PROJECT DELIVERABLE REPORT

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Powerweave

Development of Textiles for Electrical Energy Generation and Storage

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Advanced textiles for the energy and environmental protection markets

D9.4 Final Public Report

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Final Public Report

Powerweave - Development of Textiles for Electrical Energy Generation and Storage

A project funded by the European Union Seventh Framework Programme, running from June 2012 to November 2015.

The fabric power supply

The World's first continuously processed PV fibres and energy storage fibres have been developed in the Powerweave project. They can be woven into a fabric which would act as a standalone power supply. The fabric would harvest and store electrical energy from the sun within its fibrous matrix. It is an easily deformable, storable, lightweight and transportable power supply.

Objectives

This project aimed to develop a fabric to harvest and store electrical energy within its fibrous matrix, to fulfil a need for an easily deformable, storable and transportable power supply (see Figure 1).

This was through the development of photovoltaic fibres and energy storage fibres integrated with control electronics into a textile. This unique approach, moving on from the current state of the art using rigid cell or film based PV materials and rigid bulky batteries, allows development of large-area deformable products, including agricultural shading, automotive soft-tops, building facades, rollable shades, curtains and roofing, aerospace fabrics, and outdoor goods.

The key challenges were:

• Formulation of PV and energy storage materials to be applied as flexible thin coatings on monofilament fibres. SME materials suppliers PPC (polymer coatings) will work with universities, EPFL (PV) and Brunel (energy storage) who are leaders in these fields.

• Development and application of fibre spinning and coating methods to make the two multi-layer fibre types, followed by generation of a textile combining the two. Fibre and fabric manufacturers Sefar, CeNTI (SME) and VDS weaving (SME) will work with textile and coating experts, Centexbel and TWI.

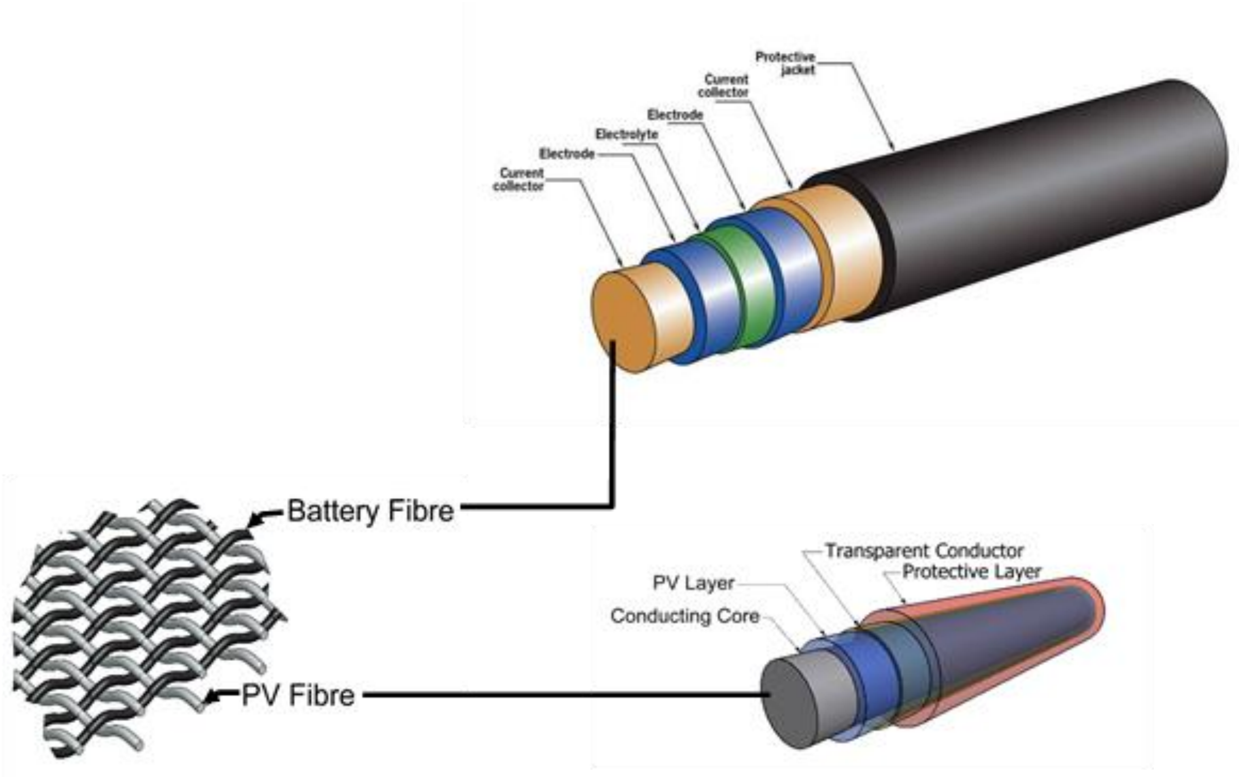

Figure 1: Diagram showing the concept of combining energy generation and storage fibres into a fabric.

• Integration of the two fibres, requiring end preparation to reveal conductors, interconnect and micro-circuitry, followed by attachment to a load device. Materials joining and smart textile experts, TWI, Eurecat and Ohmatex (SME) will work on this.

• Demonstration activities included a 23m long electric powered airship by Lindstrand (SME), and agricultural textiles by Bonar, both strong innovators in their fields.

The 5 innovative SMEs, 2 LEs and the RTOs with extensive links in solar power, microsystems and textiles industries, are well placed to quickly exploit the project developments and provide extensive exposure of the ideas into a wide variety of markets requiring a continuous, fully autonomous and truly flexible power supply.

Summary of main results

In the early stage of the project, specifications for the PV fibre, storage fibre, fabric, interconnections and demonstrators were completed.

Materials were identified to make a photovoltaic cell suitable for construction in fibre form. Continuous PV fibres have been made for the first time using a perovskite solar cell platform and a coaxial coating procedure combining an inner conductor with active PV material coatings, an outer conductor and an outer protective coating. These fibres have been demonstrated to give a power output under simulated solar lighting. A patent has been applied for to protect the design and manufacturing techniques.

Energy storage fibres have also been produced using a continuous process for the first time using a coaxial coating procedure. These are based on single wire supercapacitors with a gel electrolyte, carbon based storage media, an outer conductor and a final protective coating. These have been fabricated, tested, and shown to light an LED. Lengths of fibre materials, totalling 1700m, have been prepared and woven into a fabric. The storage fibres have been shown to be robust, without loss of performance after bending tests and weaving. A patent has been applied for to protect the design and manufacturing techniques.

Fabric structures feasible for PV/Storage interconnect have been identified and evaluated theoretically in terms of PV efficiency, stresses placed on the fibres and suitability for fibre interconnections to be made.

Techniques for interconnecting the fibres using laser fibre end preparation to reveal the conductors in the fibres, followed by application of fabric tape conductor buses and moulded polymer encapsulation have been developed. These methods have allowed a single wire output to be designed and made with a simple USB attachment for powering external loads. Systems for the control of the energy generated, stored and for use, have been developed and tested.

A prototype energy storage fabric has been manufactured (see Figure 2).

An airship has been designed and constructed to demonstrate the concept of using electric motors to drive the vehicle and remote-control operation. In the demonstration, batteries were used to provide energy for the motors, but the potential for replacing these with coated fabric for the airship envelope for both energy generation and storage is clear (see Figure 3).

Further work would develop mass production methods for the two multi-layer functional fibres, and hence towards a fabric prototype combining both the fibre types. Work proceeding now to integrate these developments into demonstration pieces.

Figure 2: Leno woven sample by VDS Weaving with Energy Storage demonstrator fibre

Figure 3: 23m long helium filled airship by Lindstrand Technologies Ltd, with an electric motor and remote-control.

Final results and impact

The original objective of demonstrating the operation of a solar generating and energy storing remote power supply has not been achieved in full. This was because there was not enough stable PV and storage fibre to be converted into fabric by the end of the Powerweave project.

However, many of the technical challenges leading towards this objective have been achieved, including a number of important developments demonstrated for the first time. In summary, these have been:

- Development of a photovoltaic energy generating fibre with a demonstrated power generation under a solar simulator.
- Demonstration of continuous processing methods for the PV fibre for the first time.
- Development of a supercapacitor based energy storage fibre with functional energy storage.
- Demonstration of continuous process methods for the energy storage fibre for the first time.
- Novel continuous coating deposition methods to apply a thin, even coating to a moving fibre have been developed.
- Textile design using leno or double layer weaving processes to accommodate active fibres with high exposure for the PV fibre, lower layers of energy storage fibre, and minimal flexing of the fibres during manufacture.
- Control electronics have been designed to act as an interface between the energy generation and storage, and to provide a stand-alone power source.
- Interconnection methods using laser processing to reveal conductive contacts, and connection of fibre bundles using a flexible fabric bus-bar have been demonstrated.
- Encapsulation of the connection regions has been demonstrated using flexible polymer mouldings.
- Fabric based USB connectors with strain relief have been designed, constructed and tested to connect the fabric power supply to an external load.
- A sample of energy storage fabric has been fabricated and connected.
- A remote-control airship powered by an electric motor has been demonstrated. It is 23m long and shows the potential for an airship that could be flown indefinitely, powered from its own fabric envelope.

The new fibres which result from Powerweave are likely to have many unique benefits and will find use in both technical and consumer applications. Technical applications will be found in a wide range of fields such as transport, construction, clothing, agriculture and electronics. The market consists of specialised niches which require lower volumes, but high levels of quality and performance characteristics. New applications are expected to be created, such as power supply fabrics for buildings, tents, automotive roofs, emergency or alternative and portable power supply facilities.

Several properties differentiate this textile solution from traditional solar and energy storage solutions and will make this a unique product:

- It is fibre-based; making it possible to weave modules with a large surface area.
- Combined energy harvesting and power storage (solar cells on the upper surface and batteries below, for example). It will also be possible to introduce 100% solar or 100% storage fabrics, or any combination in between, depending on the application requirements.

- Flexible and conformable – facilitating new applications.
- Bendable interconnects – the entire module can be folded and bent.
- Significant reduction in weight compared with 1st, 2nd & 3rd generation solar cells and batteries.
- From rollable to foldable, reduced size / volume = reduced transport costs
- No installation is necessary; fold out and plug in.

The materials and improved performance developed in photovoltaic and electrical energy storage will also have implications well beyond textiles applications. There is potential for lower cost, more widely applicable solar energy generation. The developments from Powerweave are appropriate for generation in low light levels and a wide range of wavelengths. The energy storage materials are also low cost, readily available and light weight, and derivatives may find applications in automotive or domestic power units.

Amongst others, the following markets are envisaged:
- Sun screens / shading for commercial greenhouses
- Off-grid applications (incl. 3rd World)
- Wearable technology
- Airships with greater distance capability

For more details see the project web page: www.powerweave.eu.

Project partners

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Brunel University, UK	www.brunel.ac.uk
CeNTI - Centro de Nanotecnologia e Materiais Tecnicos Funcionais e Inteligentes Associacao, Portugal	www.centi.pt
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