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D1.2 Market Analysis Report

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Abstract

Flexible electronics & R2R markets are expanding fast, supported by even stronger needs of portable equipment and wearable devices. The market of wearable medical devices was valued above 15 billion USD in 2020 and should grow at +30% CAGR for the next years to come. It was pushed by the extension of continuous glucose monitoring needs for the treatment of type I diabetes. And it will be supported by emerging new indications such as wound healing monitoring and point of care diagnosis devices including blood test devices.

Statement of originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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1 Electronics for healthcare applications – General trends

1.1 Portable medical equipment products (PMEPs)

Portable medical equipment products (PMEPs) represent a growing and transforming trend of the medical device industry. These devices can broadly be categorized into products for diagnosis and testing, therapy, and first aid and other applications.

"Historically, the term medical electronics was used to indicate not only electronic equipment and devices (including implants) for patient care, but also for a variety of related electronic healthcare services (such as remote patient monitoring, telemedicine, and wireless technologies)." [1].

Progress in the miniaturization in electronics (e.g. microprocessors and electronic circuits) enabled the development and commercialization of PMEPs for healthcare applications. And the demand of PMEPs is steadily increasing as fuelled by growing remote monitoring needs and home care practice. It is supported by the rising prevalence of chronic diseases or at risk to become chronic (e.g. type II diabetes, skin ulcers), the aging of the population and healthcare expenditures. Major players in the PMEPs market are healthtech corporates including Philips Healthcare, Panasonic Corp., Abbott Laboratories, Hitachi Medical Corp., GN Resound, Smith & Nephew, Nipro Diagnostics, GE Healthcare and Medtronic Inc. The global market of PMEPs is estimated to represent more than 70 billion USD, in 2021. The home care market is the largest end-user market with more than 35 billion USD, in 2021. The compound annual growth rate (CAGR) is expected to be between 4 & 5%, between 2021 and 2027. The leading regional market is North America (close to half of the market), followed by Europe and Asia Pacific with similar shares (close to a fourth of the market).

In the category of Diagnosis and Testing, PMEPs are predominantly represented by ultrasound, X-rays, and electrocardiogram devices. Coming aside are portable or wearable glucose meters, blood analyzers (e.g. blood count, gases, electrolytes, metabolites and coagulation). Electronics miniaturization has already led to devices requiring tiny amounts of body liquids or tissues to run the testing such as glucose sensors used for the continuous monitoring of glucose concentration for the insulin administration in diabetic patients.

Rising healthcare cost pressures and reimbursement policies as well as increasing regulatory pressures are seen as the main market restraints for PMEPs. But it should be counterbalanced by the recent advancements in PMEPs generating more accurate and reliable devices while increasing functionality, with the advantages of cost efficiency and portability or wearability. The recent COVID-19 pandemic should also accelerate home care practice and adoption of PMEPs.

Diagnosis and Testing is planned to contribute for a market valued at +40 billion USD, in 2027, (half to come from glucose meters), at a similar level of the therapy segment. First aid and other applications should contribute at a much lower level, about 7 billion USD.

By portability, the wearables are the leading application by market value (23 billion USD in 2020) and the CAGR (above 5%). The next segment coming close to the wearables is the handheld devices. (20 billion USD in 2020). Diagnosis and Testing market is currently dominated by handheld devices with a market value 2.4-fold higher than wearable devices, in 2020, but a difference tending to decrease over the time. The global market for portable medical equipment products for diagnosis and testing is as expected led by home care settings end users (close to half of the market).

1.2 A focus on wearable devices and diagnostics

"A wearable medical device is autonomous, non-invasive and performs a specific medical function such as monitoring, support or activity tracking over a prolonged period. Wearable medical devices provide next-generation support with intelligent patient monitoring and real-time feedback. They help monitor chronic diseases like heart disease, diabetes, and asthma, and provide vital parameters like heart rate, blood oxygen levels, respiration and body fat levels."

The global market for wearable medical devices was valued at 15.3 billion USD, in 2020. The market is expected to grow at a compound annual growth rate (CAGR) of 33.1% to reach approximately 83.9 billion dollars by 2026 [2].

Wearable devices are used for fitness and activity tracking but have penetrated the area of medical applications like diagnosis, monitoring and, to a certain extent, the treatment of chronic diseases. All are key factors of the booming market of wearable medical devices.

The market expansion of wearable devices should be restrained, to some extent, by data privacy, security, regulatory landscape, the cost of the devices and adoption in emerging countries - due to low per capita income, lack of government funding and limited access to technologies. But the market penetration will be supported by the newer advancements in technologies (e.g. IoT, flexible electronics, smart materials, and low-power computing and networking), making them smaller, lighter, and less invasive while delivering the requested level of accuracy for medical use

For example, continuous glucose monitoring devices have drastically changed the treatment of diabetes and represent a high share of the current market of wearable medical devices. The market is also pulled out by activity and fitness trackers, not anymore coming as standalone products, but integrated in smart watches equipped with a range of sensors (e.g. accelerometers, gyroscopes. pressure and temperature sensors).

Main wearable medical device applications are listed below:

Healthcare and medical

- Blood pressure monitors
- Defibrillators
- Continuous glucose monitoring
- Drug delivery products
- Hearing aids
- ECG monitors
- Smart glasses
- Insulin pumps
- Patches
- Personal Emergency Response Systems - PERS
- Pulse oximetry

Fitness and wellness

- Activity monitors
- Fitness and heart rate monitors
- Emotional measurement
- Heads-up displays
- Foot pods and pedometers
- Smart clothing
- Smart watches
- Sleep sensors
- Others

The wearable medical devices market come into 4 main categories, according to their application: Health and fitness, Diagnostic, Therapeutic & Rehabilitation. The leading indication is health and fitness with a CAGR above 39% between 2019 and 2026, with a market value at +30 billion USD in 2026. The second application by importance is Diagnostic, about 20% behind Health and Fitness. Therapeutic is another fast-growing segment to contribute at a level of +17 billion USD in 2026. Rehabilitation is the last segment (a projection at 8 billion USD in 2026) with a slower CAGR, 23% compared to the CAGR of the other segments with values above 30%.

The global market for diagnostic wearable medical devices is planned to grow from 3.4 billion USD in 2019 to 26 billion USD in 2026 (CAGR: 34%), North America, the leading region, followed by Asia and Europe at the same level, with a 30% less market.

Wearable devices are already by patients with diabetes, blood pressure abnormalities, sleep apnea, dialysis, and other chronic conditions. Wearable sensors in the form of smart bandages / patches and smart clothing are technologies, expected to expand the commercial portfolios of wearable medical devices. Other devices to emerge rapidly will provide solutions to measure disease markers in tears, saliva and sweat.

1.3 The case of wound diagnosis and monitoring

Chronic wounds have a steadily growing impact on healthcare expenditures as driven by increasing incidence of obesity, diabetes, and population aging. They include pressure ulcers, diabetic foot ulcers, and venous ulcers. Delayed healing and associated complications are commonly observed. And they have a high impact on the quality of life of patients and put pressure on healthcare systems with high cost of treatments and mortality rates.

For example, the total annual cost of hospital-acquired staged pressure ulcers was above 25 billion USD. The annual incidence of diabetic foot ulcers is between 2 and 5%. Venous ulcers affect about 3% of the world population [3].

Wound diagnosis and monitoring are currently limited by inaccurate wound measurement by rulers, painful and challenging tracing of non-viable tissues and discoloration in the wound and delayed diagnosis by biochemical analysis which can take days, even weeks, before returning results.

Wound diagnosis and monitoring should benefit from advanced technologies such as hyperspectral imaging, multispectral imaging, biocapacitance, fluorescence imaging, thermal imaging, biosensors, and AI which should help in overcoming the limitations of the conventional methods. These technologies are expected to reduce i) inaccuracies and inconsistencies in recording objective wound parameters, including simple dimension parameters such length, width, volume, depth, and perimeter of the wound and ii) the discomfort of patients with non-invasive testing methods.

Imaging of the wound can be achieved by using hand-held scanners and portable screening devices. Wound measurements and documentation can be performed by smart phone and tablet compatible applications. And sensors can be associated with wound dressings or skin patches, insoles, and mattresses.

Key molecular signals in the wound bed can be possibly tracked by skin patches embedded with sensors such as pH, moisture, temperature sensors, and other bioelectronics. The data can be wirelessly and remotely exchanged with the medical team, for a more adapted and timely treatment of the wounds which should prevent non-healing or poorly healing wounds and decrease wound care-related costs. For example, Grapheal, a French company has developed a wearable graphene-based skin patch including wireless electronics and biosensors for real-time monitoring of the wound bed by transferring the sensor information to a mobile application.

In a near future, these novel tools are expected to be increasingly deployed and use by the healthcare providers, owing to the immense potential benefits offered by these tools.

2 Sensors for medical use – General Trends

2.1 A high level snapshots

Rising healthcare costs, an aging population and the need for medical diagnosis and treatment in developing and underdeveloped regions are driving the sensor market in medical applications.

Implantable sensors, self-powered sensors (e.g., sensors that convert body movement to mechanical energy and muscle stretching into electricity), biosensors, MEMS and nanosensors are expected to strongly grow during the next decade. Most common sensors are temperature, pressure, flow, encoder, SQUID, accelerometer, image, and biosensors. The latter category has generated so far, the bulk of the total revenues.

Biosensors have grown from an R&D concept in the 1960s to a commercial reality in 1970s with the introduction of Clark oxygen electrodes which were subsequently developed by Clark and Lyons for glucose biosensing. Point-of-care is currently the largest market for biosensors, and it is likely to continue to dominate during the next years. Glucose monitoring is the leading indication of biosensors with both point-of-care and home diagnostics applications. But despite product and technology innovations and improvements, the market growth of biosensors is restricted. This may be explained by several limitations including readout time, miniaturization, and cost-effectiveness.

2.2 Biosensors

"A biosensor is an analytical device that employs a biological material to specifically interact with an analyte. This interaction produces some detectable physical change, which is measured and converted into an electrical signal by a transducer. Finally, the electrical signal is amplified, interpreted and displayed as analyte concentration in the solution and preparation. The transducer may be optical, electrochemical, thermometric, piezoelectric, magnetic, or micromechanical. The biological component is most commonly an enzyme or an antibody." [4].

Commonly used secondary transducers come into these main categories:

- Electrochemical.
- Bioluminescent.
- Piezoelectric quartz crystal.
- Resonant mirror.
- Opto-electric.
- Light addressable potentiometric.
- Thermistor.
- MEMS.

The market of Biosensors and Nanosensors is estimated to be over 30 billion USD, in 2023, with high single digit annual growth. The health application segment is leading the biosensor market with half of the share. MEMS and electrochemical sensors are the most contributing technologies, representing each, a volume close to 10 billion as projected in 2023.

Biosensors are increasingly finding health application in blood glucose & gases monitoring, drug discovery, drug analysis and whole blood analyzers, including real-time point-of-care testing. Glucose sensors are the dominant use, notably for the monitoring and/or the close loop treatment of diabetic patients whose number is steadily increasing. Other sensors to benefit from strong growth are cholesterol, urea, blood gases and other blood parameters. Touchless sensors, an emerging technology from a commercial perspective, are expected to rapidly expand. They can sense remotely physiological parameters – from vital signs to blood glucose –, without physical contact with the human body. A similar technology, pseudo-touchless sensors, uses a hybrid of infrared, optical and piezoelectric technologies for the same purpose.

Another popular category is wearable sensors, equipping devices such as pulse oximeters, heart rate straps/watches and ECG, relying on contact sensing with its own performance and functional limits.

Nanosensors are estimated to contribute at 1 billion USD in 2023. It is still a nascent market, but a strong market potential. They detect changes and sense material at submicroscopic levels. For example, they can accurately identify cells and help in the diagnoses of same disease. By using nanotubes, they can sense gas properties such as the ionization of gases and the concentration of hydrogen and oxygen. Large scale manufacturing is critical to guarantee a wider adoption of nanosensors.

High throughput screening is an application with a rising potential and interest for biosensors. For example, advances in microfluidics and nanotechnology have led to the design and manufacturing of biochips with high density of genetic information (DNA / RNA).

The growth of biosensors will be further substantiated by improvements in key manufacturing technologies, leading to more compact and/or cost-effective sensing systems. "While micromachining has enhanced the scope of sensor fabrication applications, nanotechnology and microelectromechanical technology have led to improvements in sensor development and the design and production of inexpensive, compact sensors. These developments have resulted in the production of more compact implantable biosensors, biomedical sensors and electronic noses." [5].

2.3 Trends of the global sensor market

A series of emerging technologies should make sensors more adopted and smarter.

IO-Link, The Intelligent Communication Technology, should facilitate sensor connections and effective data transmission [4]. Benefits of the IO-link are multiple. For example, the working configuration of actuators and sensors can be stored in up to two KB on IO-Link masters and be updated remotely. Equally, the state of sensors can be monitored by IO-link, at distance. And, thus, issues can be analyzed and cleared in a more effective way. IO-link can be integrated using simplified wiring, the same low-cost, unshielded three-wire cables that are used for traditional discrete I/O.

Improvements in sensor system miniaturization led to smaller, more portable devices embarking very sensitive sensors and satisfying data processing capacities. For healthcare applications, medical teams, healthcare providers and even patients themselves required greater functionalities and portability of sensor-based diagnostics and monitoring devices. Thinner, smaller, and more compact medical equipment allows earlier hospital discharge of patients and favours care at home.

Sensor systems will become even smarter with AI enabled software, and, potentially, self-learning.

The trend of sensor systems is the inclusion of different types of sensors whose data can be fused to generate more meaningful information. For example, accelerometer magnetometer and gyroscope data when fused can generate accurate sets of data, guaranteeing a better compliance to physiotherapy activities. In the same way, the combination of lidars, radars and cameras information can generate an accurate and real-time single image or representation around a vehicle with possible translation for healthcare.

2.4 The case of thin film sensors

Thin-film sensors are segments in the thin-film industry with reported steady growth over the last 30 years. Its global market should represent over 3 billion USD annually with healthcare applications contributing to about 500 million USD.

"Films with thickness below 25 microns are generally divided into thick and thin-films. The generally accepted industry definition of a thin film is a layer thinner than five microns. By comparison, a layer thickness above five microns is usually defined as a thick film." [6]. Films are obtained by two major techniques, physical deposition (e.g. evaporation and sputtering techniques) and chemical deposition (e.g. sol-gel technique, Chemical bath deposition, Spray pyrolysis technique, plating, Chemical vapor deposition).

Main types of thin-film sensors are in the order of importance, pressure, temperature, humidity and gas, biochemical sensors. In its basic design, a thin-film sensor is composed of three elements: a bottom electrode, a sensing layer, and a top electrode. One or more of these layers is formed using a thin-film deposition method. Manufacturing processes of thin-film sensors can also include subtractive methods. Mass market thin-film sensors are mostly produced by roll-to-roll (R2R) processes.

Healthcare applications of thin-film sensors are mainly driven by remote monitoring. Glucose sensors, the main type of biochemical sensors, are used for diabetes care with steady growing needs over the next years. The market of glucose monitoring devices is expected to reach 27 billion USD in 2025. Glucose is mainly tested by strips with optical reading. With increasing adoption and innovation in thin-film technologies, strips can also be manufactured through thin-film technologies. Optical strips are being replaced with electrochemical sensors with a dry reagent layer sandwiched between two electrodes (carbon electrodes in the case of thick-film and gold or platinum in the case of thin-film), including a current in the circuit which can be converted in glucose concentration values by adapted reading devices. New applications of thin-film sensor technologies are emerging for temperature, pressure, light (e.g. used for radiotherapies) and biochemical (e.g. to test food allergens) sensors.

Patient care at home will strongly increase with the aging of the population and a new generation of patients that are more self-reliant and capable of managing their own health, for early diagnosis, prevention, and monitoring of non-life-threatening chronic disease. Testing and monitoring will be delivered by even more miniaturized and portable devices with expected expansion of the adoption of thin-film sensor technologies. For example, thin-film-based pressure sensors have applications i) in wound monitoring for diagnosing lower limb issues such as leg ulcers and assisting in muscle rehabilitation and ii) in curing chronic venous insufficiency by assisting the limb compression therapy.

In 2020, the main types of thin-film sensors were biochemical (28%; mainly glucose sensors), pressure (25%), temperature (24%) and humidity and gas sensors (9%) [6].

3 Battery – General Trends

3.1 Current trends

Secondary batteries – rechargeable batteries – represented 77% of the global market of batteries in 2018. Primary batteries are disposable batteries, commonly powering portable devices, requiring low current [7- 9].

The global market of batteries was estimated at about 100 billion USD, in 2022, with a CAGR % above 8%, during the last years.

3.2 Consumer and Electronic Appliance Batteries

Consumer and Electronic Appliance are currently mainly powered by alkaline and Li-ion batteries. Li-ion batteries are frequently used for consumer rechargeable electronics such as computers and cell phones. rechargeable electronics like computers, cell phones and medical devices.

3.3 Recycling

Although lithium-ion batteries don't contain dangerous chemicals, storing and shipping them poses several safety and environmental problems. The need to encourage consumer battery recycling must now be focused on the prospect of resource conservation and reducing the quantity of virgin material required to make batteries, rather than on the possibility of potentially dangerous chemicals.

Battery recycling is currently hindered by many devices with non-removable batteries, such as found in phones and tablets.

The market of consumer and electronic appliance batteries recycling is expected to represent more than 2.7 Billion USD, in 2027, with a CAGR% 2022–2027 of about 8%.

3.4 What may come next?

Batteries manufacturing market is currently shaped by the rising clean energy demand, emerging eco-friendly technologies and increasing environmental regulations.

As an example, mobile phone manufacturers expect batteries to last longer periods and to charge faster compared to traditional batteries. Silicon Anode Batteries, Solid-state Li-ion batteries and Energy-harvesting Nano generators are recent technology advances which may benefit the mobile phone market.

Graphene-based batteries are another fast-emerging technology with interesting features. They can provide durable high-capacity energy storage device with some key advantages, fast cycle times, high electrode density and long battery lifespan.

The chemistry of batteries is expected to continue to drastically evolve during the next decades, with the replacement of metals with organic compounds and their design to consider more deeply the life's materials, as well as the product's total life cycle goods.

Though alternative technologies like graphene batteries or nanoscale hydrogen batteries are under development, the segment of the consumer electronics batteries will still be dominated by lithium-ion batteries until 2024, at least.

For consumer electronics, Lithium titanate (Li_2TiO_3)—LTO battery, Lithium nickel cobalt aluminum oxide ($LiNiCoAlO_2$)—(Li-NCA) battery, Lithium iron phosphate ($LiFePO_4$) or LFP reached a cumulated market value of 4.5 billion USD in 2018 with other sustainable battery technologies planned to emerge with projected market at 0.2 billion US in 2024. Asia Pacific – APAC – is the leading and fastest growing region for sustainable batteries for consumer electronics applications.

To note: Cymbet Corp (North America) is the manufacturer of EnerChip thin film rechargeable solid-state smart batteries (SSB), used for Medical, industrial control, communications, sensor, RFID, and other portable electronic devices.

4 Flexible electronics

4.1 General trends

“Flexible electronics or flex circuits are electronics designed and constructed on flexible substrates. Flexible electronic devices are generally foldable, twistable, bendable, and can be wrapped due to their structure. Electronic device structures consist primarily of four parts, that is, substrate, back-plane electronics, front plane, and encapsulation.”

“Flexible electronics are developed either by fabricating the circuits directly on a flexible substrate or by bonding and transferring the circuits onto a flexible substrate.” [10].

Royole Corp., AU Optronics Corp., The Cubbison Co., Ensurge, Tekscan Inc., Enfucell Flexible Electronics, Pragmatic, PANASONIC Corp., FlexEnable Ltd., KONICA MINOLTA INC., E Ink, Blue Spark Technologies, Pragmatic, BrightVolt Solid State Batteries, Imprint Energy, and Buhler are some of the major players operating in the global flexible electronics market.

Flexible electronics is an area, strongly expanding with major investments in the development of the technology to support the market growth. For example, Pragmatic IC launched a new, flexible version of its 6502 processor, which should open new doors for the evolution of personal computers.

Among the major trends is the increasing adoption of flexible electronics in healthcare applications. A major restraint comes from a complicated design and assembly process to support the adoption of sensor technology.

Consumer electronics, healthcare, automotive, aerospace and defence, energy and power are the main applications of the flexible electronics market with consumer electronics as the leading one in 2020. The total market should be above 50 billion USD, in 2026. The healthcare segment is the fastest growing as planned between 2020 and 2026 (CAGR: 13.5%) and is expected to be the leading market segment in 2026 with a projected market value at 14 billion USD. It is dominated by the glucose monitoring devices and the fast expansion of self-care kits and remote health monitoring devices. North America is the dominating region and Asia Pacific the fastest growing between 2021 and 2026.

In terms of flex hardware solutions, the leading ones, by order, are sensors (26%), displays (23%) and batteries (17%).

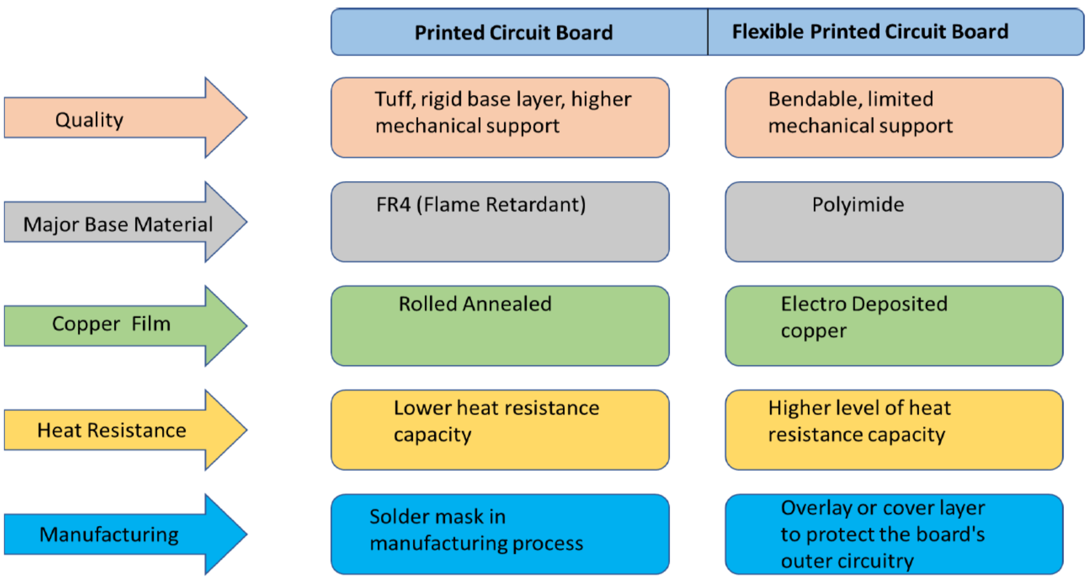
The major commercial polymer substrates are polyimide (PI), polyethylene (PE), polyethylene terephthalate (PET), and polyvinyl alcohol (PVA) with PI, the most used. The sustainability pressure should promote the use of alternative materials, environmentally friendly and biodegradable, such as gelatin, chitin, silk, or paper.

For electrodes, Indium tin oxide (ITO) is a widely used but suffers from shortcomings, performance degradation and expense. Other materials are listed in Table 1:

Table 1 Electrode materials

Soft metals	Conductive nanomaterials	Conductive polymers	Hybrid materials
Galinstan (Ga-In-Sn) Alloy	Carbon materials	Polyaniline (PANI)	Polymer/Metal
Metal nanoparticles and nanowires.	Carbon nanotube and graphene	Poly(3,4-Ethylenedioxythiophene) (Polystyrene Sulfonate) (PEDOT:PSS)	Carbon/Metal

A comparison between rigid Printed Circuit Board (PCB) and flexible PCB is given in Figure 1.



Source: BCC Research

Figure 1 – Major differences between Printed Circuit Board and Flexible PCB

4.2 The case of roll-to-roll (R2R) processing – A snapshot

"R2R processing is also stated as reel-to-reel processing, web processing or R2R technologies (R2R), which is the procedure of manufacturing electronic devices on a roll of flexible metal foil or plastic. R2R technologies are widely utilized in many applications in the manufacturing of flexible electronics devices, solar panels, fibres and textiles, medical products, and wearable devices. This is a forthcoming technology that substitutes conventional substrate materials such as traditional silicon wafers and glasses with flexible ones, namely thin plastic substrates, glass, and metal foils, which are normally called as flex circuits or flexible electronics. Its perceived benefits such as light weight, flexibility, and ultra-thin texture are significantly useful in producing large volume of advanced electronic devices. The global market for R2R technologies for flexible devices is expected to expand at pace in the near future because of the aforementioned reasons.

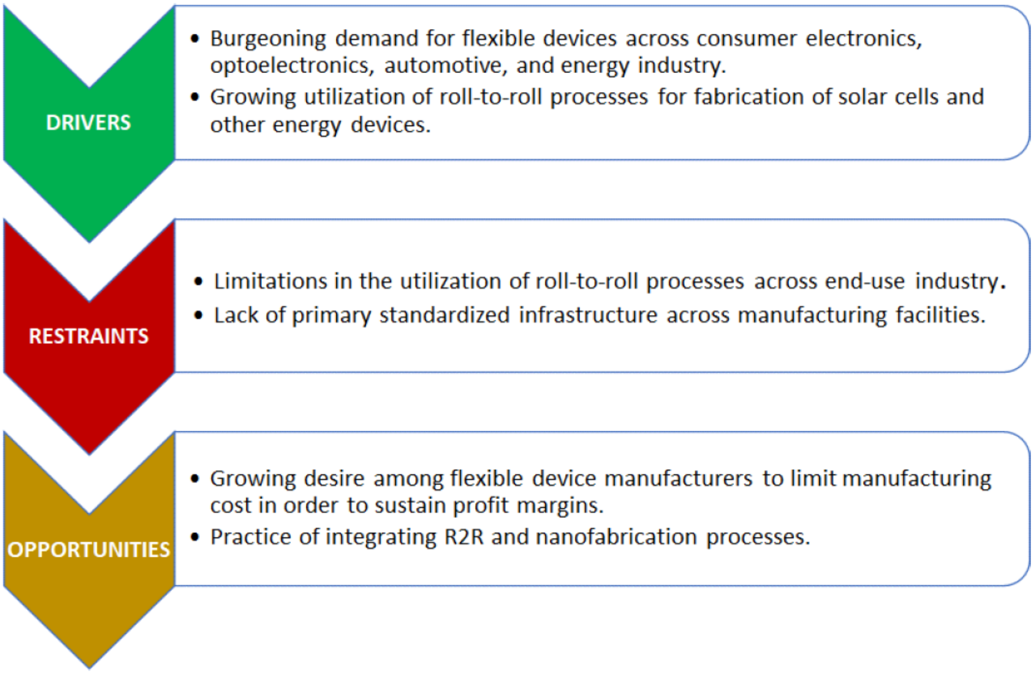
R2R (R2R) signifies a set of advanced manufacturing approaches that involved in continuously processing of flexible substrates while they are being assigned in between moving rolls of specific materials." [11].

The R2R technologies should greatly expand as driven by the rising mass demand of flexible electronics (e.g. flexible displays, flexible solar cells, and wearable electronics). They are substantially pushed by low-cost applications namely FPCs (Flexible Printed Circuits) and OLED (Organic Light Emitting Diodes) displays. The market is also supported by new demand of flexible devices for electronics, optoelectronics, energy, sensors, and healthcare sectors and fuelled by a growing penetration of lightweight, thin, portable, and/or wearable devices.

R2R technologies represented a global market in 2020 above 20 billion USD, expected to grow with a +12% CAGR between 2020 and 2026. The main contributing segments are consumer electronics (37% of the market in 2021) & optoelectronic devices. (19% of the market in 2021). Additive processing (37% impact printing vs 63% non-impact printing) processing contributes to about 40% of the market and subtractive to the rest (23% physical processes vs 77% chemical processes). For R2R technologies, thin film deposition represents about 25% of the market and thick film deposition about 75%, in 2020. By substrates, in 2020, the market was shared by polyimide (44%), other polymers (27%), metals (20%) and other metals (9%). Other materials include paper, flexible glass substrates, alumina, aluminium nitride (AlN), beryllium oxide (BeO), and ferrite substrates, whereas the other polymers include polyethylene terephthalate (PET), polyethylene naphthalate (PEN), and polyetherimide (PEI). Polyimide is presently a class of materials of choice for its high dimensional stability, heat resistance, good flexibility, and dielectric strength. Metallic substrates have excellent dimensional stability and lack of deformation. Stainless steel is commonly used when transparency of the flexible substrate is not an issue. Other types of metal foils that are finding application primarily as flexible substrates for solar cells and displays are titanium, tantalum, aluminium, copper, Inconel (e.g., nickel/chromium/iron alloy) and Kovar (nickel/cobalt/iron). Paper substrates are gaining interest by providing low cost and low environmental impact advantages. They have been introduced in the fabrication of batteries and disposable devices.

The healthcare segment represented 7.4% of the market of the flexible devices processed by R2R technologies, in 2020, with a market at 1.9 billion USD. The market is dominated by consumer electronics (38%), optoelectronics (19%), and energy (16%). CAGR for all listed segments are slightly over 10% between 2020 and 2026. The global market for R2R flexible devices for healthcare applications is led by the Asia Pacific region, with slightly over 1 billion USD market expected in 2026. North America and Europe should contribute nearly at the same level, at about 0.8 billion USD, in 2026. In all these regions, the CAGR is about 12%, between 2020 and 2026.

The value chain of R2R technologies for flexible devices includes three main stages: research and technology development; technology integrators; and end-use industrial implementation.



Source: BCC Research

Figure 2 - Drivers, restraints & opportunities of the R2R market, extracted from the BCC Publishing report.

R2R vs batch processing offers several advantages, among them:

- Increased throughput (up to 300 m/min)
- Improved automated process control.
- Lower manufacturing costs.
- Higher process efficiency.
- Reduced consumption of materials and energy for processing.
- Low capital investment for high volume production.
- Greater process reproducibility.
- Consistent product quality

R2R technologies is still an intensive field from an innovation perspective. The number of patents since 1970 has nearly increased from one year to another, since 1970, starting at the beginning with 2 patent applications to 4,255 in 2021.

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