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David Schmid, CSEM

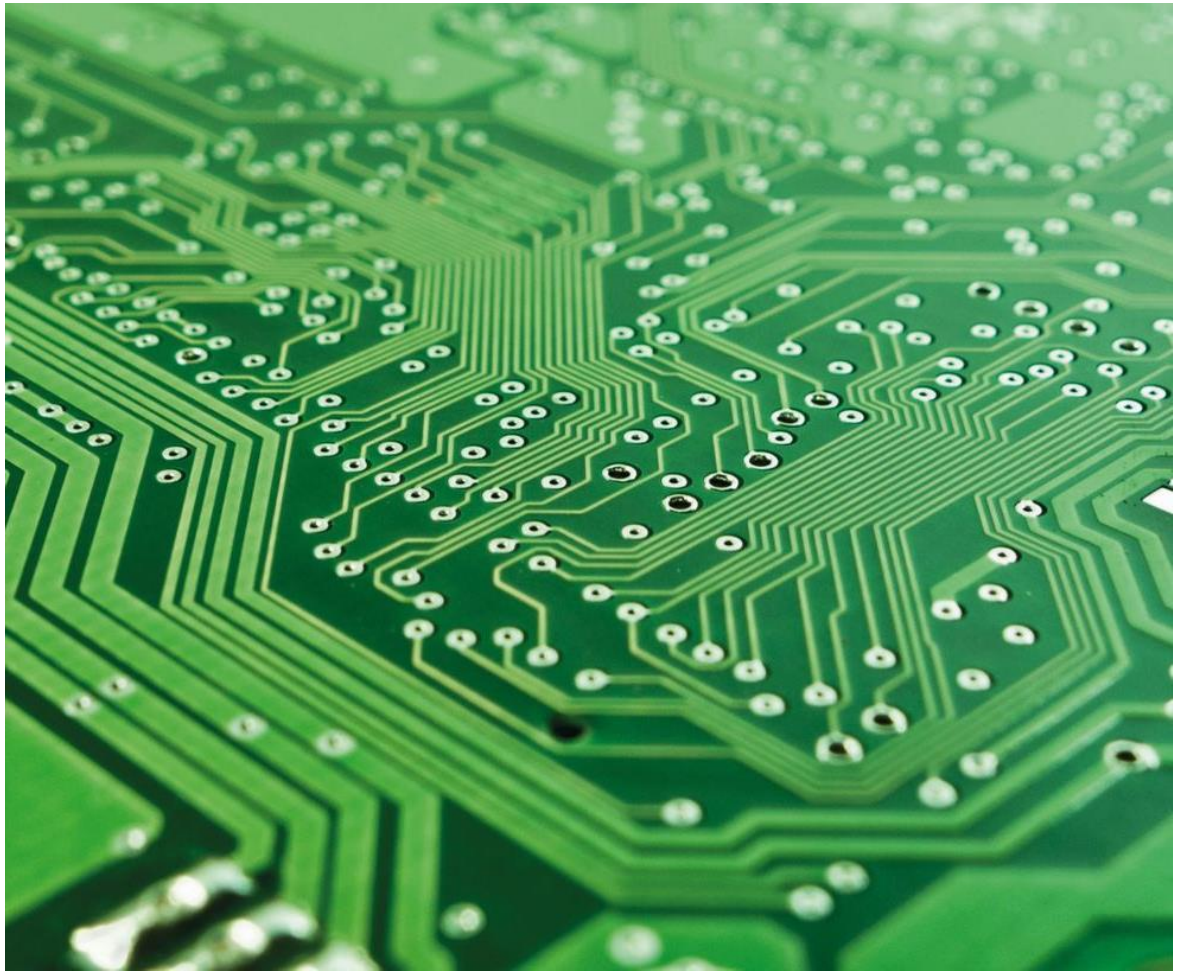
27.9.2023

PERSPEKTIVEN FÜR BIOPOLYMERE IN ELEKTRONIK UND SENSORIK

ELECTRONICS & SENSORS

CLASSIC PRINTED CIRCUIT BOARDS – A BAD EXAMPLE

- FR4 (epoxy-glassfiber composite)
- 50’000’000 e-waste tons annually
- 3’000’000 tons FR4 waste
- Almost no recycling, no sustainable materials
- Notoriously resistant industry
- Alternatives lack physical and economical characteristics (lightweight, stability, robustness, low-cost, multi-source)
- Lack of legal basis / pressure to change
- Flexible PCBs (e.g. wearables) 13% market share (CAGR 11% vs 4% total PCB market), 1% paper-based



Khrustalev D. et al. A new approach to designing easily recyclable printed circuit boards. Sci Rep 12, 22199 (2022)

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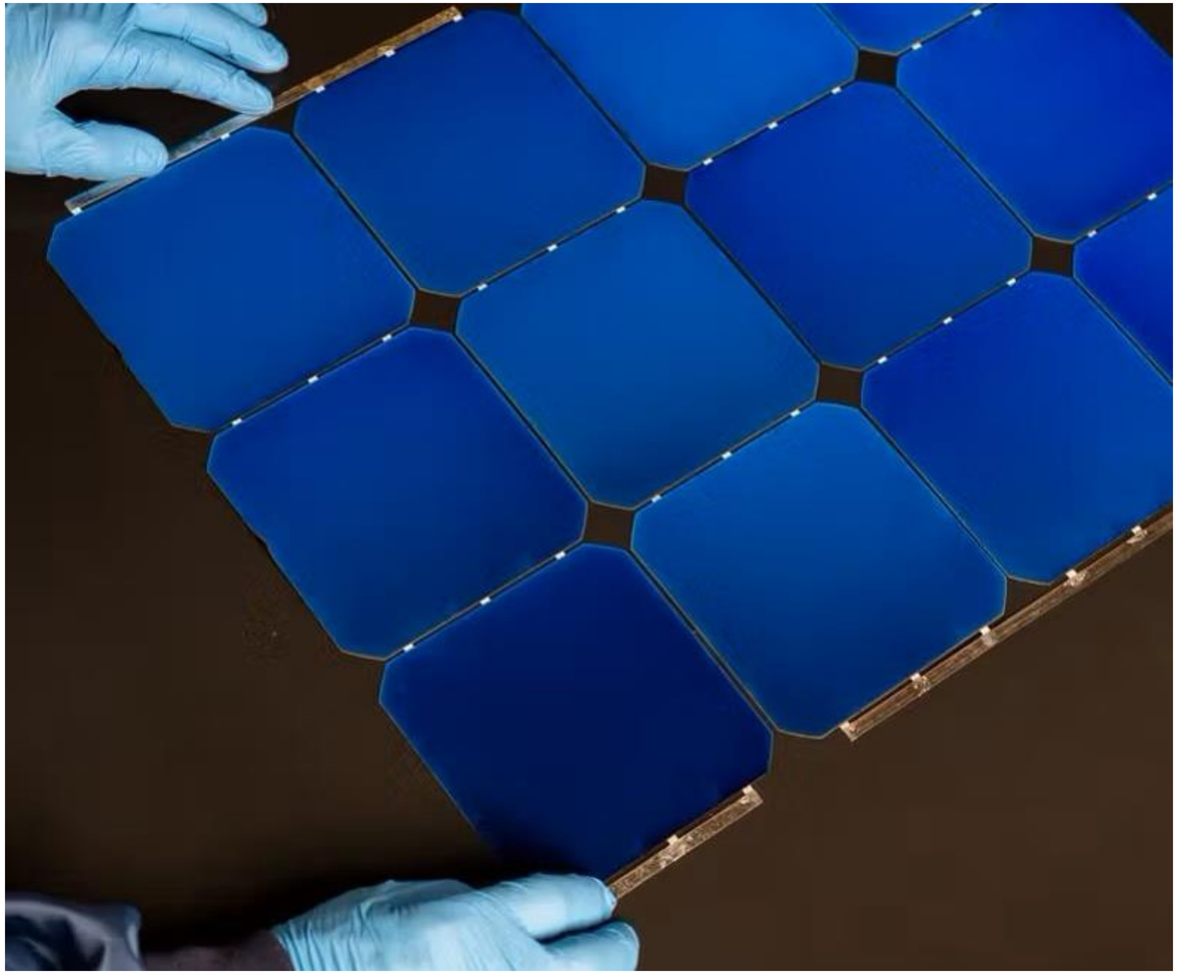
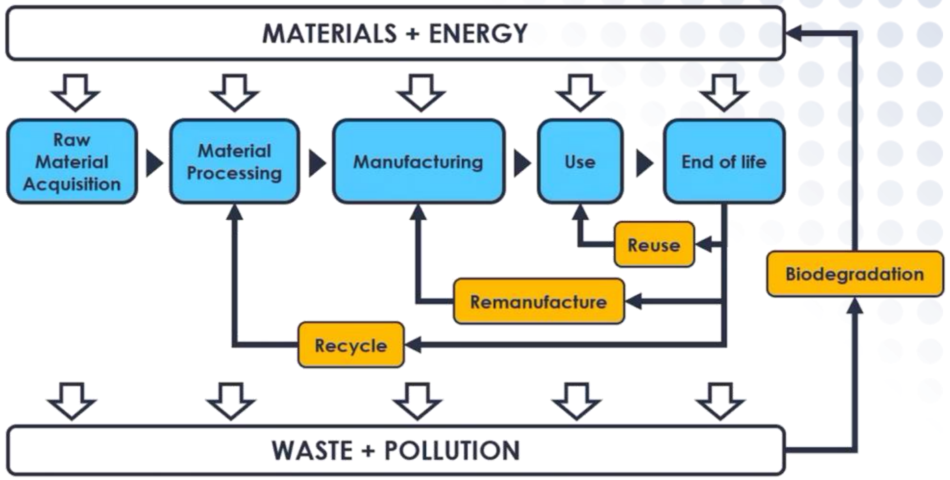
PHOTOVOLTAICS – A PROMISING EXAMPLE

- Traditional PV glass-based
- Lightweight PV for buildings (BIPV) and mobility (VIPV)
- Plastic/composite substrate/backsheet
- Highly transparent frontsheet
- Plastic replacing glass: Lower weight, reduce cost and energy for mobility
- Ethylene-vinly acetate (EVA), polypropylene (PP), polyethylene (PE)
- Plastics sustainability not yet relevant
- Life Cycle Assessment: HJT solar cells with significantly lower CO_2 footprint

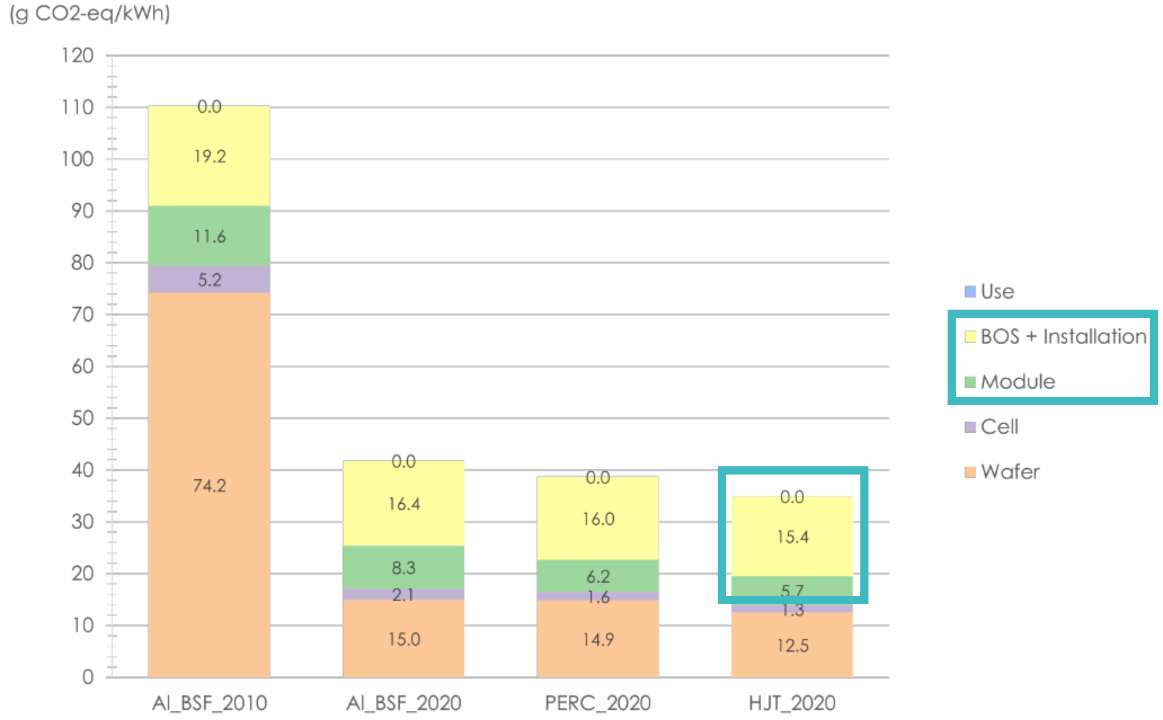


UNDERSTANDING THE IMPACT



©CSEM – Life cycle analysis (LCA) and carbon footprint optimization

- Study environmental impact of electronics & PV products and develop LCA models
- Heterojunction solar cells (HJT): Highest cell efficiency architecture
- HJT to overtake Al-BSF market share to become second-most adapted commercial technology (after PERC)
- Energy payback time 0.94 y (vs 1.2 y for regular monocrystalline)
- Life cycle carbon footprint per produced electricity: 34.9 g CO_2-eq/kWh (PERC +11%, Al-BSF-2020 +20%)
- Plastics CO_2 influence can be significant, is now being addressed!



Alexis Barrou 2022, Master Thesis EPFL-CSEM, Life Cycle Analysis of Heterojunction Solar Cells – From Raw Material to Final Device

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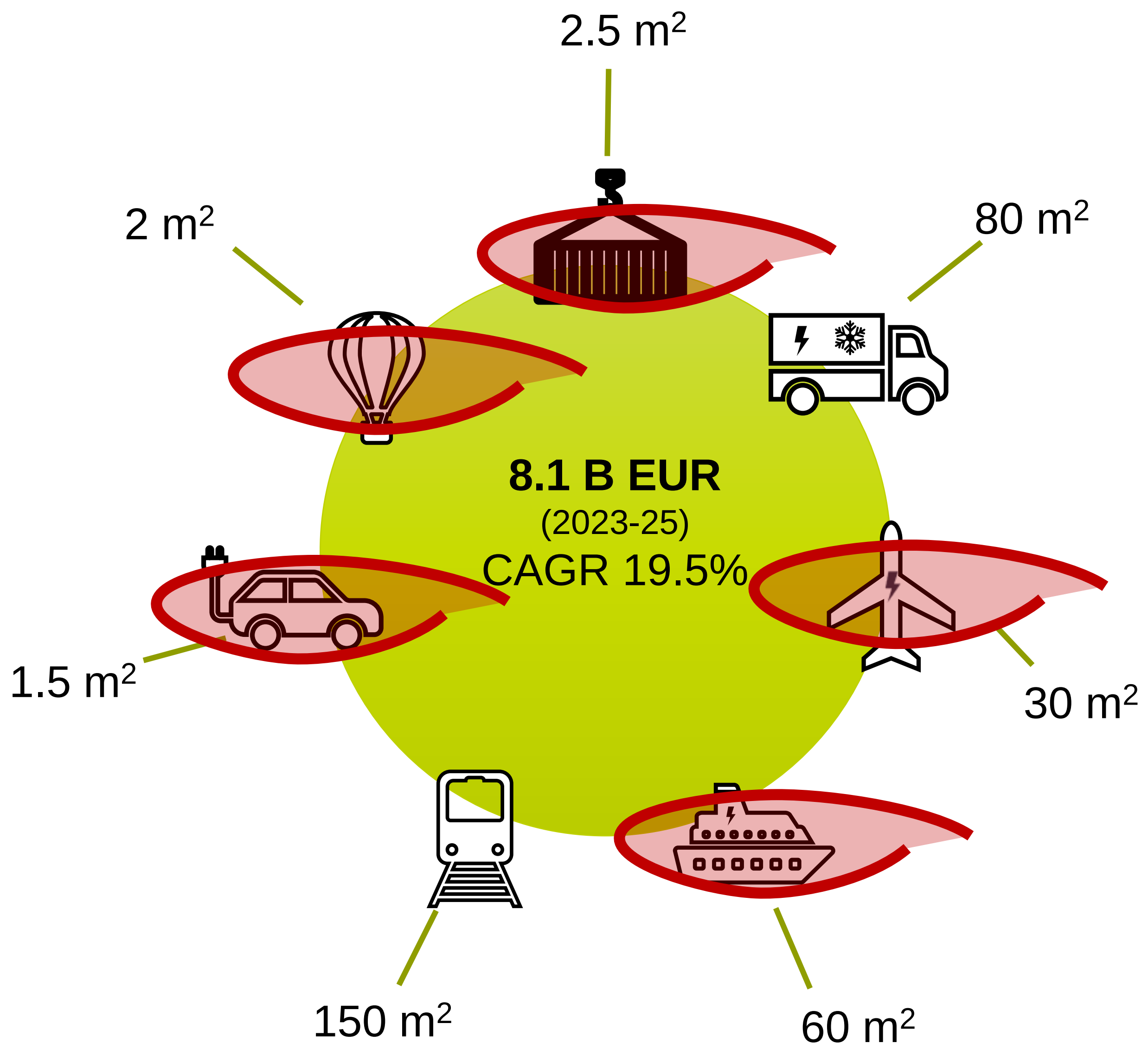
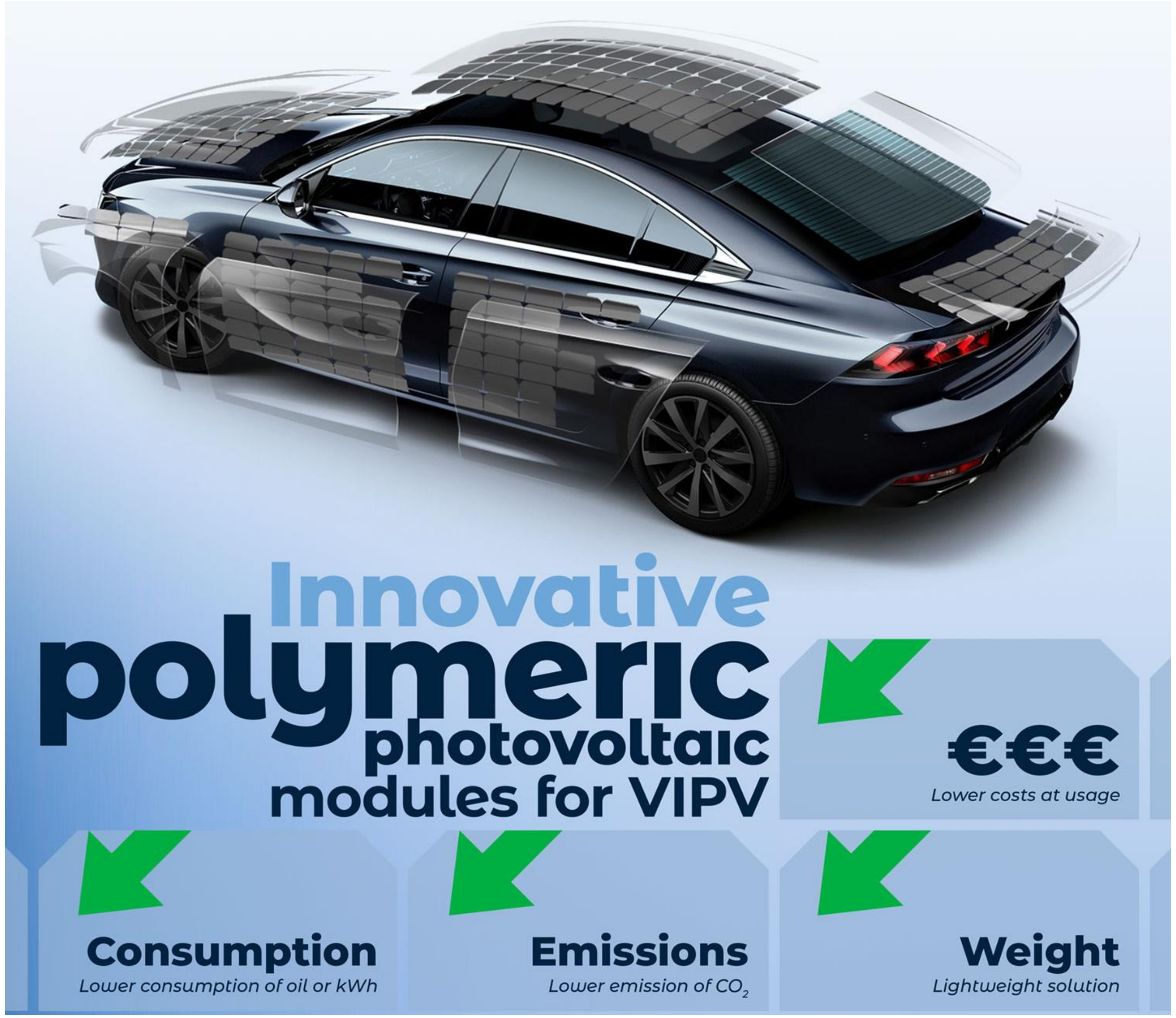
THE SOLAR MOBILITY MARKET



Project PVAB: PhotoVoltaic Automotive Body



COMPETE 2020 PORTUGAL 2020 UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional Simoldes Plastics CEiiA csem STELLANTIS

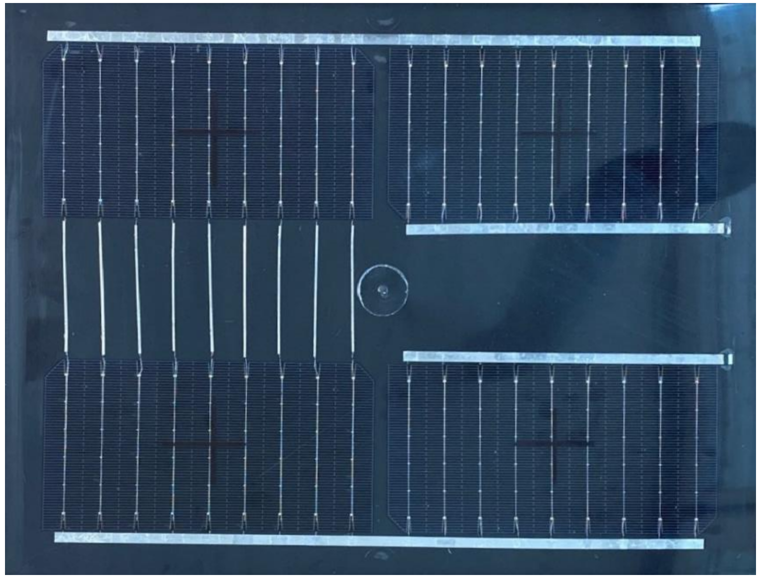
MECHANICAL LOAD TEST EXPERIMENT

- **Goal of the experiment:**

Validate the mechanical simulation model of glass free-based modules

- **Methodology:**

The applied force is increased by step of 50 N up to the breakage of the cells

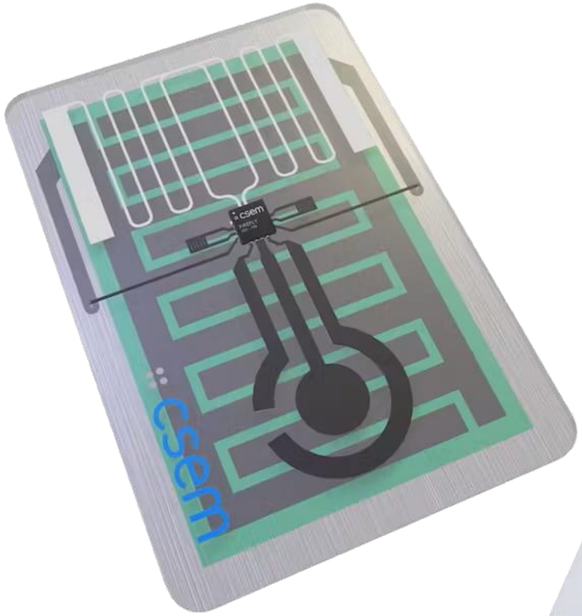


SENSORS – A POTENT EXAMPLE

- Design for disposal: Materials enabling bio-sourcing, clean incineration, or biodegradability
- Design for disassembly: Minimizing usage through smart miniaturization
- Design for longevity: Extended operational lifespan

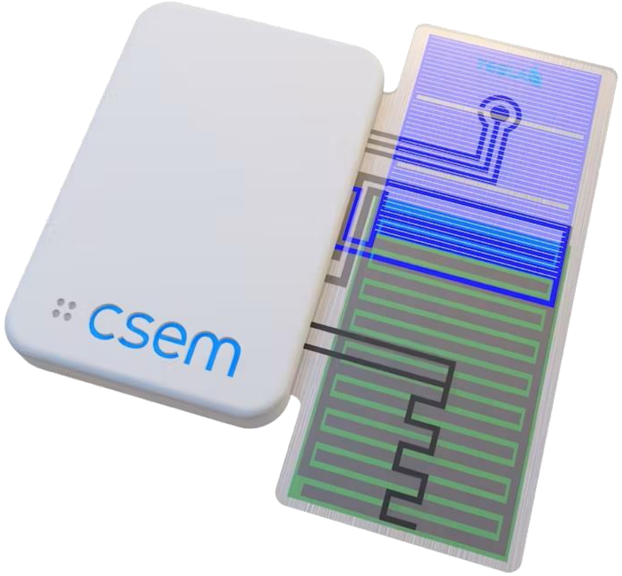
Sensors in

- Smart packaging
- Wearables
- Point-of-care systems



©CSEM – Disposable biomarker detector

CSEM Long-term heavy-duty springs monitoring sensor



©CSEM – Smart agriculture sensor for leaf monitoring

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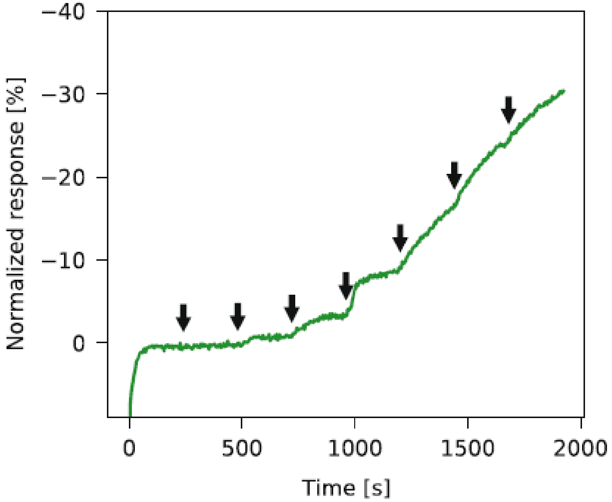
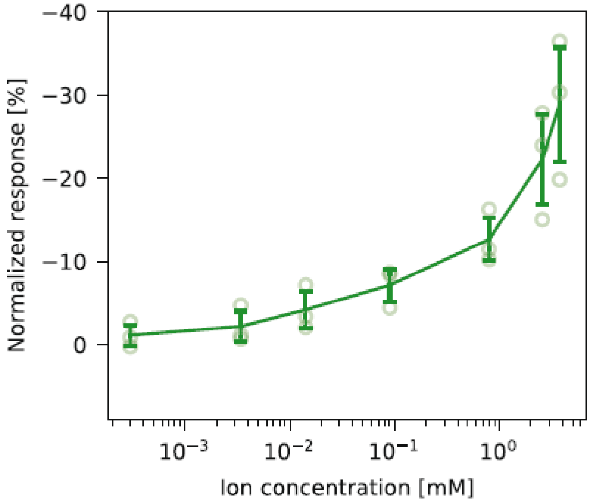
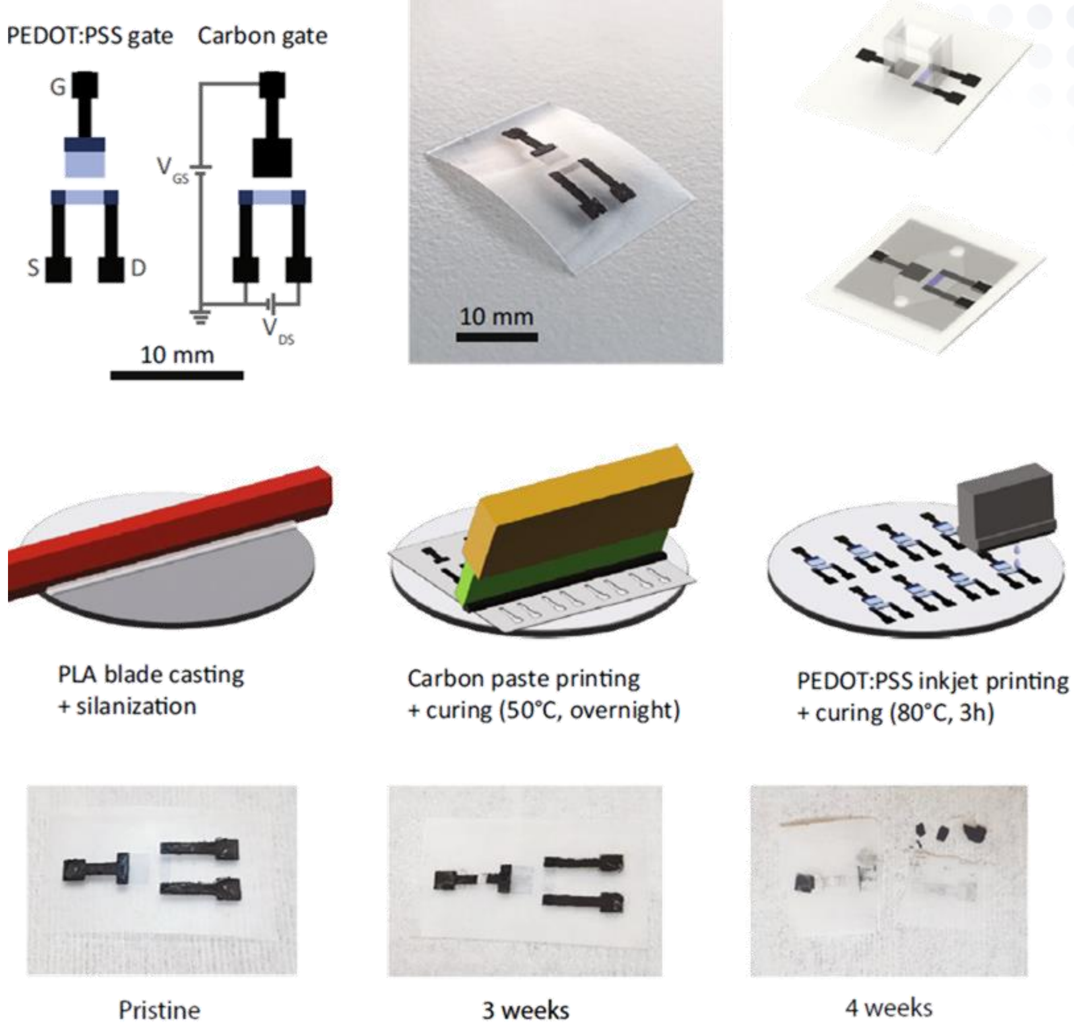
TRANSIENT ELECTRONICS: ORGANIC BIOCHEMICAL SENSOR

EPFL Soft Transducers Laboratory, EPFL

- Organic electrochemical transistor
- Printed from degradable materials on bioresorbable substrate
- Showcase with glucose monitoring
- Demonstrated comparable performance to classic non-degradable sensors
- Future POCdx, wearables, implanted biosensors







Fumeaux N. et al. Organic electrochemical transistors printed from degradable materials as disposable biochemical sensors. Sci Rep 13, 11467 (2023)

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MATERIALS

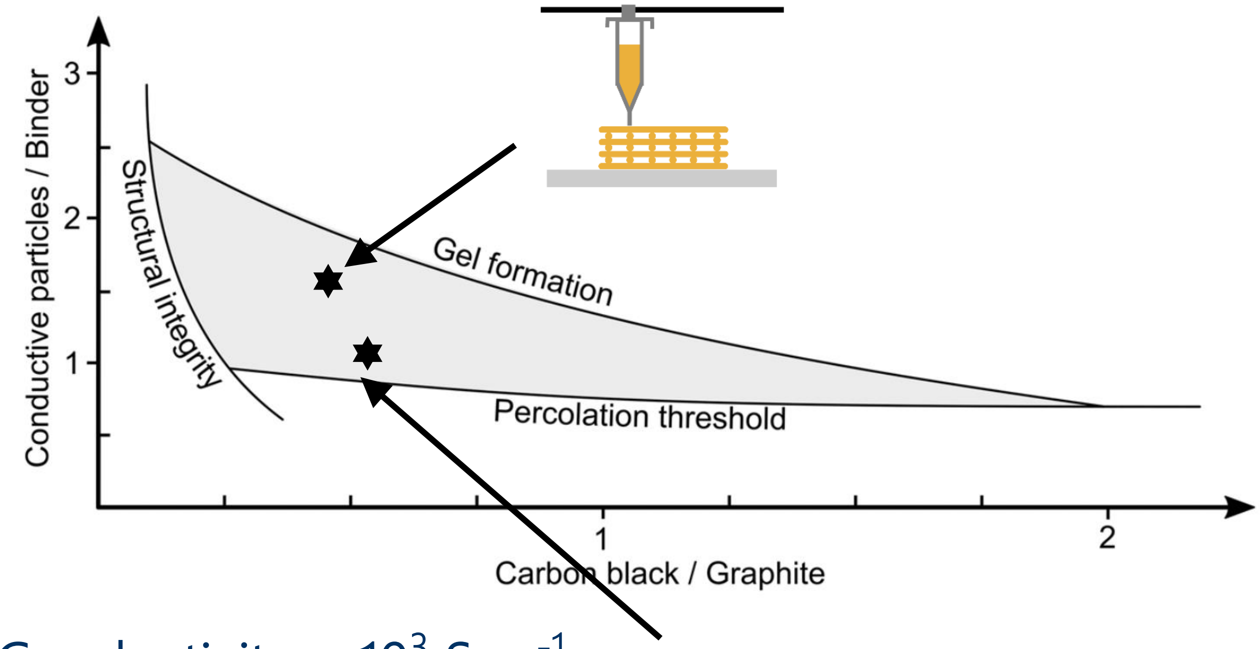
MATERIALS AND PROCESS DEVELOPMENT AT EMPA

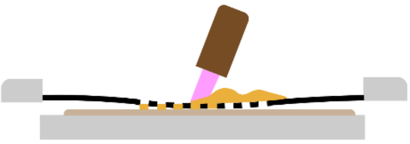
- New biopolymer integrated electronics and sensing requires new materials development and integration with relevant process technology
- At EMPA the Coating Competence Center offers state-of-the-art coating, printing, surface, analytics etc. technology to bridge R&D with Swiss industry
- Emerging class of responsible/sustainable electronics applications need to balance performance, stability and end of life management

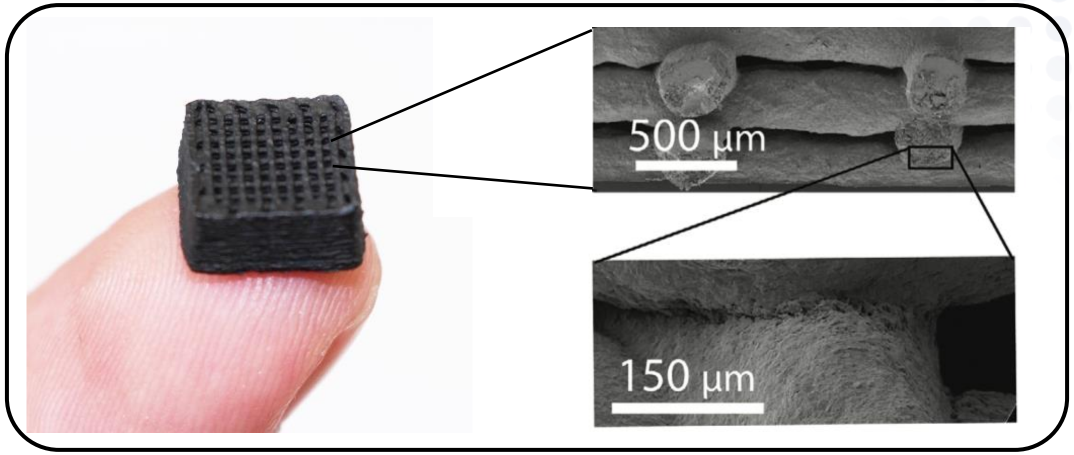
BIOPOLYMER INTEGRATED MATERIAL SOLUTIONS

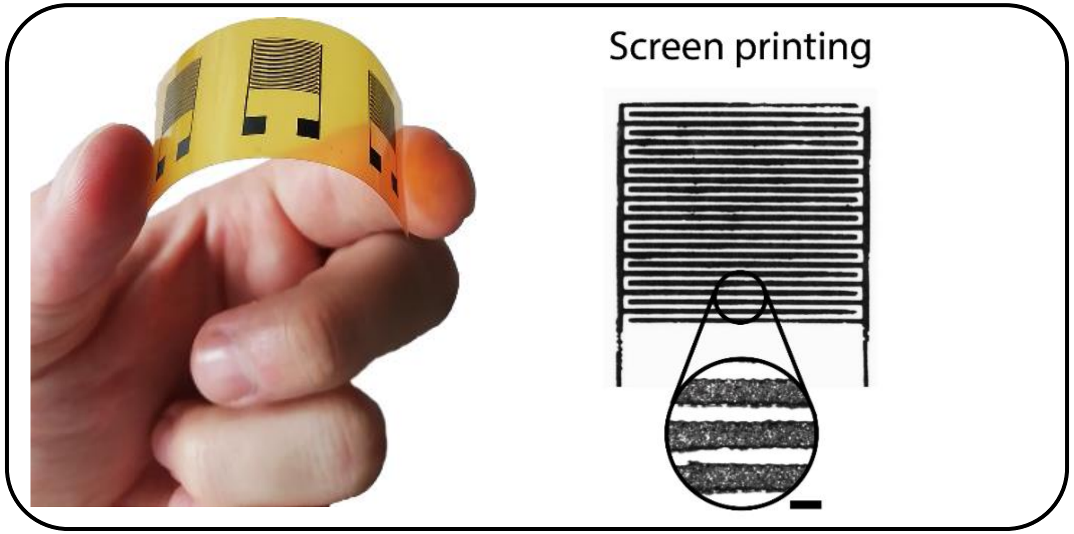
- We develop sustainable electronic materials where biopolymers are used as building blocks for:
  - Inks
  - Substrates
  - Passivation / encapsulation
  - Sensing layers
- Challenges to solve:
  - Materials interfaces & compatibility
  - Manufacturing reproducibility
  - Operational stability and reliability

MATERIAL EXAMPLE: DISPOSABLE CONDUCTIVE BIOPOLYMER-CARBON INKS









- Conductivity: ~10^3 S m^{-1}
- Tunable formulations
- Moisture stable
- Biocompatible / non-toxic
- Biodegradable

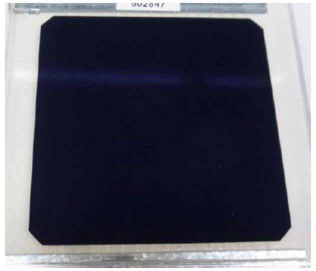
Poulin et al, Scientific Reports (2021) 11:23784; Patent pending: EP21151491

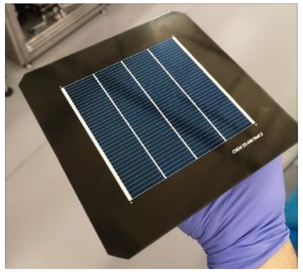
PV RESEARCH AT EPFL PVLAB & CSEM SUSTAINABLE ENERGY CENTER

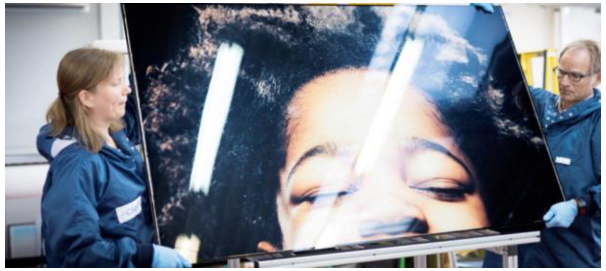
In Neuchâtel, Switzerland

>2000 m^2 of laboratories from cells to module manufacturing, metrology, reliability testing…

PV, Battery Storage and Energy Data

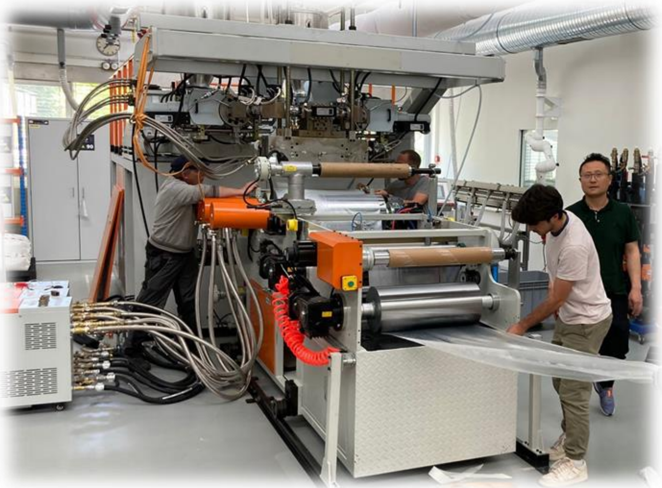






FACILITIES FOR ADVANCED POLYMERS IN MARIN (NE)

Underwater pelletizing line, most advanced pelletizing equipment



Facilities shared with «PV & Solar Buildings» Focus Area

Cast film co-extrusion line, compounder, dryer, pelletizing, storage

Extensive materials reliability testing

Characterization lab for polymers (rheology, DSC, UV-Vis spectroscopy, FTIR…)

- Base materials: **EVA, PP, PE**
- **Polymer formulation** development
- Specific **Additive package, mechanical properties & processing temperature**

➡ **Unique solutions for Solar Mobility**

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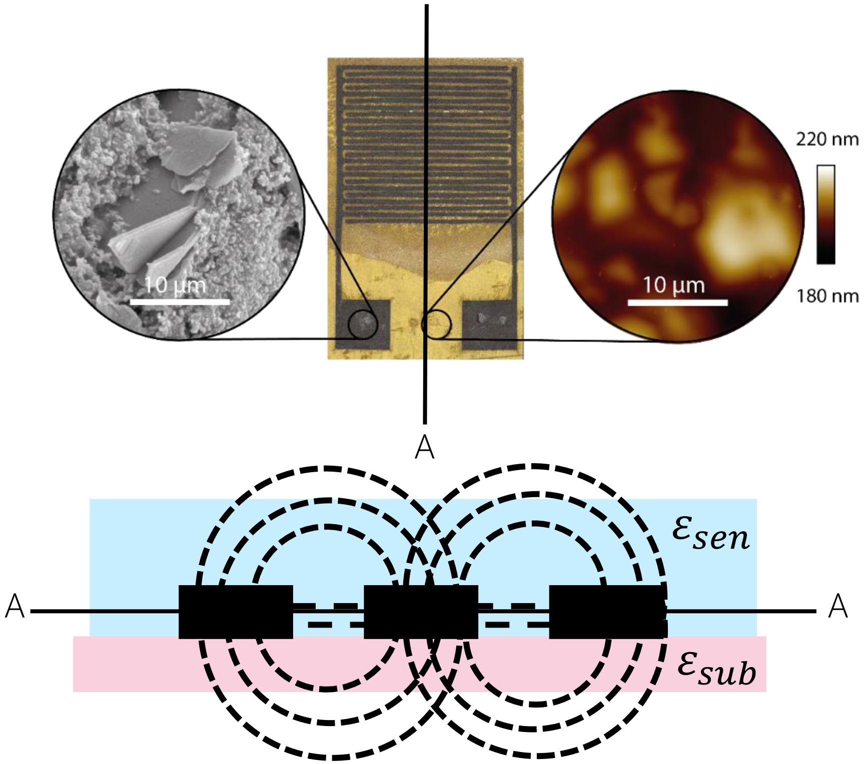
APPLICATIONS

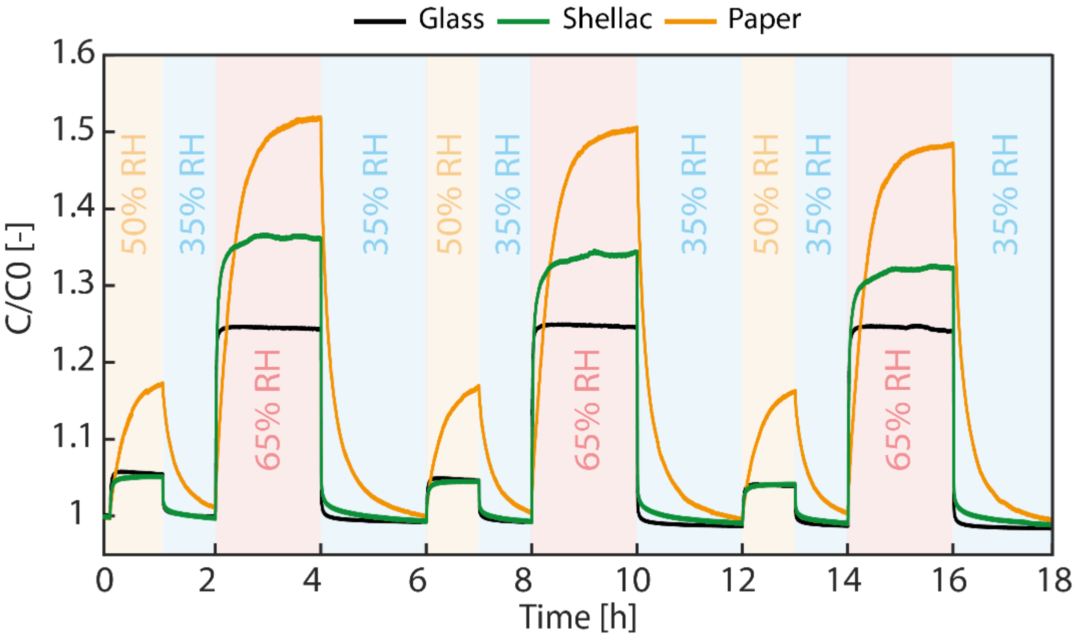
BIOPOLYMER BASED FULLY BIODEGRADABLE HUMIDITY SENSORS



Carbon electrode
Biopolymer substrate
Biopolymer sensing layer

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

$$\Delta RH\% \rightarrow \Delta\varepsilon_r \rightarrow \Delta C$$



- Exclusively biodegradable materials
- Shellac, carbon, protein
- Sensitivity 0.011% RH^{-1}
- Response / recovery time >10x on paper

Aeby & Bourely et al. Advanced Materials Technologies, 8, 2201302, 2023

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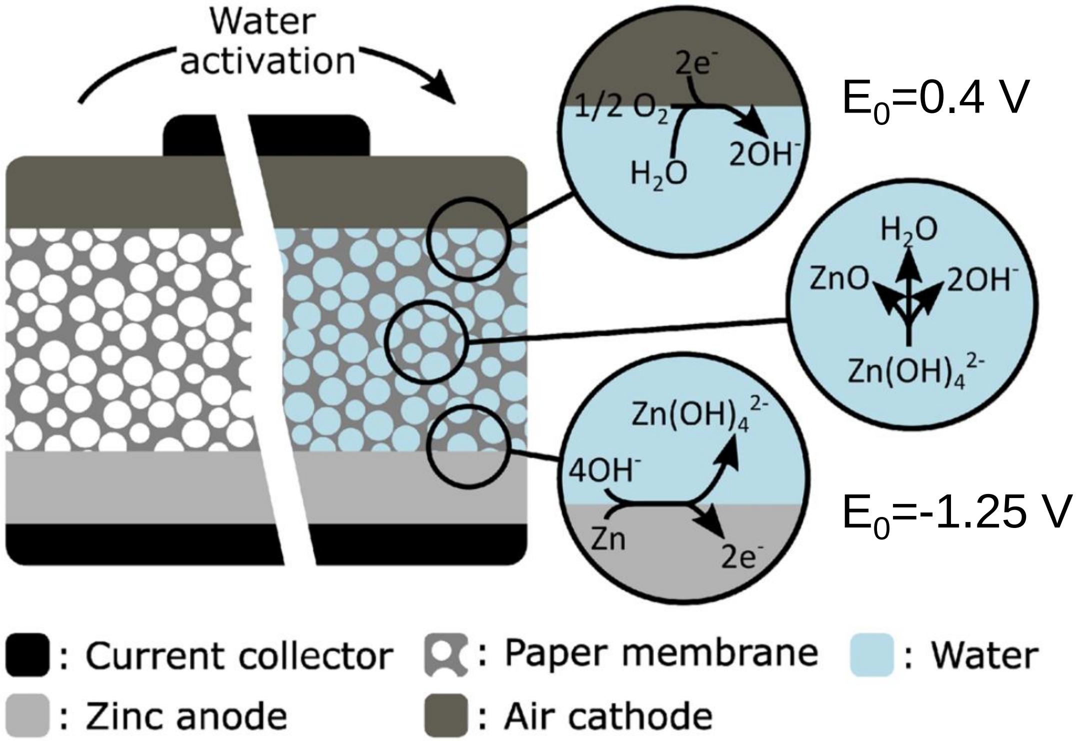
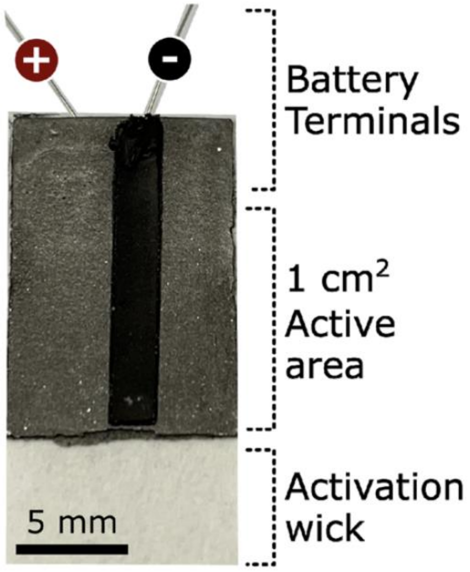
EMPA WATER-ACTIVATED PAPER BATTERIES

TIME BEST INVENTIONS 2022

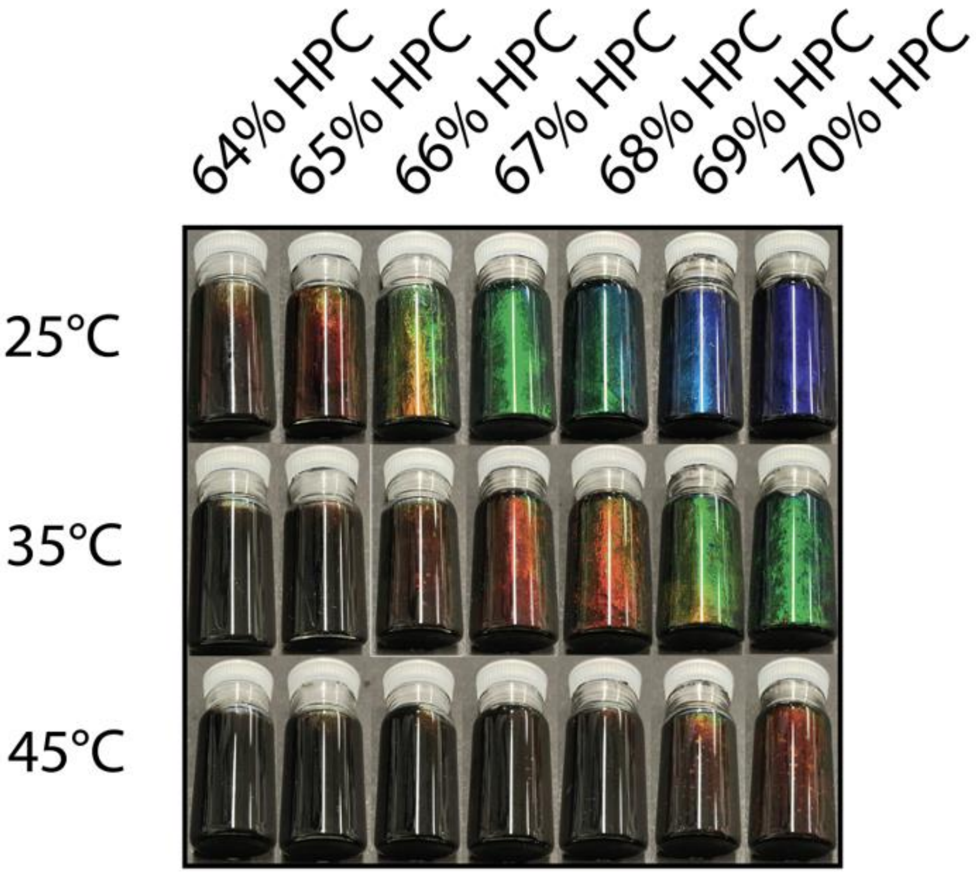




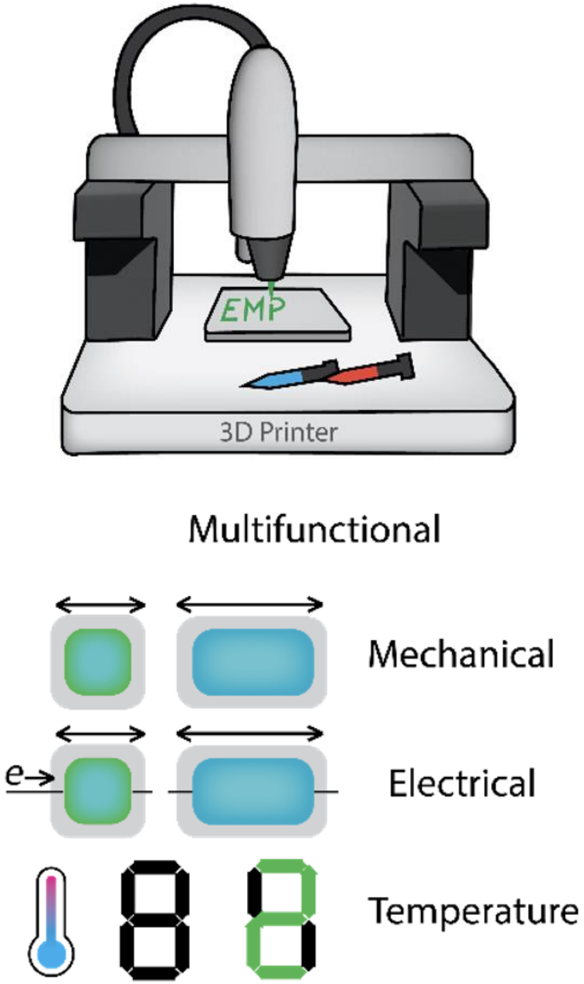
- Zinc-air batteries have high energy density (theoretical limit: 1084 Wh/kg).
- Zinc is one of the few existing bioresorbable metals.
- The water-activated design enables extended shelf life.

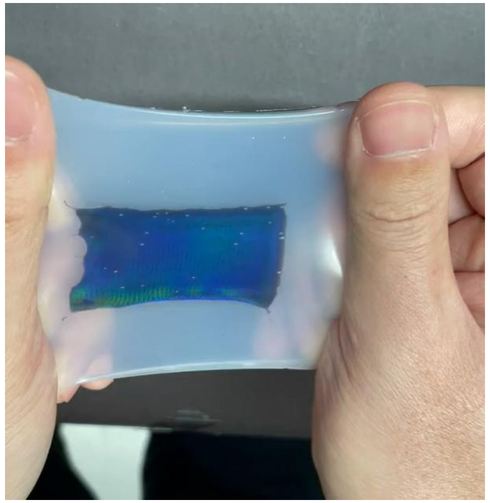
Poulin et al, Scientific Reports, 12, 11919, 2022

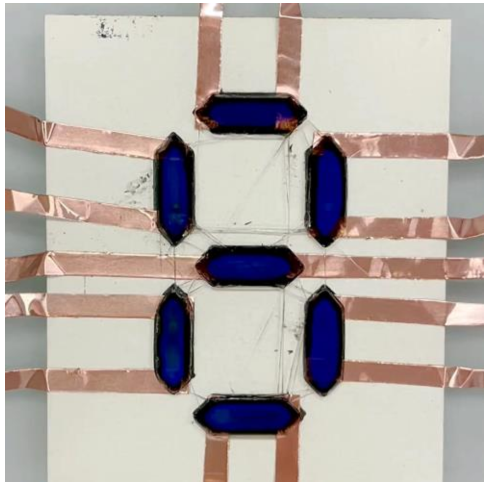
BIOPOLYMER BASED BIODEGRADABLE MULTI-STIMULI STRUCTURAL COLOR MATERIALS



Wei et al Advanced Materials Technologies, 8, 2200897, 2023

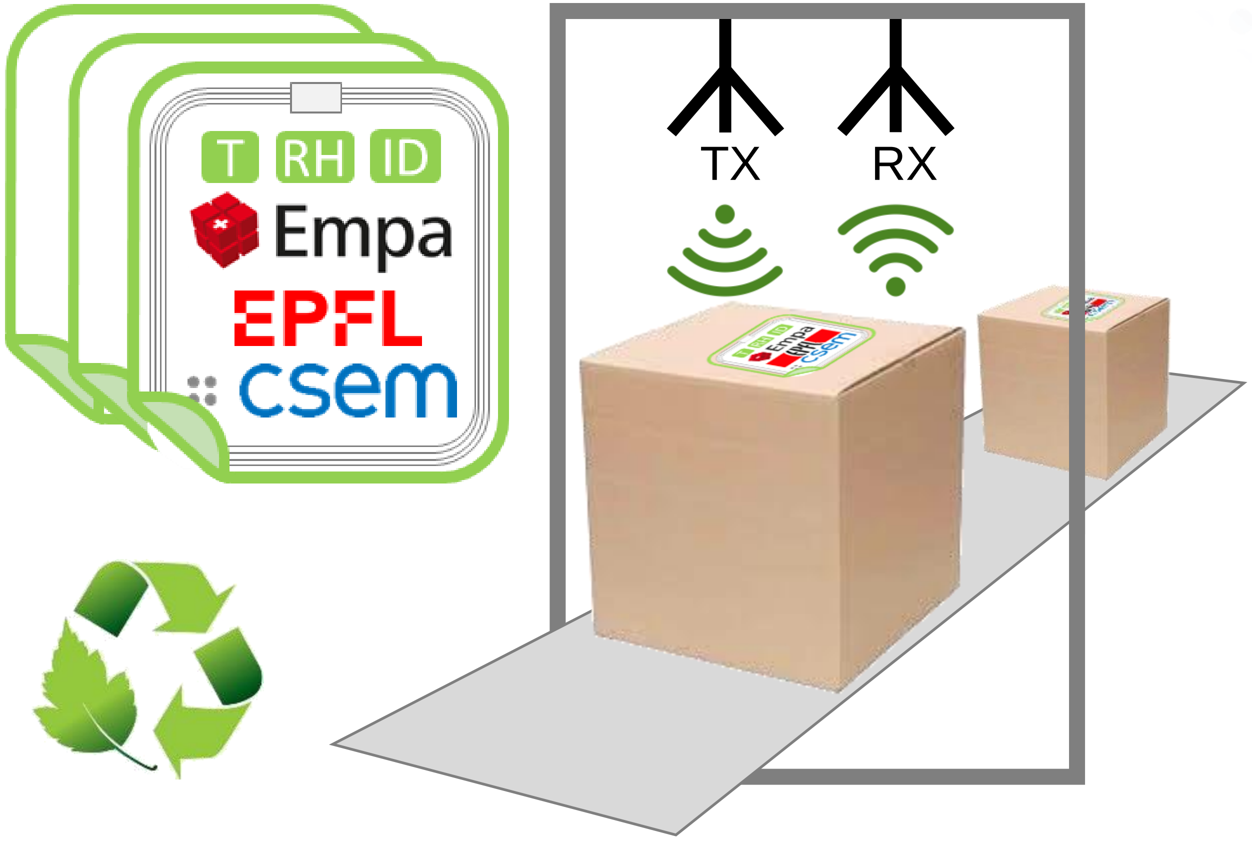






GREENsPACK: GREEN SMART PACKAGING

- Bridge Discovery project where EMPA, EPFL and CSEM together develop green materials and efficient processing for biodegradable wireless sensing tags
- Customized biopolymer substrates, biodegradable conductive inks, material driven sensing, integration and wireless sensor design
- Applications in:
  - Smart packaging
  - Logistics monitoring
  - Food quality monitoring
  - Environmental sensing
  - …
- Project webpage: empa.ch/greenspack



MOTIVATION: NEED FOR SUSTAINABLE MATERIALS

(georgerothert.com, theoceancleanup.com)

TARGET APPLICATION: PERISHABLE GOODS

$35 billion annual temperature-related losses of pharmaceuticals

Pharma transport specs

- Authentication
- Vaccines 2-8 **°C**
- Other med. 15-25 °C
- Rel. hum. **<60%**
- No return chain
- Low cost

CHF 50.-

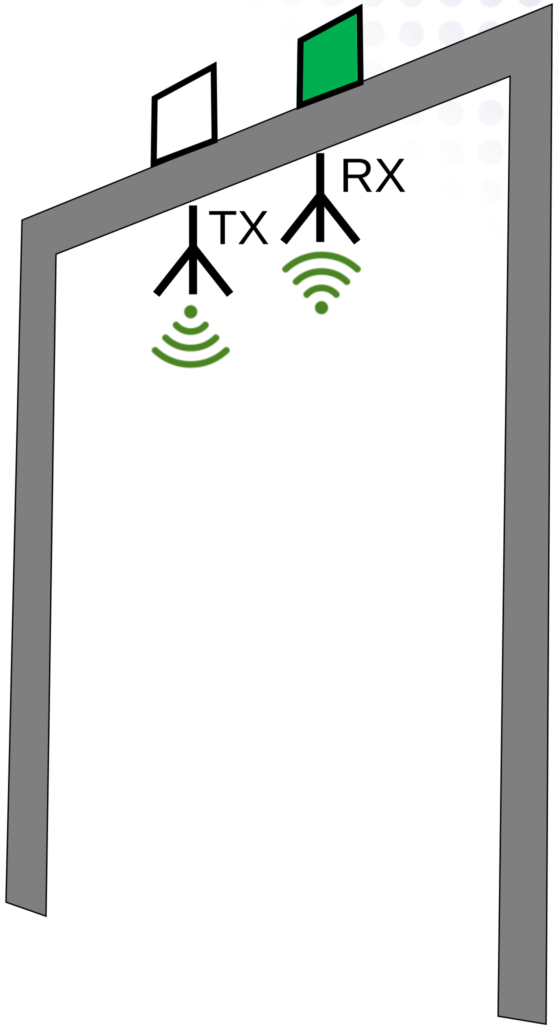
Pharmaceuticals

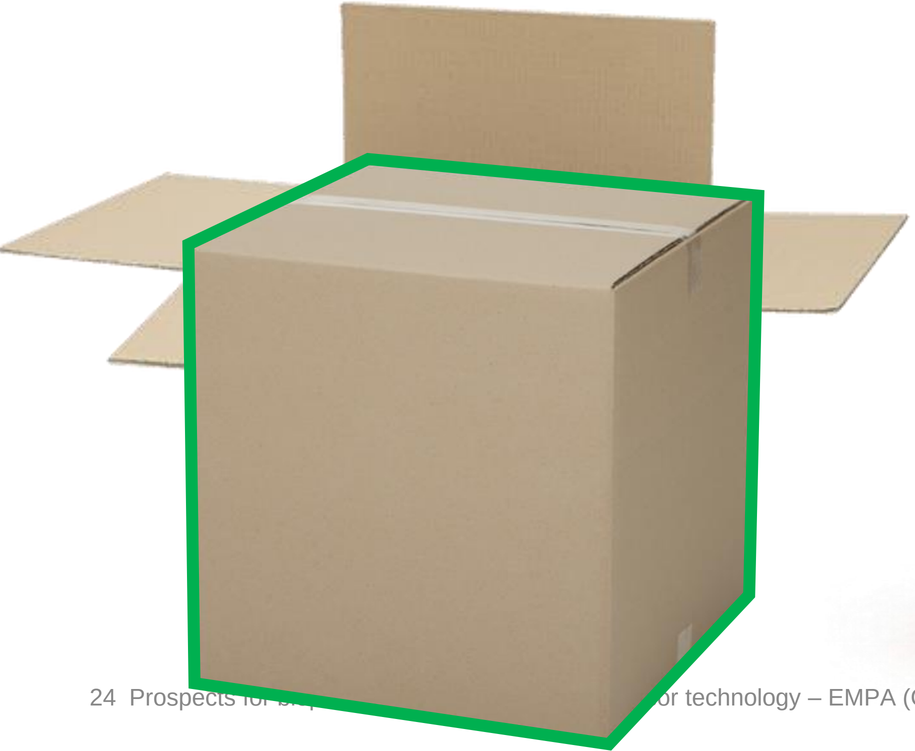
Flowers

Food

Application principle

- Perishable pharmaceuticals
- Packed in shipping boxes
- Option 1: Measurement inside box
- Option 2: Measurement outside
- Pass control gate
- Out for shipping





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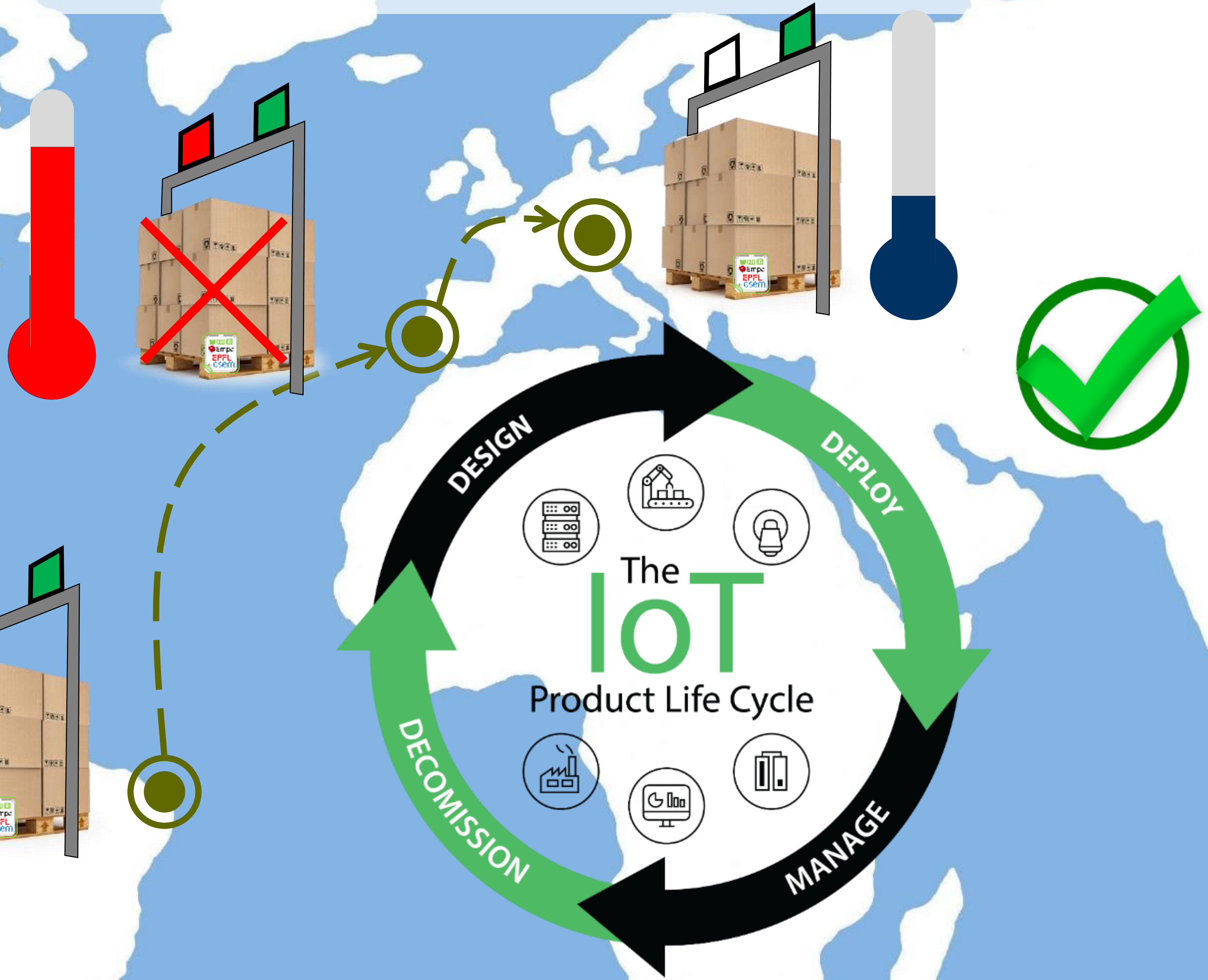
APPLICATION PRINCIPLE

- Check at manufacturer site
- Shipping
- Check at central warehouse
- Faulty units can be detected
- Check at distributor site
- Out for further dispatching
- Green tags for life cycle management

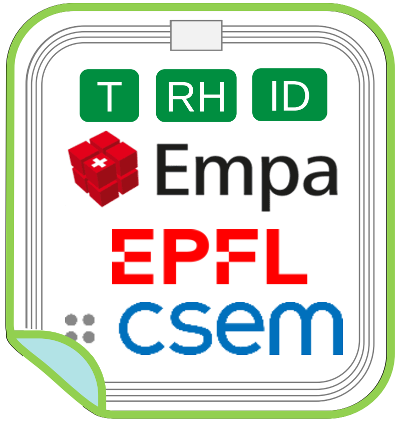


OUR TECHNOLOGY SOLUTION

Low-cost ecotags for monitoring the quality of goods in the logistics chain

Characterisitics:

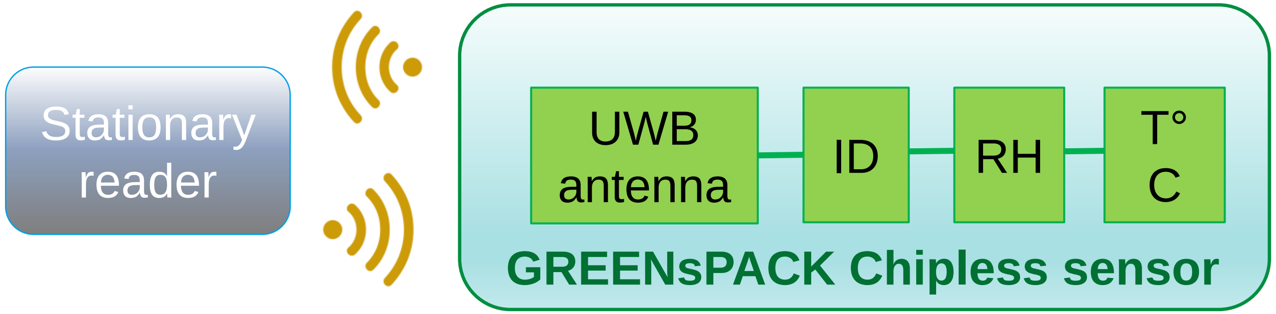
- Easy to attach to pellet/boxes
- High volume manufacturing
- Automated wireless read-out
- Green disposability



Functionalities:

- Identification: authentication & traceability
- Temperature and humidity sensing: Current values or threshold limit

- 13.5 MHz – 5.8 GHz
- Readout 20 cm - 5 m
- Up to 8-bit



- Few cm^2
- Sensing R & C
- Temp$_{threshold}$ ≤25 °C
- Rel.Hum$_{threshold}$ ≤60%

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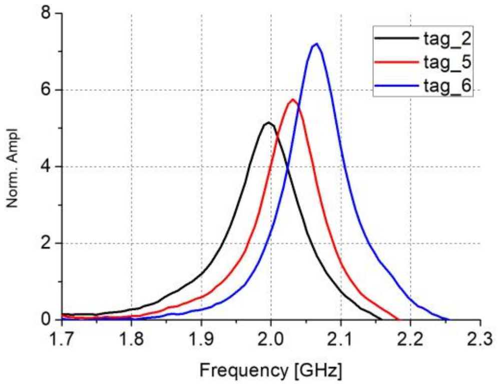
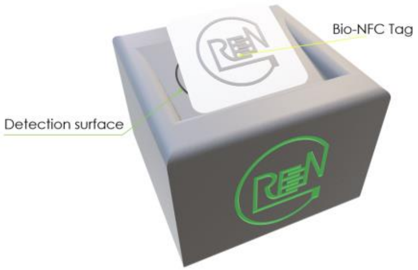
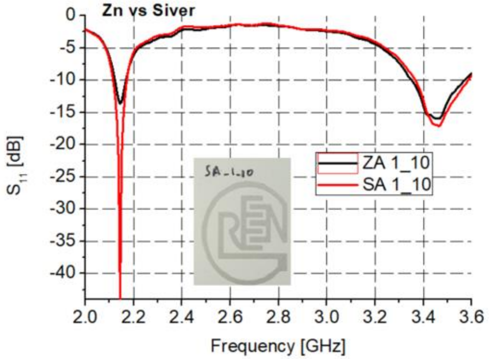
GREENsPACK: KEY RESULTS (SO FAR)

Short range TAG

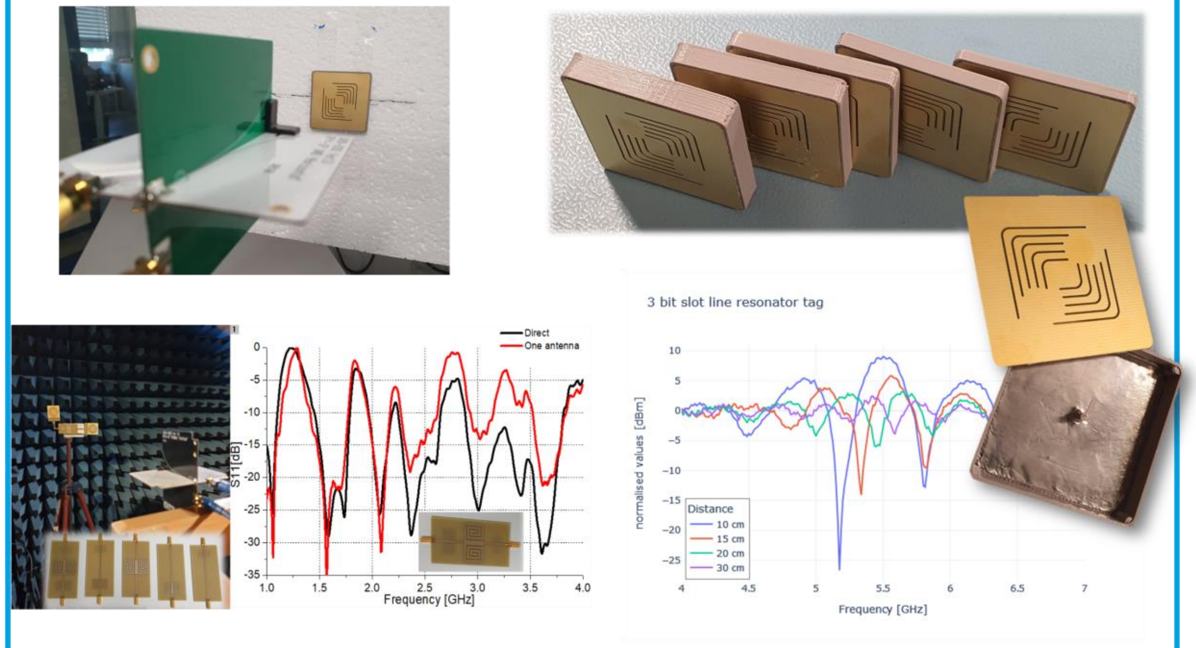






Zn vs silver:
Zn is less conductive, but still can be used for short-range TAGs.

Long range TAG



- Different passive tags prototyped & characterized, UWB reader
- Spectral signature-based 8-bit ID & T, rH threshold sensing
- Short range: Magnetic coupling LC resonance 1-10 GHz (<10 cm)
- Long range: Retransmission of interrogation signal (<1 m)

FUTURE

CHALLENGES TO SUSTAINABLE ELECTRONICS

- Mature and optimized manufacturing industry – notoriously resistant to changes
- Only incremental changes so far – radical transformations to identify, evaluate & implement
- Complex problem with no straightforward or unique solution – team up with others

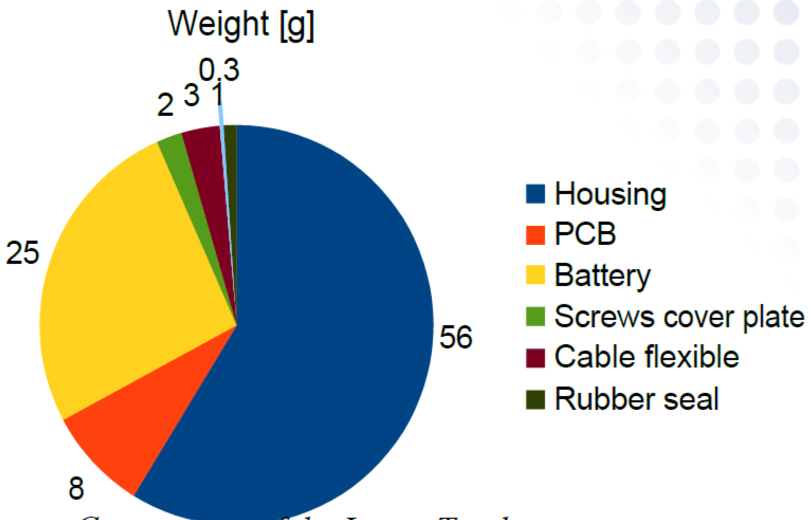
Chipless RFID tags (e.g. GREENsPACK)

- Will play increasingly important role in logistics, healthcare, retail
- Provide accurate & reliable data in real-time
- Integration with IoT
- Key challenge: Electric and electronic limitations of materials (conductivity)

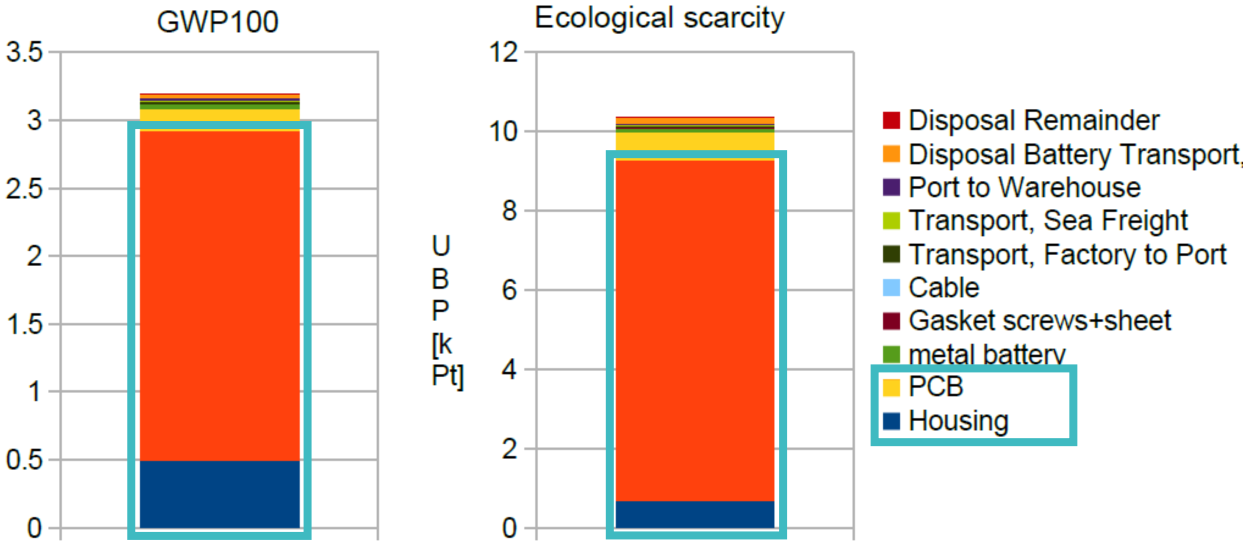
ENVIRONMENTAL IMPACT OF IOT TECHNOLOGIES

- FHNW study on IoT technology environmental impact: Greenhouse gas potential (GWP100) in CO_2 equivalent and ecological scarcity in environmental impact points (UBP)
- Highest weight: Plastic housing (ABS, PA, fiber reinforcement, etc.)
- Highest GWP100: PCB (75.8%), housing (15.6%)
- Highest ecological scarcity: PCB (83.1%), housing and battery (6.7%)
- Energy for gold mining, energy for wafer and IC-fabrication
- Bioplastics: Potential for limited, but significant impact

Lycan tracker



Components of the Lycan Tracker



Environmental impact Lycan tracker

FHNW, E. Möri 2022, Management MAS Thesis

SATW TECHNOLOGY OUTLOOK

- Regulations, high cost & lack of technical implementation in products hindering spread of applications
- High-tech and niche products have great potential in CH
- Plastic waste valuable resource
- Targeted use of bioplastics enabling sustainable circular economy

technology-outlook.ch

https://technology-outlook.satw.ch/en/technologies-in-focus/bioplastik

SATW TECHNOLOGY OUTLOOK

Bioplastics

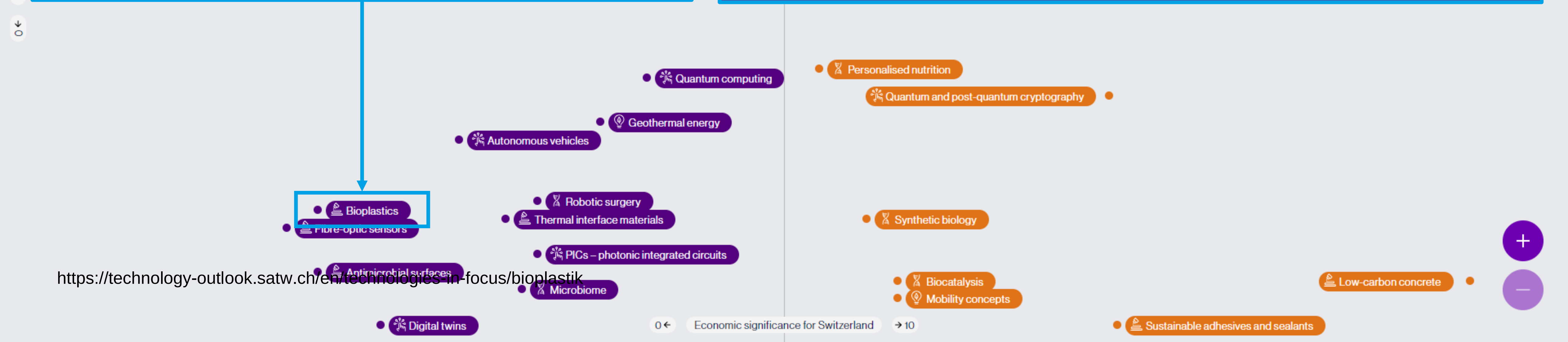
Importance: **2.8/10**

Competence: **0.8/10**

The use of bioplastics represents a great opportunity to improve the sustainability of plastic products. At present, regulations and high costs, as well as a lack of technical implementation in products that offer properties similar to those of established products, are hindering the spread of applications. For Switzerland, the development of high-tech and niche products has great potential, which could be tapped with targeted funding. In order for the topic to gain momentum, it is essential that firms, legislators and the general public alike realise that plastic waste is a valuable resource, and that targeted use of bioplastics could make a sustainable circular economy a reality.

Specialised high-tech and niche applications, such as *anti-microbial surfaces, bioplastics, digital twins, photovoltaics and photonic integrated circuits (PICs),* offer great potential for Switzerland as a business location.

These technologies and the resulting applications can be developed by established firms of all sizes, but also by start-ups. In addition, there are opportunities for interesting business cases. This generates jobs and added value in Switzerland.



https://technology-outlook.satw.ch/en/technologies-in-focus/bioplastik

Technology Outlook

Innovationen auf dem Weg in die Zukunft

13.12.2023 @ Trumpf, Grüsch GR

csem

satw technology for society

TRUMPF

PV IN MOTION 2024

Conference & Exhibition on Vehicle Integrated PV

March 6-8 | Neuchâtel, Switzerland

Since 2021, PVinMotion conference connects acknowledged scientific with industry experts and provides the unparalleled opportunity to present their innovative work among the global PV community. The conference program explores cutting-edge technologies and frameworks of integrating PV into different vehicles. Together, let us advantage of the current, unprecedented momentum in both VIPV research and practical application.

Call for papers:

- Oral presentations and Posters
- Best abreacts to be selected in Special Issue with SolMat
- Deadline: 1st of November 2023

Conference focus topics:

- Integrated PV Cell & Module Technology
- Vehicle Technology & Vehicle Type
- Electronics & System Energy Management
- Characterization and Performance Monitoring of VIPV
- Modelling of Performance and Energy Production
- Production & Implementation
- Safety & Standards
- Environmental & Social Impact
- Government & Policy

We are happy to invite you to PVinMotion 2024, the world's first scientific conference dedicated to vehicle-integrated photovoltaics. **#PVinMotion**

THANKS TO OUR TEAMS AND SUPPORTERS

CSEM

- Alexander Vorobyov
- Alexis Barrou
- Antonin Faes
- Christian Beyer
- Pascal Nussbaum
- Roger Limacher
- Silvia Demuru

EMPA

- Gilberto de Freitas Siqueira
- Xavier Aeby
- Xiaomei Yan (new Lanzhou Institute)

EPFL

- Danick Briand
- Jaemin Kim (new CSEM)
- James Bourely
- Nicolas Fumeaux

BRIDGE

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VISIT OUR POSTER

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Materials Science and Technology

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FACING THE CHALLENGES OF OUR TIME