4ZDM Zero Defects Manufacturing

EFFRA EUROPEAN FACTORIES OF THE FUTURE RESEARCH ASSOCIATION

**Digital manufacturing industrial workshop**

**26th March 2025 – SPARKS, Brussels**

# Platform-ZERO

## TOWARDS ZERO-DEFECT MANUFACTURING IN THE PV INDUSTRY: REAL-TIME PROCESS MONITORING DRIVEN BY MATERIALS CHARACTERIZATION AND AI ALGORITHMS

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Co-funded by the European Union

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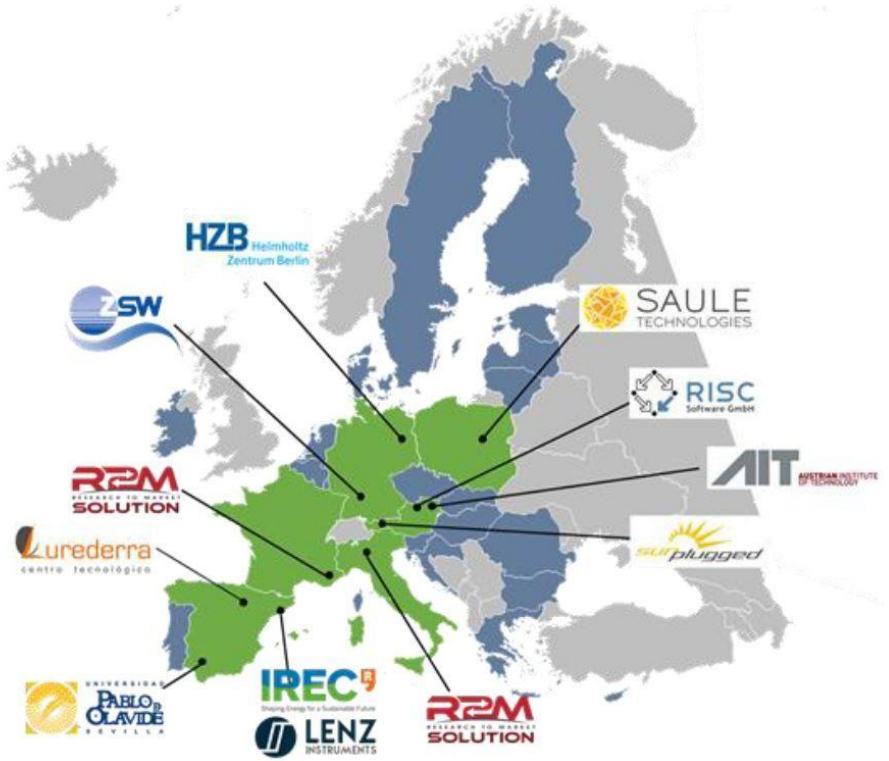
# Meet the Consortium

## 12 European Partners

1. **<u>Technology developing partners:</u>**
   a) **Four research centers** and **one university** with knowledge in the development of spectroscopic methodologies (IREC, HZB), imaging (AIT), device optoelectronic assessment (UPO), AI analysis (AIT, IREC, RISC) and data management (RISC).
   b) **Metrology SME** with strong know-how in the implementation of industrial process monitoring applications (LENZ).

2. **<u>Technology testing partners (Demo sites):</u>**
   a) **Two research centers** with know-how in advanced PV technologies and with industrial pilot lines to validate concepts based on CIGS solar modules (ZSW) and nanoparticles-based surface processes and coatings (Lurederra).
   b) **Two third-generation PV manufacturing SMEs** (SUNPLUGGED and SAULE), both providing their production lines for demonstrating the Platform-ZERO technology.

3. **<u>DEC:</u> two partners** (R2M Solution France and R2M Solution SRL Italy) for dissemination, exploitation and communication actions.




# THE CONSORTIUM

# Context

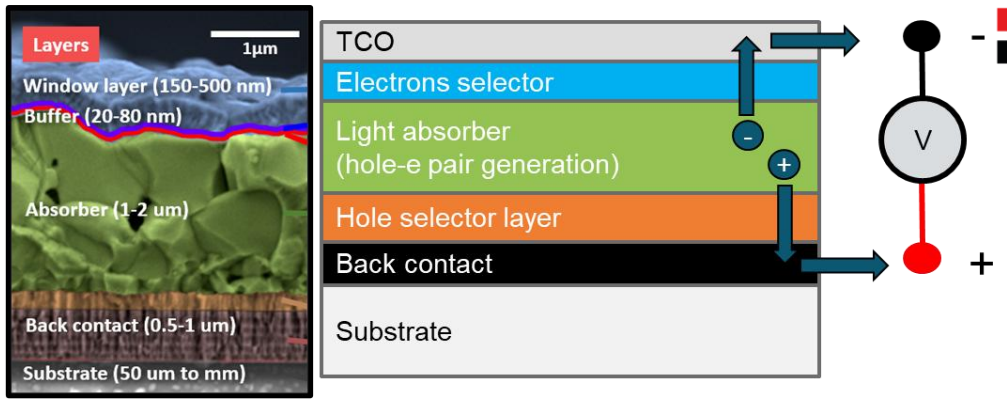
- Solar **photovoltaic** (PV) provides an important **contribution to the European energy** mix, equal to 3.1% of EU-28 gross electricity generation in 2020 (source: Eurostat).
- Furthermore, **solar energy has the potential to meet 20% of the EU electricity demand** in 2040 (source: BloombergNEF).
- The **latest generation of PV technologies combine high performance with a strong flexibility for integration** in buildings, vehicles, agrivoltaics and internet-of-things devices.

However, the high **complexity of the latest generation of PV technologies** makes them **prone to the appearance of critical defects**, leading to significant production waste

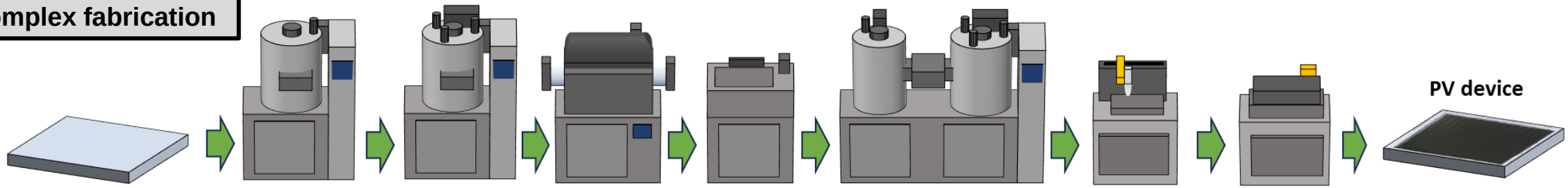
**Complex device**

***➔ Stack of ≥6 layers.***
***➔ Hundreds of fabrication parameters***
***➔ Strong interaction between layers and parameters***

**Cross-section of a PV device**




**Complex fabrication**




**Glass Substrate**

**Sputtering:** Metallic Back contact

**Sputtering:** Absorber precursor

**Annealing:** Light Absorber synthesis

**CBD:** Carriers separation stack

**Sputtering:** Front Transparent contact stack

**Annealing:** System stabilization

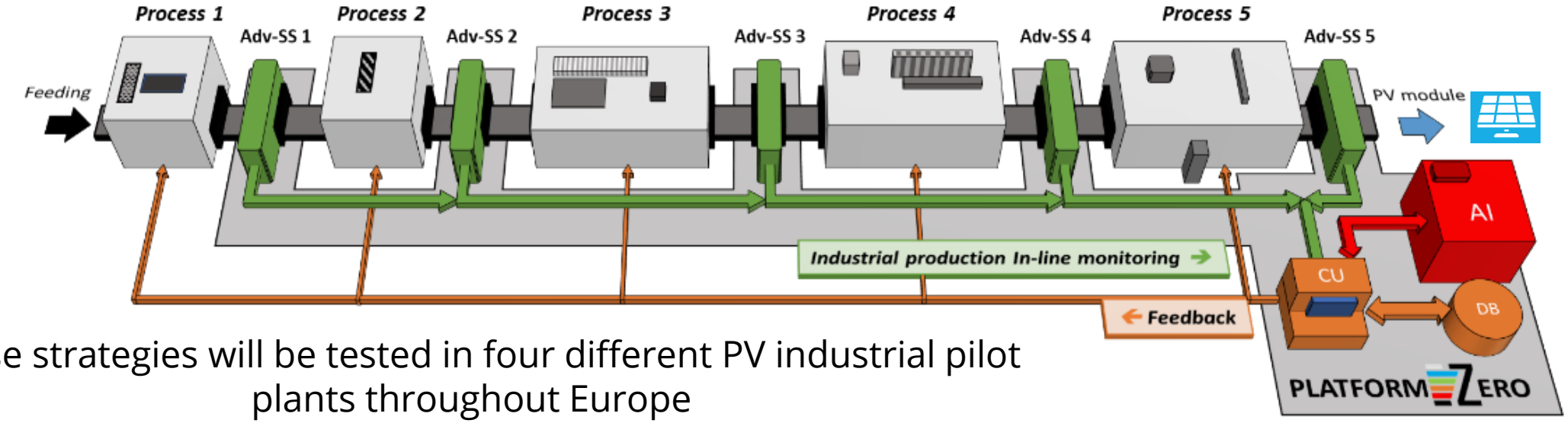
**Scribing:** Devices discretization

# ABOUT THE PROJECT

**Platform-ZERO addresses this challenge aiming at reaching zero defect manufacturing for the photovoltaic industry**

**In-line process monitoring**, control and artificial intelligence strategies are key technologies:

- to **allow early detection**, correction and/or prevention of pre-critical production faults
- to substantially **reduce production costs and improve quality** for industry in the photovoltaic sector

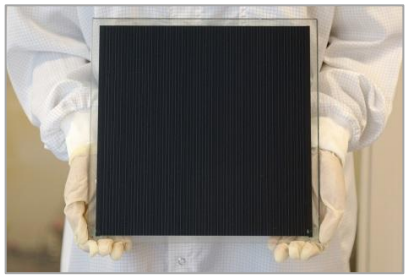
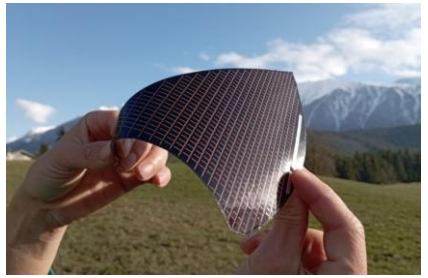
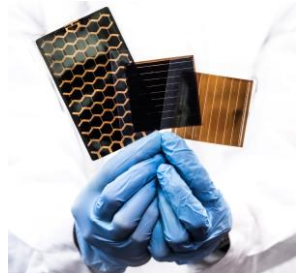



These strategies will be tested in four different PV industrial pilot plants throughout Europe

# ABOUT THE PROJECT

# Demo sites

Platform-ZERO innovations will be tested in 4 PV industrial pilot plants throughout Europe: Spain, Germany, Poland and Austria

| Pilot Line | Lurederra centro tecnológico | ZSW | sunplugged | SAULE TECHNOLOGIES |
|---|---|---|---|---|
| Pilot line objective | Technology Demonstration / optimization | Technology Demonstration / optimization | Production | Production |
| Products | Oxide based smart coatings | High efficiency CIGSe-based PV | Customizable CIGSe-based PV | Customizable Perovskite-based PV |
| Product Image |  |  |  |  |
| Production process | Discontinued (batch) | Sheet-to-Sheet (StS) | Roll-To-Roll (RtR) | Front end of Line (FEOL) |
| | Research Pilot-line (Laboratory to Industry) | | Industrial Pilot-line | |

Different type of industries in terms of:
PV products, production methods, materials fabrication, and samples management

→ Demonstration of suitability of Platform-Zero process monitoring platform

# OVERALL OBJECTIVES

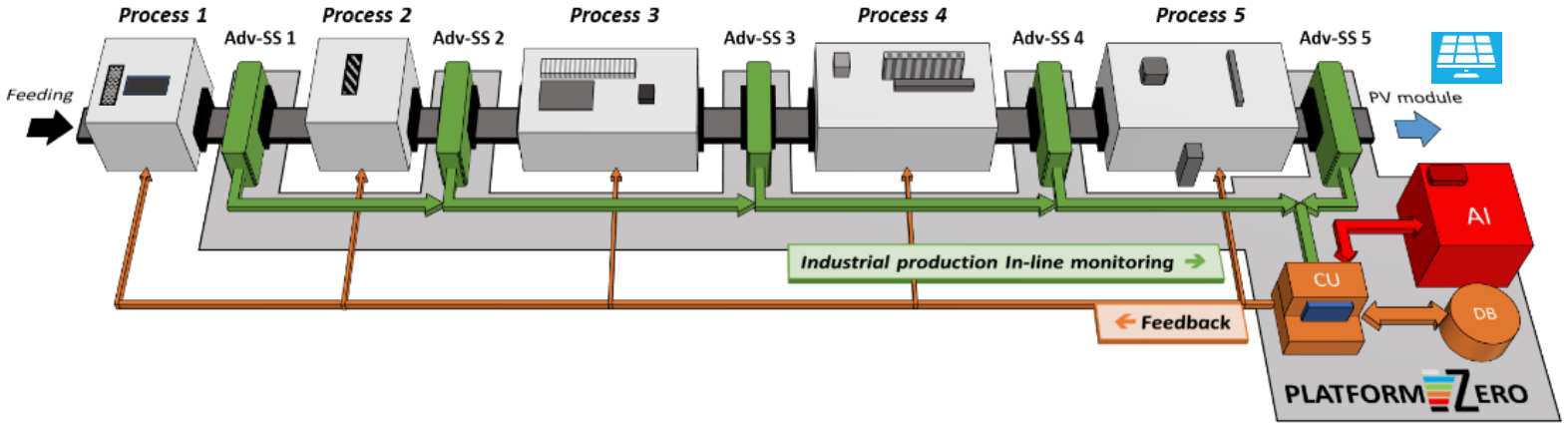
To develop a modular in-line process monitoring and control solution for the third-generation PV industry

**Sensor Stations**
To develop advanced sensor stations compatible with customizable sensor arrays for morphological, physicochemical and optoelectronic in-line inspection of PV materials and devices

**Data Management**
To develop a big data infrastructure, control unit and GUI software for managing the large amount of data generated by the platform

**AI System**
To develop an innovative AI-based prediction and decision-making system along with methodologies compatible with heterogeneous data, real-time monitoring, and process control

**Monitoring Platform**
To implement and install a process monitoring platform in 4 PV manufacturing lines across Europe

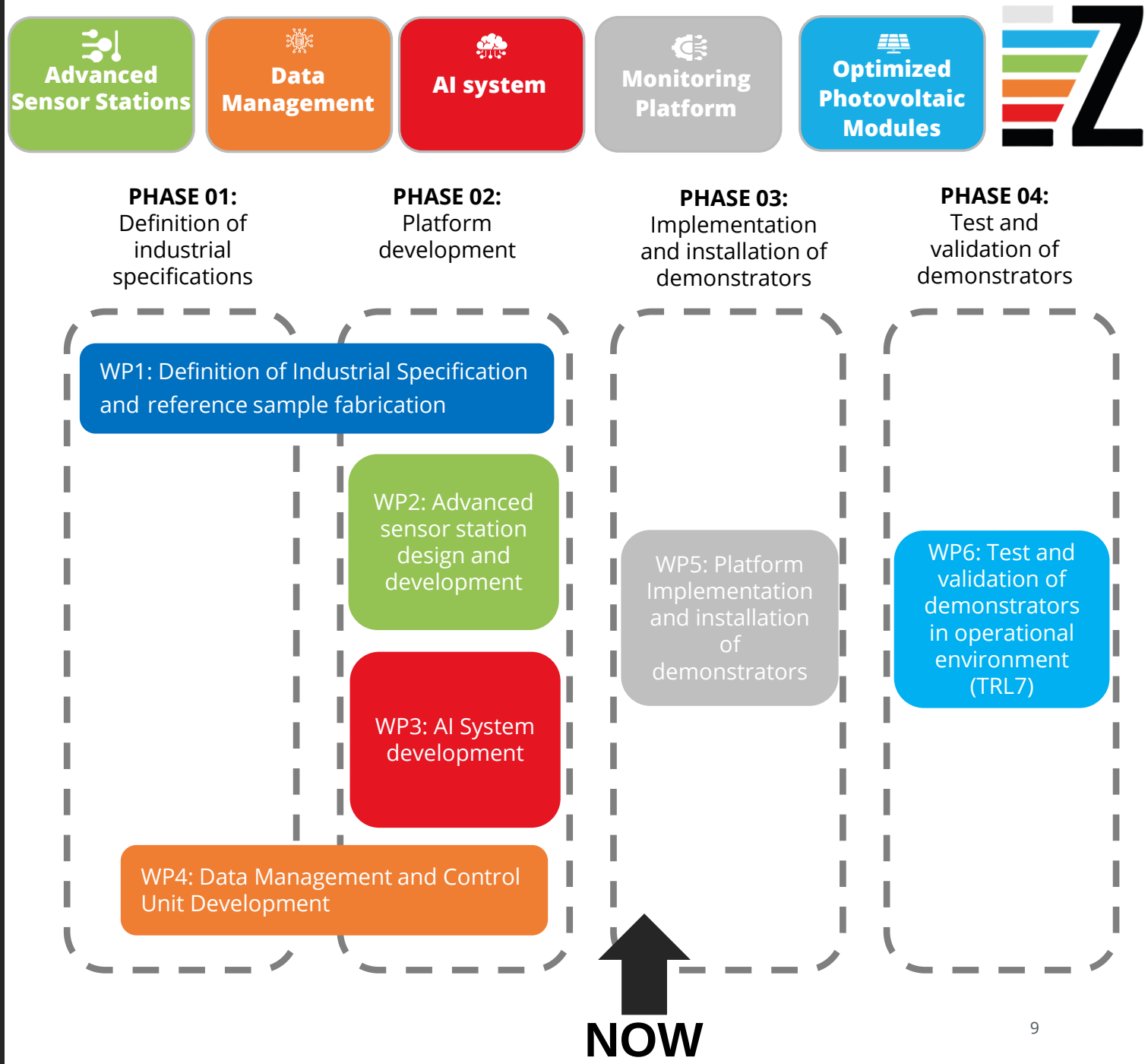



**Photovoltaic Devices**
To optimize PV manufacturing by validating the process monitoring and control platform developed to minimize production defects

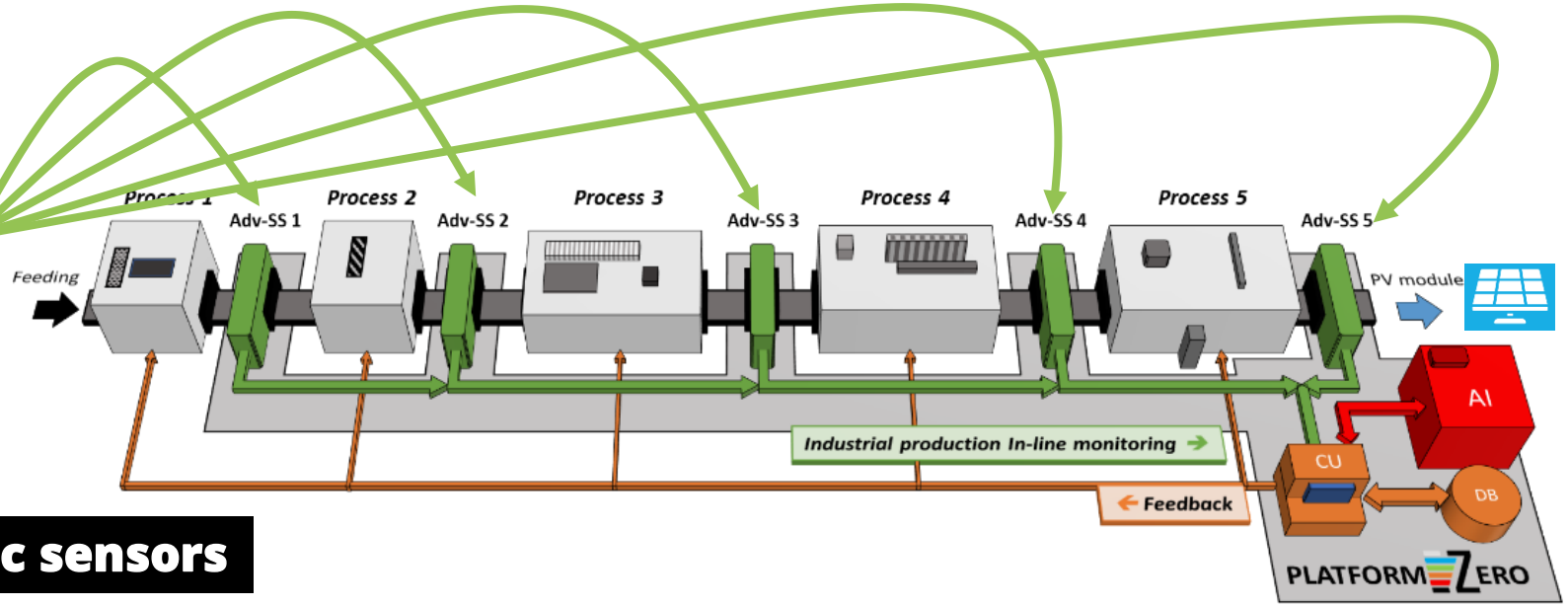
# TECHNICHAL MAPPING & METHODOLGY

**4M approach**

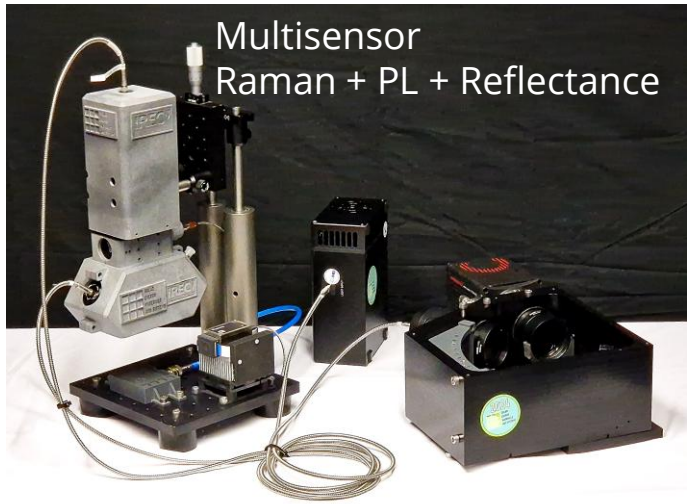
- Mapping (year 1)
- Manufacturing (year 2)
- Making (year 3)
- Monitoring (year 4)

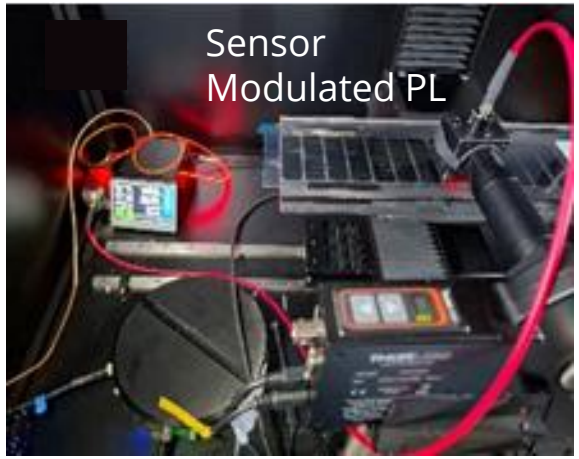


**Advanced Sensor Stations** (Adv-SS)

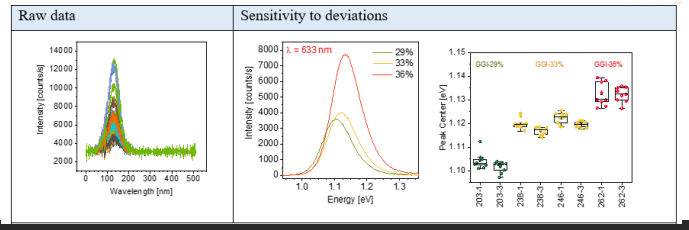


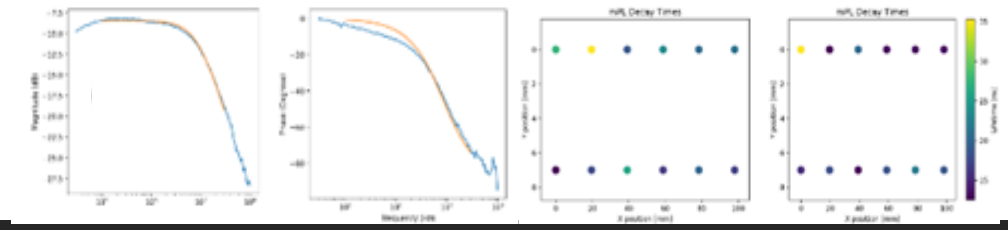

# Spectroscopic sensors

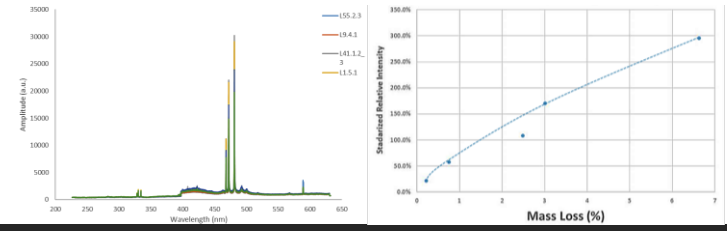


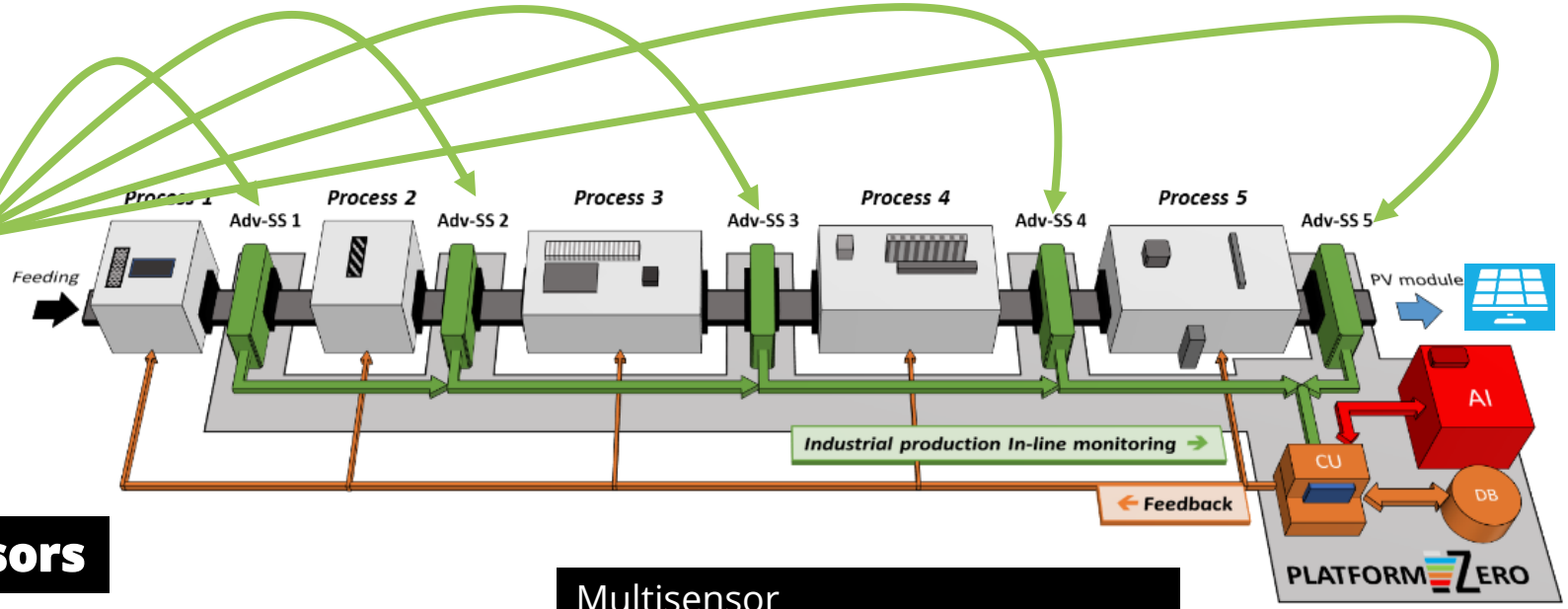




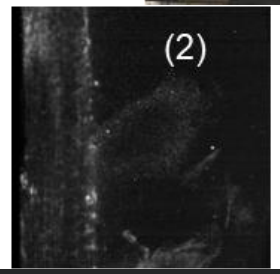



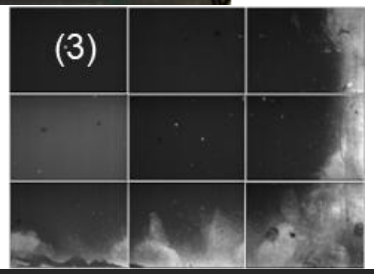


**Advanced Sensor Stations** (Adv-SS)

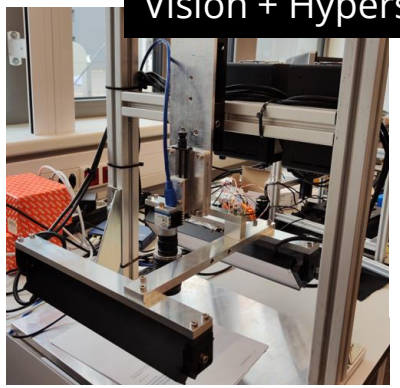


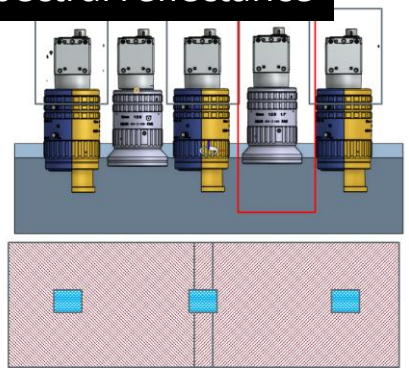

## Imaging sensors

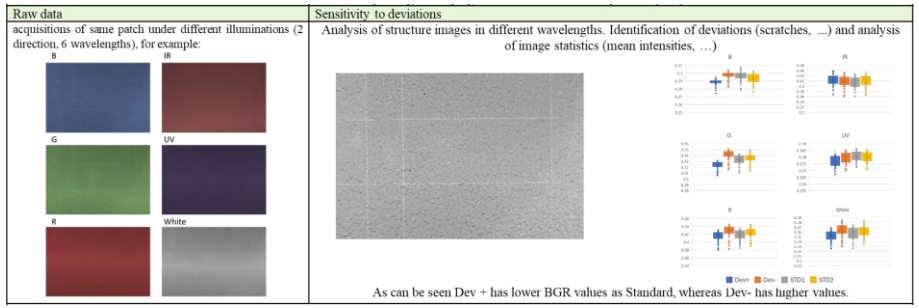



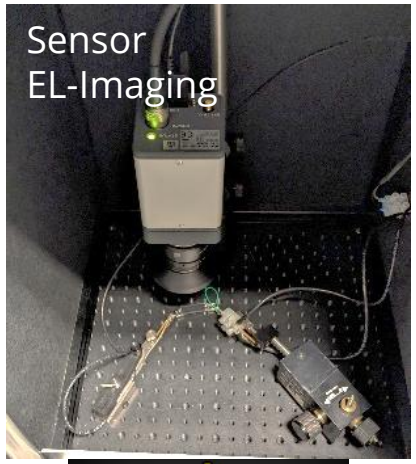



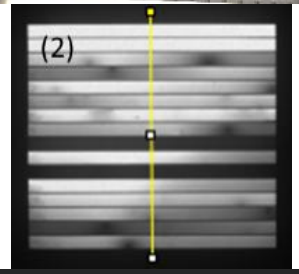

Multisensor
Vision + Hyperspectral reflectance



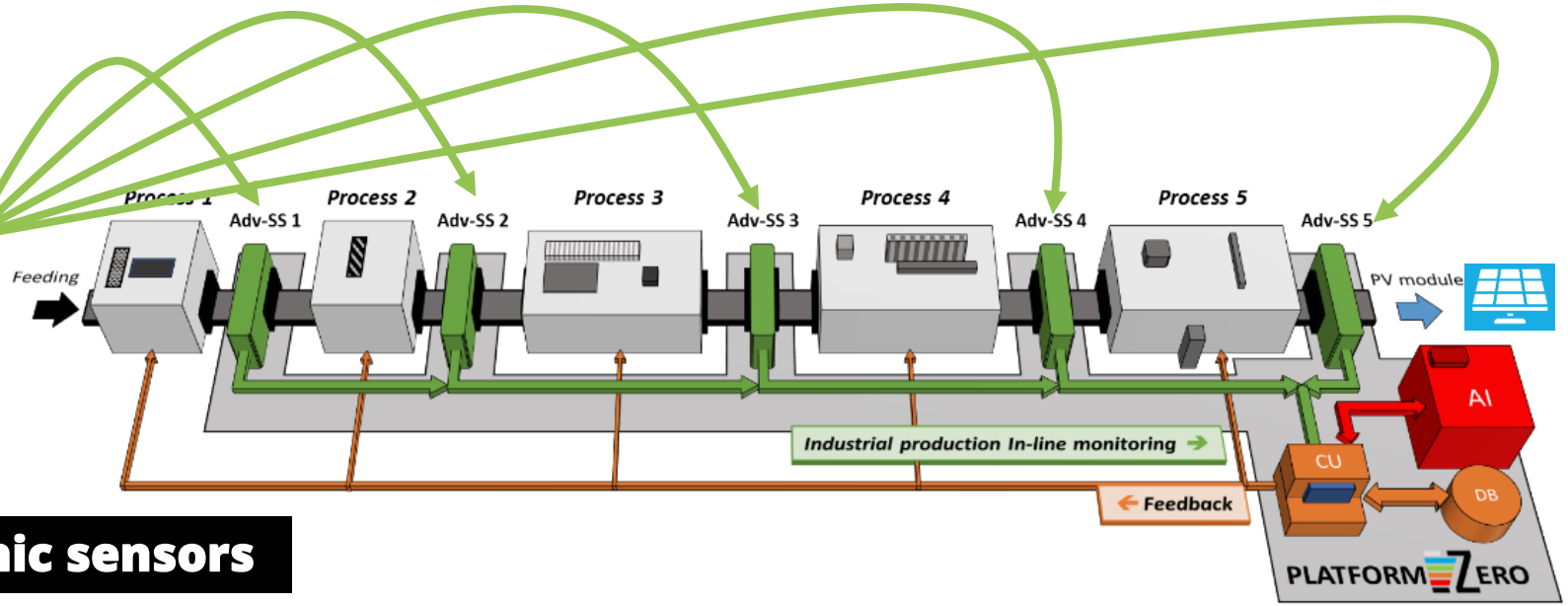




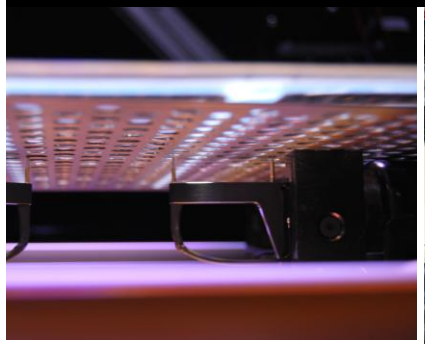



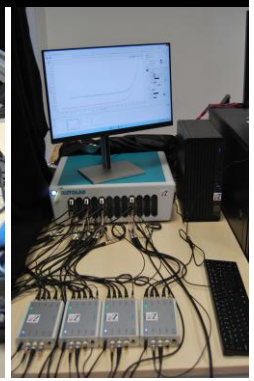
**Advanced Sensor Stations** (Adv-SS)

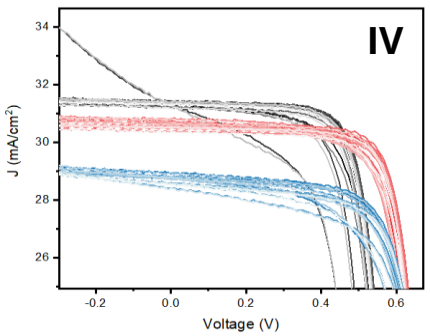


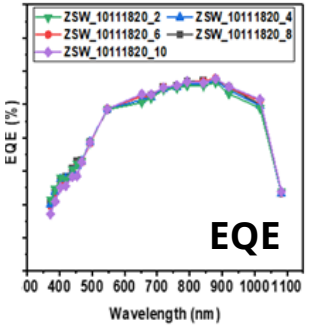

# Optoelectronic sensors

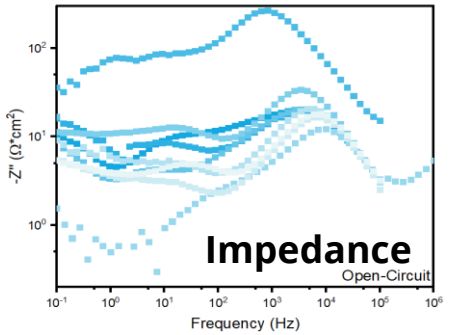
## Multisensor
IV + EQE + Impedance



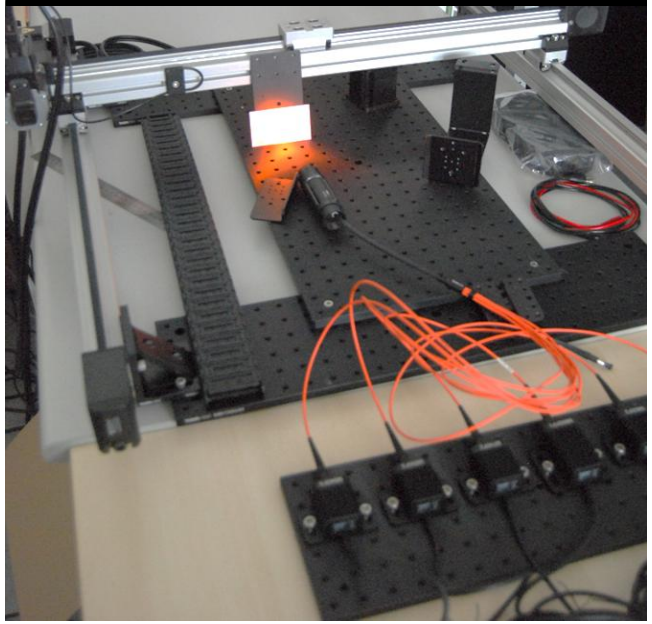




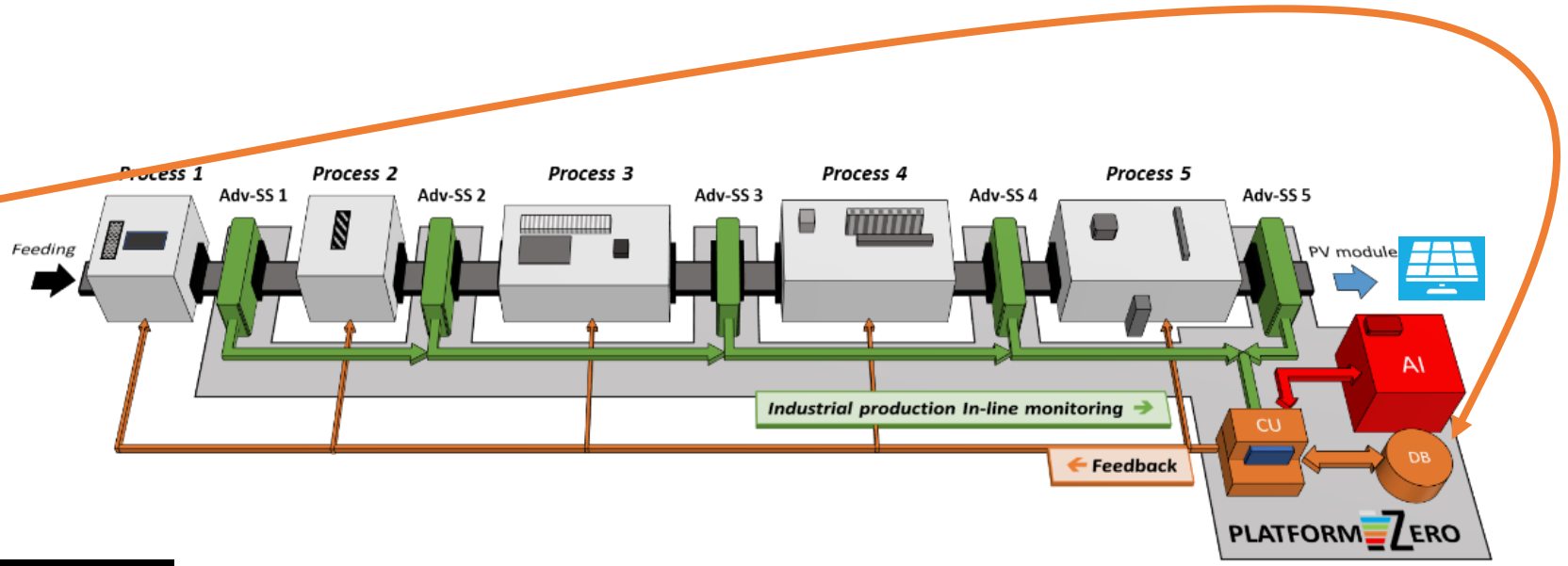



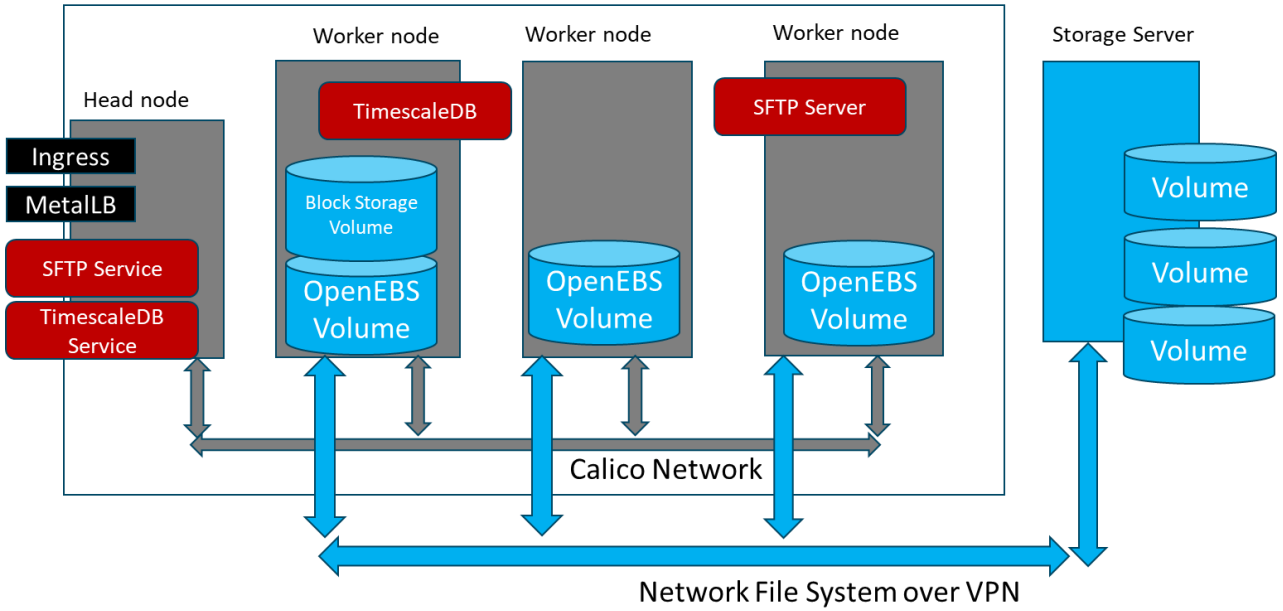

## Functional prototype

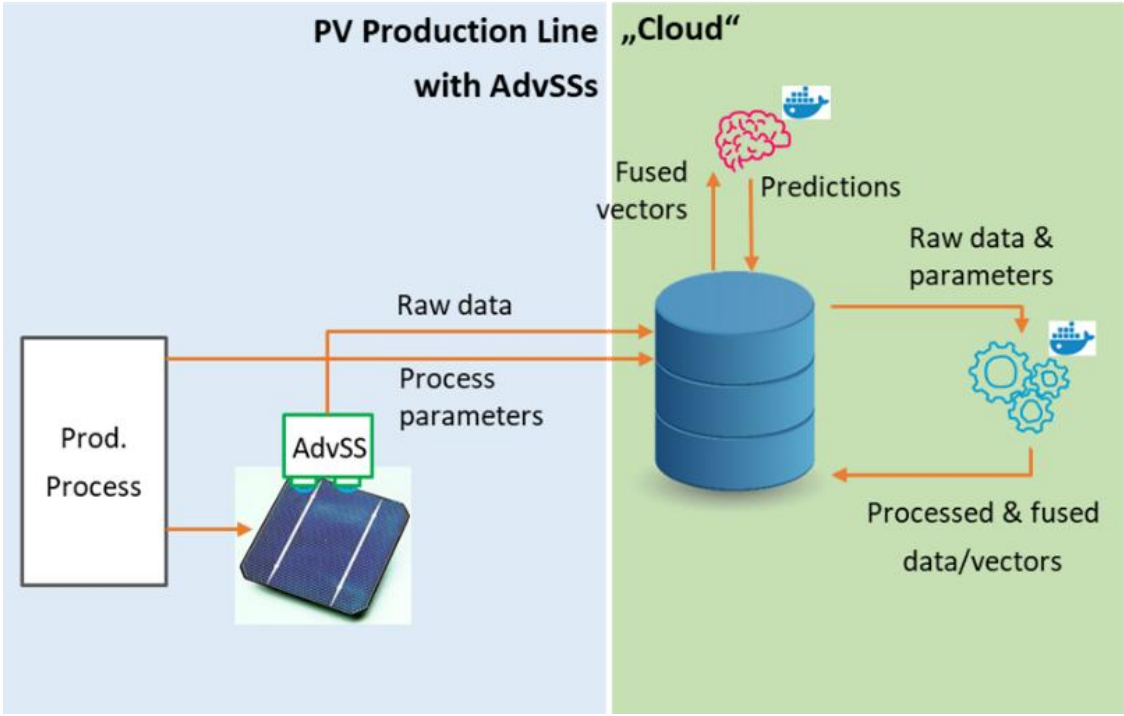


**Data Management** (CU and DB)

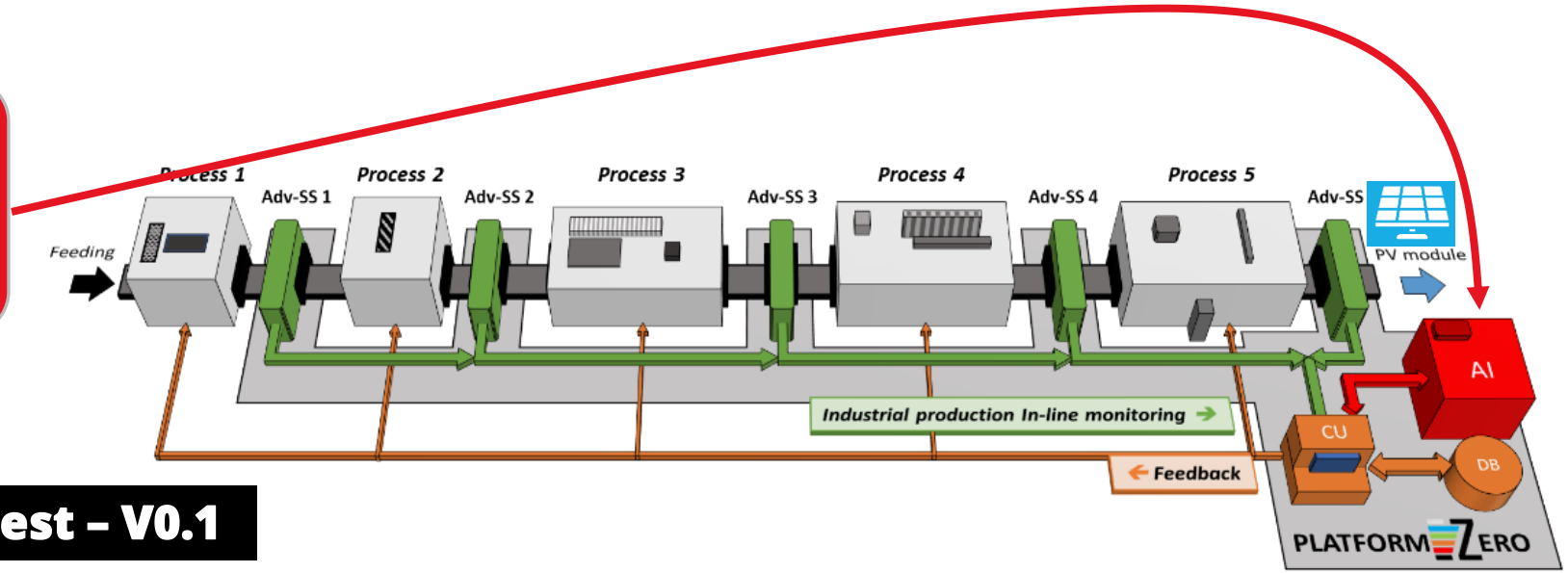



## Kubernetes Cluster



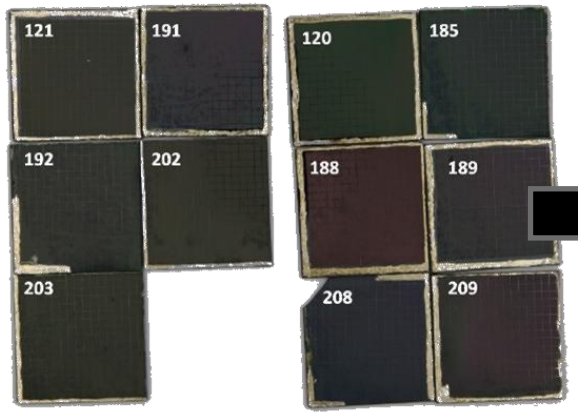



**AI system**
(AI)

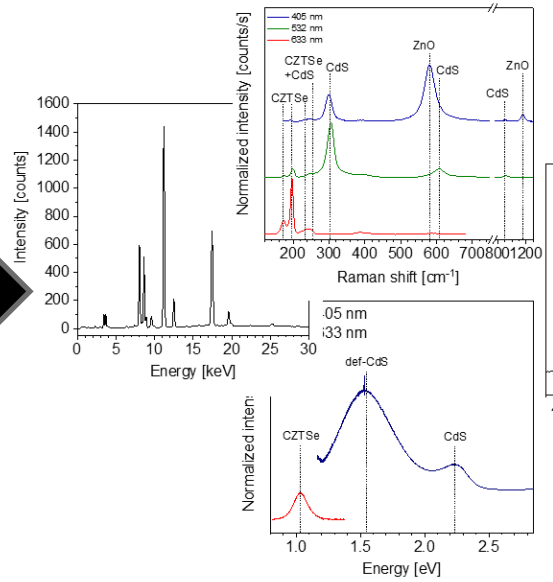


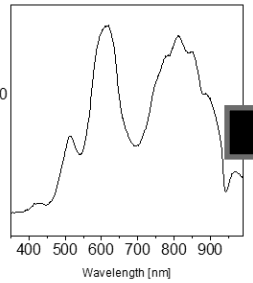

# AI system test – V0.1

Research samples with >1500 data points split in 3 classes: 1 – good; 2 – acceptable; 3 – bad.

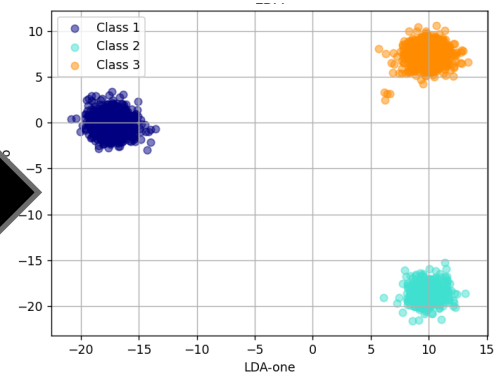



Coherent dataset with results from combined characterization by means of XRF, Raman, PL, Reflectance



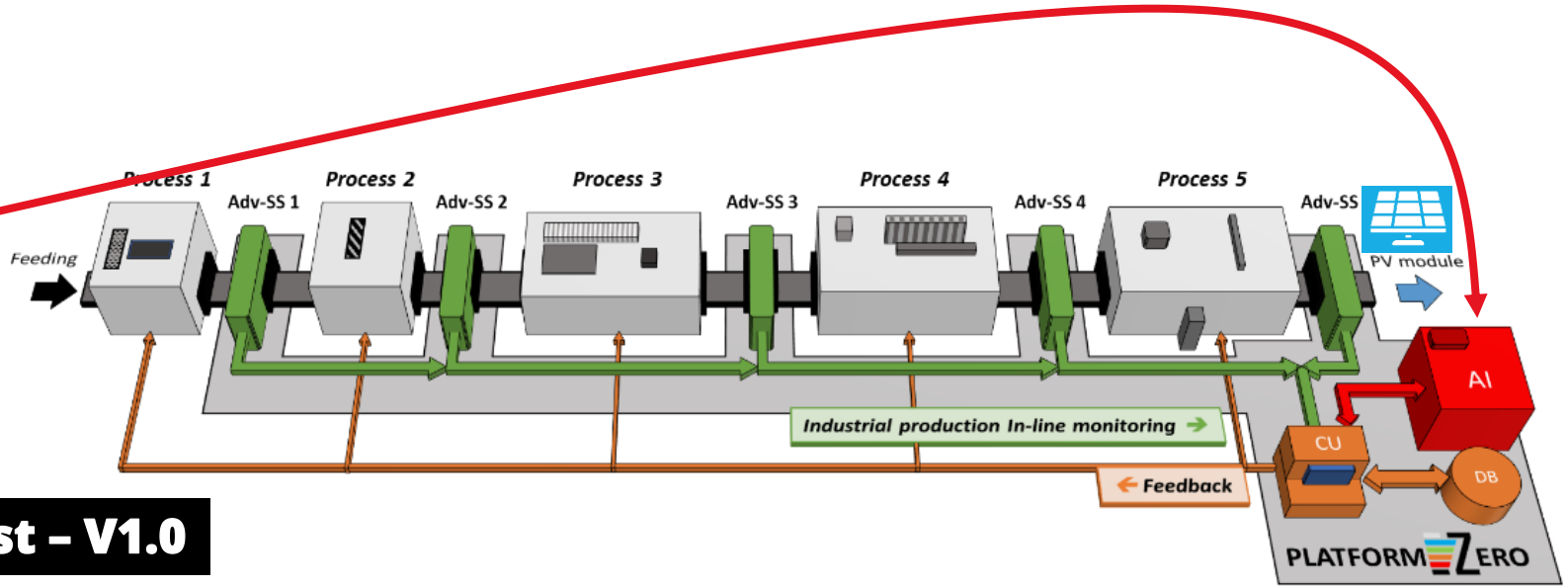

Latent space




Classification scores

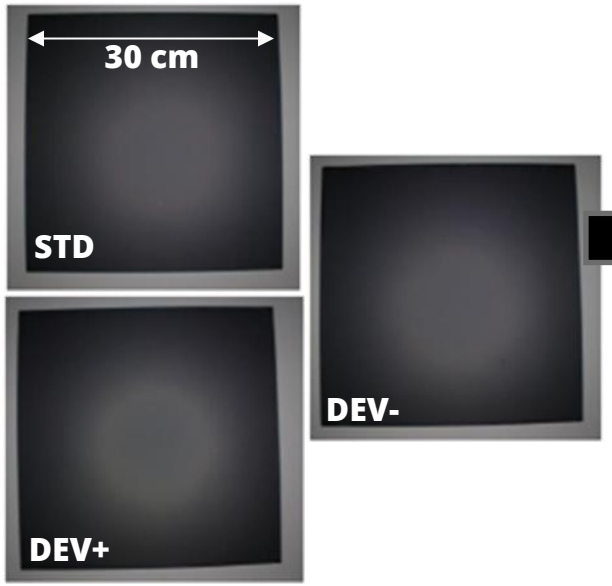
| | Accuracy (%) | F1 score (%) |
|---|---|---|
| PL405 | 87.5 | 87.3 |
| PL633 | 83.8 | 83.5 |
| Raman405 | 69.8 | 69.2 |
| Raman532 | 69.4 | 68.7 |
| Raman633 | 56.6 | 55.9 |
| Hyp.-Img. | 29.2 | 37.4 |
| Reflectance | 97.0 | 97.0 |
| XRF | 51.5 | 54.8 |
| **ALL** | **100.0** | **100.0** |

**AI system**
(AI)



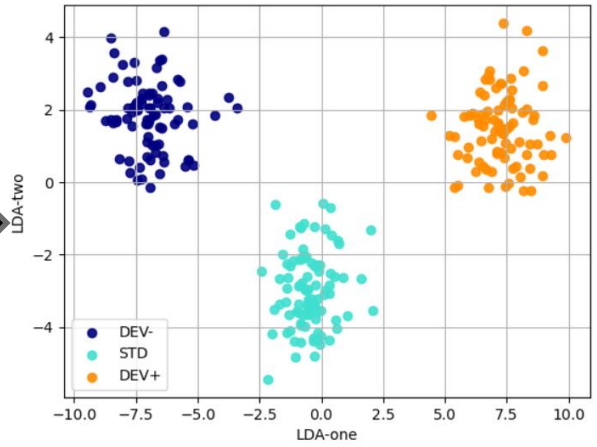

## AI system test – V1.0

Samples from a pilot line split in 3 classes: DEV- – deviation -; STD – standard; DEV+ – deviation +

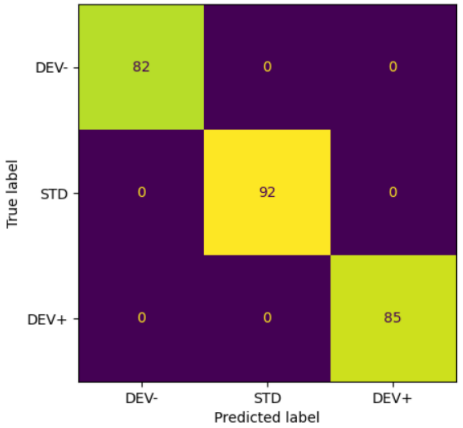



Coherent dataset with results from combined characterization by means of Raman, PL, Reflectance, Vision, Hyperspectral Imaging

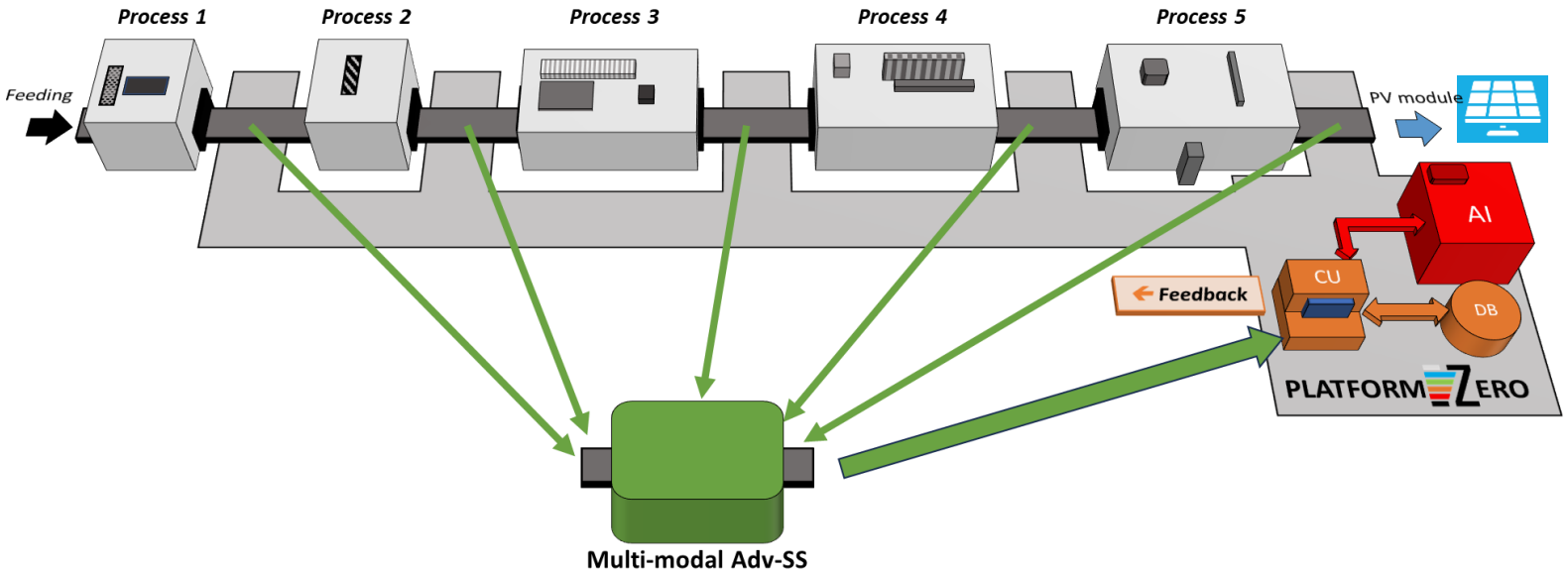
Latent space




Confusion matrix



**Monitoring platform**



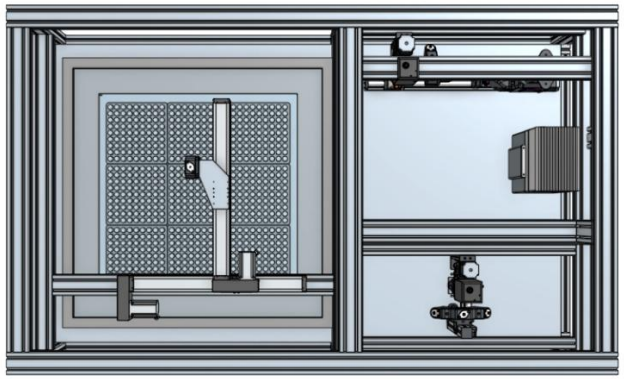

## First design

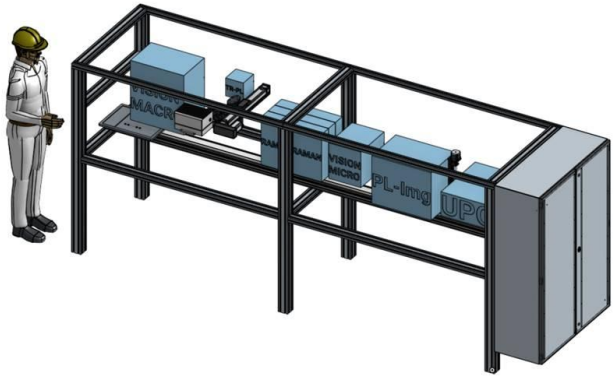
Oxide based smart coatings

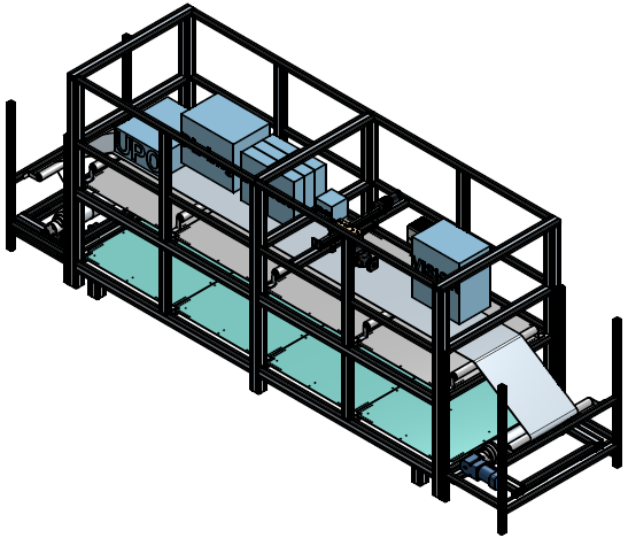
High efficiency CIGSe-based PV

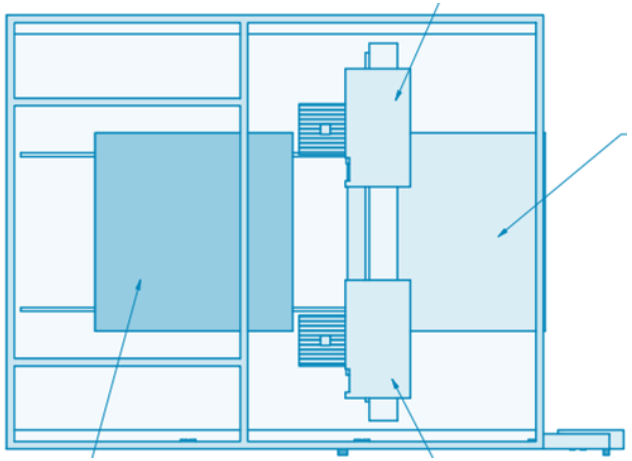
Customizable CIGSe-based PV

Customizable Perovskite-based PV







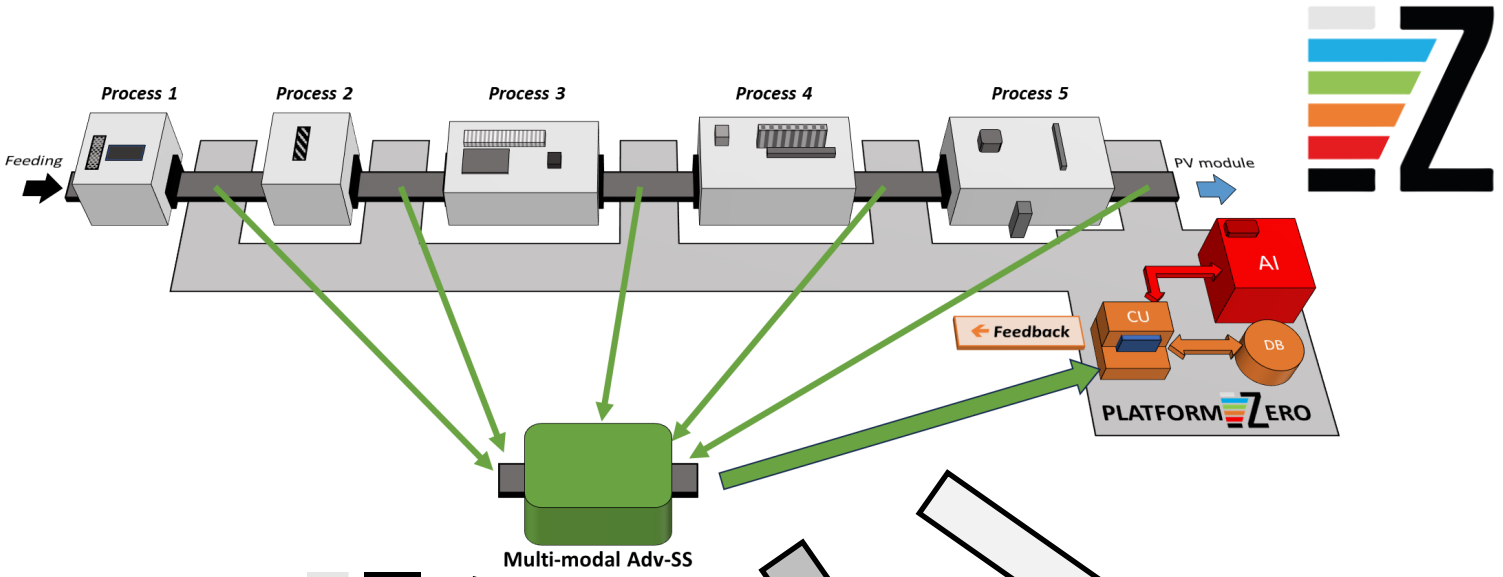


# PROJECT OUTPUT, KERs AND IMPACTS

Advanced Sensor Stations | Data Management | AI system | Monitoring Platform | Optimized Photovoltaic Modules

- Develop of dedicated high sensitivity inspection sensors
- Develop strategies for real StS and RtR in-line monitoring
- Implementation of AI-based algorithms library
- Implementation of data management and control algorithms library
- Implementation of costumizables GUI software for monitoring, data visualization and decision-making advising
- Implementation of fully operational platform demonstrators compatible with a real-time industrial process monitoring
- Detection of process deviations
- 10% increase in productivity of the EU's PV industry
- 10% decreased requirement of high-value raw materials required for the production of PV devices

# FUTURE TRANSFERENCE




**Full integration in Platform-Zero pilot lines**

**Different PV technologies**

New PV technologies
Silicon
Organics
Etc.

**Different semiconductor technologies**

Batteries
General Smart coatings
Functional materials
Etc.

**Other applications**

Smart sorting for recycling


# THANK YOU , GET IN TOUCH

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