EnerHarv 2024

PSMA International Workshop | 26-28 June, 2024 | Perugia, Italy

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EnerHarv 2024 Workshop:

Sustainable Fabrication of Low-Environmental Impact Devices for Future Green Wearable Electronics

Presented By –

Daniela Iacopino, Dr
Tyndall National Institute
daniela.iacopino@tyndall.ie

Thursday, June 27, 2024

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OVERVIEW

- **E-waste, eco-design approaches**
- **Direct Laser Writing (DLW) as sustainable fabrication**
- **DLW of biomaterials**
- **Realisation of biodegradable modules**
- **Conclusions**

Tyndall: Deep-Tech Research & Innovation

Tyndall is the national institute for photonics and micro/nanoelectronics and a research flagship of UCC
Largest ICT research centre in Ireland
Specialising in electronics and photonics – materials, devices, circuits and systems
Tyndall employs 600 researchers, engineers and support staff, including 120 full-time graduate students.

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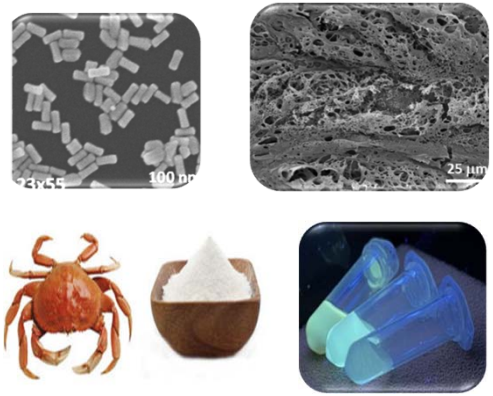
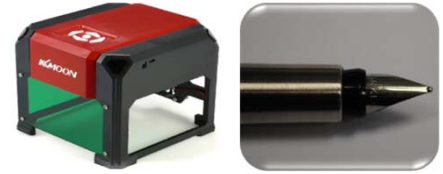
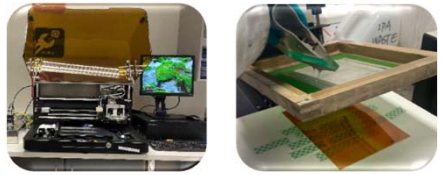
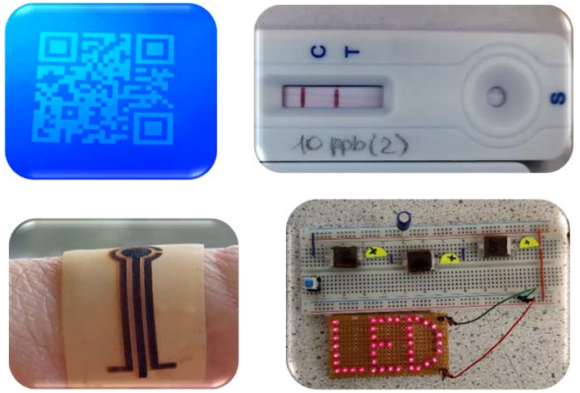
Team Research Expertise & Research Themes

Materials → Printing/Writing → Products



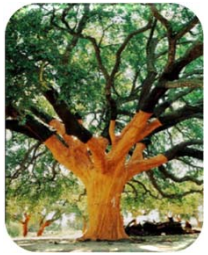






Health & Wellbeing

Sustainable Electronics



Food Monitoring

Security

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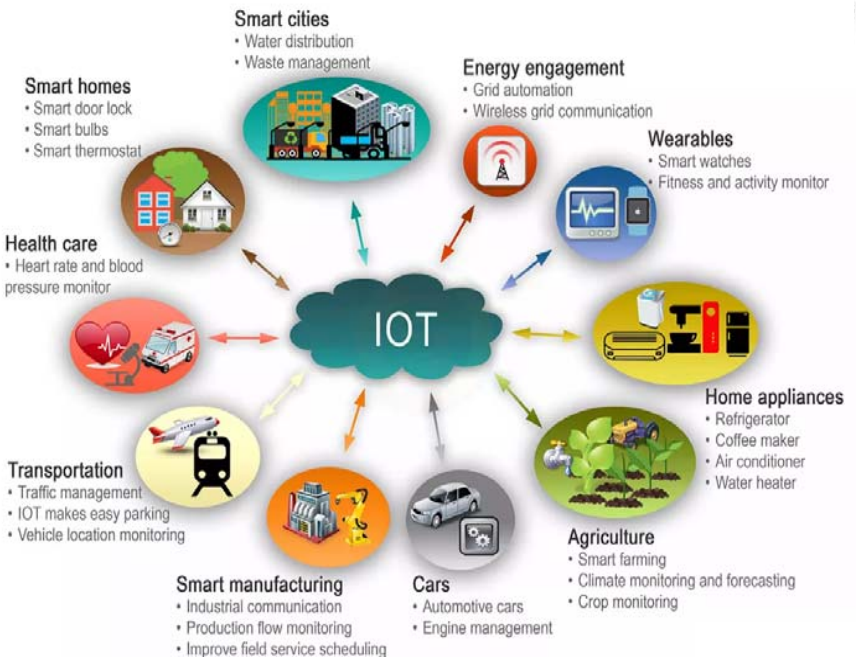
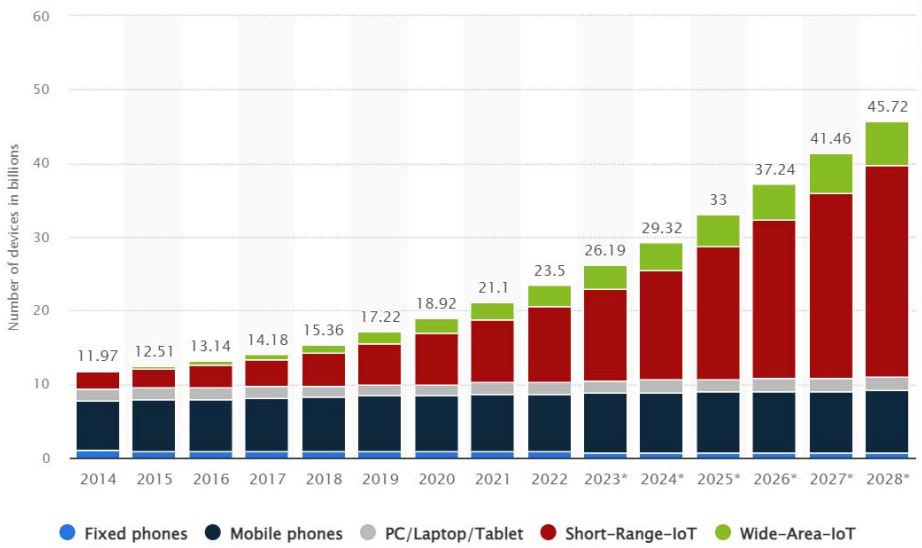
IoT is Going Mainstream





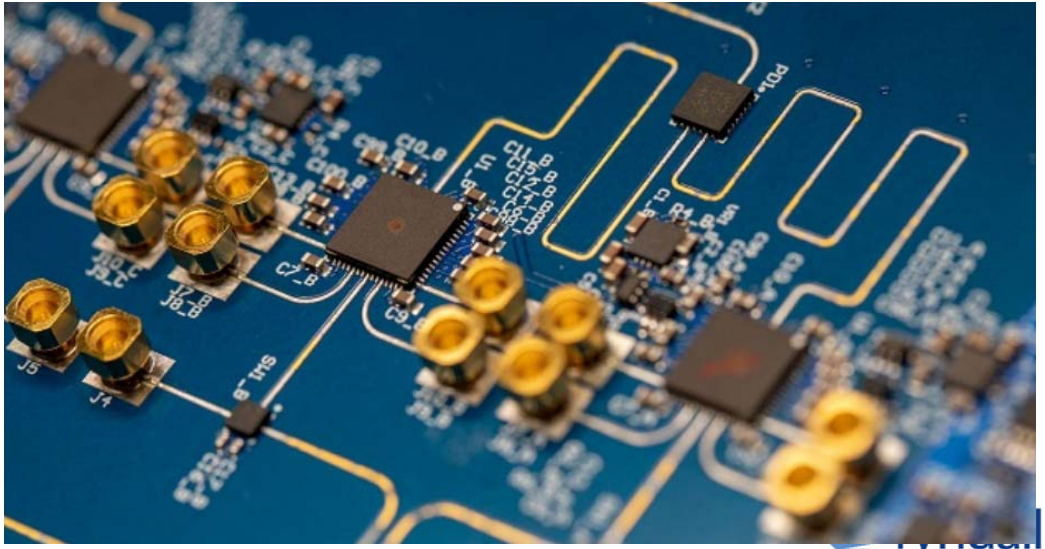
5G Technology & Industrial IoT (Internet of Things) - DREAMLNK (iot-rf.com)

Connected devices worldwide 2014-2028 | Statista

Electronics Production & Environmental Impact

- Significant carbon footprint => energy-intensive processes needed to produce printed circuit boards (PCBs) and integrated circuits
- Electronics production = mining and extracting of different materials, including critical raw materials . leakage of toxic chemicals into the environment, high levels of water use,
- Recycling these materials is inefficient and labor-intensive.

- Energy consumption
  - Reduce battery need
  - Incorporate harvesting solutions



E-waste: a Global Environmental Crisis

- **Disposal of electronic devices is the root problem of an environmental crisis: the production and management of electronic waste (e-waste)**
- **> 50 million tons of e-waste produced globally every year, Less than 20% recycled (UN SDG Report, 2020)**
- **Expected production of trillions of smart connected devices will lead to an increase of e-waste of 6.5% yearly**
- **Projected 74 million tons in 2030**

- **Global consumption of material resources expected to double between 2015 and 2050, access to materials at risk reduced**

Health, Environmental & Societal Concerns

- **ENVIRONMENTAL: spread over far distances. Water, soil, air, aquatic ecosystems and food sources**
- **HEALTH: include brain, heart, liver, kidney, and skeletal system damage, adverse birth outcomes.**
- **Children exposed to lead in e-waste recycling have a higher chance of developing neurocognitive issues, and the presence of chromium, manganese, and nickel affected their lung function as well**
- **SOCIETAL: disproportionately affects developing countries, where e-waste is often shipped by developed nations.**
- **75% of the global e-waste is shipped to Africa and Asia (up to 1.3 million tons only from EU)**
- **But many of these developing countries do not have the right facilities to properly dispose of the waste, which can affect the people and the environment.**

Transition Linear to Circular Economy

Linear economy

Take Make Dispose

Circular economy

Make Use Recycle

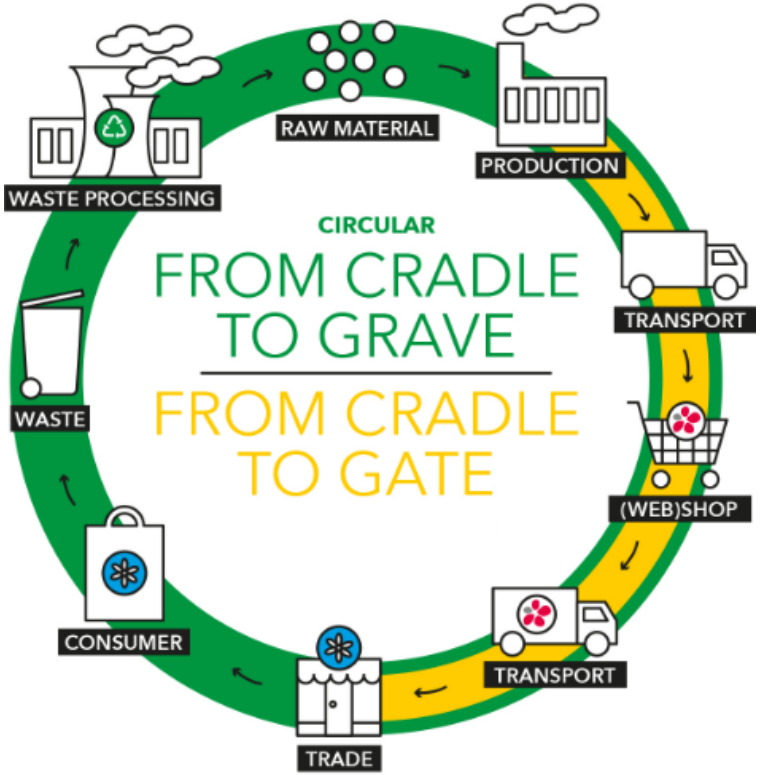
- **Up to 80% of a product's environmental footprint is predetermined at the design board***
- **Implement Eco-design approaches**
  - **Design with circularity in mind: LCA approaches**
  - **Modular designs**
  - **Longevity**
  - **4R sustainable circle = repair, reduce, reuse and recycling**

*Circular economy action plan - European Commission (europa.eu)

Design for Circularity: Life Cycle Assessment Models

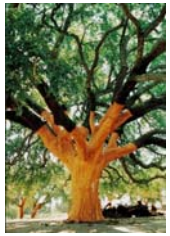
Three main product lifecycle models in LCA:

- **Cradle-to-gate: only assesses a product's footprint until it leaves the factory gates before it is transported to the consumer**
- **Gradle-to-grave: includes all life stages in your footprint measurements. Full footprint representation from start to end.**
- **Cradle-to-cradle: exchanges the waste stage with a recycling/upcycling process that makes it reusable for another product – essentially "closing the loop".**



https://www.dillewijnzwapak.nl/en/respect-for-people-and-planet/environmental-impact-of-our-products

ECO-Design

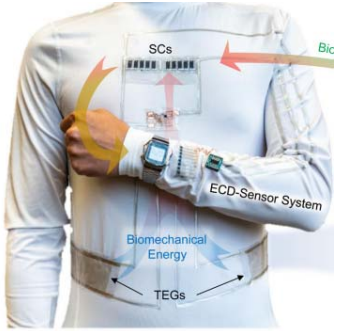


Sustainable Materials

Energy and resource efficient manufacturing processes

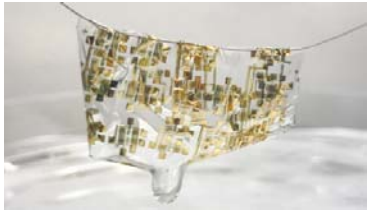
Appl. Phys. Rev. 8, 021319 (2021)

Recycling/Upcycling



Modular designs

https://doi.org/10.1038/s41467-021-21701-7



Sustainable use & disposal

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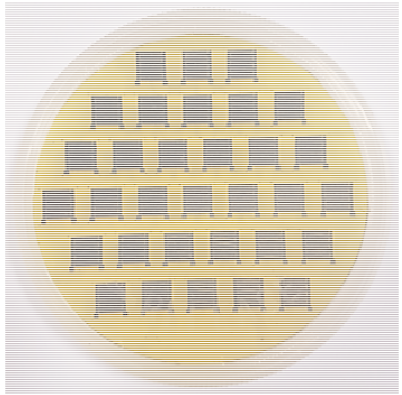
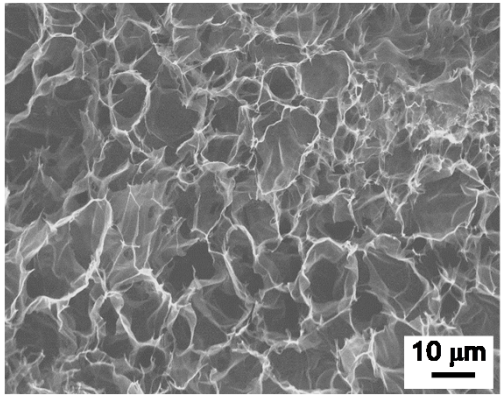
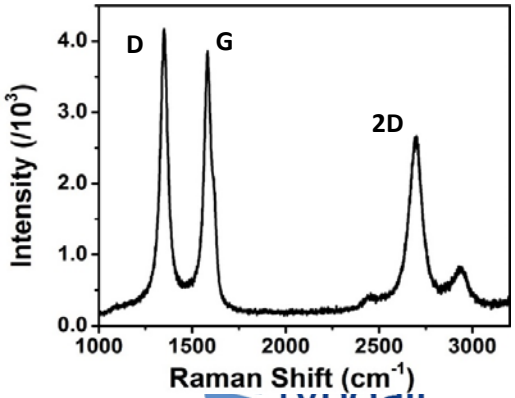
Alternative Fabrication: Direct Laser Writing

- breakage of C-N, C-C bonds
- Formation of volatiles and solid carbonized materials (char)
- Char degradation => refined aromatic chemicals formation

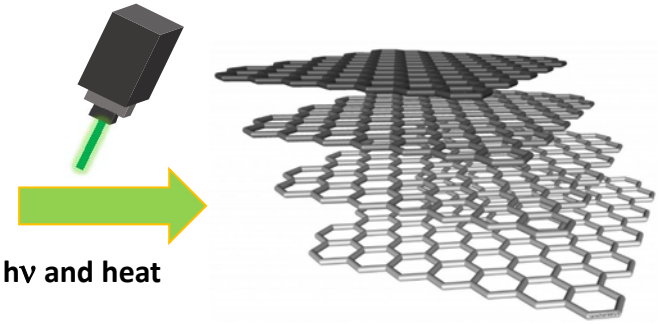


- **Versatility of design**
- **Suitable for scaling up (wafer scale and above)**
- **direct patterning (no waste material, no chemicals)**
- **Low cost equipment (hobbyist lasers are used)**
- **Mild fabrication conditions (room temperature and ambient conditions)**
- **Resolution ca. 200 um**
- **Low resistance < 50 Ohm/sq**



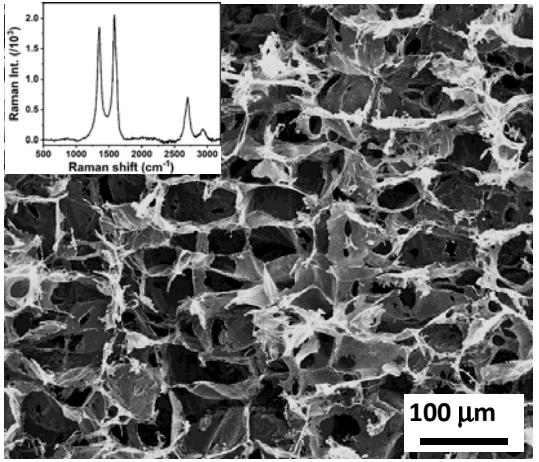


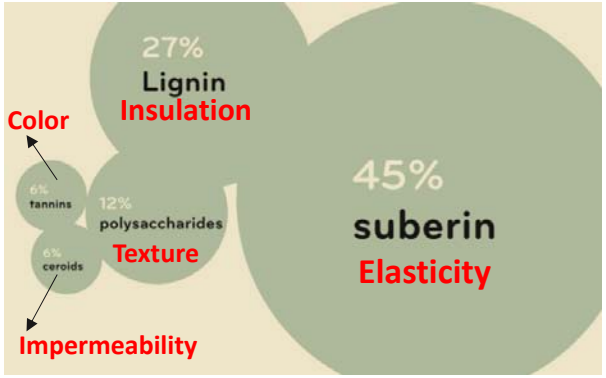
Direct Laser Writing of Cork



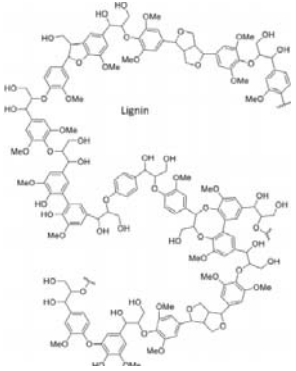
Aromatisation & intramolecular condensation

Cork Laser Induced Graphene (LIG)

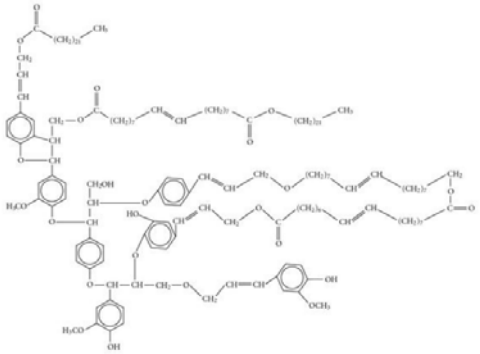




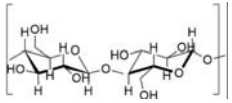
Lignin



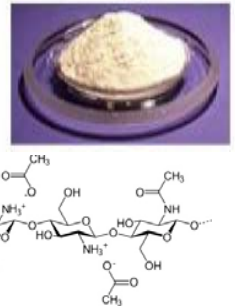
Suberin

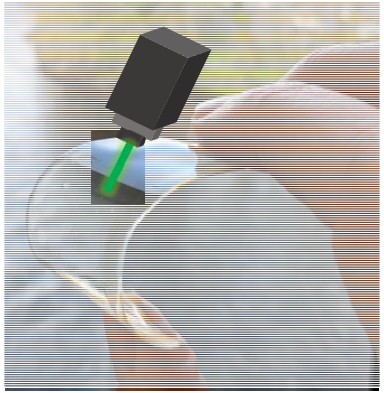


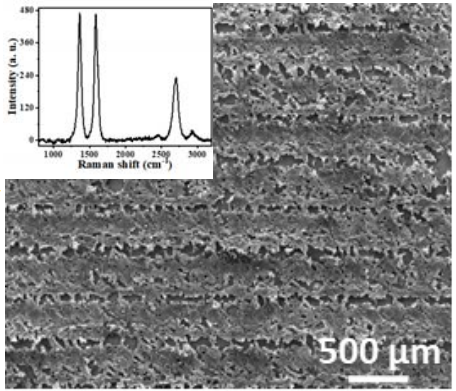
Cellulose



Fabrication: Direct Laser Writing of Bio-Polymers

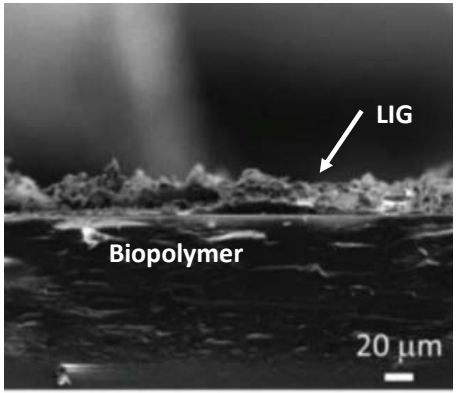


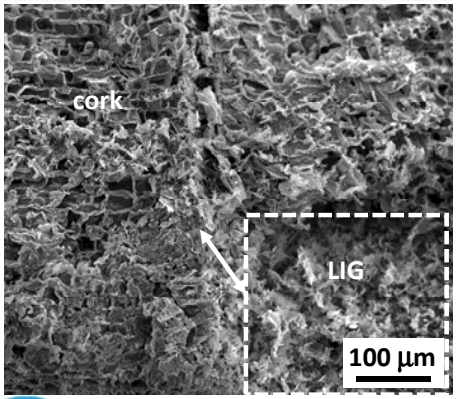




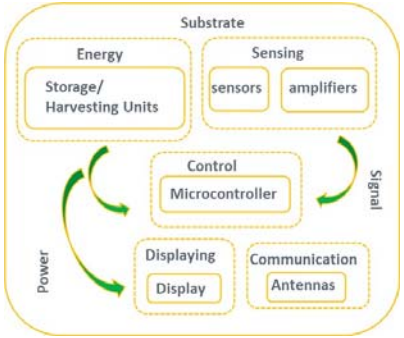
- **2019: > 16 million metric tonnes global crustacean production**
- **60% of crustacean is inedible = waste**
- **Chitosan extracted from crustacean waste.**
- **Biocompatible and biodegradable**
- **Valorisation of crustaceans' waste aligns well with SDGs**

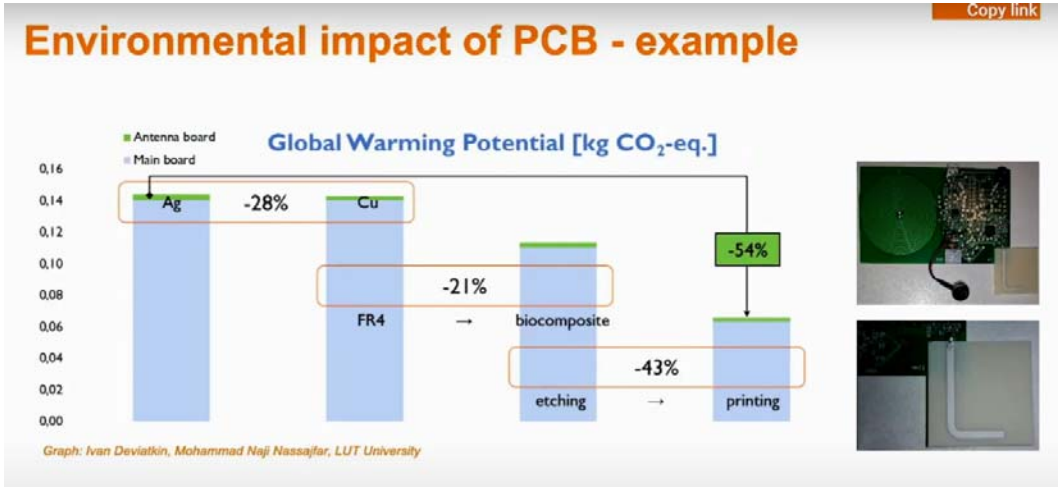
The Substrate





DLW = electrode materials on sustainable substrates

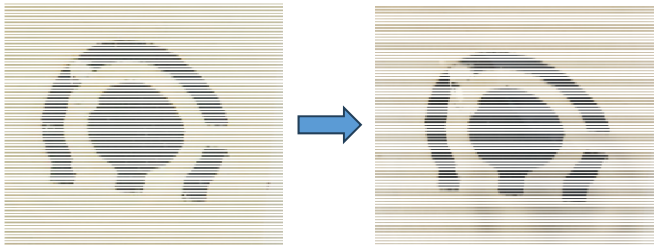


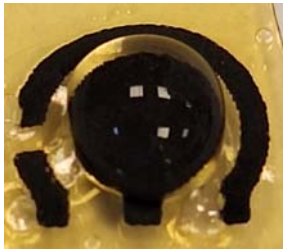


ECOTronics, www.ecotronics.fi,
https://doi.org/10.3390/su132112126

Biodegradable Robust LIG

Water immersion, 1 week





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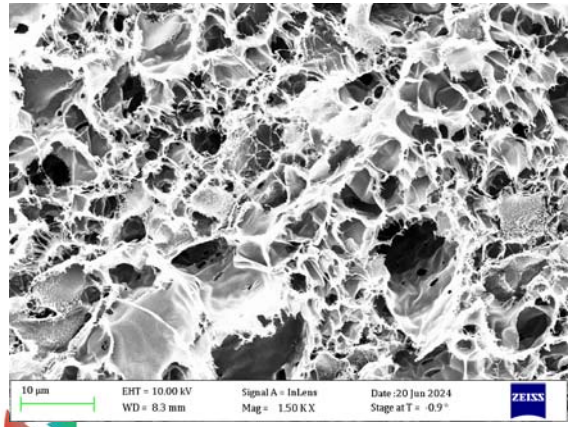

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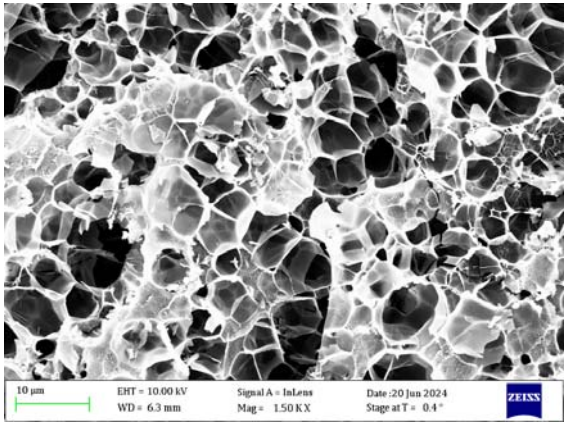
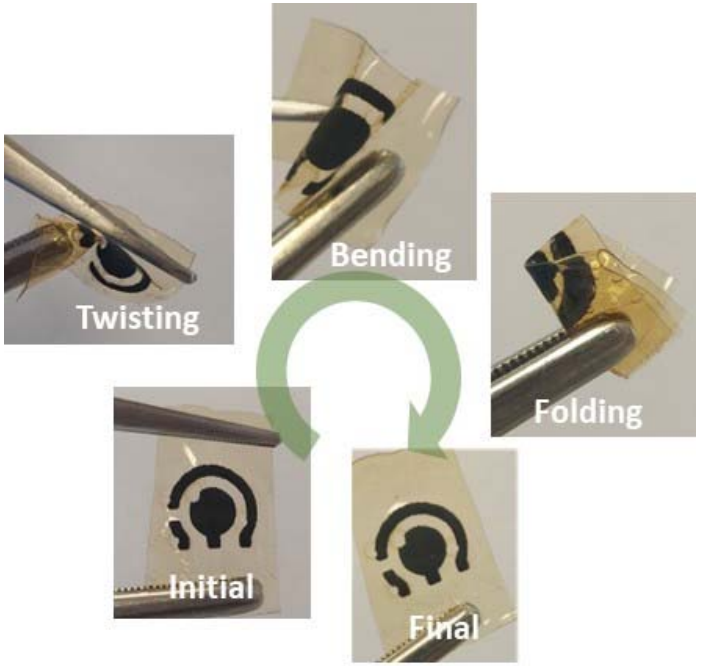
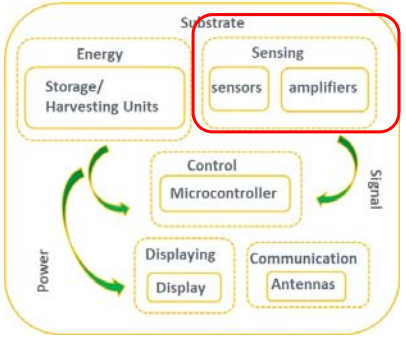
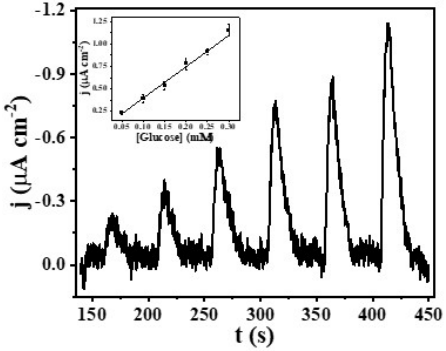


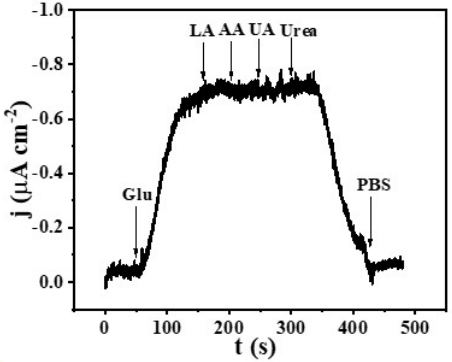


Sensing Units

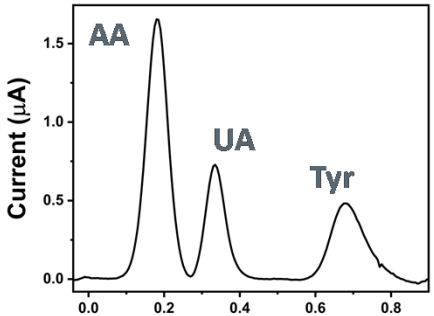


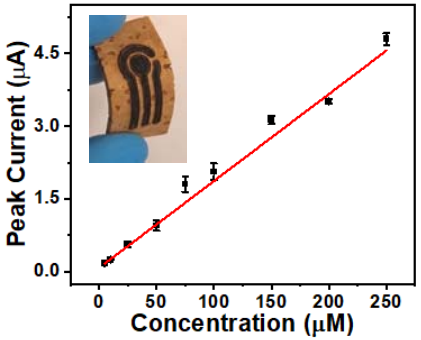
Enzymatic GLU sweat sensor



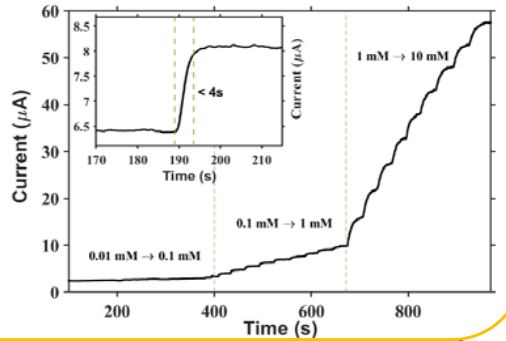


Biomarkers in sweat

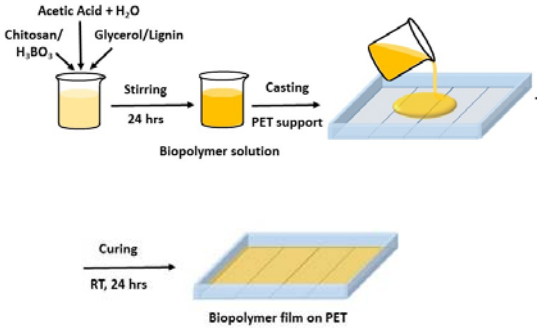


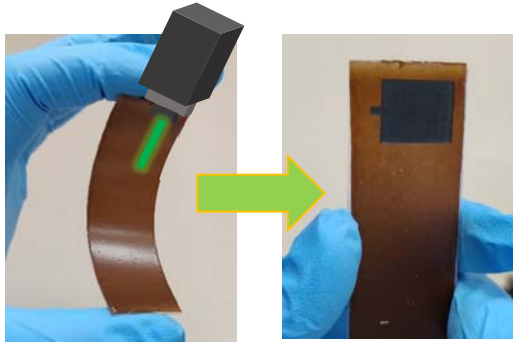


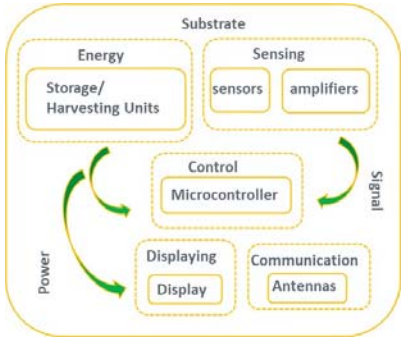
NE GLU urine sensor

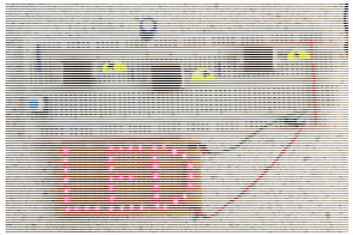


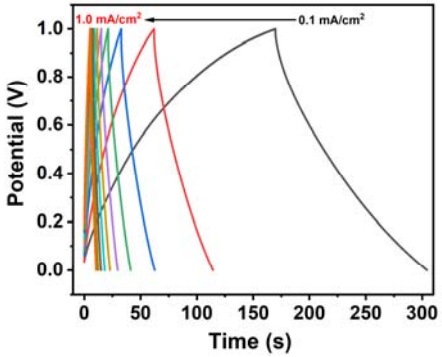
Energy Storage Units: Supercapacitors

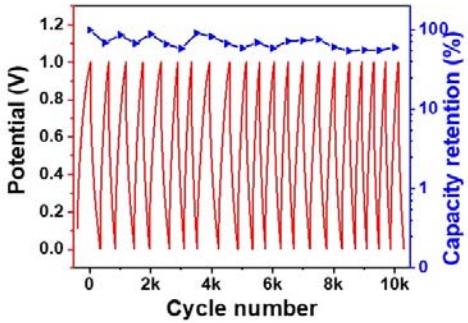


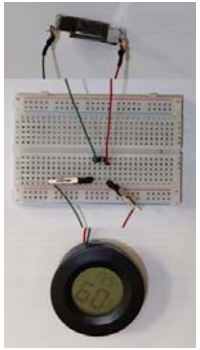




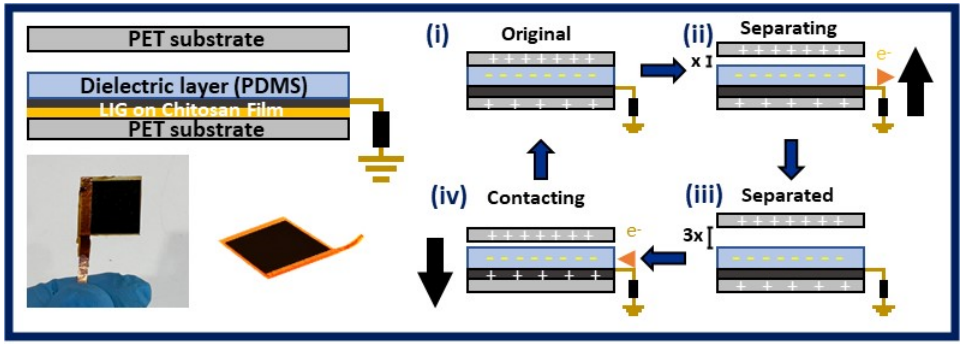


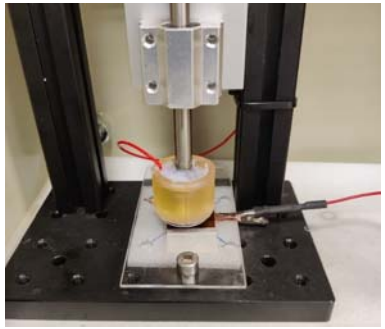


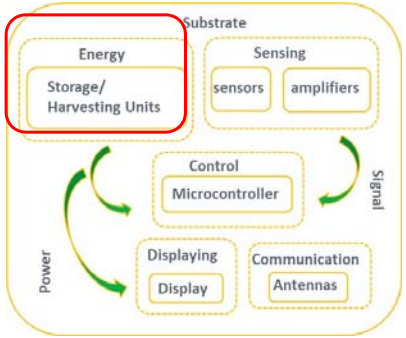


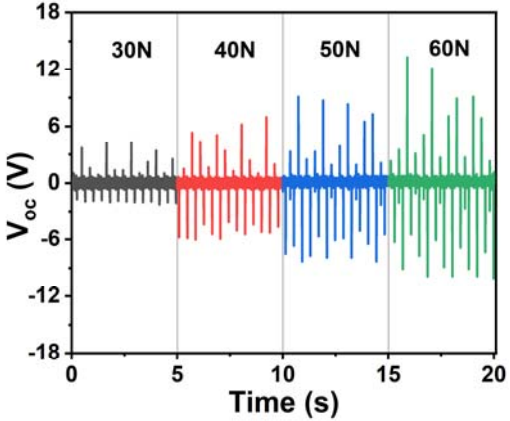


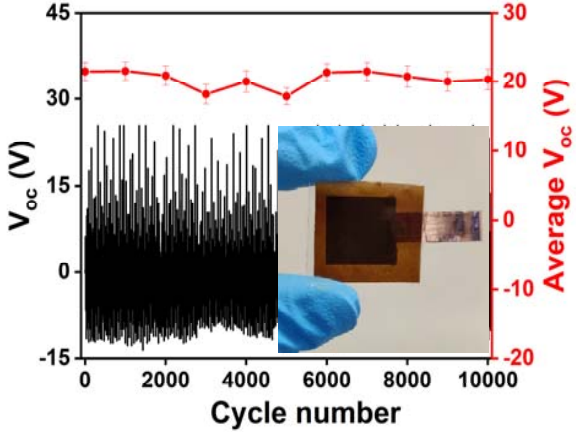
Energy Harvesting Units: TENG

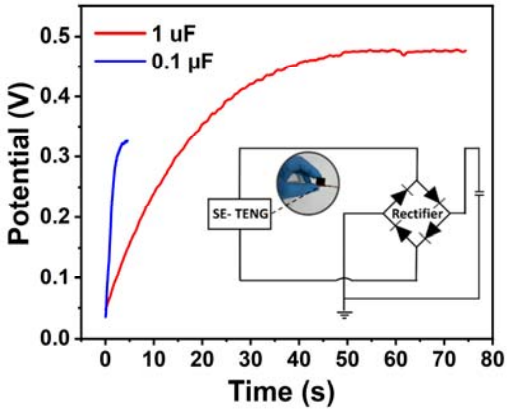












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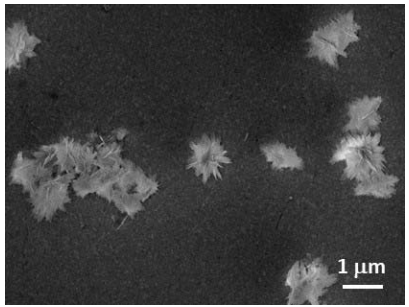
Antennas, Circuits & Electrodes

Laser Induced Copper (LIC)

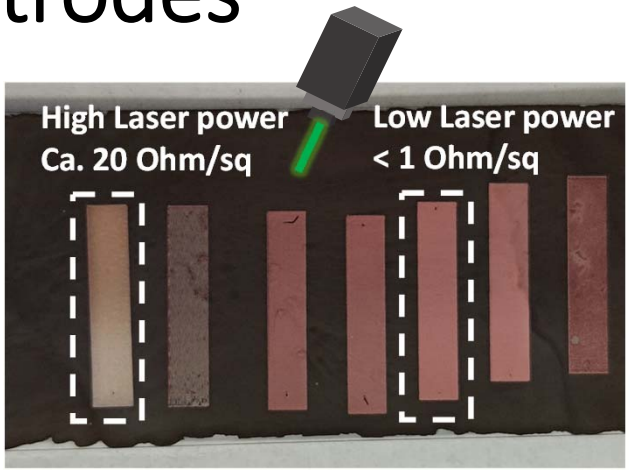


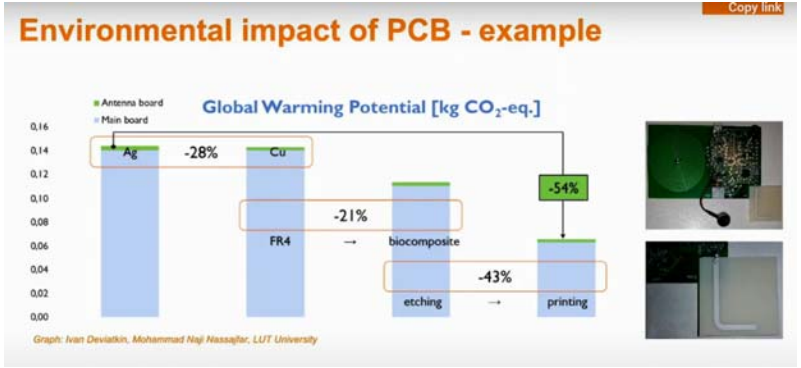
CuO NPs

CuO NP inks

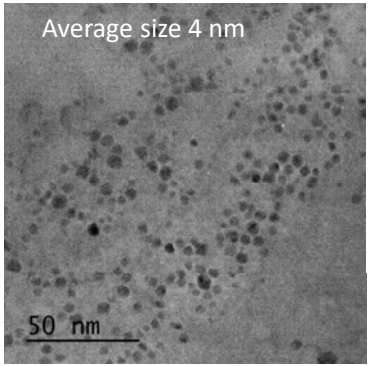
PVP, CTAB

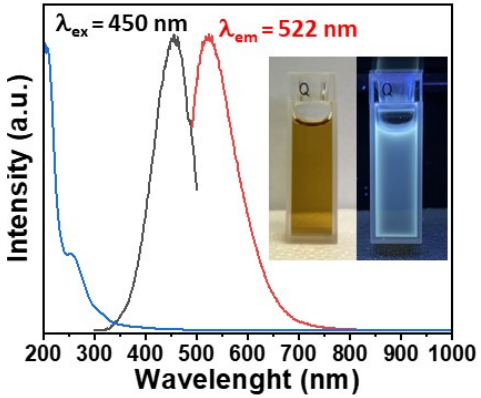
Deposition on substrate

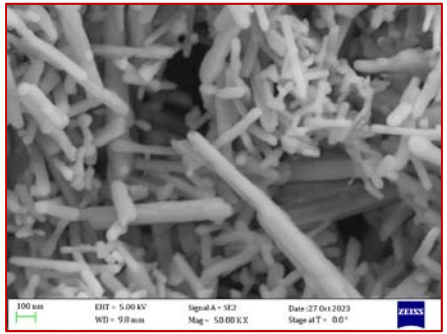


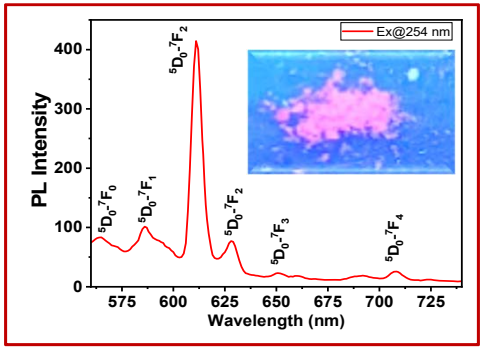


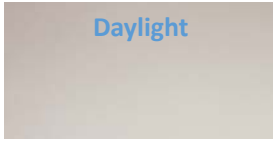
EL Materials

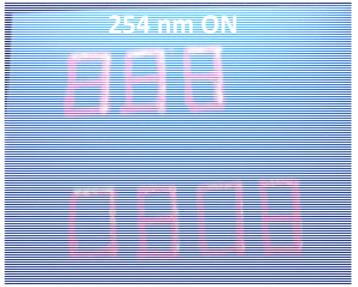


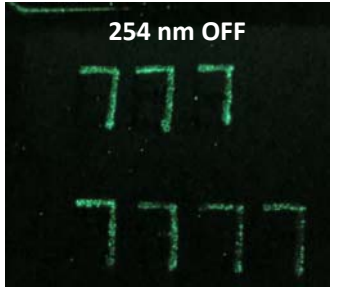












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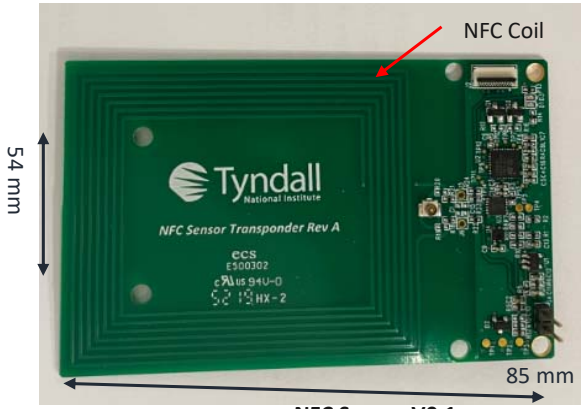
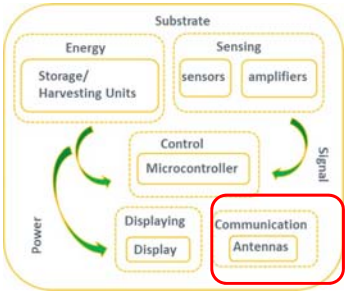
Communication Units



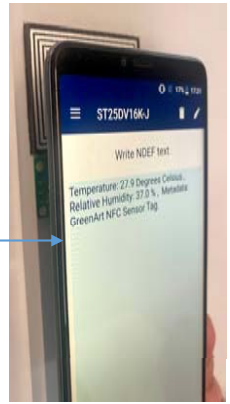
NFC Sensor V0.1

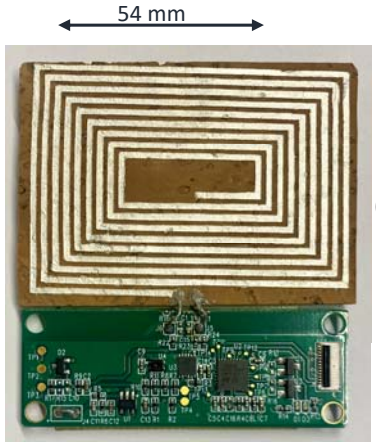
EU project Apache



EU project GreenArt

Screen printed antennas on lignocellulose substrates





NFC-type 5 enabled smartphone (Samsung Galaxy A52)

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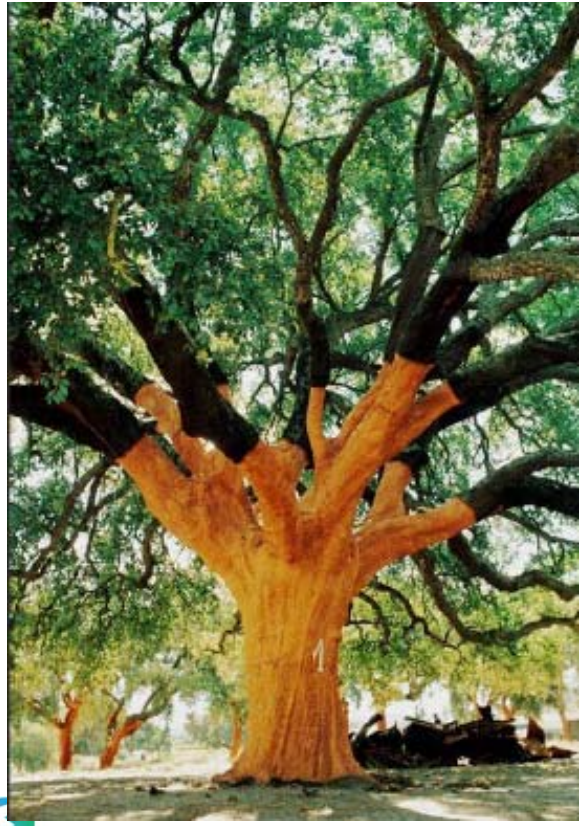
Conclusions



- DLW Simple, cost effective, scalable production of technological components
- Can be used in combination with abundant materials for the production of functional units
- Will likely play a relevant role in FUTURE market of flexible technologies
- Energy harvesting, storage and sensor devices fabricated
- Synthesised EL inks compatible with printing technologies useful for displays

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Q & A

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Thanks very much for your time and attention!

Questions/comments???

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