www.noe-flexnet.eu

FlexNet

White Paper on the definition of research priorities within the FlexNet consortium "Critical Research Issues"

by: The FlexNet Consortium,
Dario della Sala, Riccardo Miscioscia (ENEA)

The NoE FlexNet receives funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 247745.
For further information please visit: www.noe-flexnet.eu

SEVENTH FRAMEWORK PROGRAMME

INTRODUCTION

This report contains the description of the work done in the FLEXNET consortium to define the "critical research issues" in the field of materials, technologies, and applications for Organic Thin Film Transistors (OTFT), as defined by the Description of Work (DoW) of this Network of Excellence, which is funded by the EU's FP7 under Grant Agreement No. 247745.

The multi-stage process of definition of these issues involved all FLEXNET partners and also external stakeholders, over a span of 7 months, with a mix of bottom-up and top-down actions, resulting in the definition of 7 Critical Research Issues that will help to focus the collaborative research of the partners.

CRITICAL RESEARCH ISSUES – DEFINITIONS AND METHODS

The critical research issues (CRIs) are defined in this way in the DoW of the FlexNet project:

"…topics which will be important in the nearest future, concerning the materials for OTFTs and FOLAE systems and their characterisation and preparation, the devices fabrication and their integration into systems….."

CRIs should be rather broad topics, able to link many partners' capabilities and expertise, and able to generate practical collaborations between them.

In a large network like FLEXNET, which includes 17 partners committed to work on 9 technical task forces of the Project, it is not easy to match the need of comprehensive technical discussions, that are the basis of networking among experts, with the necessary convergence speed.

The method to obtain this goal is based on a two-fold input, from the consortium partners and from external stakeholders, arrranged in three phases (Fig. 1):

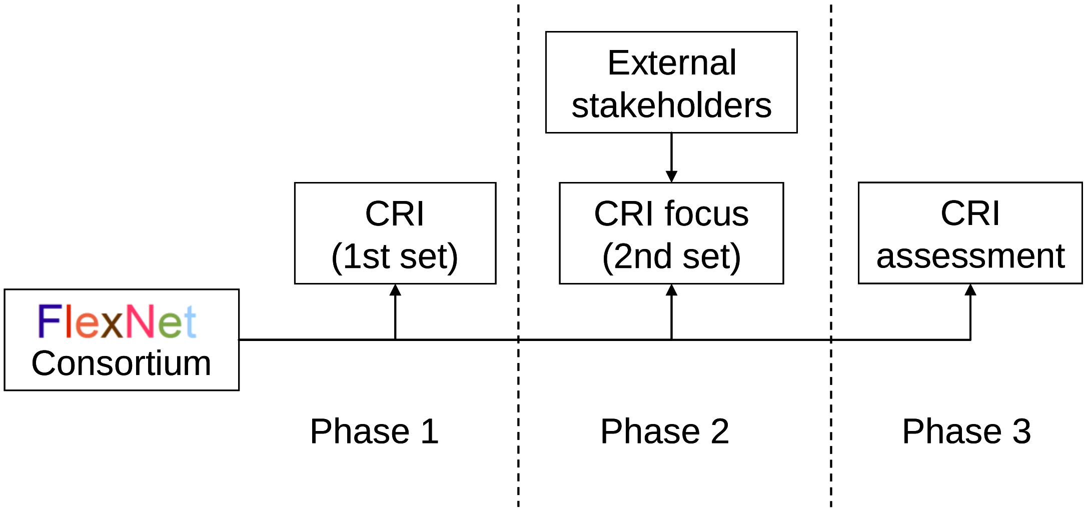

Fig. 1. Logic scheme of the process of CRI definition

In Phase 1, the first selection of CRI has been a completely "bottom-up" process.

In Phase 2, focussing of CRI has been done, and the results were tested with external stakeholders.

In Phase 3, CRI were assessed and accepted by the consortium, as prioritary themes to prompt collaboration work between partners

PHASE 1 –THE POLL ABOUT OPEN ISSUES IN THE FIELD OF OLAE

The collective work to obtain the first set of CRIs required the setup of an effective method of interaction during the first four months of the contract, when the standard interactions tools between the partners (project website, equipment database, mailing lists, …) were still being assembled.

As there are specific "technical work packages" to deal with collaborative work (Fig. 2), the coordinator of Work Package 1 – Critical Research Issues, has proposed the method to collect data to the partners involved in Work Packages 2 and 3.

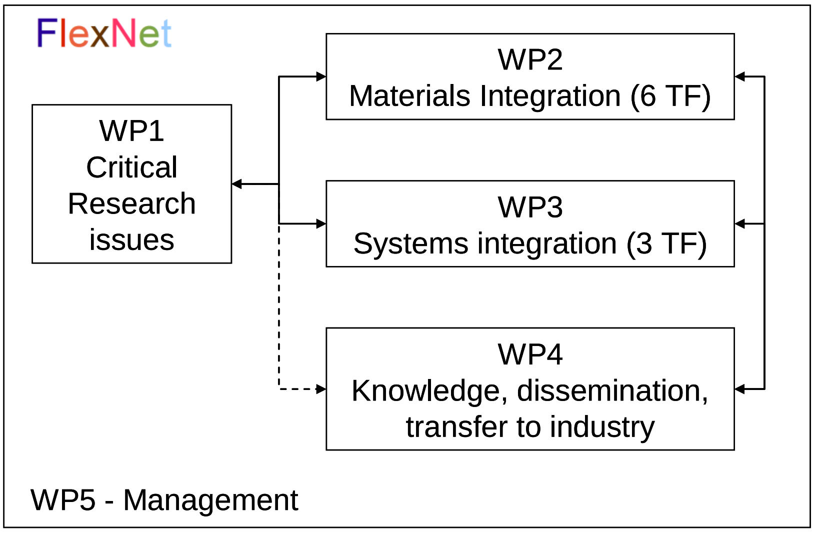

Fig. 2. The Work Packages in FLEXNET

The method was based on "scoreboards" (in Microsoft Excel format). They were provided with the necessary instructions for use:

- There is a scoreboard (SB) for each of the Task Forces (TFs) that make up the technical work packages WP2 and WP3; the contents of the preliminary version of the scoreboard are proposed by the coordinator of WP1
- The scoreboard consists of a square grid of items, base on a limited list of "open issues" (≤ 10), and a limited list of "relevant questions" (10). The partners will assign their votes to the most important couples of "open issues" and "relevant questions".
- The questions are the same for all Tasks, and based on relevant documents (e.g. the FLEXNET DoW, the Strategic Research Agenda of the OE-A) and are related to technology, strategy, and networking:

Relevant questions for the issue (technical, strategic)	Addressed before in publically funded (EU, nat., ...) Projects ?
	Solved by industrial R&D, solution publically not available?
	Will result accelerated development of optimized OTFT-performance?
	Will improve production yield?
	Potential for commercial exploitation ?
	Will decrease toxicity / improves recycling of the product (GreenTech, REACH) compatible ?
Relevant questions for the issue (Networking)	Appropriate technological facilities / critical mass among FlexNet partners ?
	Extension of the network to relevant SMEs?
	Impact on NW European industries ?
	Impact on SE European SMEs ?

- The “issues” are only of technical nature and are Task-specific.
- In conclusion, there are 9 different SBs, one for each of the 9 Tasks.
- Each group of partners working in a specific TF is allowed to update or improve the list of “open issues” proposed by the WP1 coordinator, in order to match them with their vision of the TF activities. The only constraint is to maintain the total number at about 10.
- Each partner of each TF receives the scoreboards of its Tasks. The TF leader is invited to manage the data collection and the discussions about CRI, among the partners of his TF
- Each partner has 20 votes available, that must be assigned in groups of 0, 2 , 4 only, to avoid a homogenous spreading of preference and to incentivise accurate selection of priorities
- All partners, before starting with the procedure, have been proposed to:
  - Read a few reference documents (“suggested readings”): OE-A Strategic Research Agenda; Organic and Large Area Electronics Project Portfolio – 6th and 7th R&D FPs – Jan 2008; White Paper on PolyNet Critical Research Issues.
  - Create a list of their competences / equipment on the project website, and read there what expertise the other partners can offer.
- For each TF, the “open issues” that will receive the highest number of votes from TF partners, will be selected as the “critical issues”.

After handing out the scoreboards in the first meeting of the project, in a span of two months:

- The data collection was completed at 100%.
- TF leaders provided 9/9 final scoreboards
- Partners sent 71/71 contributions requested by TF leaders

In spite of the fact that they were free to improve the list of issues with their partners, the TF leaders in most cases used the list of issues provided by the coordinator of WP1. In a few special cases, they decided to use a special approach:

- for TF2.1, a Task Force with very few partners, the poll was extended to the whole consortium.
- for TF2.5, a very “horizontal” Task Force, the list of issues has been greatly revised

In the figures 3 to 11 on the following pages, you can find the features and the results of the 9 polls that took place in parallel: the assessed open issues, the bar graph of the assigned votes, the vites as the percent value from the total.

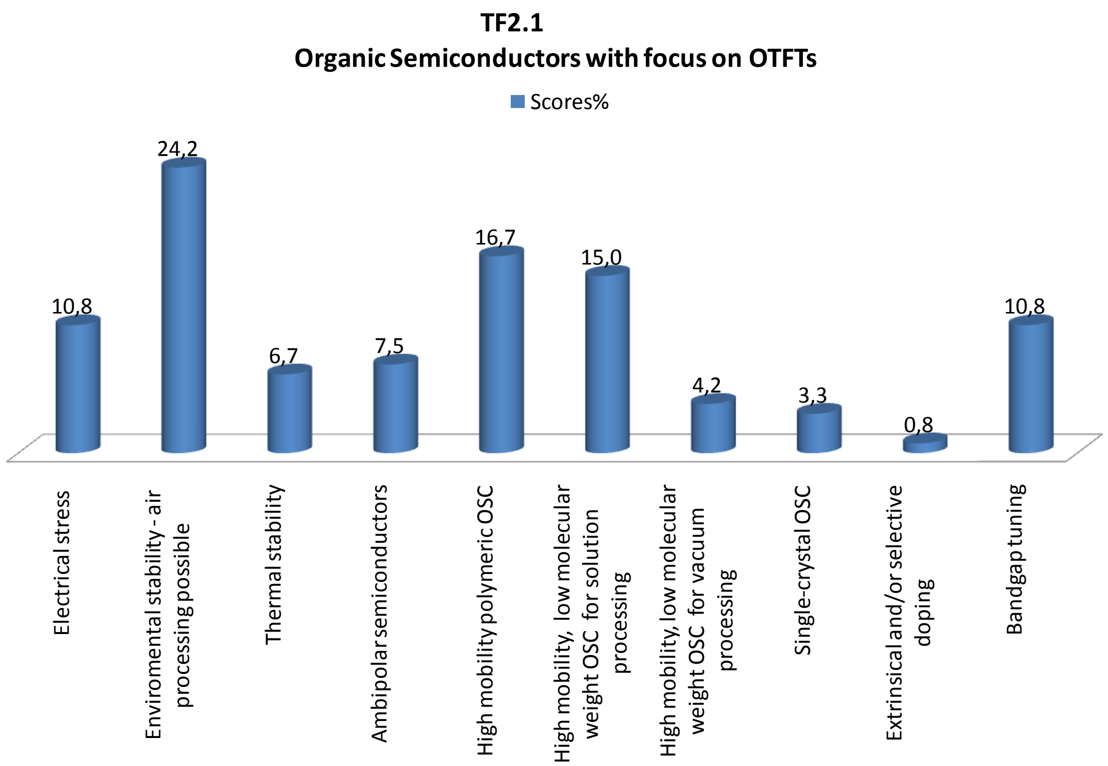

Fig. 3. Final scoreboard with issues and votes for Task Force 2.1

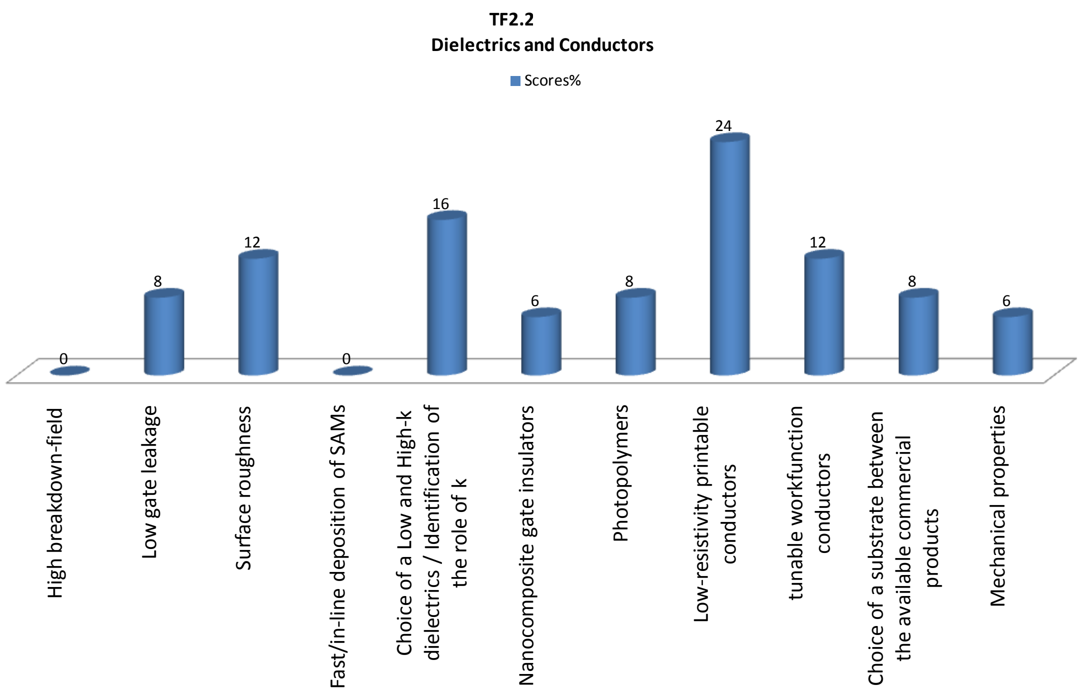

Fig. 4. Final scoreboard with issues and votes for Task Force 2.2

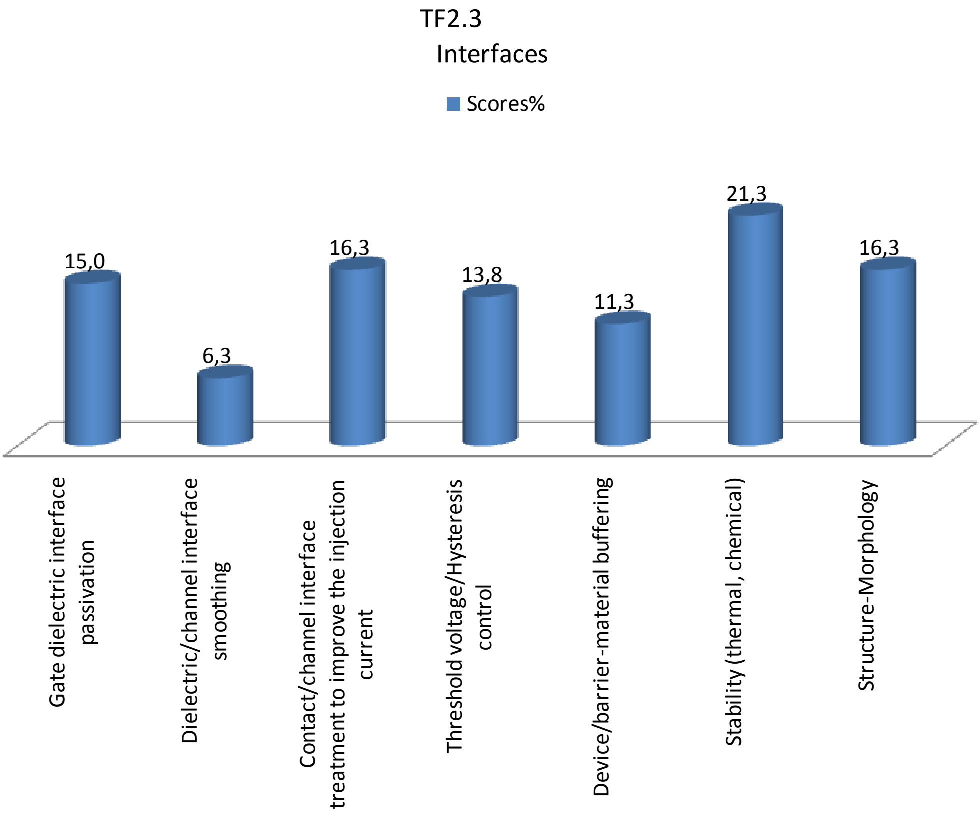

Fig. 5. Final scoreboard with issues and votes for Task Force 2.3

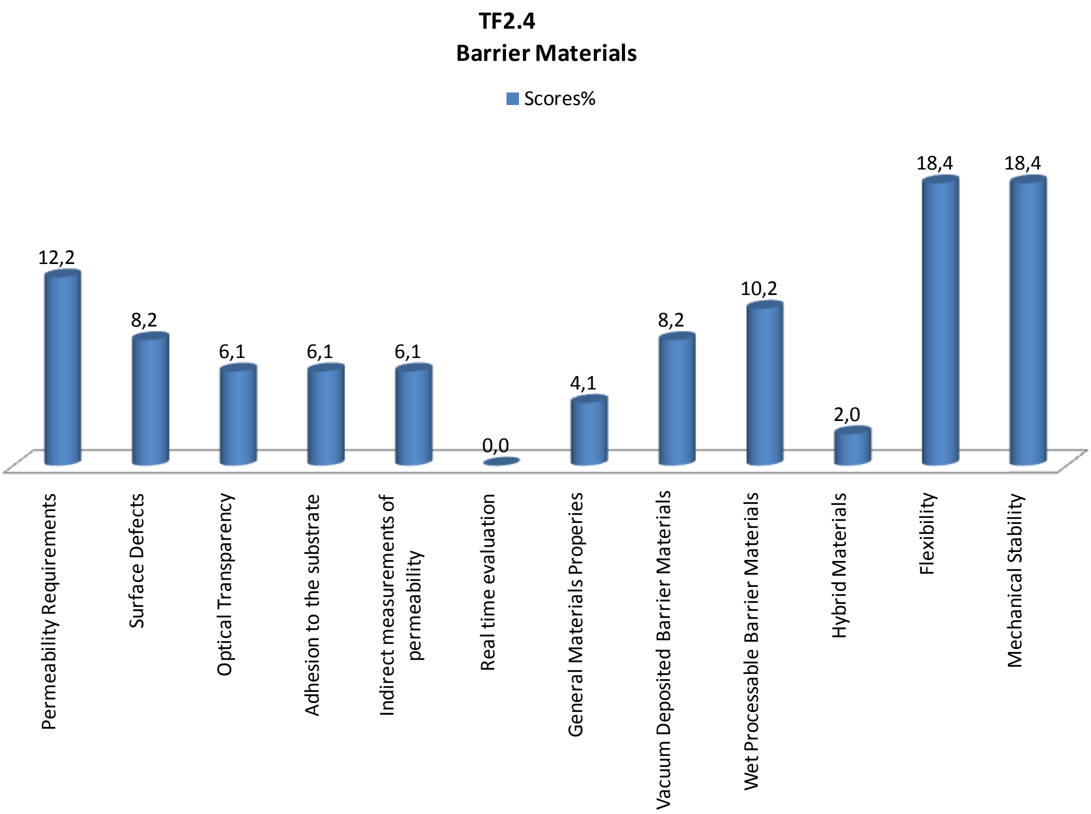

Fig. 6. Final scoreboard with issues and votes for Task Force 2.4

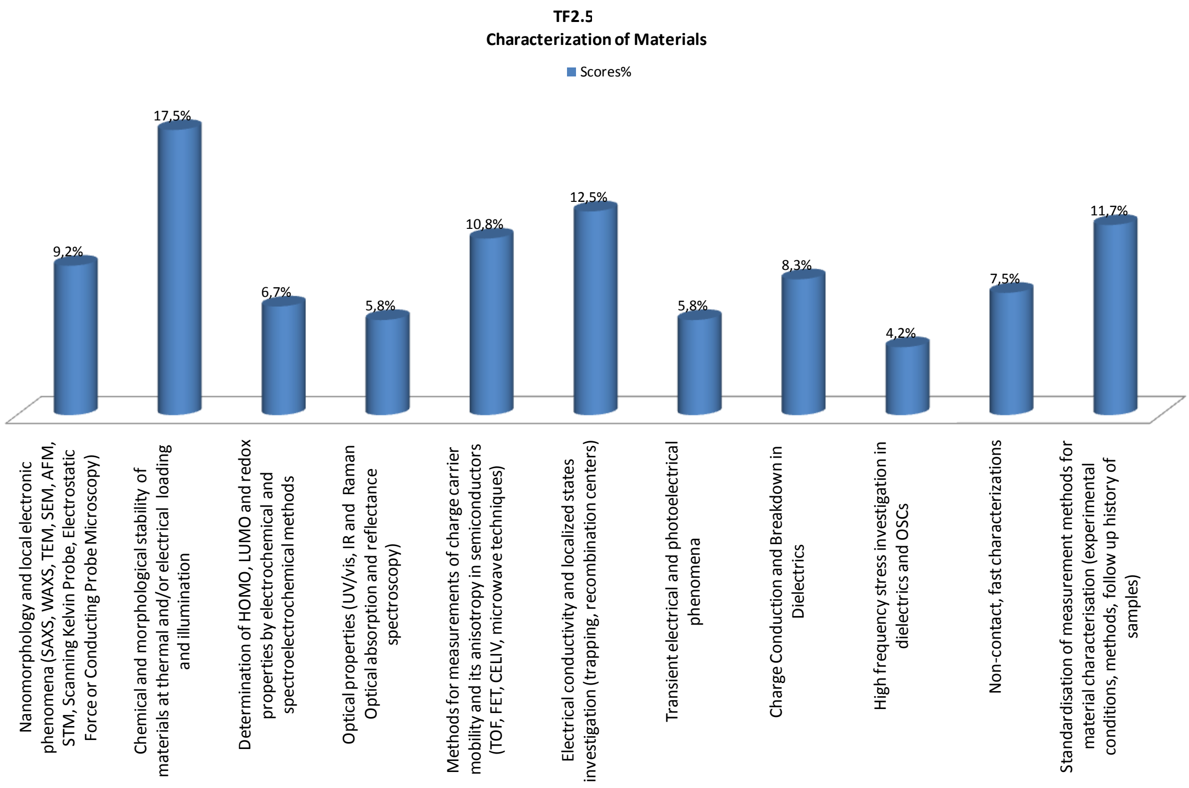

Fig. 7. Final scoreboard with issues and votes for Task Force 2.5

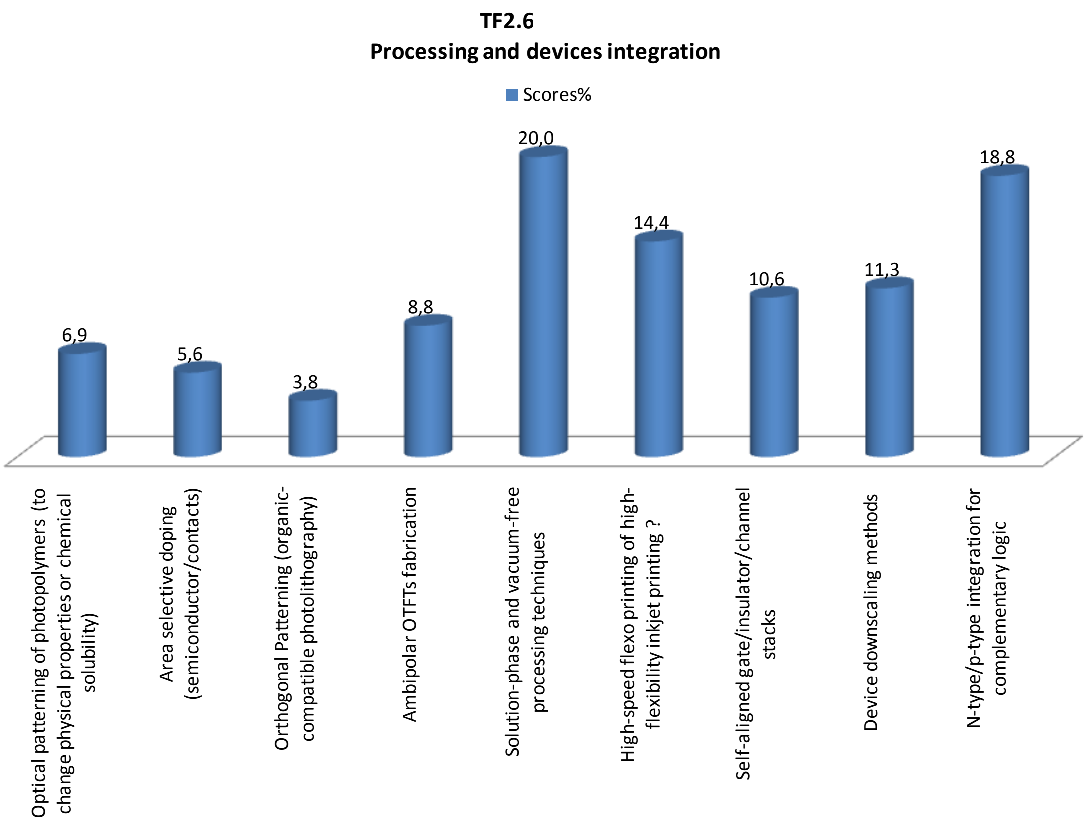

Fig. 8. Final scoreboard with issues and votes for Task Force 2.6

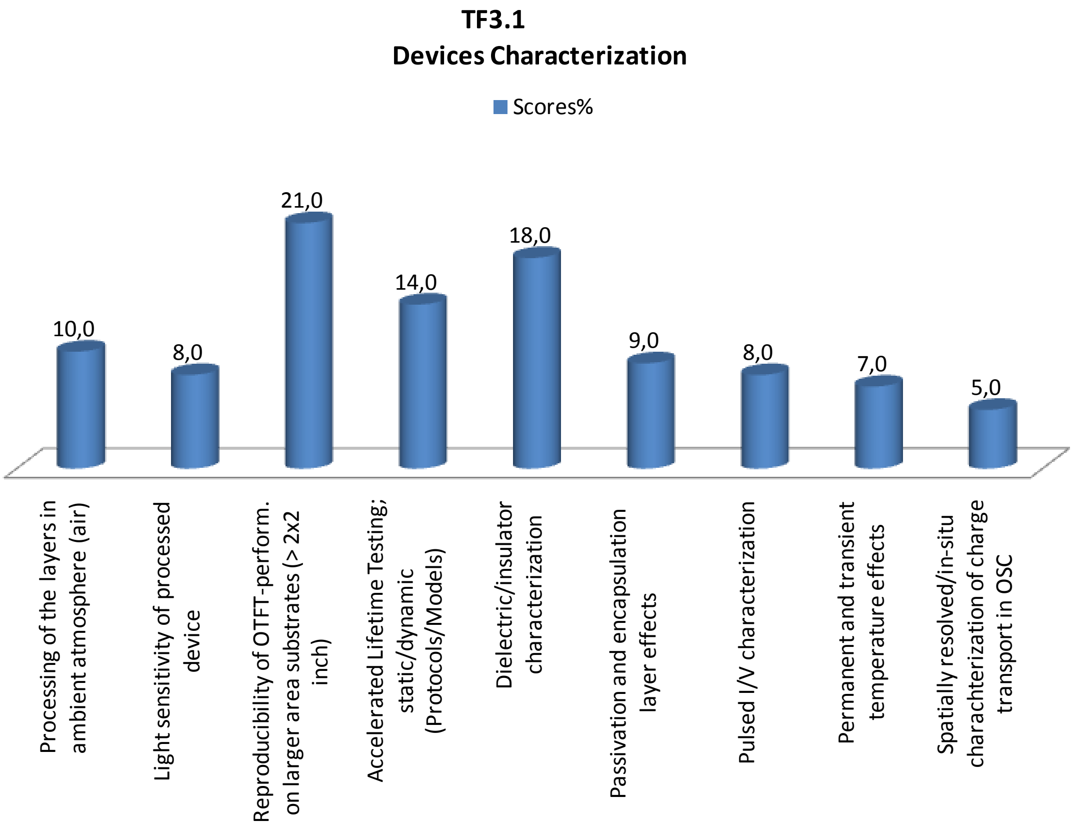

Fig. 9. Final scoreboard with issues and votes for Task Force 3.1

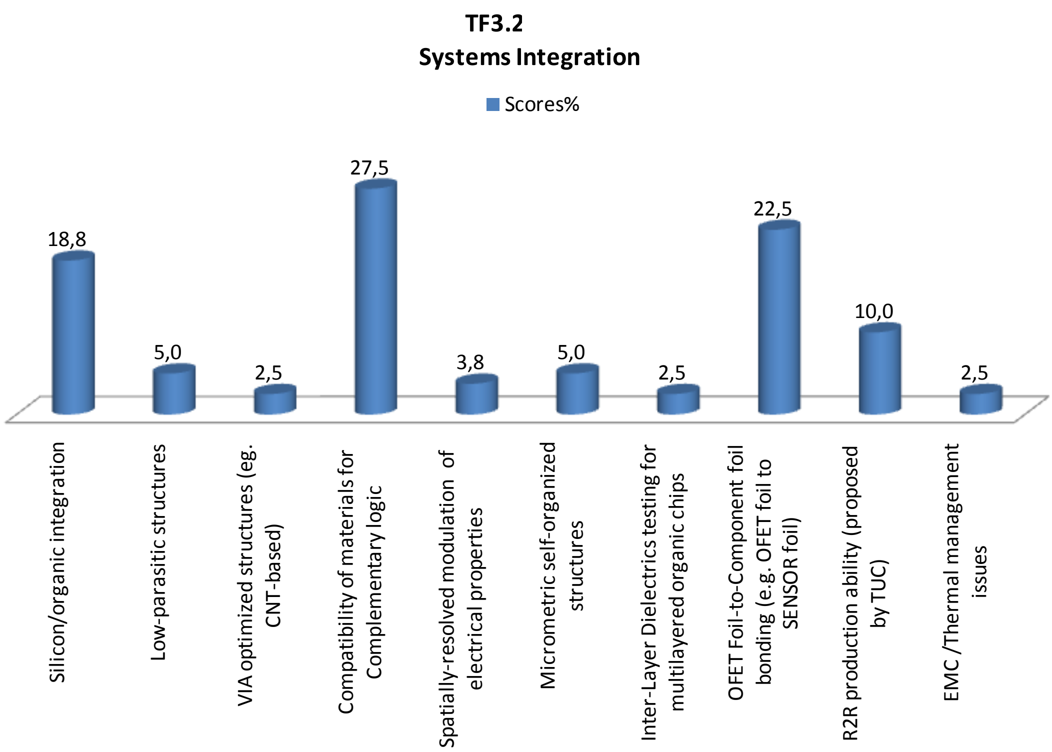

Fig. 10. Final scoreboard with issues and votes for Task Force 3.2

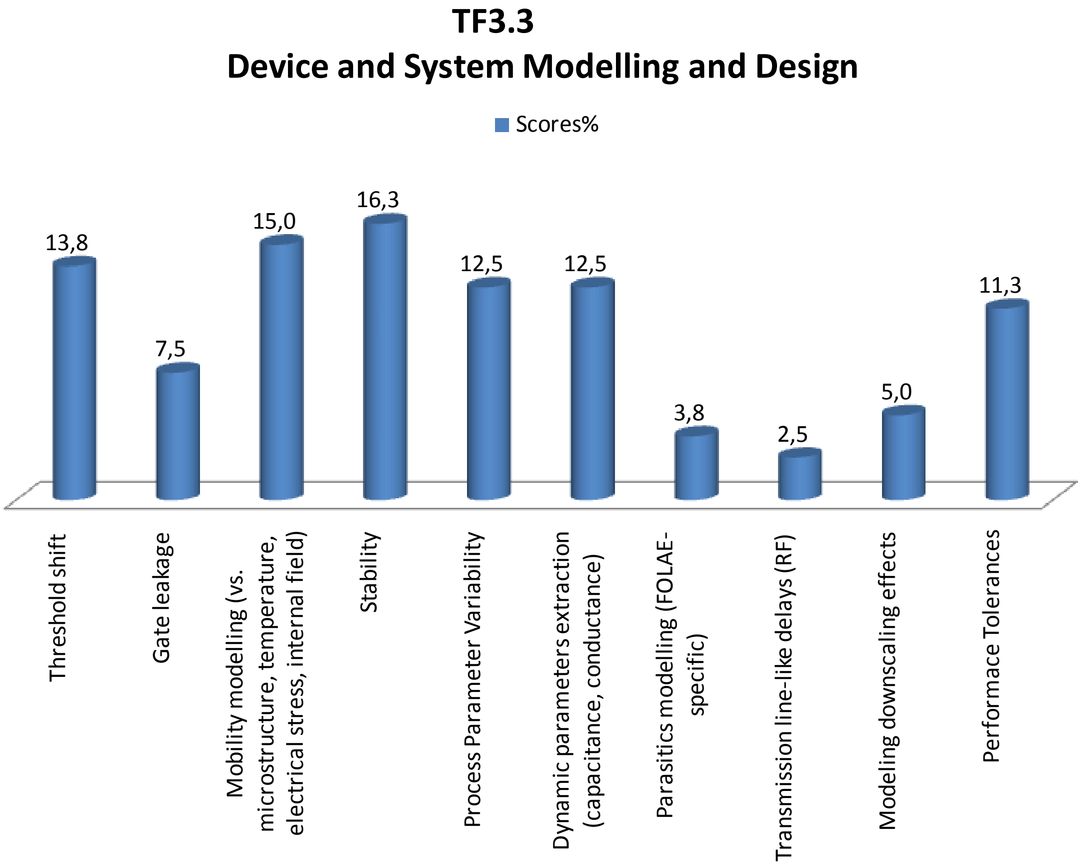

Fig. 11. Final scoreboard with issues and votes for Task Force 3.3

At first sight, we can realize that the procedure has been generally able to select a limited number of prioritary issues: in most of the TFs, few issues stand out from the arithmetical average value (that is about 10%). For all TFs, 2-3 CRIs emerged from the group, with more than 15% of the votes; there are also 6 CRIs with more than 20%.

The most homogeneous spreading of votes is for Tasks 2.3, 2.5, 3.3 (“Interfaces”, “characterization of materials”, “device and system modelling and design”). We feel that it depends intrinsically on the missions of the Tasks which are more “horizontal” than others.

Among the 89 questions that the TF leaders proposed to the partners, only 3 received 0 votes, and should be considered “wrong questions” (not well-defined enough or not important enough to draw considerable attention and votes from the partners).

PHASE 1 - ASSESSMENT AFTER THE POLL AND CHECK OF FEASIBILITY

The CRI should be managed in the consortium in terms of practical technical cooperations (called “subtasks”, see Fig. 12). Therefore, the selected CRI should be not only relevant (in the field of organic electronics), but also “feasible” for the consortium, meaning that the partners have real capabilities and equipment to work on them.

The step to define the technical cooperations from the CRIs required deep discussions about the details of the technical competences and facilities of the partners themselves. Such discussions have been coordinated by the leaders of the Work Packages 2 and 3 (Fig. 12), and took a considerable amount of time.

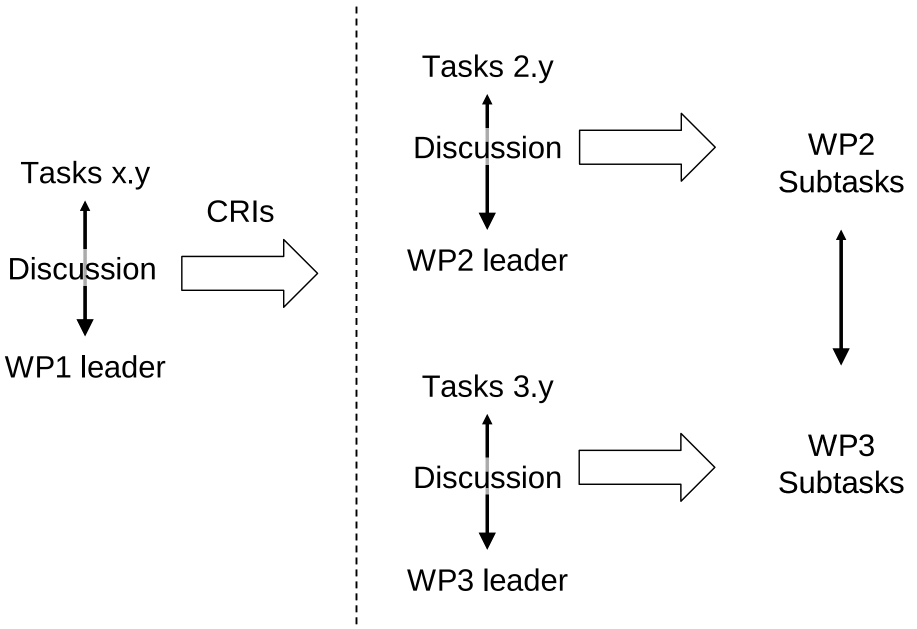

Fig. 12. Relationship between Critical Research Issues and technical cooperations (“subtasks”)

The discussions about feasibility involved the three leading CRIs in the rankings, and resulted in the final assessment as illustrated in the following Table 1.

TF	Topmost CRI in the SBs	Assessment result	Notes
2.1	Enviromental stability - air processing possible	C	Try to obtain materials processable in air
	High mobility polymeric OSC	C	Try to obtain high mobility polymeric materials
	High mobility, low molecular weight OSC for solution processing	C	Try to obtain high mobility soluble low molecular weight materials
2.2	Low-resistivity printable conductors	C	Innov. materials synthesis and printing experiments
	Choice of a Low and High-k dielectrics / Identification of the role of k	C	Start with: innovative materials; screening of comm. Materials
	tunable workfunction conductors	R	-
	Surface roughness	U	Updated to: “substrate layers with modified surface” (with focus on

			polyanyline composites)
2.3	Stability (thermal, chemical)	C	Start in month 5, only for the materials
	Structure-Morphology	R	No critical mass between the partners
	Contact/channel interface treatment to improve the injection current	C	Start from Month 4-5, only for the materials
2.4	Flexibility	J	Focus on barrier layer systems & bending tests. Adhesion of Parylene barrier layers will be tested with nanoindentation
	Mechanical Stability	J	
	Permeability Requirements	C	Start with permeability tests
2.5	Chemical and morphological stability of materials……	C	-
	Electrical conductivity and localized states investigation .	C	-
	Standardisation of materials characterisation	C	-
	Measurements of charge carrier mobility	C	-
	Nanomorphology and local electronic phenomena	New entry	Replaced by “optical properties” (ranked 9) to achieve critical mass
2.6	Solution-phase and vacuum-free processing techniques	C	OK to start from M4. there is a sufficient critical mass
	N-type/p-type integration for complementary logic	D	Needs further analysis about feasibility and running EU projects (e.g.: COSMIC) – see also 3.2
	High-speed flexo printing of high-flexibility inkjet printing ?	R	Best to limit efforts to 2 CRIs in TF2.6
3.1	Reproducibility of OTFT-perform. on larger area substrates (> 2x2 inch)	C	Embedded in the work for Round Robin Testing (TF 3.1)
	Dielectric/insulator characterization	C	Embedded in the work for Round Robin Testing (TF 3.1)
	Accelerated Lifetime Testing; static/dynamic (Protocols/Models)	C	Embedded in the work for Round Robin Testing (TF 3.1)
3.2	Compatibility of materials for Complementary logic	R	Beyond the scope of this project
	OFET Foil-to-Component foil bonding (e.g. OFET foil to SENSOR foil)	C	OK to start from M4 Further analysis on the capabilities of organic materials
	Silicon/organic integration	R	Beyond the scope of this project
3.3	Stability → updated to: “Performance tolerances”	U	Perf. Toler. analysis will proceed with the modelling of the impact of device parameter variability
	Mobility modelling (vs. microstructure, temperature, electrical stress, internal field)	C	mobility will be evaluated with compact modelling and/or as a function of electrical stress
	Threshold shift → updated to: “Performance tolerances”	U	see above cell

Table 1. List of CRIs having the three highest votes in the score boards, and results of their assessment taking into account the principle of “feasibility”
[Abbreviations: C = Confirmed, R = Rejected, U = Updated, J = Joined together, D = Delayed]

The numerical result of the assessment is this: starting from 30 CRIs, 17 are confirmed, 6 are rejected, 3 are updated, 2 are joined in 1, 1 is delayed, 1 has been included as a "new entry".

There are 22 assessed CRIs that have been selected for technical cooperation; they have also many affinities that are shown in the figure below as graphical hyperlinks (see Fig. 13). This is due to the fact that poll, selection and discussions were carried on in parallel in the different Task Forces. The affinities can help to merge partners' collaborations and results, improve the critical mass of partners' efforts and thus were the starting point for further focussing.

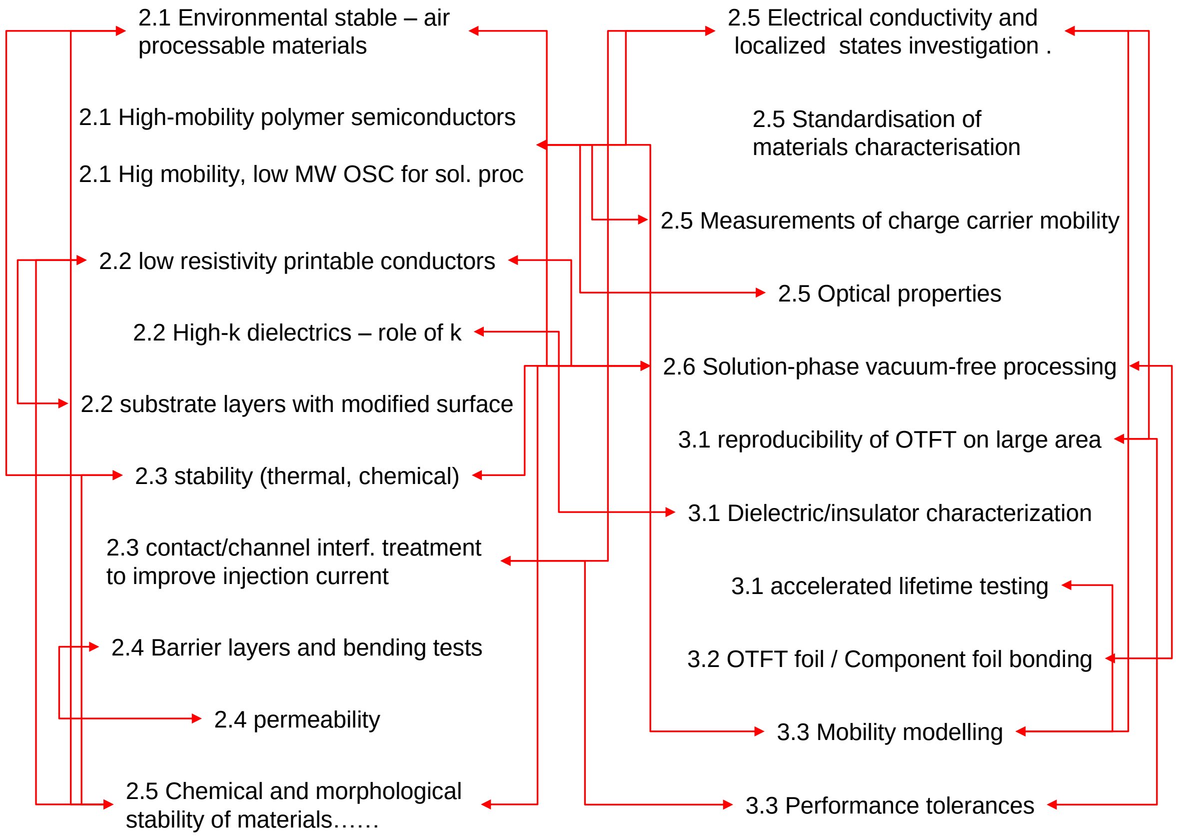

Fig. 13. Logical links between assessed CRIs, selected by FLEXNET consortium

PHASE 2 – FOCUSSING AND CONSULTATION WITH STAKEHOLDERS

During the Review Meeting No. 1 of the Project, a further refinement of the CRIs was formally requested by the review panel of FLEXNET. The requests in brief are these: "Updating of the critical research issues (CRI) based on input from the strategic board and industrial partners, to ensure that sufficient focus is achieved on the topic of industrial interest", and also "…it would be judicious to align even further and reduce the twenty (20) CRIs to ~5-10".

The strategy that was agreed among the FLEXNET partners to address reviewers' requests was:

- arrange a smaller set of CRI (the "new set") together with all the FLEXNET partners;
- include in the analysis relevant stakeholders selected from other running projects in the field of OLAE, by way of consortia that a FLEXNET partner is involved with, and from the FLEXNET strategic board;
- submit to those stakeholders the "new set" of CRI asking for their approval, suggestions, integrations.

The first step, the focussing process, was rather easy, owing to the existing interlinks between CRI (as shown earlier in Fig. 13). These interlinks were further discussed in the Consortium to generate a set of 5 CRIs (Fig. 14):

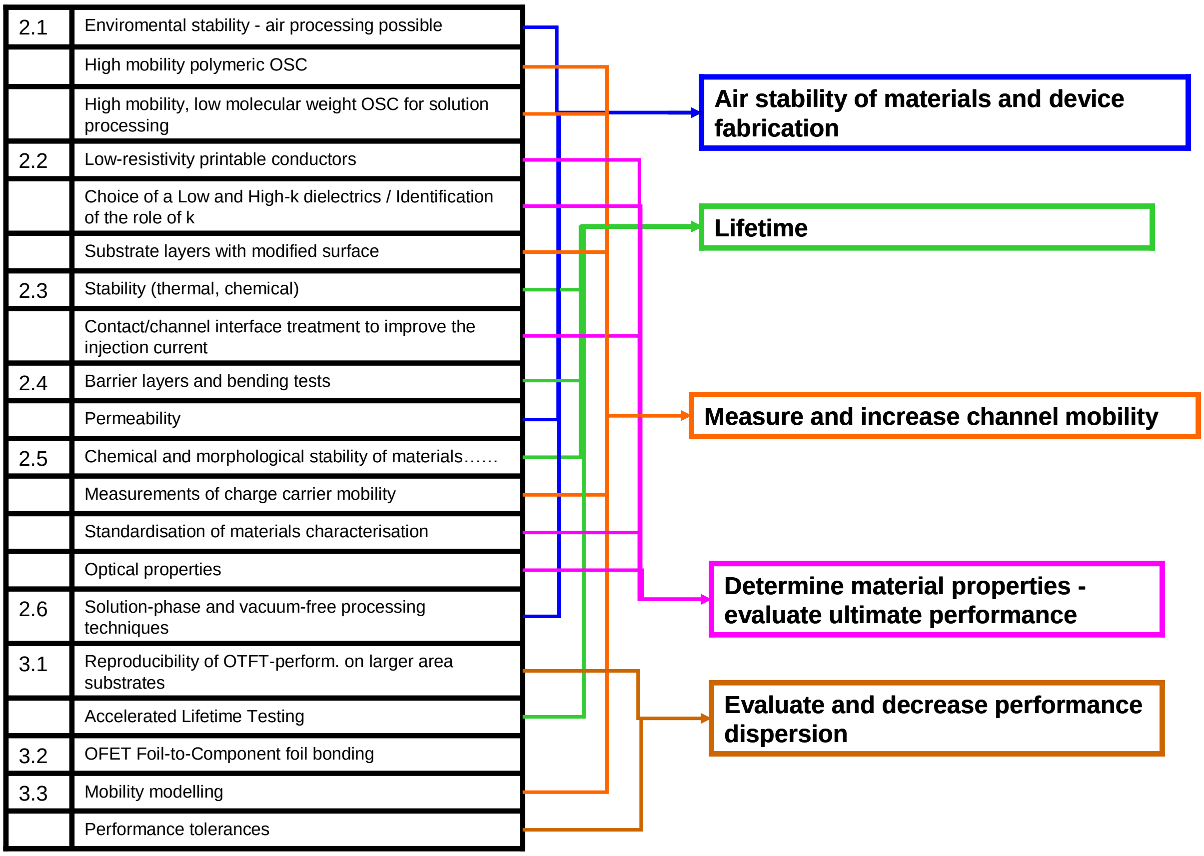

Fig. 14. The "new set" of CRI defined in the consortium, to better focus the collaborative work

The internal discussion ended up not only with the statement of the titles, but also of the goals of the new CRI, in order to have a precise target for the definition of all the collaborative work.

Titles and goals of the 5 CRI were provided to the external stakeholders, with the request to give their free opinion on them, or suggest further items and issues that are worth to be studied in FLEXNET technical work.

The result is that the 5 CRIs have been generally considered relevant and adequate by the external stakeholders. Most of the comments consisted in refinements in the definition of the goals of the CRI. The very few proposals for additional CRIs, to be included in the proposed set of 5 issues, actually were very similar to the existing ones, and additional CRIs were merged with the others.

PHASE 3 - THE FINAL FORMULATION OF CRITICAL RESEARCH ISSUES AND THEIR GOALS

The updated definitions of the 5 CRIs were first discussed in a General Assembly Meeting of the Consortium, and assessed shortly after,

The final definitions are as follows:

Air stability of materials and device fabrication

Make a survey of commercial materials that are stable in air or allow easier fabrication, with the minimum involvement of vacuum equipments, glove box, gas-proof enclosures, with special attention to inks and printing methods, also for interconnections, and to n-type materials. Foster the use of such materials in the experiments and characterizations and device fabrication, as well in the synthesis of new materials of the FLEXNET partners, in order to improve cost reduction without decreasing quality. Analyze compatibility of such materials with barrier materials and encapsulation methods

Lifetime

Discussing, and possibly testing and characterizing lifetime of materials and devices, and take into account all kind of stresses that have an impact on lifetime – mechanical, chemical, thermal, morphological, etc. and also real operation of the device. Starting point for the analysis are the current accelerated testing methods of microelectronic industry, to evaluate if new standards are needed, pointing to an operational lifetime of years. Analyze how degradations affect materials and device electrical performance parameters for modelling and characterization

Measure and increase channel mobility

Select commercial or new semiconductor, insulating and conductive materials that can improve the lead performance parameter of OFETs: the channel mobility, including also parasitic effects like: 2nd order effects, SCLC, contact resistance, short channel, etc. Improve and disseminate the best characterization and modelling methods available for that (taking into account what is available from OE-A working groups), providing a feedback to materials development, both for p- and n-type materials. Evaluate what can be the expected ultimate value for the channel mobility - and if it can reach 5-10 cm^2/Vs - and what is the impact on device and systems performance with special attention on the dynamic response of logic gates. Try to include ageing effects in air in the modelling to forecats performance degradation.

Determine material properties - evaluate ultimate performance

Use characterization methods and information from the commercial and scientific state-of-the-art, for all other materials parameters that have an impact on device performance and identify possible useful characterization methods. Compare them with OE-A roadmaps and possible standardization for measurements for materials. Use these studies to define the expected ultimate performance parameters, especially for n-type materials.

Evaluate and decrease performance dispersion

Analyze with experiments and discussions what are the main sources in the scattering of device performance, with the help also of modelling tools, including the application to system and circuit simulation. Evaluate the range of scattering and the methods to minimize it.

It is worth pointing out that the procedure for the selection and the assessment of CRIs was very successful (in terms of partners' involvement, transparency, assessment speed and quality) in almost all the research areas encompassed by the partners' expertise, with one exception: the work on systems integration which is also a relevant part of the Project.

This lack of CRIs related to systems is due to the fact that there are only few partners in the consortium with extended capabilities, experience, and equipment in this specific field, so that it became difficult to have a deep discussion on the subject, and even more difficult to share important facilities when it came to proposing work towards technical solutions of some of those bottlenecks defined as CRIs. However, it is important to maintain the emphasis on the item of "system integration" and to define some relevant issue for it in order to address the related work to do.

Therefore, two issues about "system integration" have been added straight on to the previous list. They are related to the issue of "foil integration" that was already deemed relevant by the partner in the 1st poll on CRIs that took places in months 1-4 (see first section of this White Paper). The two specific issues are:

Foil to foil integration

Foil to foil integration, FOLAE system puzzle, will focus on finding out the best current practices, bottlenecks, and future essential research topics related on FOLAE systems to be built up using devices prepared on separated foils. In such a system integration work lamination technique, materials used for interconnections and adhesion, mechanical tolerances and properties are of special interest. FlexNet partners are to find out basic methodologies first of all how to reliably integrate devices on a carrier or PCB type foil to perform its operation as a part of the system without affecting the performance of the device to be integrated. Further activities will be in reliability of the system and in the evaluation of the usability and possible industrial applicability of used technologies and/or technology proposals.

On foil integration

The highest integration level and the most efficient production of FOLAE based systems can be achieved if the system can be built on a single carrier foil by adjacent device processes on a continuous or stop and go type of manufacturing line. In FlexNet, partners are going to evaluate the usability and device related manufacturing technology restrictions in this type of manufacturing process. Among these are system layout requirements of different type of devices, process flow, positioning, mechanical and chemical tolerances as well as the reliability of the system. OTFT will obtain the main attention in these studies.

These two additional CRIs on "foil integration" have been evaluated and approved by FLEXNET partners after their meeting in spring 2011.

CONCLUSIONS

During the three phases of the procedure to define the Critical Research Issues for the FLEXNET Consortium, a free poll among a large number of relevant issues in the field of OLAE (bottom-up process), ended up with the definition of a handful of CRIs and their goals that have been checked and substantially approved by external stakeholders (top-down process).

The FLEXNET Consortium successfully achieved to have a set of 7 validated Critical (e.g. prioritary) Research Issues that will drive all the technical cooperations of the partners.

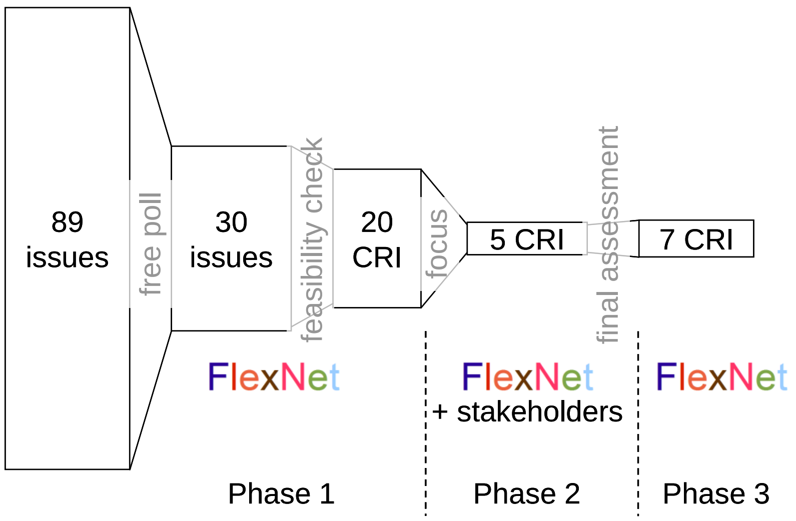

Fig. 15. The figures of the process to define the Critical Research Issues of FLEXNET consortium..

Even though the process of CRI definition is now completed, another update of these issues is planned for the last phase of the project. Consequently, all interested parties or experts are more than welcome to give their opinion and input for further definition of the research work in the consortium. **Your view will be highly appreciated**, so please do not hesitate to contact:

Network Partner responsible for the next update of research priorities:

Tomasz Marszalek Tomasz.Marszalek@p.lodz.pl phone (fax) +48 42 631 32 -05 or -24 (-18)	Department of Molecular Physics (K-32), Faculty of Chemistry Technical University of Lodz ul. Zeromskiego 116 90-924 Lodz / Poland

Coordinator of FlexNet:

Constantin von Dewitz Constantin.vonDewitz@vdivde-it.de phone (fax) +49 30 310078 -328 (-223)	 VDI/VDE Innovation + Technik GmbH Steinplatz 1 10623 Berlin / Germany

Authors of this White Paper:

Dario della Sala (dario.dellasala@enea.it) and Riccardo Miscioscia, both with ENEA/Italy