EnerHarv 2024

PSMA International Workshop | 26-28 June, 2024 | Perugia, Italy

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EnerHarv 2024 Workshop:

Sustainable materials for electrochemical energy harvesting and storage devices: development and integration

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Wednesday, June 28, 2024

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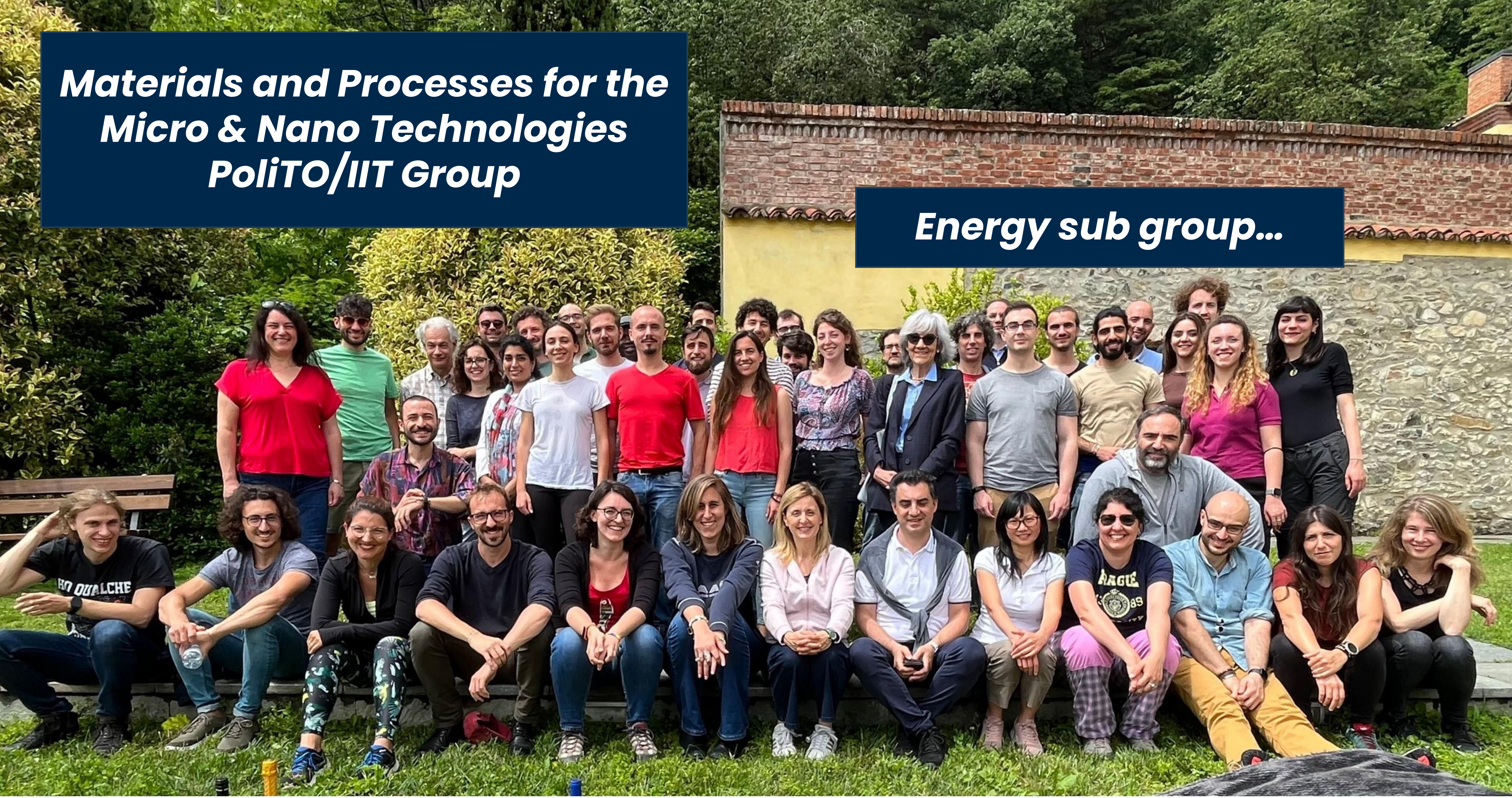
Materials and Processes for the Micro & Nano Technologies PoliTO/IIT Group

Energy sub group…



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iit @PoliTo

Materials and Processes for the Micro & Nano Technologies PoliTO/IIT Group

- 4 locations
- DISAT PoliTO + IIT
- Biggest university research group in Italy
- > 120 people (> 50 PhD Students)
- International collaborations

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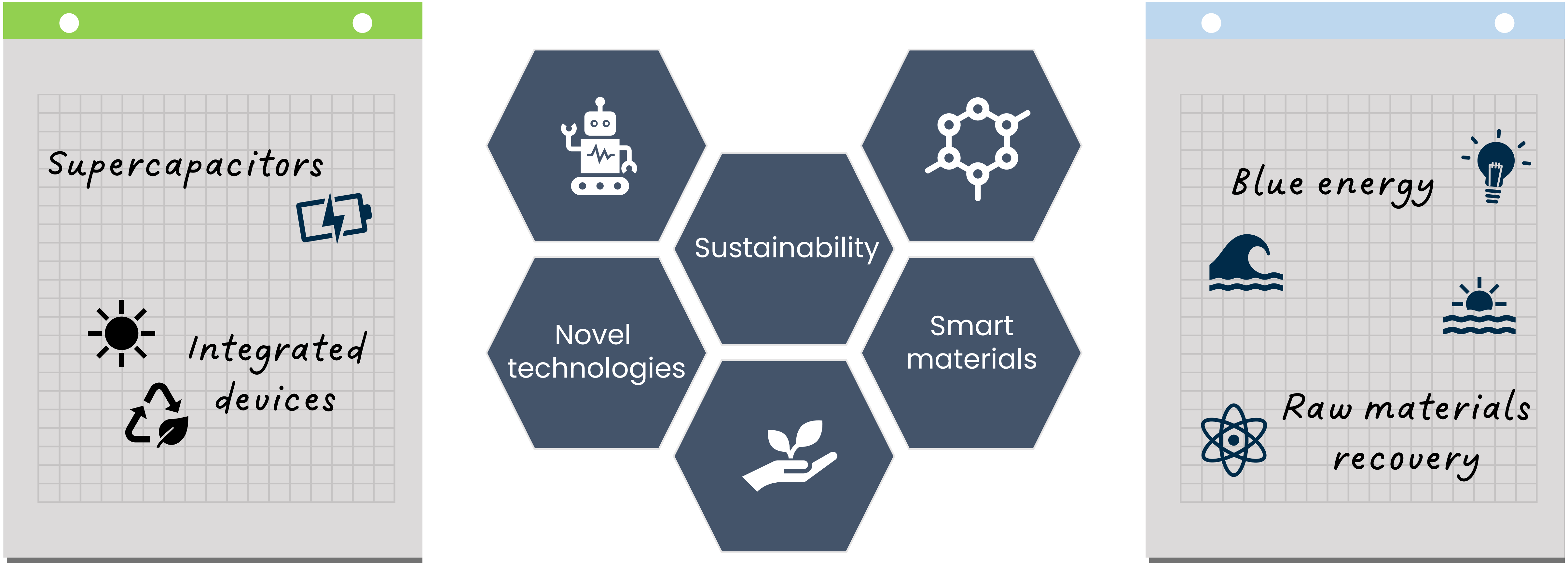
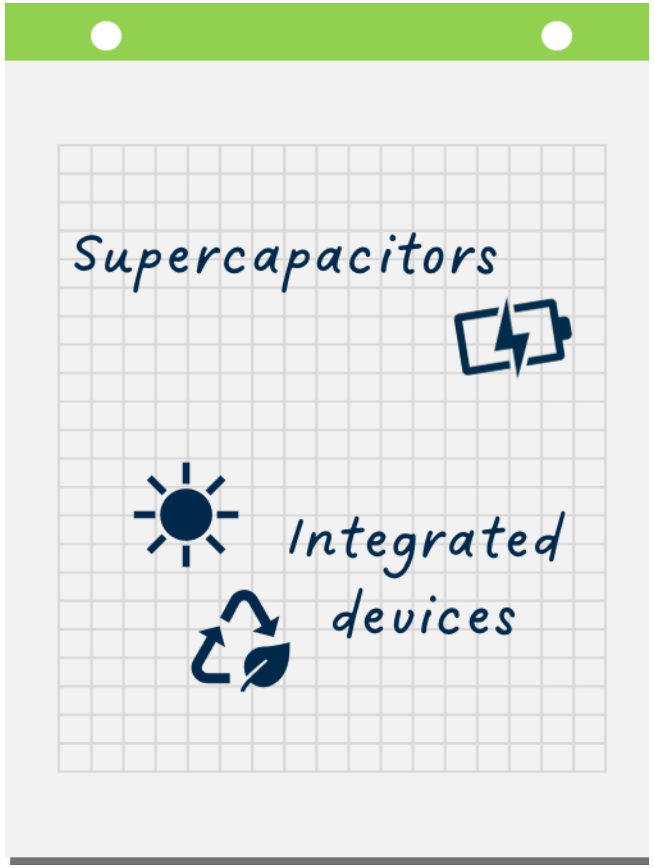
EARN&ST research line

Energy Harvesting & Storage Devices

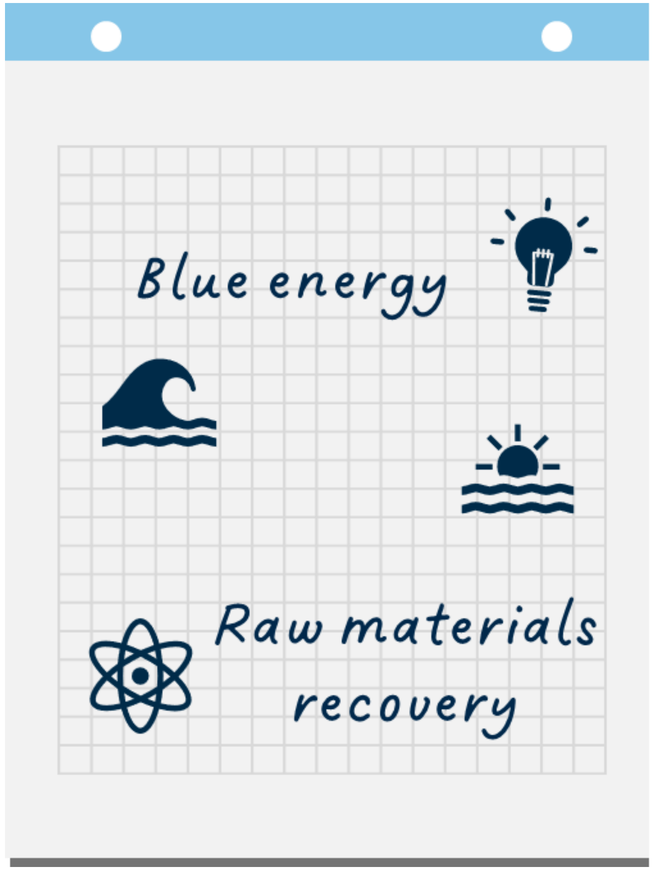
Energy Harvesting and Storage Devices



Energy Harvesting and Storage Devices

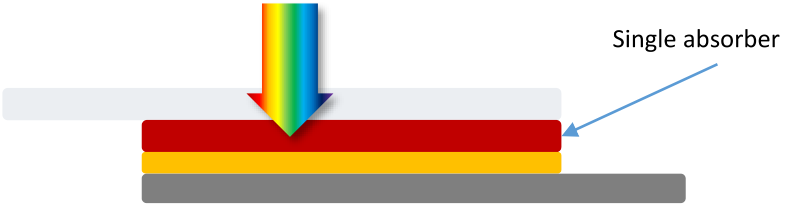


1. **Energy harvesting: solar cells**
2. Energy storage: supercapacitors
3. Integration
4. Energy harvesting (2): blue energy
5. Energy harvesting (3): from CO_2 emissions

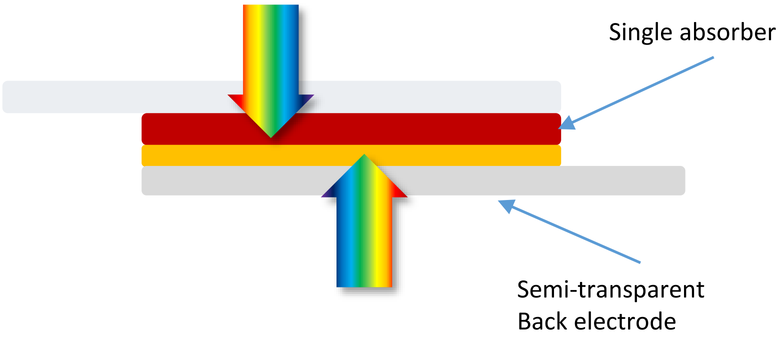


Dye Sensitized Solar Cells

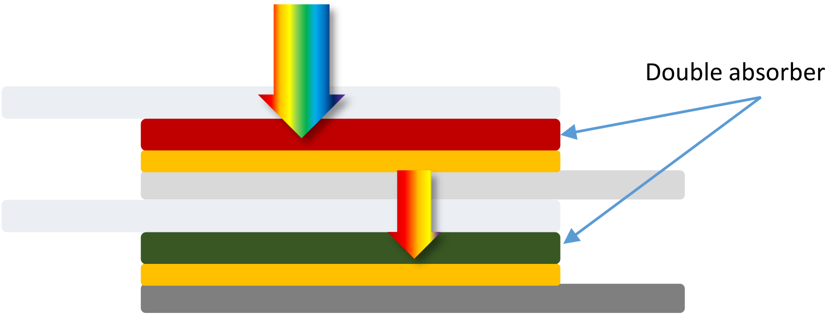
Standard Solar Cell



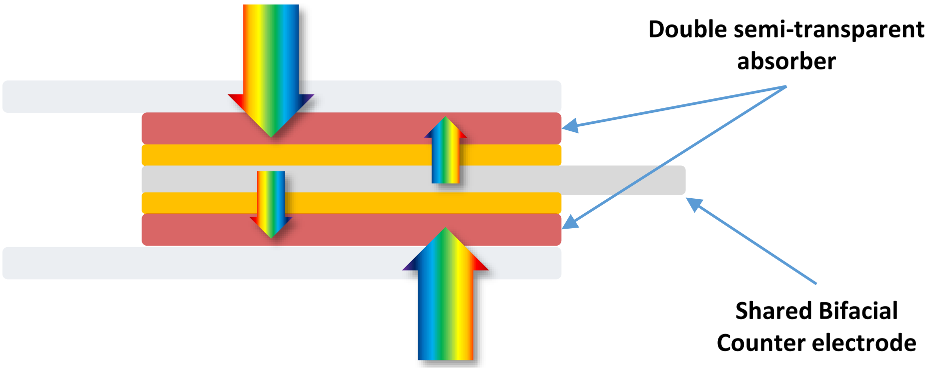
Bifacial Solar Cell



Tandem Solar Cell

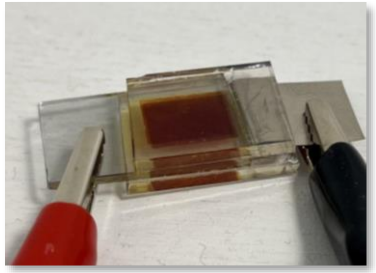


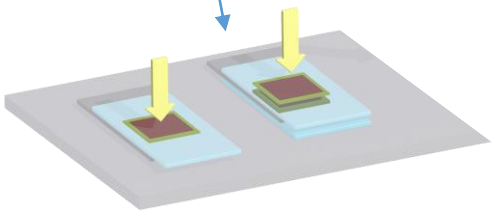
SYMMETRIC-TANDEM-BIFACIAL DSSC

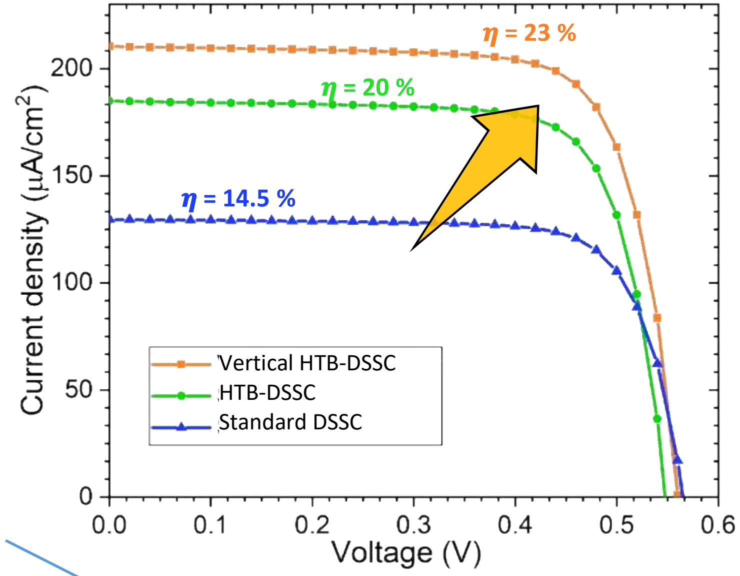


Dye Sensitized Solar Cells

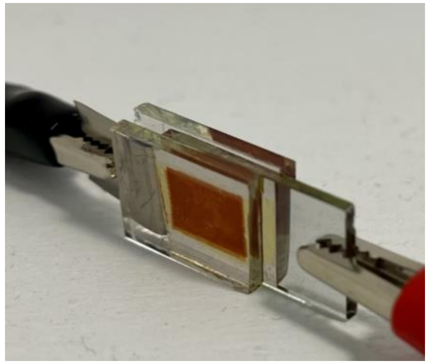
HTB-DSSC







"Light-antenna" in vertical configuration



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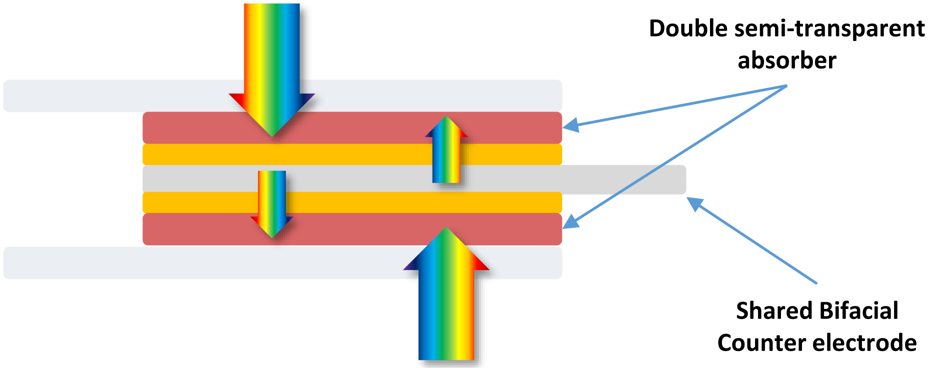
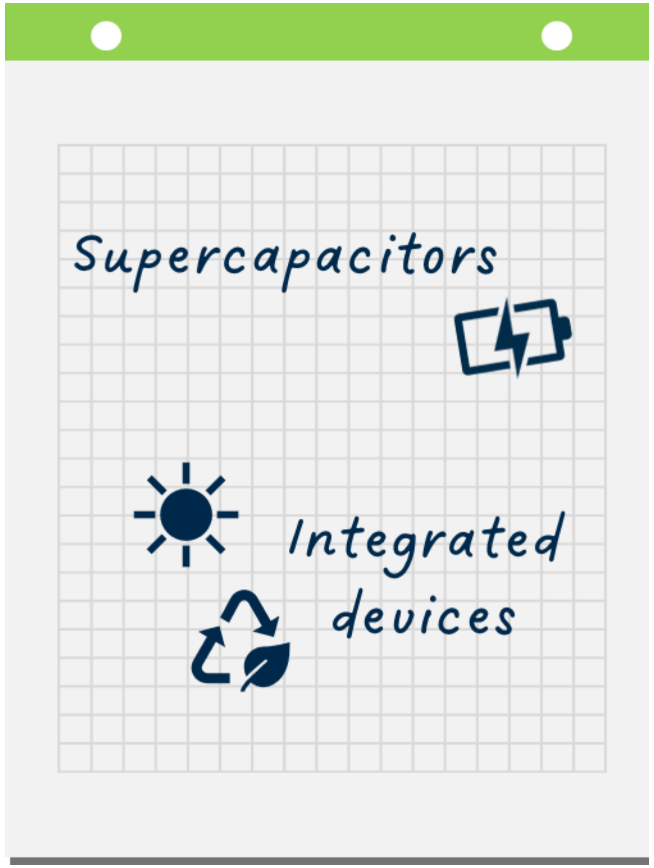


G. Gianola et al **2023**, *Solar Energy* **265**, 112116.

Energy Harvesting and Storage Devices



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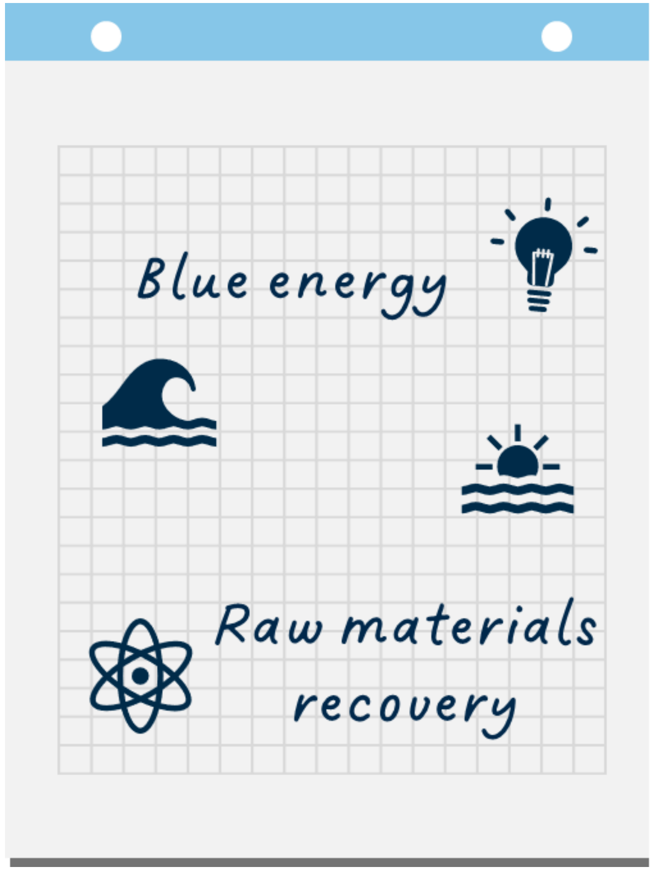
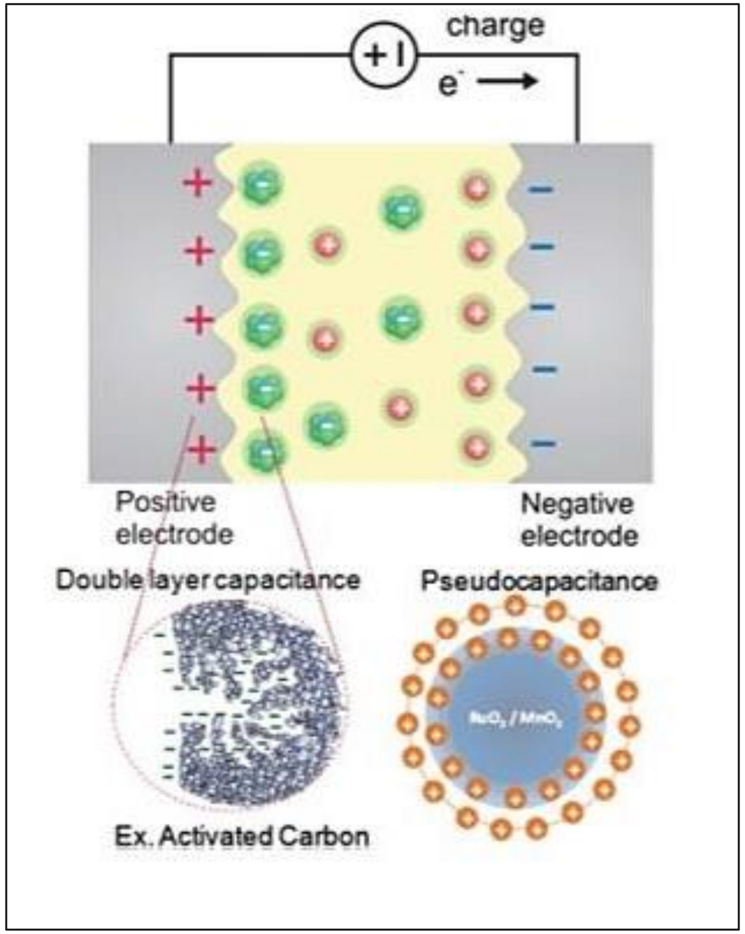


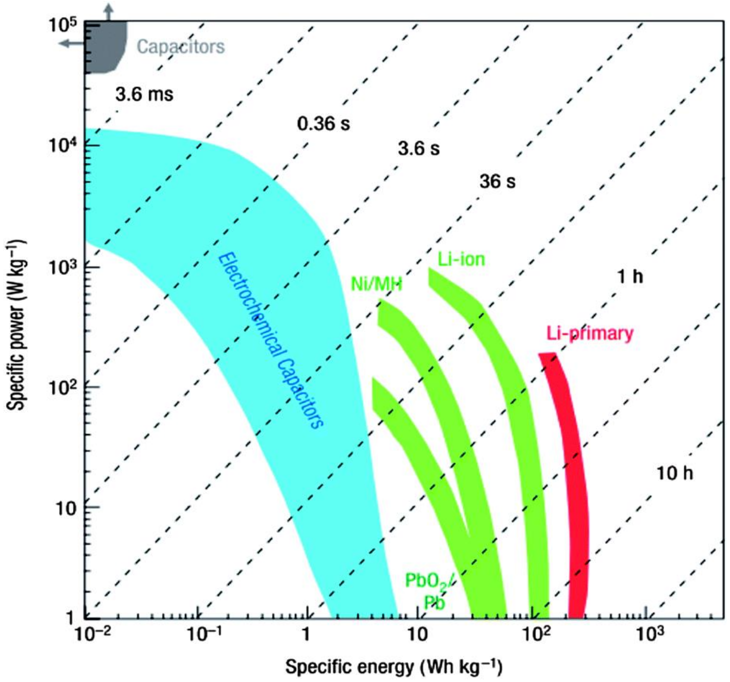
Electrochemical capacitors or Supercapacitor

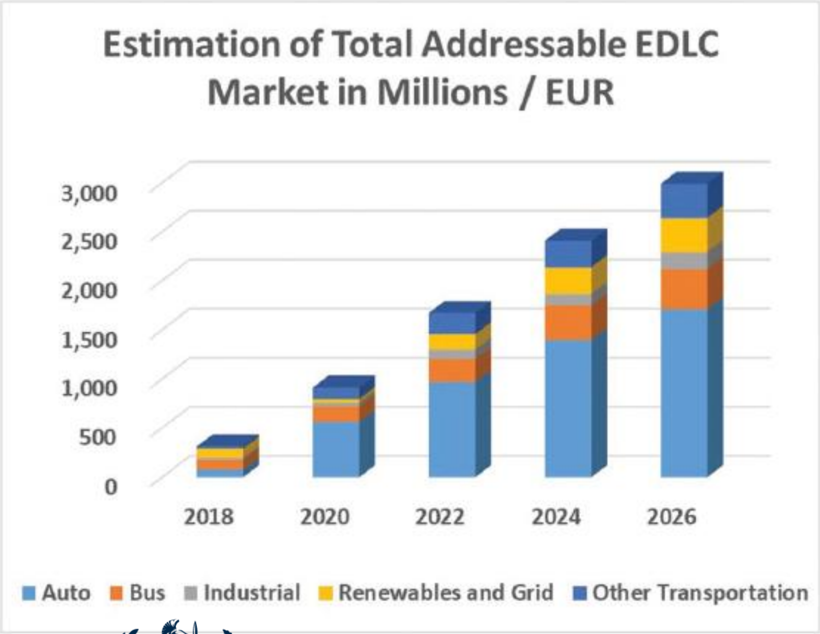
Supercapacitors are finding increasing interest in the scientific and industrial community due to their exceptional power density and long life cycle.

Applications:

- Automotive
- Renewables source & grids
- Remote applications requiring long-life and no maintenance
- Self-rechargeable portable power systems
- Wearable electronics.







From the literature: Schütter et al. *Advanced Energy Materials* 9.25 (2019): 1900334.

Supercapacitors - Applications

Packs

222 F
51 V
420 x 180 x 180 mm

Lamborghini Sian FKP 37

- Supercapacitor – Fuel Hybrid
- 610 kW -> from 0 to 100 km/h in 2.8s
- Regenerative breaking

Miniaturized device

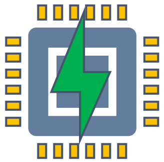
Type	CPH3225A
Max. Use Voltage(V)	3.3
Capacitance(F)	0.011
Internal Impedance(Ω)	160
Size L x W x H(mm)	3.2 x 2.5 x 0.9
Weight(g)	0.024

Seiko Instruments K8373

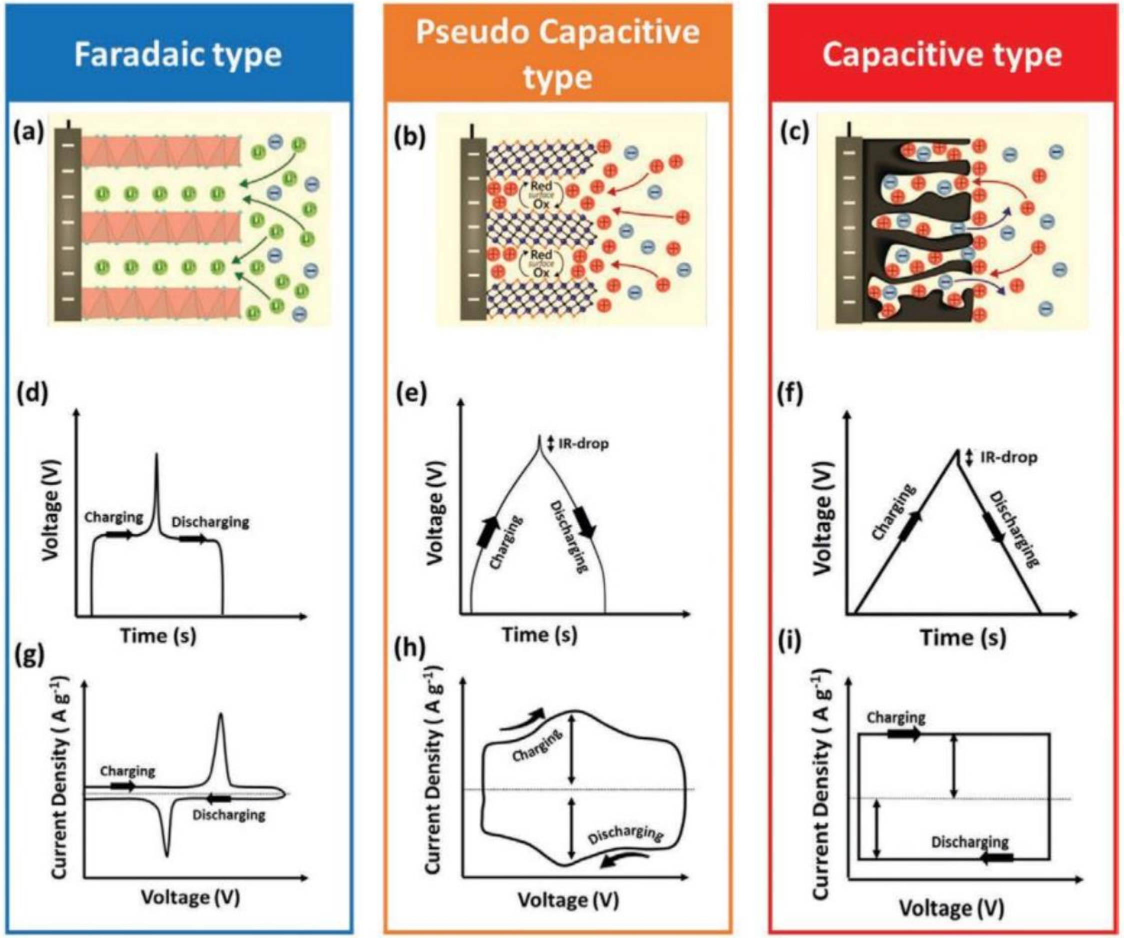
Dialog Semiconductor DA14580 SoC

Samsung Galaxy Note 9 Stylus

- Micro-Supercapacitor
- Fully charged in 40s
- 30 minutes of use
- Replace batteries



Electrochemical supercapacitors



3 **different storage mechanisms**

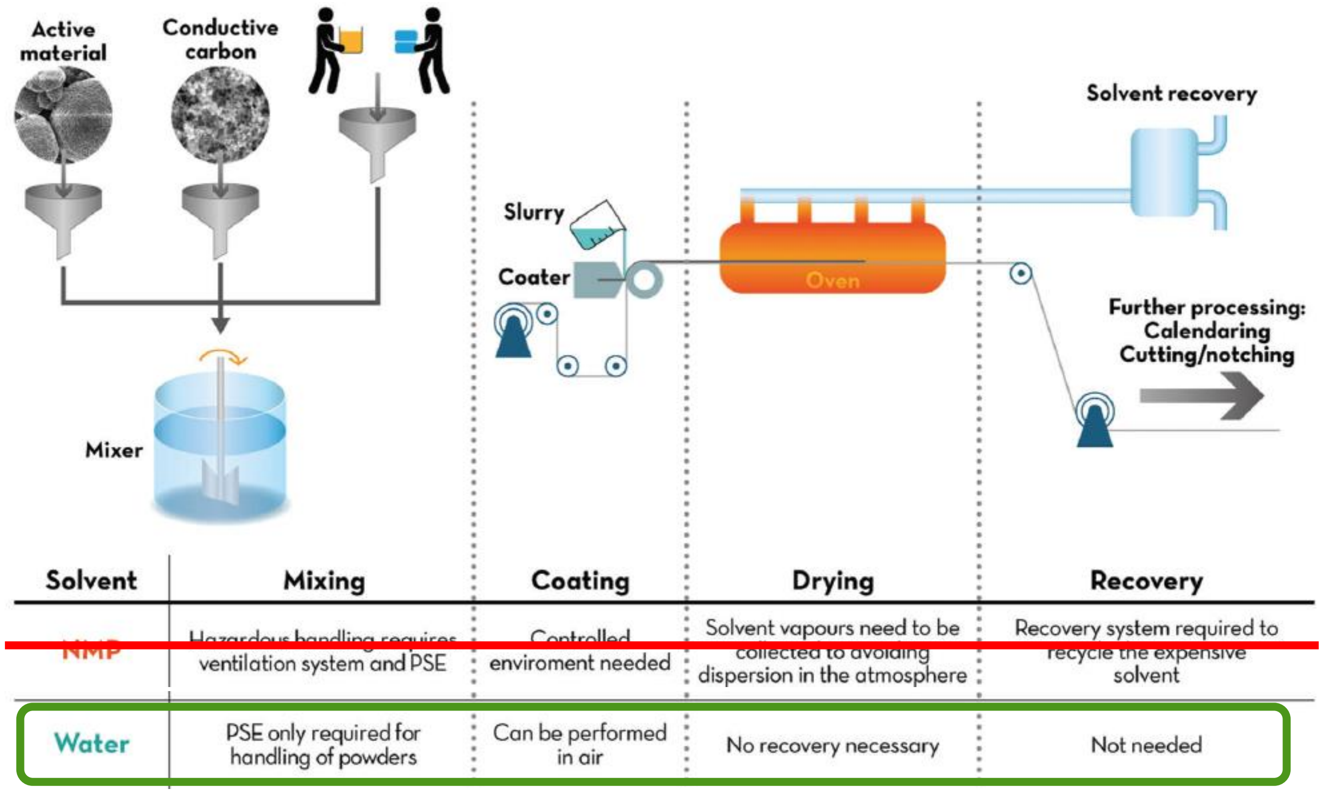
- **Faradaic**: chemical intercalation of ions into the structure -> *battery-like*
- **Pseudocapacitive**: surface redox reactions
- **Capacitive**: electrostatic charge accumulation in the electrical double layer

Green Supercapacitor

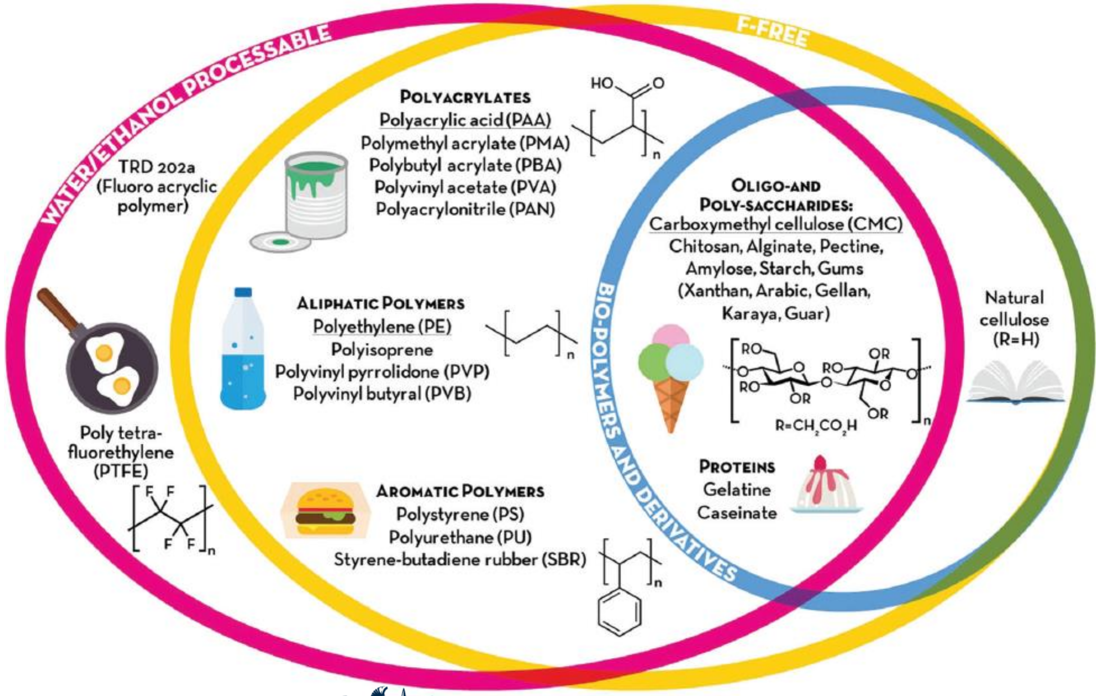
Selection of the advanced materials able to warrant the green route for the fabrication of sustainable energy storage

In particular:

- aqueous electrode processing & green electrolytes



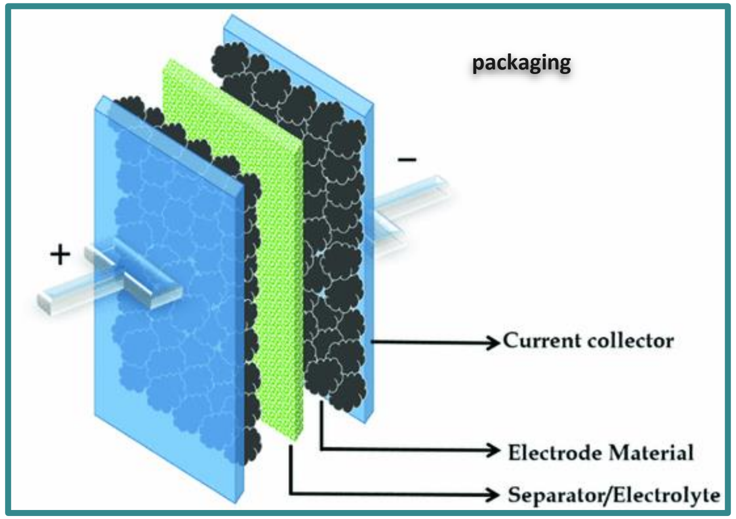
- active materials derived from biomaterials and bio-derived polymers as binders



Politecnico di Torino
1859
ISTITUTO ITALIANO DI TECNOLOGIA

From the literature: Bresser et al. *Energy & Environmental Science* 11.11 (2018): 3096-3127.

Technologies, competencies and facilities on electrochemical devices



Electrodes

- 2D nanomaterials (graphene, MoS2, MXenes)
- Metal-oxides (MnO2, ZnO, Fe2O3, TiO2, …)
- Thin film technologies (CVD, PDV, ALD, laser)
- Chemical synthesis (hydrothermal, electrochemical deposition)
- Innovative current collectors

Electrolytes

- Water-based (liquid and quasi solid gel)
- organic solvent-based
- Ionic Liquids (commercial and homemade bio-derived)
- polymeric

Packaging

- Coin cell
- Pouch cell (coffee-bag)
- Flexible homemade (planar, wire-shaped)
- Wounded homemade

Electrochemical characterization

- EIS
- CV
- CCCD
- Leakage current
- Self-discharge

Politecnico di Torino 1859

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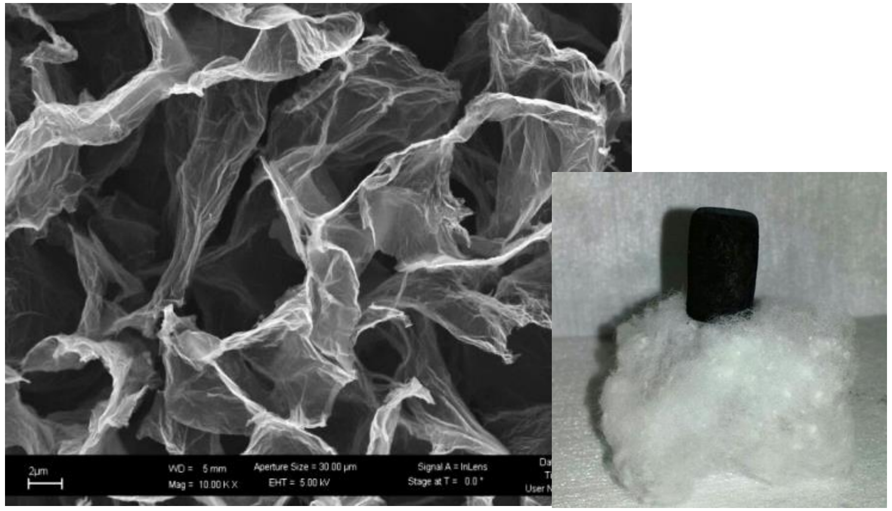
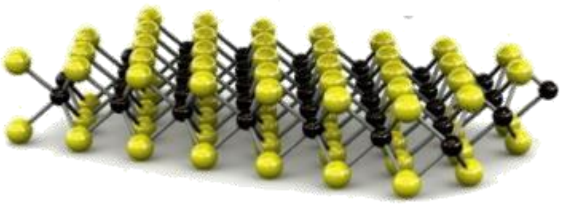
Where can contribute?

3D Graphene aerogel

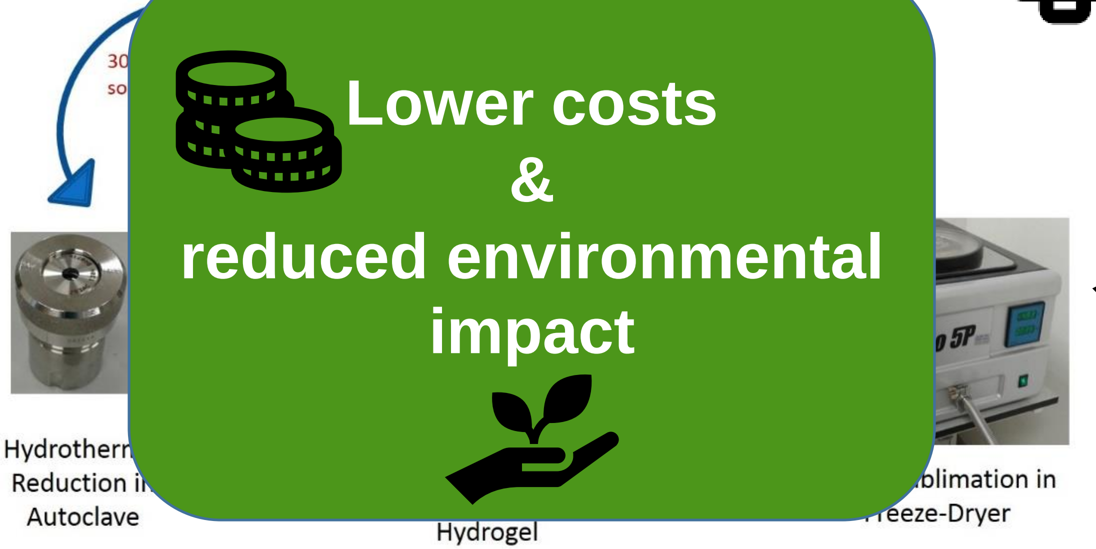


+ Pseudocapacitive materials



Requirements

- high electrical conductivity
- controlled porosity
- high exposed area

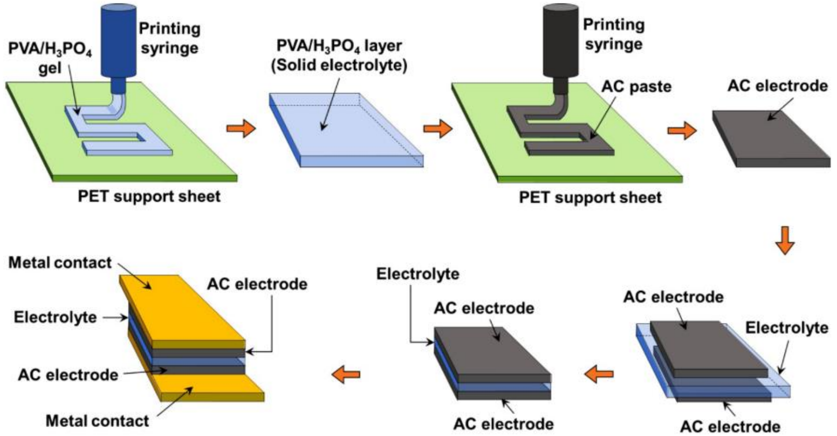


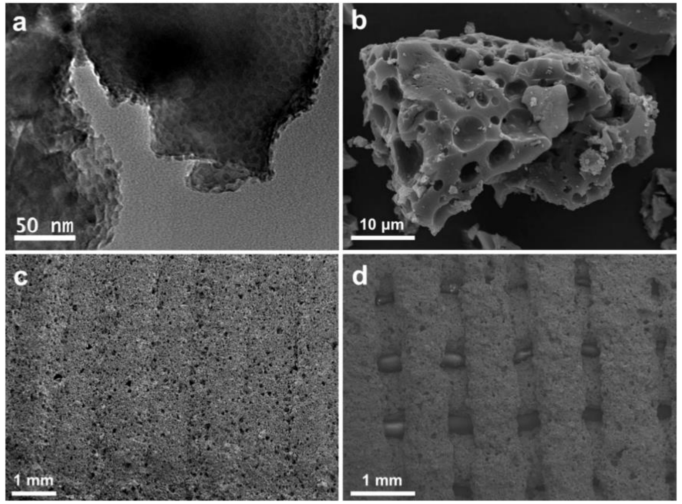
Lower costs
&
reduced environmental impact

Gigot et al. ACS Appl. Mater. Interf. 8 (2016)
Gigot et al. Materials 11 (2017)
Lamberti, Mat. Sci. Semic. Process. 73 (2018)
Garino et al. Electrochimica Acta 306 (2019)
Serrapede et al. Materials 13 (1) (2020)

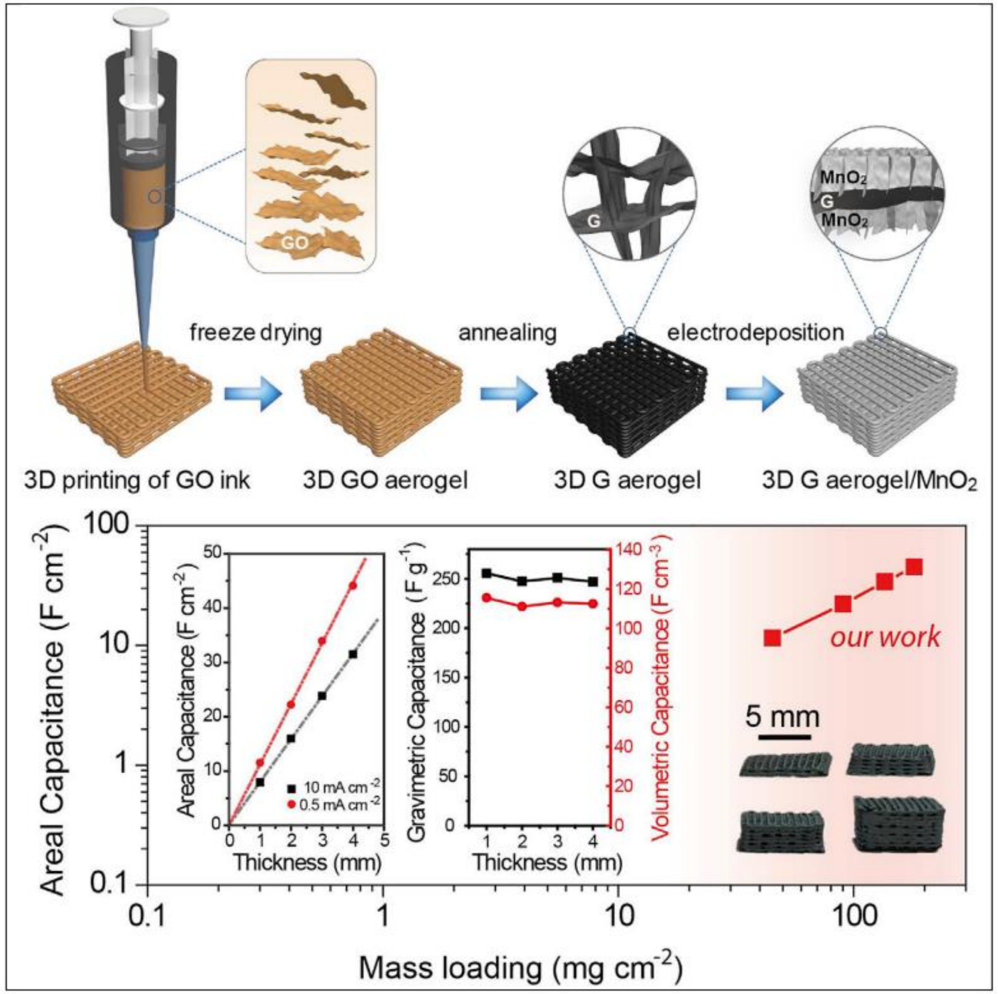
Lamberti et al. Nanotechnology 28 (2017)
Lamberti et al. 2D Materials 4 (2017)
Clerici et al. ACS Appl. Mater. Interfaces 8 (2016)
Parmeggiani et al, ACS Appl. Mater. Interfaces 11 (2019)
Zaccagnini et al, Electrochimica Acta 357 (2020)

2 and 3D micro-Supercapacitors





330 mF cm^{-2}
1.0 V in PVA H_3PO_4

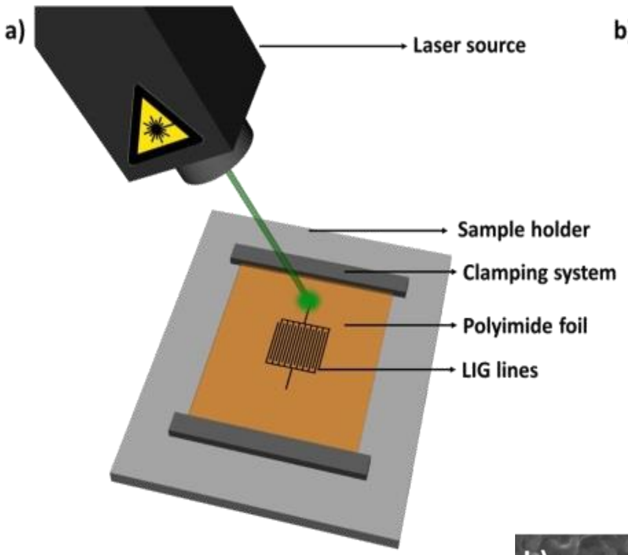


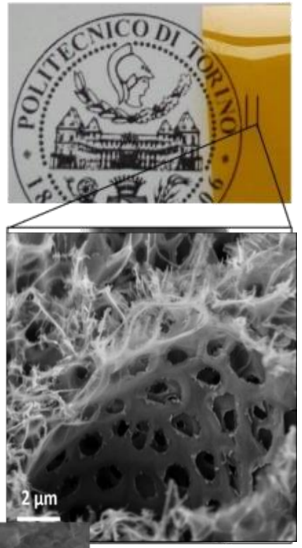
10.1016/j.addma.2020.101525

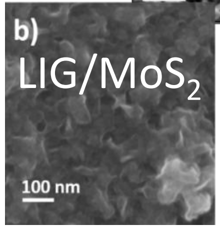
10.1016/j.joule.2018.09.020

Where can contribute?

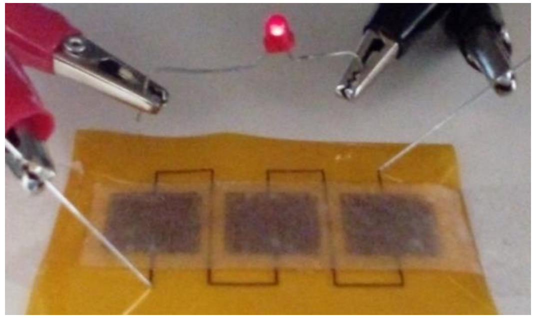
microSupercapacitors (uSC) by laser induced graphene (LIG)







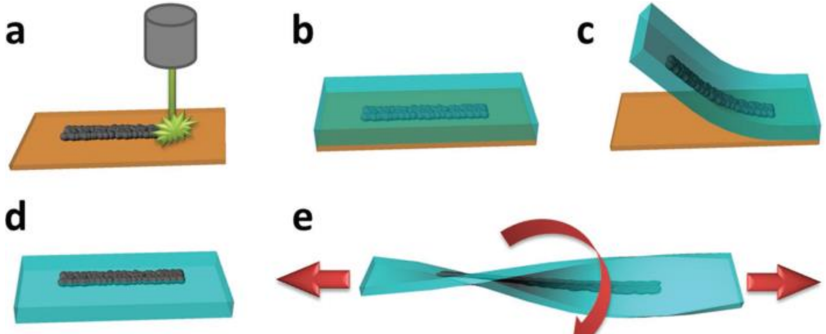
+ Pseudocapacitive materials

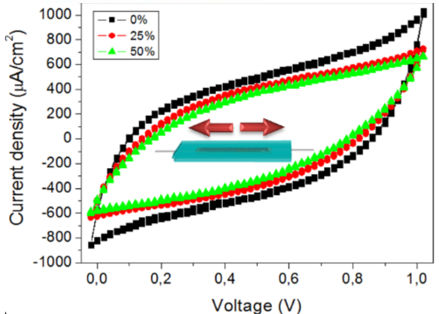


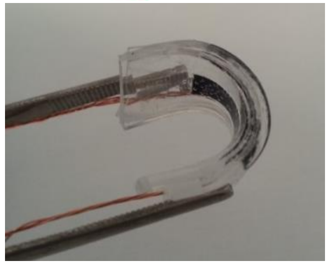
LIG disruptive technology for flexible electrodes:

- Direct laser writing → no mask or patterning
- One step process → fast
- Low temperature → flexible substrates
- Low cost → compatible with flexible electronics
- Versatile → many polymer as precursor

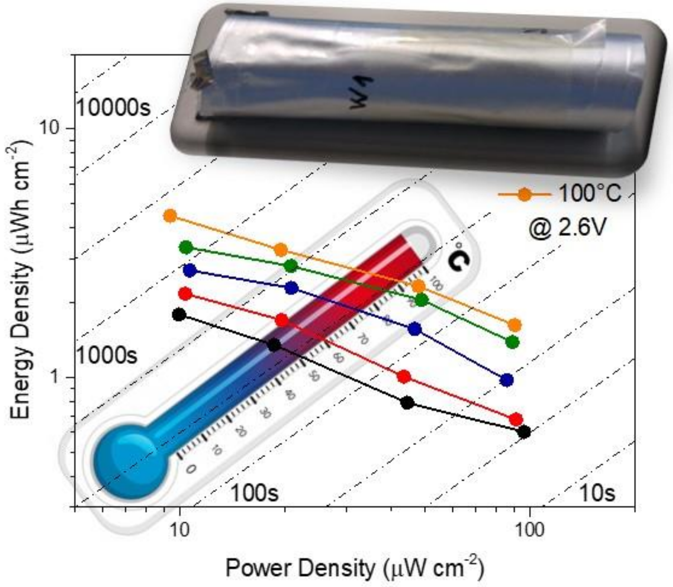
Flexible and stretchable devices







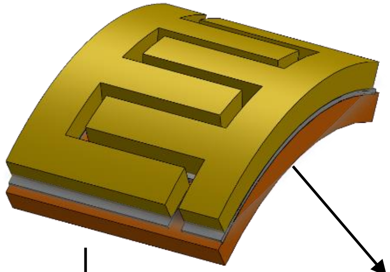
High temperature application

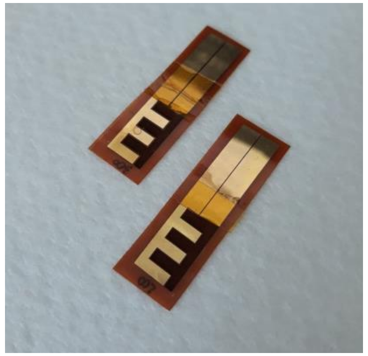


Where can PoliTO & IIT contribute?

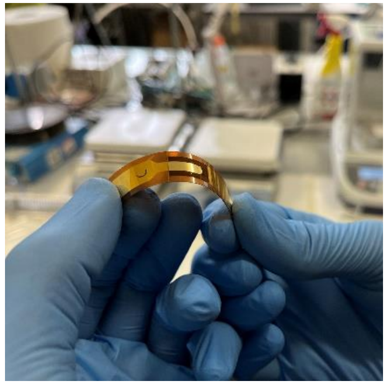
microSupercapacitors (uSC) by micromachining and polymeric additive manufacturing

Flexible or rigid uSC





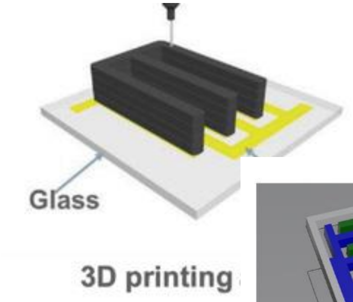
Electroplating Deposition
For The Active Material

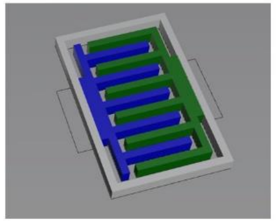


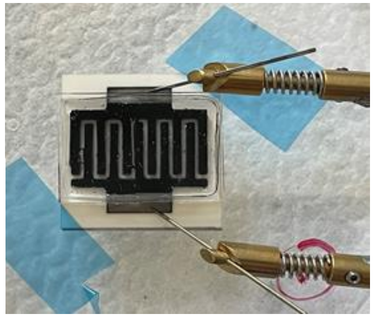
Pouch Sealing

- Green Process for Electroplating
- Water Based Electrolyte
- Large Voltage window 1,5 V
- Asymmetric Configuration
- Capacitance 1 to 5 mF/cm^2
- ESR around few Ohm

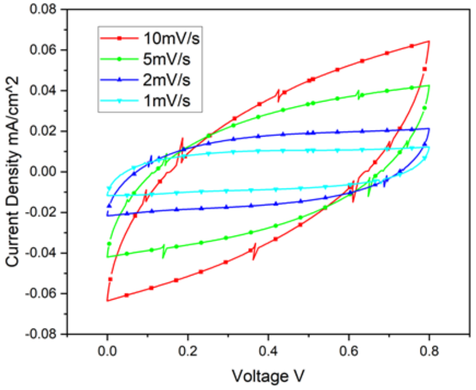
Polymeric uSC by 3DP

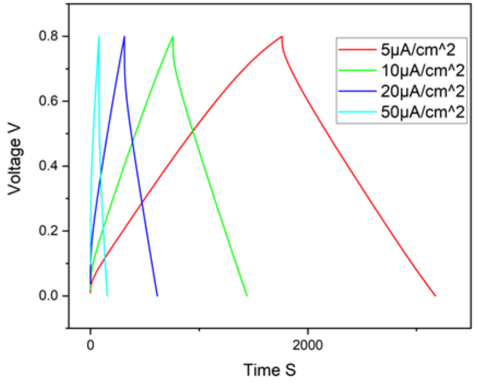






3D printed interdigitated electrodes made of PEDOT
1M Na_2SO_4 Gel Electrolyte

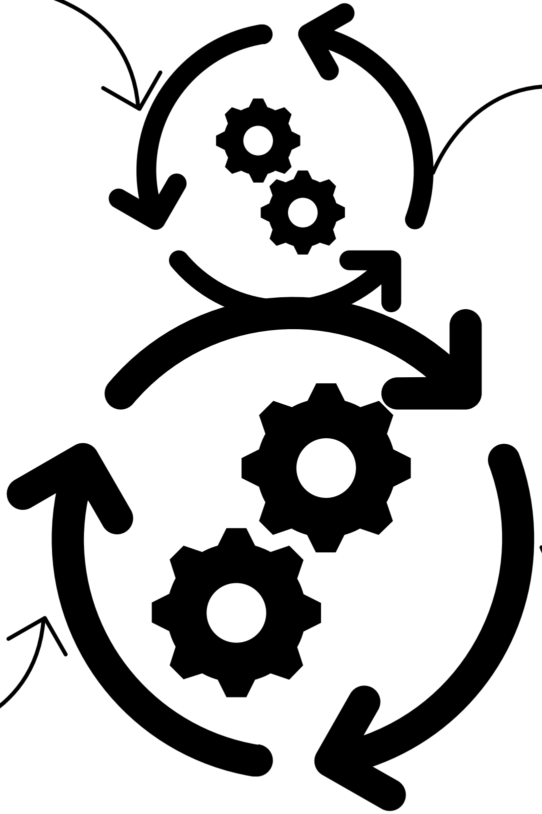




The infrastructure from the point of view of covering a wide TRL range is summarized in the idea…

Nanotechnology
Electrochemistry
Material Science

RESEARCH
INFRASTRUCTURE



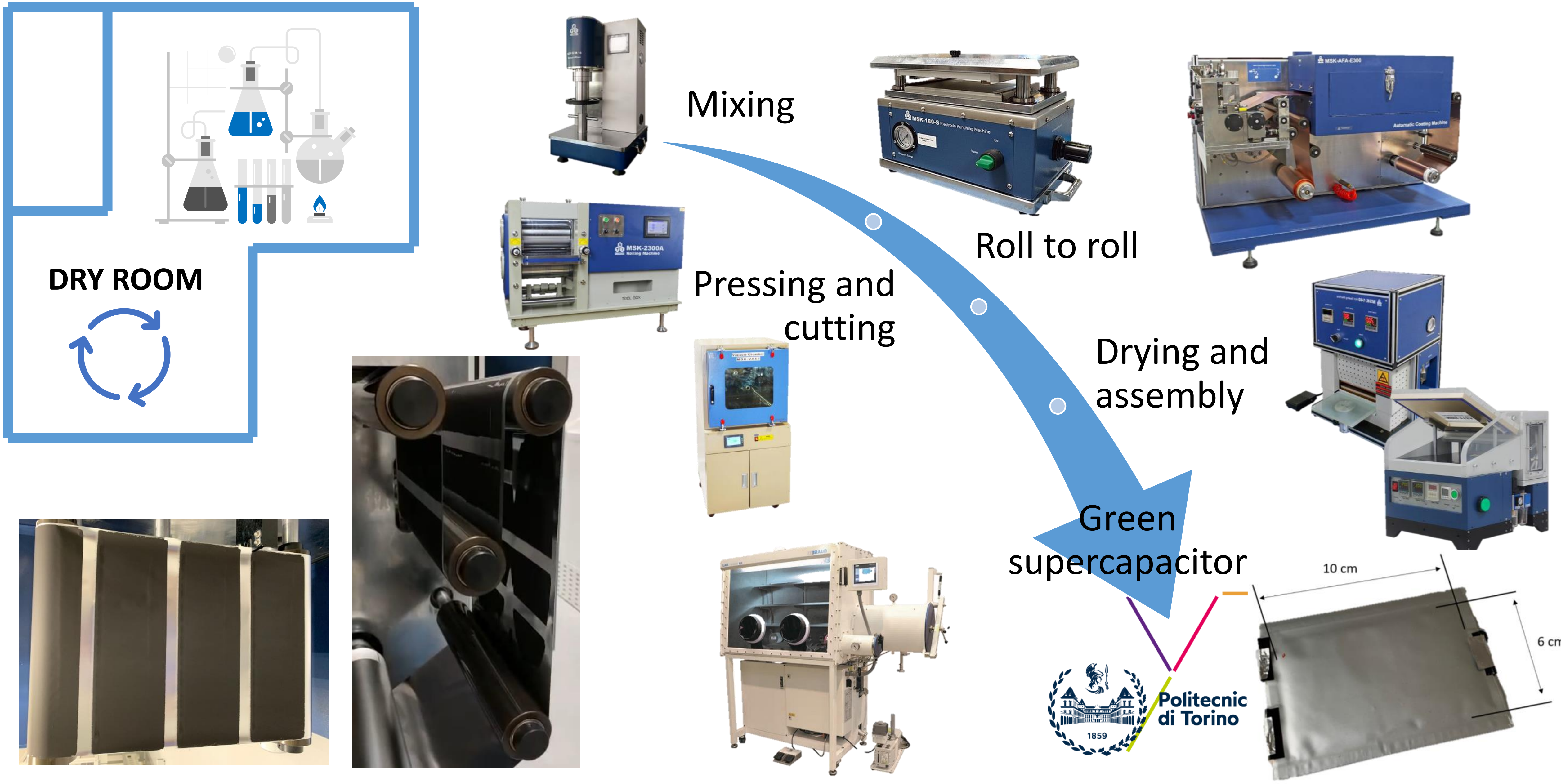
Research
Outputs

Prototypes

Industrial
Needs and
Requirements

INNOVATION
INFRASTRUCTURE

Where we are: Envipark Labs - Energy storage pilot line/dryroom



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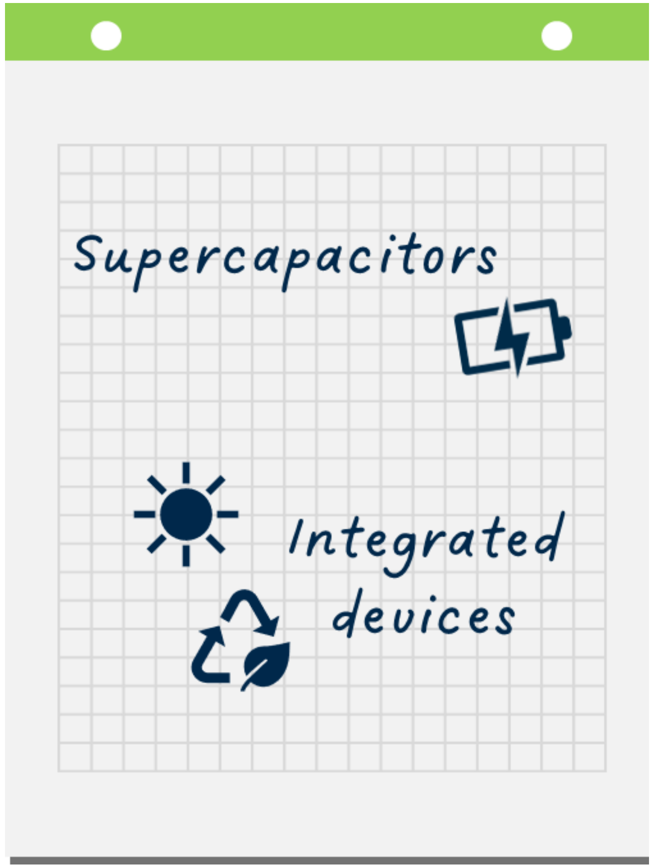

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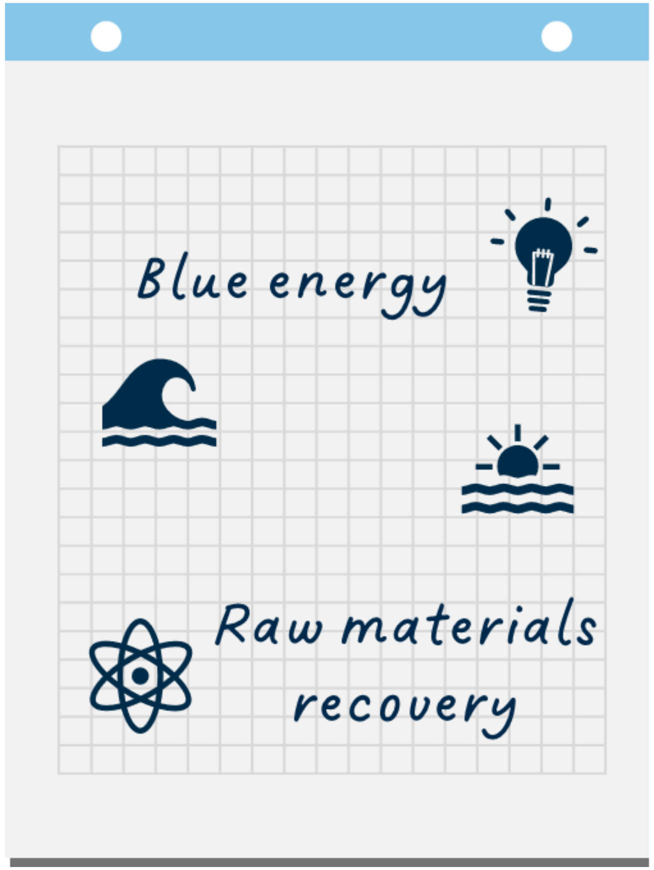
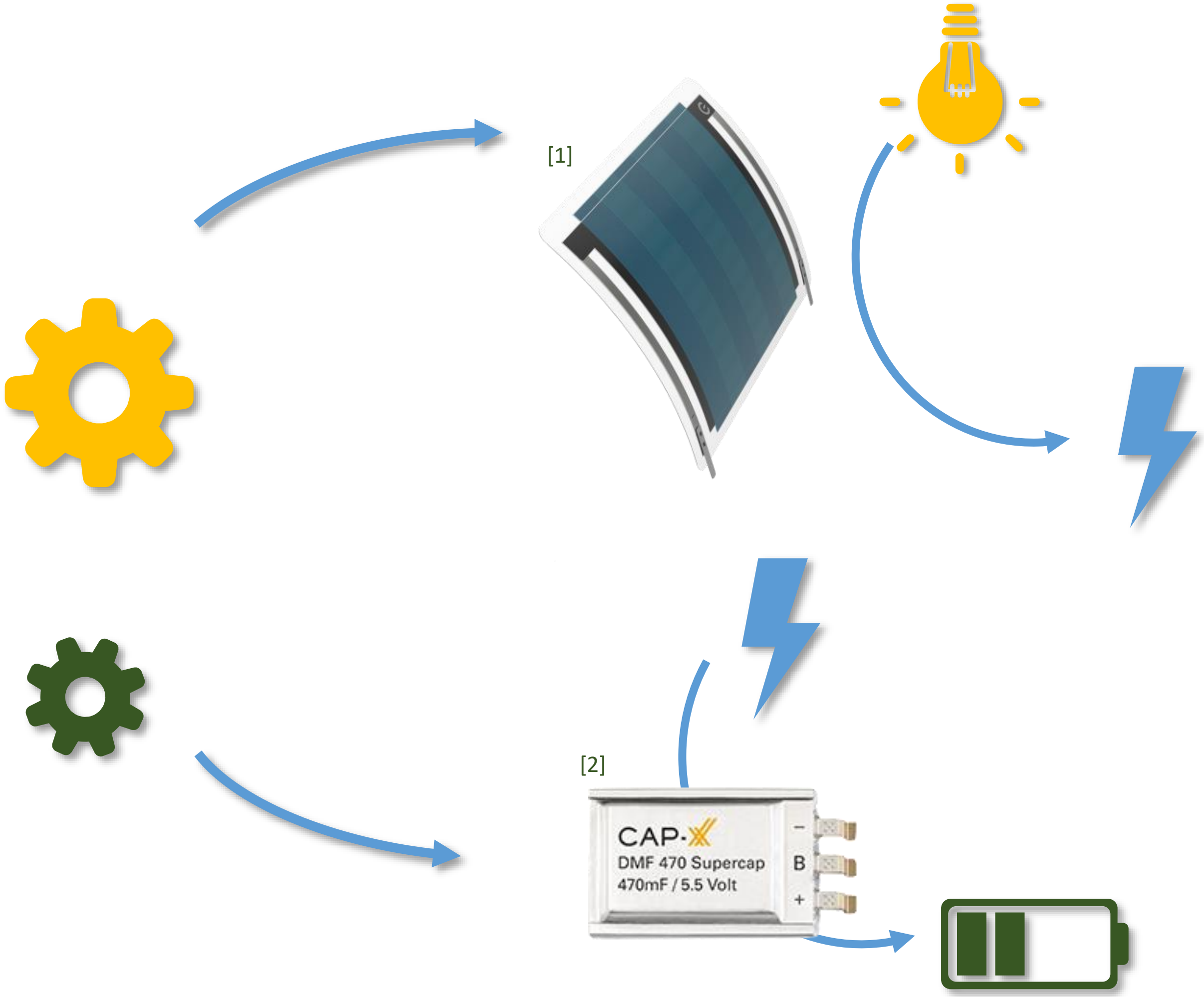


Integrated **energy harvesting and storage** systems



Sustainable energy from ambient light

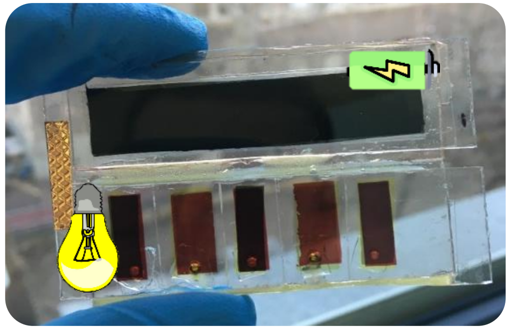
Intermittent power generation

Stored energy available **on demand**

Need to **recharge** periodically

[1] www.epishine.com/product
[2] www.cap-xx.com/product/

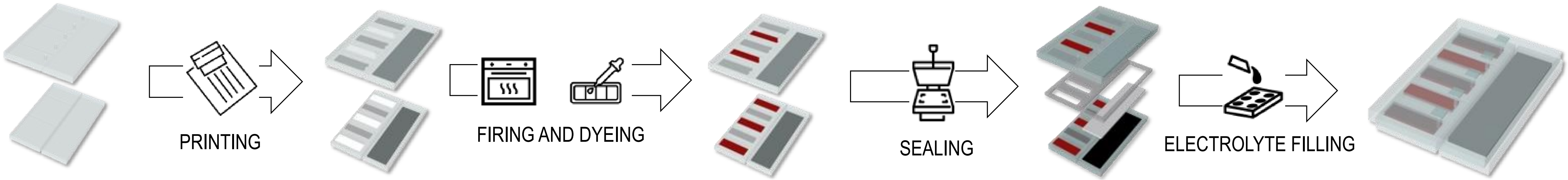
Integrated **energy harvesting and storage** systems



Self-charging under **artificial indoor light**

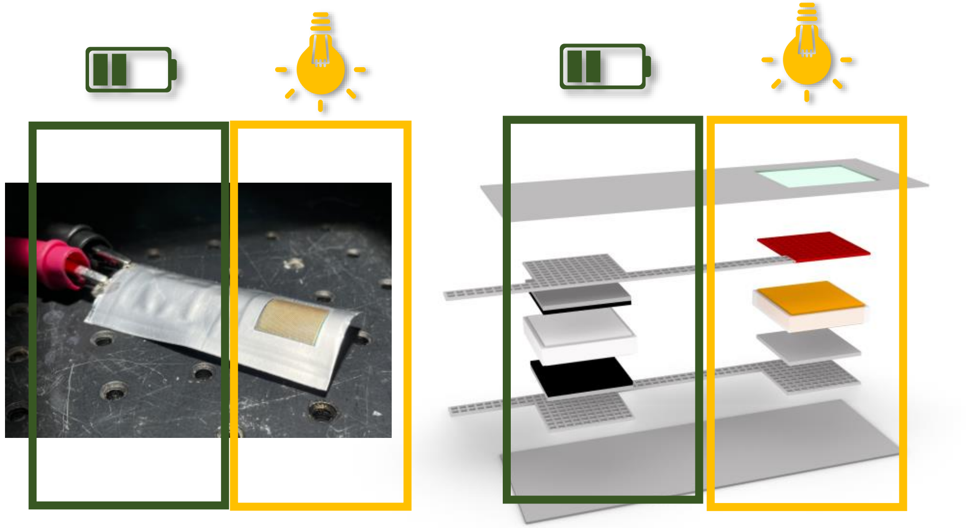
Maximum **charging voltage 3 V**

Shared **fabrication** process on **shared** substrate

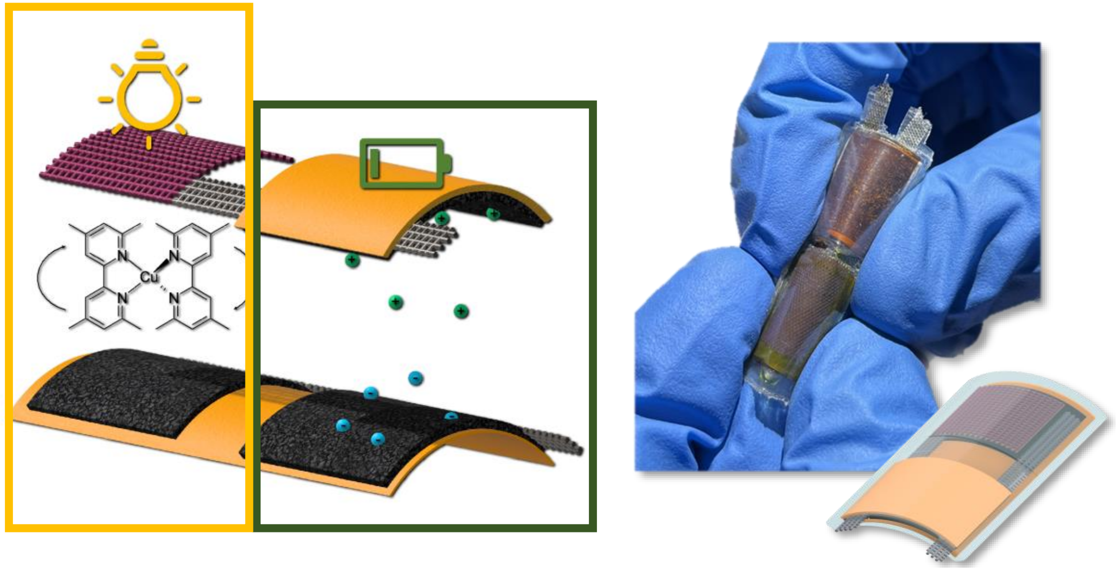


R. Speranza et al. 2023, Solar RRL

Integrated **energy harvesting and storage**



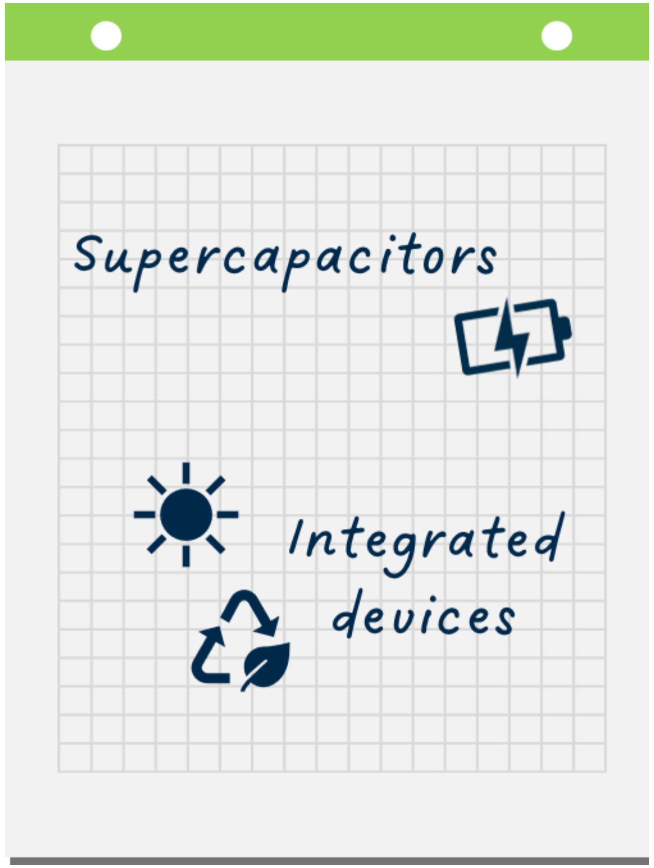
Expensive metals



Easy, low cost, flexible

R. Speranza et al. 2023, Journal of Power Sources; R. Speranza et al. 2023, Electrochimica Acta

Energy Harvesting and Storage Devices



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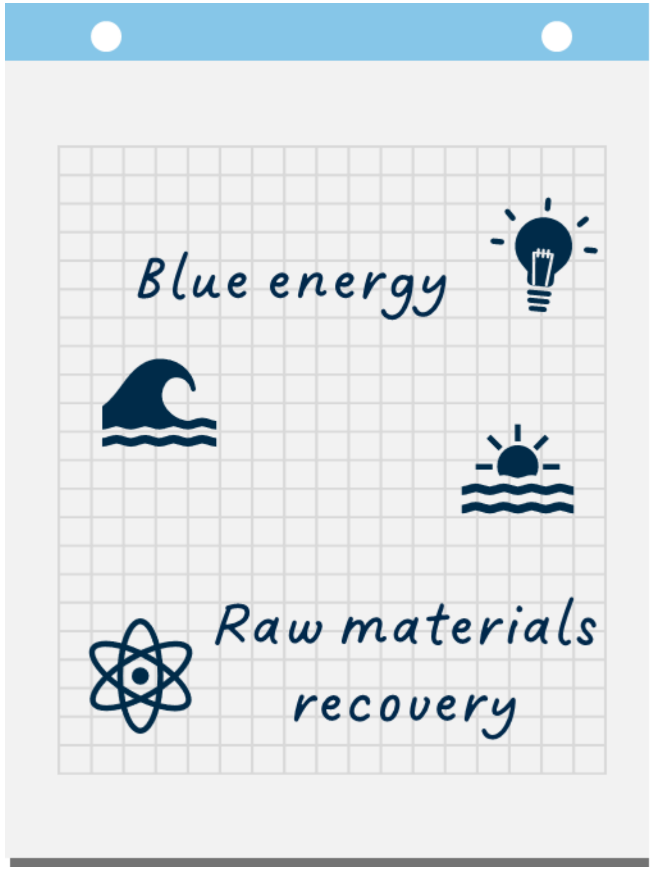


Blue energy

✓ Secure
✓ Large scale
✓ Reliable
✓ constant

Ocean energy resources

- sea waves
- sea tides
- temperature gradient
- salinity gradient

Complementary technologies to **desalination**: use of Gibbs free energy of mixing

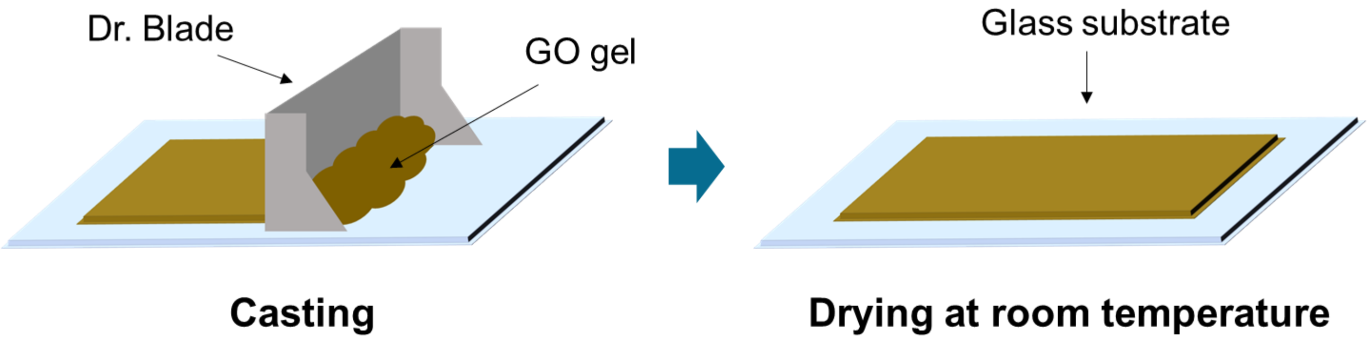
- Pressure Retarded Osmosis (PRO)
- Reverse Electrodialysis (RED)
- Capacitive Mixing (CapMIX)

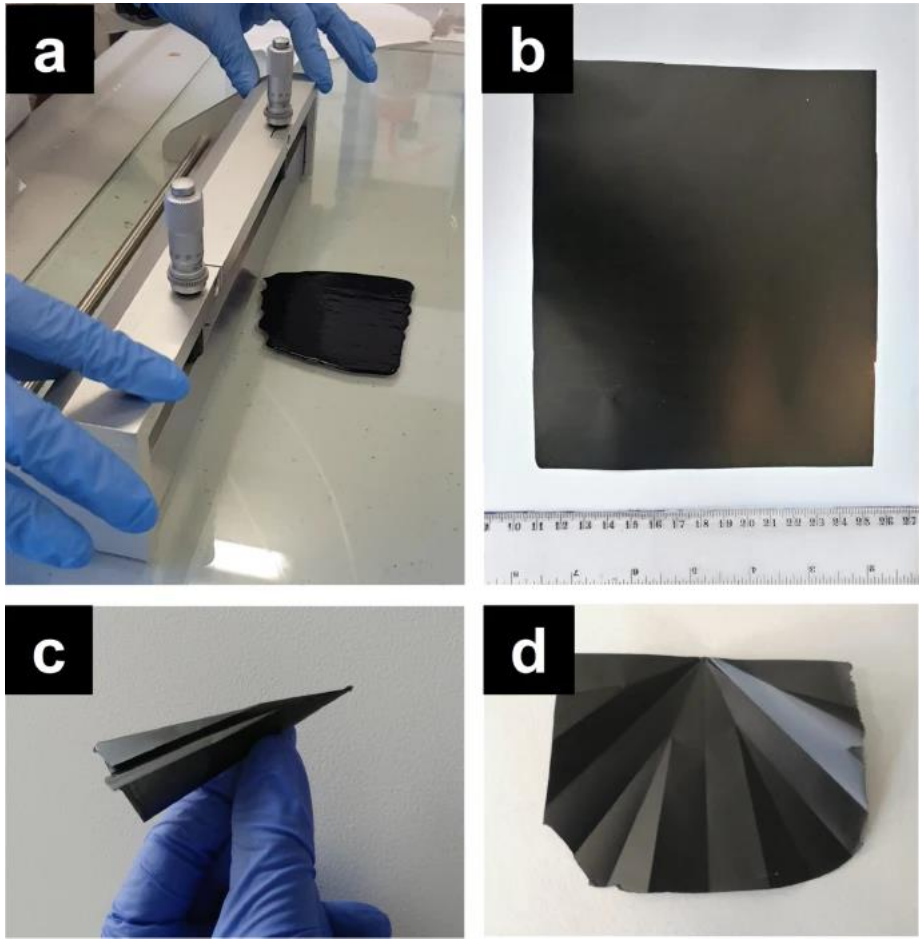
Can use the discharge brine of desalination plants!

Logan, Bruce E., and Menachem Elimelech. *Nature* 488.7411 (2012): 313-319.

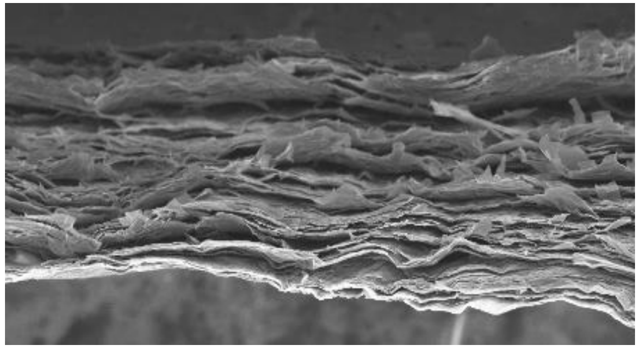
Fabrication methods

20 cm x 20 cm





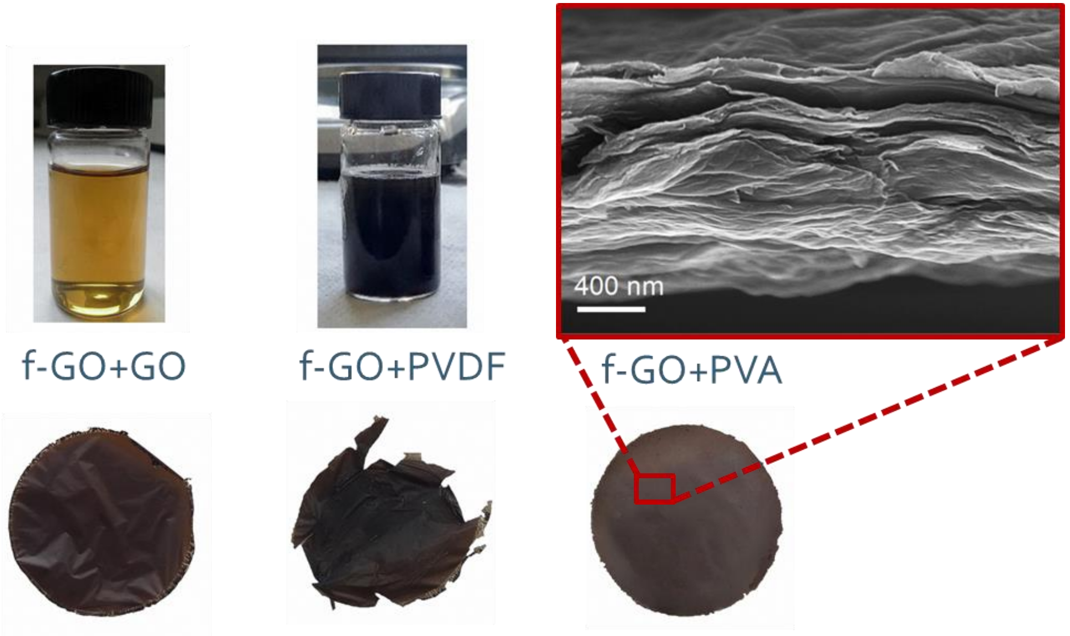
- ✓ **Medium control on order degree (influences the permeability and selectivity)**
- ✓ **High thickness control**
- ✓ **Scalable technique**



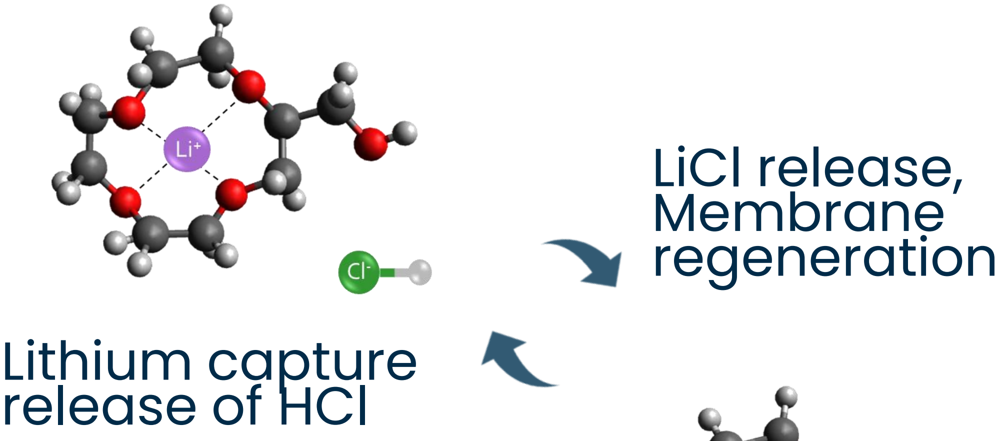
A. Aixalà-Perelló *et al.* **2023**, *npj 2D Mater Appl* 7, 46.

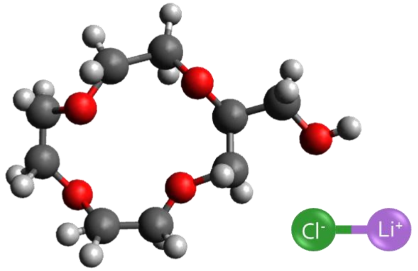
Lithium recovery

Stability and morphology



Capture mechanism

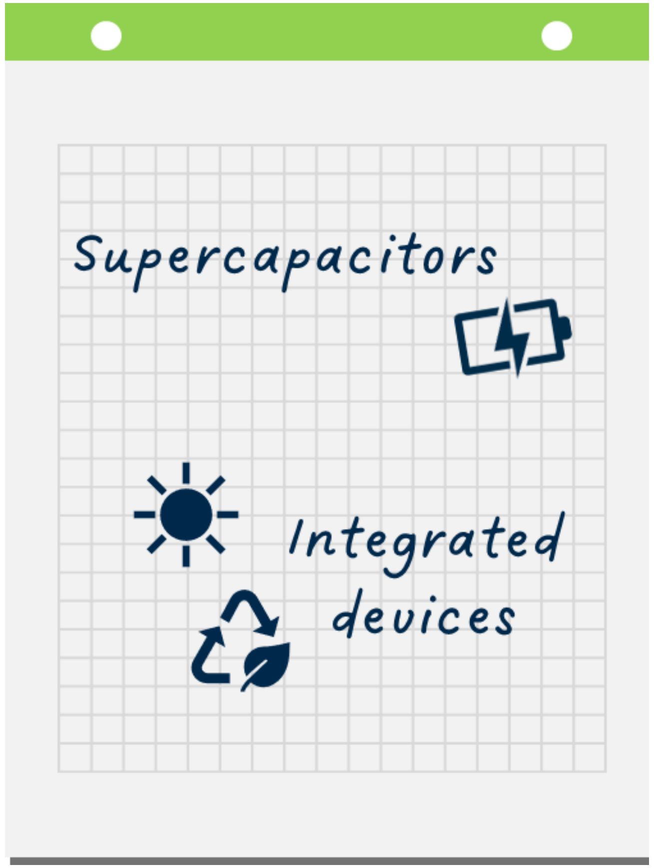




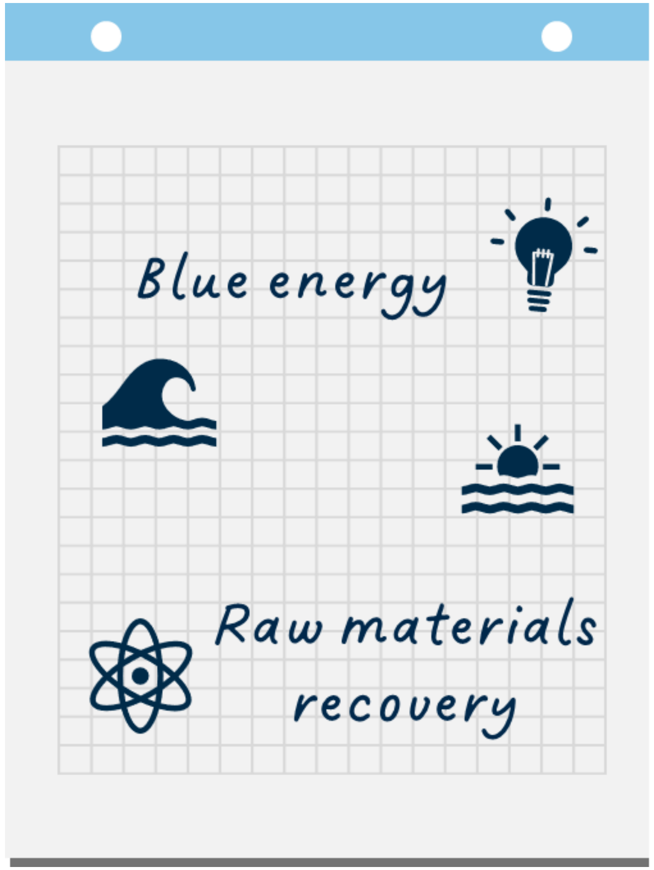
70% of lithium recovered from 1mM solutions in just a few hours!

L. Baudino et al. **2022**, *Membranes*, 12, 233.

Energy Harvesting and Storage Devices

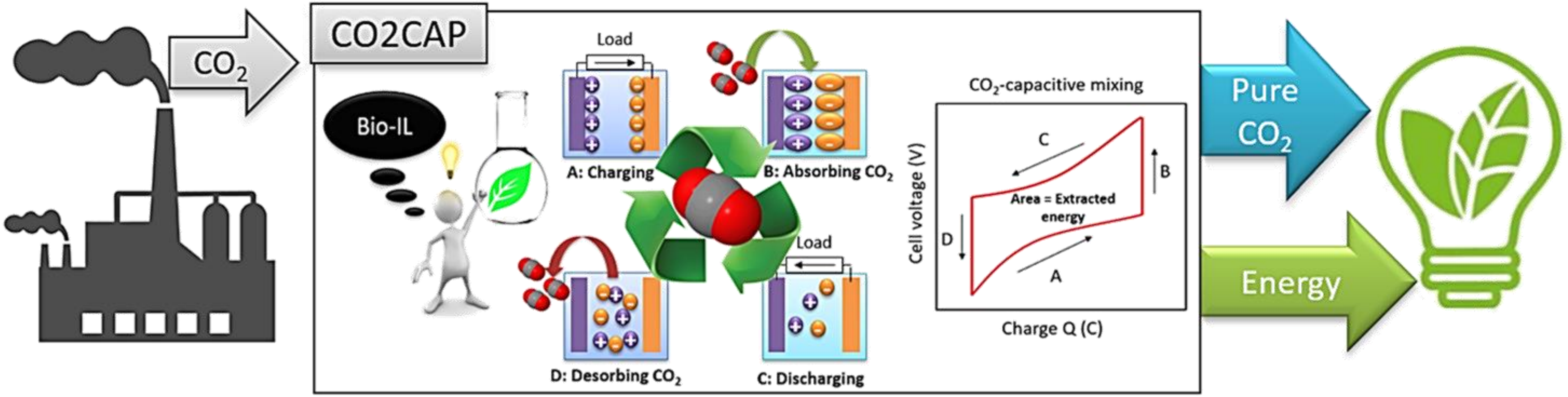


1. Energy harvesting: solar cells
2. Energy storage: supercapacitors
3. Integration
4. Energy harvesting (2): blue energy
5. **Energy harvesting (3): from CO_2 emissions**



Energy Harvesting and Storage Devices

Harvest energy from CO_2 emissions



Capacitive mixing of CO_2 into ionic liquid

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FRAMEWORK PER L'ATTRAZIONE E IL RAFFORZAMENTO DELLE ECCELLENZE PER LA RICERCA IN ITALIA

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SUSTAINABLE MATERIALS, PROCESSES AND SYSTEMS FOR THE ENERGETIC TRANSITION

Prof. Andrea Lamberti

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- **3 research centers**

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- management of renewable energy

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Acknowledgements

Curious about our activities? Want more info on our ***projects*** *and* ***papers****?*

Let's keep in touch!

Q & A

EnerHarv 2024

PSMA International Workshop | 26-28 June, 2024 | Perugia, Italy

Thanks very much for your time and attention!

Questions/comments???

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