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Advanced Technologies for Industry – Product Watch

Flexible and printed electronics

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Table of contents

Section 1

1. Background and objectives of the report

Background

The Product Watch Reports have been developed in the framework of the 'Advanced Technologies for Industry' project and serve to identify and analyse 15 promising advanced technology (AT)-based products and their value chains, with an assessment of the strengths and weaknesses of the EU positioning.

Promising AT-based products can be defined as "*enabling products for the development of goods and services enhancing their overall commercial and social value; embedded by constituent parts that are based on AR/VR, Big Data & Analytics, Blockchain, Cloud, Artificial Intelligence, the Internet of Things (IoT), Mobility, Robotics, Security & Connectivity, Nanotechnology, Micro-nanoelectronics, Industrial Biotechnology, Advanced Materials and/or Photonics; and, but not limited to, produced by Advanced Manufacturing Technologies*".

1.1 Background of this report

Flexible electronics refers to a class of lightweight, flexible and electronic sensing components and electronic devices built on stretchable substrates[1] that are used (and can be used) for a broad set of products and applications such as displays and sensors. The most prominent characteristic is that they can bend in contrast to electronic systems built in rigid materials. They are manufactured on flexible plastic substrates, such as polyamide, PEEK[2] or transparent conductive polyester films[3], or other materials such as paper, textile, or thin glass. The term flexible also refers to the roll-to-roll manufacturing process.

Printed electronics is often considered to be part of flexible electronics. It refers to the method used to create electronic devices by printing them on various (flexible) substrates. The technology used has evolved over time, and now enables to print electrical circuits quickly and inexpensively thanks to inkjet printers. Printed electronics is one of the fastest growing technologies and is becoming a key element in several industries such as healthcare, aerospace or transport. Printed electronics techniques can take the form of roll-to-roll gravure, flexography, inkjet and screen printing of electrically functional materials[4].

Flexible electronics can have organic materials (e.g. polymers, cellulose, molecules or 2D materials) as substrate or component (mainly for non or semi conducting components). These materials can be used in printing – to print on or to print with. Flexible electronics rely on the fact that these (organic) polymers maintain their electrical and structural properties even when deformed. The field of organic electronics currently studies the further use of organic materials in electronics, often having beneficial flexible and biodegradable characteristics.

Metals and inorganic materials are also used in flexible electronics. Metals have high conductive properties and are used as conductors in electronics. Among others, silver, copper, nickel and carbon (e.g. graphene) have been used in flexible electronics in various forms (incl. flakes, nanowires, nanotubes). These metals can be printed as metallic inks. Inorganic materials, having no or limited conductivity, are used as insulator (dielectric) or semiconductor in electronics. Polymers, titanium oxide and zinc oxide have for instance been used as semiconductors in flexible and printed electronics. Several other oxides and polymers have been used as dielectrics, such as PMMA and poly urethane. In combination with binders, solvents and additives such materials can be printed on flexible substrates.[5]

[1] https://www.semi.org/en/collaborate/flextech-infohub/whatareflexibleelectronics
[2] PEEK is also known as Polyether Ether Ketone.
[3] The polymers PET or its thermally stable variant PEN becomes conductive when they deposit a material called ITO (Indium tin oxide) on top that is transparent.
[4] Avuthu (2016). An Introduction to the Process of Printed Electronics
[5] D. Maddipatla, B.B. Narakathu and M. Atashbar (2020). Recent Progress in Manufacturing Techniques of Printed and Flexible Sensors: A Review. Biosensors 10

In comparison with silicon-based, conventional electronics, that are prominent in the market now, flexible electronics have several advantages apart from their flexibility: low cost of manufacturing thanks to the inkjet/screen printing and roll-to-roll imprinting, and inexpensive flexible substrates such as plastics[6]. These characteristics make flexible electronics a key player to produce lightweight, bendable, portable and low-cost electronics. Another advantage is that flexible electronics can be more easily recycled compared to conventional electronics. The used materials can be separated leading to high-value waste streams that can be recycled. This contributes to an overall lower environmental footprint of flexible electronics as compared to conventional electronics.

Flexible electronics can be used for electronic devices, which for instance enable specialised smart labels, chemical sensors in cold chain logistics and wearables[7]. Flexible printed circuits allow the production of tightly assembled electronic packages, for example used for cameras and electrical connections where the assembly is required to bend during its normal use, such as foldable smart phones.[8].

Flexibility opens the door to many new applications in various sectors. There are plenty of potential markets for this technology:

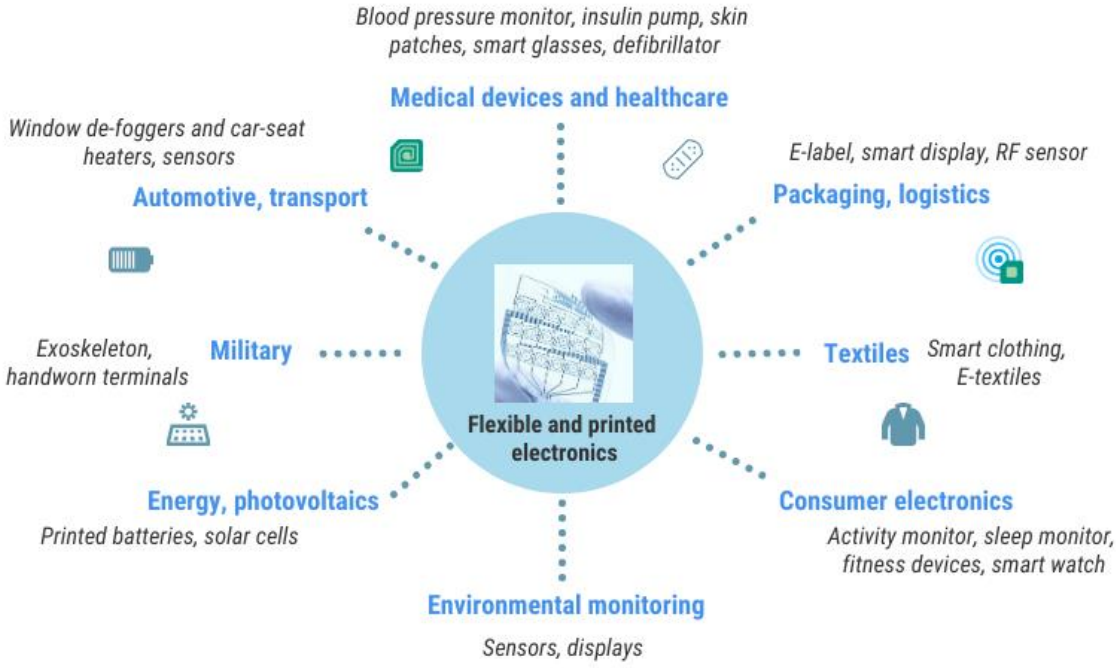
- ***Healthcare and wellbeing*:** currently this application area is the main focus of various research centres and several businesses across Europe. Applications include pain relief patches, smart plasters that continuously monitor the healing process or sensors that are attachable to the body of the patient and can monitor several health parameters. In terms of wellbeing, applications of flexible electronics are in wearables for sports and fitness.
- ***Automotive industry:*** flexible electronics can be used in displays, special sensors, contactless sensing for vehicles. The application is also relevant for electric vehicles. However, this market is currently a difficult market for flexible electronics, due to the difficulties that the European automotive industry is facing (years 2020/21).
- ***Building and construction*:** sensors and RFID (radio frequency identification) components are used in various IoT applications. An example is smart buildings that continuously measure the quality, temperature or moisture level and communicate the data to the building automation system[9].
- ***Energy and Photovoltaics*[10]:** flexible photovoltaics can be used as a sustainable energy source for indoor and outdoor applications. They can be easily integrated into products of diverse shapes and sizes. Flexible solar cells are lightweight and created on flexible substrates by high-throughput technologies. Europe is not strong in the current market for crystalline photovoltaics, but may capture some position in flexible (integrated) photovoltaics. Flexible electronics are also used for other energy applications, such as batteries and capacitors, although this is still very much in development.[11]
- ***Textiles*[12]:** by using printed electronics, clothes could interact with touch gestures, measure body values, activate digital services, or provide light on request. They can have the form of sensors, displays, solar cells or complete control systems.
- ***Consumer electronics:*** from tracking devices such as smartwatches, to foldable smartphones there are plenty of products in the market that use flexible electronics, for example, flexibility can be found in the new smartphones with bendable, conductive screens.
- **Smart packaging and logistics**: smart packaging is defined as packaging systems that are capable of performing intelligent functions. Flexible electronics enables detecting, sensing, recording, tracing and communicating, which can improve the extension of shelf life, safety and quality of products and tracing during logistics. Smart packaging is a mature application area/sector, deploying for instance RFID and NFC (near field communication) flexible electronics.

To highlight one important application area, flexible electronics products in healthcare have the potential to be used on and in the human body. The flexibility of these electronics allows for better wearability and, when organic materials are used, better compatibility with the human biological system is possible as compared with silicon-based alternatives[13]. Such applications include skin patches, test strips and smart packaging in healthcare. The demand for such flexible wearables that monitor physiological parameters has been rapidly increasing. Flexible sensors can measure various health conditions such as heart rate, pulse, body temperature, blood glucose, in a non-invasive manner and in real time by simply

[6] Kwang-Ting and Tsung-Ching (2009). What is flexible electronics?
[7] Bringans and Veres (2016). Challenges and opportunities in flexible electronics
[8] Gates (2009). Flexible electronics
[9] https://www.lopec.com/en/general/sectors/buildings-architecture/
[10] https://pubs.rsc.org/en/content/articlelanding/2014/tc/c3tc32197e#!divAbstract
[11] D. Corzo, G. Tostado-Blázquez and D. Baran (2020). Flexible Electronics: Status, Challenges and Opportunities. Frontiers in Electronics, September 2020.
[12] https://www.lopec.com/en/general/sectors/textile/
[13] NAP (2014). Assessing the Potential of Flexible Electronics

attaching them to the human body. Flexible multifunctional sensors used in wearables are relatively cheap, reproducible, accurate and have good mechanical stability and high sensitivity[14]. The use of flexible healthcare devices is driven by the uptake of telemedicine and remote patient monitoring, requiring sensing of patients' health conditions. Continuous monitoring, enabled by connected medical devices and wearables, improves diagnoses and prevention[15]. Another example is the integration of flexible sensors into the patient's bed to provide real-time data on the patient's movements. The resulting information can be used to prevent the formation of bedsores and pressure ulcers.

Figure 1: Application areas of flexible and printed electronics



Source: Technopolis Group

The market share of flexible and printed electronics has been growing steadily in Europe. Some estimations highlight that the market for printed, flexible and organic electronics will grow more than €30.2 bn ($32.88 bn) from 2020 to 2030 (from €37.8 bn to €68 bn - $41.2 bn to $74 bn)[16]. Even though stretchable electronics, logic and memory, flexible batteries and capacitive sensors are a smaller segment of the total, they do have a strong growth potential. Applications like antennas, displays, photovoltaics and circuitry resulted in a global market for printable electronics of €24.7 bn in 2016 ($26.9 bn)[17]. The growth of the market is driven by the development of smart and connected devices including the Internet of Things (IoT), rise in the global demand for energy-efficient, thin and flexible consumer electronics and by cost advantages[18]. Flexible electronic components such as RFID tags and sensors are considered to be the technological basis of IoT[19].

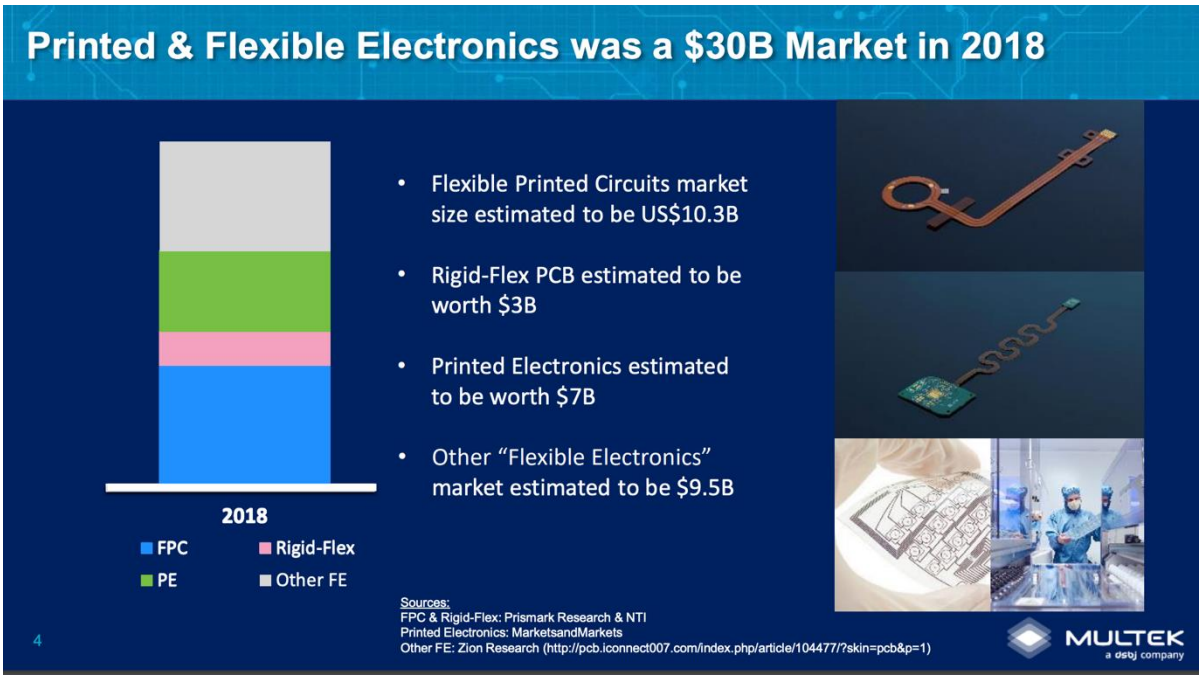
Printed electronics is a smaller part of the flexible electronics market with a size of €5.8 bn ($6.8 bn) in 2018, with an expected growth to €11.5 bn ($13.6 bn) in 2023[20]. In 2017, Europe had a 23% market share in printed electronics, slightly lower than North America (29%). The Asia-Pacific region had the highest market share with 47%[21]. The printed electronics market is growing fast, with strongest growth expected in lighting solutions (+29%), batteries (+24%) and sensors (+13%). In terms of application areas, the strongest growth is expected in Aerospace and Defence (+21%), Retail and Packaging (+19%) and Medical (+15%[22]).

[14] Sreenilayam (2020). Advanced materials of printed wearables for physiological parameter monitoring
[15] https://www.idtechex.com/en/research-report/flexible-electronics-in-healthcare-2020-2030/731
[16]https://www.idtechex.com/en/research-report/printed-organic-and-flexible-electronics-2020-2030-forecasts-technologies-markets/687
[17] https://oe-a.org/viewer/-/v2article/render/26785800
[18] https://www.marketsandmarkets.com/pdfdownloadNew.asp?id=197
[19] https://www.mordorintelligence.com/industry-reports/flexible-electronics-market
[20] Peter Yu (2019). Flexible Electronics Outlook & Lessons Learned. MULTEK: April 2019.
[21] Ibid
[22] Ibid

Globally, most of the growth in flexible electronics overall is expected to originate from OLEDs, printed biosensors and conductive inks. The global conductive inks market size is expected to grow at a compound annual growth rate of 4.1%, by value, during 2020-2025[23]. By value, 95% of the conductive ink supply is used for printed photovoltaic solar cells, exterior automotive heating applications and edge electrodes for touch screens[24].

Germany is the dominant flexible electronic market, followed by Spain and France, the latter with the highest growth trend[25]. Other important markets include Finland and Sweden. Growth on the EU market is mainly attributed to the penetration of smart consumer electronics and in particular to recent trends in the **growing field of medical applications**. Having said that, flexible and printed electronics is an industry that is growing slowly as pointed out by several companies interviewed for this report. The technology cannot compete with standard electronics in many application areas due to high costs. Even if there are improvements, flexible and printed electronics need to find application areas where it does not have to compete with silicon technologies per se.

Figure 2: Market opportunity in flexible and printed electronics



Source: Peter Yu (2019). Flexible Electronics Outlook & Lessons Learned. MULTEK: April 2019.

1.2 Objectives of this report

As presented above, flexible electronics offers opportunities for various applications such as rollable, foldable displays, smart patches and smart packaging on paper and plastic substrates. Recent progress in materials, devices and fabrication techniques enables the development of new sensors and prototype systems for various applications ranging from medical devices to automotive.

This report aims to provide an overview of relevant stakeholders with an analytical and empirical base to see how AT-based products can help EU industry to stay ahead of global competition. The objective is to map the EU flexible and printed electronics industries and their interactions in the value chain, as well as to identify their strengths and weaknesses. Analyses were based on desk-research as well as on interviews with relevant actors. The report aims to provide relevant stakeholders with a thorough overview on the flexible electronics sector.

[23] Markets and Markets Research, 2020
[24] IDTechEx, 2020
[25] Inkwood Research, 2019

Section 2

2. Value chain analysis

2.1 Value chain structure

Flexible electronics is a fast-developing sector driven in particular by advancements in material science and chemistry. Its value chain is very much similar to traditional electronics, but it has different and unique features especially in terms of the following aspects:

- **Flexible electronics value chains rely on different materials.** In order to make flexible electronics, the components used must be bendable to some extent. This has to be possible without losing their functionalities. Traditional silicon-based electronics use rigid substrates that do not allow bending. In flexible electronics, organic materials like organic thin films, plastics, thin glass or textiles are used. Also, during production different materials are used – or similar materials in different form – as production methods are different, e.g. printing instead and roll-to-roll production.
- **Flexible electronics value chains incorporate different production processes and thus different equipment (suppliers).** As different materials are used, the processes for conventional silicon electronics cannot be fully replicated. For instance, high-temperature deposition is not possible on many flexible substrates. Also, less precision is needed/possible, allowing for different processes at lower temperatures such as printing.
- **Flexible electronics does not serve exactly the same customers and is used for different and a limited number of applications than traditional electronics**. With flexible electronics nano-scale precision cannot be attained as with the complex manufacturing processes of silicon/rigid electronics, and thus no high-density memory or processors can be produced for e.g. computing. Applications are focused on larger structures, such as in lighting, security tags and others described in the previous chapter.

The flexible electronics value chain includes segments such as research and technology development, material supply, design, printing, components manufacturing that work with original equipment manufacturers (OEMs) and Tier 1[26] electronics companies, product integration and end-user segments.

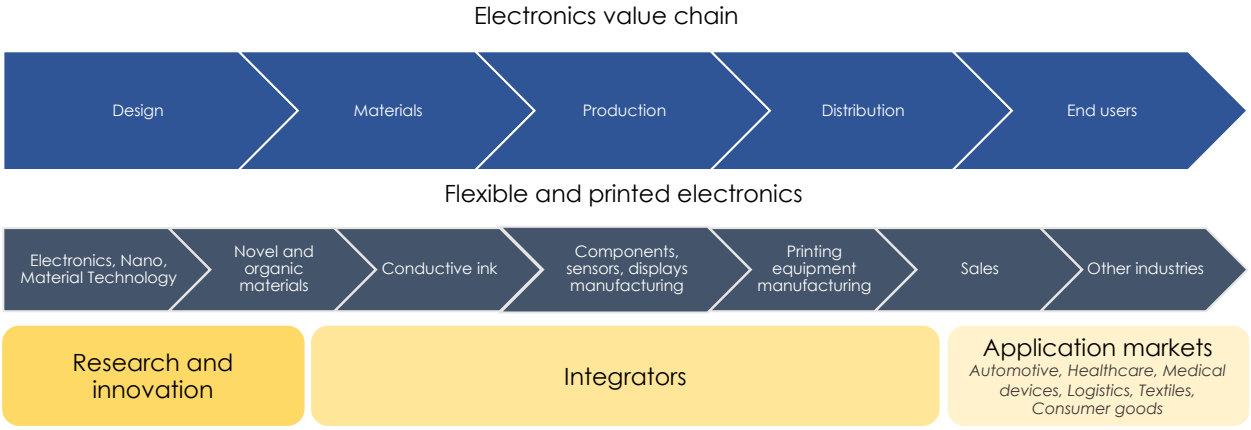
Beyond thinking in value chains, it is important to adopt an ecosystem perspective. The flexible electronics ecosystem brings together competences from various public and private actors including material science, mechanical and electrical engineering, physics/chemistry, technical companies involved in equipment manufacturing, electronics and application systems. Partnerships and collaboration platforms play a critical role to enable European players to stay competitive and develop the market for flexible electronics in Europe.

Startups play a central role in the flexible and printed electronics ecosystem due to the fact that innovation in this field is very risky and it is usually not targeted by larger companies.

Figure 3 depicts the generic value chain structure, which may differ regarding individual characteristics of the product.

[26] Tier 1 supplier is a firm that supplies directly an original equipment manufacturer (OEM).

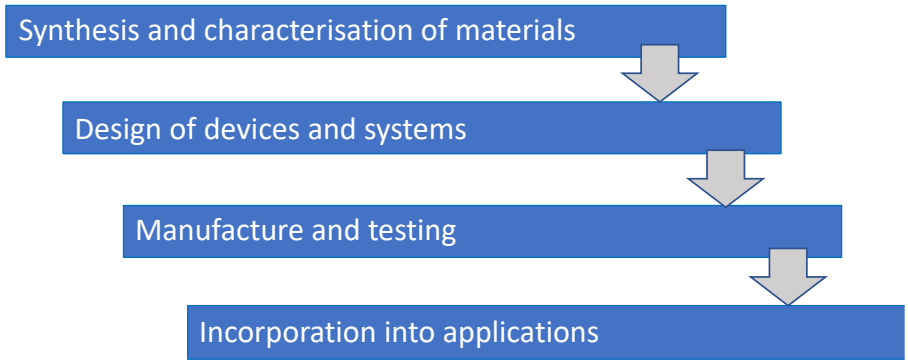
Figure 3: Flexible and printed electronics value chain



Source: Technopolis Group

Figure 4 shows in more detail the process of manufacturing flexible electronics.

Figure 4: Process of manufacturing flexible electronics



Source: Technopolis Group based on PEC[27]

Additionally, several industries are involved in the process. The most notable ones are the chemical industry, mechanical and electrical engineering, printing industry, packaging and finally consumers goods[28].

The flexible electronics market in Europe is still in development. The segments of the value chain are there, but the business activity in flexible electronics is still limited to some niche areas in Europe. These include mainly RFID/NFC tags, but also wearables and healthcare. Most of the flexible electronic market concerns semi flex solutions notably conventional electronics on flexible substrates. Fully flexible electronics is still in an early stage, leaving ample room for further technological development. The largest application area of flexible electronics is in displays and lighting (large-area flexible electronics), where Europe has no significant presence as this market is dominated by actors in Asia and North America. Nevertheless, Europe has a strong research base and boasts a lot of innovative companies that have spun off from strongholds in applied research in electronics such as Imec, TNO, Holst Centre and VTT. Therefore **the role for Europe is seen in niche areas derived from innovation that create more complex, high value-added applications.**

Additionally, some interviewees indicate that for various applications the production costs in Europe are still too high to make flexible electronics attractive not only for producers, but also for consumers. As interviewees explained, production costs will have to decrease to sell at competitive prices, reinforcing interest and uptake of (semi) flexible electronics. Displays and lighting, and RFID tags for clothing, transport and healthcare have been mentioned as a notable exception – here prices of flexible electronics are competitive.

[27] PEC, Value Chain. Available at https://sites.google.com/a/pec4.net/home/offer/value-chain-value-net
[28] ibid.

As mentioned in the previous chapter, flexible and printed electronics can be applied in a broad range of products and sectors, making them technologies with strong potential for the future.

2.2 Key actors in the value chain

There are several relevant partners in the flexible electronics value chain that go from research centres and manufacturers to the end users.

1) Research and technology

Europe has a strong position when it comes to the research and development of flexible electronics. There are high quality, applied research centres and innovation networks that drive developments in the field. Among the most relevant **research centres** we can find the following ones:

Table 1: Research centres in the field of flexible and printed electronics sectors, examples

Organisation	Country	Research areas and main products
CEA-LETI	France	CEA LETI is involved in the functionalisation of sensitive surfaces and electronics for wearables, energy harvesting, power management circuits, low-power electronics, and wireless power transmission. https://www.leti-cea.com/cea-tech/leti/english/Pages/Welcome.aspx
Eurecat	Spain	Eurecat is the key technology centre of Catalonia. It provides the industrial and business sector with technology and advanced expertise and offers solutions to innovation needs and boosts competitiveness. The Functional Printing & Embedded Devices Department at Eurecat is specialised in the formulation and development of materials, printed electronics and conventional electronics. The department adds functionality to rigid and flexible surfaces and objects. https://eurecat.org/en/field-of-knowledge/functional-printing-embedded-devices/
Fraunhofer Microelectronics Group	Germany	The group was founded in 1996 and is a service provider for R&D in smart systems. It combines the expertise of the 16 Fraunhofer Institutes. They provide services on the seven cross-institute technological core competences: semiconductor-based technologies, sensors and sensor systems, power electronics and system technologies for energy supply, design for smart systems, radio frequency (RF) and communication technologies, quality and reliability, and system integration technologies. https://www.fraunhofer.de/en/institutes/institutes-and-research-establishments-in-germany/fraunhofer-groups/microelectronics.html
Helmholtz Zentrum	Germany	Helmholtz Zentrum is one of the largest non-university research centres and a member of the Helmholtz Association. The centre is involved in materials science research in several application areas and as such also involved in projects related to printed and flexible electronics, e.g. flexible transparent electrodes based on nanowires. https://www.helmholtz.de/
Holst Centre	Belgium / The Netherlands	It is an independent research and innovation centre, jointly operated by TNO and imec. Their objective is to provide innovations that will not only improve the vitality and wellbeing of people, but which can ensure sustainable environments as well. Wireless sensor technologies and flexible electronics are one of the technologies they focus on. They are known for their ability to develop demonstrators and prototypes, which are later turned into new products and new manufacturing process by their partner companies. https://www.holstcentre.com/technologies/hybrid-printed-electronics/
imec	Belgium	imec has been working in joint research with several electronics businesses in Europe, including ASML (one of the world's leading equipment suppliers for the semiconductor industry), during the last 30 years. They have developed pilot lines for various electronic products and are involved in flexible electronics as well. https://www.imec-int.com/en/flexible-electronics
Institute for Microelectronics	Italy	IMM is one of the sections of the Italian National Research Council. It is a multi-disciplinary research centre which has been working on the study of materials and devices for microelectronics for more than 30 years. In the

Organisation	Country	Research areas and main products
and Microsystems (IMM)		area of flexible and large area electronics, they are working on how to use graphene and graphene-based materials for flexible electronics and wearable sensing applications. This activity is divided in two research streams: one stream is focussing on the growth of graphene membranes by Chemical Vapor Deposition (CVD) and in the process and transfer into flexible substrates. The other stream is focussing on the CVD growth of graphene membranes on 3D porous substrates. https://www.imm.cnr.it/
Joanneum Research, Institute for Surface Technologies and Photonics	Austria	Joanneum Research develops solutions and technologies for a broad range of industries and public agencies and is engaged in applied research at an international level. It is active in flexible and printed electronics, including organic electronics, and has developed for instance PyzoFlex®, which is printable sensor technology. https://www.joanneum.at/materials
Leibnitz Institut for Polymer Research, Dresden	Germany	The Leibniz Institute of Polymer Research in Dresden (IPF) is one of the largest polymer research facilities in Germany. They have a holistic approach covering synthesis and modification of polymer materials, characterisation and theoretical investigation, up to processing and testing. They work closely with engineers. Pilot plants are available, allowing the development of materials and technologies under industry-relevant conditions. They focus on the development of materials, technologies and systems which are considered crucial to guarantee the future strength of Germany's economy and to ensure both quality of living and sustainability. The polymer materials address innovations for further development in, e.g. medicine, transport and mobility, as well as energy efficiency and advanced communication technologies. https://www.ipfdd.de/en/about-us/
RISE – Research Institutes of Sweden	Sweden	The research institute offers more than 100 testbeds and demonstration environments. Printed and organic electronics is one of their research areas. Printed electronics being a very broad area, they focus on packaging, MedTech and healthcare, construction and printed electronics. Rise works at molecular level (inks, electrolytes, material combinations for novel sensors, synthesis and characterisation), but also creates custom prototypes (various substrates, chip integration or electronics design) or production of small series. They also work on up-scaling and production related topics. https://www.ri.se/en/what-we-do/expertises/soft-electronics-and-bioelectronics
TNO	The Netherlands	TNO is an independent research organisation in the Netherlands that focuses on applied science. In the area of flexible and large area electronics, TNO offers R&D services in the area of respectively flexible electronics and photovoltaics under its brand names Holst Centre and Solliance. https://www.tno.nl/en/focus-areas/industry/roadmaps/flexible-free-form-products/
VTT	Finland	VTT is a research institution in Finland owned by the Finnish state. Its task is to advance the utilisation and commercialisation of research and technology in commerce and society. They are active in flexible and printed electronics, including production processes and innovative products such as wearables. https://www.vttresearch.com/en/ourservices/printed-intelligence

Source: authors compilation

2) Material suppliers

Thin plastics films and flexible substrates (largely polymers, semiconducting or insulating), coatings, photo resist, metal connects (e.g. copper or silver) and inks also play a significant role in the development of flexible electronic devices. Graphene is an interesting and useful interconnect material in such electronics given its ultra-thin thickness and conducting properties. One of the challenges is that some of these new materials need to be processed and characterised differently, for example in order to take into account both their electrical and mechanical performance. Most of these materials and

components are produced or available in Europe, but the challenge lies in bringing them together and ensure the interconnection between mechanical and electrical components.

Table 2: Material suppliers for flexible and printable electronics, examples

Company	Country	Research areas and main products
Agfa-Gevaert	Belgium	Agfa-Gevaert develops, manufactures and distributes analogue and digital imaging products, software and systems. It offers integrated prepress and industrial inkjet systems to the printing and graphics industries. https://www.agfa.com/corporate/about-us/our-company/business-groups/
BASF	Germany	BASF offers solutions across various areas and technologies such as display, photovoltaics, solid state lighting, communications, computers, consumer electronics, smart wearable devices and quantum dot display. https://www.basf.com/be/en/who-we-are/can-you-imagine-the-world-without-chemistry/chemistry-enhances-digital-life.html
Evonik	Germany	Evonik Degussa is a multinational corporation and a chemical company. The company opened a facility, the Nanotronics Science to Business Center, in Marl, Germany, for developing technologies like thinner printed electronics for RFID tags and flexible displays, conductive indium tin oxide nanoparticles for displays, and films to seal organic light-emitting diodes besides producing electronic nanomaterials. https://corporate.evonik.com/en
GenesInk	France	GenesInk is specialised in the conductive and semi-conductive inks market. https://www.genesink.com/company/
Henkel	Germany	Henkel specialises in high-impact engineering solutions for electronic and industrial key accounts. They offer their bonding, connecting, sealing, coating, protection and thermal management solutions to some of the world's most recognisable brand and products. https://www.henkel-adhesives.com/us/en/industries/electronics.html
Merck	Germany	Merck develops materials for printed electronics. Merck KGaA officially opened its Research Centre for electronic applications on the campus of its headquarters in Darmstadt, Germany in 2020. With an investment of €50 million, the company created a research hub to further advance innovation for the display and semiconductor industries. https://www.merckgroup.com/en/news/opening-e65.html
DuPont / DuPont Tejin Films	Luxembourg/UK	Provides various materials for the electronics industry, including materials and thin film solutions for flexible electronics. http://www.dupontteijinfilms.com/

Source: authors compilation

3) Printing companies

Printing processes for flexible electronics can include film casting, inkjet printing, spray coating or screen printing. Inkjet printing enables adding small amount of material as an ink to specific location of substrate and hence printing electronic devices such as circuit boards, solar cells, OLEDs, and RFIDs with accuracy.

Table 3: Printing companies for flexible and printable electronics, examples

Company	Country	Research areas and main products
Ceradrop	France	Cedadrop designs and markets materials deposition digital printers for the printed electronics industry and smart 3D printing. http://www.ceradrop.com/en/

Company	Country	Research areas and main products
Coatema Coating Machinery GmbH	Germany	Coatema Coating Machinery GmbH offers production equipment and R&D for coating, printing and laminating plants for roll-to-roll and sheet-to-sheet applications. It provides high precision register and controlled printing systems like screen, gravure, flexo and inkjet to nanolayer coating systems and over 30 different application systems. https://www.linkedin.com/company/coatema-coating-machinery-gmbh/?originalSubdomain=np
Demcon	The Netherlands	Demcon is a high-end technology supplier of products and systems. https://www.demcon.nl/en/demcon/
Heidelberger Druckmaschinen AG	Germany	Heidelberger is a solution provider for the printing industry. They provide expertise in printed electronics with a focus on flexible printed sensors and an understanding of materials, processes and printing technologies which are essential for the development of flexible and hybrid electronic systems. https://www.heidelberg.com/global/en/other_business_areas/print_solutions/ printed_electronics/printed_electronics
Mekoprint A/S	Denmark	Mekoprint is manufacture-to-order high-tech company. They provide solutions for industrial and electronics companies and manufacture customer-specific operating solutions, industrial graphics solutions and electronic print on flexible foils. https://mekoprint.com/
Océ	The Netherlands	Inkjet specialist Océ – a Canon company – has developed a so-called 'drop-on-demand' printhead which can 'jet' various types of metal drops at temperatures of up to 1 800 degrees Celsius. Possible applications range from metal tracks on flexible electronics and ultra-thin connectors for chips, to microstructures on machine parts. https://www.demcon.nl/en/showcase/the-worlds-first-multi-metal-printer/
Schreiner Group	Germany	Schreiner Group specialises in the development and manufacturing of functional labels and labelling solutions for a wide variety of industries. Schreiner PrinTronics has know-how in the field of printing silver, carbon, insulation and die-cutting of metal foils as well as contacting and industrial processing from roll-to-roll. https://www.schreiner-group.com/en/business-units/schreiner-protech.html

Source: authors compilation

4) Components, displays and design

There are several companies that work on the production of components, such as sensors, displays or on the design of (flexible) electronics.

Table 4: Components, displays and design companies for flexible and printed electronics, examples

Company	Country	Description
FLEEP Technologies	Italy	Fleeptech is an Italian company that started as a spin-off project of the Italian Institute of Technology and produces now flexible integrated circuits, based on Organic Thin Film Transistors (OTFTs), and integrated systems. FLEEP is a sustainable electronics solution for flexible, transparent and recyclable electronics. All their electronics devices are recyclable as a consequence of only using carbon-based materials in the production process. Their technology is used in the biomedical, automotive or packaging industry among others. https://www.fleeptech.com/
Isorg	France	Isorg was established in 2010 by experts from the hi-tech electronics and optical industries. The company offers complete solutions for large-area image sensors. The company's core technology integrates printed photodiodes on different substrates to enable large-area image sensors for the smartphone and security markets and extended applications in medical X-ray imaging, non-destructive testing and stock management. https://www.isorg.fr/meet-isorg/who-we-are/

Company	Country	Description
Nanoident Technologies	Austria	Nanoident Technologies AG is an acknowledged firm in the development and production of printed semiconductor-based sensors and was the world's first company to commercialise printed sensor products for high volume applications. https://www.protolabs.co.uk/resources/case-studies/nanoident-technologies-ag/
PolyIC	Germany	PolyIC develops products based on printed electronics and produces individually manufactured transparent and flexible metal-mesh touch sensors. https://www.polyic.com/company/
Quad Industries	Belgium	Quad Industries produces printed and flexible sensors and passive electronics and it offers R&D, engineering, prototyping and manufacturing services. https://www.quad-ind.com/about-quad-industries/
PragmatIC	UK[29]	PragmatIC offers a flexible electronics foundry service to designers of electronic devices. The company also offers own products, such as flexible RFID and NFC tags and sensors. In addition PragmatIC is offering a 'fab-in-a-box' production system for flexible electronics. https://www.pragmaticsemi.com/

Source: authors compilation

5) Integrators

Device manufacturers and integrators focus on integrating multiple steps in the value chain and have the potential to exploit the information flow and increase the added value.

Table 5: Integrators for flexible and printed electronics, examples

Company	Country	Description
ASML	Netherland	ASML is specialised in the semiconductor industry, focusing on lithography solutions. https://www.asml.com/en/company/about-asml/organization
Infineon Technologies	Germany	Infineon works on semiconductor solutions for automotive, industrial and multimarket sectors, as well as chip card and security products. Infinenon has subsidiaries in the US and in Singapore and Japan. https://www.infineon.com/
infinityPV	Denmark	infinityPV is a Danish company with background in printed photovoltaic technology. It is focused on supporting the development of roll-to-roll (R2R) printed solar cell technology within academia and industry through open sharing of the technology and through education. https://infinitypv.com/
NXP	The Netherlands	NXP is a Dutch company that started its activities 60 years ago. The company is active in several sectors such as the automotive, industrial & IoT, mobile and communication infrastructure markets. https://www.nxp.com/company/about-nxp/worldwide-locations/netherlands:NETHERLANDS
Philips	The Netherlands	Philips is a Dutch corporation focused on electronics products in several application areas including healthcare. The lighting division of Philips has been spun off and is now a separate (Dutch) company called Signify that still uses the Philips brand for its products. R&D at Philips is focused on healthcare applications, making use of electronics and data. https://www.philips.com/a-w/about.html
Robert Bosch	Germany	Robert Bosch is a multinational engineering and technology company. The company develops inks required for the manufacture of organic thin film transistors, semiconductor and dielectric inks as well as those for planarisation, passivation and insulation layers. https://www.bosch.com/company/
Soitec	France	Soitec produces silicon-on-insulator based on the smart cut technology. It enables to produce engineered substrates, consisting of multi-layer materials. https://www.soitec.com/en/products

[29] Not part of EU27, but has strong collaborations with European partners.

Company	Country	Description
Schneider Electric	France	Schneider Electric is a French multinational company providing energy and automation digital solutions for efficiency and sustainability. https://www.se.com/ww/en/about-us/
STMicroelectroics	France/Italy	STMicroelectronics is a semiconductor company delivering semiconductor solutions across the spectrum of microelectronics application. The main technology they work with is System-on-Chip (SoC). https://www.st.com/content/st_com/en.html
Stora Enso	Finland	Stora Enso is a reneable materials company that delivers packaging solutions among others. It has introduced the ECO RFID Tags which are manufactured with a scalable plastic manufacturing solution. https://www.storaenso.com/en/products/intelligent-packaging/eco-rfid-tag-technology
TactoTek	Finland	TactoTek has developed injection moulded structural electronics solutions that integrate and encapsulate printed electronics as well as standard electronic components within durable 3D injection-moulded plastics.. https://www.tactotek.com/this-is-imse/
UMS – United Monolithic Semiconductors	France and Germany	United Monolithic Semiconductors offers monolithic microwave integrated circuit based products and foundry services for defence and space, telecommunications and automotive industries. https://www.ums-rf.com/company/company-profile/
Walter Pack	Spain	Walter Pack produces thermoformed plastic parts for a wide variety of industrial sectors. Walter Pack has collaborated in the development of a multi-touch surface that will include sensors and lighting. https://www.walterpack.com/empresa.php?sec=empresa; https://industriesdelfutur.cat/en/ppt-plastfun/

Source: authors compilation

6) End users

As mentioned above, flexible electronics can be used in a broad spectrum of industries and have many different applications, which make them interesting for various end-consumer segments. An example of innovative use of flexible electronics was highlighted in one of the interviews: during the 2018 FIFA World Cup in Russia flexible and printed electronics were used as a way to prevent tickets from being counterfeited. Additionally, the balls had integrated NFC (Near-Field Communication) tags. This allowed the user to interact with it using their smartphones and changed the user experience.

Three main characteristics make flexible electronics interesting for end-users[30]:

- **Portability:** in contrast to conventional technologies using mostly glass-based displays, with the inconvenience of rigidity and potentially being breakable, flexible electronics are thinner and lighter. This change makes the use of flexible electronics easier and allows for portability of the products.
- **Personalisation:** Flexible electronics offers higher personalised experiences (e.g. smart bands and other similar wearables). Furthermore, with the use of flexible devices, consumers can access an array of data generated in and by the device. Wearable flexible electronics can provide information that facilitates the monitoring of their health, as well as to interact with each other (e.g. the case of smartwatches that measure the health of the user). Finally, thanks of the inclusion of flexible polymer film substrates instead of traditional rigid printed circuit boards, flexible electronics can be better tailored to the specific requirements of each application.
- **Product paradigm:** Flexible electronics make a diverse range of applications possible thanks to their versatility and practicality. These characteristics offer designers and consumers many innovative factors and features.

[30] Promerus (2018) 3 advantages of flexible electronics that consumers love

2.3 Linkages along the value chain

Several linkages take place along the value chain and among different sectors, due to the manufacturing process of printed and flexible electronics as seen in the value chain analysis. Innovations in this area transform traditional companies, such as those active in printing, chemical and semiconductor industries, and connect novel technology with traditional techniques.

In the case of printed electronics, there are for example strong relations with the chemical sector in order to develop the inks used in the printing process. In addition, material science also has a big role, since it is important to conduct research and develop the appropriate materials and substrates in which to print the electronics.

All these linkages have resulted in new processes and applications for flexible and printed electronics, many of them promising and with potential for growing the market. As explained by interviewees, flexible electronics applied in sensors will offer a broad range of applications **in medical devices and healthcare, but also in a range of other sectors,** that require creating new connections among industries and firms.

Section 3

3. Analysis of EU competitive positioning

Figure 5: Overview of the strengths, opportunities, challenges and risks for the flexible and printed electronics value chain

Source: authors

3.1 Strengths

The main strength of Europe lies in its strong research and development capacities. Europe has several high-quality research centres and innovation networks working on flexible and printed electronics. This contributes to availability of skills and expertise for flexible electronics in Europe. Europe is investing strongly in micro- and nanoelectronics and in flexible electronics in particular. In the period of 2007-2020, more than €300 m public funding was destined for research and innovation in flexible and printed electronics. This funding covered a wide spectrum of devices, systems and processes and supported fabrication. For instance, in 2019 the Horizon2020 call Smart Anything Everywhere[31] had a specific area dedicated to flexible and wearable electronics. The objective of the call was to help companies to mature, innovate and validate their products in this field, which is something that is still very relevant for the further development of the flexible electronics industry.

Europe is very well positioned in the low and mid-volume manufacturing segments with high added value. European companies are in general better suited for manufacturing high quality, high value devices in smaller volumes, but mass production of commodity electronics is not done in Europe. High throughput manufacturing of large-area flexible electronics, for instance displays and lighting, is happening mainly in Asia. To produce in high volumes, European firms need to build international partnerships in particular for certain materials and certain manufacturing elements. For sensors in application areas such as IoT, digital medicine, diagnostics and wearables Europe could provide high quality, high value flexible electronics.

The EU has relevant **assets in equipment manufacturing**. Equipment concerns in particular printing equipment for screen printing, atomic layer or chemical vapour deposition, inkjet printing, gravure printing, nano imprinting, transfer printing and coating systems. European players developed global

[31] Horizon 2020 calls – Smart Anything Everywhere https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/dt-ict-01-2019

strengths thanks to systematic and significant public and private investment made in equipment manufacturing. Equipment manufacturing is also the traditional stronghold of Europe in the conventional (silicon) electronics value chain.

The **European Single Market** is also seen as a strength for the sector as it allows manufacturers from different countries to work together to develop a single end product.

3.2 Opportunities

According to the interviews conducted for this study, the main factor that will allow European stakeholders to seize the opportunities in flexible electronics is **differentiation**. In order to strengthen its competitive advantages, the EU should focus more on building capacities and cost leadership in certain (complex) high value application areas as well as production of more unique products based on clients designs (foundry services). A strong differentiation strategy should be accompanied by marketing and creating visibility for European products in order to be able to target the main customer segments and increase sales.

Opportunities also lie in creating **cost-effective access to manufacturing foundries in Europe** that will serve for prototyping and for production of low- and mid-volumes of flexible and printed electronics products[32]. However, currently very few of such foundries exist in flexible electronics. Those that exist are small companies, such as PragmatIC[33], that are also involved in R&D as flexible electronics is still very much in development. Scale-up of such facilities will require investment from public funding and venture capital.

Interviewees highlighted the opportunity of the EU in **positioning itself in some of the emerging end-markets** of printed and flexible electronics such as in the areas of healthcare, packaging and other industrial areas. Niche applications are also considered as important future sources of revenue for European companies for example in the area of logistics such as supporting cold chain logistics or environmental sensors. Devices that European business could focus on are sensors or antennas (e.g. Bluetooth), such as those required in IoT or healthcare. Innovations are abundant in, for example, advanced materials and novel manufacturing methodologies that enable flexible and printed electronics products with a diverse set of applications. In the past, the EU has lost the opportunity to become a strong player in the solar panel market. The EU should therefore seize the momentum now and establish a position in specific application areas for flexible and printed electronics:

- **Healthcare applications:** all interviewees stressed the importance of healthcare applications as a key market for flexible electronics and a market where Europe could attain position. Such applications include sensors for monitoring, wearables, health care patches (e.g. ECG patches), or tags for digitally processing/tracking pharmaceuticals or samples for diagnostic analysis. Such medical applications are promising as they can generate high added value[34]. Bioelectronics (which connects flexible and printed electronics technology with the human skin and nervous system) helps remote monitoring of patients and thus improve quality of life. Europe is well-placed to lead breakthrough products in this area in the future.
- **Sensors for industry and environmental monitoring:** flexible electronics enables the development of sensors that are easily integratable and have a low carbon footprint. Flexible and printed electronics is a key enabler for the development of sustainable IoT, which in industry can contribute to the adoption of Industry 4.0.
- **Organic and Large Area Electronics (OLAE):** OLAE is a new branch of electronics that works on conductive polymers, plastics and small molecules. OLAE devices are made of carbon-based materials which are widely available, cheaper and less toxic than traditional silicon-based electronics[35].
- **Fashion and textile:** Another specific, but emergent, application area of flexible electronics, that could be an opportunity for Europe, is within creative industries. Here substrates such as textiles and paper are used, to integrate flexible electronics into – for example – fashion. As the technology for flexible electronics on these materials is not well developed yet, this may only be a relevant niche for Europe in the long-term. In Europe, several initiatives promote the development of flexible electronics in textiles, such as SmartX[36], the European Smart Textiles Accelerator – bringing together expertise across Europe.

[32] Ibid.
[33] This example is from the UK, not part of EU27.
[34] https://www.idtechex.com/fr/research-article/printed-and-flexible-electronics-key-technology-highlights-in-2020/22318
[35] https://madras-project.eu/olae/
[36] https://www.smartx-europe.eu/

3.3 Risks

One of the main risks of the market is the **relatively low entry and exit barriers** (in terms of costs) in comparison with other segments in the overall electronics market. In conventional silicon electronics significantly higher investments in equipment (nearly €5 bn) are required to enter the market. This makes it more difficult for Europe to have a leading position in the sector since other countries can easily invest in this sector too. Although a minimum level of technology is required, it is not possible to install a factory without expertise according to the interviewees. Differentiation and quality (as pointed out above) will be the key elements to address this risk.

Risks also lie in jeopardising **strategic autonomy** in the flexible and printed electronics value chains in Europe and efforts will be necessary to guarantee resilience especially in times of Covid, which puts an additional pressure on the value chain.

Regulation is also considered to be a relevant risk. A major difficulty that companies are facing when bringing flexible and printed electronics enabled products (such as smart wearables) to the market is related to meeting product regulations. In most cases standards, on which industry could rely to ensure conformity with health and safety requirements, are in the development stage or are simply non-existent. In order to address this risk, there is a clear need to develop common approaches for intellectual property rights, licensing, certificates, standards and training in flexible and printed electronics.

Many businesses producing flexible electronics are still small businesses that need to upscale to establish the market for flexible electronics. To attain a strong position of Europe in flexible electronics, these businesses need to scale-up and acquire investments. For that the technology and processes for flexible and printed electronics need to further mature. Investments in projects that intend to commercialise flexible electronics in application areas that match Europe's societal needs and strengths, could push some products successfully to the market – creating success stories to attract investments.

3.4 Challenges

According to the interviewees, one of the key challenges the EU flexible electronics value chain is facing is linked to **production volumes and costs**. Quite some products and goods that have flexible electronics incorporated (RDIF and similar tags) have high manufacturing costs, which then cause higher retail prices as well. The cost structure of printed electronics products where all components are printed on the same substrate is very tight. Producing organic and printed electronics-based products can become very expensive and allow only for a lower profit margin.

To unlock the potential in this technology, it is key to increase the adoption rate so that **manufacturing costs per unit product reduce and products can be sold at lower prices to consumers**. This is expected to increase sales and establish the market for flexible and printed electronics.

The potential in flexible and printed electronics is hindered by the **slow response** rate of traditional electronics companies that are more risk averse and do not invest enough in this area. In this regard large Asian companies are more advanced and venture more quickly in innovative projects.

Most innovative ideas in flexible electronics come from **startups that face financial and sustainability challenges** (as any startup). Large companies have their well-established supply chains and agreements that are hard to change. For instance, Philips had to create a separate company in order to develop a new production line of lamp shades that are 3D printed using flexible electronics.

Companies need to overcome the **critical stage of commercialisation and scaling-up** that can ensure the integration and demonstration of products and processes. On the one hand, an important weakness of the system is linked to the often risk averse European culture and the fear of failing, which does not help creating the appropriate conditions to start companies specialised in this area. On the other hand, **entrepreneurs who do take risks face the harsh reality of very complex market conditions** (especially in areas such as healthcare) **and a lack of appropriate non-dilutive funding** when they want to scale up their operations. The European investment system is appropriate to provide early-stage funding to companies, but it is not up to the level required when it comes to provide capital for scaling up. EU funds can be still difficult to access for new players, venture capital is not always available and conditions to obtain private equity funding can raise concerns about losing control over the company. There is a need for more European or national non-dilutive funding where the company does not give away any ownership or equity. Grants available through the European Innovation Council Accelerator funding mechanism[37] are seen useful, however, they do not cover the costs of equipment and cannot finance capital intensive innovation projects.

[37] https://ec.europa.eu/easme/en/section/sme-instrument/eic-accelerator-funding-opportunities

A key obstacle to adoption is **the whole ecosystem that needs to be changed** in order to convince a range of stakeholder about the advantages of flexible electronics. For instance, practices in hospitals, reimbursement schemes, procurement of medical devices need to be changed in order to allow wider adoption. Another ecosystem challenge is related to technology infrastructure. Access to technology facilities are easier to access in countries such as Germany, France or the Netherlands, however, startups in other countries (e.g. Italy) without key printed electronics facility are disadvantaged. More cross-border cooperation across Europe could be helpful in this area.

It also has to be clear that **flexible electronics will not replace conventional electronics**. Basically all flexible electronics that is currently on the market is considered semi flex, using conventional electronics on flexible substrates. Miniaturisation to the level attained in conventional semiconductor electronics is not likely attainable for flexible electronics (due to materials and processes used), limiting applications to areas where larger electronic structures are allowed. Application such as memory and processors will remain in the realms of conventional electronic, while flexible and printed electronics can replace some applications of sensors, antenna's, displays, tags etc.

The higher costs of flexible electronics will not necessarily bring **enough added value for customers to pay a higher price**. Technology push is not enough to bring products successfully to the market. There should be a demand for applications of flexible electronics as well and it has to be assessed whether the consumer really wants such products and if there is also a real market pull. For instance, consumers might not want to spend more money on a T-shirt just because it has built-in sensors or displays relying on flexible electronics.

Another challenge that the European market is facing is **fragmentation,** as explained by the interviewees. This fragmentation happens at three levels:

- **Applications:** most companies are working on the same developments but instead of working together they compete. This takes research longer to be commercialised. European businesses along the value chain working and developing together could lead to more and faster innovations in flexible electronics.
- **Finance and capitals:** several differentiated capital markets and investments opportunities are spread across the continent. This makes it difficult for companies to receive the required capital to scale-up and grow.
- **Research:** in spite of the efforts of the European Commission to bring researchers together, research efforts are still fragmented.

Although interviewees highlighted the importance and positive impact of the Horizon research and innovation funding of the European Commission, they also pointed at the fact that in the US there are also targeted defence funds that push the development of various applications of flexible electronics and can be highly effective. Including the objective to **foster the use of flexible electronics within the EU defence programmes** might boost the European sector as well. There are also additional challenges that are sector specific[38]:

In the **automotive and transport sector**, it is important to respect safety requirements and public regulations. However, developments in this area require long timeframes. It would be beneficial to have common approaches across the continent when it comes to prototyping and integration of components for aspects such as volume, weight and packaging, that could potentially boost the uptake of flexible electronics by automotive Tier 1 suppliers.

In the **healthcare and wellbeing** area, the biggest challenges are linked to specific sector requirements and to comply with stringent medical device regulations. In case the companies want to scale up their production in this field, high investments are required in order to support pre-testing and demonstration activities to adapt and comply with current standards. The **further development of standards** specifically applicable for flexible electronics will be criticial to secure European competitiveness.

Finally, **integration of flexible electronics and containing costs** can be challenging in this market. Containing the cost of goods in order to achieve the targeted retail price and to implement an optimal timescale for manufacturability can be challenging for flexible and printed electronics. In addition, integration, such as fashion with technology – the inclusion of lighting system in different garments – can require up to two years of design and development before moving to the manufacturing phase. Also the integration with power sources for active electronics may, for some applications, be challenging.

[38] European Commission (2019). Workshop in Flexible and printed electronics "Manufacturing and Access to New Technologies for Innovative Products"

Section 4

4. Conclusions & outlook

4.1 Conclusions

Flexible electronics is a field where the EU has world-renowned expertise in terms of research and development and industrial capabilities. Renowned research centres specialised in the field drive continuous innovation: from the use of novel materials to new processes and manufacturing techniques. Despite all the great potential, the industry of flexible and printed electronics is growing slowly as pointed out by several companies interviewed for this report. The technology cannot compete with standard electronics in many application areas due to high costs. Even if there are improvements, flexible and printed electronics need to find application areas where it does not have to compete with silicon technologies per se.

Europe is well positioned in the low and mid-volume segments for high added value products and has relevant assets in equipment manufacturing. Nevertheless, when it comes to manufacturing displays and small, commodity/high-volume, electronics, China and other Asian countries perform better.

Key factor for success will be the ability to differentiate the European offering in terms of quality, added value and specific application areas. The role for Europe is seen in niche areas derived from innovation that create more complex, high value-added applications. Upscaling the application and the businesses producing flexible electronics will be important for further development of the market.

Capacity, high added-value products in niche markets, reducing costs of production and the availability to supply at short notice are elements that will ensure European competitive advantage on this market. More demonstrators are needed for specific application areas such as healthcare or automotive to develop the market and the position of Europe. It is a key challenge that the entry and exit barriers are comparatively low compared to the investments required in silicon technologies, which makes this opportunity more fragile and volatile[39].

Companies will need to overcome the critical stage of commercialisation and scaling-up, and work on integration and demonstration of both products and processes.

4.2 Outlook

Flexible electronics will not fully replace conventional electronics, but it is expected to be a preferred and competitive technology in several sensor and passive components applications, including RFID/NFC tags and displays/lighting.

For European businesses, flexible and printed electronics offer opportunities in high value-added products, with most potential in several specific application areas. These application areas are healthcare and medical devices, smart packaging and logistics, sensors for IoT, industry and environmental monitoring, and automotive. An emergent area for Europe lies within the creative industries, although applications in e.g. fashion, require further maturity of flexible electronics on textile substrates.

For Europe it is important to build on current strengths and capitalise on its strong research and innovation position. This requires commercialisation by businesses in Europe, which are currently small-sized. Further upscaling of these businesses is required to gain a strong position in the market of flexible and printed electronics. This could be stimulated with targeted investments in specific application areas for flexible electronics, fulfilling societal needs in strategic areas, such as in healthcare. Demonstrator projects (higher level TRL) could further enhance business cases of smaller companies in flexible electronics, enabling them to acquire private investments for upscaling.

[39] European Commission, 2018

4.3 COVID-19 impact on flexible electronics

The outbreak of the COVID-19 pandemic negatively impacted the growth of the flexible and printed electronics market, as it caused major delays for manufacturers and suppliers based in China who struggled to keep factories running at full speed. European electronic manufacturers depend on China for certain components. IPC, an electronic equipment trade organisation, ran a survey in February 2020 and 65% of the 150 electronic manufactures and suppliers surveyed reported delays from suppliers due to the spread of COVID-19[40]. The pandemic had negatively effected startups that have now less opportunities to network, find investors and partners. Even if there are virtual events, they do not allow for creating the required level of business partnerships.

On the other hand, the Covid crisis created new opportunities as well. In some cases, firms developed new wearable electronics solutions to address the Covid situation. For instance, as the need for remote patient monitoring increased, electronic skin patches have seen strong interest for monitoring a patient's temperature remotely. Continuous monitoring enabled by connected medical devices and wearables improves diagnostic capability and prevention too[41].

Wearable devices can play a vital role in predicting certain diseases by combining essential vital signs with clinical symptomology. Conductive ink has been used in sensor test systems to detect infections or nano copper has been developed with an anti-viral characteristic. In retail, printed force sensors have been applied that alerted shoppers if they are standing too close to each other[42].

For the period after the COVID-19 pandemic, interviewees expect a further orientation of flexible electronics on healthcare applications and wearables. **Opportunities are seen in low-cost diagnostics with flexible electronics.**

[40] https://www.mordorintelligence.com/industry-reports/flexible-electronics-market
[41] https://www.idtechex.com/en/research-report/flexible-electronics-in-healthcare-2020-2030/731
[42] https://www.idtechex.com/fr/research-article/printed-and-flexible-electronics-key-technology-highlights-in-2020/22318

Section 5

5. Annexes

5.1 List of interviewees

Interviewee	Company	Country
Antti Kemppainen	VTT	Finland
Björn Norberg	RISE, Research Institute Sweden	Sweden
Christian May	Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP	Germany
Giorgio Dell'Erba	FLEEP Technologies	Italy
Haydn Thompson	Thhink 'SmartEverythingEverywhere'	European Union
Mike Glennon	IDC	United Kingdom
Lotte Willems	Holst Centre	The Netherlands
Richard Price	PragmatIC	United Kingdom
Romano Hoofman	Imec	Belgium

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https://www.mordorintelligence.com/industry-reports/flexible-electronics-market

About the 'Advanced Technologies for Industry' project

The EU's industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies is needed. To this end, the *Advanced Technologies for Industry* (ATI) project has been set up. It provides policymakers, industry representatives and academia with:

- Statistical data on the production and use of advanced technologies including enabling conditions such as skills, investment or entrepreneurship;
- Analytical reports such as on technological trends, sectoral insights and products;
- Analyses of policy measures and policy tools related to the uptake of advanced technologies;
- Analysis of technological trends in competing economies such as in the US, China or Japan;
- Access to technology centres and innovation hubs across EU countries.

You may find more information about the 16 technologies here: https://ati.ec.europa.eu.

The project is undertaken on behalf of the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the Executive Agency for Small and Medium-sized Enterprises (EASME) by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA.

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