device characterisation
- Role of long-range ordering in organic semiconductors

New or improved components

- Organic photovoltaics with increased lifetime and improved efficiency
- Improved charge injection in organic transistors
- Low drive voltage in organic transistors
- Non-volatile organic memory
- UHF rectifiers

Circuits and design

- Integration and interconnection of components towards systems on flexible substrates
- Circuit design and materials selection aiming to minimise the number of materials and layers needed for production
- Robust circuit design for complex circuits
- Design kits for enterprises
- Standardisation of interfaces
- Adaption of signal levels and impedances between different components in a device

Printing and R2R fabrication

- In-line testing and quality control
- R2R UV-Nanoimprint Lithography
- Improvement of printing resolution, precision and registration accuracy
- Semiconductor ink formulations for printing on hydrophilic surfaces
- Semiconductor ink formulations for inkjet printing
- Improved range of electrode deposition methods and geometries (e.g. buried electrodes)
- Improved materials, design and processes for UV and thermal imprinting

Other manufacturing

- Cost efficient production methods for organic photovoltaics
- Integration of environmental compatibility issues into manufacturing of organic electronics
- Organic sensor packaging processes
- Manufacturing in neutral atmosphere
- Chip mounting on flexible substrates
- Manufacturing methods for printed Li-based batteries
- Design and process integration of post-production treatments

A few observations concerning these lists:

- There is demand for many types of improved materials.
- Many high-ranked issues are related to production of circuits and devices, emphasizing the fact that the OLAE field is becoming more mature, but also that there are still hurdles to overcome in many cases before mass production can be started.
- There is still a need for more knowledge and improved understanding of materials and components.
- Environmental compatibility has been ranked as important and should be considered already at the R&D stage.

Comparison with similar initiatives

Several reports exist that address the questions of R&D strategies within the field of OLAE. Here, we will compare the PolyNet CRIs with two other recent initiatives – the OE-A roadmap and the Strategic Research Agenda prepared within the Opera project.

OE-A Roadmap

The 3rd edition of the Organic Electronics Association (OE-A) brochure was released in June 2009 and contains the OE-A roadmap for organic and printed electronics. In the technology section of this report, there is a section on challenges and so called red brick walls – challenges that can only be overcome by major breakthroughs. In the table below, the red brick walls are compared to the PolyNet CRIs.

OE-A red brick wall	Corresponding PolyNet CRI
patterning resolution (<10 µm)	R2R UV-Nanoimprint Lithography Improvement of printing resolution, precision and registration accuracy
patterning registration (<resolution)	Improvement of printing resolution, precision and registration accuracy
patterning process stability	Improvement of printing resolution, precision and registration accuracy
mobility of semiconductors (>1 cm^2/Vs, better 5-10 cm^2/Vs)	New high-mobility semiconductor materials – printable, air-stable, especially n-type
high quality semiconductors, both p- and n-type	New high-mobility semiconductor materials – printable, air-stable, especially n-type
electrical conductivity of conductors	New high-conductivity materials – printable and air-stable
circuit design for CMOS and for low supply voltages	Robust circuit design for complex circuits
high speed in-line measurement and electrical testing	In-line testing and quality control

Clearly, the issues addressed in the OE-A red brick walls were also considered to be important by the PolyNet partners. All of the 8 red brick walls are matched by CRIs that essentially give the same message.

Strategic Research Agenda

The Strategic Research Agenda (SRA) for organic and large area electronics was made public in September 2009 as a joint effort between the Opera (Organic/Plastic Electronics Research Alliance) project, Photonics 21, OE-A (Organic Electronics Association) and EPoSS (European Technology Platform on Smart System Integration).

In the SRA, detailed research agendas are given for 5 different OLAE topics, divided into short-, medium-, and long-term efforts. The topics are:

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

For each topic, detailed research topics and technical objectives are given. The table below gives the results of a comparison between the short term objectives (for the years 2011-2013) and the PolyNet CRIs.

SRA topic	Correspondence to PolyNet CRIs
Lighting	Lighting, in particular OLED lighting which is the main focus in the SRA, is not heavily represented in the CRIs. The correspondence is limited to encapsulation materials and new materials for OLEDs. Most of the objectives in the SRA are focusing on OLED performance improvements, and for that reason may have been viewed more as industrial development by the PolyNet members that made the selection of CRI candidates.
Organic Photovoltaics	Some of the materials- and production-related SRA objectives for OPV are represented in the CRIs: Improved OPV materials, better electrodes, encapsulation, and optimized production. In the CRIs, issues are usually formulated in a general way (e.g. "new high-conductivity materials") and as a result, those SRA objectives that are very specific for OPV (e.g. infra-red absorbers or transparent ITO replacement materials) do not correspond to any specific CRIs.
Displays	Two of the short term SRA objectives for displays, conformable substrates and inline process monitoring/control, have counterparts in the PolyNet CRIs. The other objectives are more directly concerned with display backplanes and frontplanes, which are not covered by the PolyNet CRIs.
Electronics	There are 12 short term research topics for electronics in the SRA. For 9 of them, there are CRIs that cover the same subject. This is a close match, and reflects the fact that "electronics" in the SRA covers many materials-related topics, especially such that concern transistors and transistor circuits.
Integrated Smart Systems	The short term objectives for ISS are held rather general and it is no surprise that they are well matched – 4 out of 5 – by the PolyNet CRIs. Briefly, there are matches for enhanced materials, component integration, process control and system modelling. The SRA also provides a breakdown into research objectives for a range of specific devices, which is too specific to have any matches in the list of CRIs.

In summary, there is a large overlap between the PolyNet CRIs and two of the five SRA topics, namely Electronics and ISS (Integrated Smart Systems). In particular, many of the CRIs in the group New or improved materials are represented in the SRA. The other three SRA topics (Lighting, OPVs and Displays) are more application-specific, which is a probable reason for why they are less well represented by corresponding PolyNet CRIs. Many of the SRA objectives for these three topics are related to improvements in device performance, which is not really the same as the "high priority knowledge gaps" that are mentioned in the definition of the CRIs.

The OE-A red brick walls, on the other hand, are almost fully covered by the PolyNet CRIs. This is probably because the red brick walls, like the CRIs, are more general than application-specific.

Conclusions

The critical research issues defined within PolyNet give important hints about R&D areas where efforts are needed to bring the European OLAE research community and industry forward. The CRIs cover many topics, but has the largest representation in issues related to materials and process&manufacturing. Emphasis is more on basic materials and methods than on specific devices or applications, which follows naturally given the definition of the CRIs. There are many similarities between the CRIs and the OE-A "red brick walls", and also between the CRIs and the SRA from the Opera project. This adds credibility to all three initiatives, but also hints that there is valuable information where they *differ* from each other. As an example, the SRA has more details about research objectives for specific devices than the PolyNet CRIs.

It is our hope that these CRIs will be useful for the European OLAE research community as well as within PolyNet.