SMART TEXTILES VALUE CHAIN: A ROADMAP

Introduction: A complex value chain

The smart textiles value chain comprises multiple actors from three distinctive industries, namely electronics, textile, and ICT (Information and Communications Technology). This underlines both the need for cross-sectoral partnerships and how challenging it is to bring together competencies, energies and strategies based on three very different industries, viewpoints, and mindsets.

Currently, product development is predominantly driven by a technology push. Many products only reach the prototype stage because of the absence of (large-scale) manufacturing capabilities and the challenges related to the difficulty of finding the right long-lasting partnerships.

Figure 1 shows the full value chain map of smart textiles. The cross-sectoral value chain covers the hardware part, the software part, the textile part, and the end-product. Each part of this map is described in detail in the following pages.

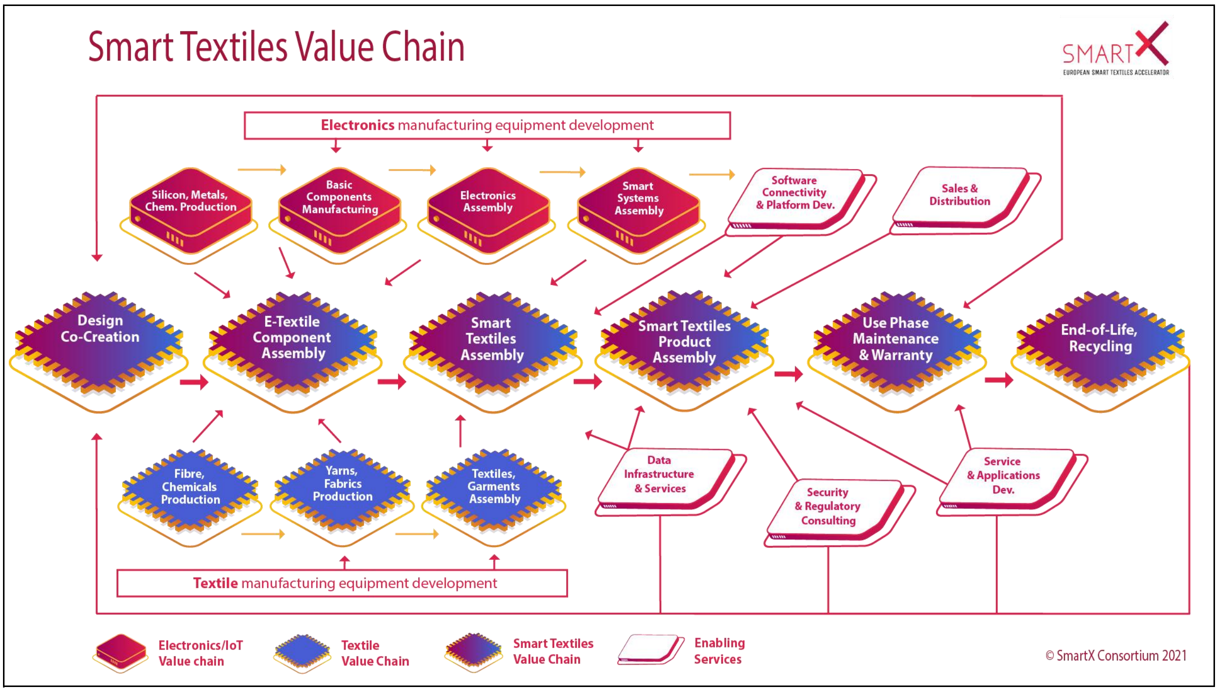

Figure 1: Full SmartX Value Chain Map

This analytical map has been designed by SmartX Europe partners, putting together their knowledge of the different stages, nodes, and components of this smart textiles value chain. It aims to give a clear vision of the whole interactive pattern, but more specifically to identify the current gaps that slow down or jeopardise the successful development of the European industry of smart textiles.

Current challenges facing European smart textiles

In short, one can say that there is no clear absence of any specific element, but rather a weakness in many of them that comes from **little collaborative history between the three industries concerned**. Furthermore, the still insufficient development of volume markets prevents most of the large businesses that predominantly supply equipment machinery, chemical, and electronics components from dedicating much effort and investment to smart textiles production.

Another key issue is that the whole value-chain is driven by technology more than by market demand and does not rely enough either on **market research or promotional activities**. From the earliest research and development stages of any project, it is particularly crucial to ensure that the unique properties of textiles are indeed essential for the desired use case and cannot be more competitively supplied by alternative solutions (e.g. wearables, external monitoring etc.). This condition would often need to be more carefully validated.

1. Textile value chain

a. Textile manufacturing equipment development

The upscaling of smart textiles manufacturing increasingly requires the development of adapted machinery and production processes, as all desired functionalities and the use of new materials can no longer be integrated into existing ones.

The traditional textile manufacturing industry needs to be more engaged in order to help equipment manufacturers fully grasp the ongoing and emerging market needs and fully design new, adapted machinery. In this realm, EU research centres have acquired unique skills in recent years and have shown the feasibility of many new techniques for the manufacturing of smart textiles. These centres need to be more involved in transfer manufacturing skills from lab to fab to support the successful industrialisation of smart textiles.

b. Textile chemistry production

Most of the smart textile functionalisation relies on chemical substances, typically via a coating or finishing process. Chemistry thus brings key materials for sensors, electrodes with good skin contact, conductive (water-soluble) inks, adhesives and glues, pastes for screen printing, encapsulation materials, etc.

Such inputs clearly are outside of the scope of the smart textile value chain (e.g. metals, pigments, etc.) with the exception of conductive inks. In the traditional value chain, ‘chemistry products’ are typically made in very large quantities by large players. However, smart textile businesses usually need very specific materials, depending on the substrate and wanted functionality. They have to rely on intermediates, often SMEs, that specialise in making dedicated formulations for use on textiles.

c. Yarns and fabric manufacturing

Smart yarns span a wide range: they can be yarns that serve as transistor, battery, solar cell or LED via a coated structure, they can be twisted yarns of conductive threads into which (small) electronic devices are integrated, or they can be ‘simply’ conductive yarns. The conventional process is to produce metal monofilaments that can be blended with all sorts of fibres or can be directly used in weaving and knitting.

Conductive yarns and threads can be incorporated in textile substrates to provide electrical conductivity. The use of various materials, including copper, stainless steel, silver, or carbon, as well as with metallisation technologies, allow for properties of such yarns to be fine-tuned and adjusted to the need of the application, for example: data/signal transfer, power transfer, heat or light generation. Other types of smart yarns are much less advanced. Of special interest are the filaments/yarns that are an electronic device by themselves (mostly via the application of coatings).

Smart fabrics are woven or knitted fabrics that have integrated some electronics or electronic components. Fabric structures can provide a complex network that can be used as electrical circuits with electrically conducting and non-conducting parts and can have multiple layers and spaces for electronic devices.

Coatings can be applied to the surface of fibres, yarns, or fabrics to create electrically conductive textiles.

Conductive structures can also be attached to a 'common' fabric by using the **embroidery** technique, by stitching patterns that can define circuit traces, component connection pads, or sensing surfaces.

To innovate in smart textiles, most traditional textile manufacturers are lacking in some key competencies to use new processes, new materials, or design new commercial strategies to develop, manufacture, and bring products to the market. Employees with specific education are necessary for the industry to meet these challenges. In particular, textile companies usually lack specific knowledge of electronics, which prevents them from being actively involved in scaling up the smart textile manufacturing.

However, a group of smaller (niche) textile players have emerged, producing specific types of smart textiles (e.g. heated textiles for sportswear). They typically have limited production capacity and perform manufacturing only at a small scale. Scaling up is difficult because of the lack of proper equipment (see also earlier) or the major investment it would require.

d. Textiles and garments assembly

The design and assembly of textile articles or garments using fabrics equipped with (often textile-based) sensors or conductive threads without the loss of the intended functionality often represents a big challenge.

The latest design and CAD software, enabling the creation and alignment of cutting patterns for the textile articles assembly can be used to integrate complex networks of e.g. conductive tracks. However, a more automated large-scale production is difficult to achieve, especially because as smart functionalities are part of yarns/fabrics, assembling textile parts cannot be only limited to a mechanical fixation. Electrical functionalities e.g. need to also assume electrical conductivity between the parts.

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2. Electronics/IoT value chain

a. Electronics manufacturing equipment development

Traditional electronics, such as integrated circuits, are generally built on thick inflexible substrates and are not very compatible with the flexible environment present in a textile. Instead, flexible electronics – built on substrates like plastic or metallic foil – can be folded, wrapped, rolled, and twisted with a negligible effect on its electronic function. Flexible electronics are typically composed of a bilayer of a thin passive substrate (e.g., plastic, textile, etc.), topped with a second layer of active electronic components. In some applications, additional layers may be used for encapsulation and packaging.

Conventional rigid integrated circuits are fabricated in batches through film deposition, photolithography and etching. The manufacturing of flexible and stretchable electronics, however, requires totally different processes like pattern transfer, solution printing, roll-to-roll capabilities and additive manufacturing.

b. Silicon, Metals, Chem. Production

Silicon, being the most common of semi-conductors, is a critical element for fabricating most electronic circuits, like transistors. Its electrical properties are often modified by doping with small amounts of pentavalent (, , or) or trivalent (, ,) atoms.

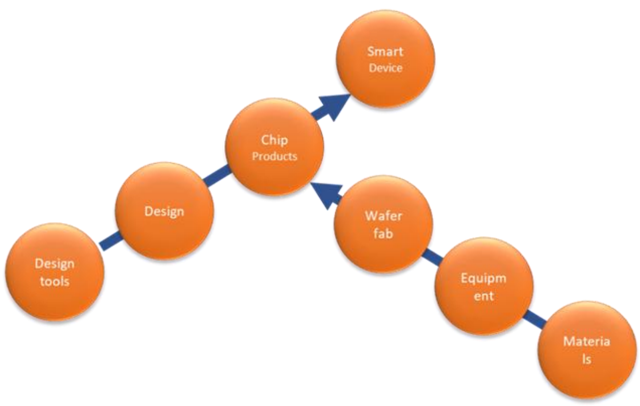
For the fabrication of integrated circuits, crystalline silicon is transformed into thin slices (wafers), serving as the for devices built in and upon it. It undergoes many processes, such as , , , of various materials, and patterning. Finally, the individual microcircuits are separated by and as an integrated circuit.

The latest chip platforms use hybrid architecture, combining a system-on-chip with a low-power coprocessor. This type of platform delivers significant performance improvements given its upgraded CPU and GPU, faster memory and a range of platform power optimizations. Improving the performance of chipsets for wearables has clear benefits. It delivers a better user experience, including apps launching faster, providing richer graphics and user interfaces, and improved photo and video functionality.

Aside from the technological developments, the main challenge in the area of silicon chip manufacturing, is their availability. The huge demand for chips has created a shortage that could be a threat to the development of smart textiles applications.

c. Basic electronic components manufacturing

In general, one or more of the following functions will be present in electronic modules used for smart textile products: sensor devices, internal computation devices (data acquisition – microcontroller), power supply, and a generated output functionality that can range from lighting (for instance for integrated LED-devices) to specific data communication.



Electronic components and chips are made along the above map and are at the intersection of two different tasks.

- The design process (left branch): engineers design the component in a digital way, providing a series of files with which the chip can be physically built (via the right branch).

- The physical construction process of electronics (right branch). The files from the design process are used here to make a "maskerset" for a kind of photographic process, creating a layer structure a few nanometers thick, which then forms the chip and electronically provides the correct functionality. Different components are made ~~in~~ this way: memory elements, processors, sensors, MEMS, actuators, etc.

Sometimes a chip can be made, where several of the aforementioned functionalities are embedded. We call this a SoC (System on Chip).

The traditional production system tends to be too costly for many applications. Much interest is given to the up-and-coming field of organic electronics, which offers lower production costs and attractive new properties: higher electrical conductivity, mechanical flexibility, and thermal stability. This field of materials science concerns the design, synthesis, characterisation, and application of organic molecules or polymers that show desirable electronic properties. Unlike conventional inorganic conductors and semiconductors, organic electronic materials are constructed from organic (carbon-based) molecules or polymers using synthetic strategies developed in the context of organic chemistry and polymer chemistry.

d. Electronics assembly

A Smart System or an electronic system is made up of different components (sensor, actuator, energy supply communication, memory, and processing unit). They are put together on a PCB (Printed Circuit Board), where connections are made between the various inputs and outputs of the components.

e. Smart objects assembly

The electronics assembly needs to be prepared to be attached to and integrated into the smart textile fabric or article. This requires adapted interconnection technologies and processes that allow for a durable and robust connection of the electronics to the smart textile.

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3. Smart Textile Value Chain

a. Design and co-creation

Design and co-creation are two crucial stages to the success of the whole and too often missing, as the technological innovation push tends to drive developments very far without letting other concerns, like customer acceptability, impact the whole development process.

The key to a successful smart textile product is to make sure it looks, does, and delivers what is expected and needed by the potential end-user. Therefore, it is crucial in any smart textile development project to actively involve all relevant stakeholders as early as possible. This includes the designers, manufacturers, end users, experts on end-of-life treatment, as well as experts on service and application development.

b. E-Textile Component assembly

One key condition of the efficient integration of electronics into textiles at different stages (i.e. at the level of yarn or fabric) is the use of coating or encapsulation techniques to avoid removal of the electronics prior to washing/cleaning.

Substrates can be any textiles that include conductive circuitries, e.g. by the use of conductive yarns or wires or by printed conductive circuits using electronic inks or pastes that could receive electronic components by a manual or automated process. Screen printable inks of silver, carbon, or silver-chloride can be placed on TPU film in intricate patterns, then laminated into the fabric to create pathways to a circuit. The resulting e-textile is super flat, light weight, and stretchable.

Assembly techniques include gluing using electrically conductive adhesives, soldering, laser soldering, embroidery, stitching, or snap fastener. Still a large part of the integration process is based on manual processes.

Most challenging is the need for a robust integration and contacting technologies that can resist normal usage of clothing and the miniaturisation of power supply and storage devices. In addition, fully automated manufacturing capabilities are still missing and machine development that covers the entire process chain of the integration of electronic components in textiles clearly needs to be intensified.

c. Smart Textiles assembly

The integration of electronics or textile electronic objects into garments or other articles (upholstery, bedding, carpets, etc.) relies in most cases on functions already present in the textiles, like conductive tracks for sensing, heating or power transport, and resistive or capacitive sensors or switches. They create an interface between the textile and ~~the~~ electronics, and they can be connected using different methods.

Production is made by 'System Integrators', essentially SMEs that have acquired the competences for putting textiles and electronics components together and producing actual garments. These companies typically bridge textile and electronics companies by providing electronics-related expertise to textile companies and textile-related expertise to electronics companies. However, their limited production capacity implies high costs and restricts consumer markets to high-end ones.

Two other barriers currently slowing down the development of smart textile assemblies are the lack of specific design software and of guidelines or even standardisation of components specifically dedicated ~~for~~ to smart textiles.

d. Smart textile product assembly

The Smart Devices or Smart Systems resulting from the smart textile product assembly are used in smart applications heavily relies on the additional use of software.

Each device is part of a network of Smart Devices, the so-called Smart Network. Data that is used in this Smart Network is in the cloud and is therefore linked to security, data analytics, data processing, etc.

These networks and devices are then built into and used for applications, so-called Smart Applications.

e. Use Phase Maintenance, Service and Warranty

After-sales service is a key element of the customer relationship in general. It encompasses all the services a customer receives following a purchase. It is not enough to offer good quality products, you also need to offer services that customers appreciate. The latter influence customer satisfaction just as much as the nature or quality of the products they purchase.

To ensure the durability of the properties of intelligent textile materials or systems, the manufacturer must first provide information to its professional service providers and customers on the operating methods and conditions of storage, use, cleaning and maintenance.

It's important to efficiently manage the after-sales support and to react to any negative feedback in real time. Responsiveness is widely known to be the key to quality after-sales service.

f. End-of-life and recycling

Smart textiles integrate textiles with electronics and such products might, if they became mass consumer applications, result in a new kind of waste that could be difficult to recycle and would have to comply with WEEE waste regulations. Implementing eco-design in the technological development process could help to minimize future waste. However, the existing design for recycling principles for textiles or electronics most often do not match with the properties of the combined products. Therefore, life-cycle thinking needs to be implemented together with the technological development process.

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4. Enabling Services

a. Software Connectivity & platform development

Companies belonging to this node in the value chain are experts in building interfaces to connect different materials, processes, and systems. They aim to establish platforms and the respective interfaces, software and hardware, to collect ~~the~~ data provided by smart textiles and their production processes for the development of additional functionalities.

Basically, inputs are the pieces of information gathered from sensors and actuators in smart textiles, while the outputs are the software platforms and cloud-applications for gathering, storing and securing sensor data.

b. Data Infrastructure & Services

Companies in this node of the value chain are experts in data collection, data management, and data analysis. The main objectives in this node are the collection and pre-processing of sensor data, data analysis with e.g. Big Data- and AI techniques, ~~and~~ the processing of data for software applications, and actuator control. Additional data (not originating from smart textiles) e.g. about personal behaviour or object environment (temperature, humidity etc.) may be included.

These companies transform sensor data and processing data into data that is ready for use in software applications to implement the "smart" functionality of textiles.

c. Sales & Distribution

Mainly through online sales or customised sales to elite clients (professional athletes, artists, celebrities etc.).

d. Service and applications development

Does the profit come mainly from software selling rather than from the clothing itself?

It can be assumed that the mostly digital services associated with smart textiles will account for a significant proportion of the future economic performance of these products.

e. Security and regulatory consulting

There is a regulatory gap in terms of guidance to companies when it comes to compliance (e.g. testing, assessment, labelling). Some parts of the regulation are already present, but are reported to be highly fragmented; others are still missing and need to be developed. At the same time, stakeholders emphasise that there is no need for more regulatory control. For example, in Asian countries, the regulatory climate is reported to be more flexible. In Europe, there is rather a need for more clarity and systemisation.

More standardisation is required to facilitate stakeholder interactions, e.g., creating interfaces between electronics and textiles, contacting, data standards, testing standards, etc.

Regulations and legislation are needed that support the intended usage scenarios and preventing misuse.

Created by SmartX: The European Smart Textiles Accelerator
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