

# Intelligence (Nano)Manufacturing of Flexible Printed Organic Electronics by in-line Metrology, Digitalization and AI

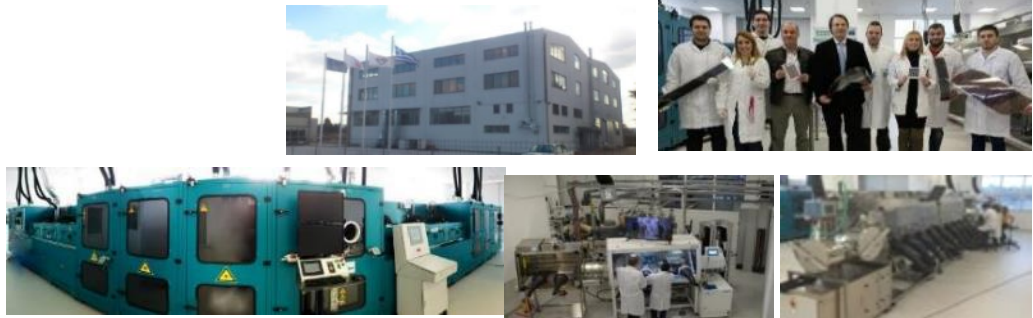
**Prof. Stergios Logothetidis**

Founder of Nanotechnology Lab LTFN, AUTH  
President HOPE-A



# Nanotechnology Lab LTFN: A Competence Center & DIH

- **Multidisciplinary Team** of 30 Expert Scientists in 2500 m<sup>2</sup>
- **HOPE-Association** of Greek Companies & Agreements with >1200 Companies Worldwide
- **Nano-Net** Network (>670 Entities Worldwide)
- **Digital Innovation Hub, 10 Pilot Lines**
- **EIB & GOV Investment (>50 M€) for Extension**



**In-Line Precision Metrology Pulsed Laser Digital NanoManufacturing**



**Automotive**

**Greenhouses**



Factories of the Future  
Public Private Partnership

**Wearables, IoT**

## Core Competences & Excellence

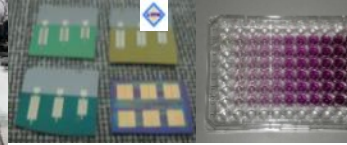
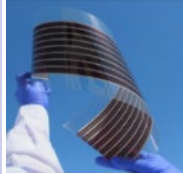
- Thin Film Technologies & Nanoengineering
- Organic & Printed Electronics & Photonics
- Nanomedicine & Nanobiotechnology
- Nanometrology & Optical Technology
- Computational/Modelling at Nano-/Micro-/Macro-Scale

- **Intelligent R2R/S2S PilotLines**
- **NanoManufacturing by OVPD, CVD, PVD Pilot Lines**
- **NanoBio-Fabrication of Novel Systems**

**OPVs, OLEDs, Photonics**

**OTFTs**

**Biosensors**



# Περιεχόμενα

**Εργαστήριο Νανοτεχνολογίας LTFN:** Ευρωπαϊκός Πόλος Νανοτεχνολογίας, Ψηφιακής Καινοτομίας, Νέων Τεχνολογιών & Προϊόντων στα **Οργανικά Ηλεκτρονικά**

## Horizon 2020



### 6 Ευρωπαϊκά Έργα και Συνεργασίες για την Ανάπτυξη της Νανο- Ψηφιακής & Πράσινης Βιομηχανίας

- **SmartLine:** Το Εργοστάσιο του Μέλλοντος στην Βιομηχανία των ΟΗ
- **CORNET:** Περιβάλλον Ανοικτής Καινοτομίας για την Παραγωγή των ΟΗ
- **RealNano:** Τεχνολογίες Νανο-Χαρακτηρισμού & Ψηφιακής Παραγωγής για ΟΗ
- **FF2S:** Open Innovation Test Bed στην Βιώσιμη Ανάπτυξη & Πράσινη Βιομηχανία
- **MUSICODE:** Μοντελοποίηση ΟΗ σε Περιβάλλον Ανοικτής Καινοτομίας
- **nanoMECommons:** Πρωτόκολλα Μηχανικού Νανο-Χαρακτηρισμού για τη Βιομηχανία Αιχμής

- **NANOTECHNOLOGY multi-event:** 19 Χρόνια στη Θεσσαλονίκη

# LTfN στην Ανάπτυξη της Νανο- Ψηφιακής & Πράσινης Βιομηχανίας ΟΗ (6 EU Ερευνητικά Προγράμματα, >40Μ€, 52 Ευρωπαϊκοί Φορείς)



## Real-Time NanoCharacterization Tools 2020-2023

## Factory of the Future 2017-2020

## Open Innovation Test Beds 2020-2024

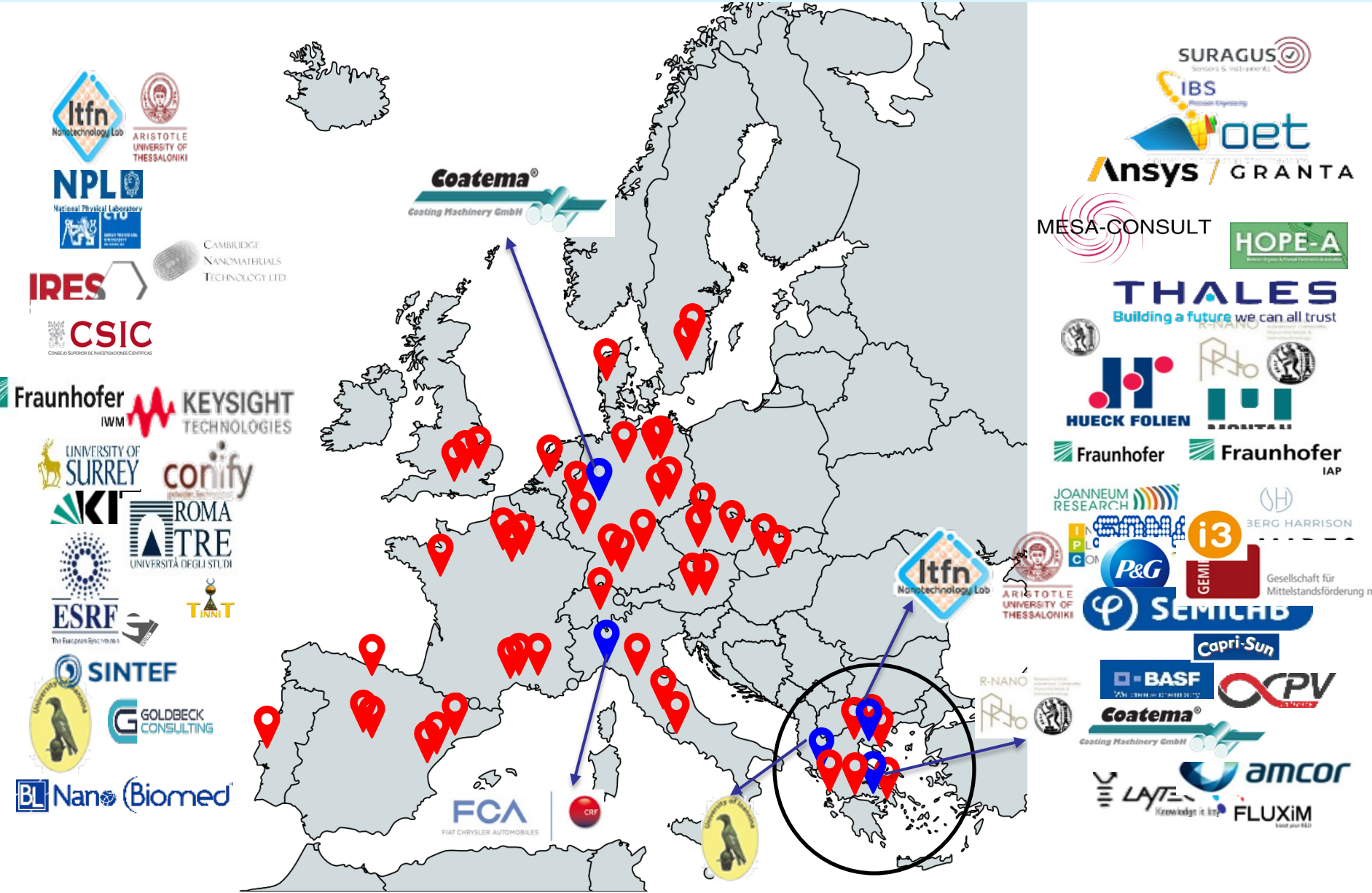
## Open Modelling Platform 2021-2024

## Open Innovation Environment 2018-2021

## Multiscale Characterization 2021-2024

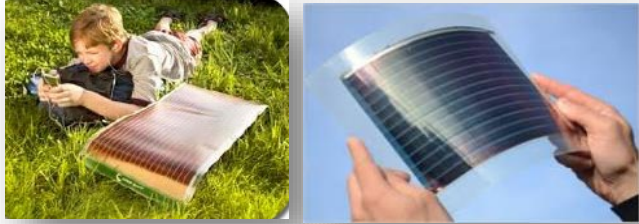


# 6 EU Ερευνητικά Προγράμματα, >40Μ€, 52 Ευρωπαϊκοί Φορείς (36 Βιομηχανικοί & 17 Ερευνητικοί - Ακαδημαϊκοί), 9 Ελληνικοί Φορείς



# Flexible Printed Organic Electronics will Revolutionize our lives

## Energy, Energy Autonomy



## Flexible Displays



## Flexible Lighting (OLEDs)



## Sensors, Biosensors, RFIDs, Smart Packaging



## Transport, Automotive, Mobility



## Energy Efficient Buildings Greenhouses Mobility

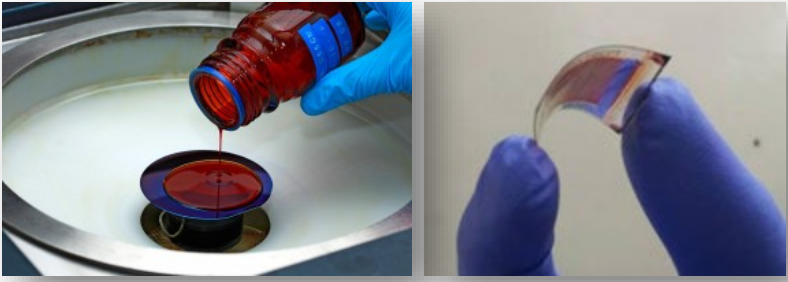


## Wearables, IoT



# How to Upscale Innovations in OEs from Lab to Large Scale and Accelerate Business Uptake?

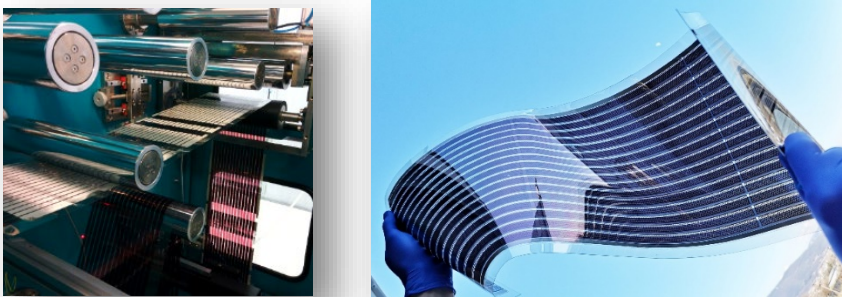
From Lab scale Innovations....



Mainly Universities, Research Institutes



... to Large Scale Manufacturing...

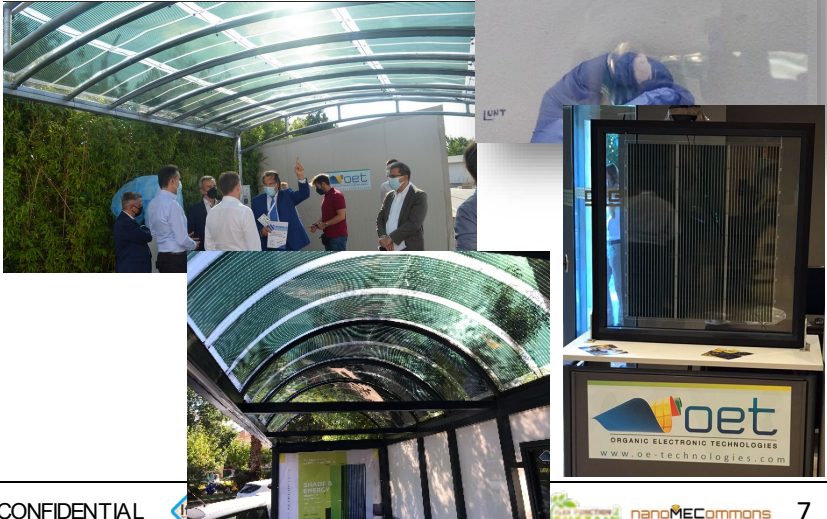


Research Institutes, SMEs, Industries

... and to Commercial Products!



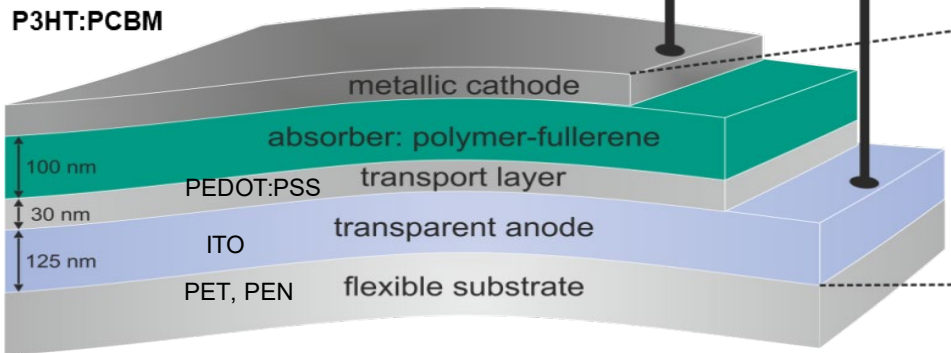
?



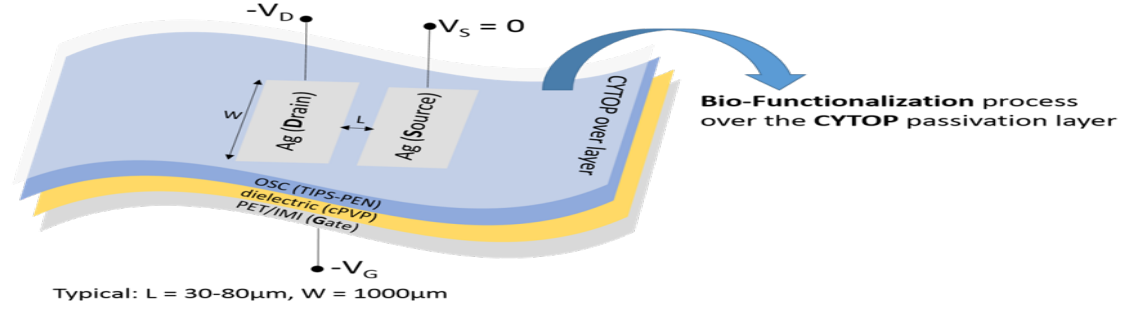
# Main Challenges on the road to Commercialization...



## Organic Photovoltaic – OPV



## Organic Transistor (OFET)-based Biosensor:



## Challenges for Materials

- **Synthesis of OSCs** of high performance and stability
- **Upscaling** of materials in high quantities (>kg scale?)
- **Eliminate deviations** in different material batches

## Challenges for Manufacturing

- **Scalable Processes** (R2R Printing, Vacuum)
- **Reliable** (repeatable with homogeneity in properties)
- **High Yield** (max functional devices, zero defects)
- **Cost Effective** (min use of resources & material waste)





# H2020 Factory of the Future SmartLine (2017-2020)

**Title:** Smart in-line metrology and control for boosting the yield and quality of high-volume manufacturing of Organic Electronics (**SmartLine**)

- **Type:** Innovation Action
- **Work programme:** H2020-FOF-08-2017 (In-line measurement and control for micro-/nano-enabled high-volume manufacturing for enhanced reliability)
- **Duration:** 3+ years (1 September 2017 - 30 Nov 2020)
- **Total Budget:** 5.424.875 Euros
- **Project Website:** <http://smartline-project.eu>



M18 Consortium & Review Meetings, Munich



This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 768707.

# Building the Factory of the Future for FPEs Manufacturing

H2020 FoF Project SmartLine 2017-2021 ([www.smartline-project.eu](http://www.smartline-project.eu))

## Metrology Tools & Methodologies



Spectroscopic Ellipsometry (SE)  
Raman Spectroscopy (RS)



Reflectometry Tools (REF)



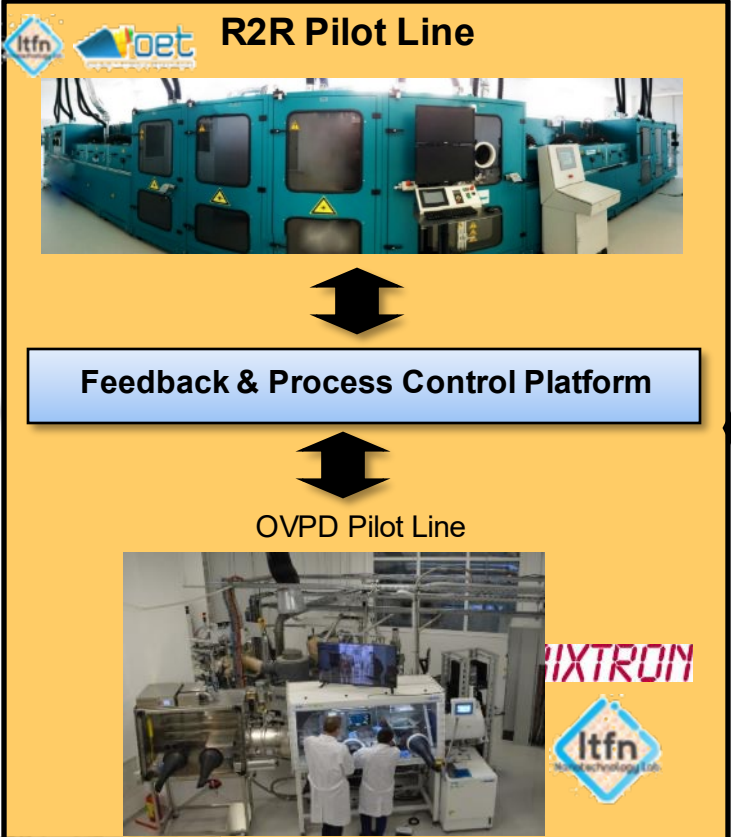
Interferometer (WSI)



Eddy Current Tool (EC)



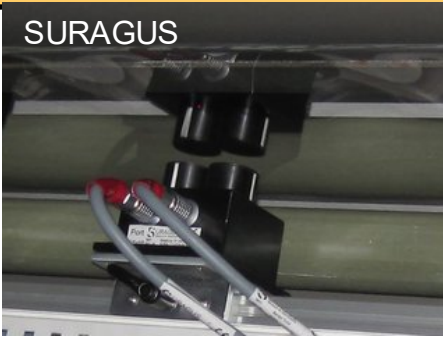
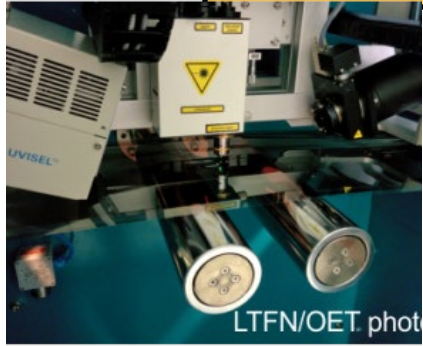
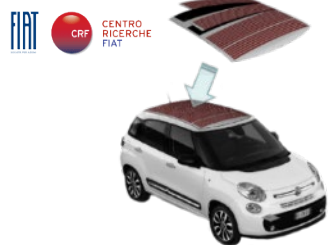
Methodologies for In-line Measurements & Modelling Tools



## High Quality and Efficient Manufacturing Processes



## Validation of Products Quality

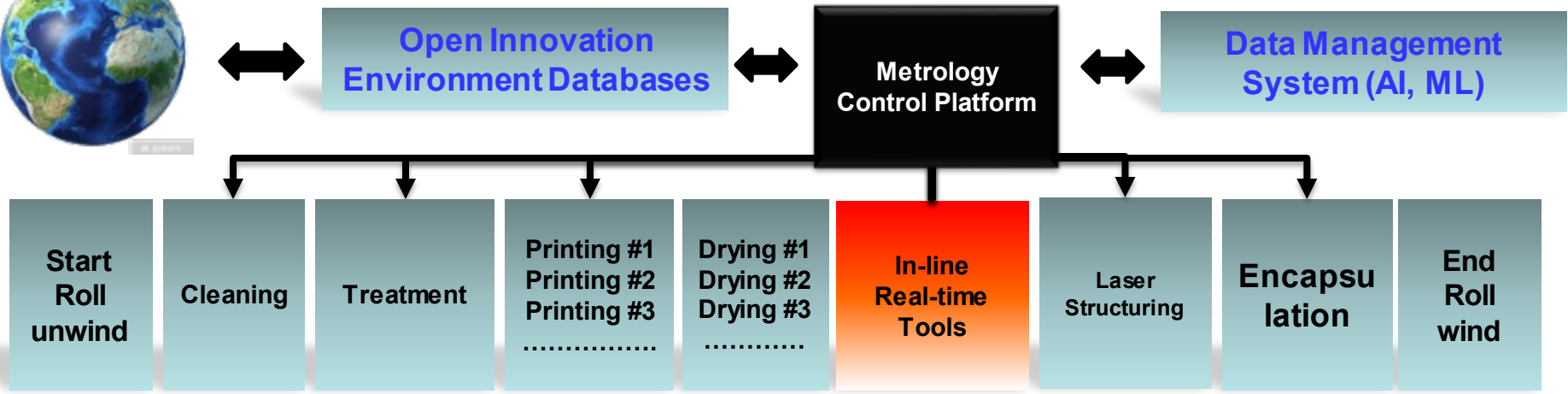


This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 768707.

# Towards Intelligent & Digital NanoManufacturing



## Feedback to the Manufacturing Line for Process Control



### Synthesis - Structure - Property Relations

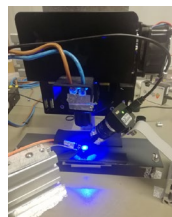
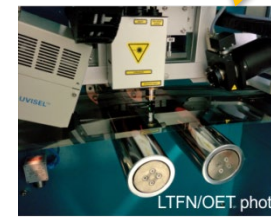
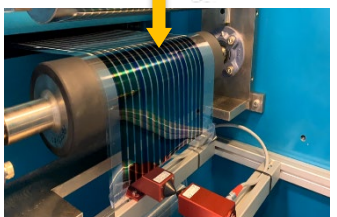
- Thickness (nm)
- Optical/Electrical properties
- Quality of surface patterning
- Structure & Composition
- Blend Morphology

### Process Optimization

- Ensure** Thickness homogeneity
- Maintain** Properties stability
- Keep** Film/Device Reproducibility
- Enable** Fault detection
- Eliminate** Batch-to-Batch variations

# Unique R2R Pilot to Production Line for OEs Manufacturing

## Roll-to-Roll Printing Pilot to Production Line



4axis Slot Die Automated Coating Station with Camera Registration

In-Line Reflectometer

In-Line Eddy Current Tool

In-Line WSI

In line Optical Metrology (SE, Raman)

Imaging PL

In-line LBIC

In-Line & Real-Time Communication to the Pilot Line

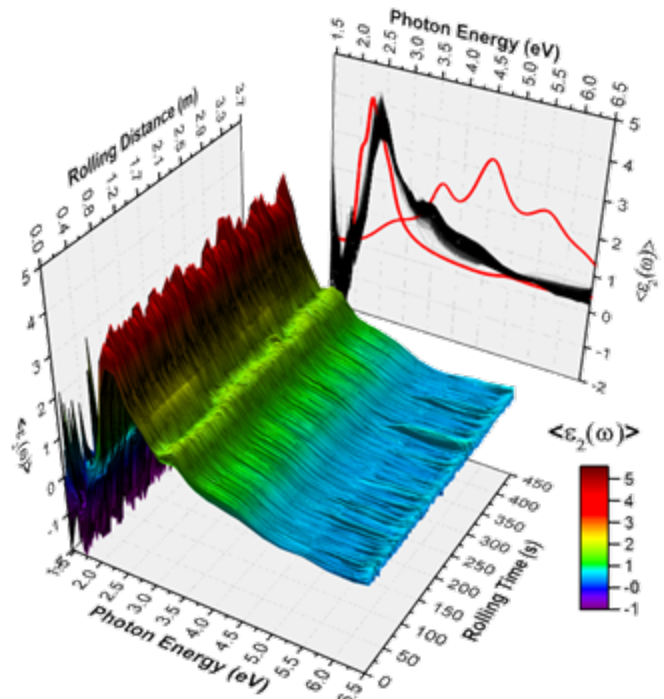


## Intelligent Digital Metrology Control Platform



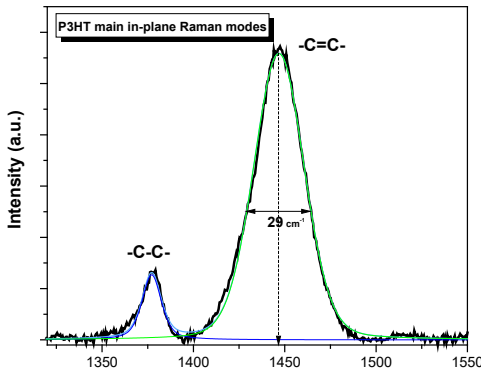
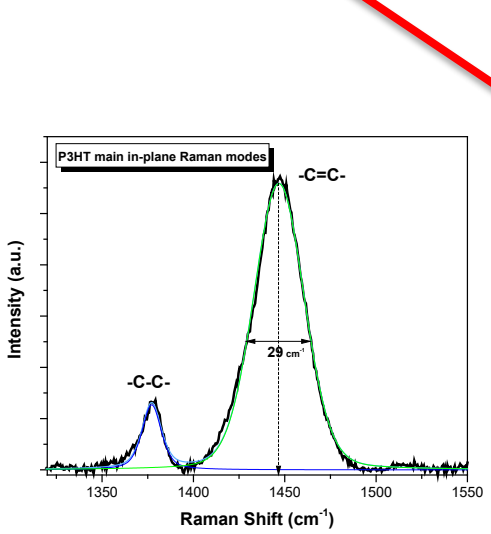
# R2R Pilot Line equipped with Robust In-line Metrology Technologies

## In-line Spectroscopic Ellipsometry



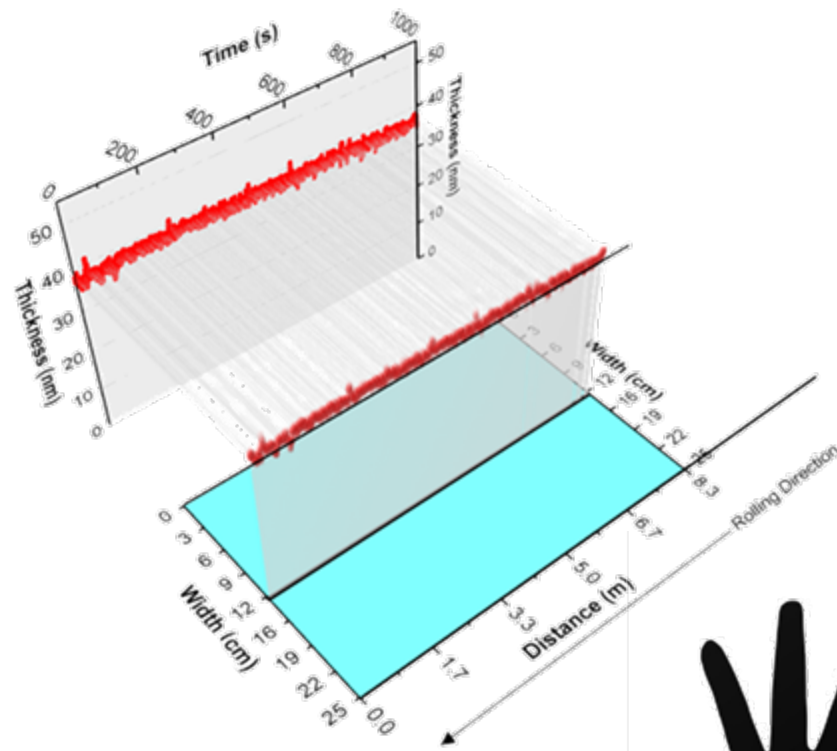
Measurement Time 200 ms  
Spectral Range: 1.5-6.5 eV

## In-line Raman Spectroscopy

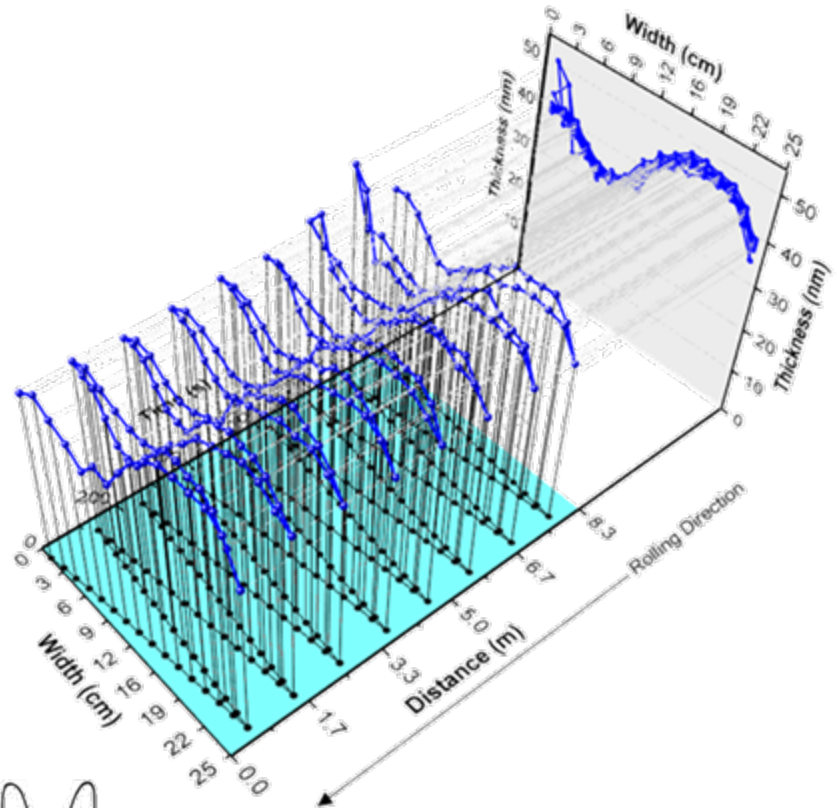


# Inhomogeneities in R2R Printing of transparent electrodes

Scan parallel to the Rolling direction  
 Homogeneous Large scale Printing (?)



Thickness inhomogeneities  
 between different stripes

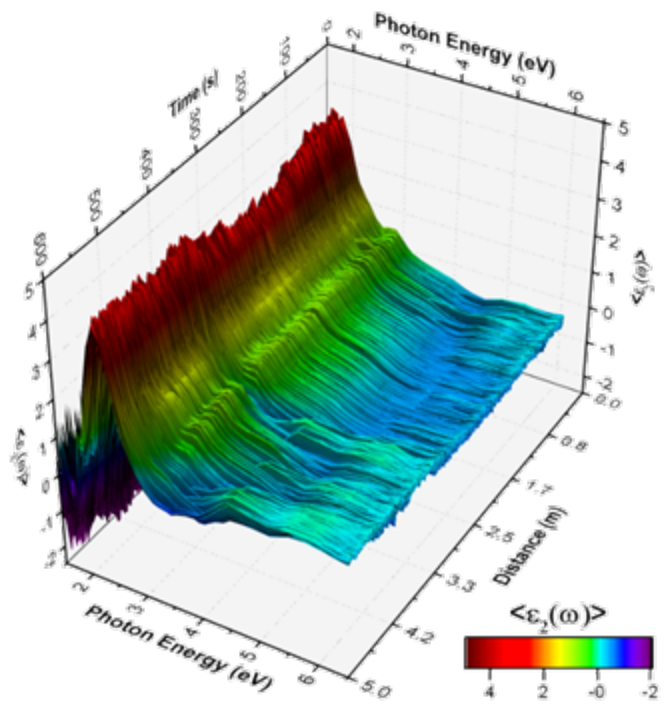


Fully Coated PET/IMI/AZO  
 0.25 x 8.3 m



- ✓ Consistent thickness distribution parallel to the web.  
 $37.16 \pm 0.93$  (33.5min – 41.2 max)
  - ⚠ Inhomogeneous thickness profile perpendicular to the web  
 $40.8 \pm 4.6$  (31.6min – 50.6 max)
- Thickness inhomogeneity may be attributed to:
- Slot Die Misalignment ?
  - Variation on driers static pressure over area ?

# How to Manage, Analyze, Evaluate, Save,... (giga)Metrology Data?

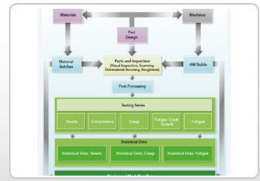


Total Measured length: 5 m  
 Number of Spectra > 5000

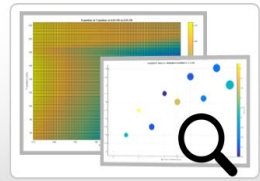
Point Measurement Dataset Size → 50kB/spectra

Full Measurement Dataset Size → 5000\*50kB = 250000 kB = **250MB!!**

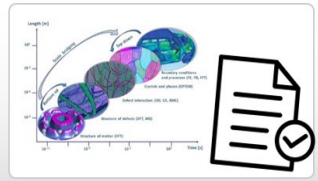
Data Output from 1 Sensor: **50MB / meter Printed Roll!!**



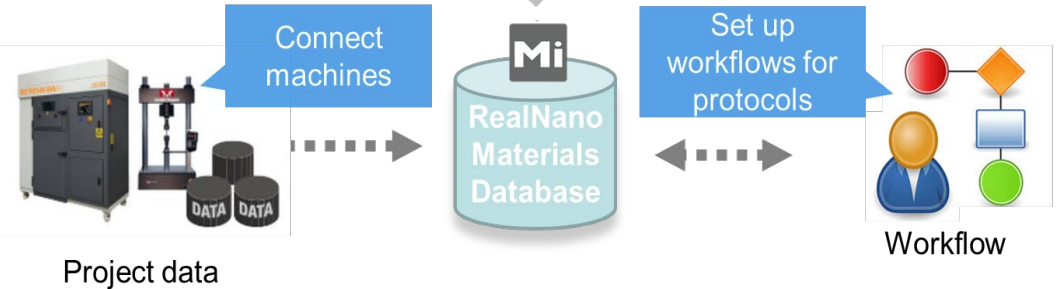
**TRACEABILITY**  
 Capture complete OE process information



**ANALYSIS**  
 Explore property / process relationships



**Validation**  
 Follow standard protocols and ensure error-free reports



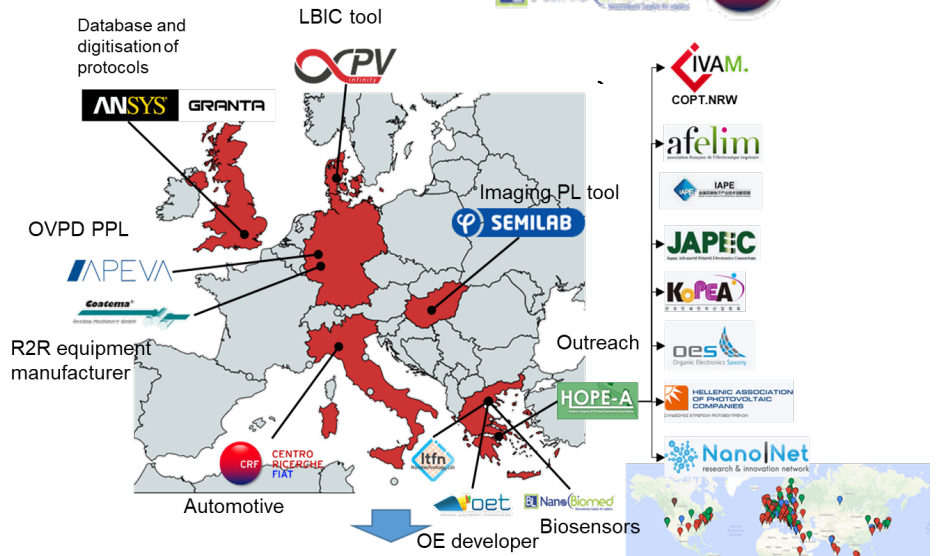
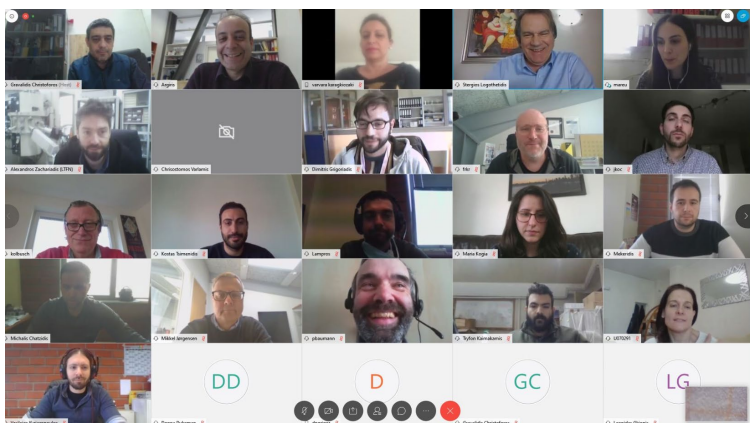
# H2020 RealNano (2020-2023)

**Title:** In-line and Real-time Nano-characterization technologies for the high Yield Manufacturing of Flexible Organic Electronics (**RealNano**)

- **Type:** Research and Innovation Action (RIA)
- **Work programme:** H2020-DT-NMBP-08-2019
- **Duration:** 36 Months (01/03/2020 – 28/02/2023)
- **Total Budget:** 4.978.750 Euros
- **Consortium:** 10 Partners from 6 EU countries



**RealNano Kick-Off Meeting Tuesday  
31 March 2020**



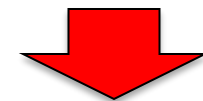
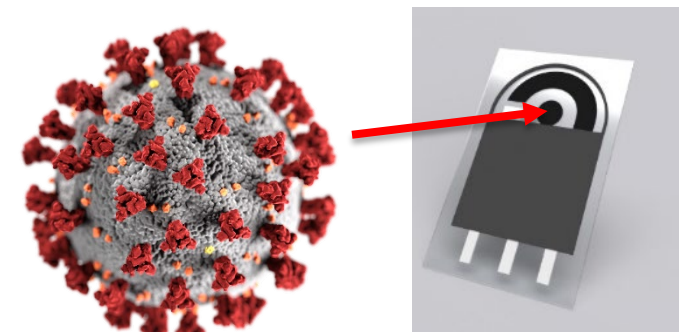
This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 862442.



# To RealNano στην Ανίχνευση του COVID-19

September 2020:

**EU research and innovation in action against the Coronavirus: Funding, Results and Impact"**  
*"RealNano is an example of a project that successfully reoriented its activities to focus on the manufacturing of low cost and printable biosensors to detect the coronavirus."*



*"Knowledge and innovation save lives. Since the start of the COVID-19 outbreak, EU research and innovation has been one of our most impactful tools to tackle the disease. And it will also provide solutions to major concerns of citizens, frontline workers, policy makers and industry for living with the virus in the years to come."*

Mariya Gabriel, Commissioner for Innovation, Research, Culture, Education and Youth



# RealNano Contribution to EU COVID-19 Task Force

## BIOSENSORS for Electrochemical Detection of Covid-19

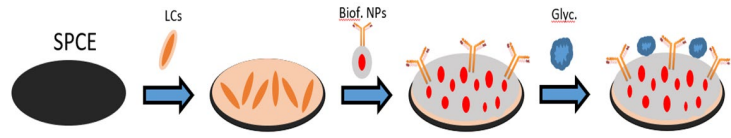
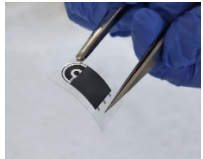
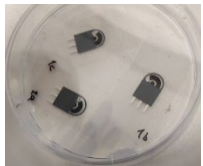
### Characterization of selected steps of Production with RealNano Tools



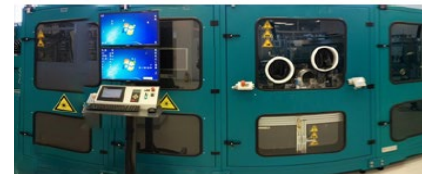
Lab scale  
Proof of Concept

- Specifications
- Functional Characterization of Product

Upscaling of  
Production



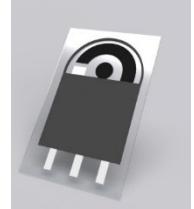
Biofunctionalization of Working Electrode (SPCE)



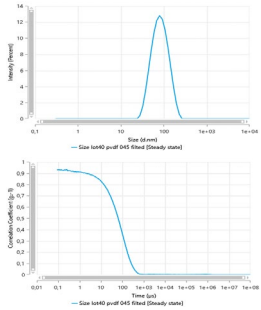
Upscaling of Production and Characterization with RealNano tools



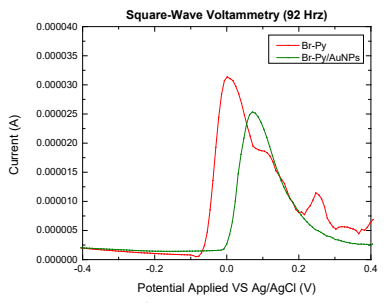
Screen Printed Biosensors



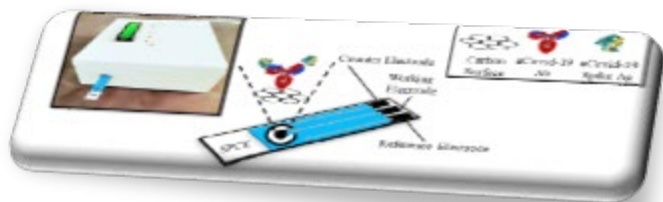
Screen Printing and Co-design



DLS measurement of Biofunctionalized NPs



Square-Wave Voltammetry

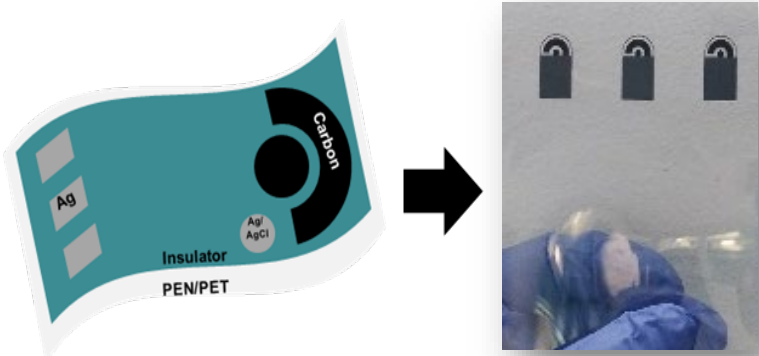


Electrochemical Detection of Covid-19 Ag

# Demonstration & Applications to Consumer Products

## Printed Biosensing Devices

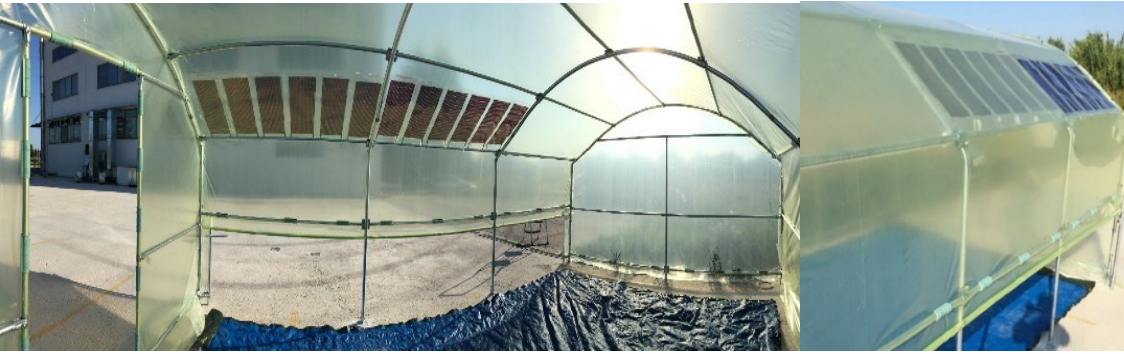
- Assessment of the nano-scale precision characterization with the RealNano tools
- Biofunctionalized nanomaterials and Printed Biosensors (chemical structure, biomaterial nanolayer thickness, Biofunctionalization dynamics) (BL, OET)



## Automotive (OPVs for exterior, OLEDs in interior)



## Mediterranean Greenhouses (Energy Harvesting by Semitransparent OPV Panels)



# Open Innovation Environment: CORNET (2018-2021)

## Multiscale Modelling and Characterization to Optimize the Manufacturing Processes of Organic Electronics Materials and Devices (CORNET)

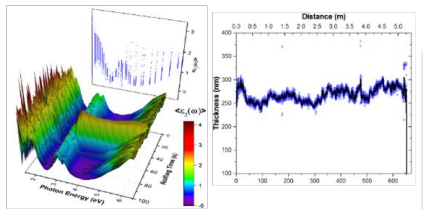


cornet-project.eu



Coordinator

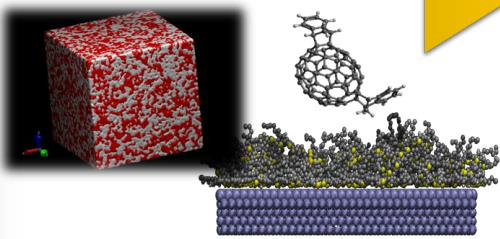
Multiscale Characterization (optical, electrical, structural, etc)



Large Scale Manufacturing (R2R Printing, OVPD)



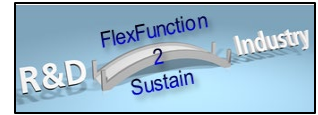
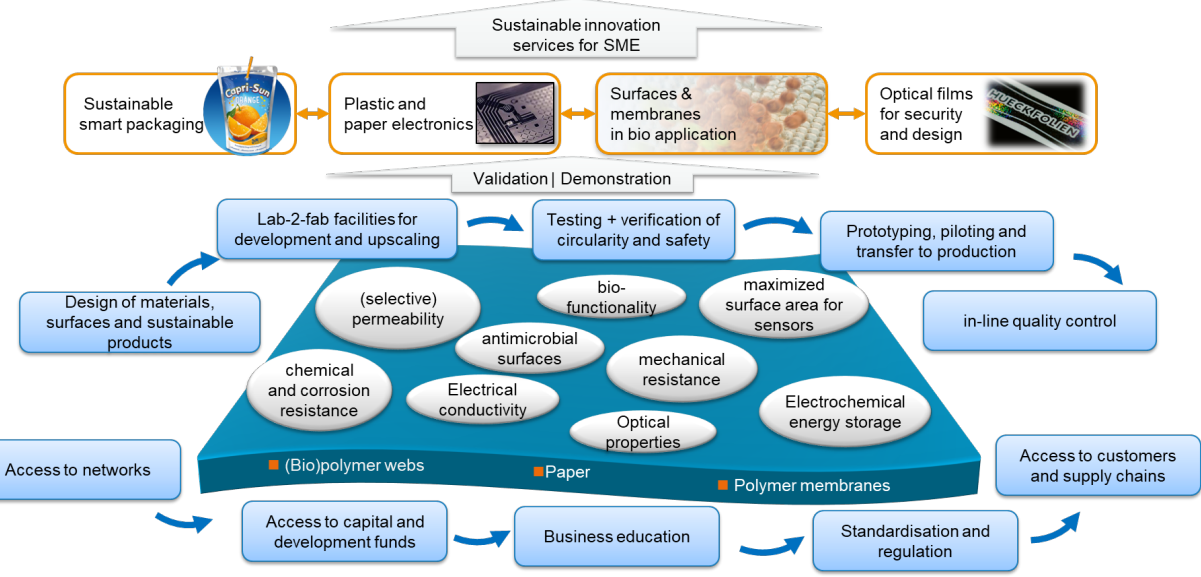
Multiscale Modelling (Ab-initio, MD, MC, Mesoscopic, Compact, Device)



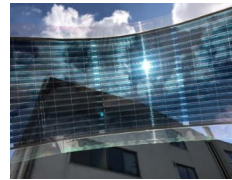
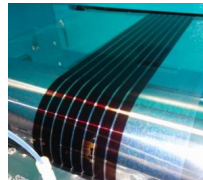
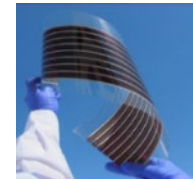
This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 760949.

# FlexFunction2Sustain OITB (2020-2024)

## Open Innovation Ecosystem for Sustainable Nano-Functionalized Plastic and Paper Surfaces and Membranes (FF2S)



### Unique Pilot Lines for Organic Electronics Manufacturing



OITB Members	Industrial Validation	Potential Clients	External Stakeholders
		<p>20 pilot cases (selected during the project)</p>	<p>Board of Investors and Foundations</p> <p>External Advisory Board</p> <p>(Networks, Regulations, Standardisation, and others)</p>

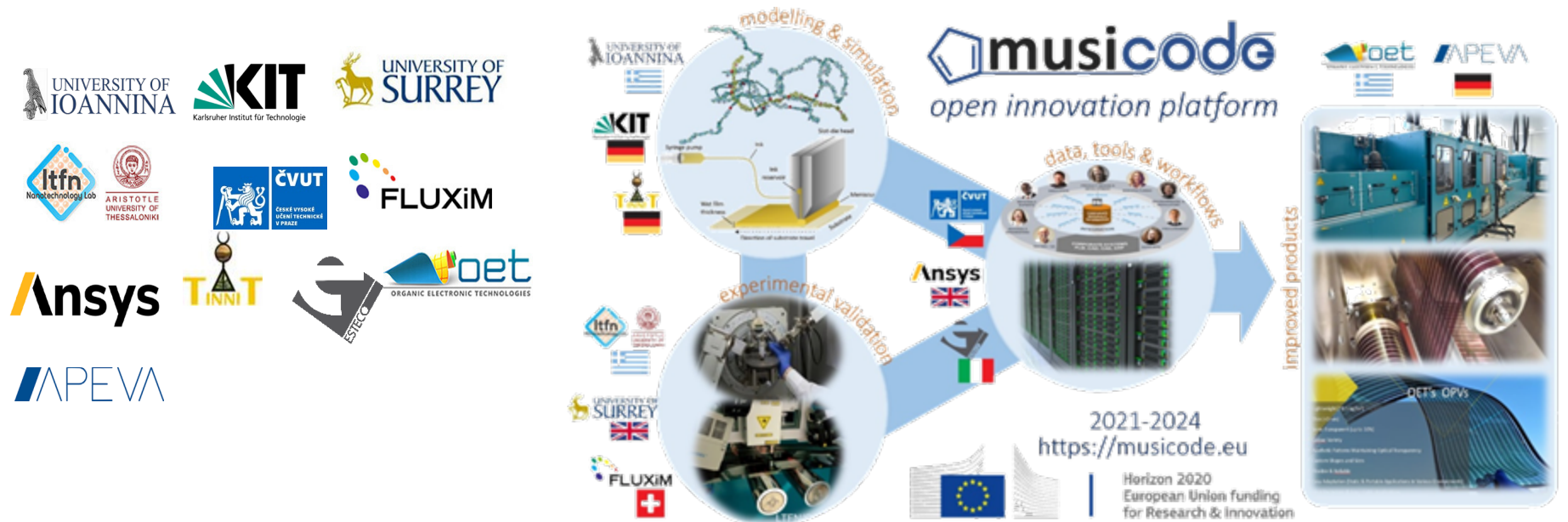


This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 862156.

# H2020 MUSICODE (2021-2025)

“An Experimentally-validated **Multi-scale** Materials, Process and Device Modeling & Design Platform enabling non-expert access to Open Innovation in the Organic and Large area Electronics Industry (**MUSICODE**)

H2020 Call DT-NMBP-11-2020 “Open Innovation Platform for Materials Modelling”  
**10 Partners from 5 EU Countries**



## MUSICODE Objectives:

- O1:** Validated multiscale modelling workflows for OLAE materials, processing, and devices.
- O2:** Ontology-based integrated modelling platform for workflow design, execution, data management.
- O3:** Cooperation with stakeholders (Marketplaces and HPCs) for complete customer offer.
- O4:** Implementation for industrial manufacturing of OPV & OLED and demonstration in applications.

 This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 953187.

# H2020 NANOMECCOMMONS (2021-2024)

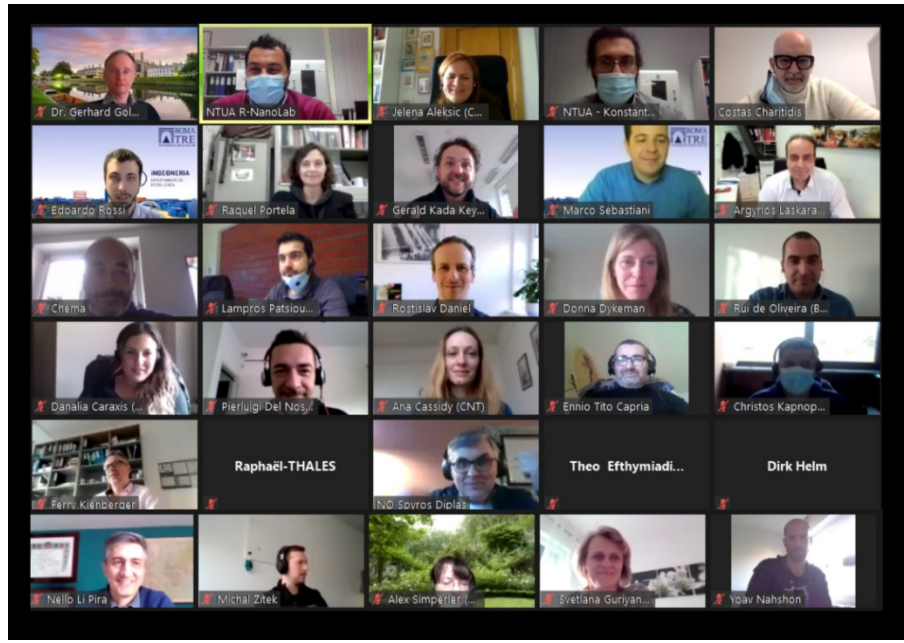
## Nanocharacterization Protocols in EU Scale

“Harmonization of EU-wide **Nanomechanics Protocols** and relevant data exchange procedures, across representative cases; Standardization, Interoperability, Data workflow” (**NANOMECCOMMONS**)

H2020 DT-NMBP-35-2020 “Towards harmonized characterization protocols in NMBP

### 19 Partners from 10 EU Countries

NTUA, UNIROMA3, SINTEF, AUTH, MUL, CSIC, IRES, Fraunhofer, GCL, ESRF, CNAT, Granta, KEY, TRT, CRF, OET, BASF, CONIFY, MESA



This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 952869.

# LTfN στην Ανάπτυξη της Νανο- Ψηφιακής & Πράσινης Βιομηχανίας ΟΗ (6 EU Ερευνητικά Προγράμματα, >40Μ€, 52 Ευρωπαϊκοί Φορείς)



## Real-Time NanoCharacterization Tools 2020-2023

## Factory of the Future 2017-2020

## Open Innovation Test Beds 2020-2024

## Open Modelling Platform 2021-2024

## Open Innovation Environment 2018-2021

## Multiscale Characterization 2021-2024



# THANK YOU FOR YOUR ATTENTION

## Acknowledgements



<http://smartline-project.eu>

GA 768707

FOF-08-2017



<http://cornet-project.eu>

GA 760949

NMBP-09-2017

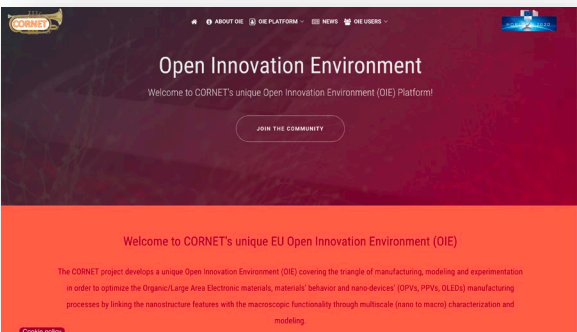


<http://realnano-project.eu>

GA 862442

NMBP-08-2019

# CORNET Open Innovation Environment Platform (Digital Marketplace)



LOG OUT	User Details	Registered Organizations
	Mark Andria Affiliation: University of Ioannina, ISI Position: PhD	
	Shiva Giovanna Antonello Affiliation: CNF Scpa Position: Project Management	
	Daniela Braga Affiliation: Flaim AG Position:	
	Sandra Juretsch Affiliation: Flaim AG Position: R&D Scientist	
	Konstantinos Kaklamatis Affiliation: University of Ioannina (UOI) Position: PhD student	
	Stelios Karamanidis Affiliation: Nanotechnology Lab LFN - Aristotle University of Thessaloniki Position: IT/Tech support, Webmaster	
	MARIA KODIA Affiliation: Partner in CORNET Position: Project Manager	
	Agneta Lantieralis Affiliation: Nanotechnology Lab LFN Position: Head of Organic Electronics Group	
	DAVID BANT Affiliation: University of Surrey	

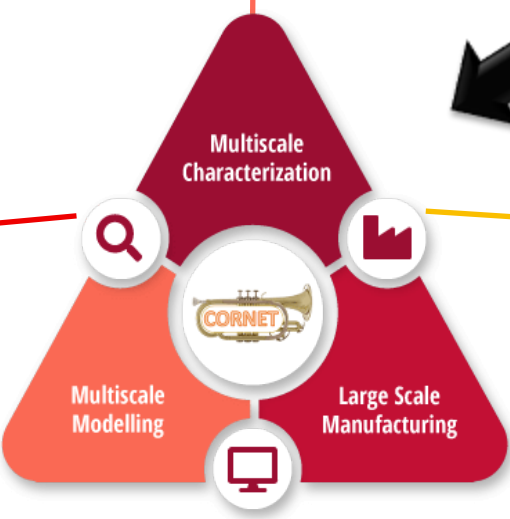


- ✓ Industries post Challenges & Requests
- ✓ Innovators identify Capacities
- ✓ Infrastructure List

Connection between Users and Organizations (Connection Requests)

Discussion Area (Discussion Posts)

Instant Messaging and emailing



- ✓ Instant messaging
- ✓ Contacts Identification
- ✓ Posting of success stories
- ✓ Best Practices Listing

- ✓ Immediate Contact between Entities
- ✓ Fast Access
- ✓ Building of Synergies & Collaborations

Join the CORNET Platform:  
<https://www.cornet-project.eu/oie/index.php>



This project has received funding from the European Union's HORIZON 2020 research and innovation programme under Grant Agreement No 760949.

# NANOTECHNOLOGY 2021 (3-10 July 2021), [nanotexnology.com](http://nanotexnology.com)

- Organized annually since 2004, Bringing > 800 experts from >60 Countries
- Hybrid event during COVID-19 Pandemic supporting on-line Participation from all over World



2021 nanotexnology  
INTERNATIONAL CONFERENCES & EXHIBITION ON NANOTECHNOLOGIES - ORGANIC ELECTRONICS & NANOMEDICINE  
3-10 JULY 2021, THESSALONIKI, GREECE  
www.nanotexnology.com

**18<sup>th</sup> International Conference in Nanosciences & Nanotechnologies, 6-9 July**

**Workshops**

- W1: Nanoelectronics, Photonics, Plasmonics & NanoEnergy
- W2: Nanomaterials, Fabrication, Engineering & Construction
- W3: Nanomedicine
- W4: Biosensors & Bioelectronics \*
- W5: Graphene & Related Materials \*

**Parallel Events & Special Workshops**

- Computational Modeling of Materials & Devices \*
- New Business Development & Commercialization \*
- Special Workshop on EU Projects
- Matchmaking Event
- and many more to be announced...

**14<sup>th</sup> International Symposium on Flexible Organic Electronics, 5-8 July**

**Workshops & Sessions**

- OLAE Materials
- OPVs & Perovskite PVs
- OLEDs, OTFTs & Sensors
- Smart Textiles, Wearables & IoT
- Graphene & 2D Materials \*
- Biosensors & Bioelectronics \*

**Parallel Events & Special Workshops**

- Computational Modeling of Materials & Devices \*
- New Business Development & Commercialization \*
- Special Workshop on EU Projects
- Matchmaking Event
- and many more to be announced...

**4<sup>th</sup> Int. Conference on 3D Printing, 3D Bioprinting, Digital & Additive Manufacturing, 7-8 July**

**Topics**

- 3D Printing • Materials, Functionalities, Architectures • 2D to 3D Printing • 3D Bioprinting • Cell Printing Technologies • Bioinks
- Additive Manufacturing • R2R Printing Processes • Ultra Fast Pulsed Lasers processing, tools, photonics, etc.
- Digital Manufacturing & Applications • Gas transport & Vacuum Processes • Pilot Lines etc.

**15<sup>th</sup> Int. Summer Schools on Nanotechnologies, Organic Electronics & Nanomedicine, 3-10 July**

**Schools**

- School 1: Nanosciences & Nanotechnologies
- School 2: Organic Electronics
- School 3: Nanomedicine

**Schools Program Includes**

- Parallel Workshops/Schools • Fix-and-attend Lectures
- Tutorials & Demonstration Lessons • Poster Session
- Gain 3 ECTS Credits

**11<sup>th</sup> Int. Exhibition on Nanotechnologies, Organic Electronics & Nanomedicine, 5-9 July**

**Exhibition Topics**

- Materials, Chemicals & Inks • Fabrication & Manufacturing Equipment • 3D Printing - 3D Bioprinting
- Metrology & Instrumentation Systems • Organic & Printed Electronics • Photonics & Nanoelectronics
- Nanomedicine & Pharma • Sensors & Biosensors • Wearables - IoT • Smart Packaging • Applications • Services, etc.

**Matchmaking Event**

**Business forum**

more information:  
 ISFOE21: Dr. A. Laskarakis, A. Theodosiou (isfoe@nanotexnology.com), T: +30 2310 998266/998091  
 NN21: Dr. C. Gravalidis, A. Theodosiou (nn21@nanotexnology.com), T: +30 2310 998850/998091  
 IS3D21: Dr. A. Laskarakis, Dr. C. Gravalidis, A. Theodosiou (is3d@nanotexnology.com), T: +30 2310 998850/998091  
 ISSON21: Dr. C. Gravalidis, A. Theodosiou (isson@nanotexnology.com), T: +30 2310 998850/998091  
 EXPO21: A. Theodosiou (expo@nanotexnology.com), T: +30 2310 998091

