BEDIMENSIONAL

A deep-tech company at the roots of a new age of industrial innovation

# Solution Processing 2D Materials for Energy Applications


***Francesco Bonaccorso***

*Co-Founder & CSO*


Polymeris-Aramco Workshop – 17 June 2025

BEDIMENSIONAL

**2016**
Foundation

**2018**
10M€+ round

**2020**
R&D labs, pilot production site

**2023**
15M€+ round

**2024**
Industrial production site, 40+ FTEs

**2025**
7-digit in revenues

# Who we are

## Cutting-edge products

At BeDimensional, we are revolutionizing materials science with our **cutting-edge 2D crystals**, including Few-Layers Graphene and Hexagonal Boron Nitride.

Our **versatile 2D crystals**, available in both powder and liquid forms, seamlessly integrate with other products to deliver exceptional performance in **advanced electrical and thermal management, mechanical reinforcement, and lubricant enhancement.**

## Maturity and large-scale capacity

Our products have been **already tested in several applications with industry leading partners.**

Starting with our first industrial plant in Genoa dedicated to large-scale production, we currently have a **capacity of up to 3-5 tons** of 2D crystals, with plans for further expansion over the next two years.

## Push for Innovation

We are a spin-off of the Graphene Labs at **Istituto Italiano di Tecnologia (IIT).**

Our Team is composed **by World Class experts with 250+ scientific publications** in 2D crystals.

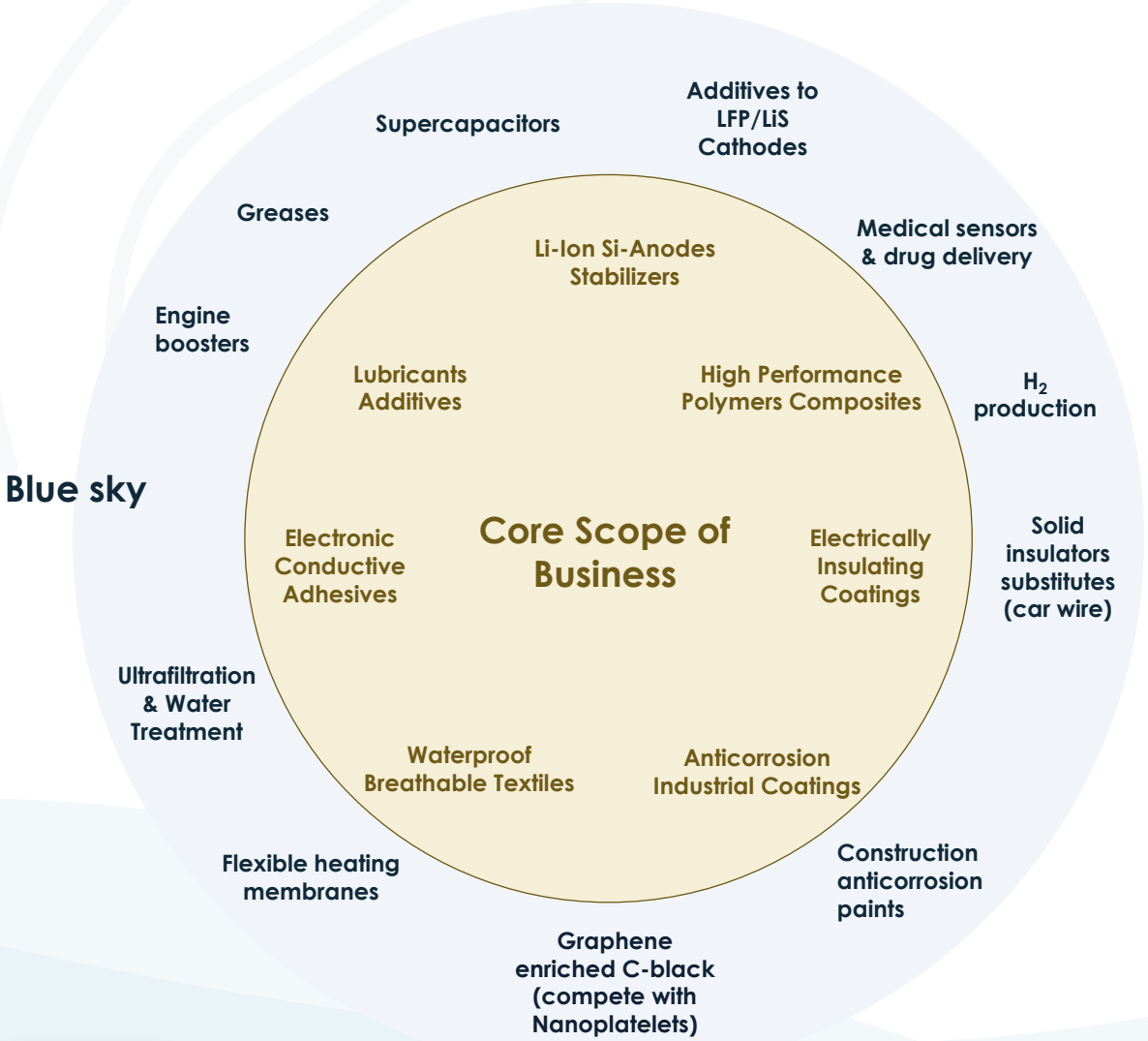
We also partner with the **European Graphene Flagship Programme** and the Innovative Advanced Materials Initiative (IAM-I).

***World's leading 2D materials production plant***


# OUR BUSINESS LINES

- Paints & Coatings
- Polymer Compounds
- Energy storage and conversion
- Lubricants

# OUR PRODUCT INNOVATION







# PRODUCTS ON THE MARKET

**G-LEAF**

Few-layers graphene powder


**B-LEAF**

Few-layers hexagonal boron-nitride powder


**TECHNOPOLYMER MASTERBATCHES**

PEEK and PPSU pellets masterbatch for:

- Impact reinforcement
- ESD conduction


**WATER-BASED LIQUID CONCENTRATES**

Stable water-based concentrate dispersions


**SOLVENT-BASED LIQUID CONCENTRATES**

Stable solvent-based concentrate dispersions with different polarities


**POLYMER MASTERBATCHES**

pellets masterbatch for:

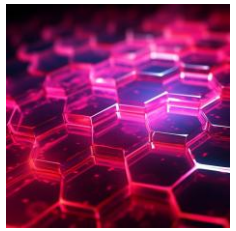
- Impact reinforcement
- ESD conduction

# CUSTOMIZATION AND PRODUCT DEVELOPMENT

## Electrical management

**G-LEAF** makes the most common paints (acrylic, polyurethane or epoxy) **electrically conductive**.

**B-LEAF** makes the most common paints (acrylic, polyurethane or epoxy) **electrically insulating AND thermally dissipative.**



## Heat generation

Homogeneous heating of any substrate can be obtained thanks to **G-LEAF** and a voltage source.

We have prototyped paints to heat-up textiles, buildings and any flexible or solid substrate (electrical connections are required).

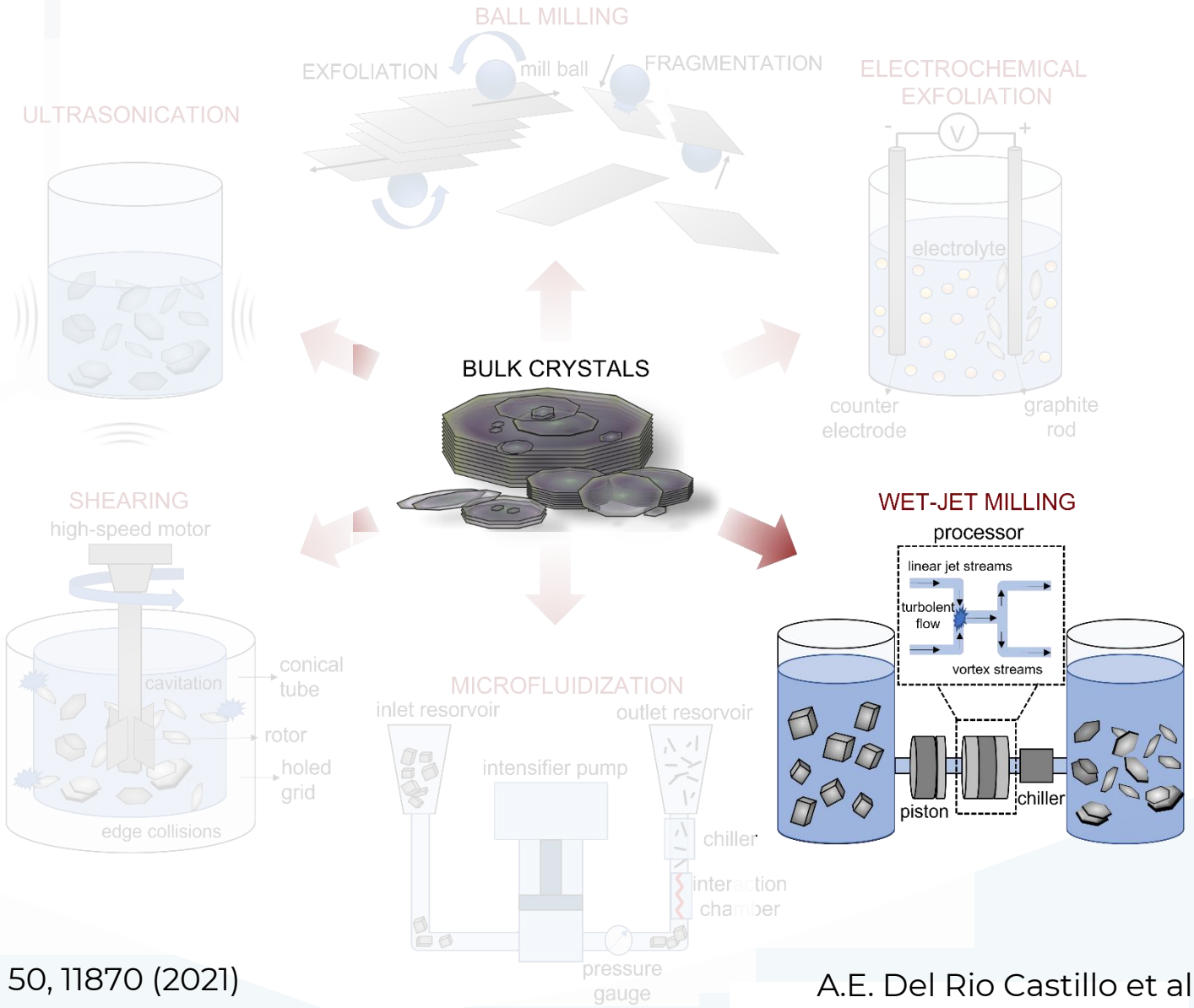
## Heat management

Membranes for **fabrics**, **textiles** and **leather** compatible with standard processes and techniques.

## Electrochemical applications

Graphene for silicon-dominant anodes in Li-ion batteries with increased storage capacity by 30%. Developed in collaboration with VARTA Gmbh.

# EXFOLIATION FROM BULK CRYSTALS

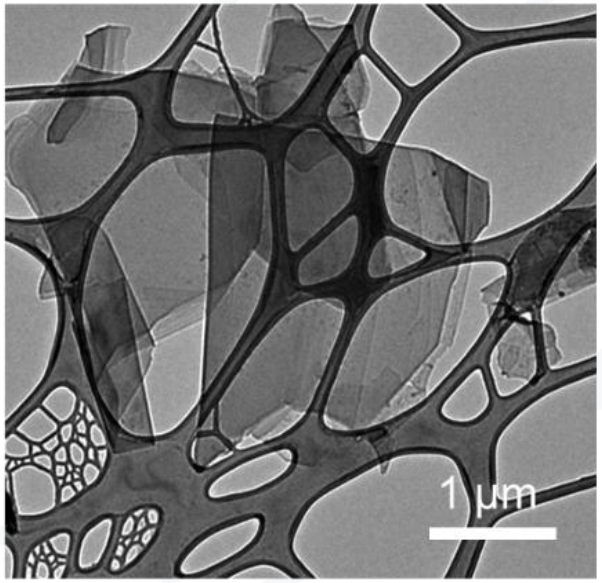


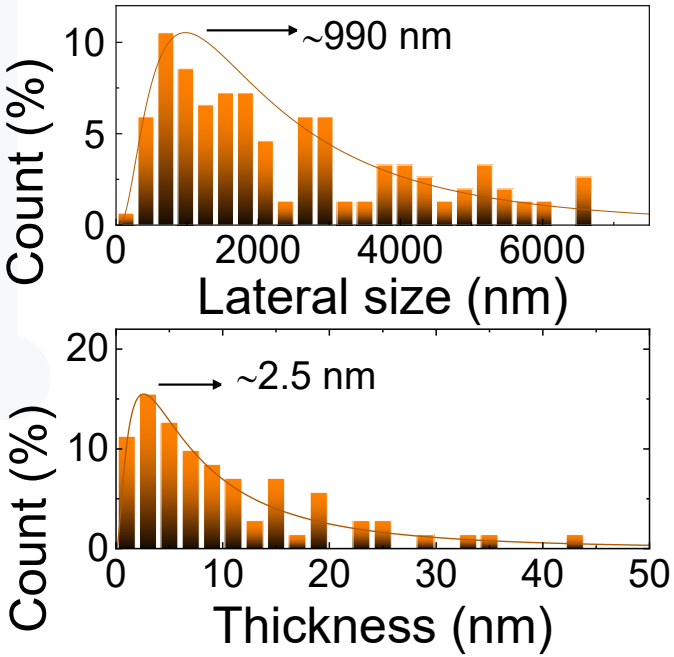

***Granted Patents***:
IT 102015000077259
EP 3380435
US 10407308
JP 6791965
KR 101969118

S. Bellani et al. Chem. Soc. Rev. 50, 11870 (2021)

A.E. Del Rio Castillo et al., Mater. Horiz. 5, 890, (2018)

# HIGH QUALITY GRAPHENE FLAKES

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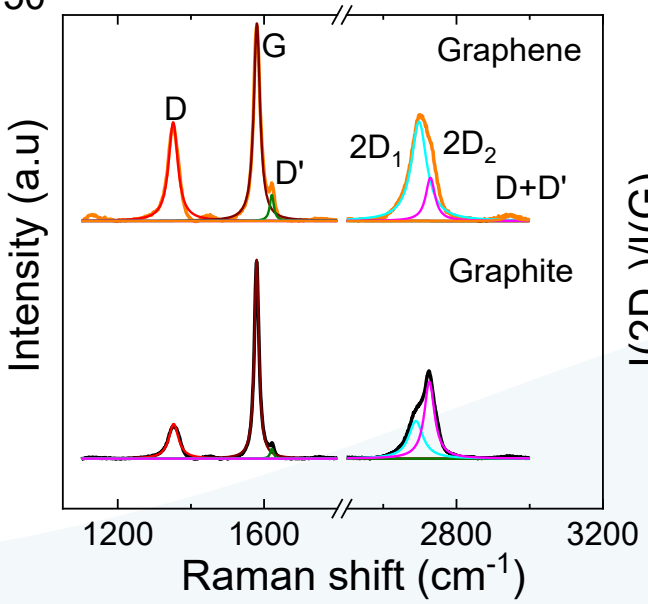
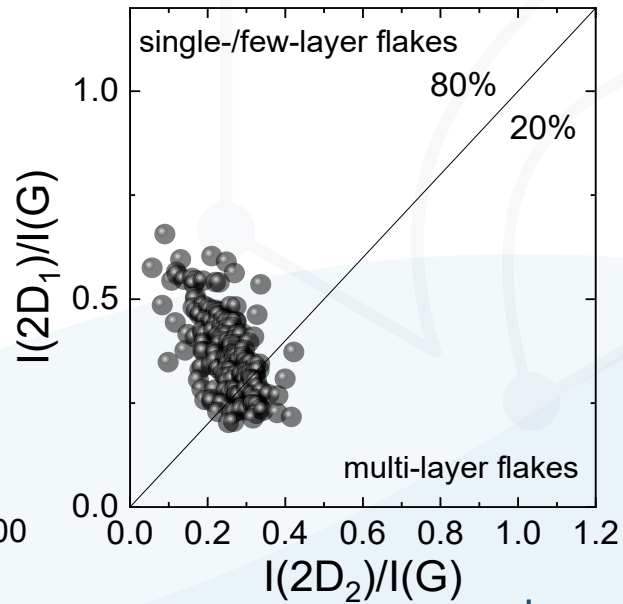



A.E. Del Rio Castillo et al., Mater. Horiz. 5, 890, (2018)

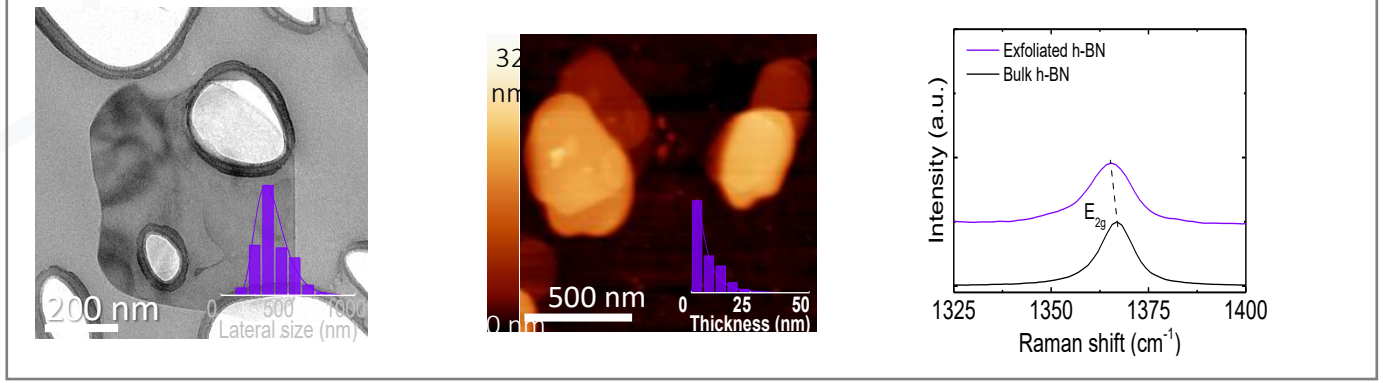
# EXFOLIATION OF OTHER LAYERED CRYSTALS

## BeD standard quality control

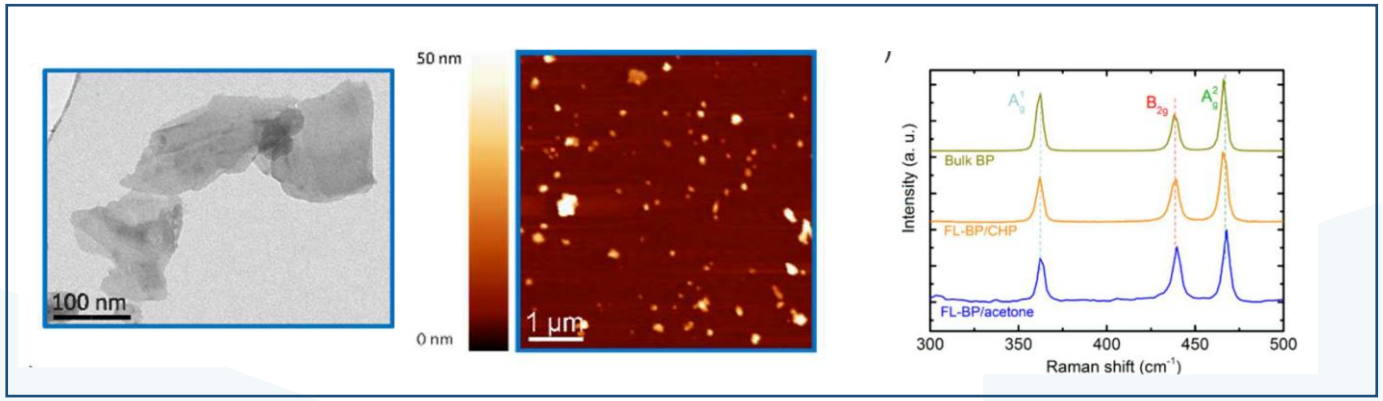
MORPHOLOGICAL CHARACTERIZATION OF THE EXFOLIATED MATERIALS

STRUCTURAL CHARACTERIZATION

**h-BN**




**BP**





A.E. Del Rio Castillo *et al.*, Mater. Horiz. 5, 890, 2018

A.E. Del Rio Castillo *et al.*, Chem Mater. 30, 506, 2018

J. Ren *et al.*, 2D Materials 7, 045023, 2020

Y. Zhan *et al.*, Nanoscale 12, 7782, 2020

# PAINTS & COATINGS

A rich set of functional inks with flakes having different (opto)electronic-(electro)chemical properties

**Graphene**

**Bismuth selenide** ($Bi_2Se_3$)

**Tungsten diselenide** ($WSe_2$)

**Molybdenum diselenide** ($MoSe_2$)

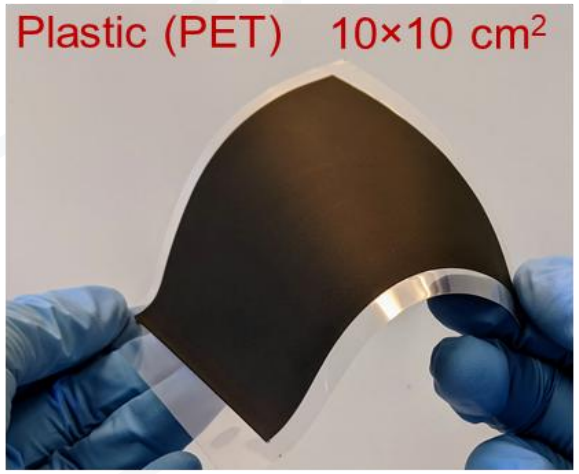
**Molybdenum disulfide** ($MoS_2$)

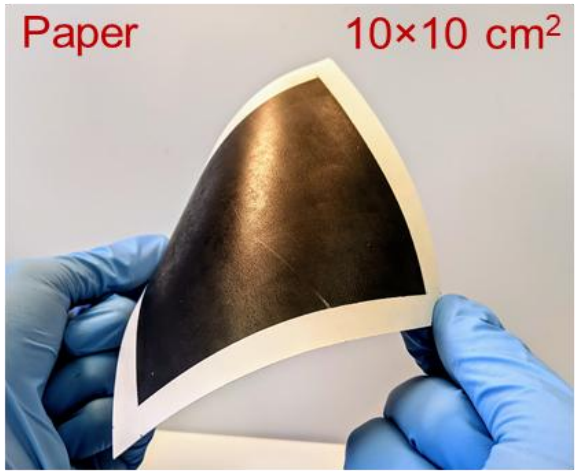
**Tungsten disulfide** ($WS_2$)

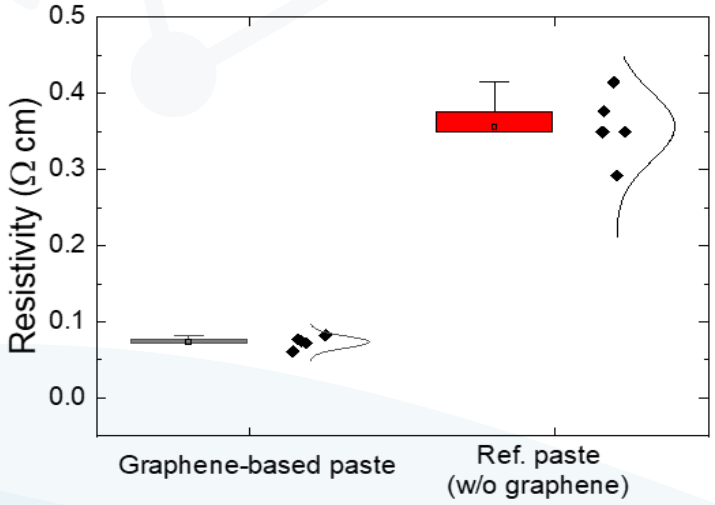
**Hexagonal boron nitride** (h-BN)

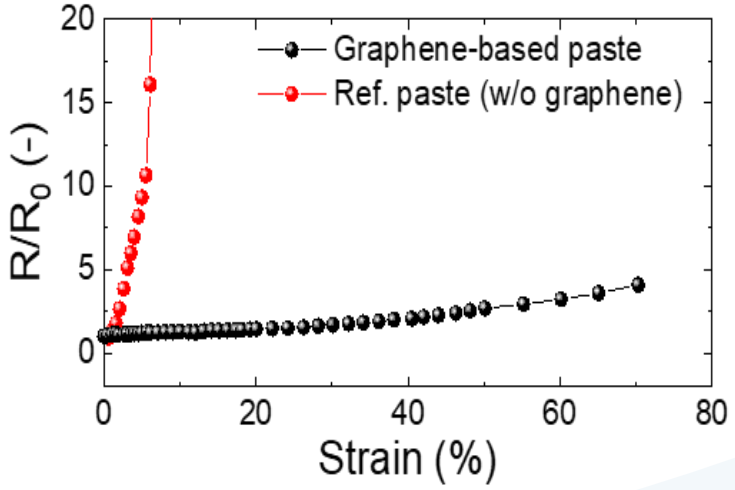
F. Bonaccorso et al. Adv. Mater. 28, 6136-6166 (2016)

# PAINTS & COATINGS: SOME EXAMPLES OF PERFORMANCES /1

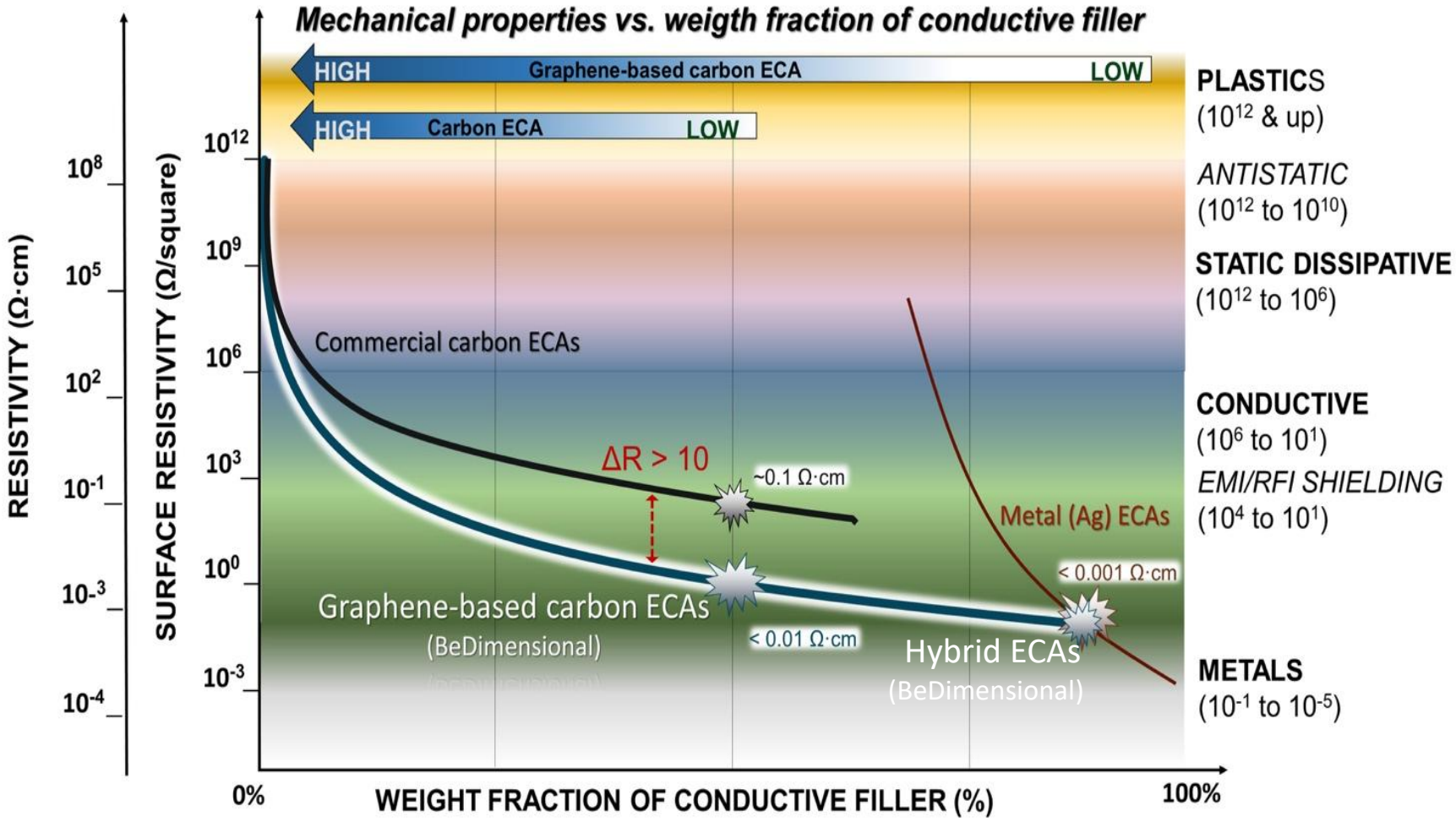




P. Mariani *et al. ACS Appl. Mater. Interfaces* 2021, 13, 22368

# GRAPHENE-BASED CONDUCTIVE PASTES: PERFORMANCES





**Thermoplastic ECA**
Resistivity : 0.0091 Ω·cm
Ag content <70%

**Thermosetting ECA**
Resistivity : 0.00033 Ω·cm
Ag content <50%

BeD graphene-based pastes surpass the performances of other conductive pastes both in terms of electrical resistivity and mechanical resistance

Patent pending: IT 102022000007325

# HOW TO USE 2D MATERIALS IN PEROVSKITE PHOTOVOLTAICS

## ETLs

- Graphene & derivatives
- Transition metal dichalcogenides (*e.g.*, $MoS_2$, $TiS_2$, $SnS_2$)
- MXenes (*e.g.*, $Ti_3C_2T_x$)
- Elemental 2D materials (*e.g.*, black phosphorous/phosphorene)

## HTLs

- Graphene & derivatives
- Transition metal dichalcogenides (*e.g.*, $MoS_2$, $MoSe_2$, $WS_2$, $WSe_2$, $TaS_2$, $NbSe_2$
- Group-15 metal calchogenides (e.g., $Bi_2Se_3$
- MXenes (*e.g.*, $Ti_3C2T_x$
- III-VI compounds (*e.g.*, $In_2Se_3$)
- Elemental 2D materials (*e.g.*, black phosphorous

## Dopants for CTLs

- Graphene & derivatives
- Transition metal dichalcogenides (*e.g.*, $MoS_2$, $WS_2$)
- Elemental 2D materials (*e.g.*, black phosphorous, Antimonene
- g-$C_3N_4$
- Group-15 metal calchogenides (*e.g.*, $Bi_2Te_3$)

## Electrodes (current collector)

- Graphene & derivatives
- MXenes (*e.g.*, $Ti_3C_2T_x$)

## Additives for photoactives

- Graphene & derivatives
- Transition metal dichalcogenides (*e.g.*, $WSe_2$)
- Elemental 2D materials (*e.g.*, black phosphorous/phosphorene)
- MXenes (*e.g.*, $Ti_3C_2T_x$)
- Metal oxysulfides (*e.g.*, $Bi_2OS_2$)
- MOFs
- 2D perovskites (*e.g.*, $(PEA)_2PbI_4$)
- g-$C_3N_4$

## Buffer layers (protective layers and passivating layers)

- Graphene & derivatives
- Transition metal dichalcogenides (*e.g.*, $MoS_2$ and $TiS_2$)
- Elemental 2D materials (*e.g.*, black phosphorous)
- Group-15 metal chalcogenides (*e.g.*, $Bi_2Te_3$)
- g-$C_3N_4$
- 2D c-MOFs
- 2D perovskites

## Interconnecting layers

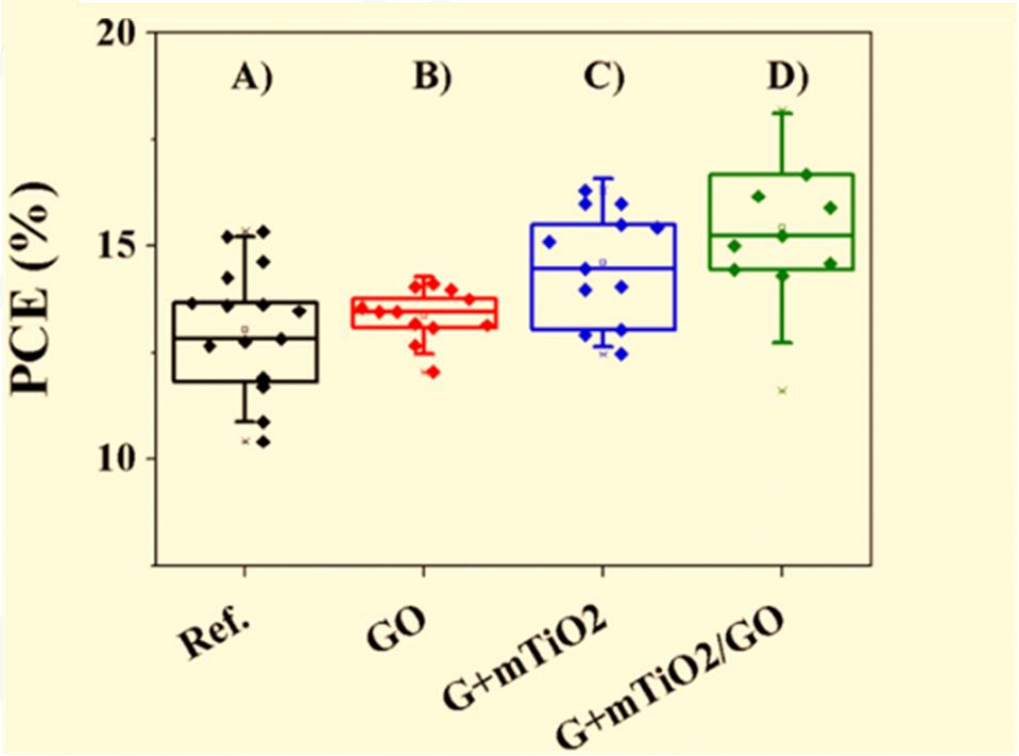
- Graphene & derivatives
- Transition metal dichalcogenides (*e.g.*, $MoS_2$)

## Encapsulants

- h-BN

S. Bellani et al. Chem. Soc. Rev. 50, 11870 (2021)

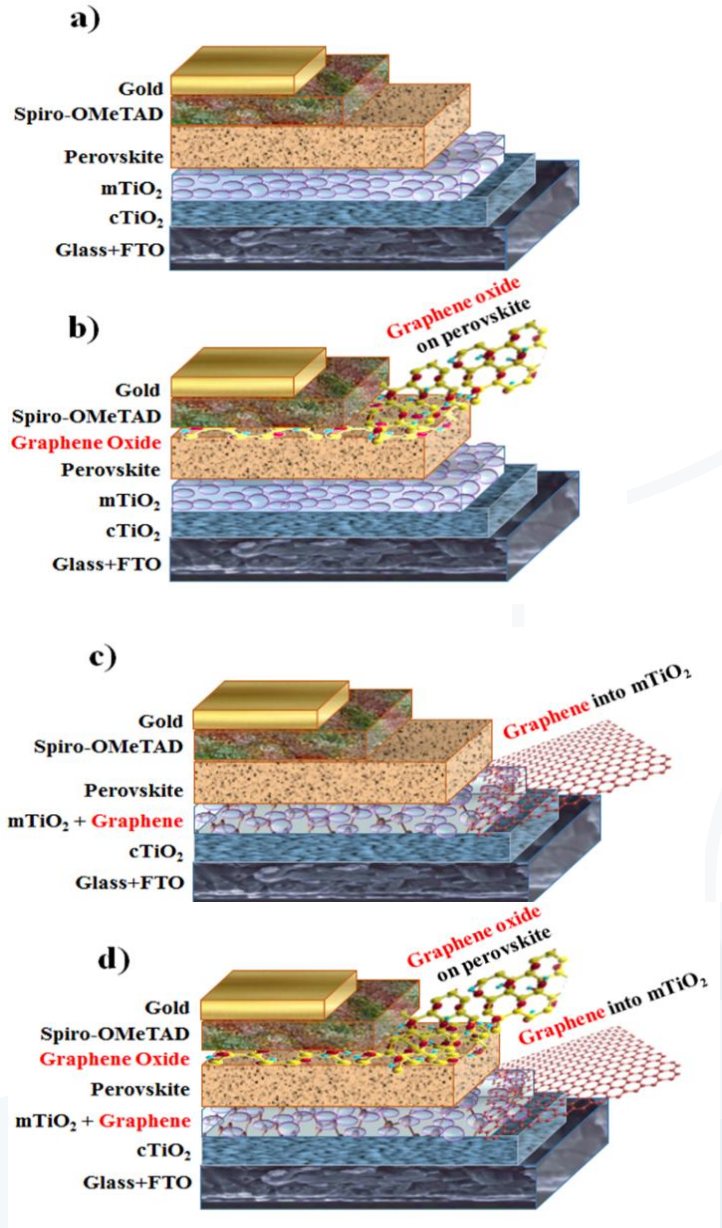
# 2D MATERIALS INTERFACE ENGINEERING




$MoS_2$ flakes and QDs as active buffer layer

GO as perovskite/spiro-OMeTAD interlayer

Graphene-doped mesoporous $TiO_2$ is exploited as electron transporting layer





A. Capasso *et al.*, *Adv. Ener. Mater*. 6, 1600920 (2016)

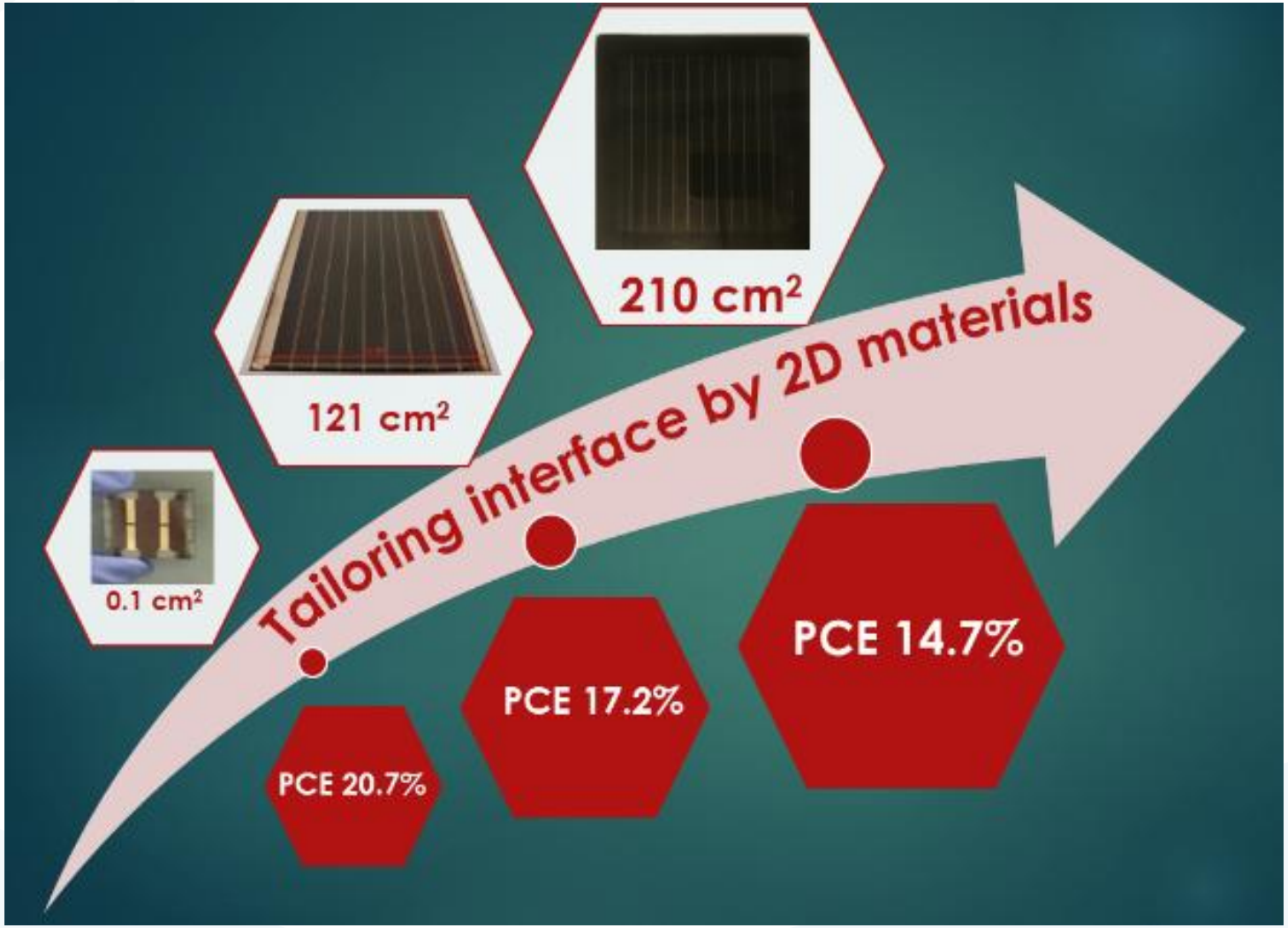
L. Najafi, et al, *ACS Nano*, 12, 10736 (2018)

A. Agresti *et al.*, ChemSusChem 9, 2609 (2016)

P. Mariani *et al*. Nature Communications 15, 4552 (2024)

# FROM CELLS TO MODULES

Multi two-dimensional (2D) material as intra and inter layers in a mesoscopic PSC

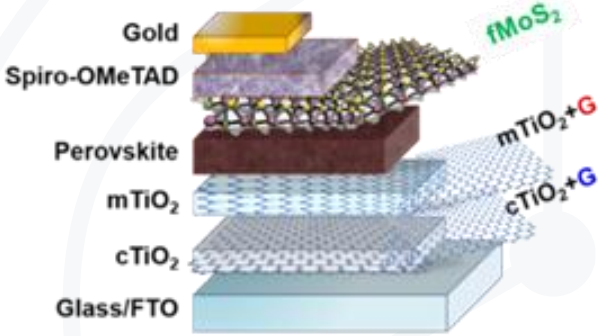


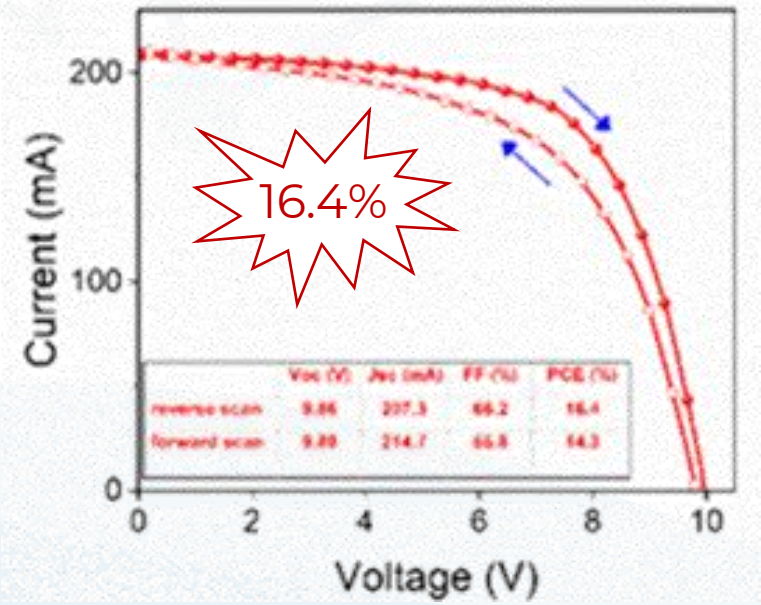

A. Agresti *et al.*, ACS Energy Letters 2, 279 (2017)
A. Agresti *et al.*, ACS Energy Letters 4, 1862 (2019)
S. Pescetelli *et al.*, Nano Energy 107019 (2022)

# 2D MATERIALS-BASED PEROVSKITE SOLAR PANELS

## THE WORLD'S FIRST SOLAR FARM INFRASTRUCTURE BASED ON GRAPHENE-PEROVSKITE PANELS

GRAPE panel




SOLAR FARM

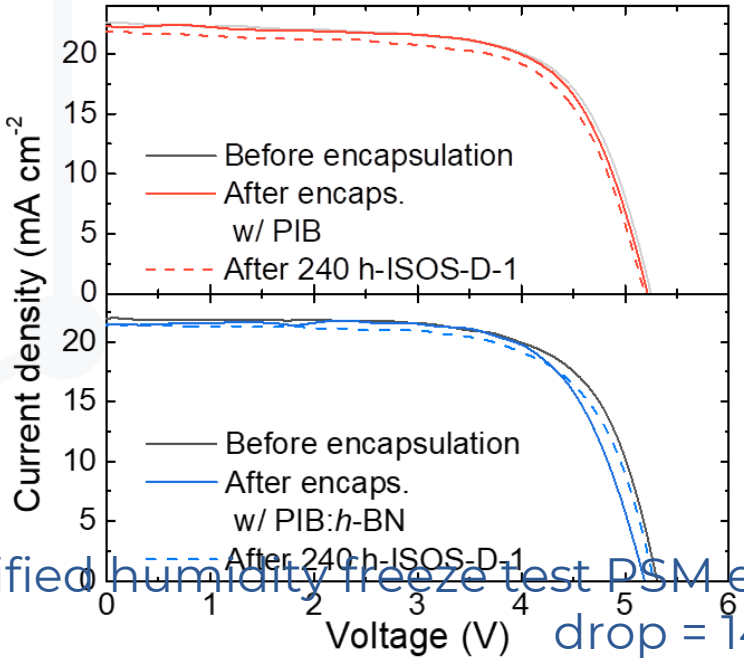
- Maximum output power of ~261 Wp
- PCE drop of ~16% after 6 months (ISOS O-2 test)

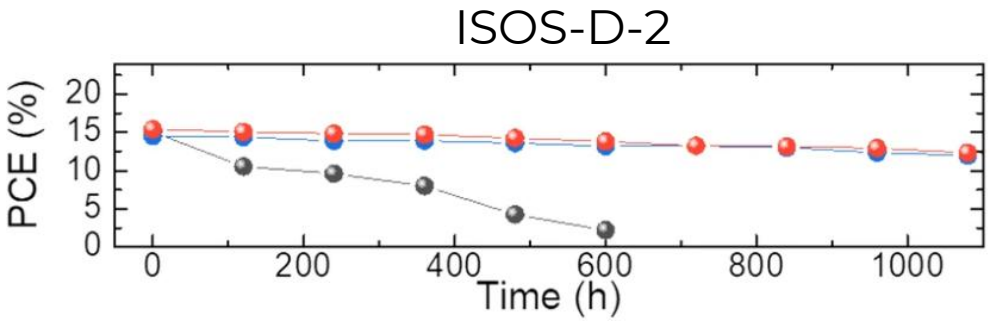
Collaboration with Di Carlo and Kymakis groups

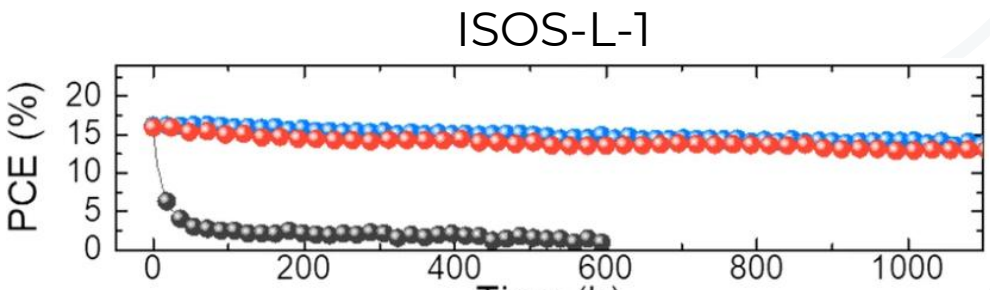
S. Pescetelli et al., Nature Energy 7, 597 (2022)

# 2D H-BN/POLYMER COMPOSITES AS PSC ENCAPSULANT

Test on a 10 $cm^2$ mesoscopic PSM




- After 10 cycles modified humidity freeze test PSM encapsulated with PIB:*h*-BN have shown a PCE drop = 14.0%

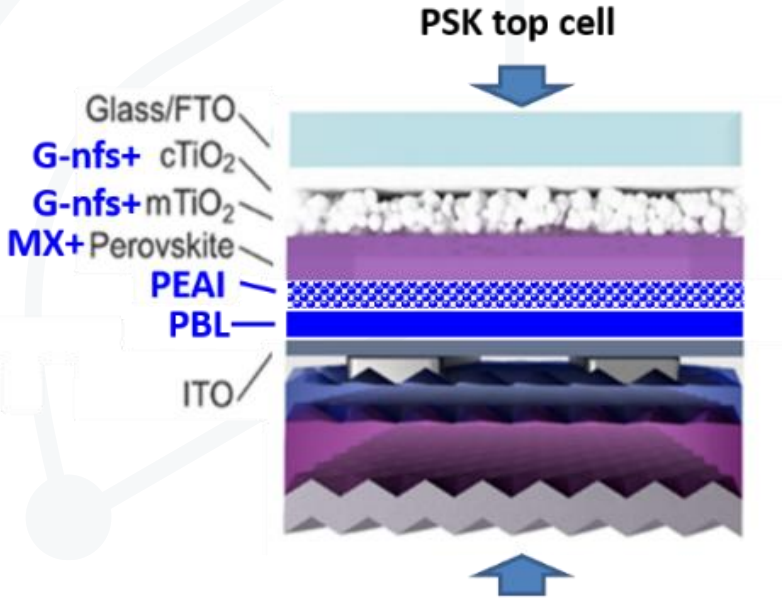
w/o encapsulation — PIB — PIB:*h*-BN

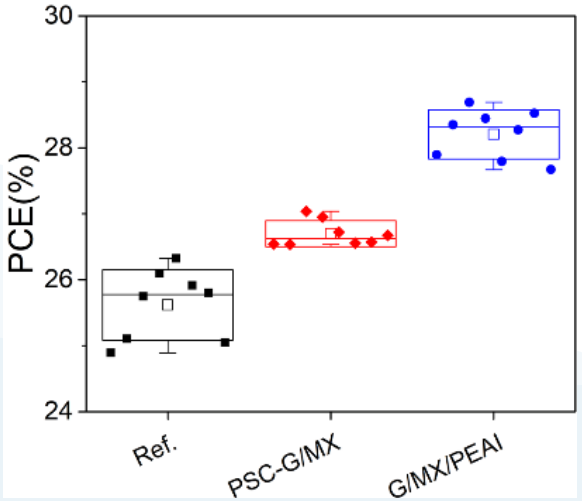
- PSM encapsulated with PIB:*h*-BN withstood thermal shock tests (PCE drop after 200 cycles= 17.9%)
- Reduction of PCE after encapsulation < 1%
- Unencapsulated samples fast degraded in ISOS-D-2 and ISOS-L-1 ($T_{80}$ < 100 h and <3 h, respectively)
- Encapsulated samples have shown stability >1000 h in ISOS-D-2 and ISOS-L-1

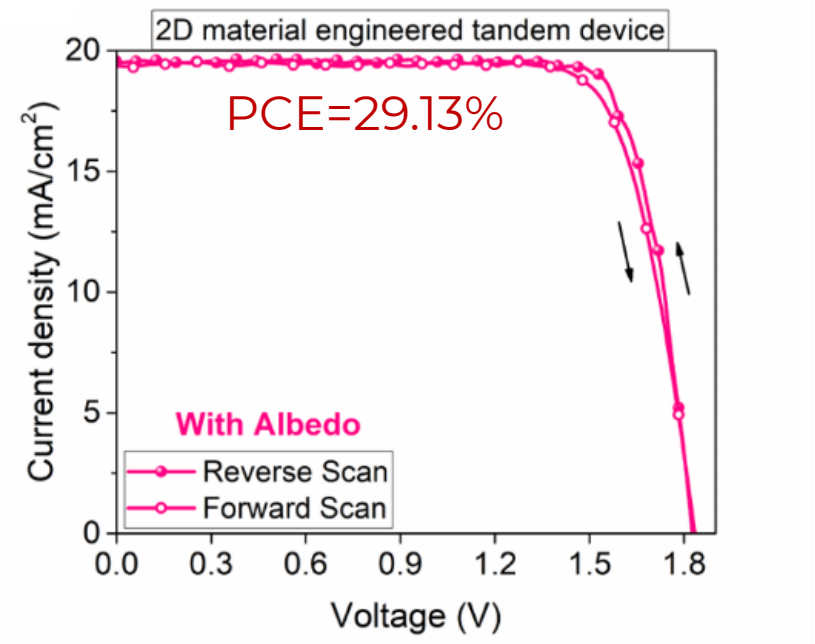
P. Mariani *et al*. Nature Communications 15, 4552 (2024)

# PEROVSKITE/SILICON TANDEM SOLAR CELLS

## *MECHANICALLY STACKED BIFACIAL PEROVSKITE/SILICON SOLAR CELLS*




Use high-energy photons to reduce the thermalization losses

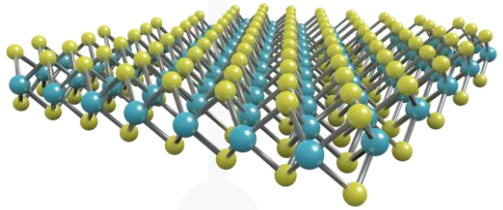
The current generation difference between perovskite and c-Si cells is compensated by exploiting the albedo radiation thanks to the bifaciality of the commercial c-Si bottom cell.

# Water splitting

# 2D CRYSTALS AS ELECTROCATALYSTS

## GROUP-6 TRANSITION METAL DICHALCOGENIDES

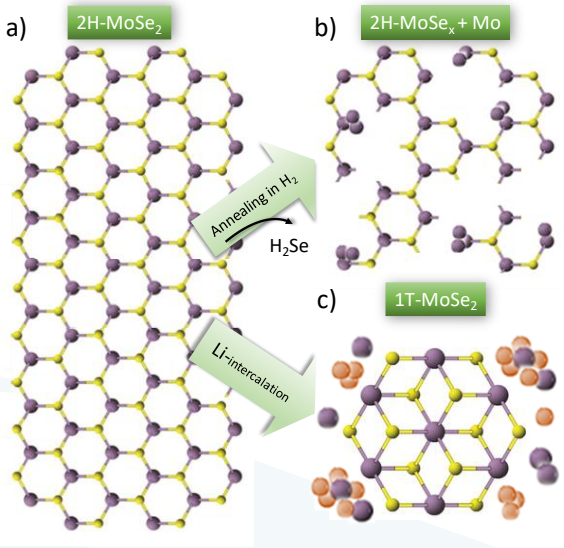
$MoS_2$, $WS_2$, $MoSe_2$, etc…

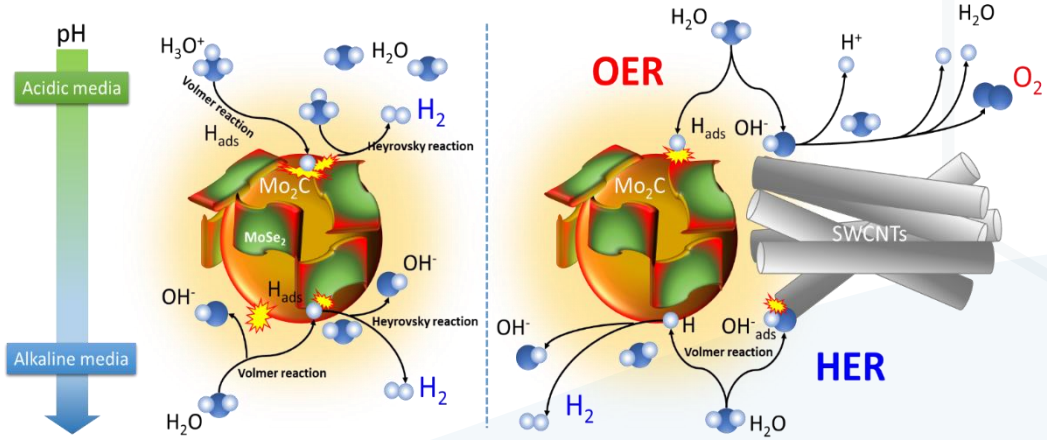


…catalytic models to perform the water splitting reactions…

- ❑ Surface nanostructuring
- ❑ Defect engineering
- ❑ Creation of «synergistic» hybrids

## Thermal texturization and phase engineering



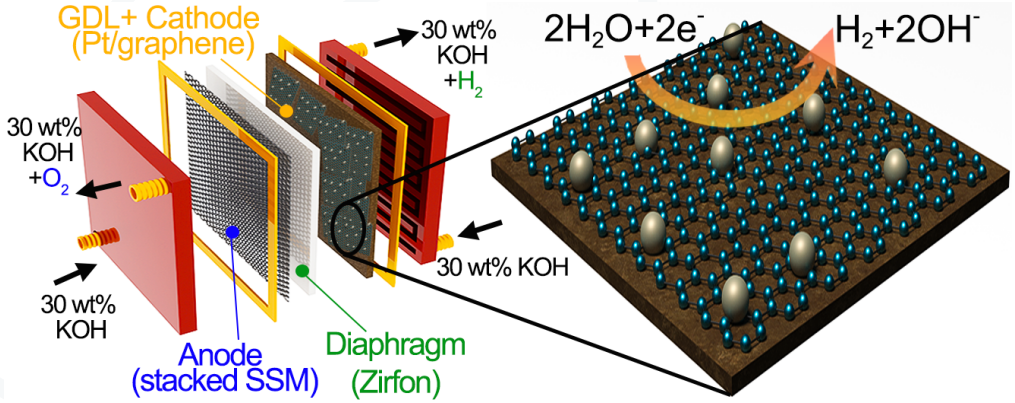

Morphology tuning with $H_2O_2$-aided LPE

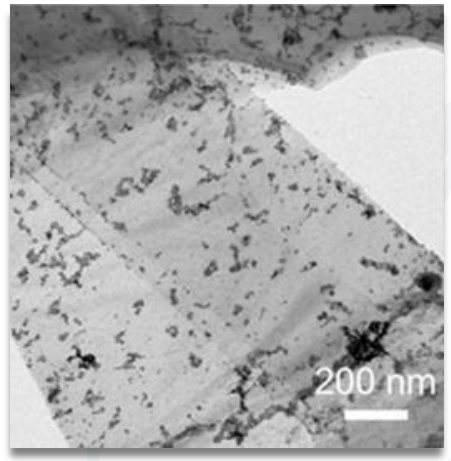
*Najafi et al., Adv. Energy Mater. 2018, 8, 1703212*
*Najafi et al., Adv. Energy Mater., 2018, 8, 1801764.*
*Najafi et al., ACS Nano 2019, 13, 3162-3176*

*Najafi et al., Chem. Mater. 2017, 29, 5782*
*Petroni et al., Small 2018, 14, 1800749*
*Najafi et al., ACS Nano* 2022, 16, 351–367

# CATALYST FOR ALKALINE ELECTROLYZERS

## Platinum nanoparticles/FLG-based catalyst: Validation in alkaline electrolyzers (4000 cm$^2$)




$H_2$ production @ 0.6 A/cm$^2$ at <1.8 V

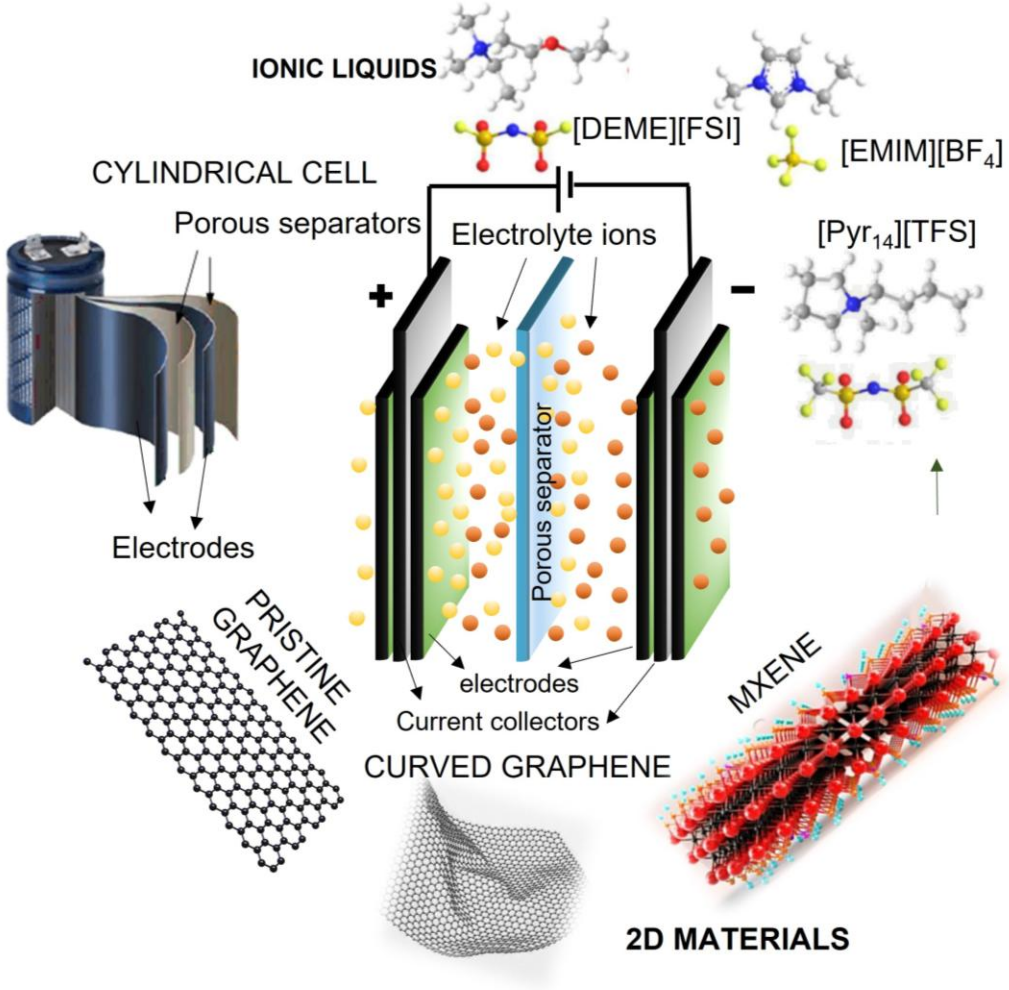

Y. Zuo *et al.*, JACS, **2023**, 145, 21419

V. Mastronardi *et al.*, *Electrochim. Acta*, **2023**, 462, 142696

Y. Zuo *et al.*, *Nat. Commun.*, **2023**, 14, 4680

# Supercapacitors

# EU GREENCAP PROJECT




- To produce 2D materials with sustainable components in industrial way
- To develop CRM-free supercapacitors
- To exploit graphene and MXenes as electrode materials
- Use of ionic liquids as high-voltage electrolytes
- Development of a novel supercapacitor management system

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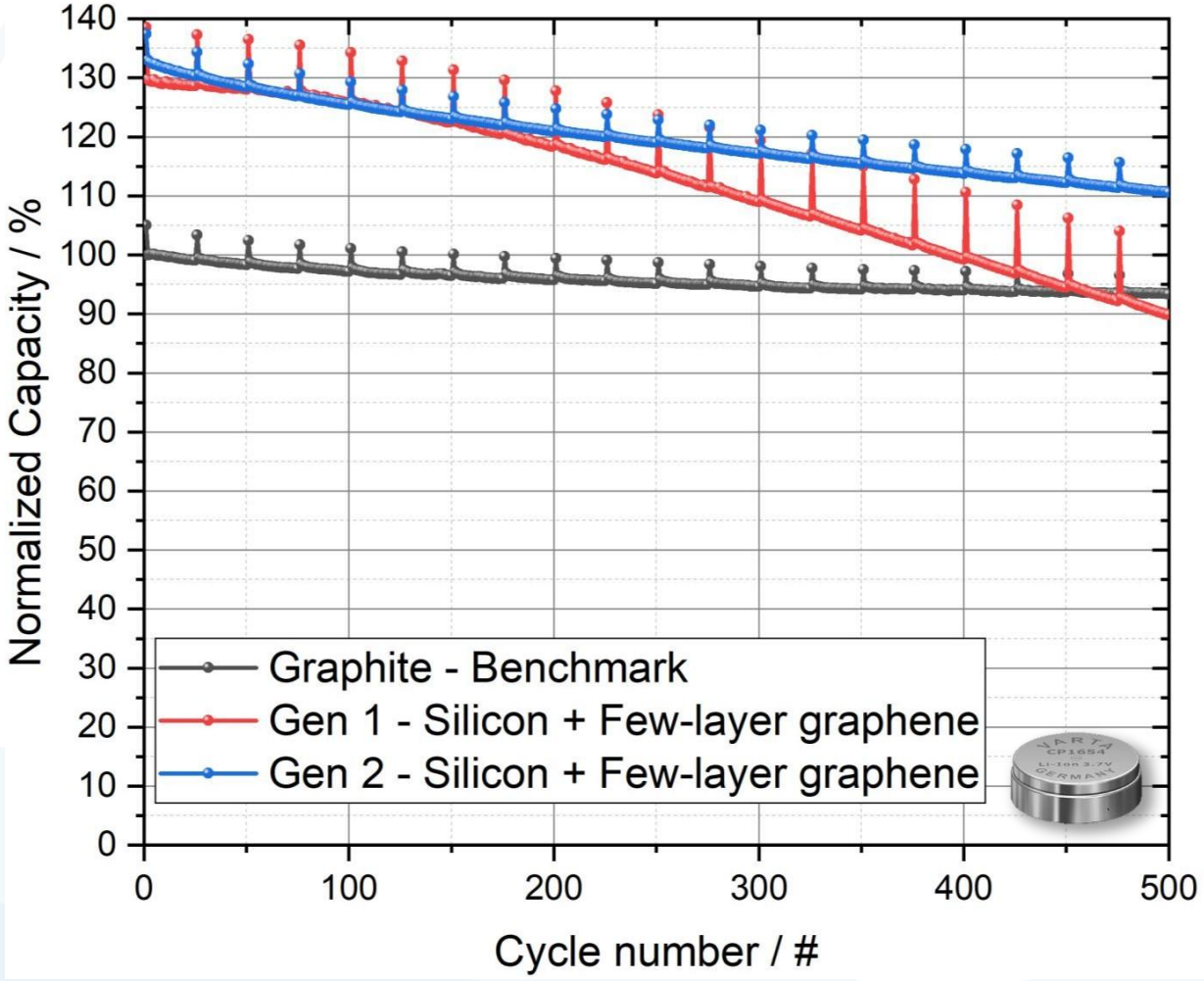
GREEN CAP

# *Li-ion batteries*

# PRODUCT CASE: GRAPHENE-SILICON ANODES FOR LI-ION BATTERIES

## Current Status @ VARTA with Gen1 and Gen 2 Silicon




- ✓ 40% thinner anode
- ✓ 30% improved capacity
- ✓ 25% improved energy
- ✓ 65% usable capacity @2C
- ✓ Competitive Cost (€/kWh)
- ✓ Comparable temperature range

# ACKNOWLEDGEMENT


GREEN CAP

2D PRINTABLE

DIAMOND

GRAPHENE FLAGSHIP

PERSEUS

LAPERITIVO

MINISTERO DELLA TRANSIZIONE ECOLOGICA

ULTIMATE

sensibat

Ministero dello Sviluppo Economico

# Contact Us

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We are hiring: looking for talented people who want to grow together with us