FINAL REPORT

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1.1. - Executive summary

A new generation of **sustainable paper-based products** with specific autonomous functionalities aiming at interacting with their users and/or reporting changes in their environment is developed in the frame of A3Ple project. A major focus is placed on the development of **electronic circuit with printing technology and low power consumption.**

12 research and industry partners with different backgrounds, going from materials science and engineering, to chemistry, physics, electronics and micro/nano-technologies worked in a multidisciplinary approach and developed:

- Advanced functional materials (paper, fibres, inks), functional components (battery, temperature and gas sensors, electrochemical display and transistors), and peripheral components (conductive lines, resistors and interconnections (bridges)).
- Electrical simulation tools in order to define the electrical design and physical layout of printed circuits.
- Specific on-line quality control of the printed electronic paper products.
- Cost-effective manufacturing process flows based on printing and embedding techniques commonly used in the printing industry.

During the international conference LOPEC (March 2015), the final demonstrators were awarded by OE-A as the best demonstrator realized in the frame of a collaborative public funded project (Figure 1):

- Demo1: an “on/off” device that gives information on the occurrence of a dangerous gas. The label can detect the lethal gas H_2S in a room. However, for live demonstration in a show room a temperature sensor is used instead of the H_2S gas sensor.
- Demo2: a paper poster (A0 format) that is able to distinguish 3 gas levels and shows the value reached instantaneously.

a) functional and graphic label | b) award | c) printed roll | d) poster

Figure 1: Demo1 (a and b) & Demo2 (c and d)

The manufacturing process flow takes into account the need to split the printing of the electronic components from the printing of the aesthetic visual label that covers and protects the electronic circuit. The electronic printing parameters influence the conditions of graphic printing and vice-versa. The printer has to master these influences before launching the manufacturing of final products.

For both Demos, the printing design takes into account physical constraints for electronic behaviour and printing issues, and graphic identity of the real product such as poster size, display dimension, how to read / understand the colour change, etc…

The methodology developed for these Demos can be used efficiently for developing any other electronic printed paper product based on the combination of a sensor, display, battery integrated in a dedicated electrical circuit. Furthermore other components (capacitor, NO_x sensor and memory transistor) were also optimized. They can be introduced into more complex circuits developed in the future.

Finally the Life Cycle Analyses (LCA) of printed circuits on paper shows a very low impact on CO_2 emission and other environmental factors compared to conventional electronics. Interviews with different potential end-user show the possibility of a rather huge market development and the social impact of such technologies.

1.2. - **Summary description of project context and objectives**

Paper is a green, renewable and recyclable commodity product. With a production of about 100 million tons and a recycling rate above 66% in Europe[2], the industrial sector is currently facing difficulties, mainly because of the competition of electronic media, and needs the development of new high value added products.

Paper and fibres, as a substrate, have very interesting properties, in particular the thermal and mechanical dimensional stability of paper compared to for example plastics, for the printing of electronics as well as the capacity of electric charge accumulation at the fibre surface for the integration of electronic components. In addition, the use of paper as main printing substrate has led to the development of specific knowledge in printing technology and long-term experience in large area roll-to-roll (R2R) printing processes. Besides, the miniaturized flexible electronic components (battery, sensors, display, etc) developed during the last few years open new opportunities. The combination of the advanced properties of paper/fibres and the transfer of knowledge developed in paper printing together with the actuation properties of electronic components could enable the development of new integrated multi-functional products.

The objective of the **APPLE project is to develop the next generation of sustainable paper-based products** with specific autonomous functionalities aiming at interacting with their users and/or reporting changes in their environment. A major focus is placed on the **development of new and flexible manufacturing concepts based on printing technology** to produce large area hybrid organic/inorganic papers with improved performance at competitive cost.

To this aim, the APPLE project is focused on 1) the integration of recent advances in functional materials (paper, fibres, inks) and functional components (battery, sensors, display, memory) and their production process upscale and 2) the development of innovative, flexible and cost-effective manufacturing processes based on printing and embedding techniques for the integration of all these functional components on the smart paper substrate. Figure 1 illustrates the concept of the APPLE project.

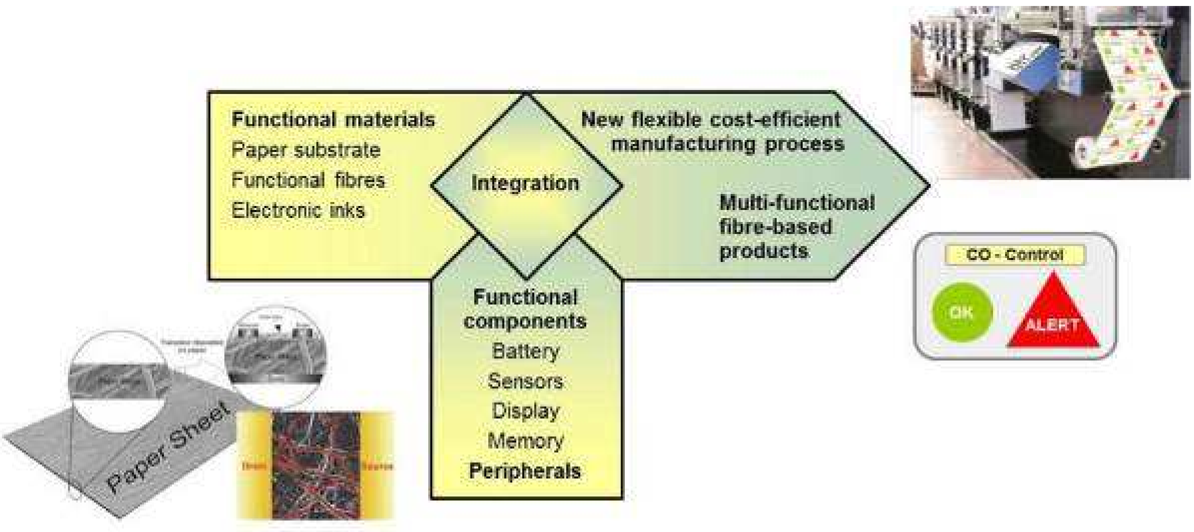


Figure 2: Concept of the APPLE project

A very special highlight of this project is the fact that the new APPLE products will make extensive use of the specific properties of both fibre based products and (nano)fibres individually. Indeed, **the paper is not only used as substrate** providing the required mechanical, surface and barrier properties for the printing and integration of the functional components, but the fibres including the incorporation of nanofibres are also used as active elements with **integrated high levels of intelligence**, namely the display and the memory.

[2] Confederation of European Paper Industries - CEPI countries

The project is expected to open new opportunities for the paper and printing industries (132 000 printers in Europe, among which 85% are SMEs) in the growing market of low-cost and high value added printed electronics. We will then be able to produce a plethora of low cost and disposable applications, **of great impact for SMEs**, such as smart labels and packaging to control product quality (e.g. food and medicine industry) and air quality (car cockpits, in house and industry environments, etc.) answering societal needs. This will generate a wide range of spin-off products.

The project is built on a set of main technical objectives towards the development of the APPLE product manufacturing concept and the fabrication of APPLE demonstrators for defined markets.

The 4 main technical objectives are described below.

Develop new functional materials at industrial relevant scale (paper, fibers and inks)

- To **develop an advanced paper/board** with **functional barrier properties** and **very low surface roughness** achieved using bio-sourced materials (extrusion coating of biopolymers) “green” chemistry (innovative grafting process) and with **fibre charge accumulation properties**, as required for the integration of all the electronic components.
- To **optimize advanced materials**, including organic polymers for conductive inks, functionalised carbon nanotubes and inorganic nanomaterials oxide based for battery, display and sensor components.

Develop printable functional components at industrial relevant scale

- To **adapt and optimize a printed thin-film battery** (power, capacity and voltage) for the different sensors (sensitivity) and the displays (size and contrast).
- To **print gas sensors** (CO, domestic pollution and H_2S, oil refineries pollution) and **temperature control sensor**.
- To **adapt and print display and memory transistor components** able to satisfy the application requirements regarding voltage bias and power consumption, display contrast ratio, information retaining and switching times.

Optimise design integration and develop a new manufacturing process

- To **design the integration** of the different components on paper substrate for the different targeted labels or poster sizes
- To **develop cost-effective manufacturing processes** essentially based on **printing** (ink jet, R2R, reduced assembling steps, combining lamination) and with a **new quality-controlled, flexible concept**.
- To **assess the sustainability** of APPLE products (LCA, recyclability, end-life and industrial safety) and to evaluate their potential for further development.

Demonstrate the manufacturing process: To **manufacture on industrial printing and converting lines 3 smart multifunctional demonstrators** through technical and cost assessment:

- **Autonomous paper labels for environment and safety** – novel dynamic concepts for pollutant control management and person safety (to identify pollutants emission in interior buildings or emergency situations and alert personnel).
- **Multifunctional paper posters for environment and advertising** – innovative self-powered and long autonomy gas sensor solutions for environment with integrated displays and memory for delivery of information. The expected gains on the ratio performance cost will be over 100% of today’s technology.
- **Multifunctional paper labels for smart packaging** – innovative track and trace systems, displays for information delivery with integrated temperature sensors for consumer satisfaction and safety.

Table 1: demonstrators description.

1. Environment & safety labels (A5-A6)	2. Environment & advertising posters (A3-A1)	3. Smart packaging labels (A6-A7)
		
Difficulty of demonstrators		
Low technological risk (small-size display)	Medium technological risk (large-size display)	Medium-high technological risk (small-size display and memory)

The scope of the project requires a **multidisciplinary approach**, involving research and industry with different backgrounds, going from materials science and engineering, to chemistry, physics, electronics and micro/nano-technologies. The consortium is then composed of:

- RTD providers for development of functional materials (paper, fibres by CTP and UNL) and components (sensors by CEA and TNO, display; memory by UNL), design and integration (CEA, UNL, VTT, CTP), printing processes (CTP and VTT);
- Industry/SME technology providers for development of functional inks (Poly), advanced base paper (FS) and components (printed battery by Varta), the integration of the components (BA, Poly and Varta), the development of the APPLE manufacturing process (printing technology and equipment by LT) and finally the on-line product control (ICS);
- SME end-users (RGP and LT as end-producers)

Table 2: Partners involved in APPLE

5 SMEs		IN-CORE Systèmes	LabelTech	polypore	RG Plastiques GROUPE G-PACK
2 Industries		Felix Schoeller Group Best Performing Papers. Worldwide.		VARTA THE BATTERY EXPERTS	
4 Institutes 1 University	ctp	cea	TNO	VTT	UNINOVA CEMOP FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

1.3. - Main S&T results/foregrounds

1.3.1. - WP1. APPLE Value chain (RGP)

Task 1.1: Specifications (RGP)

End-user functions and constrains were defined for the three demonstrators. Then the global technical specifications were specified according to foreground results and discussions between partners.

Task 1.2: Environmental sustainability and safety (CTP)

LCA (life cycle analysis) methodology for printed electronic consists of a comparison between a “paper demonstrator” and a “conventional demonstrator” that present the same electrical function. Conclusion on the functional unit defined as “Produce a surface of conductive lines which will support the same electronic functions” shows that all environmental impact factors are 1000 times lower for a paper demonstrator.

Several scenarii for product end of lives were assessed. Evaluation of recyclability, incineration and compostability leads to the conclusion that the three demonstrators, as they are currently produced, are compatible with those 3 types of end-life. These studies also underlined the necessity to explain to the consumer what a Printed Electronics product is and how to handle the end of life of such a product.

Main assessment of printed electronic is the impact of silver ink on safety, recycling and the environment. The impact was studied in detail for each aspect; the selected silver ink is recyclable and does not disturb biodegradability and phytotoxicity of paper.

Task 1.3: Potential market development (RGP)

For each demonstrator an evaluation of the potential direct market and other possible markets was performed. The price affordable by the consumers was also estimated. This was realized via an inquiry: several persons operating in different fields such as fire-brigade or city hall were invited to deliver their opinions towards the interest of the A3Ple’s demonstrators.
The interest of the demonstrators goes far beyond the specific functionalization targeted in the 3 demonstrators. The industrial development performed can serve a very important field of applications and different new markets.

Demo1: All the interviewed persons were interested by the product. However the following conditions were outlined:

- The final system should detect several gas if possible.
- It must be easy to use.
- It must be secure.
- The price must be reasonable.

In conclusion this product can open several markets that lead to big quantities.

Demo2: This demonstrator doesn’t seem to have a big interest for the people questioned. They are not enthusiastic as they find it complicated to set in place and not really needed or expected. Some electronic panels already exist in big cities; there is no need for new systems. Anyway these new Demo2s must be tested and approved by the end-users before being implemented at larger scale.

Demo3: The food industry is not interested in this system at the moment. Its organization is efficient in regards to the “cool chain”. The system of a label could engage the responsibility of the food industry that is reluctant because it is impossible to control the attitude of the final consumer.
Some other activities, such as following of human implant or medicine, could find an interest in the functionalities aimed in Demo3. In that case the cost of the label is not a key problem and the final user is ready to pay if the safety of the product is guaranteed.

Conclusion: The 3 demonstrators have a potential to find a market. They have to be adapted to the real need of the consumer or the industries concerned. A specific label or poster needs to be developed according to the final require from the final end-user or industry targeted.

1.3.2. - WP2. Functional materials (Poly)

This WP deals with the development of functional materials needed to manufacture the functional components and final products: *1)* Functional and barrier extrusion coated paper, *2)* Functional fibres for paper memory and *3)* Functional inks.

Task 2.1: Functional barrier extrusion coated paper (CTP)

Three commercial papers derived from commercial available paper grades, already developed by Felix Schoeller for printed electronics purposes (Figure 3), were selected as reference papers (Ref FS1, FS2 and FS3 in the project).

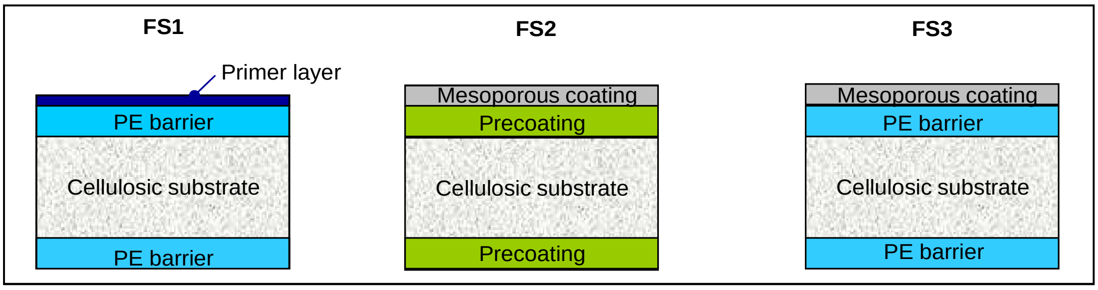


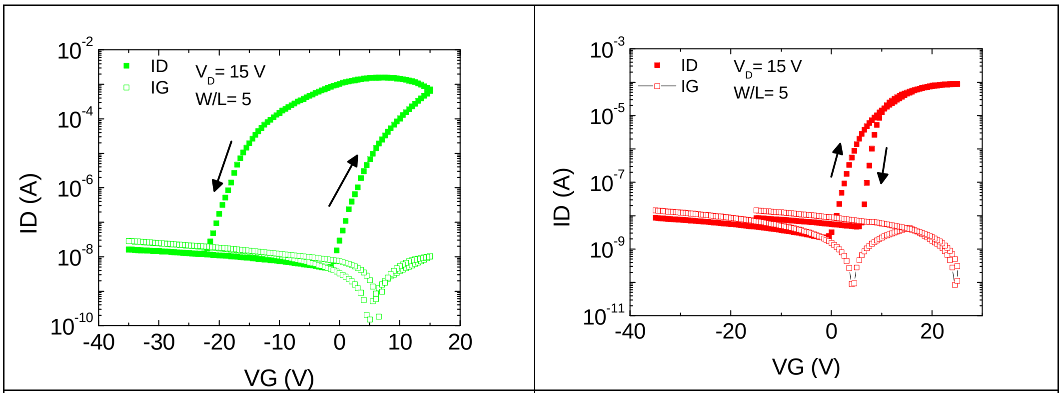
Figure 3: Description of the three reference paper grades

A new paper, referenced as FS4, was developed from paper FS2. Its design is the same as FS2, but based on a thinner and lower weight raw paper. In accordance with the needs of all partners and printing tests performed in WP4 and WP6, finally FS3 paper was chosen for Demo1 and 2.

When needed, the barrier layer is made of polyethylene. However, polyethylene is known to have major drawbacks when married with paper. It can possibly create issues in waste paper recycling streams and it is non-biodegradable. This task intends to minimise the environmental impact of the barrier paper by associating either bioplastics or biodegradable plastics with a paper substrate.
5 polymers were selected to substitute the PE and they were tested at laboratory scale. Production of samples was completed and comparative biodegradability tests were performed on the CTP's pilot platform. Coated samples show a good biodegradability, close to cellulose. As expected, the polyethylene coating is not biodegradable. However, the cost of all biodegradable substitute candidates for polyethylene are significantly (factor of 5 or more) higher than that for polyethylene, and the substitution generates some processing issues lowering coating process efficiency and yield. Furthermore, all biodegradable substitute candidates naturally show lower barrier properties for water and water vapour.

Task 2.2: Functional fibres for paper memory paper (CTP)

UNL was responsible for the development of conventional transistors and memory transistors starting from different paper samples developed by CTP. The difference between the devices is the fact that in a conventional transistor it is expected that the hysteresis effect is small (or even negligible) while in the memory transistors a large hysteresis cycle must exist on the transfer characteristics (variation of the source-drain current, V_{DS}, as a function of the gate voltage, V_{GS}).
Many papers and micro fibril cellulose (MFC) self-standing films were produced by CTP, characterized and selected as memory transistor or regular transistor. Initial results showed that pure MFCs and MFCs coated papers are the most promising ones regarding their application as dielectric, suggesting that MFCs are highly relevant in achieving high capacitance, extremely useful for transistor application. It was also observed that the treatment of the MFCs in acid or alkaline medium results in different electrical behaviour of the transistor. The acid treatment is more suitable for memory transistor (counter clockwise hysteresis) while alkaline treatment seems more suitable for regular transistor (low hysteresis), as seen in Figure 4.



a) behaviour suitable for memory	b) behaviour suitable for regular transistor

Figure 4: Transfer characteristics of transistors produced in the classical configuration using MFCs paper a) microfibrils treated in acidic medium, and b) microfibrils treated in alkaline medium

Task 2.3: Functional inks (Poly)

Sub-Task 2.3.1: Primer layer ink

The purpose of the primer layer ink is to treat a substrate in order to modify surface properties as smoothness, surface tension, barrier effect and electrical insulation. This is useful in a multi-layer component if a substrate requirement for a functional ink is different from another. A UV-curing ink was selected to have a quick drying. Two inks were developed, for inkjet and for flexography.

Sub-task 2.3.2: Advanced functional ink

An aqueous transparent conductive ink, based on carbon nanotubes and a conductive polymer (Pedot-Pss), was developed for inkjet printers. Different kinds on CNTs and grades of Pedot-Pss were evaluated, and the best combination allowed obtaining a high transparency of 90 %, a low sheet resistance of 75 Ω/sq on PET and FS1, with a high flexibility and a low cost.
Electrical and optical performance of the printed ink was similar to ITO, an oxide used in the electrochromic display concept (task 3.3). Samples on PET were tested by UNL to be used instead of ITO. Electrical and optical performance was interesting but, in this configuration, the Pedot-Pss has the same electrochromic behaviour and colour changes as WO_3.

An adaptation of the conductive ink was performed to fulfil the requirement of the flexographic process. Due to a too low viscosity at the rotation speed of the flexography, there are a low ink deposition and a high resistance of the printed film (few kΩ/sq on FS1). The ink cannot be used in the project and was replaced by commercial flexographic silver ink.

1.3.3. - WP3. Functional components (CEA)

Task 3.1 – Thin film batteries (CEA)

The Thin Film Battery (TFB) selected to supply the A3PLE demonstrators is based on the lithium-ion technology, because of its higher energy density and its ability to be implemented in flat and flexible configuration. Taking into account several key criteria such as state-of-charge operating range, safety and cost, the 3.2V Graphite/$LiFePO_4$ couple was selected among the possible Li-ion systems. Indeed, this technology remains hugely competitive in terms of performances compared to the commercial primary TFB even if its rechargeable properties are not used.

As the final design of the A3PLE battery is strongly linked to the manufacturing process flow, two specifications were considered: the Thin Film Battery will be reported (i.e. hybridizised) onto the paper substrate in a continuous way and it will be manufactured in a R2R process. As a consequence, it was decided to develop the manufacturing process with the objective to produce a rolled band of operational batteries. The process is based on the combination of techniques in continuous mode with screen printing, co-lamination and thermosealing. It consists of co-laminating two rolls (Figure 5):

- the first one carries patterned negative electrodes printed onto structured Cu current collector and covered by printed membrane;
- the second one carries corresponding patterned positive electrodes printed onto Al current collector

where the base material of the rolls will constitute finally the soft packaging of the battery.

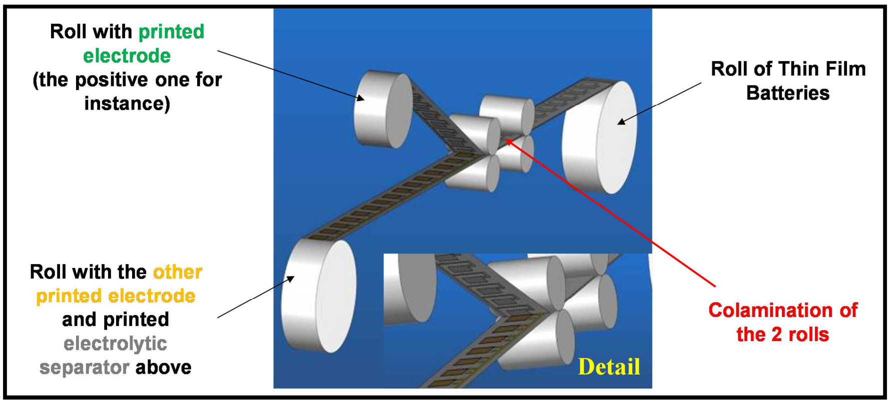


Figure 5: Roll to roll process for battery manufacturing

The process in line based on the combination of the use of smart packaging, printed components with specific design and screen printing techniques for thick layers (~100µm) was assessed. The manufacturing of the battery core was demonstrated at labscale. Several solutions for hermetically closing the smart packaging were tested. Finally, the obtained battery exhibits the expected recovered capacities with stable behavior fully compatible with conventional Cgr/LFP based batteries.

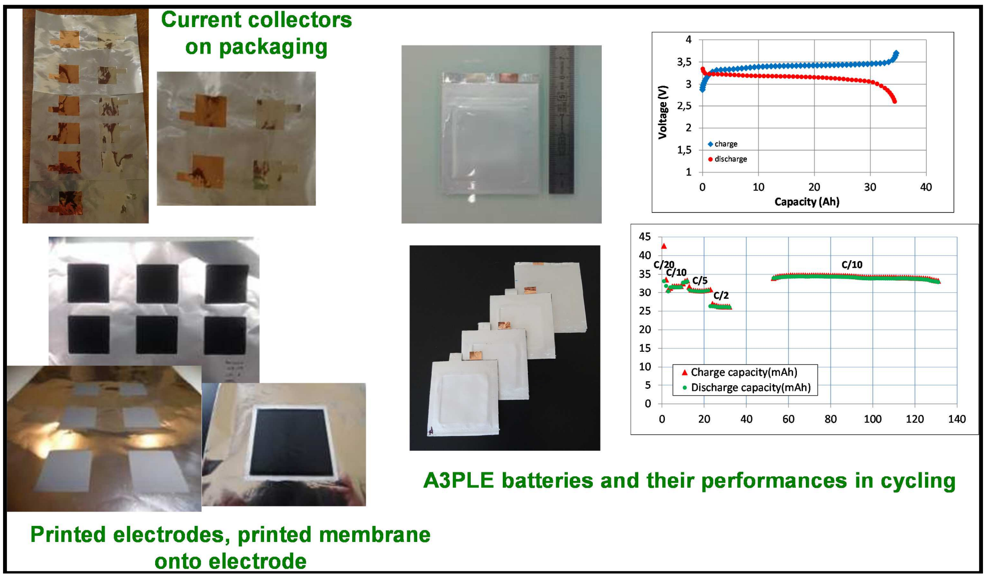


Figure 6: overview of battery at different steps and electrical characterization

Task 3.2 – Printable gas and temperature sensors (TNO)

Task 3.2.1 – CO and NO_2 sensors (CEA)

The gas sensors provided in the A3Ple project are based on single walled carbon nanotube CNT network as the sensitive material working at room temperature and low power consumption. Electrical detection is studied for two gas targets along the project: CO and NO_2 gases.

Water based inks were developed for spray coating of the CNT network (Figure 7). Gas characterization was performed in a gas probe station allowing good control of the gas concentration.

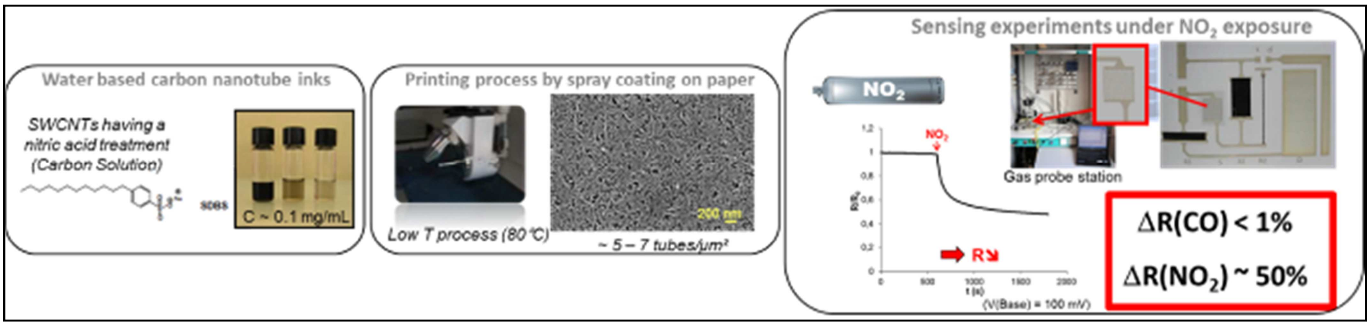


Figure 7: Process flow of the gas sensor elaboration

Pristine CNTs were then platinum-coated to produce CO sensors on paper. Poor resistance variations were obtained with the fabricated devices. Compared to the sensor's sensitivity to relative humidity (average resistance variation of the CNT network is around 15-20% from the initial value for relative humidity between 40 to 70%), CNTs hybrids show poor CO sensitivity (less than 1% of resistance variation under 100ppm CO). These observations clearly push the consortium to modify the gas target to the NO_2 gas which is a strong environmental pollutant and toxic for the respiratory system. In this case, raw CNT networks exhibited more than 50% of resistance variation under NO_2 exposure (50ppm).

The objective of the project was to integrate the NO_2 sensor into a smart poster for air quality monitoring (Demo2). For that, 3 levels of NO_2 detection were required (< 5 ppm - 5 to 50 ppm - > 50 ppm of NO_2)

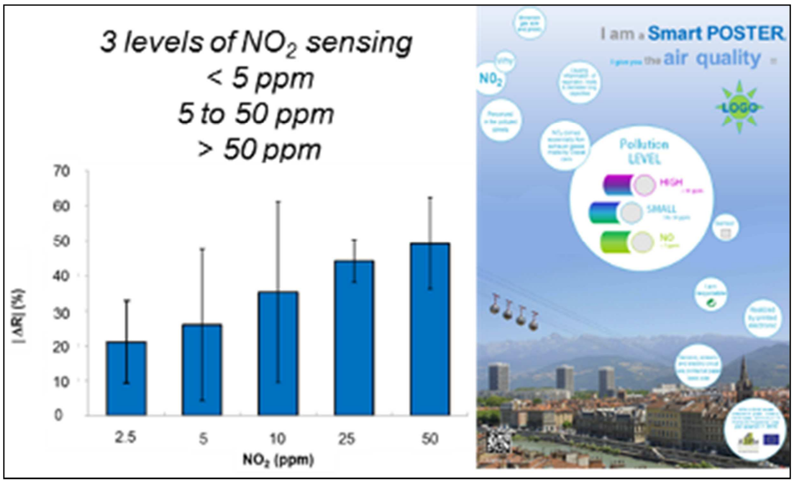


Figure 8: NO_2 sensing and it integration into poster

Clear increase in resistance variation under various gas concentrations was observed. More than 25% of resistance variation was measured between 5 and 50 ppm gas exposure (Figure 8). This significant resistance variation promoted development of 3 distinct levels of sensing (< 5 ppm - 5 to 50 ppm - > 50 ppm). The resistance variations were correlated to the gas concentrations allowing the detection of the level of exposure in the range previously defined in the project. The resistance variations were compatible with the electronic on paper provided in A3ple project.

In the framework of the A3Ple project, NO_2 gas sensors based on printing of carbon nanotube networks on paper were developed. Strong resistance variation under gas exposure has allowed clear measurement of three levels of detection.

Task 3.2.2 – H_2S sensor (TNO)

The H_2S sensor is based on copper(II)acetate ($CuAc_2$) in water. There are no environmental issues with respect to application as the system is waterborne. An interdigitated finger structure is the basis of the sensor. Then, the $CuAc_2$ solution is inkjet printed on this structure, (Figure 9a). This H_2S sensor on a specific commercial paper is humidity independent up to about 80% of humidity.

The sensor gives a good response by exposure to H_2S gas. The resistivity drops from non conductive to 10 kΩ at 2 ppm of H_2S gas (Figure 9c). The formation of the conductive path of CuS between the Ag fingers takes approximately 15 minutes. The colour of the greenish $CuAc_2$ layer changes to a brownish colour (Figure 9b).

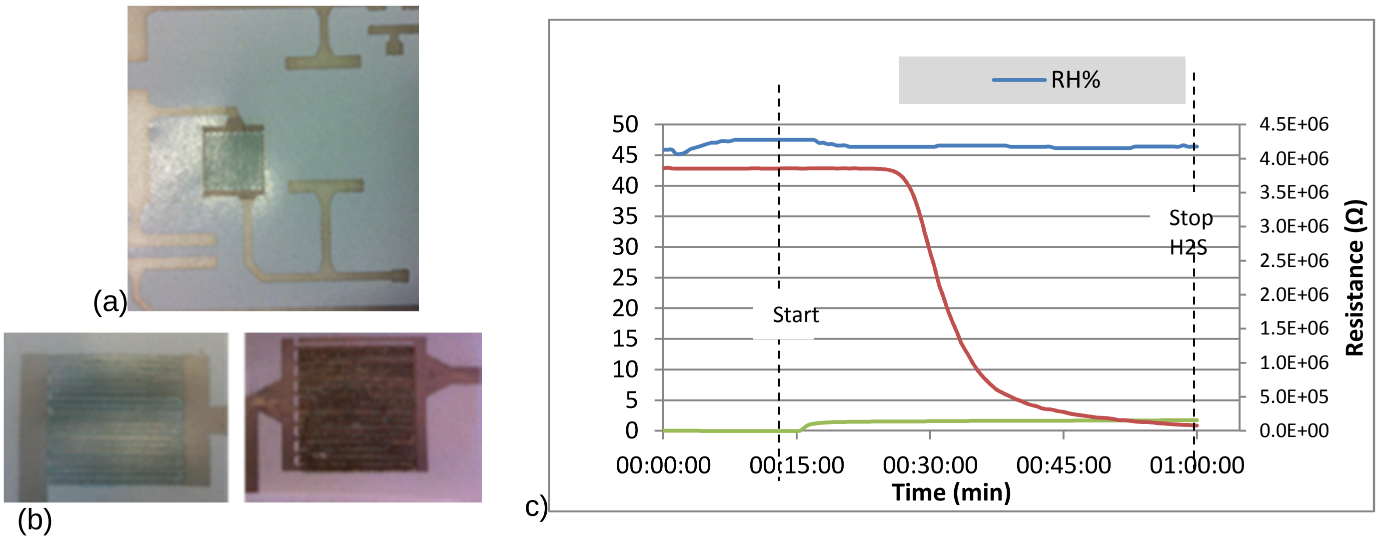


Figure 9: (a) Ink jet printed $CuAc_2$ on commercial paper with flexo gravure printed silver. (b) color change of $cuAc_2$ after H_2S exposure; c) Response of H_2S sensor based on ink jet printed $CuAc_2$ implemented

The sensor was integrated in a security label, Demo1 (Figure 10). The fingers were printed on an industrial machine (at LT) and the active solution was inkjet printed at TNO.

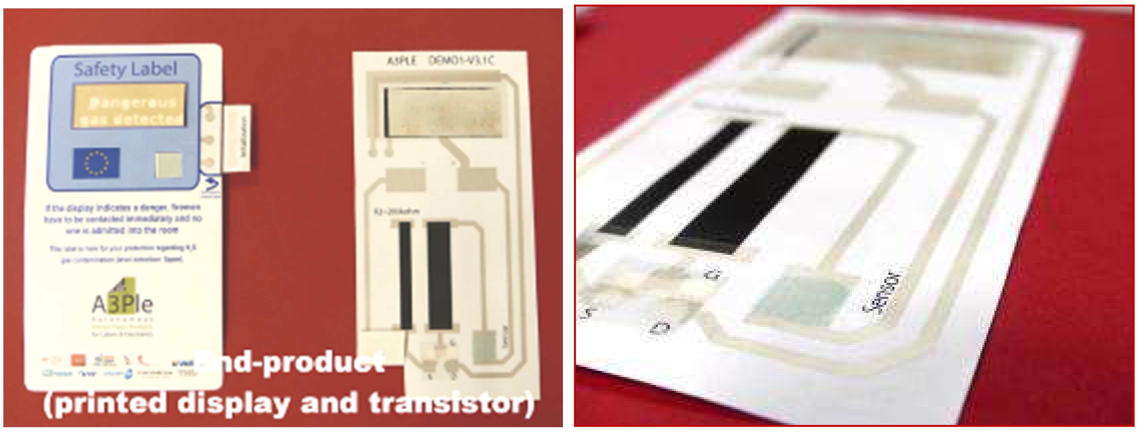


Figure 10: Printed H_2S sensor integrated in Demo1.

Task 3.2.3 – Temperature sensor (TNO)

Ceramic thermistor material based on inorganic spinel structures were made at TNO with a multistep synthesis and firing. Two kind of particles were tested: $CuFe_2O_4$ and a newly developed material built up from Mn/Zn/Cu Oxide doped with Ni and Co (general formula is $Mn_{1,71}Ni_{0,45}Co_{0,15}Cu_{0,45}Zn_{0,24}O_4$ - manganese spinel oxide). The resulting material shows thermistor behavior with a lot of advantages; low overall resistance and high temperature stability are the most important.

The sensitive ink was stencil printed on an interdigitated finger structure printed on FS3. The active layer shows a thickness of 38µm. In Figure 11 the resistance vs temperature of the manganese spinel thermistor was compared to the $CuFe_2O_4$ thermistor.
The conductivity vs temperature response of the manganese spinel markedly exceeds the $CuFe_2O_4$ thermistor performance (ie: the resistance of the manganese spinel thermistor was much lower than the $CuFe_2O_4$). Consequently less material can be deposited to get the same efficiency. In an optimal form the temperature response corresponds to a variation rate (α) of $-4\%K^{-1}$ at 25ºC and to a resistance at 25ºC of only 175kΩ.

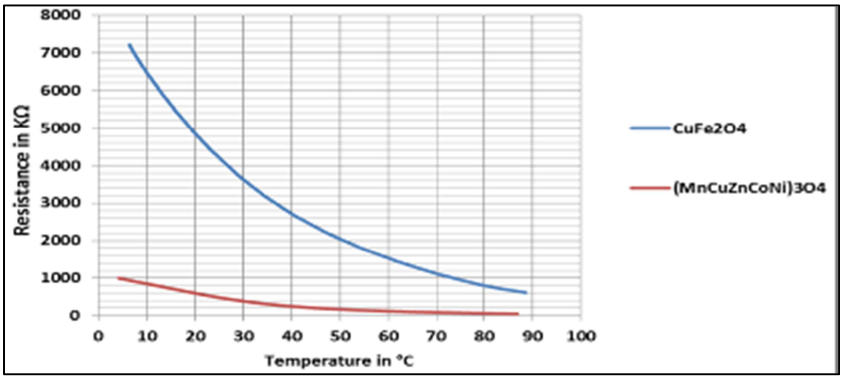


Figure 11: Comparison of copper-iron oxide and the new manganese spinel oxide

Thermistor material sent to LT and CTP were flexography printed at lab and industrial scales. As the ink layer is not thick enough using this technique, the sensor on the final Demo1 and Demo2 was stencil printed by TNO (Figure 12).

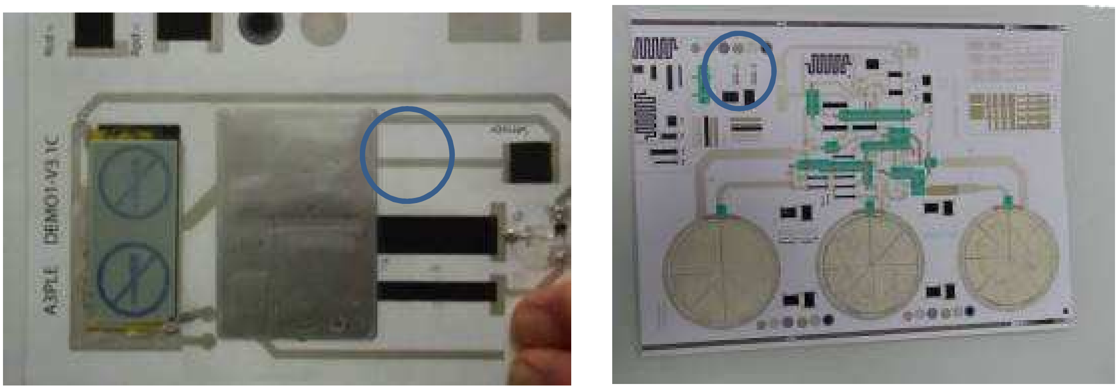


Figure 12: Demo1 and Demo2, with printed temperature sensor in blue circle

Task 3.3 – Electrochromic (EC) displays (UNL)

A notable achievement in the EC display development was the realization of a fully printed (at lab-scale) all-solid-state device based on cheap, safe and stable chemical materials while simultaneously providing proper performance under operation. The EC displays prototypes developed for the A3Ple project demonstrate that there are no major obstacles in development of this component and its application in demonstrators.

The architecture and process flow of the printed EC cells in the final demonstrators is presented in Figure 13. Some typical operational characteristics were determined at lab-conditions. As an example, the peak consumption power for coloring/bleaching ranges 100/400 $\mu W/cm^2$, respectively, and switching time is 3s for a maximum operation voltage of 4 V.

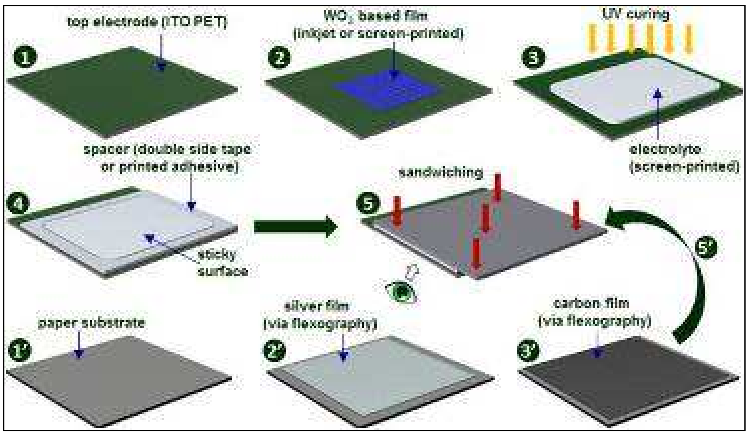
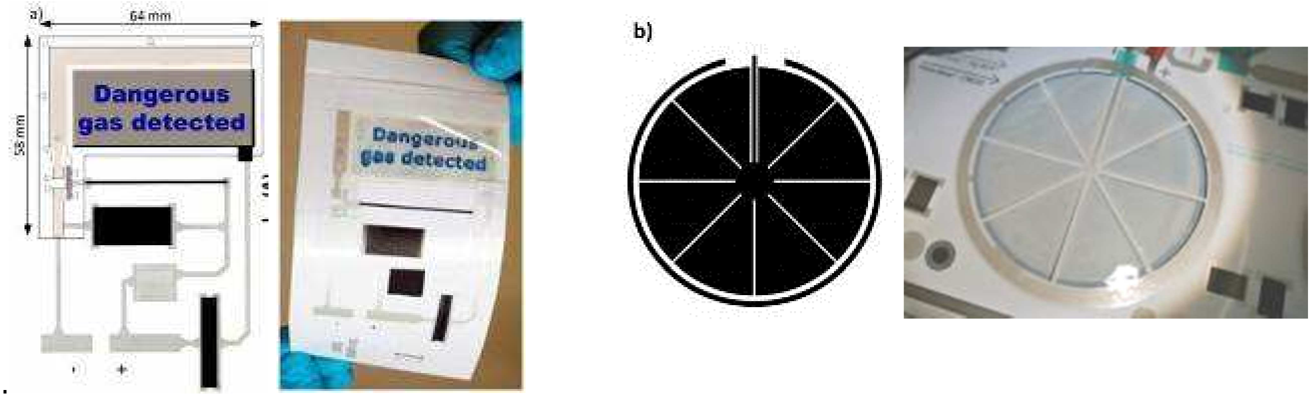


Figure 13: Schematic diagram of the process of fully printed EC display.

The first prototypes of Demo1 with a fully printed EC display on paper were demonstrated at M34. These already included a new approach for integration of the EC display with the transistor on the same PET foil. The EC display and the transistor integrated in Demo1 is shown in Figure 14a.



a) *b)*

Figure 14: Layout and EC display on a) Demo1 and b) Demo2.

The display layout for Demo2 was developed together by UNL, CTP and BA (Figure 14b). Each segment of the display is powered by silver electrodes reaching the circle from outside, while the contact to the PET/ITO foils is done from inside using a common electrode (aiming equal power repartition). Like the EC display for Demo1, silver, carbon and electrolyte films are deposited on top of the paper substrate, while WO_3 based ink is printed on ITO PET substrate. The effective EC display diameter after encapsulation is 100 mm.

There are no major obstacles in material development for the EC displays. However, there is room for improvement concerning the mechanical integrity of the devices, namely concerning the detachment of the PET foil from the electrolyte, which compromises the functionality of both EC display and EG-FETs. This is critical in the case of Demo2 EC display due to its dimensions.

Task 3.4 – Fiber-based floating gate memory (UNL)

The work performed demonstrated that paper substrates produced from micro-nano fibril cellulose (MFC) have a strong influence on the performance of an oxide based memory transistor. The effect of the fiber's type, structure and dimension was studied regarding the use of paper as the dielectric in such devices. However we must highlight that these devices were aimed only for Demo3. This means they were not integrated in a demonstrator since Demo3 was not realized.

A first set of 26 long fiber papers and 10 MFC self-standing films were produced by CTP during the first 18 months. Memory transistors were produced by UNL on both sides of the paper with a staggered-bottom gate structure as can be seen in Figure 15a. On one side a 40 nm thick GIZO (Ga_2O_3-In_2O_3-ZnO; 1:2:2 mol) film was deposited by RF magnetron sputtering to create the channel region. Then, Al source/drain (S/D) electrodes (200 nm thick) were deposited by e-beam evaporation. Finally, a 200 nm thick IZO (In_2O_3-ZnO; 89.3:10.7 wt.%) film was deposited on the other side of the paper substrate to be used as gate (G) electrode. The most remarkable observation was that CTP23 paper, with extra ionic charge added to the pulp, is the one that presents the longest retention time (time while source and drain current (I_{DS}) ratio between on and off states is above 10) of around 10^7 seconds (~4 months).

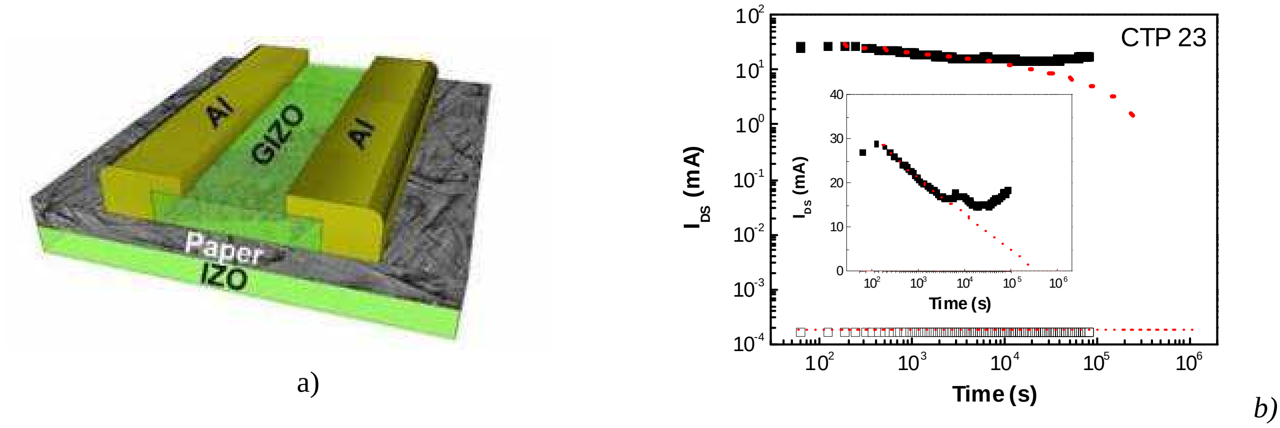


Figure 15 – a) Schematic representation of the memory transistors and b) charge retention time extrapolation for memory transistor on samples CTP 23.

Memory transistors were also made on the MFC membranes (samples CTP61 to 70) formed on top of FS3 paper with silver electrodes, that were used as gate in memory transistors (Figure 16). This approach is particularly interesting when moving towards printable devices, meaning that it is possible to have a functional cellulose layer in the transistors, with tailored properties different from those of the substrate/backplane.

The memory transistors produced with these membranes have lower retention time than those produced on paper samples, being, in the best scenario, around 46 days. Nevertheless this clearly shows that cellulose based dielectric layers can be formed on foreign substrates by printing-compatible methods, representing a big step towards printable memories integrating cellulosic materials as active component.

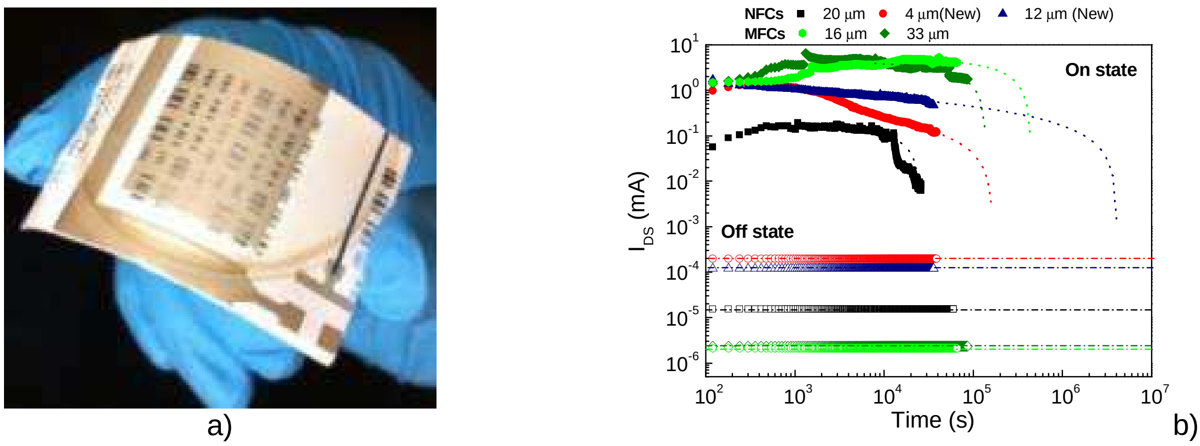


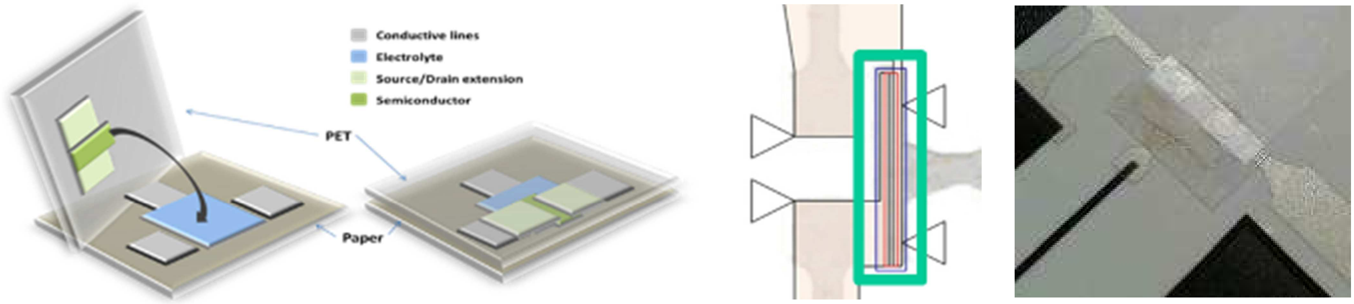
Figure 16: a) Photo of a printed MFC membrane (with transistors) on top of silver layer deposited on FS3 paper and b) charge retention time for different MFC membranes.

1.3.4. - WP4. Peripheral components. (LT)

Task 4.1 – Design and development of printed integrated devices

Active component -Transistors

UNL developed the transistors for the A3Ple demonstrators. The final strategy was based on electrolyte gated devices (EGFETs). This was the strategy followed for the transistors to be integrated in the demonstrators. GIZO was deposited on PET/ITO substrates by sputtering in order to be used as oxide semiconductor. The ITO was patterned in order to create S/D regions. The EGFETs were then hybridized on the Demos' backplane (containing the printed silver conductive lines and electrolyte, Figure 17). The connection between the electrodes of the PET foil and the printed silver conductive lines on the backplane was done by filling vias with silver paste. An adhesive layer was used in order to assure the encapsulation of the electrolyte and a better adhesion to the backplane.



a) b) c)

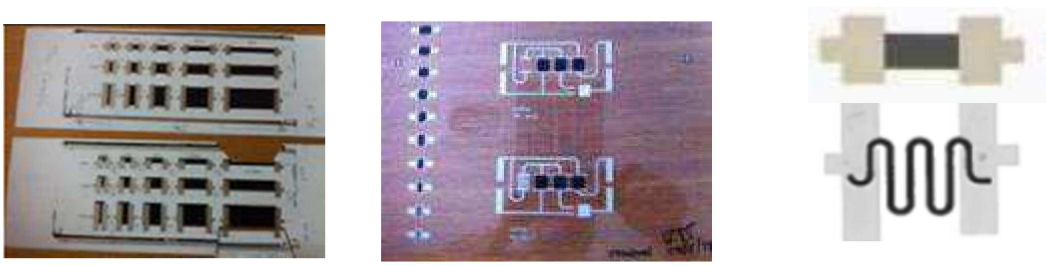
Figure 17: a) Scheme of EGFET and hybridization strategy, b) Layout with W/L ratio of 45 with adhesive layer location (green rectangle) and c) EGFET hybridized on Demo1.

With the new approach (PET hybridized system), an improvement of the current modulation was observed; a I_{ON}/I_{OFF} ratio (maximum/minimum current) up to $1.35x10^4$ was obtained on devices with a channel width/length (W/L) = 45. It is relevant that these devices still showed an adequate operation mode three weeks after production, with a I_{ON}/I_{OFF} ratio still above 1000, regardless of the W/L used.

Passive component - Resistors

VTT tested different inks and designs to combine resistance design and target values (Figure 18-b). Lab and pilot tests on PET and FS papers validated the way to make resistor components. In the project's final stage, VTT fine-tuned the quest for resistors by examining at lab-scale the variations, deviations and reliability of resistors with a final conclusion that resistors can be produced in a large range with high reliability.

CTP has development tests and method to manage and predict resistor target values: the distance between the silver square defines the length of the resistor (L) and the width (W) of the resistive square sets the resistance of the resistor. The dimensions of the resistor (W, L) are predicted by a simulation program. This program uses lab and industrial resistance values measured on samples printed at CTP and LT as input data to build this component layout (Figure 18a).



a) b) c)

Figure 18: a) CTP's design for the study of the influence of the printed area on the resistance; b) Resistor made with screen printing on PET, VTT; c)"line" and "snake" resistors, two design proposed for low and high (respectively) target values.

Industrial transfer to LT was performed since April 2012. The ink and printing parameters were chosen to reach specifications of both demonstrators (target resistor value= 100ohm to 20 Mohm). Thanks to BA's suggestion, "snake" resistors have been developed for high resistor targets in order to optimize components dimension (Figure 18c).

Passive component – Capacitors

Though capacitors were not needed as part of the electrical design, VTT worked on this component and succeed to create a workable capacitor configuration printed at lab-scale.

Task 4.2 – Interconnection techniques on paper (VTT)

VTT printed interconnection structures based on a single sided arrangement. Bridges were made by flexo printing or a combination of flexo and rotary screen printing. All printing tests were conducted on FS3 paper. Both lab scale sheet based printing and pilot level R2R printing were used. In R2R pilot level printing, 100% yield of bridge structures was achieved by printing

1) bottom silver tracks either by flexo or rotary screen (commercial micro particle silver inks)
2) insulator ink by rotary screen with double layer of UV curable commercial dielectric
3) top silver tracks by rotary screen or optionally by dual layer of flexo (Figure 19)

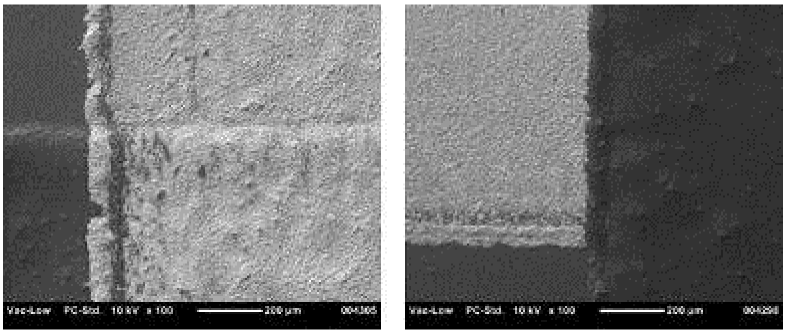
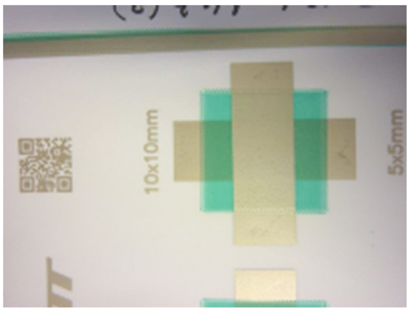


Figure 19: a) Dual layer flexo printed silver conductor going over the edge of screen printed insulator and b) Single layer flexo printed conductor on FS3 paper and edge of screen printed insulator.

The fully flexo printed bridge structure was achieved at lab scale with table top printing machines. This achievement would be very practical since the industry predominantly works with the flexo-printing method. Working insulator layers were obtained with a yield of 100 %. These results applied for bridges with areas between 1 mm² and 400 mm². Working bridges were obtained when at least 2 layers of insulator were printed to remove any pinholes and inhomogeneity of the insulator layer. This also applied to the case of rotary screen printed insulator layers where the yield was significantly reduced when only one insulator layer was used. The results are presented in Figure 20.



Number of insulator layers	Thickness (µm)	Working yield (%)
1 layer (Flexo, sheet)	5.7 ± 2.3	0 %
2 layers (Flexo, sheet)	17.5 ± 3.6	100 %
4 layers (Flexo, sheet)	39.9 ± 6.1	100 %
1 layer (Rotary screen, R2R)	7.7 ± 1.5	40-70 %
2 layers (Rotary screen, R2R)	17.5 ± 2.3	100 %

Figure 20. Printed bridges (left) and their performance as a function of layer thickness/amount of layers and printing method.

It is possible to manufacture fully-printed bridges. An excellent working yield is achieved when the layer thickness is adequate and the amount of printed layers is at least two. Both rotary screen printing and flexography were able to reproduce working bridges. In flexography, the printing parameters needed more careful optimization than in rotary screen printing.

Task 4.3 – Hybridization on paper (LT)

Optimization of hybridization parameter

All systems based on electronics use a power source to supply electrons in the circuitry. Printed electronics are no exemption to this so in the project the use of a Thin Film Battery (TFB), single or multiple, is required. The relevant parameters for the hybridization of the TFB were defined.

Functional TFBs in roll format were not available in sufficient volume to deliver a realistic test setup and make a practical assessment for TFBs hybridization onto the printed electronics labels. However, dummy batteries with physical characteristics close to the TFBs under development allowed to define the relevant parameters of hybridization:

1) Position and orientation of the electrodes (battery poles connectors) on the demo label.
2) Electrical connection and physical fixation of the battery

These parameters drive the technology and the process to properly and solidly connect the TFB on paper. The final step is to check and control the functional connection and the battery functionality.

a) b) c)

Figure 21: a) and b) materials for the production of the dummy battery roll; c) roll of dummy batteries

Development of on-line hybridization machine

For the development of the hybridization system, rolls of dummy batteries were used. A first system concept was proposed at M30 and further developed with the final R2R design of Demo1 and Demo2.

At the end, the testing was performed with commercial batteries manually placed on the test roll according to Figure 22.

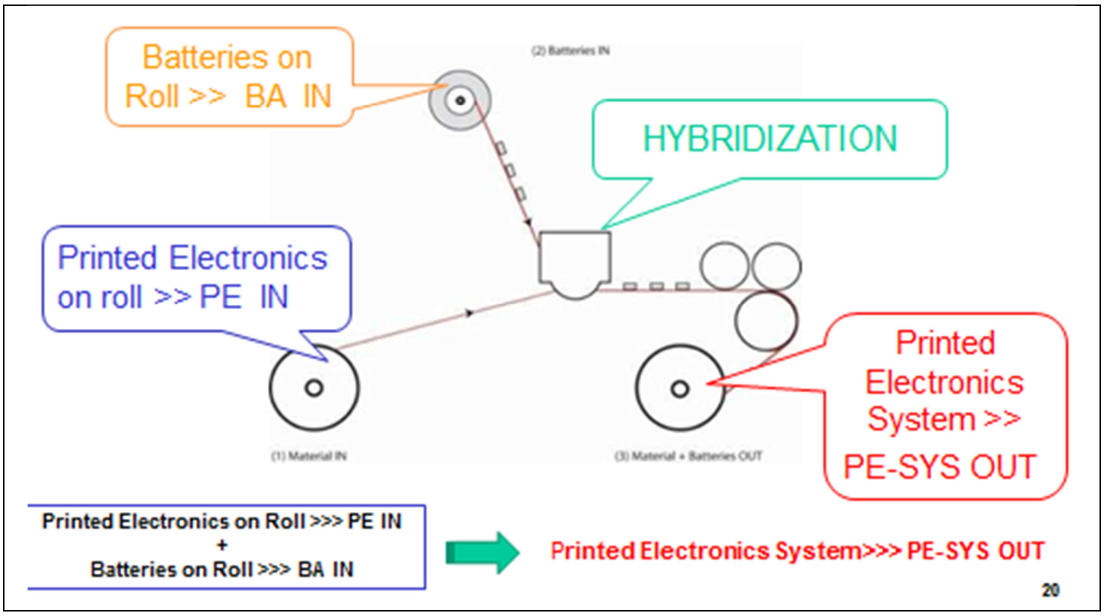


Figure 22: schematic of material flow for hybridisation

1.3.5. - WP5. Integration (BA)

The integration of components into a full functional circuit requires to define:

1. the electrical design (task 5.1) which depends on electrical behavior of printed components,
2. the printing design of layout (task 5.2) which defines the mapping of the ink layers for i) each component and simultaneously ii) for the Demo in a global manner.

The complexity of the integration required a step by step method where the electrical and physical designs evolve by iteration (task 5.3). The table 1 sums up designs and layouts that were printed in the frame of the A3Ple project.

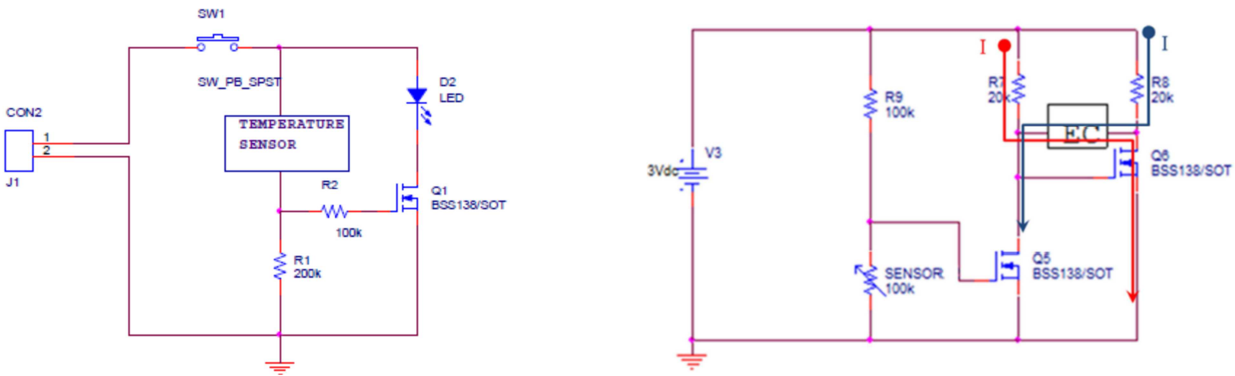
*Table 3: Summery of electrical design and physical layout (**name:** specification) for each demonstrator.*

	ELECTRICAL design	PHYSICAL design of layout
Demo 1	**Demo1-A:** Resistor values compatible with LED as display & light sensor chip	**Demo1-V1:** Resistors and lines **Demo1-V2:** […] and electrodes of components
	Demo1-B: Resistor values compatible with printed EC-Display & H2S gas sensor	**Demo1-V3 & - V4:** […] and physical constrain link to final product and graphic label
Demo 2	**Demo2-A:** 3 levels switch on/off progressively, compatible with LEDs as display & sensor chip,	**Demo2-V1:** Resistors and lines **Demo2-V2:** […] and electrodes of components
	Demo2-B: Resistor values and design compatible with EC display behaviour	**Demo2-V3:** Resistors and lines and electrodes of components and physical constrains link to final product and graphic label
Demo 3	**Demo3-A:** Design using memory effect of EC-display.	**Demo3-V1:** Resistors and lines and electrodes of components

Task 5.1 – Electrical design and simulation of circuits (BA)

Demo1. The goal of Demo1 is to make an "on/off" device that gives information about the presence of a dangerous gas. The label is used only one time and replaced after the gas detection. This "one-shut" label permits to BA to design the simplest electronic circuit: one sensor, one battery, one transistor, one display, conductive lines and a few resistors (Figure 23a). Demo1 designs do not require any interconnection (bridge).

The parameters of this circuit were estimated by a simulation tool developed in the frame of the project. The input data were electrical characterization of chips (since printed components were not ready) and then, the characteristic measured on the printed components (inputs from WP3 and WP4). BA also realized a specific Excel spreadsheet to simulate the behaviour of the Demo1 for different conditions of gas concentration.



(a) (b)

Figure 23: (a) Final electrical design of Demo1; (b) «H» cell configuration inside Demo2 electrical design

Demo2. The objective of Demo2 is to distinguish 3 levels of gas content and informs witch one is reached. Therefore the circuit was more complex compared to Demo1:

- Number of components increased: 14 resistors and 8 transistors.
- Gas sensor and displays had to show a reversible behaviour.
- Double conductive layer with interconnections was required. In a conventional circuit, the two layers are realized on the two opposite faces of the substrate and connected using drilled vias. In the project, the connection on paper substrate was made with the bridge method (task 4.2).

The first electrical design was produced with a LED as display (Demo2-A): the LED light switched off when the applied voltage drops to zero. However, a printed EC-display behaves differently and the electrical configuration did not permit to switch off the display. To solve this issue, BA introduced an “H configuration” that applied -3V to the display in the “off” state (Demo2-B, Figure 23-b). This solution required the same number of transistors as for Demo2-A, which is important in order not to increase circuit complexity.

Demo3. The Demo3 circuit should measure temperature (T) at the moment and keep its past maximum value in memory. The associated electrical circuits require a memory transistor, measurement initialisation, many displays, p- and n-type transistors, etc… In order to solve the complexity of such circuit, BA proposed to use the memory effect of the EC-display to “store” information linked to the maximum of the past temperature. The Demo3 electrical design could be seen as the combination of Demo2-A (for maximum past T) and Demo2-B (for present T).

Task 5.2 – Physical design of layout for component implantation (BA)

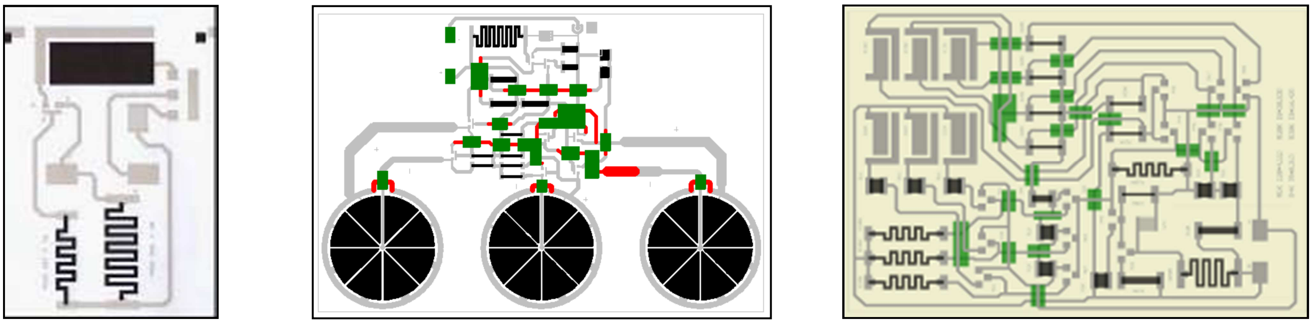
Each electrical design (only made of line connections and chips position) was validated by BA with a conventional (PCB) circuit. This conventional layout was used as the starting point (step 0) for the physical layout of the printed circuit. The physical layouts are progressively modified according to the following steps:

0- Conventional layout with only draws of conductive and insulating layers.
1- Circuit layout adapted to printed circuit dimensions.
2- Each chip area replaced by a surface corresponding to the future printed component.
3- Each chip connector replaced by the electrode layout of the associated printed component.
4- Physical layout associated to the other functional inks.

At each step, the conductive lines are arranged regarding physical constraints (components dimensions, electrode orientation, etc…).

Demo1. Development of the circuit layout on Demo1 (and the other demos) was made incollaboration between CTP (printing constraints) and BA (electronic constraints). The “physical design rules” were defined together for printed electronic on paper. These rules were very different to conventional electronic ones.

For each physical design reported in Table 3, BA & CTP proposed several layouts. The selected solution was decided by all the partners according to the other constraints (for example, display position inside the label was important for final physical aspect of the product). The validated layout was printed on industrial equipment. For Demo1, only the conductive silver ink and the resistive ink were printed at LT. At the end, the final physical design (Demo1-V4, Figure 24-a) took into account physical and graphic constraints of a real product.



a) b) c)

Figure 24: a) Demo 1- V4 printed on FS paper, b) Demo 2-V3 layout of industrial printed steps, c) Demo3 layout;
Color code: grey or red = conductive ink, black = resistive ink and green = insulator ink.

Demo2. The development of the Demo2 physical design was based on knowledge acquired on Demo1. However, introduction of new components induced new design rules and other developments:

- Locations of interconnections/bridges was not easy to define because they shouldn’t cover components that will be printed later on.
- The pixels of the EC display required a specific lines layout to split correctly the current flow.

The final design (Figure 24-b) took into account physical and graphic constraints of the real A0 poster.

Demo3. The physical dimension of Demo3 (Figure 24-c) was equivalent to an A4 format. It was four times larger than the one planned (A6 standard paper sheet) but it was not possible to make it smaller.

Task 5.3 – Components integration, lab testing and control

The complexity of the components integration required an iterative method. The printed components were introduced one after the other. The "ready to use" components were printed at industrial or laboratory level; then the other components were replaced by hybridized chips. The objective of this "hybrid circuit" was to identify problems linked to the "just introduced" component. When solved, the integration of this component was validated and the next component integration could start.

Demo1. Components integration started with resistor and conductive lines. Industrial printing of these two layers was validated at the early stage of the project. Reproducibility and value deviation during the trial were evaluated in detail by BA and ICS. The hybrid circuit had the expected electrical behaviour. They were presented in 2013 at LOPE-C in the OE-A booth for a competition.

The H_2S and the temperature sensors, and then the battery were introduced with success in the circuit (Figure 25a). Integration of EC- display showed electrical issues that lead to changes in the electrical design (resistor values in particular). The final fully printed Demo1 was composed by 2 steps made at industrial level (on LT machines) and 3 steps at laboratory level at TNO, UNL and CEA (Figure 25c).

a) b) c)

Figure 25: a) hybrid Demo1-V3.0 with printed T sensor and thin film battery; b) hybrid Demo1-V3.1 with printed T sensor and commercial EC-display; c) Demo1-V4 fully printed

Demo2. The same strategy was performed for the Demo2, thanks to the knowledge acquired in the Demo1 development. The final Demo2 was produced in 4 steps (lines, resistors and bridges) printed at LT at industrial level (Figure 1a) and 2 steps at laboratory level at TNO and CEA for the T sensor and the battery respectively. Chips were used as transistors because only one printed transistor failure prevents the full circuit to work.

Control. The image acquisition component of the inspection solution was reviewed in order to optimise the overall performance of the system for printed electronics applications. In order to achieve high contrast at all the print or production steps to be inspected, laboratory feasibility studies were performed on samples provided by partners. Depending on the material inspected, visible or ultra-violet light sources were deployed in combination with monochrome or colour line scan cameras.

Image acquisition parameters such as resolution and angular setting were optimised. Furthermore, contact image sensors (CIS) were evaluated as a valid way to perform inspection tasks in compact print machines that do not permit further components with large mounting volume. This work let to the definition and implementation of an inspection system based on line-scan cameras placed in the framework of a dynamic study at LT (image on the right side). The system, placed on a machine used to rewind the finished print, permitted due to its flexible design to record the afore on-line printed silver and carbon print steps in different conditions and allowed to reproduce lab findings in an industrial setting. The diffuse reflection image acquisition condition was the most suitable and the 50µm resolution was suitable considering current process variations and feature sizes.

1.3.6. - WP6. Flexible manufacturing process (LT)

Task 6.1 – Manufacturing process flow (LT)

The results of the lab-tests performed within WP3 and 4 were transferred into several series of test runs performed by LT and CTP on LT's machines. In 12 print sessions (trials LT01 – LT12), various aspects of the printing process were examined with the following goals:

1. Observation of conductive and various resistive inks' behaviour in relation to the machines,
2. Observation of specific paper behaviour in relation to the machines and electronic inks,
3. Optimisation of printing parameters for selected inks,
4. Optimisation of the printed patterns (lines, fingers, electrodes, resistive, etc.) in their consistency during production using the visual inspection system developed by ICS,
5. Production of dummy materials to use for the WP4 related task to hybridize TFB,
6. Printing Demo1, 2 and 3 in several versions and checking the electrical behaviour against the target values defined by BA
7. Generating a procedure for the layout of print plates in order to define the functional layout of the Demo and checking elements to control print quality during or after production.

Manufacturing process flow for Demo1

The process flow realised for Demo1 manufacturing is shown in the following schematic.

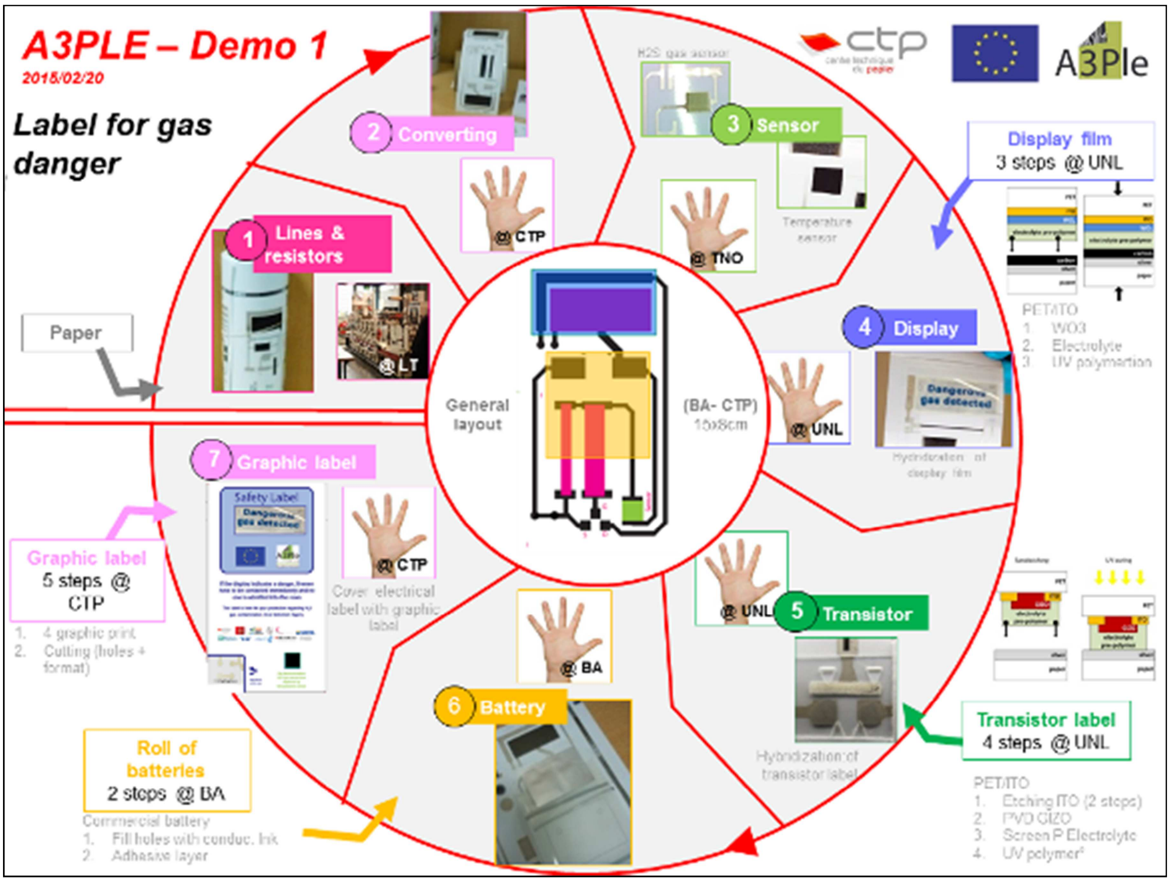


Figure 26: Process flow realised for Demo1 manufacturing

Each (numbered) step represents a production phase in the process flow. The images explain what is done by which partner and how the printing step is processed. Another picture shows the physical component.

Example: the 1st step is devoted to the printing of conductive lines and resistors. It is performed by LT on an industrial printing machine. Silver ink for conductive lines are grey while; resistive ink corresponds to the black colour layer. The 3rd step is devoted to the printing of the sensor. This step is produced at lab scale (hand image) at TNO directly on the label. Etcetera, until step 7 for the reporting of the graphic label.

The picture of the printed layout at the end of the process is shown in the centre of the diagram. Each component respects the colour code.

Converting (steps 2 and 7) and hybridization (steps 4, 5 and 6) steps could be made at industrial scale in the future, because they are linked to existing technologies. In the frame of the project, the hybridization at industrial scale was developed only for the batteries. This result may be adapted for transistor and display hybridization in the future.
The sensor printing (step 3), the battery roll preparation and the printing steps of the display film could be performed in LT's plant in the future. However, they couldn't be done at this moment due to technical or financial reasons.

Manufacturing process flow for Demo2

The process flow realised for Demo2 manufacturing is mainly based on knowledge developed for Demo1. However, the increase of the electrical circuit complexity requires interconnections (crossed conductive line without electrical connection). These "bridges" (step 2) are printed at industrial scale just after the printing of the conductive tracks and the resistors. The schematics of Demo2 follow the same logic as for Demo-1 above.

The following schematic details steps and components pictures for this Demo2.

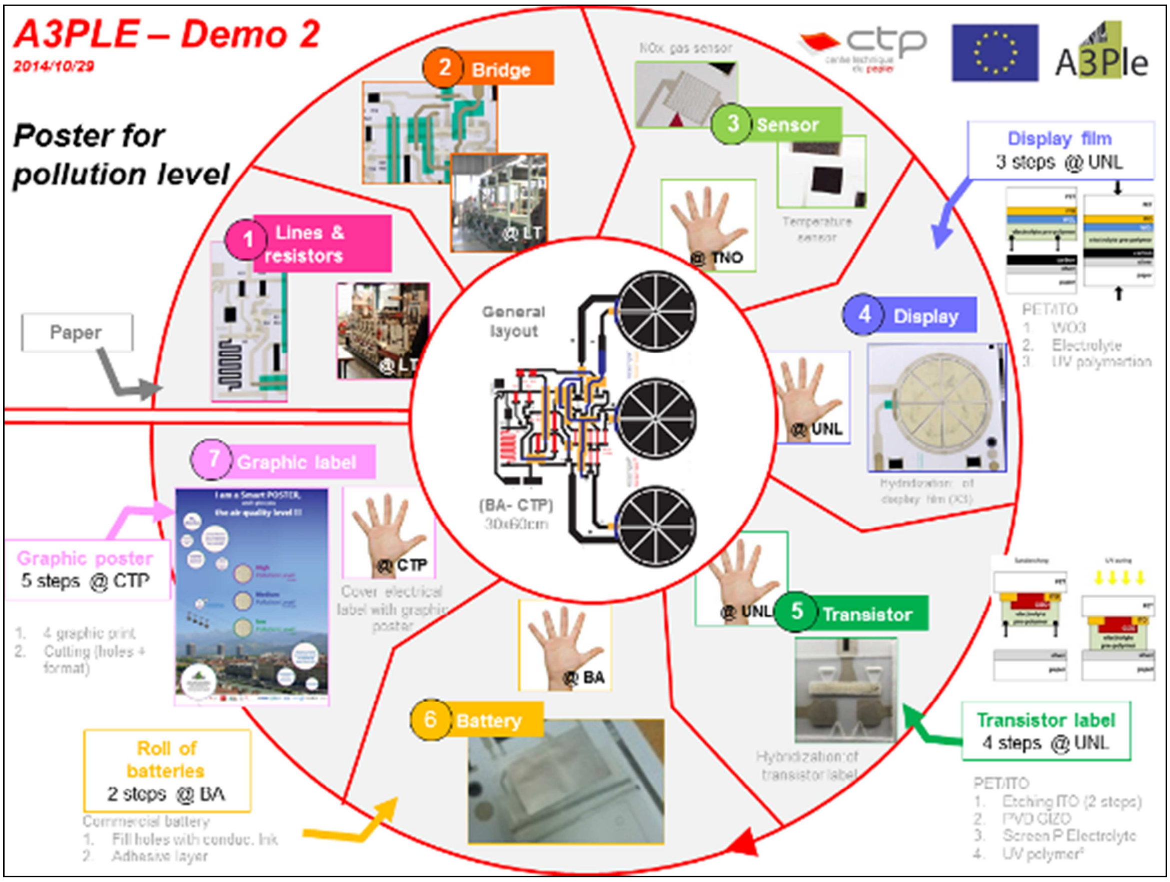


Figure 27: Process flow realised for Demo2 (and Demo3) manufacturing

Manufacturing process flow for Demo3

For Demo 3 the structure is very similar to Demo2 apart from the function of the memory and electrochromic display. The main differences are the final size of the functional label, the dimensions of the display and the increased number of components. The manufacturing process flow of Demo3 is the same as that of Demo2.

Task 6.2 – On-line quality control (ICS)

Developed algorithms and software modules were implemented into the ICS software infrastructure to generate an inspection application dedicated to the quality control of printed electronic circuitry. The below shown software infrastructure comprises of real-time inspection software and off-line inspection tools to control the quality of products and trace it over multiple production steps (Figure 28). In the context of the A3Ple project, this capability could be deployed to add multiple inspection stations at strategic production steps, i.e. not every print step needed to be inspected separately, but only those that mattered. For example, a combined inspection of the first silver and carbon print steps needs to be foreseen in order to control their quality before potentially opaque active materials are printed onto the sensor finger structure. This would impede short detection or circuit break detection.

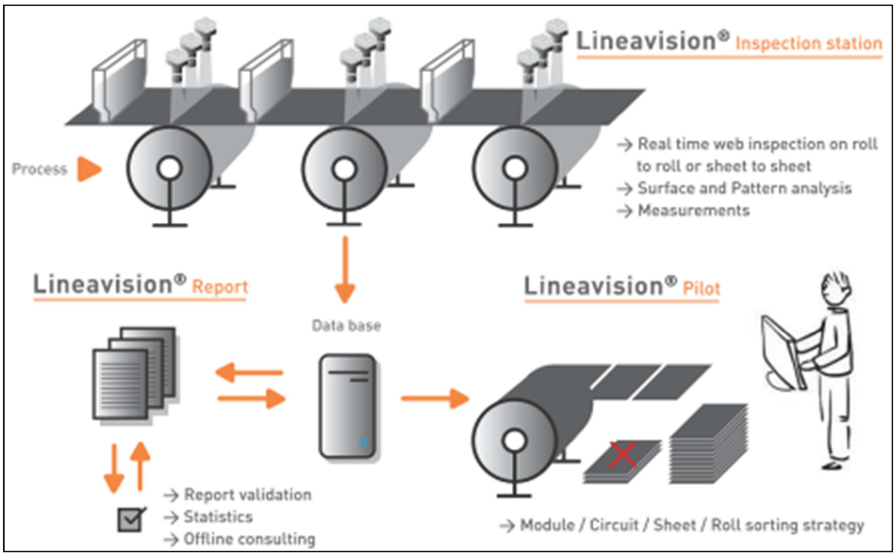


Figure 28: Inspection software and off-line inspection tools

The latest software version was successfully evaluated on the first silver and resistive inks printing steps of the different demonstrators as those were printed in longer print runs (task 6.1). Focussing on the finger structure of the sensor element, inspection settings permitted good and stable defect detection on the sensor element with a very high detection ratio for short defects in the sensor elements (Figure 29) and few false detection.

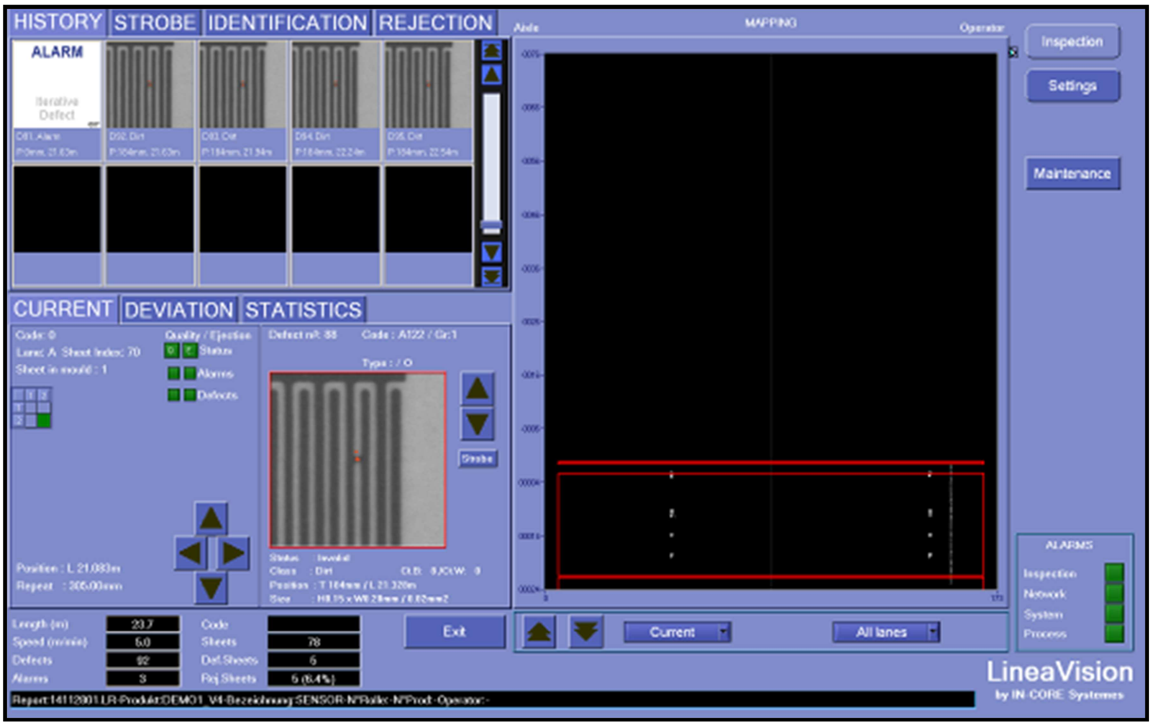


Figure 29: Screen capture of the inspection software.

1.3.7. - WP7. APPLE demonstrators (LT)

All the work performed in WPs 1-6 drove the state of art of printed electronics on paper at the end of the project. The goal was to demonstrate the production testing and evaluation of Demos1, 2 and 3 under industrial circumstances. The work demonstrated the principle of what the common printer can manufacture with his equipment and how this was made. It showed the results both from the point of production, eg the way to make the demos, and the economics behind it. Thus giving a good overview and set of information about the possibilities a common printer can expect if he considers the production of printed electronics on paper. The 3 Demos initially planned in the project were as below.

1. Environment & safety labels (A5-A6)	**2. Environment & advertising posters (A3-A1)**	**3. Smart packaging labels (A6-A7)**
		
Difficulty of demonstrators		
Low technological risk (small-size display)	Medium technological risk (large-size display)	Medium-high technological risk (small-size display and memory)

Chosen approach for the realization of WP7 – A3PIe Demonstrators
The demonstration per Demo was arranged as if the Demo was a real production order taken by LabelTech at IJsselstein to go to an End-User. The Demos were taken up in the production stream of the factory and treated as a normal job as part of the factory's planning and work flow.

The materials and equipment used for the 3 demos' manufacturing are summarized in Table 4. The industrial printing machines are presented in Figure 30 and Figure 31.

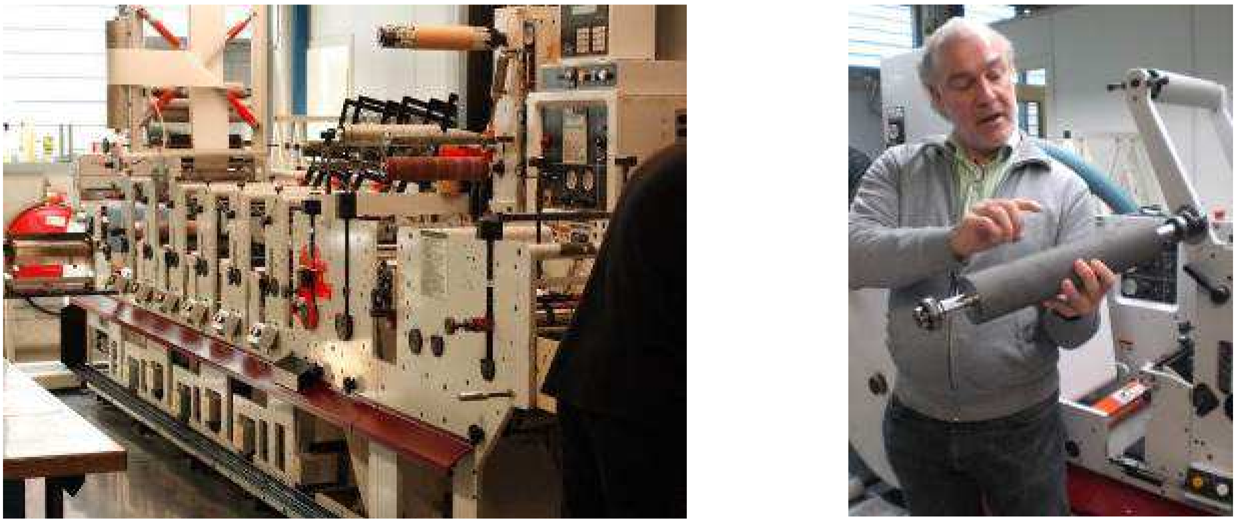
Table 4: Materials and equipment used for the 3 demos' manufacturing

		Demo1	**Demo2**	**Demo3**
Materials	Substrate: FS3 + one specific commercial paper as reference	X	X	X
	Ink-1: A commercial silver ink	X	X	X
	Ink-2: A resistive ink	X	X	X
	Ink-3: An isolator ink		X	X
	Ink-4: A commercial silver ink		X	X
	Adhesive (on a transfer roll)	X		
	TFB: Dummies and functional Thin Film Battery	X		
Equipments	Flexoprint: MA-2200 6-color Flexopress (Figure 30a)	X	X	X
	Rotary Screen (Figure 30b)		X	X
	Inspection: ICS-developed visual inspection by camera and software	X	X	X
	Finishing: table-top slitter / spooler	X	X	X
	Conversion: adhesion application and cutting to end format	X		
	Hybridization: LT-1 (dedicated conversion equipment)	X		
	End control: table-top slitter / spooler equipped with dedicated hybridization checker	X	X	X

Work plan for all Demos as common practice and reporting

Per demonstrator the following stages of production were performed:

1) Technical evaluation "How-to Make" and feasibility of production leading to a "Go/No-Go"
2) Registration of the job in the work flow / data system
3) Description of needed materials and tooling / Bill of Materials
4) Designation to specific production slot; machine number(s)
5) Preparation of the work; clearance to start
6) Production – 1st phase: building the Demo
7) Production – 2nd phase: running the job for the Demo
9) Production – 3rd phase: finishing the job for the Demo
10) Results – physical product for the Demo
11) Registration and evaluation of the job
12) Conclusion



a) b)

Figure 30: Industrial flexo printing machines used for the demos manufacturing: a) overview of the machine; b) Anilox roll for flexo printing

a) b)

Figure 31: a) Industrial screen printing machine, b) Inspection system developed by ICS installed on screen printing machine.

Task 7.1 – Production and testing of Demo1

Demo1 is an environment and safety label. The goal of Demo1 is to make an “on/off” device that gives information about the presence of a dangerous gas. The label can detect lethal H_2S gas in a room. However, for live demonstration in a show room a temperature sensor is used instead of the H_2S gas sensor.

a) b) c)

Figure 32: a) Transfer of resistive ink by flexo printing; b) Roll of Demo1 converted into adhesive labels; c) Final demonstrator fully printed: functional electronic label below the graphic label.

Task 7.2 – Production and testing of Demo2

Demo2 is an advertising poster. The objective of Demo2 is to distinguish 3 levels of gas content and informs which one is reached. It is a paper poster (A0 format) able to distinguish 3 gas levels and show the value reached instantaneously.

a) b) c)

Figure 33: a) Printing unit of ink n°1; b) Demo2 rolls produced during trial at LT; c) Final demonstrator fully printed: functional electronic label below the graphic poster.

During the international conference LOPEC (March 2015), final demonstrators were awarded by OE-A as the best demonstrator realized in the frame of a collaborative public funded project (Figure 1-b).

Task 7.3 – Production and testing of Demo3

Demo3 is a smart packaging label. Demo3 should measure temperature (T) at the moment and keep its past maximum value in memory. The physical dimension of Demo3 was equivalent to an A4 format. It was four times larger than the one planned (A6 standard paper sheet) but it was not possible to make it smaller.

1.4. - Potential impact

Benefit for paper industry. FS
During the recent years the declining real prices of paper products have been one of the main reasons for the paper industry's poor profitability. The results of the project may cause a renewal of the paper industry's products with more added-value functional products for new applications and markets. Unfortunately, although the demonstration was realized in the frame of the APPLE project, the demand from the market (end-users) must still emerge in order to make this new market opportunity become real sales volume for the paper industry.

Benefit for printing industry. LT
The new sustainable high-added value products demonstrated in the APPLE project, i.e. labels with integrated gas and temperature sensors, display functions, as well as the new and flexible manufacturing process, have been developed in a state where the used technologies are already used at industrial scale.
For the passive components (resistors, bridges), the printing technologies recommended are flexography and screen printings commonly used in the printing industry. The same technologies can be used for temperature and gas sensors.
Battery, and active components as display and transistors have to be hybridized. This hybridization step is also something commonly used in a printing shop. Furthermore, the manufacturing flow defined involves a roll to roll process.

The integration of components was performed on a manufacturing printing/converting small-scale production line. Such production lines are common for SMEs everywhere. The printing industry in the EU comprises some **121,000 firms** and employs some **714,000 people**. The turnover in the printing industry is about 88 billion EUR. The industry throughout Europe consists mainly of very small enterprises, as **90% of the graphic companies employ less than 20 persons**.

The manufacturing process developed in the frame of APPLE project is based on already existing printing lines. That means that the opportunities linked to the development of the new labels, posters, advertising don't require completely new production lines. The **existing printing lines can be adapted**, thanks to additional printing units (mainly flexible ink-jet units) and battery hybridisation in order to create new added-value products for the printing industry.

The different foregrounds of the project offer further development potential of new multi-functional fibre-based products that can **open new markets for the SME dominated sector of the printing industry**:

- Further applications in a growing market sector of integrated self-powered printable display and memory devices based on breakthrough technology using paper as passive and electronic material,
- Further industrial developments of the low-cost and flexible manufacturing concepts investigated in this project, with focus on printing technology.

Through the development on new manufacturing processes opening new markets, the APPLE project is expected to **increase the European printing industry turnover by 10% by 2020 and by 25% by 2025**, leading to the creation of highly-skilled jobs.

The market of flexible electronics is predicted to dramatically grow over the next years as shown in Figure 20 a). The growth over the longer timescale, from 2007-2027, will be very similar to the early growth of the silicon chip market in the same interval; the twenty years from 1978 to 1998 saw a similar starting and finishing value of sales of silicon chips. The Figure 20 b) confirms the high potential market for printable electronics materials.

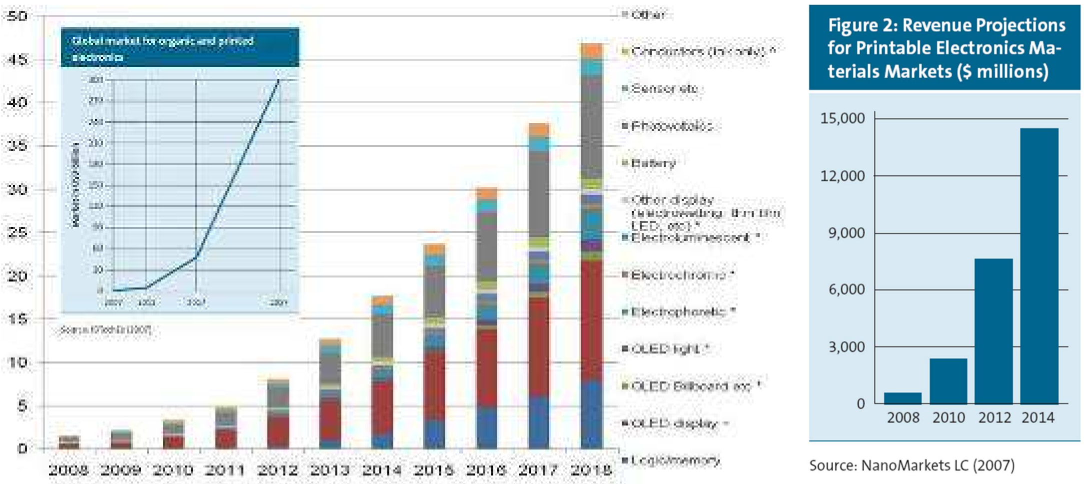


Figure 20: a) Estimated market of the main flexible electronics segments and market forecast to 2027
b) Revenue projection for printable electronics market

Unfortunately, even though the forecast for printed electronics showed a huge increase from 2008 until 2018, the printing industry has not been able to benefit yet of such an increase.

The explanation for this low benefit could be in the fact that applications and printed electronic products fulfilling needs from the market are still hard to realize in a one-on-one “Demand/Supply” relationship on end user level. The level of innovation in this industry is low and introduction of new products depends in principle on the demand by the end users or the possibility to show products to end users. The presence of printing industries in the EU and its direct contact with many end users should allow quick adoption of new products. This is not the case. The printing industry is a reactive business where demand is driving the reaction and propositions of the industry. The products can only be introduced into the market when they can be printed and shown. Due to lack of functional inks to turn into building blocks for electronic functions produced in print by ordinary, mainstream printers it is hard to move end users into adoption. But it proves the fact that end users need to see working products to motivate their adoption of the possibilities offered by the printers. It is a matter of availability of know-how on electronics combined with availability of functional inks.

LabelTech (LT) will get direct gain from the project. These results find their base in the capability developed in the project to handle materials and functional inks on standard printing equipment. The main benefit for LT in particular is directly linked to the confirmation triggered by the work in this project to be able to handle under standard industry conditions functional inks with other characteristics to print colour or contrast in patterns done in the industry for centuries. LT can now create in printed patterns with characteristics to facilitate every combination of conductive and resistive electronics. New markets showed up and new requests are “in the cocking pot”.

An example comes from recent contacts by LT with its end users. Coming from these contacts LT was able to show conductive tracks printed for the project and this lead directly to a new request to realize a new product based on simple printed electronics functions, proving the direct potential.

Another field of application directly coming as results to LT is the capability to create RFID antennae structures in various alternative ways based on techniques of material and ink handling realized during the project. Overall LT has moved forward by innovation.

Benefit for BA (electrical circuit designer)

The designing of electronic circuits printed on paper and functional inks is a novel and a very innovative matter, for this reason there aren’t mature software CAD tools to use in this field. The main innovation of this exploitation is the opportunity to use a well-tested commercial CAD software (developed to design standard PCB circuits based on discrete components and rigid substrates) to design very complex electronic circuits printed on paper. This goal has been reached thanks to the development of a

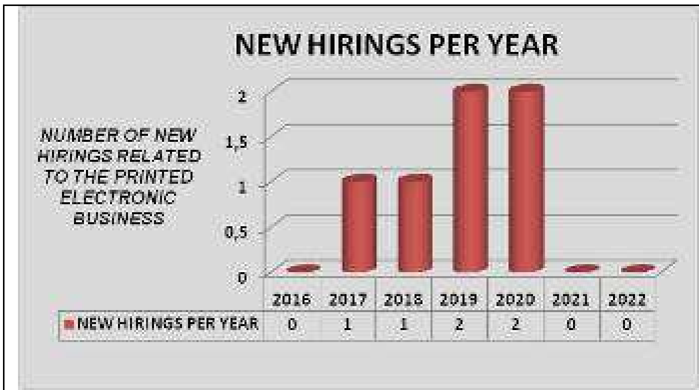
Designing Tool Kit that can be used to realize a library of electronic components to be printed on paper. Thanks to the electronics printed on paper it is possible to realize electronic devices in high volume and very low cost, without having to use a chemical etching process and with a low impact on the environment. The company will be able to provide these new services in its portfolio, to increase its turnover and its number of customers.

The following table shows an internal analysis based on new business activities (made in collaborations with other companies) and a new European project that our company has been involved in since May 2015.

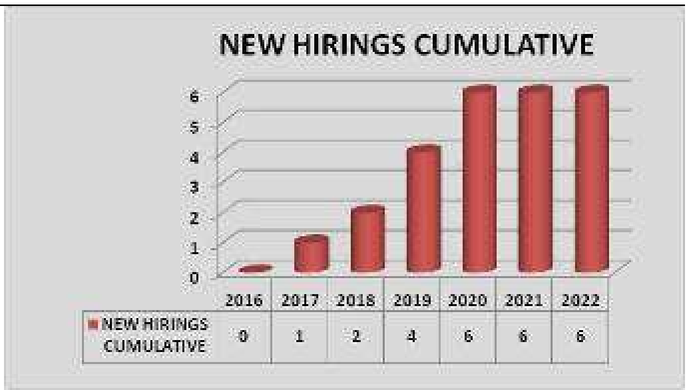
Year	2016	2017	2018	2019	2020	2021	2022
MM	6	6	0	0	0	0	0
New Hiring	0	1	1	2	2	0	0
New hiring C	0	1	2	4	6	6	6
Turnover	0%	5%	7%	10%	17%	20%	20%

MM: internal MM allocated to R&D for printed electronic development
New hiring: number of new hiring related to printed electronic business
New hiring cumulative related to printed electronic business
Turnover: Increase in turnover due to the activities related to the printed electronics

TURNOVER: increase due only to the activities related to the printed electronics



NEW HIRINGS PER YEAR: Number of new hirings related to the printed electronics business;



NEW HIRINGS CUMULATIVE: Number of new hirings related to the printed electronics business

NOTE: The internal R&D activities is specified only for the first years, in particular 2016 and 2017. This means that in the future years the Research and Developed activities will be carried out by the newly hired, for this reasons the internal MMS allocated for the future years is 0 and the future R&D activities are included in the turnover.

Benefit for Poly (ink supplier)
The added value of the APPLE project is to have a concentration of needs from substrates suppliers (papers), printing industry, electrical design and components (inks and active materials). For an ink supplier, the project offers a better knowledge of the requirements of each step of the smart label fabrication, in order to improve performance and specifications of the developed inks.
The constraint of the choice of the printing process is hard to solve from the point of view of an ink supplier. Due to the active materials requirements in printed components, many functional inks are hard to develop for flexography printing. Some inks require a high concentration of active materials to print an efficient component and the best printing process is screen printing. At the opposite, some active materials cannot be dispersed in a high concentration and resulting inks have a very low viscosity, more suitable for inkjet printing than flexography. The last point is the difficulty of drying printed inks. Many of them require a long time of drying which is not compatible with the high speed of flexography. An added

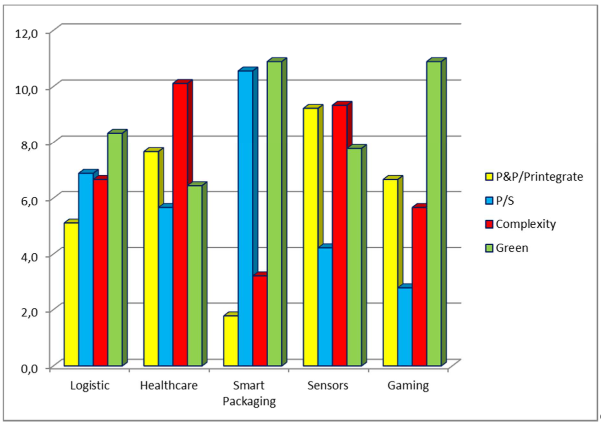
value of the project is that ink suppliers can develop different grades of their inks. A first product grade that fits well with the active material requirement can be developed, followed by other grades to be developed to fit better with the printing process needed by the project, such as flexography or screen printing.
Finally, each ink supplier has developed different grades of their functional inks which can be used by most of the printing processes on the market. Flexography appears to be the best choice to print fast a high quantity of labels but, actually, this process is little used in printed electronics.

Concerning the market of flexible electronics, one of the major parts for ink suppliers will be transparent conductive films, with the substitution of ITO in many devices like displays, OLED or photovoltaics. This market is estimated to be 4 billion $ in 2023 and more than 30 companies are actually involved, including many SME's, developing different technologies (copper and silver nanowires, organic polymers, metal grids, nanotubes…).

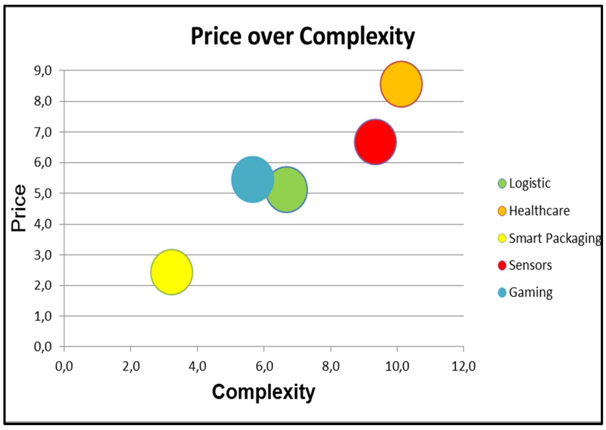
Benefit for Varta (battery supplier)

The printed batteries developed in the A3Ple project can also be used in other products. In a workshop these markets were analysed. Typical markets for Printed Batteries are:

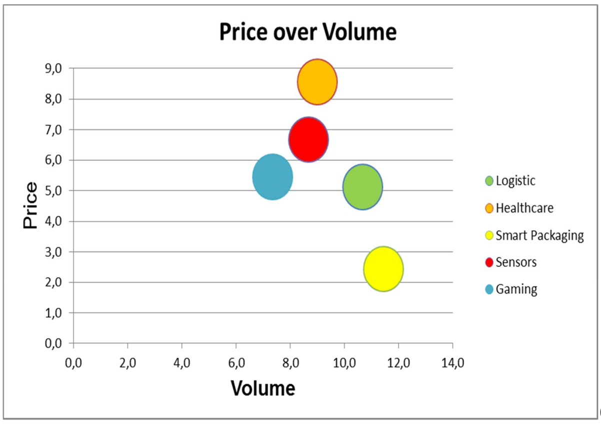
- Healthcare: Cosmetics & Healthcare, Wellness, Healthcare, active wound healing fabric, flexible body sensor, specific (single use) disposable Healthcare/Fitness/Medical devices
- Logistics:Logistics, akt. RFID, active Battery-assisted RFID, active RFID, cold chain, Logistics customized products, Supply and Cold chain, Logistics
- Smart Packaging: Smart Packaging, Smart Cards with electric functions, illuminated packages, intelligent Packackaging, Smart tags & textile, Wireless Communication
- Sensors: Sensors, Disposable Monitoring System, Wireless sensor systems, health monitoring, Disposable Long Life Ambient Sensors, Wireless sensor systems, building control, TFB Wall Paper – 5x2 m² → 200 Ah?
- Gaming: Gaming Products, Active Games, Spare Battery in the back of writing block (A4 → 1 Ah), Integration in Card Board & Paper, mobile product (foldable phone, …)



a)



b)



c)

Figure 34: a) Evaluation of the new markets in different categories ; b) Relation between Price and Complexity ; c) Relation between Price and Volume

These markets were evaluated in different categories.

- Pick&Place / Printegrate: For Smart Packaging (including greeting cards and gimmics) printegration is prefered, all others (especially sensors) prefer secondary cells.
- Primary / Secondary: Primary cells are preferred for Smart Packaging, gaming and sensors require secondary cells
- Complexity: The cells are allowed to be complex, except of Smart packaging. Here a simple solution is preferred
- Green: The green aspect is important for Smart Packaging and Gaming (perhaps because of the disposeability), for the other categories the green aspect is medium important

For a high-class manufacturer it is important to offer high complex devices for a high price. For VARTA it is important to enter markets like Healthcare and Sensors. These markets offer a high margin for low quantities. These markets seem to be present.

Benefit for ICS (quality control supplier)

The participation in the A3Ple project allowed ICS as a system integrator for optical inspection and traceability solution to improve multiple aspects of the existing LineaVision® inspection solution. Resulting is a LineaVision® printed electronics software application using algorithms and software features dedicated to the inspection of printed electronics on paper or other substrates.

Furthermore there have been improvements performed concerning the image acquisition components of the vision system. Novel monochrome and colour line-scan imaging sensors have been implemented, contact imaging sensors were tested and the range of ICS light source wavelengths was increased to the ultra-violet regime. These new means in the image acquisition part allowed us to optimise the optical image acquisition for print steps that are transparent in the visible light or of faint optical appearance, giving better detection results in multi-step processes and integration of vision systems under tight mechanical conditions.

The developed software components and most of the integrated hardware components are part of the industrial inspection solutions and are deployed in several installations for printed electronics and other applications. However, considering the market forecasts for the printed electronics sector, the printed electronics inspection application will show its real value when more PE production capacities are installed in the following years.

Benefit for RGP (packaging industry)

The marketing inquiry confirms that the food industry is well organised in regards to the cold chain and therefore there is no need for a new system for controlling the cold chain.

Nevertheless the results of A3Ple project could be interesting in order to use a label to apply on the pallets in order to be sure that that the cold chain is maintained in the different storage areas not systematically controlled.

The possibility to use a label on each packaging is only realistic if the price is low compared to the final cost of the product.

The 3 demonstrators have a potential to find a market. They have to be adapted to the real need of the consumer or the industries concerned. A specific label or poster needs to be developed according to the final request of the final end user or industry targeted. The A3Ple project opens several ways of development and probably huge markets in different directions.

Benefit for RTO (CTP, CEA, VTT, TNO, UNL)

In the APPLE project much know-how has been developed.

CTP. The technologies for producing memory fibre-based paper, for manufacturing and hybridizing batteries, for printing transistors and resistors, displays and gas sensors will be developed and scaled up for EU SME's printing companies. With the development of these new technologies, new wide markets will be addressed.

CEA. All the knowhow acquired during the A3PLE project on the battery components and manufacturing, will be used in a large R&D program performed by CEA for a major international chemical group. The objective of this new project is to develop flexible batteries for new wearable applications.

The technologies for manufacturing and batteries will be developed and scaled up for EU SME's printing companies. With the development of these new technologies, new wide markets will be addressed.

VTT. Considering VTT's development work in the A3Ple project, passive components (resistor, capacitor, conductor), and bridge interconnections are enabling components for almost all printed electronics systems. The development done in the A3Ple project enables plenty of further development and other electronics products and printed electronics systems on paper substrates since the work done in the project lead to a useful library of passive components to be utilized in different circuits.

TNO. TNO has learned extensively about the development of sensors and printing of these sensors. A lot of R&D efforts about such sensors are requested by both industrial and governmental entities. The development done in the A3Ple project enables TNO to give answers to these requests. Also plenty of further development on sensors together with the partners in A3PLE is possible. Last, the paper electronics roadmap was given a large boost with the A3PLE project and allows further development in the application of paper in security and communication products.

UNL. The work developed during A3Ple project was crucial in allowing UNL to implement and develop new strategies for printing oxide based electronic and electrochemical devices on paper. Before A3Ple, UNL was internationally recognized by transistors and memories on paper, but produced exclusively by PVD techniques. Printing techniques, and just inkjet, were being used only for the production of electrochromic (EC) displays. The constant focus of A3Ple in the up-scaling of all developments led UNL to develop EC displays using other large scale techniques, such as flexo or screen printing. The same happened for the oxide based transistors and memories: it was demonstrated they can now be printed, with a clear identification of barriers and challenges towards fully printed devices. Finally, all the collaborative work performed with all partners also contributed to strength the UNL knowhow on the topic of "paper electronics". All this was crucial in creation of new background (or even future IP) with strong impact in the participation in other collaborative research projects.

1.5. - Public website address

http://www.a3ple.eu/

2. - Use and dissemination foreground

One of the most relevant dissemination actions performed by the consortium along the project was the organization of symposia and conferences. In 2013, partners UNL, CTP, TNO and VTT were involved in the organization of a symposium at the prestigious European Materials Research Society (EMRS) Fall Meeting in Warsaw. The symposium topics were related to the use of paper in electronic devices and joined the international scientific community dealing with this topic. This was a great opportunity to present and disseminate the project activities as well as to discuss with other research groups the results achieved. A new edition of this symposium was organized by A3Ple partners again at the EMRS Spring Meeting in 2015, in Lille, France.

Symposium in Warsaw 2013

Symposium in Lille 2015

In March 2015 the A3ple consortium organized a conference, as planned in the DoW. In order to maximize the impact, it was decided to organize it in parallel with the LOPEC 2015, the most prestigious event related with printed electronics. Similarly to what happened for the symposia organized at EMRS, the organization took this opportunity to invite also another FP7 project related with paper electronics (ROPAS) to participate in the event and to present the latest results achieved The conference, combined with the presence at the VARTA and OE-A booth (A3ple was also present in 2013 and 2014) and the presentation of some demonstrators, made the presence at LOPEC 2015 a great dissemination action of the A3Ple project

A3Ple conference

A3Ple demonstrators at LOPEC 2015

During the entire project, BA was very active in organizing press conference and promoting many dissemination and popularization actions with the Italian local media in order to present the A3ple project and the activities being developed along the project. The copies of the publications resulting from these actions can be found in the periodic reports, as well as the activities of other partners.

Apart from all these actions, the consortium was very active also on the publications (either scientific or informative) and also participations in conferences and workshops. The detailed list is provided in the following tables.

2.1. - Section A: List of scientific publications and List of dissemination

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
1	Complementary Metal Oxide Semiconductor Technology With and On Paper	Rodrigo Martins et al.	Advanced Materials	23	Wiley		2011	4491-4496	DOI: 10.1002/adma.201102232	No
2	Electronics with and on paper	Rodrigo Martins et al.	Physica Status Solidi RRL	9	Wiley		2011	332-335	DOI: 10.1002/pssr.201105247	No
3	Microstructure control of dual-phase inkjet-printed a-WO3/TiO2/WOX films for high-performance electrochromic applications	P. Wojcik.et. al	Journal of Materials Chemistry	22	RCS		2012	13268-13278	DOI: 10.1039/c2jm31217d	No
4	Recyclable, Flexible, Low-Power Oxide Electronics	Rodrigo Martins et al.	Advanced Functional Materials	23	Wiley		2013	2153-2161	DOI: 10.1002/adfm.201202907	No
5	The future is paper based	R. Martins *et al*	SID journal		SID		2014		http://informationdisplay.org/IDArchive/2014/MarchApril/FrontlineTechnologyPaperBased.aspx	Yes
6	The influence of fibril composition and dimension on the performances of paper gated oxide transistors	Luis Pereira et al.	Nanotechnology	25	IOP		2014	094007	DOI: 10.1088/0957-4484/25/9/094007	No
7	Nanocrystalline cellulose applied simultaneously as the gate dielectric and the substrate in flexible field effect transistors	D. Gaspar et al.	Nanotechnology	25	IOP		2014	094008	DOI:10.1088/0957-4484/25/9/094008	No
8	Tailoring nanoscale properties of tungsten oxide for inkjet printed electrochromic devices	P. Wojcik.et. al	Nanoscale	7	IOP		2015	1696-1708	DOI: 10.1039/c4nr05765a	No

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
N.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	Oral presentation at conference	UNL	The mfo influence on paper TFT performance,	September 20th, 2011	EMRS 2011 Fall Meeting, Warsaw, Poland		Around 750 persons from Academia and researchers	All
2	Poster presentation at conference	UNL	Dependence of oxide paper TFTs performance on the channel layer thickness,	January 30th, 2012	ITC conference 2012, Lisbon, Portugal		Around 150 persons from Academia and researchers	All
3	Oral presentation at conference	UNL	High performance all-solid-state electrochromic devices based on inorganic inkjet printed films and plastic crystal/polymer/metal oxide electrolyte,	May 15-1th, 2012	EMRS Spring Meeting 2102, Strasbourg, France		Around 4000 from academia and industry	All
4	Oral presentation at conference	UNL	High Performance All-solid-state Electrochromic Devices Based on Printed Inorganic Films and Thermosetting Solid State Electrolyte,	November 25-30th, 2012	MRS Fall Meeting, 2012, Boston USA		Around 5000, Academic, Industrial	All
5	Poster presentation at conference	UNL	Metal Oxide Nanoparticle Engineering for Inkjet Printing Technology: Nanostructured WO_x Synthesis for Electrochromic Application	November 25-30th, 2012	MRS Fall Meeting, 2012, Boston USA		5000, Academic, Industrial	All
6	Plenary presentation at conference	UNL	Towards high performance printed solid state inorganic electrochromic,	25-27th May 2013	Materiais 2013, Coimbra, Portugal devices		Around 300 from academia and researchers	All
7	Poster presentation at conference	CTP	Resistors for DC- circuit printed on papers: design, method and characterizations	16th June 2013	LOPE-C 2013, Munich, Germany		Around 2000 form industry and technical center	All
8	Poster presentation at conference	BA	Electronic label printed on paper, Transducers –	June 16-20, 2013	Eurosensors 2013, Barcelona, Spain		Around 500 from academia and industry	All
9	Invited presentation at conference	UNL	Paper electronics: a challenge for the future,	May 26th, 2013	SID Display Week, Vancouver, Canada		Around 3000 from academia and industries	All

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
N.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
10	Public articles	Polypore	Polypore participe au programme européen A3PLE	2013	Le papetier francais, programme européen A3PLE	D	3 500	FR
11	Poster presentation at conference	CTP	Resistors for DC- circuit printed on papers: design, method and characterizations	September 15-18th, 2013	EMRS 2013 Fall Meeting, Warsaw, Poland		Around 850 persons from Academia and researchers	All
12	Oral presentation at conference	CTP	Electrical and printing integration for printed electronic on paper: Process, method and characterizations,	September 15-18th, 2013	EMRS 2013 Fall Meeting, Warsaw, Poland		Around 850 persons from Academia and researchers	All
13	Oral presentation at conference	TNO	Roll to roll paper sensors,	September 15-18th, 2013	EMRS 2013 Fall Meeting, Warsaw, Poland		Around 850 persons from Academia and researchers	All
14	Oral presentation at conference	UNL	Fully Printed Electrochromic Display on Paper,	September 15-18th, 2013	EMRS 2013 Fall Meeting, Warsaw, Poland		Around 850 persons from Academia and researchers	All
15	Oral presentation at conference	UNL	Influence of paper substrates on the performance of oxide based FETs,	September 15-18th, 2013	EMRS 2013 Fall Meeting, Warsaw, Poland		Around 850 persons from Academia and researchers	All
16	Oral presentation at conference	UNL	Tuning of on-voltage on planar dual gate oxide-based transistors on paper,	September 15-18th, 2013	EMRS 2013 Fall Meeting, Warsaw, Poland		Around 850 persons from Academia and researchers	All
17	Public articles	CTP	Presentation of A3PLE project	Juanary, 2014	Lettre de la Copacel (Copacel letters)	D	Public	France
18	Oral presentation at conference	UNL	Paper electronics and criativity of the future sustainable electronics	11th February 2014	JORTEC, Universidade Nova de Lisboa, Caparica		Around 150 persons from Academia and researchers	Portugal
19	Oral presentation at conference	UNL	Beyond conventional materials: metal oxide semiconductors and cellulose paper	19 - 21 February 2014	Università La Sapienza, Rome		Around 750 persons from Academia and researchers	Italy

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
N.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
20	Oral presentation at conference	UNL	The Bright Future of Materials: From basic Knowledge to the Industry	6th March 2014	IV ENEM 2014, Caparica		Around 500 from academia and industry	All
21	Public articles and interviews	BA	Presentation of A3PLE project*	Mars/April 2014	Various local and national Italian newspapers and TV chains*	D	Public	Italian
22	Seminar Training	CTP	Printed electronic for printing industry, Douai, France	April 12 & 13 2014	Seminar part 1: Training		24 persons form 8 companies	France
23	Seminar Training	CTP	Printed electronic for printing industry, Douai, France	Mai 12 & June 3 2014	Seminar part 2: Brainstorming		24 persons form 8 companies	France
24	Oral presentation at conference	CTP	Electrical and printing integration for printed electronic on paper: Process, method and characterizations,	May 26th-30th, 2014	Technical sessions, LOPEC 2014, Munich, Germany		More than 3000 attendees from academia and industry	All
25	Oral presentation at conference	UNL	Printable thermosetting composite solid-state electrolyte for flexible electrochemical devices,	May 26th-30th, 2014	EMRS 2014 Spring Meeting, Lille, France		More than 3000 attendees from academia and industry	All
26	Oral presentation at conference	UNL	Metal Oxide Nanoparticle Engineering for Printed Electrochemical Applications,	May 26th-30th, 2014	EMRS 2014 Spring Meeting, Lille, France		More than 3000 attendees from academia and industry	All
27	Oral presentation at conference	UNL	Printable materials for low-cost flexible electrochromic devices,	May 26th-30th, 2014	EMRS 2014 Spring Meeting, Lille, France		More than 3000 attendees from academia and industry	All
28	Poster presentation at conference	UNL	Hydrothermal synthesis of GIZO nanoparticles for solution-processed electrolyte-gated transistors,	May 26th-30th, 2014	EMRS 2014 Spring Meeting, Lille, France		More than 3000 attendees from academia and industry	All
29	Oral presentation at conference	UNL	CMOS Oxides used for Amplifiers and Logic Circuits on Paper	June 15-20, 2014	6th Forum on New Materials, Italy		Around 1000, Academic, Industrial	All

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

N.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
30	Oral presentation at conference	UNL	Advanced Materials and nanotechnologies for a better life	July 2-4, 2014	5th International Conference in Advanced Nanomaterials, Aveiro, Portugal		Around 500 from academia and industry	All
31	Oral presentation at conference	UNL	The (R)evolution of conventional materials: metal oxides and cellulose	24-30 August 2014	IUMRS, ICA 2014, Fukuoka, Japan		Around 5000 from academia and researchers	All
32	Booth with poster and samples	CTP	A3Ple project presentation	September 05-06th 2014	Transfert Innov'Eco, Paris, France		30 SMEs + 28 organisation or media	France
33	Oral presentation	CTP	A3Ple project presentation	September 9th - 11th, 2014	Foresight Forum from 4M2020: Micro and Nano Manufacturing for H2020, Grenoble, France		20 project leader of FP7	France
34	Plenary talk at conference	BA	The (re)evolution of conventional/old materials: metal oxides and cellulose	September 15 - 19, 2014	14th International Conference on Plasma Surface Engineering, in Garmisch-Partenkirchen, Germany		Around 500 from academia and industry	All
35	Plenary talk at conference	UNL	Advanced functional paper for electronics and bio sensing applications	12-17 October 2014	5th International Symposium on Transparent Conductive Materials, TCM2014, Platanias-Chania, Crete, Greece		Around 300 from academia and industry	All
36	Invited presentation at conference	UNL	Tungsten oxide thin films and nanoparticles: application to electrochemical devices	October 12-17th 2014	TCM2014, Crete, Greece		More than 200 attendees from academia and industry	All
37	Seminar Training	CTP	Printed electronic for printing industry, Grenoble, France	14 October 2014			3 companies	France
38	Oral presentation at conference	UNL	Advanced Materials: from Elements in Products to the Industrial Revolution of the Future,	October 24-27, 2014.	2nd International Conference of Young Researchers on Advanced Materials, IUMRS-ICYRAM 2014, Hainan Convention & Exhibition Center, Haikou, China,		Around 500 young researchers	China

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
N.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
39	Oral presentation at conference	CTP	The European Union's programme for Research and Innovation SIM	25 November 2014	Brussells, Belgium		Around 2000 form industry and technical center	All
40	Kakemono presentation at conference	CTP	A3Ple project presentation	November 25th to 27th, 2014	European Paper Week 2014, Brussels, Belgium		More than 300 attendees from academia and industry	All
41	Oral presentation	CTP	How paper becomes smart	March 4th 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
42	Oral presentation	Poly	Functional inks	March 4th 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
43	Oral presentation	TNO	Printed Sensors	March 4th 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
44	Oral presentation	CEA	Thin Film batteries for Autonomous Paper Printed Products	March 4th 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
45	Oral presentation	UNL	Development of printable WO3 electrochromic displays	March 4th 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
46	Oral presentation	VTT	Printing of multilayer connectors	March 4th 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
47	Oral presentation	BA/CTP	From circuit design to printable layout and integration	March 4th 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
N.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
48	Oral presentation	ICS	Optical inspection solution for printed electronics on paper	March 4^{th} 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
49	Oral presentation	VARTA LT/FS	Industrial perspective of the production of printed sensors	March 4^{th} 2015	A3ple final conference, LOPE-C 2015, Munich, Germany		More than 40 attendees from academia and industry	All
50	Plenary talk at conference	UNL	Materials for a new window of the ICT age	17 April 2015	3rd Dresden Nanoanalysis Symposium,		Around 300 from academia and industry	All
51	Oral presentation	ICS	Continuous Monitoring of Manufacturing Processes Dedicated to Printed Electronics	April 28-29^{th} 2015	Printed Electronics Europe 2015, Berlin, Germany		More than 2000 attendees from academia and industry	All
52	Oral presentation	CTP	How paper becomes smart?	May 06-05^{th} 2015	International Forum of POLYNAT industries (Carnot), Grenoble, France		20 international companies (Taiwan delegation) and 7 academia labolatories	Fr Taiwan
53	Oral presentation	UNL	Influence of the fibrils on the performance of oxide based FETs using paper as dielectric	May 11^{th}-15^{th} 2015	EMRS Spring 2015 Symposium, Lille, France		More than 3000 attendees from academia and industry	All
54	Oral presentation	CTP	How paper becomes smart?	May 11^{th}-15^{th} 2015	EMRS Spring 2015 Symposium, Lille, France		More than 3000 attendees from academia and industry	All

* http://lameziatermenews.it/citta/38-citta/11456-lamezia-ricerca-apple-bioage-organizza-meeting-europeo-tra-scienziati-e-multinazionali.html
http://www.lameziaclick.com/attualita/2014_03_17/a-lamezia-la-bioage-organizza-meeting-europeo-tra-scienziati-e-multinazionali_466
http://www.lameziainstrada.tv/ http://www.strill.it/index.php?option=com_content&view=article&id=191582:lamezia-meeting-internazionale-scientifico-organizzato-da-bioage
http://lameziatermenews.it/citta/38-citta/11456-lamezia-ricerca-apple-bioage-organizza-meeting-europeo-tra-scienziati-e-multinazionali.html
http://www.cn24tv.it/news/85435/lamezia-bioage-organizza-meeting-europeo-tra-scienziati-e-multinazionali.html
http://www.lameziaoggi.it/lamezia.asp
http://www.lameziaclick.com/attualita/2014_03_24/domani-a-lamezia-la-bioage-organizza-meeting-europeo-tra-scienziati-e-multinazionali_654
http://www.ntacalabria.it/catanzaro/lamezia-terme-meeting-apple.html http://www.scoopsquare.com/post/it/2014/03/19/18/2104687-lamezia-terme-meeting-internazionale-apple.html#.UyxM2gh5Njt

2.2. - Section B

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights:	Confidential YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patent	NO	2015-04-29	EP 2866285 A1	Gedruckter Ableiter für Li-Batterie	VARTA Microbattery GmbH
Patent			The possibility of filing a patent is under evaluation	Thermistor	TNO

LIST OF FOREGROUNDS								
Type[3]	**Description of exploitable foreground**	**Confidential YES/NO**	**Foreseen embargo date**	**Exploitable product(s) or measure(s)**	**Sector(s) of application**[4]	**Timetable, commercial or any other use**	**Patents or other IPR exploitation (licences)**	**Owner & Other Beneficiary(s) involved**
CE	Paper for printed electronic	No		Paper for roll-to-roll printing of functional material by Flexo, screen and inkjet technology	Printed electronics (general) Labels, smart objects, packaging etc.	Depending on market development , estimated 3 to 5 years from now	Internal know-how at FS	O: FS B: TNO, VTT, LT
GA ESI	Know how in printed electronic	No		New R&D projects Consultancies for paper and printing companies		2013		O: B: all
GA	Passive components for electrical circuit	yes		Connection lines Resistor Via, bridges Capacitor		Use in other projects and development already ongoing	no	O: VTT & CTP B: LT
GA CE	Printing of Current collector for battery	YES	2018-12-31	- Recipe for printed CC on Pouch type packaging - Screening of substrate materials	none	Same as printed battery	Not patentable	O: VARTA B: LT, CEA

[19] A drop down list allows choosing the type of foreground: GA (General advancement of knowledge), CE (Commercial exploitation of R&D results), E-R&D (Exploitation of R&D results via standards), E-EU (exploitation of results through EU policies), ESI (exploitation of results through (social) innovation).

[4] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

LIST OF FOREGROUNDS								
Type[3]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[4]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
GA CE	Ink as primer layer	Yes		Surface preparation for conductive inks	C26 - Manufacture of computer, electronic and optical products	2016		O: Poly B: LT
GA CE	Transparent conductive ink	Yes		Transparent conductive films or conductive lines	C26 - Manufacture of computer, electronic and optical products	2016		O: Poly B: LT
GA CE	Manufacturing of roll battery	No	NA	Knowhow and experience on battery hybridization	ODMs and EMSs	2017	No	O: CEA, Varta, LT B: Varta, LT
GA CE	Battery active cell structure and material	Yes	NA	Knowhow for development of efficient conformable power source	Conformable batteries	2018	No	O: CEA B: CEA, Varta, LT
GA CE	Printed NO_2 sensor	No	NA	Very sensitive flexible NO_2 gas sensor on paper	sensors	2020	No	O: CEA B:
GA CE	Printed temperature sensor			The possibility of filing a patent is under evaluation	sensors			O: TNO B: LT
GA CE	Printed H_2S sensor				sensors			O: TNO B: LT
GA CE	Printed multicomponent films	No	NA	Printed electrochromic displays and transistors	Flexible and transparent electronics	2018-2020	No	O: UNL B: CTP
GA CE	Visual inspection for printed electronic	No	NA	Inspection solution for printed electronics with improved image acquisition	R2R and S2S printing and coating processes	First installation in 2014	Internal know-how at ICS	O: ICS B: LT

LIST OF FOREGROUNDS								
Type[3]	Description of exploitable foreground	Confidential YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[4]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
GA CE	Software to design electronic circuits for printed electronic and to convert these into printing form	NO		Designing services provided for other companies, based on: 1) Development of a software library to be used with a conventional Electronic CAD to design and route electronic circuits based on distributed printed components (resistors, capacitors, EC display, sensors, transistors) to be printed on several flexible substrates (paper, plastic, Kapton, PI, PET, etc) 2) Development of a simple end powerful software tool to design the shapes of passive and active components to be printed with special functionalized inks.	Flexible and transparent electronics, Electronics printed on paper and all Flexible substrate.	2018-2019	The patent is not request	O: BA B: LT, CTP
GA CE	Label type Demo1, Poster type Demo 2, Label type Demo 3	Yes	2016	Demonstrators are not yet exploitable but the knowledge to make them and the way of working with functional inks is exploitable	Electronic industries; printing industries, logistics, packaging, healthcare, etc…	Some results already commercialized	No But valuable knowhow!	O: LT B: All A3Ple partners

2.2.1. - Paper for printed electronic (FS)

Purpose of the foreground
The purpose of the foreground is the development of optimized paper substrates for the manufacturing of the demonstrators targeted in A3Ple project: Paper with adjusted smoothness, chemical pureness and absorption / porosity properties

How the foreground might be exploited, when and by whom
FS will deliver to printing companies interested in the production of printed electronic products.

IPR exploitable measures taken or intended
2 (background) patents are pending 1 US granted up to now

Further research necessary, if any
Paper substrate is "technical ready" on lab / pilot / manufacturing scale. There is a need for Business development estimated to 0,5 Mio.€/year for 3 - 5 years.

Potential/expected impact (quantify where possible)
The forecast market is estimated between 1 to 5 M€. FS is already ready to supply the printing industry but the market does not developed as fast as forecasted at the start of the project. Time for commercial use is estimated to be between another 2 and 5 years.
The price of the special paper is around 2 € / m² (2-4 times more expensive than normal paper), compared to 4 – 5 €/m² for plastic foil. Furthermore paper based substrates show several technical (carbon foot print, mechanically, printability) advantages over most plastic film.

2.2.2. - Know-how in printed electronic (LT, CTP and other RTOs)

Purpose of the foreground
The purpose of the foreground is to be able to define according to the specifications of a printer's customer the manufacturing, printing and converting flow that will enable to produce on a paper base substrate a new type of product on an industrial printing line. This new type of paper product leads to new functionalities with the possibility to measure specific properties via a specific sensor, and to show the measured value via a display. These functional components are efficient thanks to the design of an optimised electrical circuit and the supply of the required energy via a thin battery.

How the foreground might be exploited, when and by whom
CTP is able to transfer to any printer the methodology needed to develop a printed electronic paper product that needs the use of any of the components developed in the frame of the project.
VTT is going to exploit the results internally in several applications linked to electronics printing.
TNO is using the knowhow for making printers and graphical companies aware of the new products and opportunities that paper electronics is generating.

IPR exploitable measures taken or intended
None.

Further research necessary, if any
Further research is needed in order to optimise the manufacturing steps for the development of new specific end-user products that are targeting functionalities different to those developed within the project. R&D projects are needed to get rid of bottlenecks already identified (for example the production of transistors).

Potential/expected impact (quantify where possible)
For CTP and TNO, the development of new markets for the printing industry.

2.2.3. - Passive components (VTT, LT, CTP)

Purpose of the foreground
The printing of connection lines, electrodes or pads for the active components, resistor, via bridges, multilayer circuit and capacitor. These components are either flexo or screen printed.

How the foreground might be exploited, when and by whom
VTT is going to exploit the results internally in several applications linked to electronic printing.
CTP is going to exploit the results in all the R&D projects and consultancy.
LT will exploit the results linked to the bridges printing.

IPR exploitable measures taken or intended
No actions.

Further research necessary, if any
Continuous development for better conductivity, better resolution, lower cost, lower environmental burden.

Potential/expected impact (quantify where possible)
All these components are essential for printed electronics applications, but quite a small part of the total market size. They are enabling technologies needed for other applications but they cannot be commercialized as identified products.

2.2.4. - Printing of current collector for battery (CEA, Varta, LT)

Purpose of the foreground
Experience in better substrate and current collectors CC. These can be used for all printed batteries from different systems (Zinc/Carbon, Nickel/Metal Hydride as well as Lithium-Ion LIB). Recommendation for optimised solutions. Among these the printing of brass powder as CC for contact must be outlined.

How the foreground might be exploited, when and by whom
It will be used by companies able to print small Lithium-Ion batteries. This could also possibly be used for large batteries. It is estimated that approximately 1 Million € of investment is required for supplying all the vehicle market.

IPR exploitable measures taken or intended
A patent is pending

Further research necessary, if any

Potential/expected impact (quantify where possible)

2.2.5. - Ink as primer layer (Poly)

Purpose of the foreground
Primer layer to avoid locally moisture at the paper surface in order to optimize interactions between the substrate and a printed functional ink. The ink can also be used in other applications: 1) insulate ink and 2) UV curing inkjet ink.

How the foreground might be exploited, when and by whom
Poly will supply companies dealing with printed electronics technology. The cost for Poly to upscale technology from lab to industrial scale is estimated in the range of 85 000€

IPR exploitable measures taken or intended
No specific action

Further research necessary, if any
None. In 2014 the development of the ink was already achieved and the product could have been able to be commercially delivered since with the investment mentioned before.

Potential/expected impact (quantify where possible)
he ink cost estimated at the moment reaches 1000 €/l. This cost can decrease if the market demand increases. According to IDTechEx study, the market of printed and flexible electronics is expected to reach 73 billion $ in 2025.

2.2.6. - Transparent conductive ink (Poly, UNL)

Purpose of the foreground
This ink is used to make a transparent conductive film with a simple process (inkjet), at low cost (organic material) and a high flexibility. The ink can replace advantageously ITO.

How the foreground might be exploited, when and by whom
Poly will be able to supply companies dealing with printed electronics technology. The cost to upscale technology from lab to industrial scale is around 390 000€. The commercial ink could be on the market in 2016.

IPR exploitable measures taken or intended
No specific action

Further research necessary, if any
Further development is needed in order to increase the ratio transparency/conductivity of the ink.

Potential/expected impact (quantify where possible)
The ink cost estimated at the moment reaches 4000 €/l. This cost can decrease if the market demand increases. According to IDTechEx study, the market of transparent conductive films is expected to reach 4 billion $ in 2023.

2.2.7. - Manufacturing method for the roll of batteries (CEA, Varta, LT)

Purpose of the foreground
Know-how and experience in the development of a R2R process allowing the battery hybridization in a continuous way. This leads to available batteries to be hybridized in a continuous way onto flat applications such as smart tags, smart cards, posters, etc…

How the foreground might be exploited, when and by whom
This acquired knowledge is going to be used in further projects linked to continuous manufacturing and/or integration processes.
Varta, LT, and battery manufacturers can exploit the foreground.

IPR exploitable measures taken or intended
Patents may be taken if later on, the laboratory results transferred at pilot scale lead to a potential exploitable foreground.

Further research necessary, if any
The demonstration is quite done at the lab scale. Adaptation, improvement and probably modifications will be necessary to a transfer to an industrial scale. As a consequence, investigations on a pilot line will have to be envisioned. The cost estimation of such a transfer is at least 2M€.

Potential/expected impact (quantify where possible)
The market for this manufacturing method is Li-ion battery manufacturers, but they are mainly located in Asia. Some industrials such as Varta and European SMEs wishing to enlarge their market can use the technology. The use of TFBs is already required: for instance, several millions of active cards (with primary battery) are sold per year (financial domain). The Near Field Communication technology is being developed strongly

2.2.8. - Battery: active cell structure and materials (CEA, Varta)

Purpose of the foreground

The foreground concerns high energy density batteries that are rechargeable, flexible and capable to withstand shocks. Various formats of thin and flexible batteries from 1mAh to several hundreds of mAh can be produced.

How the foreground might be exploited, when and by whom

Battery manufacturers will exploit the foreground and provide the different users of thin batteries (printers for electronic printing applications, ….)

The investment required to be able to produce at industrial scale will probably be more than 1.5M€, including improvement of the battery technology in terms of materials and architecture.

IPR exploitable measures taken or intended

Patents on materials, architecture during the new R&D program launched on the conformable batteries

Further research necessary, if any

Optimization of the materials and architecture for improved properties.

Potential/expected impact (quantify where possible)

The aimed market concerns wearable devices (bracelets …) representing 50 to 250M€ in 2018, and cosmetic and/or healthy objects (patches…) leading from 1M to 8M of battery units in 2018.

1 to 3€/TFbattery of some tens of mAh

1 to 5€ /battery of some tens of mAh

2.2.9. - Printed NO_2 sensor (CEA)

The foreground is to develop a low cost and printed highly sensitive NO_2 sensor working at room temperature and at low power consumption on paper based flexible substrate.

How the foreground might be exploited, when and by whom

The time to market is expected to be 2020. The customer needs have to be specified to clearly identify market opportunities.

IPR exploitable measures taken or intended

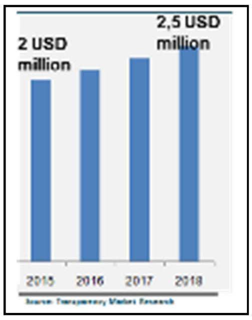
No patent.

Further research necessary, if any

The sensor response in a real environment should be evaluated to accurately measure device sensor selectivity before market introduction.

Potential/expected impact (quantify where possible)

Not clearly identified regarding customer requirements. However, as shown in the following figure, the global gas sensors market estimate and forecast for 2018 is around 2.5 million of USD.



2.2.10. - Printed H_2S sensor (TNO)

Purpose of the foreground

The flexo-gravure printed H_2S sensor developed for paper labels will warn the user for H_2S exposure in the environment. Printed sensors can be used instead of placed sensors and may be printed at large scale to make the usage much more extensive. The flexogravure application is crucial for large scale application.

How the foreground might be exploited, when and by whom

Foreground is generated on the application and integration of the sensor in a printed label

The flexogravure applications of the sensor were not successful.

IPR exploitable measures taken or intended

No IPR on the sensor will be taken. IPR on the label may be suitable.

Further research necessary, if any
No further research on flexogravure will be done.

Potential/expected impact (quantify where possible)
H_2S sensors may be deposited by inkjet printing. This is a much slower process. When inkjet is more industrial the H_2S sensor can be integrated.

2.2.11. - Printed temperature sensor (TNO)

Purpose of the foreground
Flexogravure printed temperature sensor (thermistors) developed for paper labels that can be used instead of placed thermistors. Its sensitivity is much higher than other printed NTC sensors, which is interesting in combination with its high conductivity. The ceramic thermistor material is included in the printing ink. Freedom of design due to the printing.

How the foreground might be exploited, when and by whom
Printed electronics companies, labels manufacturers and printing companies can exploit the foreground. The time to market is expected to be around 2017 – 2020.

IPR exploitable measures taken or intended
For TNO patent application costs will be 5-10k€, while maintenance is much more expensive. Therefore TNO will focus on licensing or selling the IPR. A patent is only interesting if flexogravure printing is possible. New material used for a printing ink.

Further research necessary, if any
New combinations using different ceramic NTC materials

Potential/expected impact (quantify where possible)
The thermistor material price is very cheap and negligible with respect to ink prices. Nevertheless the processing of the thermistor is expensive at lab scale, but this will be much improved in professional production.
The printing ink may be expensive when nanomaterials are involved. Nevertheless results with "grinded" samples are promising and materials are cheap. The market will follow the printed electronics roadmap.

2.2.12. - Printed multicomponent films (UNL)

Purpose of the foreground
Printed thin films of metal oxide semiconductors and ion conductors which composition and processability were optimized within the project may be used as electrochemically active films in electrochemical devices for flexible and printed electronics.
Electrochemical functionalities can be easily implemented on large area cheap substrates turning them into low cost devices for applications in which high efficiency is not the main goal.
Electrochemical functionalities are obtained without any special processing conditions.
Scaling up of the material synthesis and a proof of concept for the developed prototypes is targeted at the end of the project.

How the foreground might be exploited, when and by whom
UNINOVA has partners interested in using the developed materials and processes in order to produce:
- Large area photochemical devices on stainless steel substrates for water splitting
- Foldable pocket guides with EC displays based on paper substrates

The time to market is expected between 2018 and 2020.

IPR exploitable measures taken or intended
Not protected. The exploitability of these materials and processes are still under evaluation.

Further research necessary, if any
UNINOVA plans to upgrade their facilities to install automated screen printing machines. The estimated costs for machinery/equipment are around 400k€. Building modifications costs are in the order of 120 k€. UNINOVA may also use facilities already existing on the partner sites for device manufacturing (subcontracting).
Costs are related to scaling up the material synthesis and customization design (180 k€) including reactors and building modifications.
The material synthesis needs optimization to improve reproducibility of the product and to eliminate safety issues (elimination or substitution of potentially dangerous components).
Future possible collaborations may be tied with chemical component manufacturers in order to customize raw materials at their production stage in order to facilitate further ink formulation.

Potential/expected impact (quantify where possible)
Passive electrochromic displays are attractive where they can compete with e-paper and passive LCDs. The market for passive LCDs in 2010 was worth 7 000M€, 6% of the total display market. The e-paper market is expected to reach near 400 M€ in 2018.
The printable electronics market in general is interesting; it is expected to reach more than $50 billion in the next ten years. The final cost of new devices is potentially very low due the low cost of the raw materials and simple processing procedure/conditions.

2.2.13. - Visual inspection for printed electronic (ICS)

Purpose of the foreground
ICS developed and tested a quality control solution for printed electronics on paper products based on visual inspection. The system is based on the ICS LineaVision inspection solution and the existing know-how is adapted in order to comply with requirements of flexible electronics and to propose an innovative solution for a very promising market. In addition to PE applications, the hard- and software technologies developed as well as the experience gained in the framework of this project will also be applicable to other inspection solutions and improve our general competitiveness.
Machine vision systems are of high complexity and thus the printed electronics inspection solution cannot be seen as an independent, novel system but rather an evolution of the existing platform. The A3Ple project permitted to improve this existing solution on several critical sub-systems: the image acquisition by implementing newest generation cameras, image processing for complex surfaces and the development of a user interface dedicated to the needs of printed electronics applications. Along with the experience gained concerning the detection of hard, functionality influencing defects due to laboratory and partner based feasibility studies as well as the input of various partners, a functional inspection solution for PE applications could be developed.

How the foreground might be exploited, when and by whom
The developed tool started being implemented in 2014 on commercial production lines. The developed software modules, integrated hardware components and algorithms for the inspection solution PE solution are applicable to a wide range of printed electronic products but also interesting for applications beyond this market. The developments are implemented in the industrial inspection solution already during the course of the project and thus contribute immediately to the success of the proposed solution.

IPR exploitable measures taken or intended
No specific action

Further research necessary, if any
Main developments will be finalised during the duration of the project. However, at the current stage the system is already functional and in fact one system based on the PE software interface has been installed at a client to inspect transparent conductors and a further system sold, dedicated to OPV, benefited from experiences gained during the trials of A3Ple project. Further client or product specific developments may occur for applications of printed circuitry but cannot be specified without knowing the full project context.

Potential/expected impact (quantify where possible)

The global machine vision market is USD 2.31 billion (Transparency Market Research Report - "Surface Vision and Inspection Market - Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2013 - 2019"). The developed inspection technology is applicable to a wide range of processes and not exclusive to PE and thus enables ICS to grow further in this dynamic market field.
The pricing range of the inspection system highly depends on client specific factors such as required optical resolutions, production width and number of inspection stations, thus a price cannot be detailed.

2.2.14. - Software to design electrical circuit for printed electronic (BA)

Purpose of the foreground

Designing services provided for other companies, based on:
1) Development of a software library to be used with a conventional electronic CAD to design and route electronic circuits based on distributed printed components (resistors, capacitors, EC display, sensors, transistors) to be printed on several flexible substrates (paper, plastic, Kapton, PI, PET, etc)
2) Development of a simple end powerful software tool to design the shapes of passive and active components to be printed with special functionalized inks.
The designing of electronic circuits printed on paper and functional inks is a novel and a very innovative matter, for this reason there aren’t mature software CAD tools to use in this field. The main innovation of this exploitation is the opportunity to use a well-tested commercial CAD software (created to design standard PCB circuits based on discrete components and rigid substrate) to design very complex electronic circuits printed on paper, this goal has been reached thanks to the development of a Designing Tool Kit that can be used to realize a library of electronic components to be printed on paper.
Thanks to the electronics printed on paper it is possible to realize electronic devices in high volume and very low cost, without having to use a chemical etching process and with a low impact on the environment.
It is a well-tested Designing Tool kit and a CAD software used to design, in an easy way, very complex electronic circuits printed on paper, thanks to these our company will be able to provide new designing services.

How the foreground might be exploited, when and by whom

BA will exploit the foreground in order to design electronic circuits for companies dealing with:
#) Electronic circuits to be printed on flexible substrates
#) Electronic circuits based on active and passive components printed with special functionalized inks
#) Electronic circuits to be printed with roll-to-roll printing, flexographic printing, screen printing, inkjet printing, etc
60K€ would be needed for optimization of the software tools realized for the exploitation, internal training of the electronic designers, and depreciation of the internal equipment used to perform internal test al lab scale.
The estimated schedule for exploiting the foreground is 2018-2019.

IPR exploitable measures taken or intended

None. A patent is not required because the Designing Tool Kit and the CAD software library will be used only internally by our company, because our goal is to sell only the designing services.

Further research necessary, if any

Optimization of the software tools realized for the exploitation, internal training of the electronic designers, depreciation of the internal equipment used to perform internal test al lab scale
Further collaborations are welcome with companies involved in electronics printed on paper or industries working in printed electronics on innovative substrates. Future projects submissions are expected.

Potential/expected impact (quantify where possible)

The exploitable result is related to the sales of designing services to other companies, so it is not possible to fix a unique price range, but the usual standard approach will be used that our company follows to sells other designing services in the electronic field, mainly based on the internal time required to provide the service and the cost of the salary of the engineers involved in the activity.

The sector of application involves flexible and transparent electronics, electronics printed on paper and all flexible substrates.
The market for printed electronics applications is estimated to reach $40.2 billion by 2020(*). The e-paper market is expected to reach near 400 M€ in 2018.
(*)By: marketsandmarkets.com; Publishing Date: April 2014; Report Code: SE 2466

2.2.15. - Label derived from Demo1 (LT)

Purpose of the foreground
Production of Demo1 or variations on this specification using functionalized printing inks that can be used in and on printing industries printing equipment to manufacture labels and associated products.
To realize production of Demo1 label configuration or comparative functionalities in an industrial environment eg. the printing industry

How the foreground might be exploited, when and by whom
The knowhow, procedures, production technology including the quality control, materials handling and treating can be exploited immediately by CTP (partially), VTT (partially), ICS (partially) and LT to the full extent.

LT will offer the possibilities for (co)production using all aspects of the foreground.
CTP will offer the possibilities to advise on all aspects of the foreground.
VTT will offer the possibilities to co-develop specific aspects of the foreground.
ICS will offer the possibilities to supply and implement the quality control solution coming for the foreground.

IPR exploitable measures taken or intended: No

Further research necessary, if any
Further research and development is needed to develop, test, and benchmark more functional ink types in combination with industrial standard production machines to deliver more working products to meet the market needs.

Potential/expected impact (quantify where possible)
When the printing industry can make variations coming from the Demo1's core specification, including various formats and label sizes and a selective portfolio of sensor systems, this can turn into a multi-billion numbers business as the global market is huge for functional labels. However this gross potential is split in an enormous diversified amount of variations and specs as this is the nature of labels and the demand behind it.

2.2.16. - Poster derived from Demo2 (LT)

Purpose of the foreground
Production of Demo2 or variations on this specification using functionalized printing inks that can be used in and on printing industries printing equipment combined with printing of poster-type products and the combination of both in an end specification.
To realize production of Demo2 label configuration or comparative functionalities in an industrial environment eg. the printing industry

How the foreground might be exploited, when and by whom
The knowhow, procedures, production technology including the quality control, materials handling and treating can be exploited immediately by CTP (partially), VTT (partially), ICS (partially) and LT to the full extent.
LT will offer the possibilities for (co)production using all aspects of the foreground.
CTP will offer the possibilities to advise on all aspects of the foreground.
VTT will offer the possibilities to co-develop specific aspects of the foreground.
ICS will offer the possibilities to supply an implement the quality control solution coming for the foreground.

IPR exploitable measures taken or intended: No

Further research necessary, if any
Further research and development is needed to develop, test, and benchmark more functional ink types in combination with industrial standard production equipment to deliver more working products to meet the market needs.

Potential/expected impact (quantify where possible)
When the printing industry can make variations coming from the Demo2's core specification, including various formats and label sizes and a selective portfolio of sensor systems, this can turn into a multi-billion numbers business as the global market is huge for functional labels. However this gross potential is split in an enormous diversified amount of variations and specs as this is the nature of poster-related printed matter and the demand behind it.

2.2.17. - Label declined from Demo3 (LT)

Purpose of the foreground
Production of Demo3 or variations on this specification using functionalized printing inks that can be used in and on printing industries printing equipment combined with printing of Smart labels or similar products and the combination of both in an end specification. To realize production of Demo3 label configuration or comparative functionalities in an industrial environment eg. the printing industry.

How the foreground might be exploited, when and by whom
The knowhow, procedures, production technology including the quality control, materials handling and treating can be exploited per direct by CTP (partially), VTT (partially), ICS (partially) and LT to the full extent.
LT will offer the possibilities for (co)production using all aspects of the foreground.
CTP will offer the possibilities to advice on all aspects of the foreground.
VTT will offer the possibilities to co-develop specific aspects of the foreground.
ICS will offer the possibilities to supply an implement the quality control solution coming for the foreground.

IPR exploitable measures taken or intended: No

Further research necessary, if any
Further research and development is needed to develop, test, and benchmark more functional ink types in combination with industrial standard production equipment to deliver more working products to meet the market needs.

Potential/expected impact (quantify where possible)
When the printing industry can make variations on the Demo3's core specification, including various formats and label sizes and a selective portfolio of sensor systems, this can turn into a multi-billion numbers business as the global market is huge for functional labels. However this gross potential is split in an enormous diversified amount of variations and specs as this is the nature of poster-related printed matter and the demand behind it.