Nano Innovation 2020 Rome, 15-18 September
Conference & Exhibition

Energy storage and harvesting for Smart Wareable Electronics

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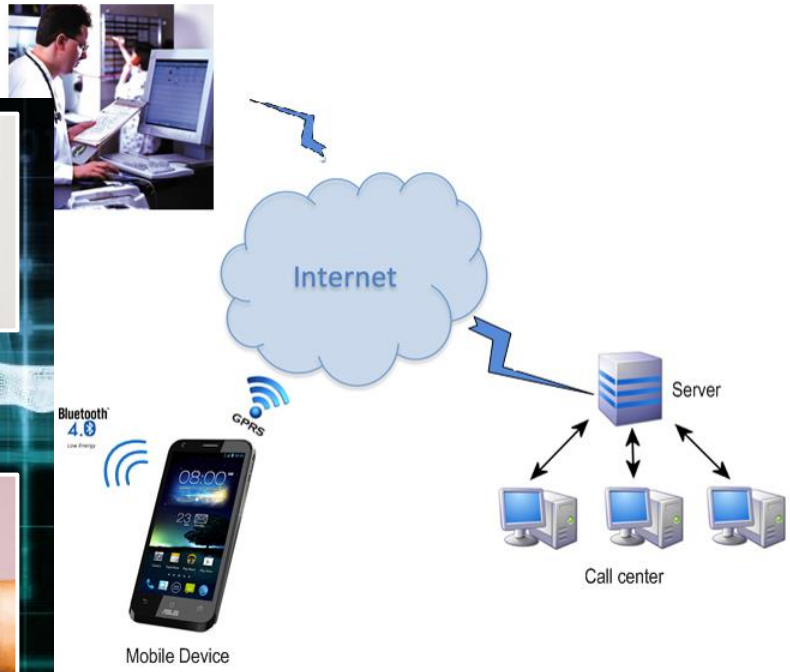
WASP
Wearable Applications enabled by electronics Systems on Paper

OUTLINE

- *Wearable electronics*
- *Wearable electronics: market roadmap*
- *Flexible Wearable electronics for health monitoring*
- *What we are doing: smart wearable devices on paper*
- *Energy storage devices*
- *Energy harvesting devices*
- *Conclusions*

WEARABLE ELECTRONICS



- Smart wearables are body-borne computational and sensory devices which can sense the person who wears them and/or their environment.
- Wearables can communicate either directly through embedded wireless connectivity or through another device.
- The data collected by the wearable device about the user or its environment is processed in a processing unit located locally or in an external server.

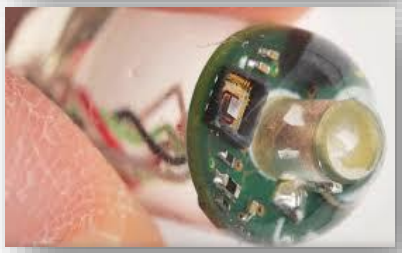
KEY ATTRIBUTE OF WEREABLE TECH

HUMAN FACTOR → COST AND DESIGN → CHIPS AND BATTERIES → SENSORS → CONNECTED TECHNOLOGIES → **TYPE OF APPLICATIONS**

Near-body electronics

On-body electronics

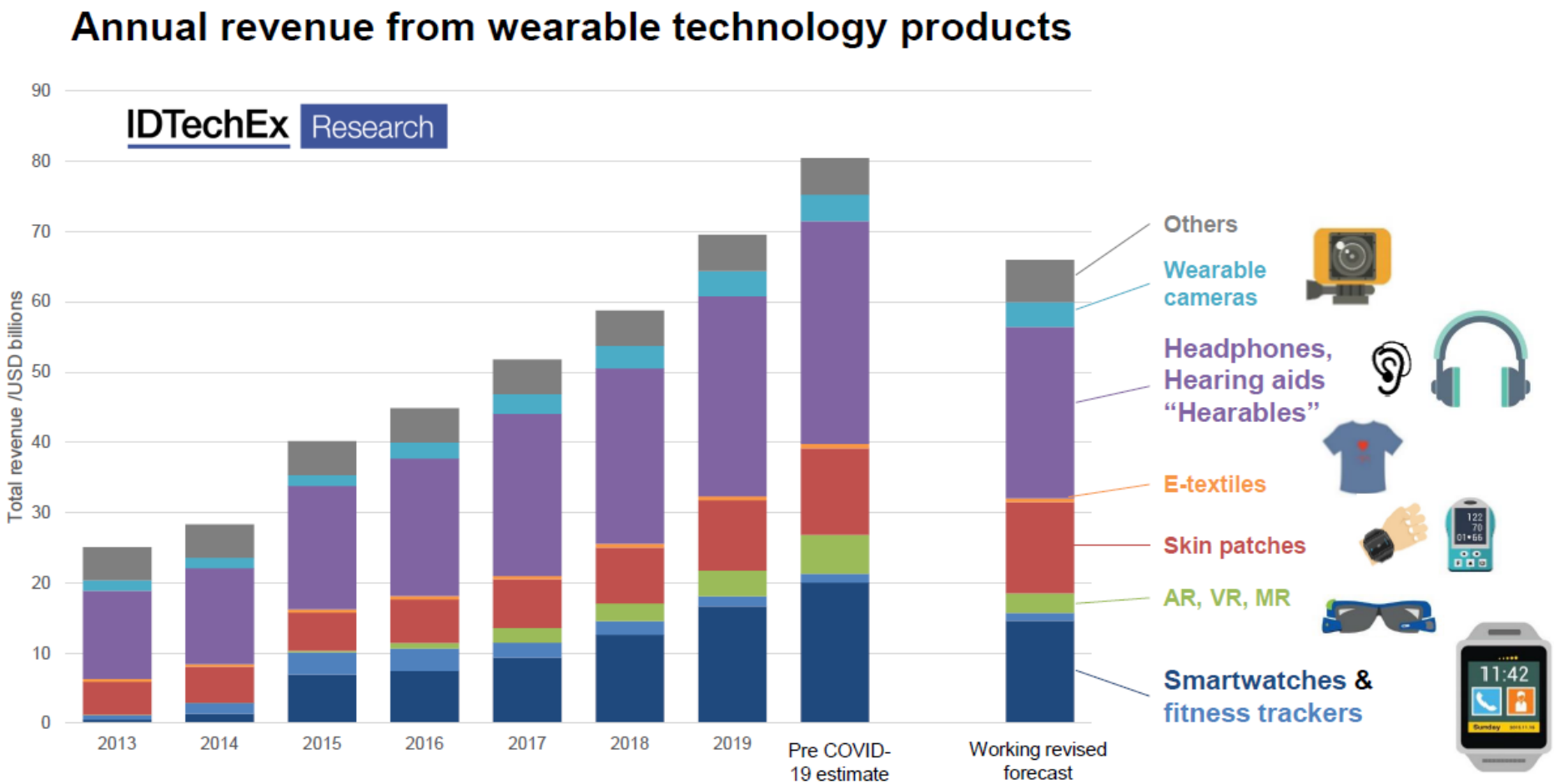
In-body electronics



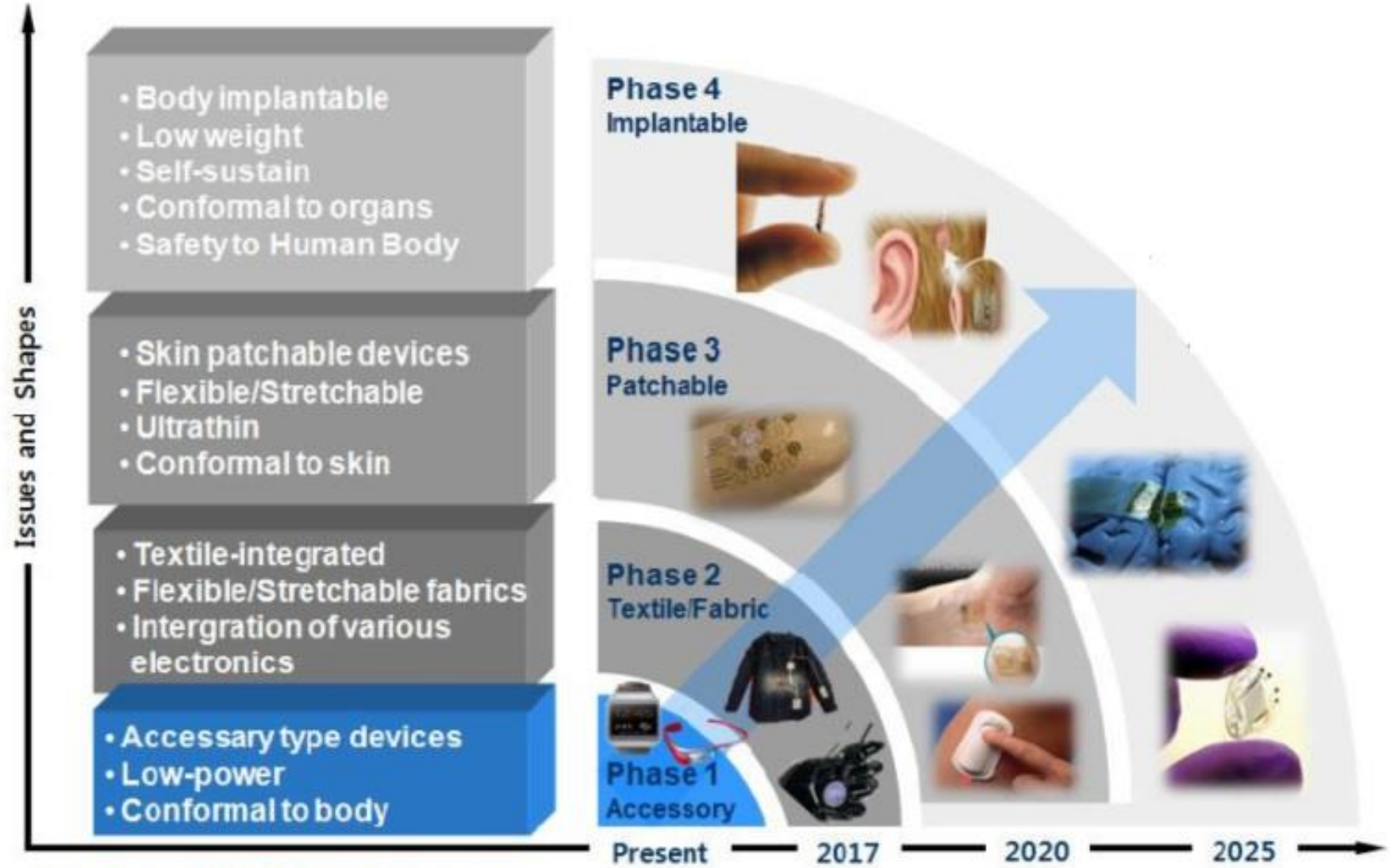
Electronic Textiles

STATE OF THE INDUSTRY

YEARS 2013-2020



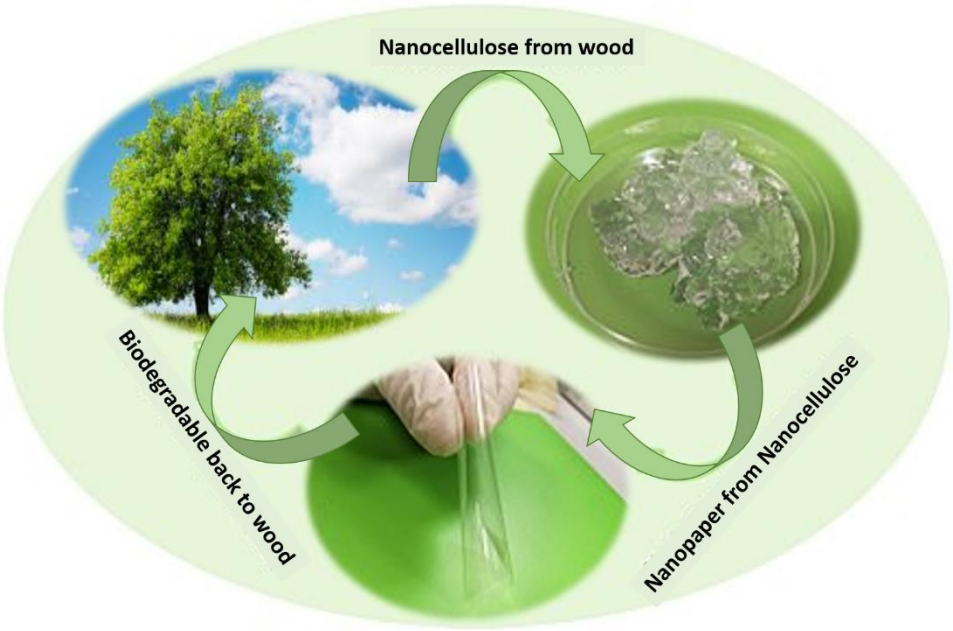
TECHNOLOGY ROADMAP

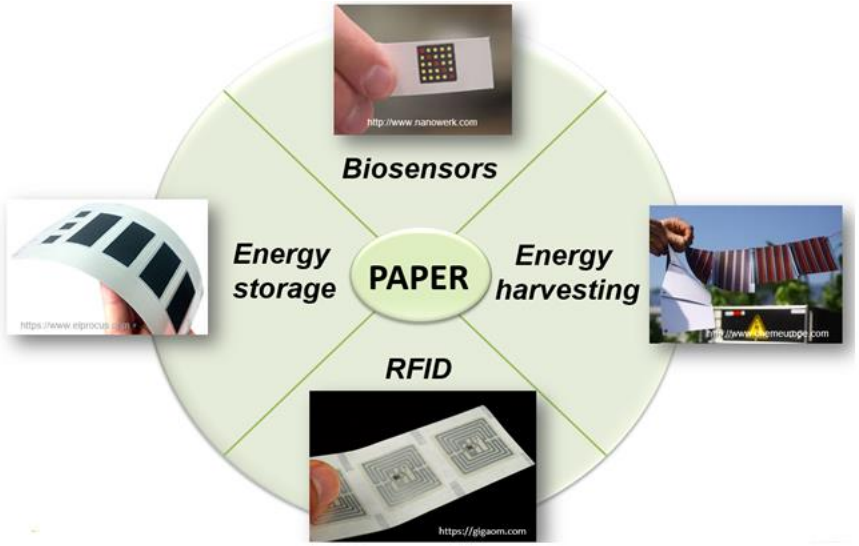


source : Ministry of Trade, Industry & Energy of Korea

FLEXIBLE & SMART PLATFORM

PAPER: WHY NOT?





- Widely avalaible
- Low cost
- Lightweight
- Flexible & Versatile
- Good dielectric properties
- Recyclable

Material	Price($\$/m^2$)
Paper	~ 0.3- 3
PET	~ 2
Polymide	~30
Si	~1K-10K

Brunetti et al, Adv. Funct. Mater. 2019

PAPER SUBSTRATES

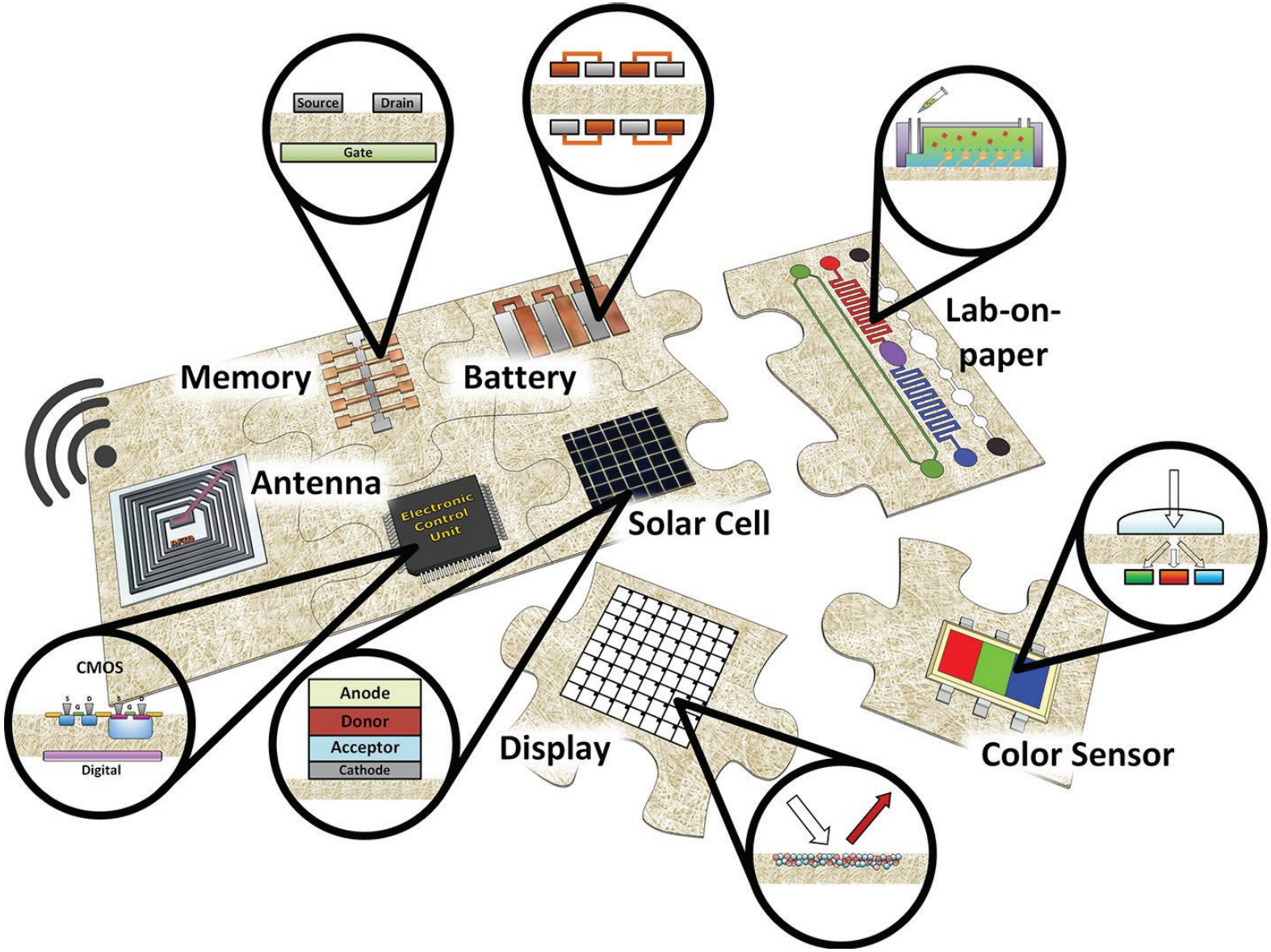
COMMON PAPER

- is recyclable and biodegradable
- High roughness (>20 nm)
- Resistant to commonly used solvents

E- PAPER

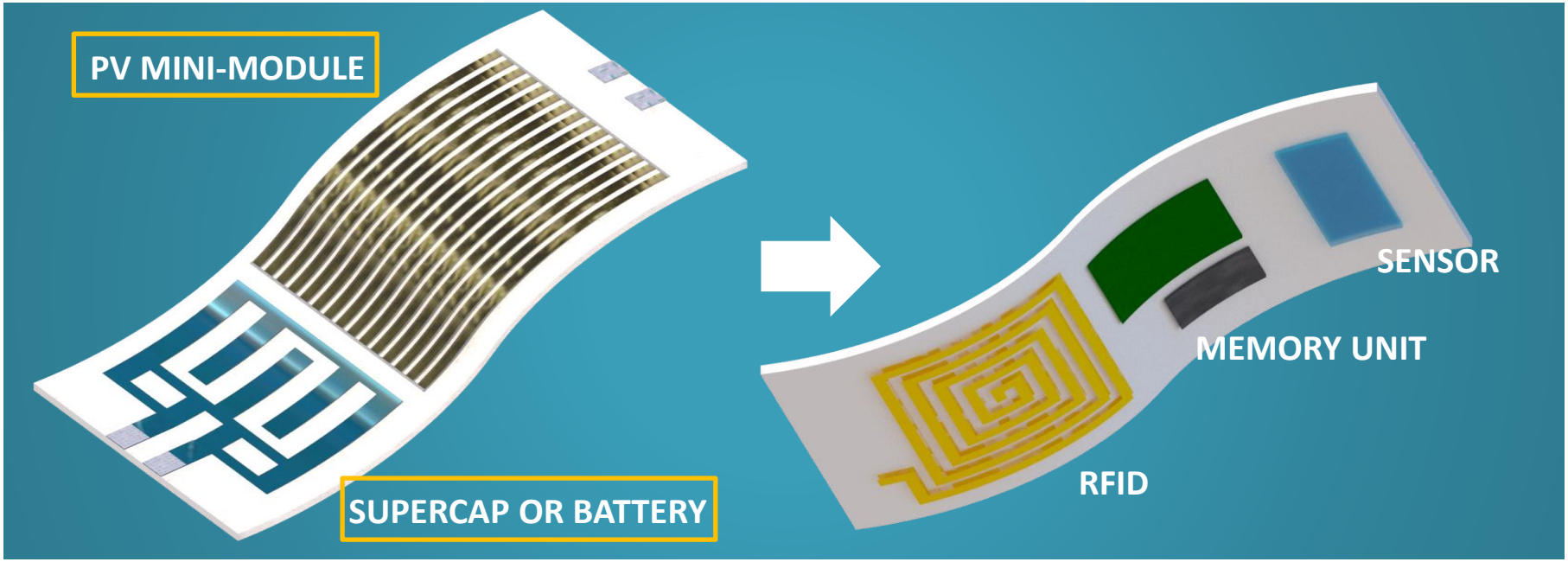
- Working temperature of up to 220 ° C
- is recyclable and biodegradable
- low roughness (<20 nm)
- Resistant to commonly used solvents

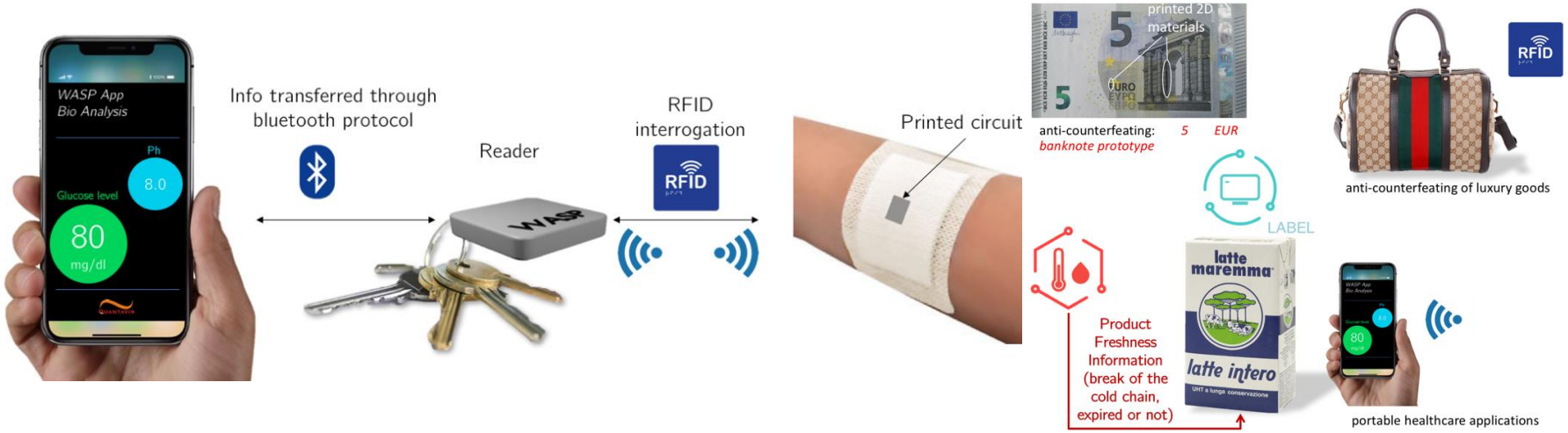
INTEGRATED PLATFORM



Optoelectronics and Bio Devices on Paper Powered by Solar Cells A.Vincente et al DOI: 10.5772/66695

ENERGY STORAGE & HARVESTING



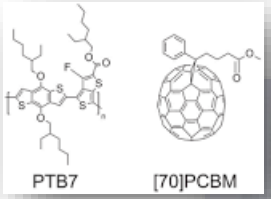


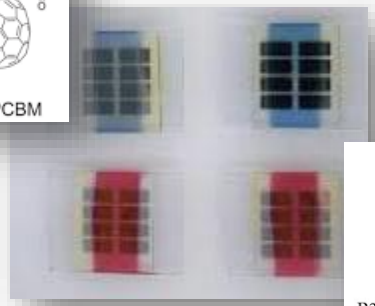
DEVICE REALIZATION: A GREEN APPROACH

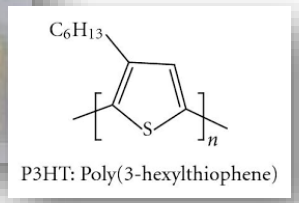
GREEN CHEMISTRY:
Non toxic and widely available materials

HIGH CONDUCTIVE PEDOT:PSS

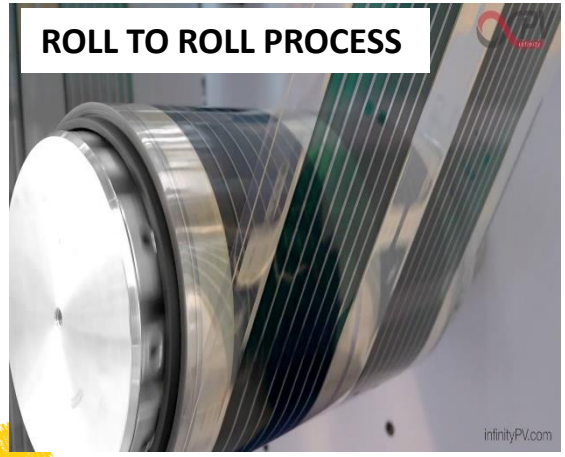
HYDROPROPOXYL CELLULOSE (HPC)

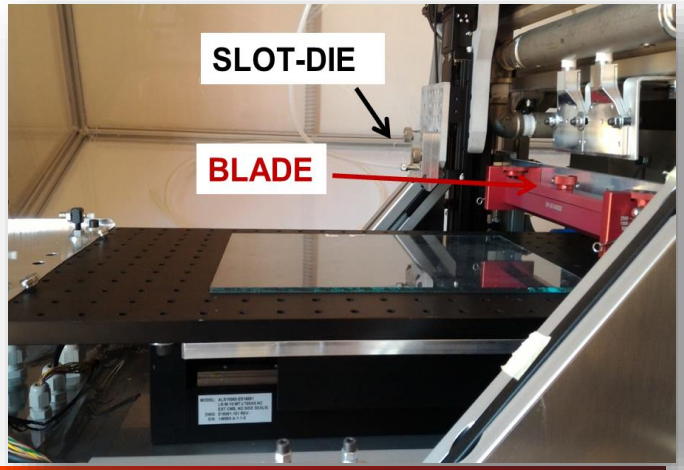




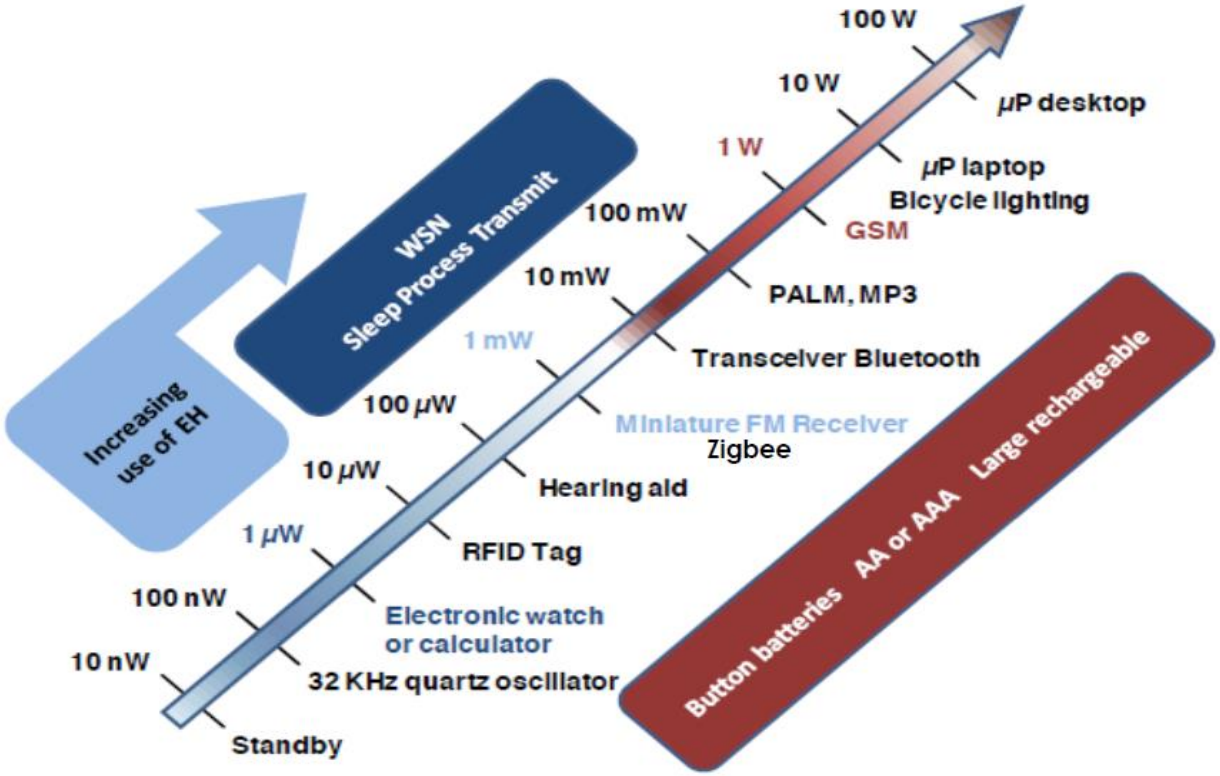


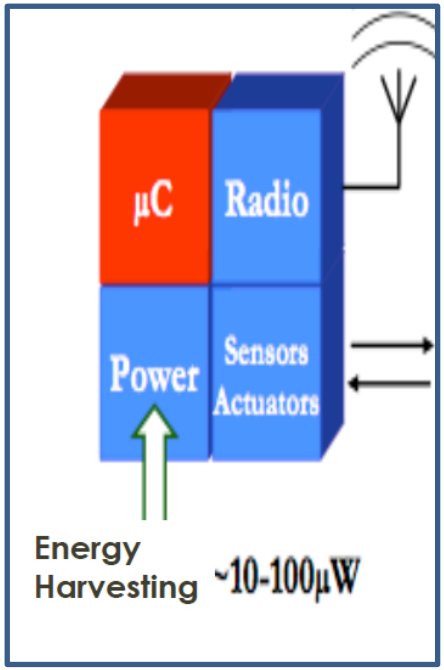
GREEN TECHNOLOGIES:
Low energy and low cost processes





POWER CONSUMPTION FOR VARIOUS APPLICATIONS

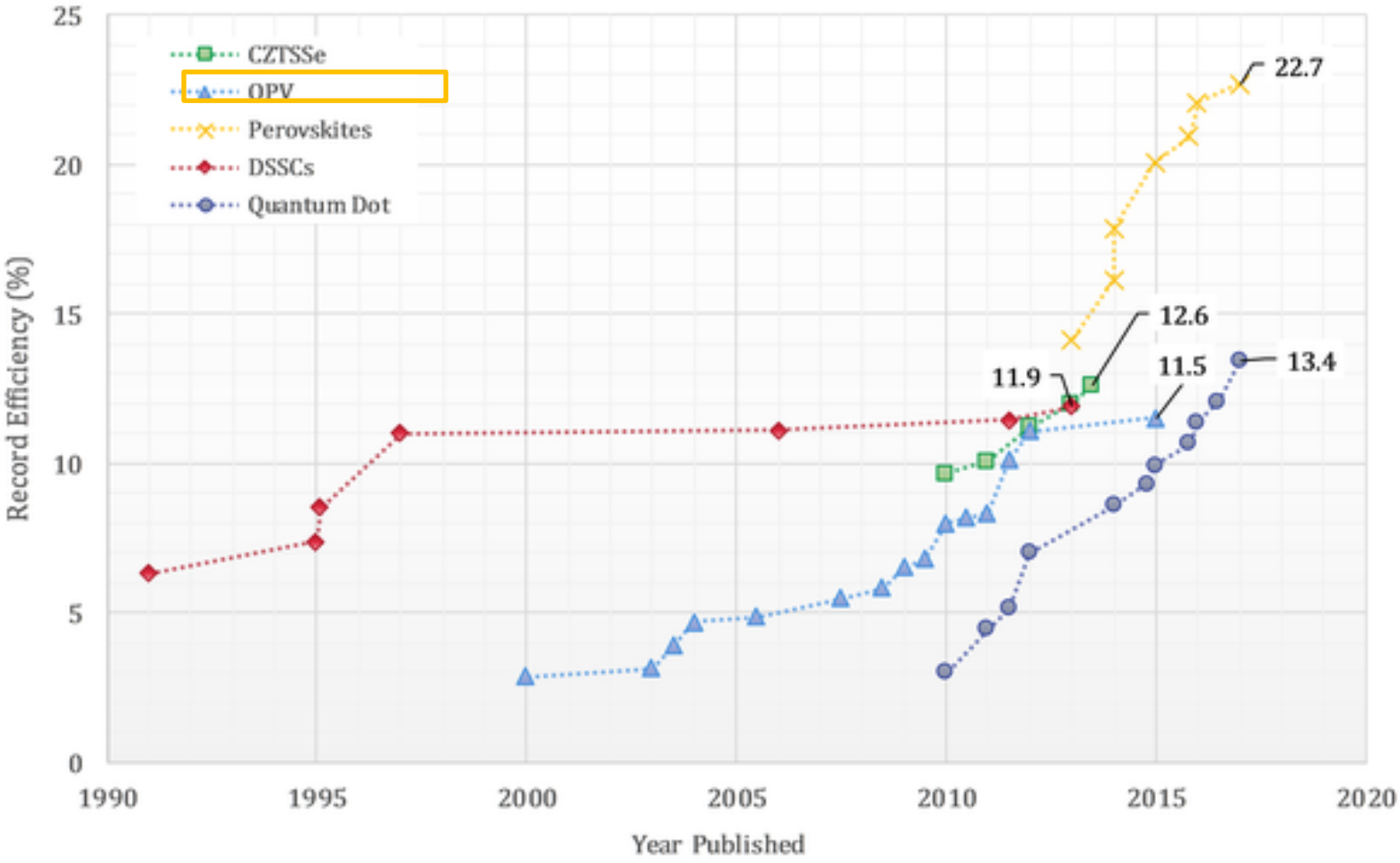




Source IDTechEx

ENERGY HARVESTING

PHOTOVOLTAIC TECHNOLOGIES



POLYMER SOLAR CELLS SCENARIO

POWER CONVERSION EFFICIENCY

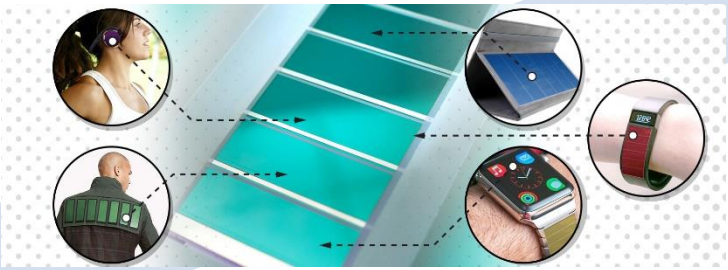
~ 15.6%

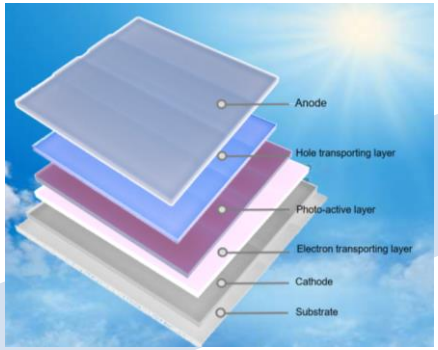
MANIFACTURING TECHNOLOGY & COSTS

<0.8€/Wp

DEVICE STABILITY

>5 years





Conformable → Low Cost

Ferlauto et al., Nature Communications, 992 (2018), DOI: 10.1038/s41467-018-03386-7

POLYMER SOLAR CELLS ON PAPER

PEDOT:PSS ELECTRODES FOR ENERGY HARVESTING

ORGANIC SOLAR CELL'S ELECTRODES REQUIREMENTS:

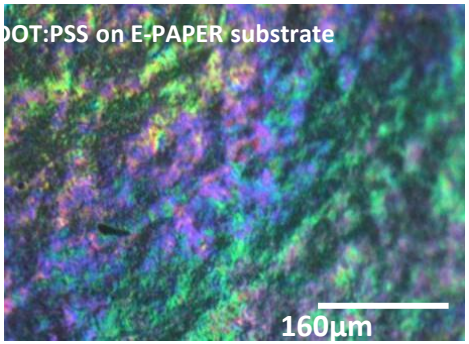
- ✓ HIGH TRANSPARENCY
- ✓ HIGH CONDUCTIVITY
- ✓ BACK SCATTERING

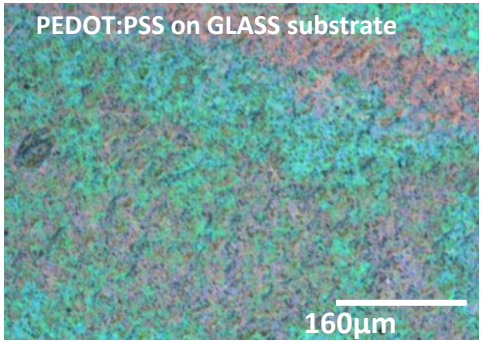
LOW ROUGHNESS SUBSTRATES

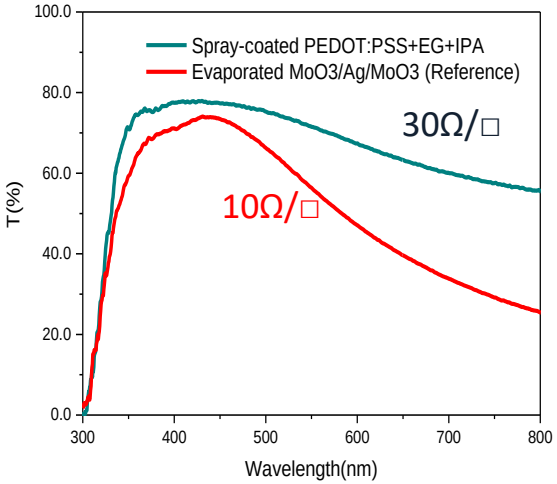
PLANARIZATION REQUIRED

OPV DEVICE

- **ANODE**
- **ORGANIC STACK**
- **CATHODE**
- PAPER



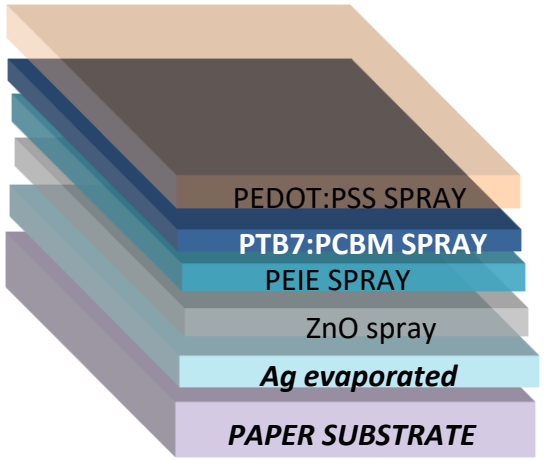


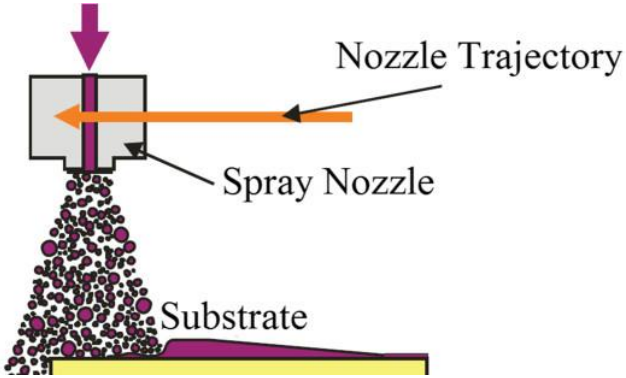


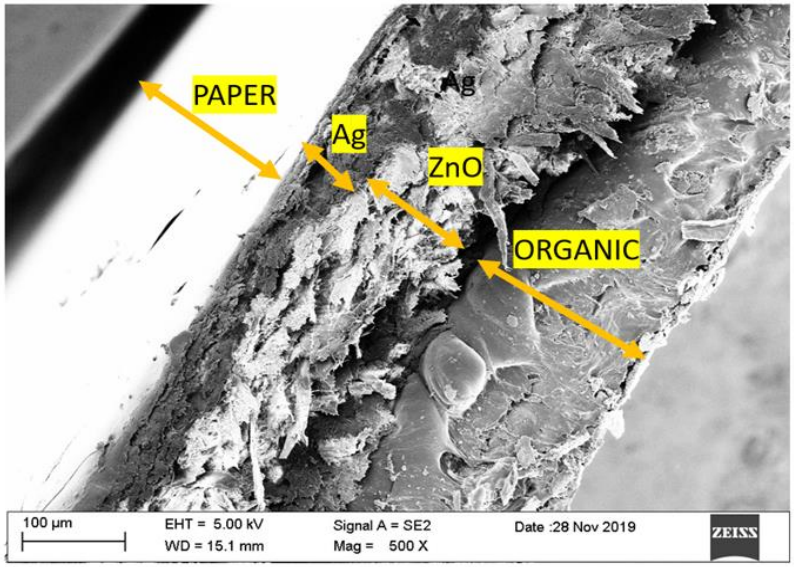
ELECTRODE (ANODE)	Technique	Thickness (nm)	Rs(Ω/□)	σ(S/m)
PEDOT:PSS+EG+IPA	Spray coating	500	30	0.03
MoO_3/Ag/MoO_3(reference)	Evaporated	8/13/25	10	0.02

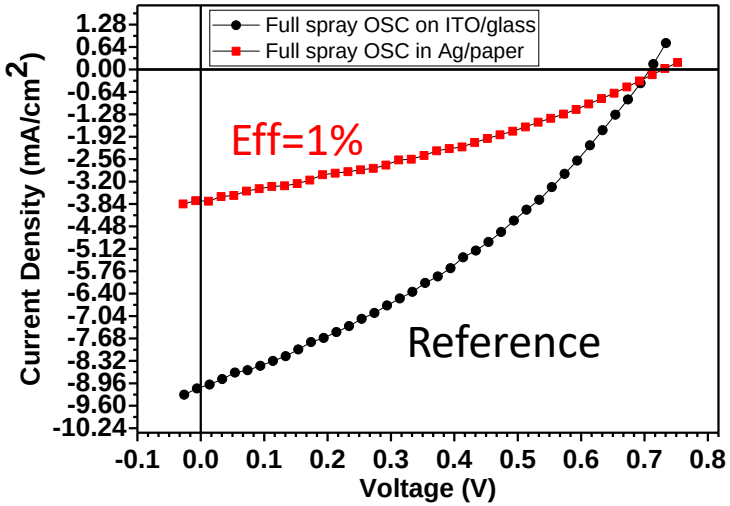
Dr. Giuseppina Polino

POLYMER SOLAR CELLS ON PAPER





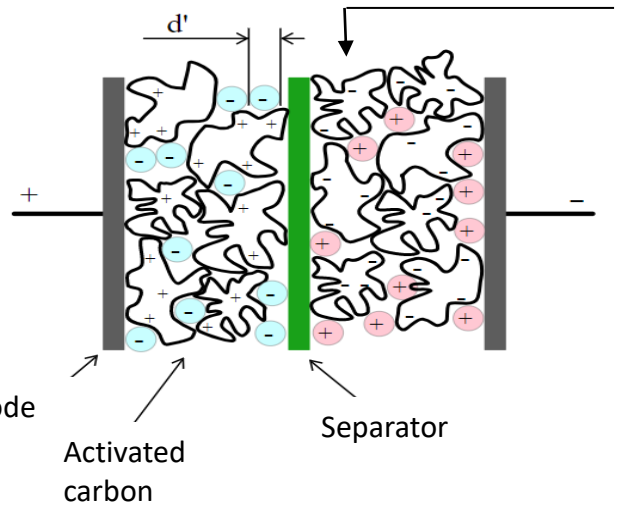




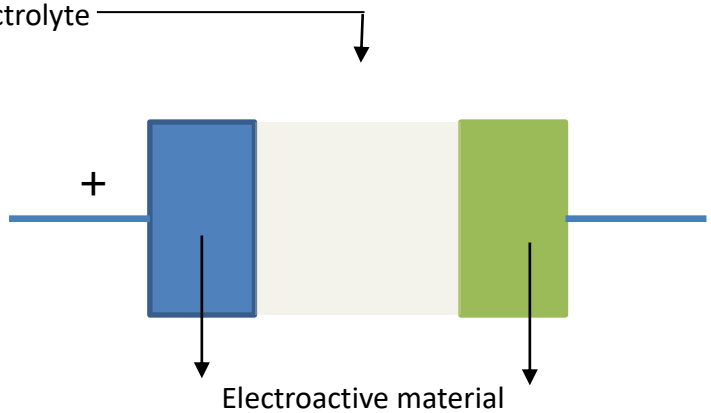
ENERGY STORAGE DEVICES

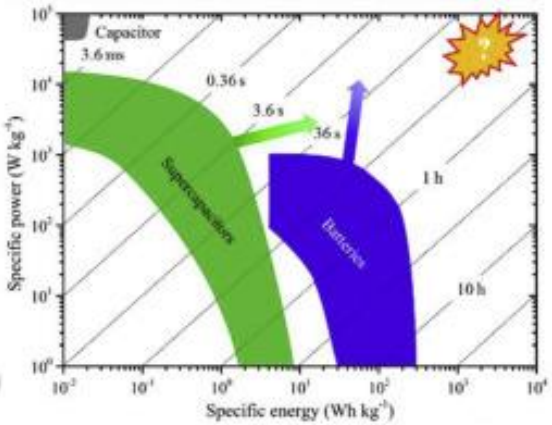
What kind of device is this?

Supercapacitor



Battery





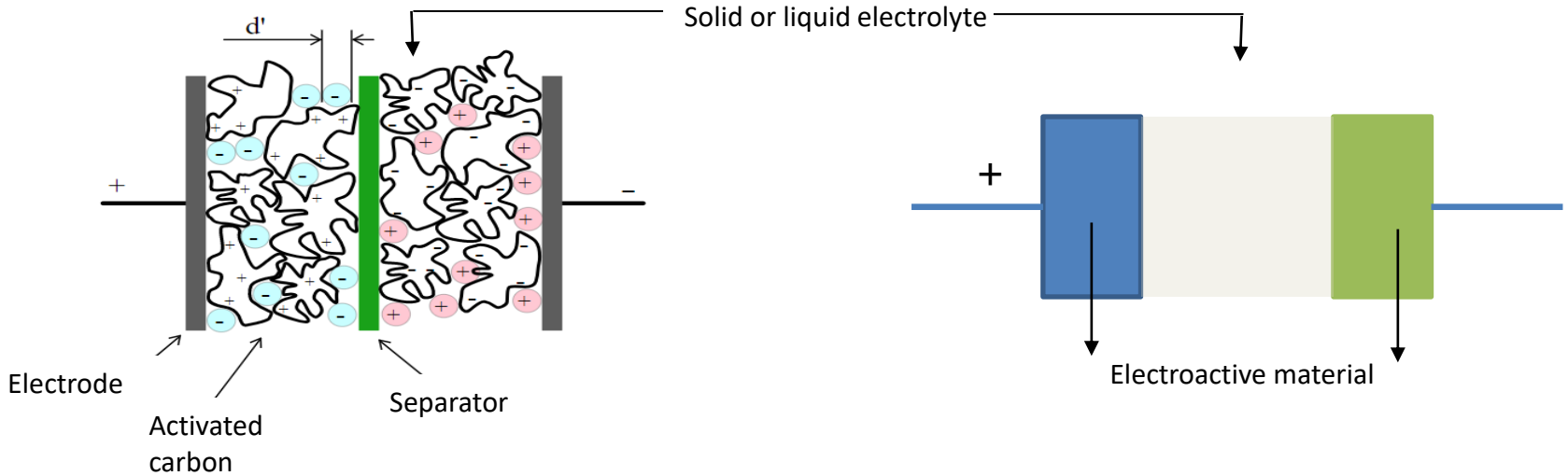
- **Batteries**: rapid surface-controlled electrochemical reactions without diffusion control and phase transformation
- **Supercapacitors**: stores energy in the crystal lattices or porous materials through much slower electrochemical reactions with limits from the phase transformation, chemical binding changes or/and reactant diffusions.

ENERGY STORAGE DEVICES

What kind of device is this?

Supercapacitor

Battery



PARAMETER	BATTERY	SUPERCAPACITOR
Energy density	100Wh/kg	10Wh/kg
Power Density	1kW/kg	10W/kg
Efficiency	80%	>90%
Cyclability	400-2500	1.000.000
Temperature	-20,+60°C	-40,+85°C
Costs	0.07-2$/kWh/cycle	0.006$/kWh/cycle

SUPERCAPACITOR ON PAPER

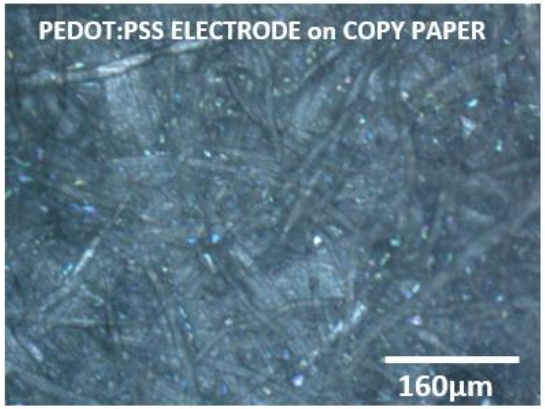
PEDOT:PSS ELECTRODES FOR ENERGY STORAGE

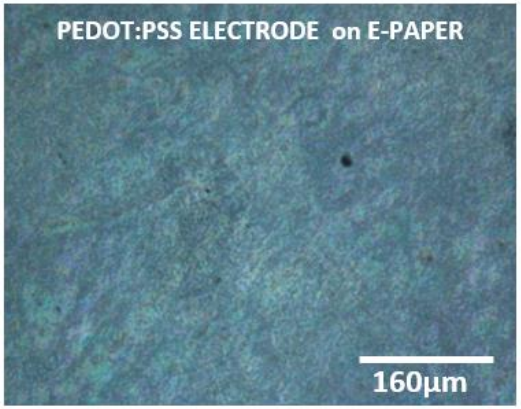
STORAGE SYSTEM'S ELECTRODES REQUIREMENTS:
- ✓ GOOD MECHANICAL PROPERTIES
- ✓ HIGH CONDUCTIVITY

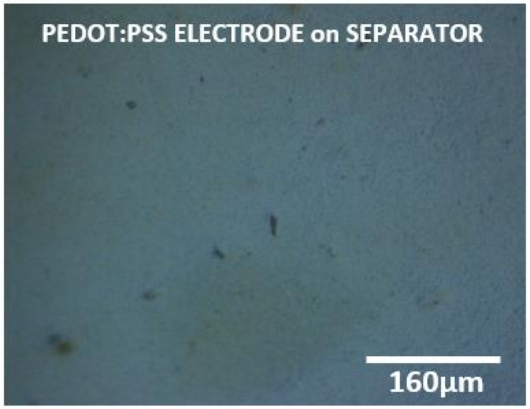
POUROUS AND ROUGH SUBSTRATE

REQUIRED

STORAGE SYSTEM
- ANODE
- SEPARATOR
- CATHODE
- PAPER





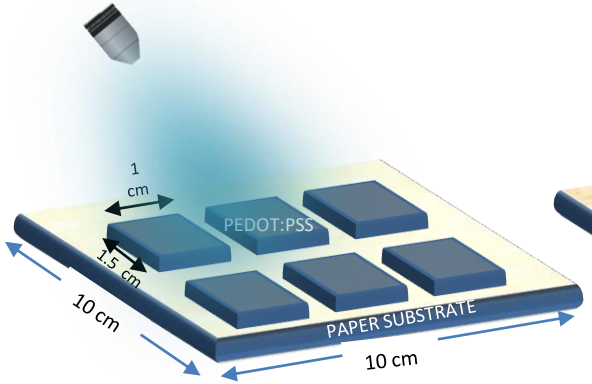


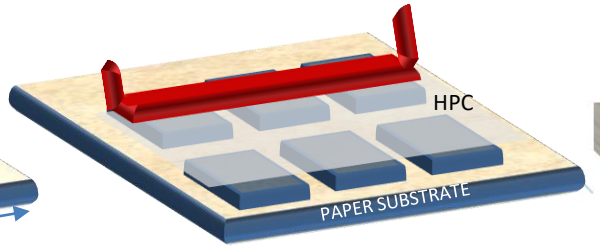
ELECTRODE	Technique	Thickness (nm)	Rs(Ω/□)	σ(S/m)
PEDOT:PSS+DMSO+IPA	Spray	500	300	0.0033
PEDOT:PSS+DMSO+IPA	Spray	600	500	0.002

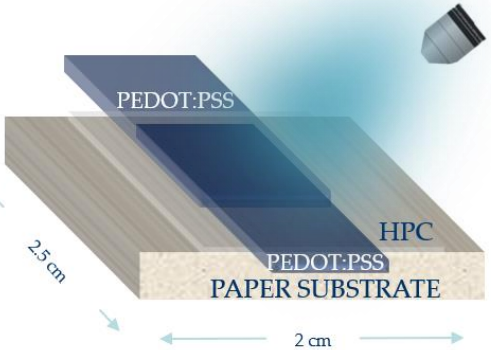
G Polino et al, Nanodiamond-Based Separators for Supercapacitors Realized on Paper Substrates Energy Technology, 8, 6-2020
https://doi.org/10.1002/ente.201901233

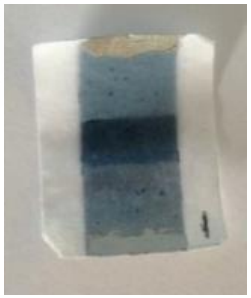
Dr. Giuseppina Polino

SUPERCAPACITOR ON PAPER





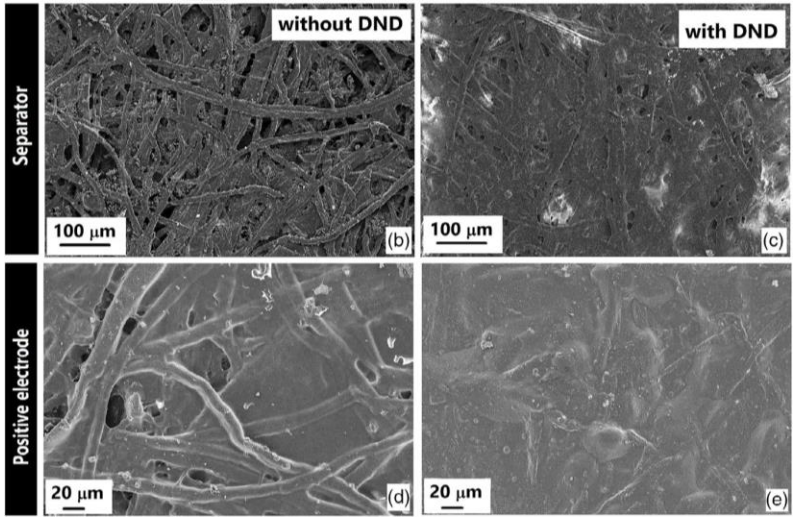


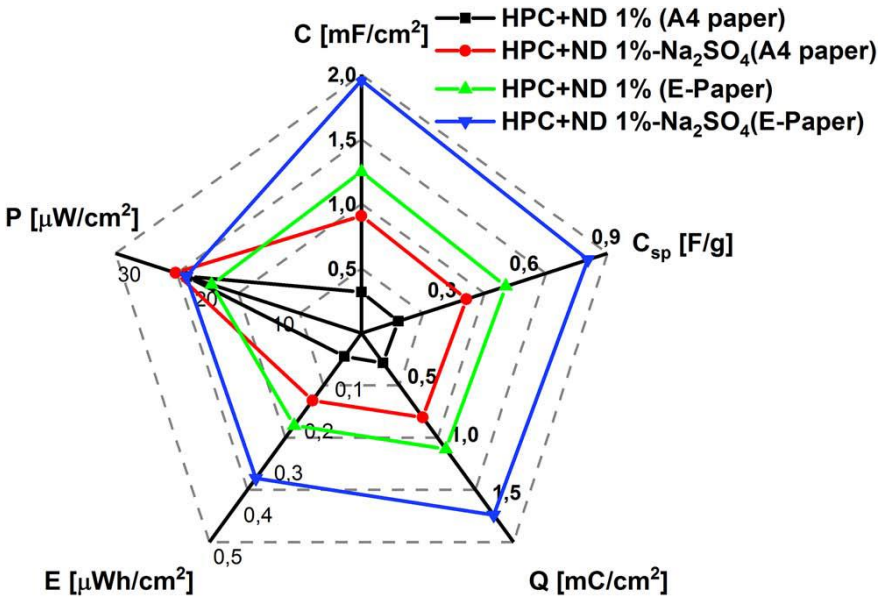


1. **Spray coating: PEDOT:PSS Bottom electrode**

2. **Blade coating: Separator and solid electrolyte**

3. **Spray coating: PEDOT:PSS Top electrode**





G Polino et al, Nanodiamond-Based Separators for Supercapacitors Realized on Paper Substrates Energy Technology, 8, 6-2020
https://doi.org/10.1002/ente.201901233

Polino et al, in preparation

CONCLUSION

In a SMART WORLD, autonomous smart devices and sensors requires:

- **Off-grid power**
- **Miniaturized and Cheap Micro-Energy**
- Efficient power management solutions
- **Scaling and materials development towards Nanotechnology**
- **Efficient smart storage devices**
- **Full printable device on flexible substrates compatible with industry processes**

Thank you for the attention!

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minimalab

CHOSE
WASP
Wearable Applications enabled by electronics Systems on Paper

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Rome, 15-18 September
Conference & Exhibition

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Dr. Elena Palmieri
Alessandro Scaramella
Ing. Valerio Manca

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