

# Printed Sensors: Transforming Technology and Expanding Application Frontiers

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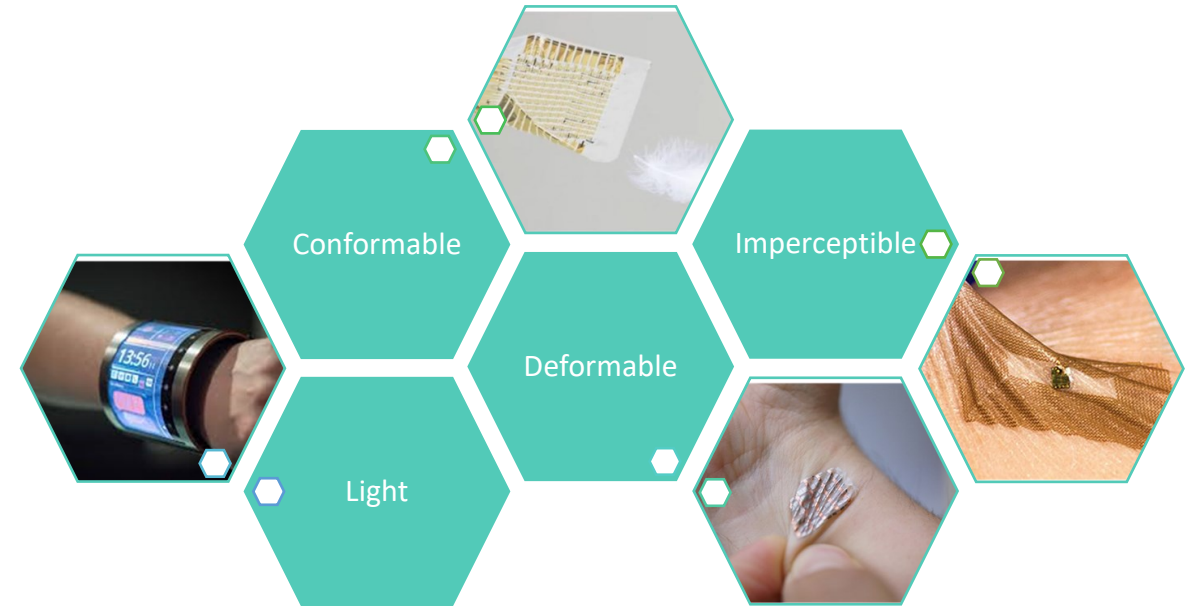
**Chips Revolution: La crisi delle forniture e il ruolo cruciale di  
tecnologia e politica per un futuro digitale**

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# From Conventional Electronics....

## ... to Unconventional Electronics

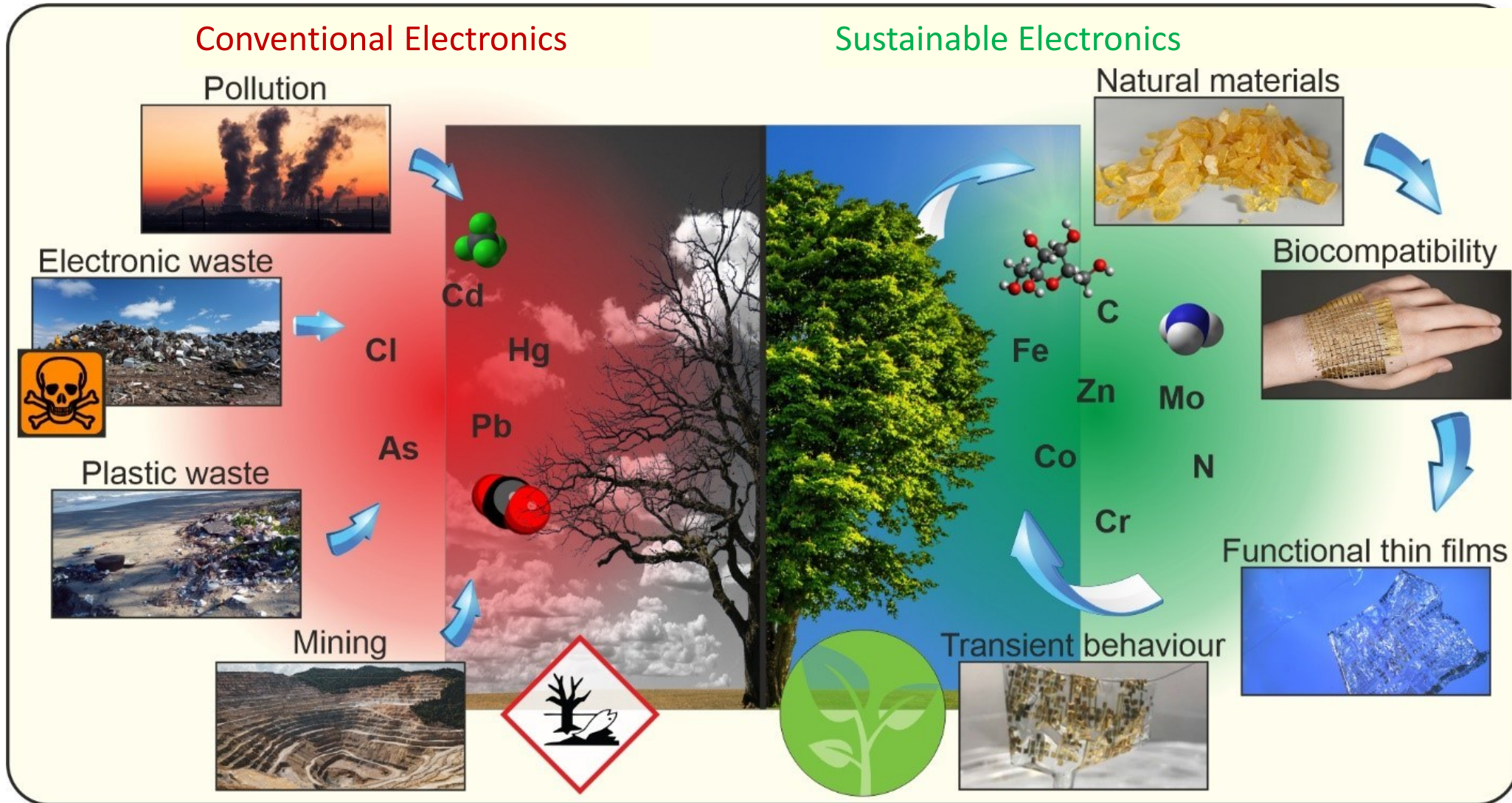


### Conventional Electronics

### Printed Electronics

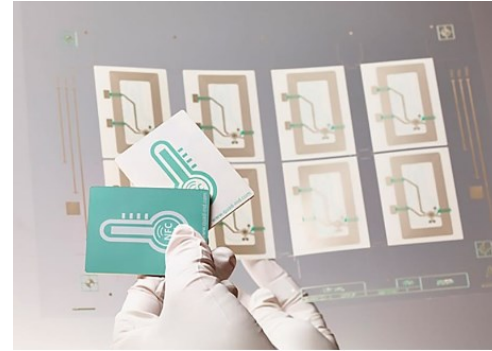
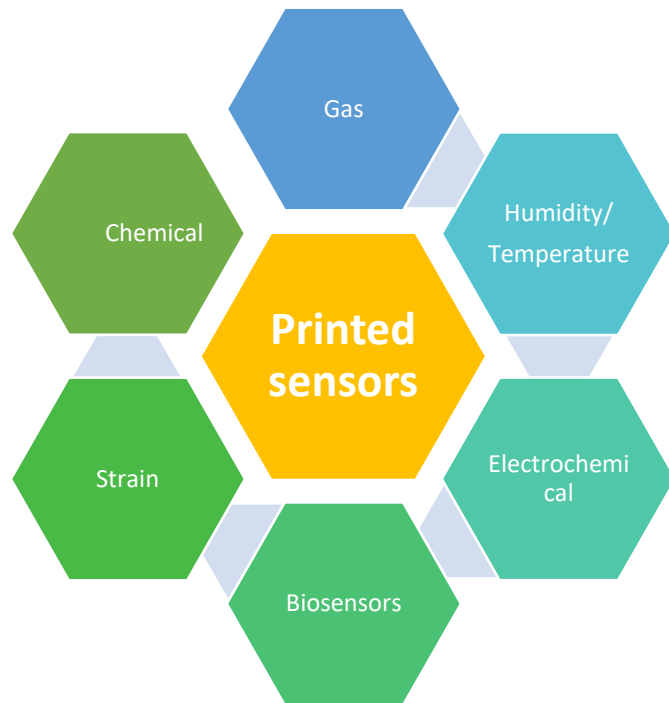
Materials	Hight temperature: silicon, ceramics, glass	Low Temperature: organic polymers, specialty inks
Manufacturing technique	Photolithography, micromachining, ablation etc.	Printed on plastic, textile, paper, foil
Product feature	Rigid, brittle, miniaturized	Flexible, robust, large-area

# ... to Printed & Sustainable Electronics



# Printed Electronics for Sensing

**Printed sensors** are devices that measure physical, chemical, or biological changes and are produced using printing technologies



[1] From Quad Industries



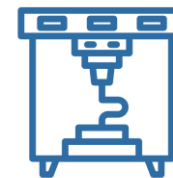
[2] From Barbosa et al., 2022



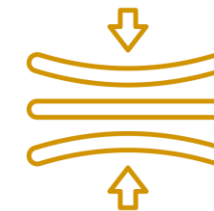
[2] From Kim et al., 2014



Cost-effective



Rapid manufacturing

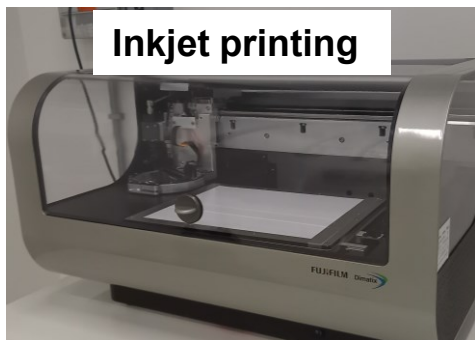
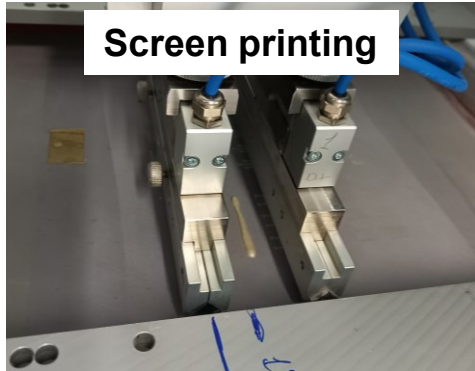
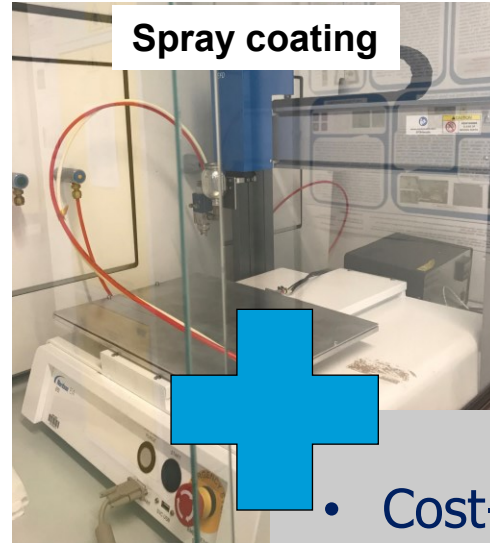


Flexibility



Eco-friendly

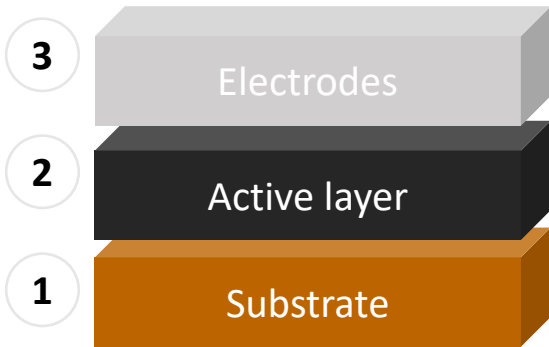
# Printed Electronics for Sensing



- Cost-Effective
- Scalability
- Customizability
- Flexibility
- Low Power Consumption
- Eco-Friendly
- Limited Material Compatibility
- Lower Mechanical Stability
- Environmental Sensitivity
- Resolution Limitations
- Slower Speed

# How are Printed Sensors made?

## Sensor cross section

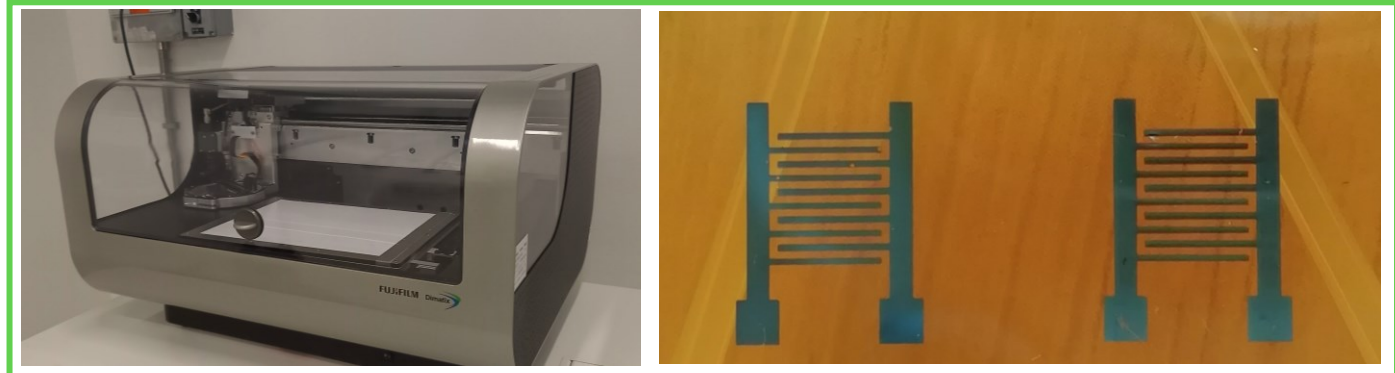
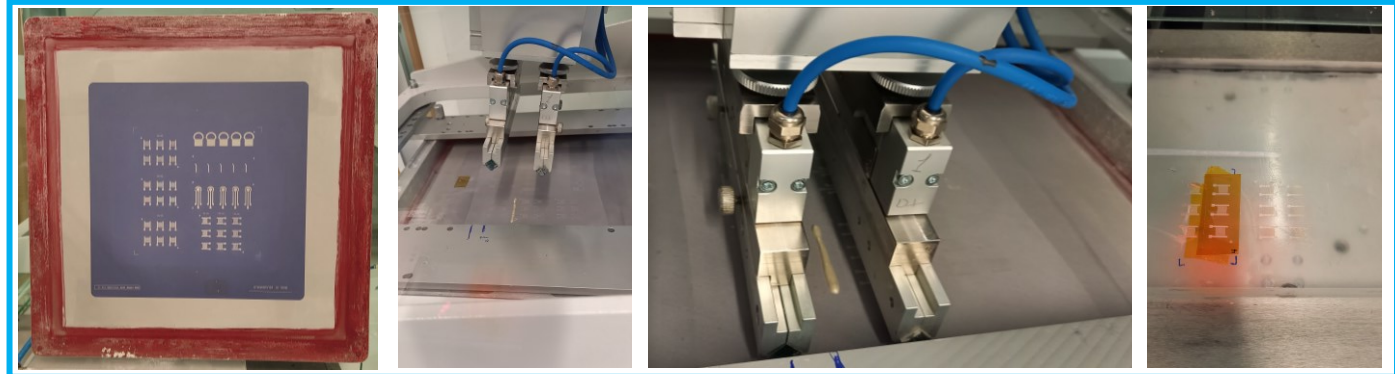
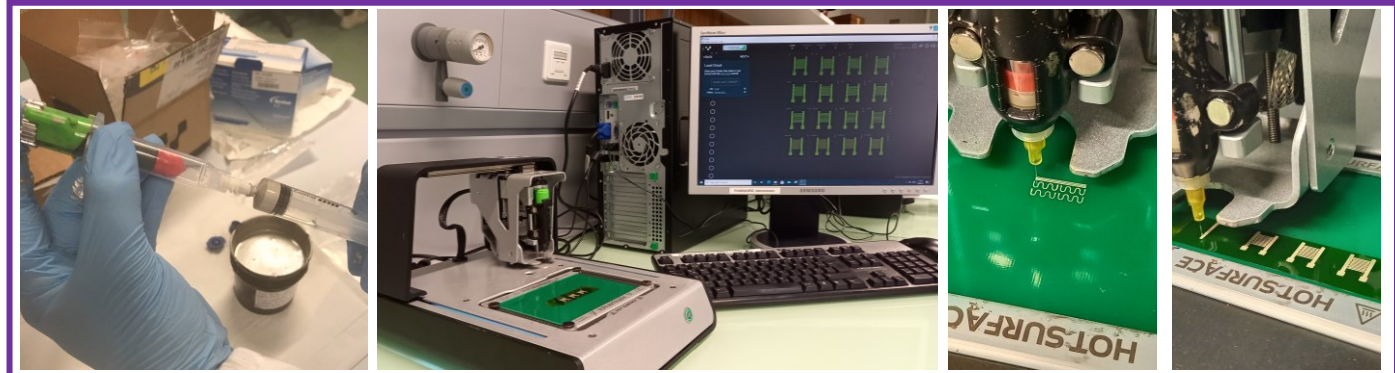


Printing technologies

Dispense printing

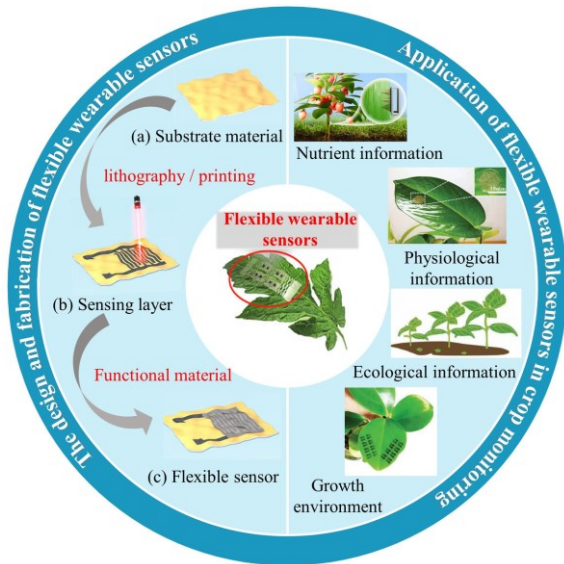
Screen printing

Inkjet printing



# Where are Printed Sensors used?

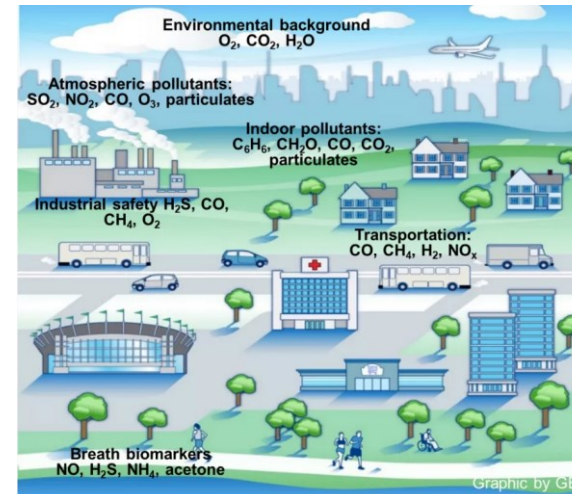
- Agriculture: soil moisture and nutrient monitoring
- Healthcare: wearable patches for health monitoring
- Environment: air quality sensors in urban areas
- Consumer electronics: flexible displays and touch sensors



[1] From Yan, et al., 2024



[2] M. A. Costa Angeli et al., Proc. of IEEE IFETC, 2023.



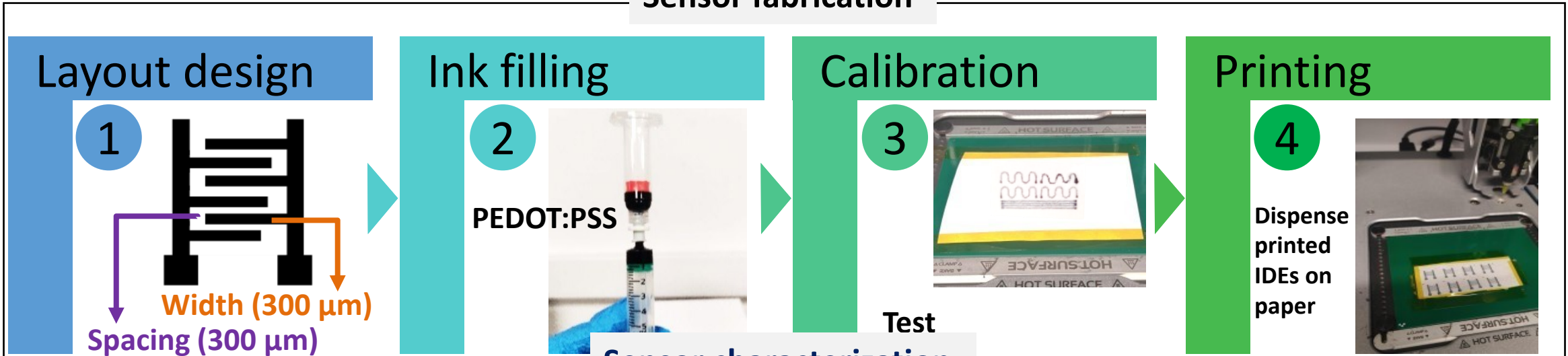
[1] From Joshi, et al., 2020



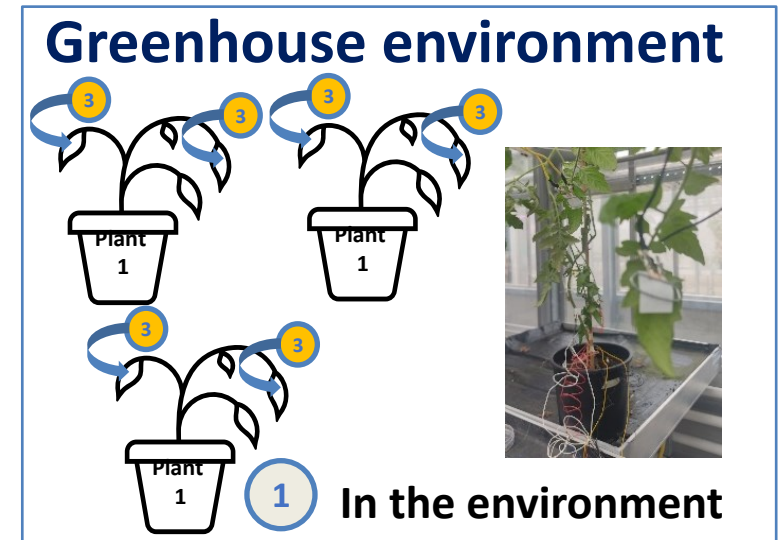
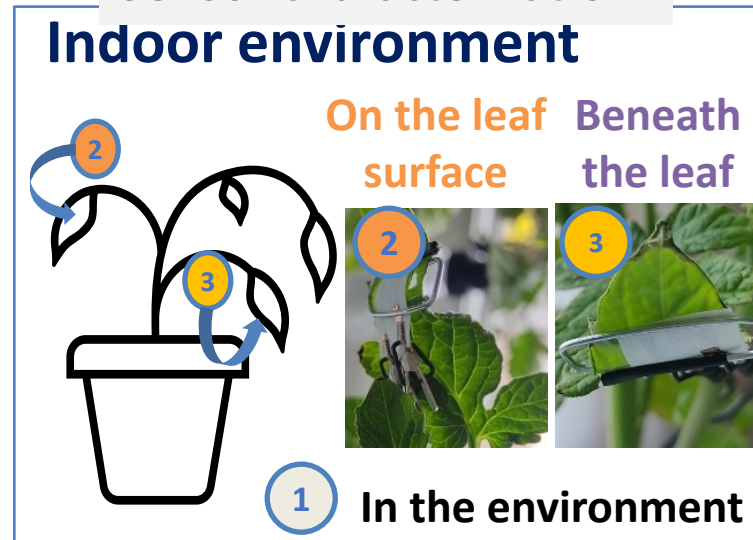
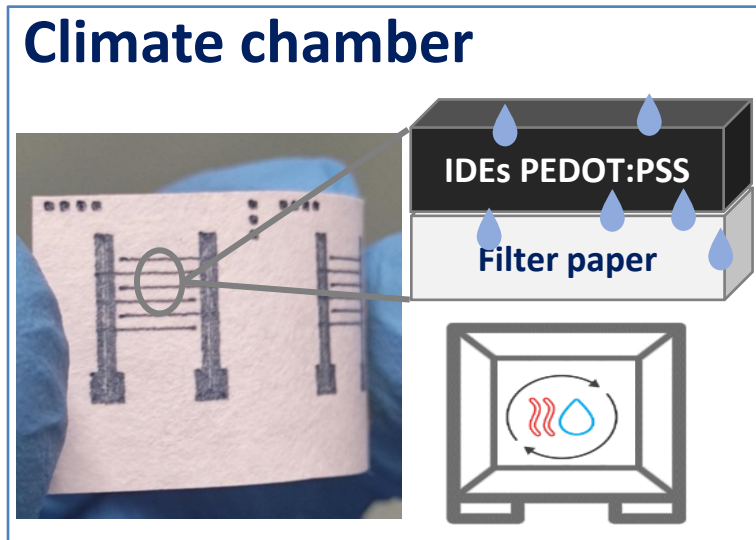
[1] From Wisecoco

# Use Case 1: Printed Paper-Based Humidity Sensor

## Sensor fabrication

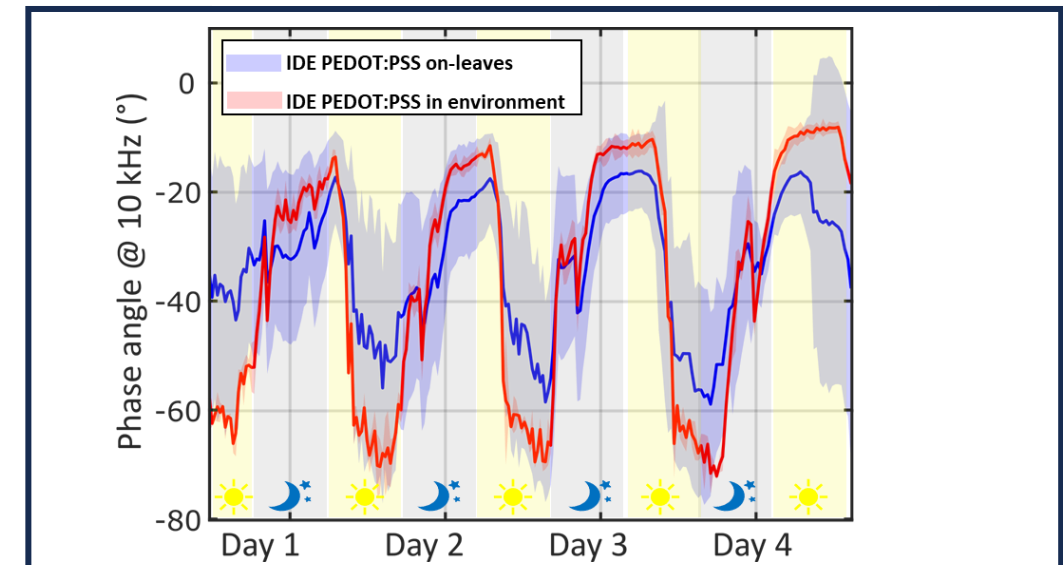
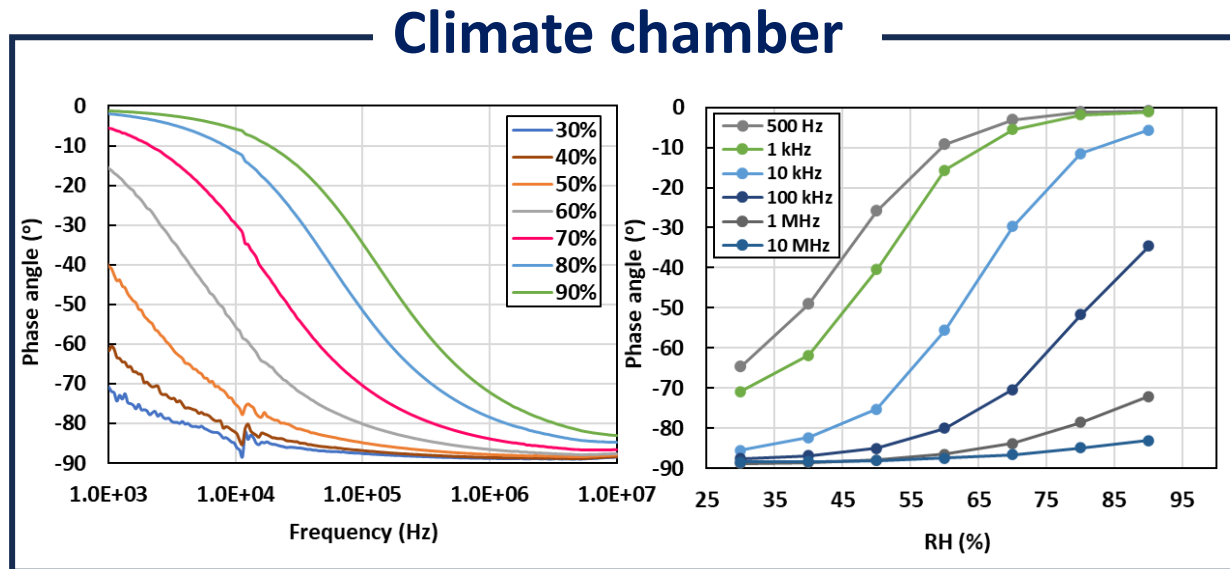
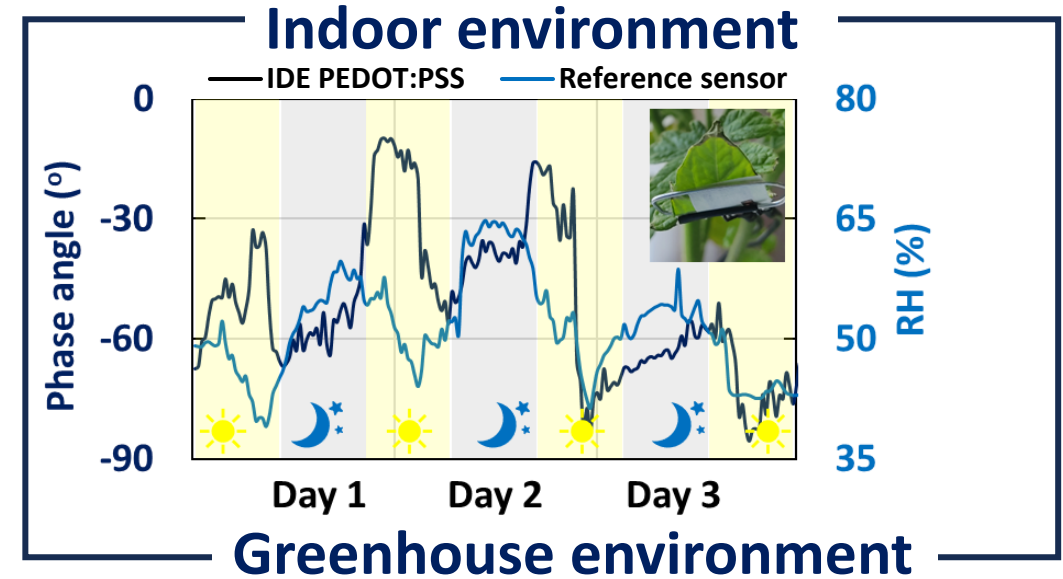
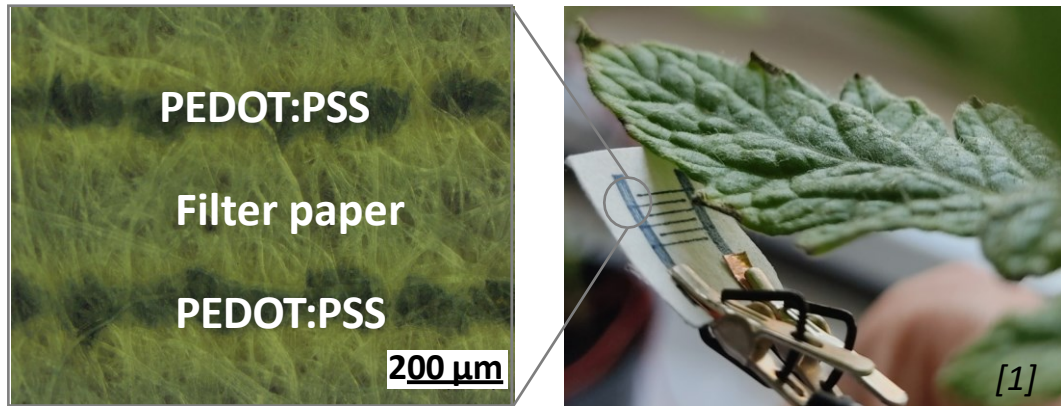


## Sensor characterization





# Use Case 1: Printed Humidity Sensor

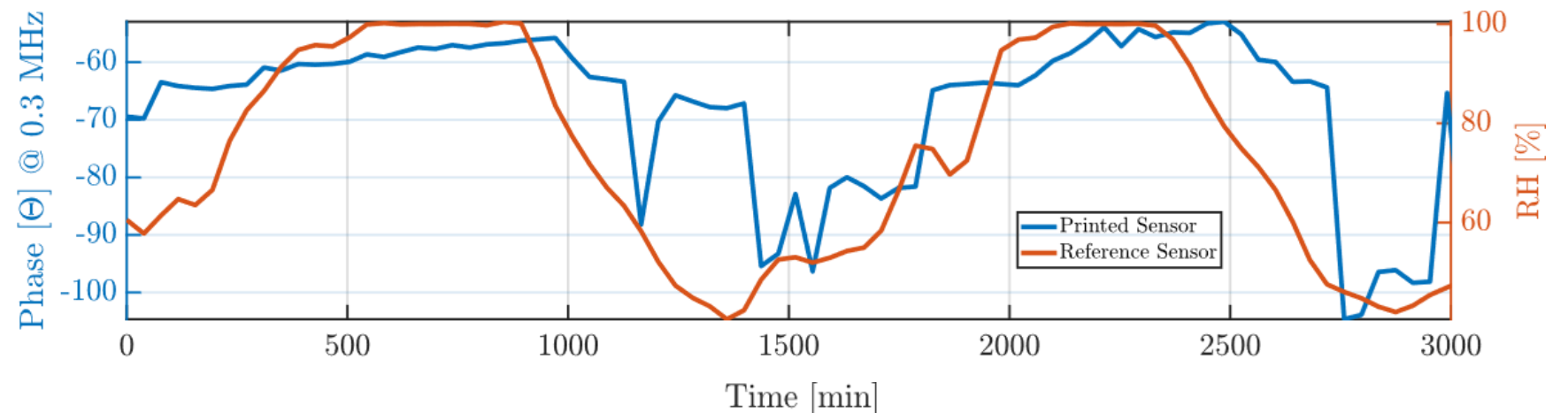


# Use Case 1: Printed Humidity Sensor



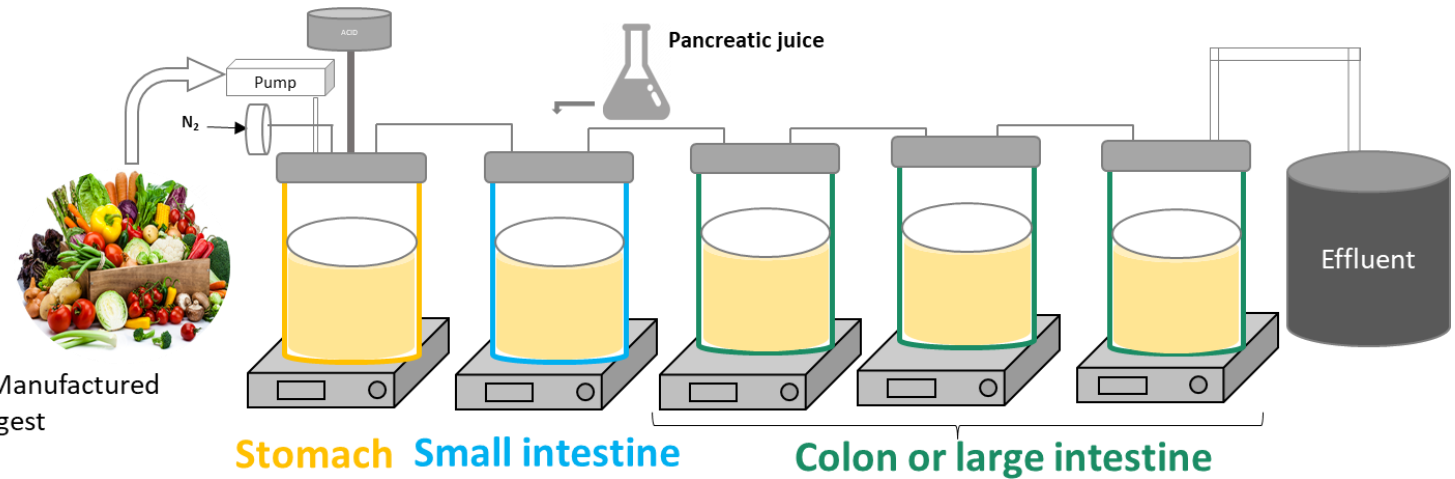
- A cost-effective, modular sensing platform for integrating and testing multiple sensor types
- The phase response tracks changes in humidity, but we observed noticeable drift due to varying environmental conditions.

## Phase Response to Environmental RH in the Apple Orchard





## Simulator of the Human Intestinal Microbial Ecosystem (SHIME)<sup>®</sup>



Working environment:

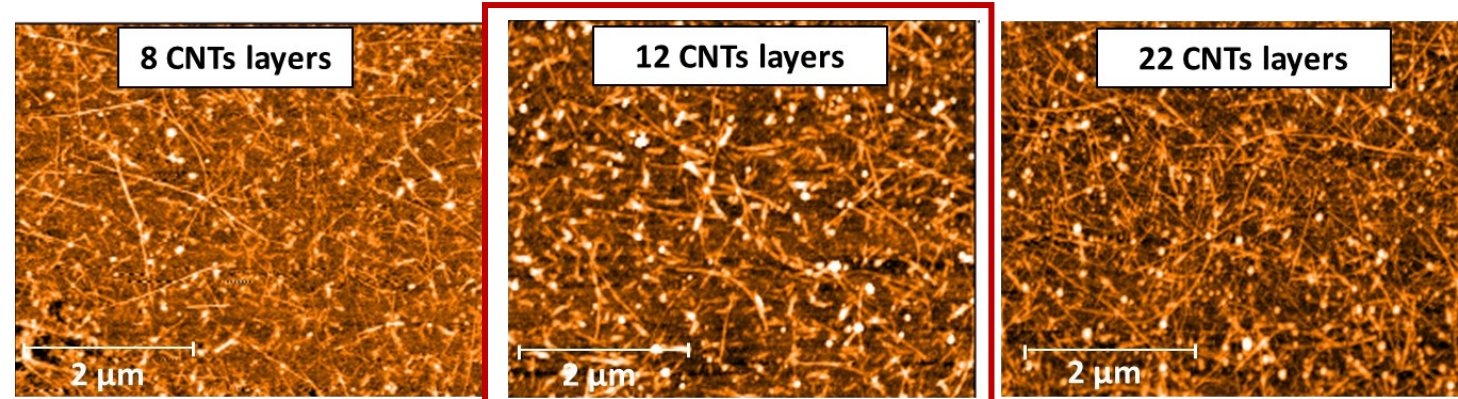
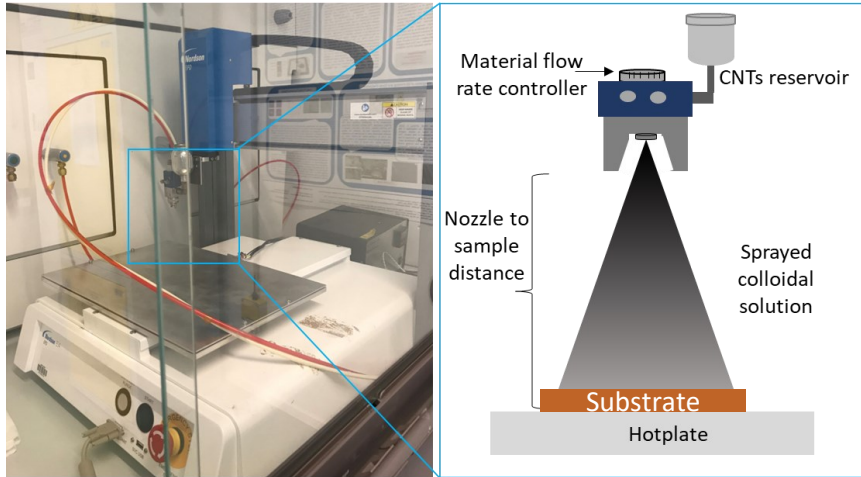
- Strictly **anaerobic**
- Acidic
- Highly humid
- Microbes

### Analysis of gases

- **Samples** are taken and analyzed using **analytical techniques** like gas chromatography or spectrometry
- Offline and limited in real-time monitoring
- Extraction of gas volume for sampling

[1]Micro4Food

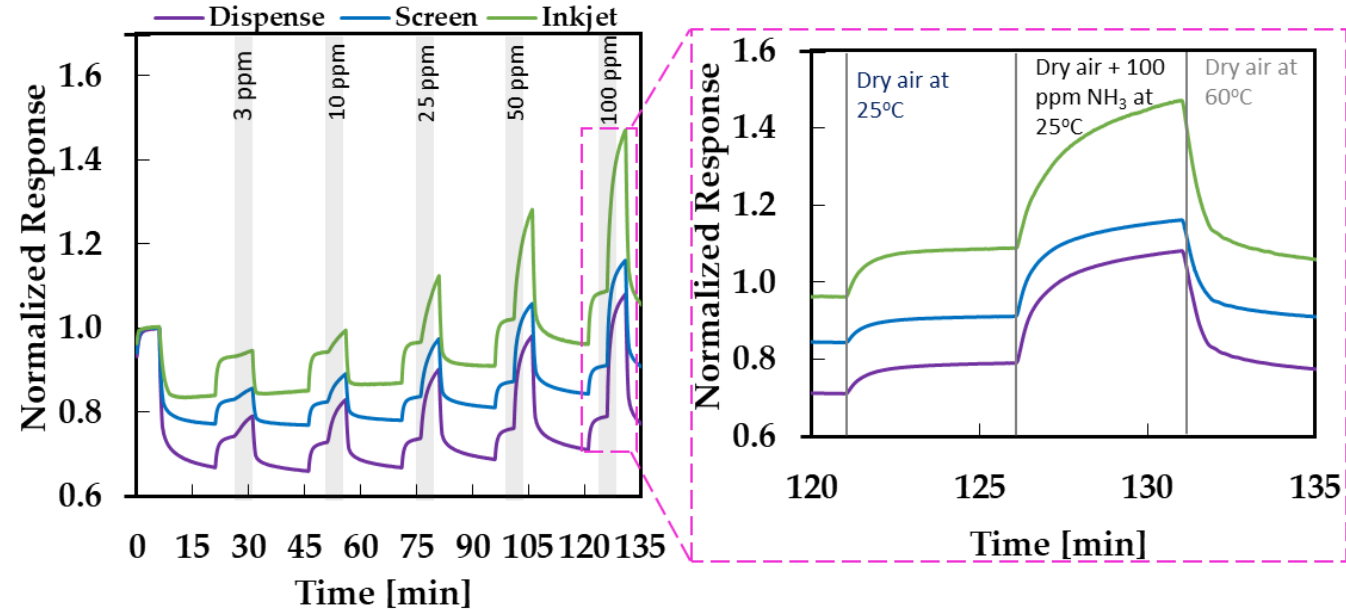
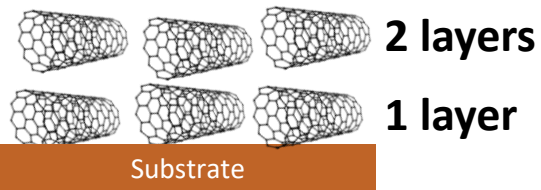
# Use Case 2: Printed Gas Sensors for Food Digestion **unibz**



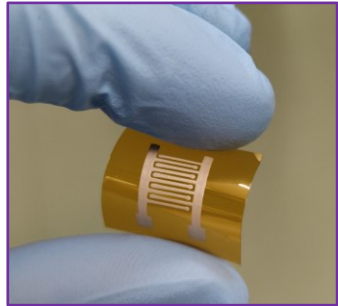
AFM images CNT layers spray coated on polyimide

## Spray coating deposition of carbon nanotubes (CNTs)

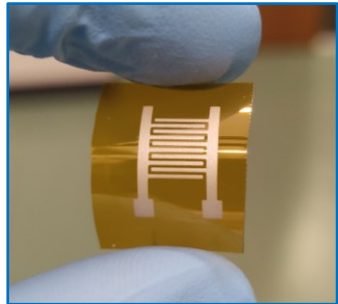
CNT Layers within the percolation threshold



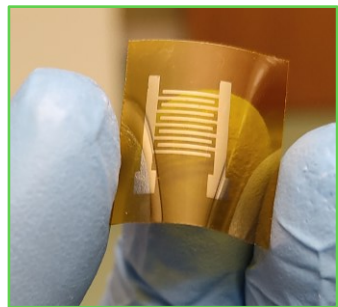
# Use Case 2: Printed Gas Sensors for Food Digestion



Dispense printed sensor

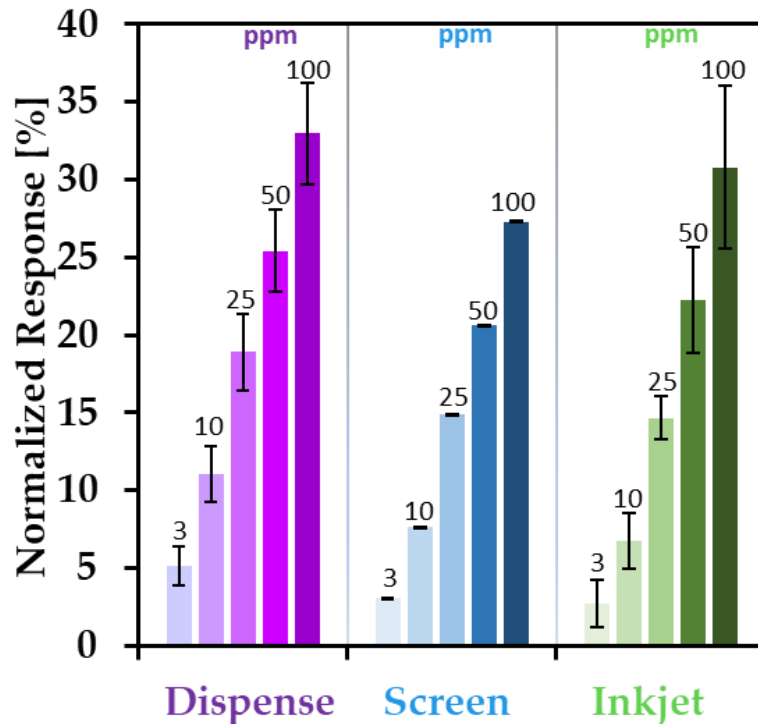


Screen printed sensor

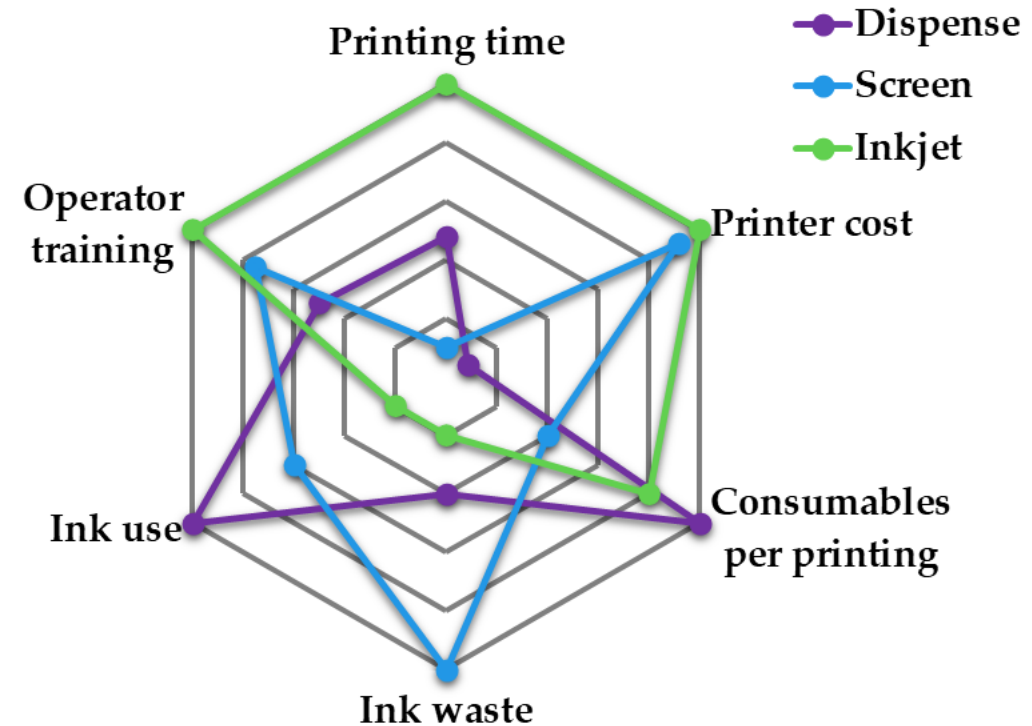


Inkjet printed sensor

## Sensor performance

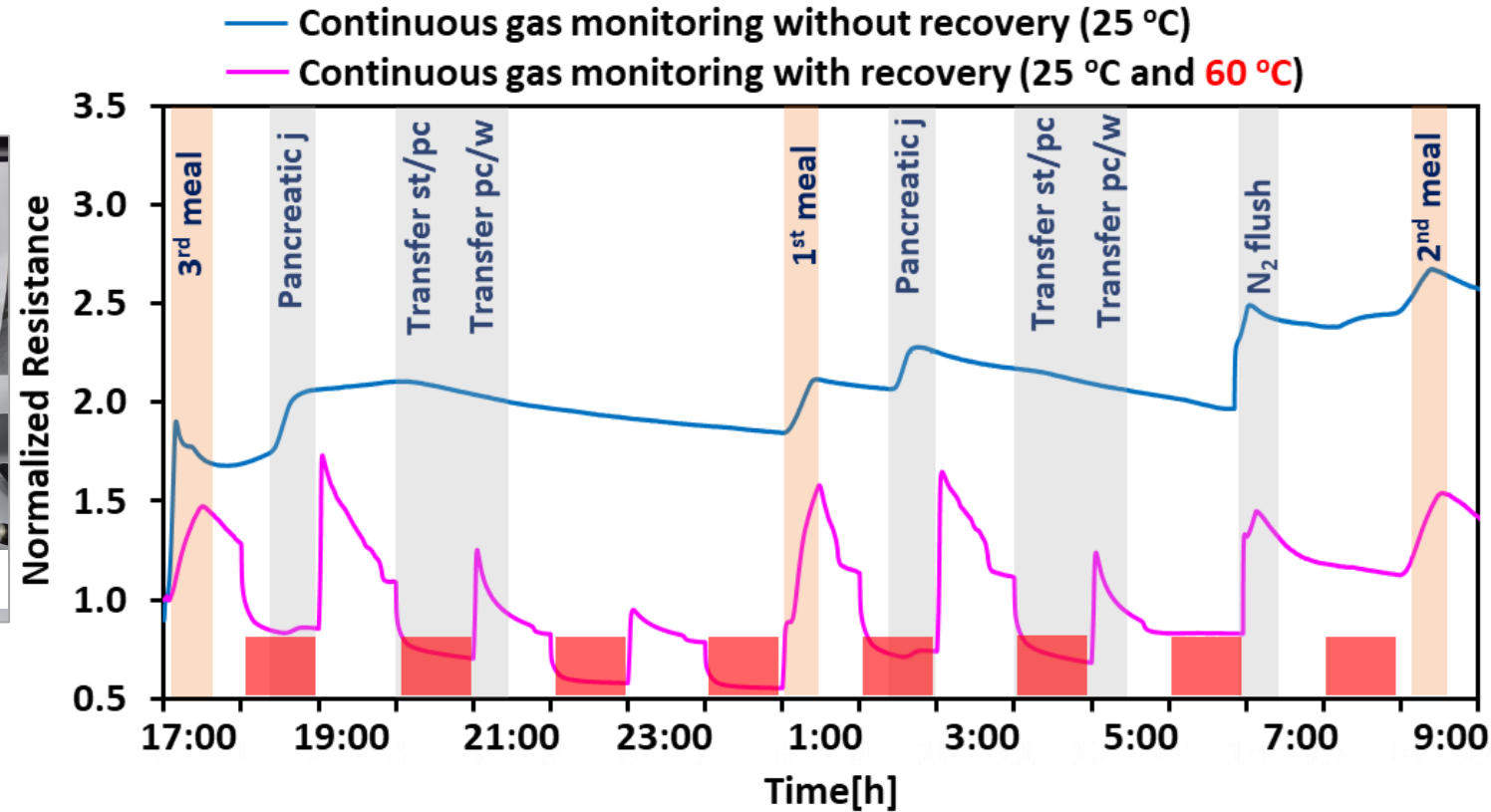
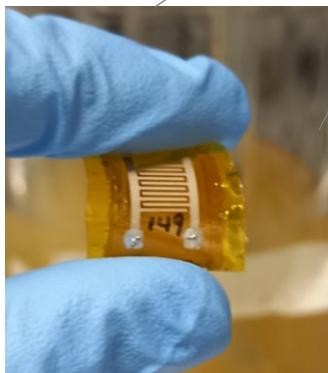
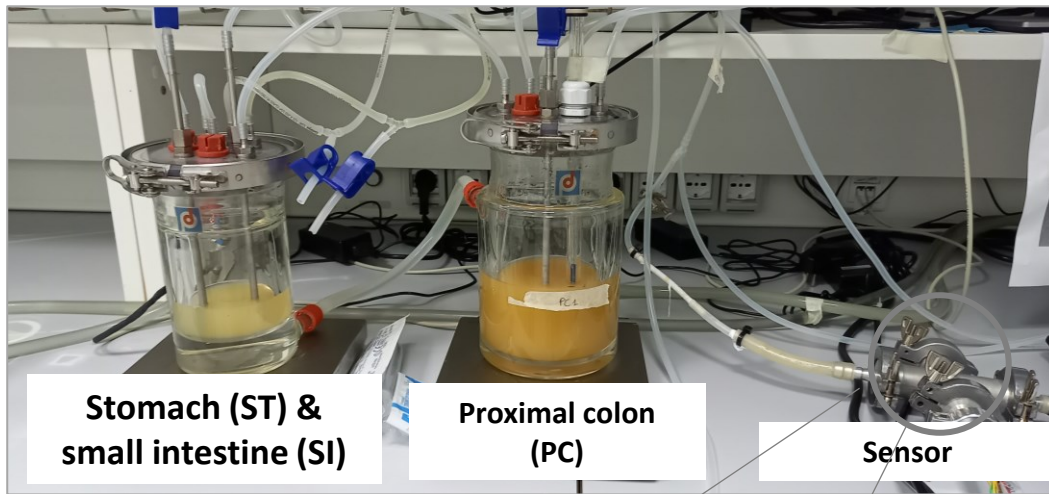


## Lab process analysis



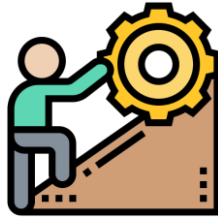
# Use Case 2: Printed Gas Sensors for Food Digestion

## Experimental set up



Vasquez et al., Scientific Reports, 2024

# Challenges and Future Directions




 Durability and Stability

 Materials innovation

 Sensitivity and Selectivity

 Enhanced Sensitivity

 Material Limitations

 Flexible and stretchable

 Environmental impact

 Wireless and energy-efficient designs

 Integration with existing systems

 Scalable manufacturing



## Conclusions & remarks

**Printed sensors are not only addressing current technological needs but are also pushing the boundaries of what's possible in applications across many sectors**





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## Thank you for your attention

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*Scan me*

