



# Hybrid Nanomaterials for Energy Storage

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Institut Català de Nanociència i Nanotecnologia, ICN2 (CSIC-BIST)

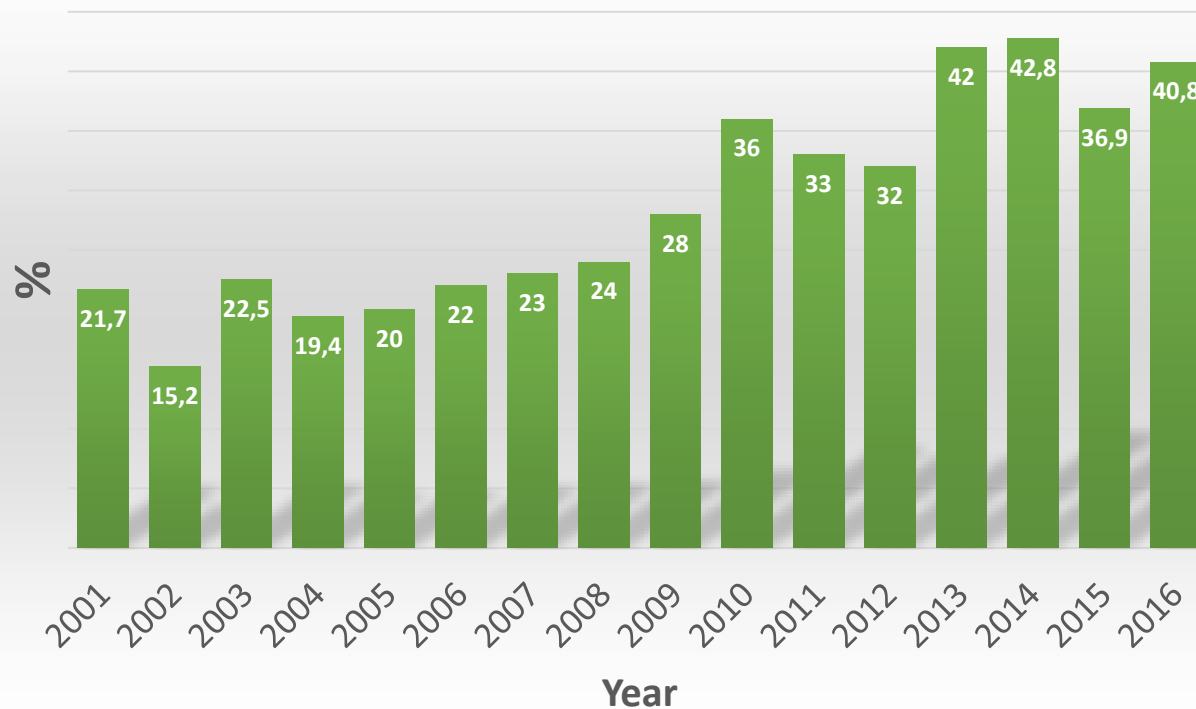
Bellaterra (Barcelona) [pedro.gomez@icn2.cat](mailto:pedro.gomez@icn2.cat)



NanoWorkshop Albania, Japan & Spain. Jan 29, 2020

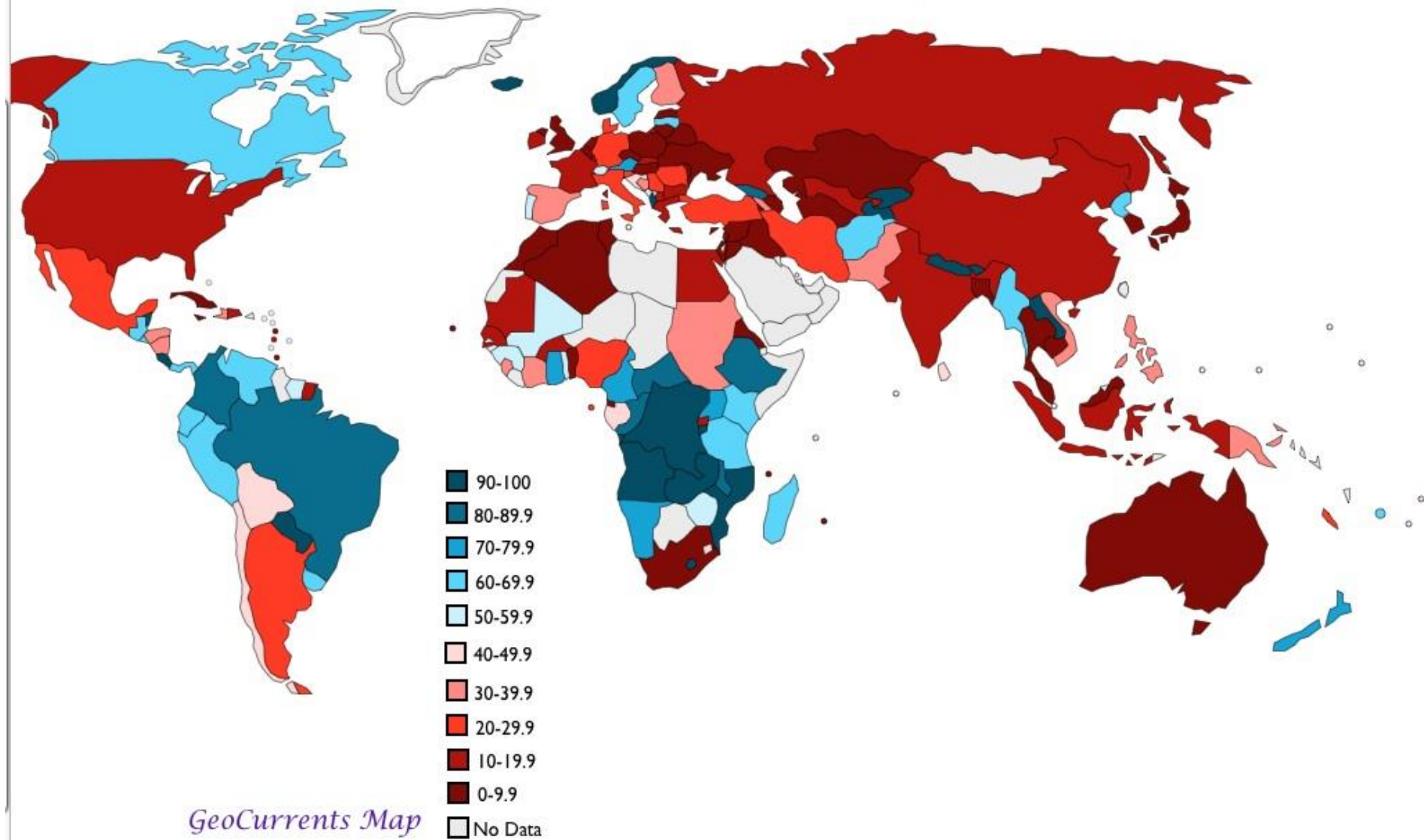
# The new Energy Landscape

Percent renewable electricity in Spain



# Percentage of Electricity Generation from Renewable Sources

(Hydro, Geothermal, Solar, Biomass, Wind)

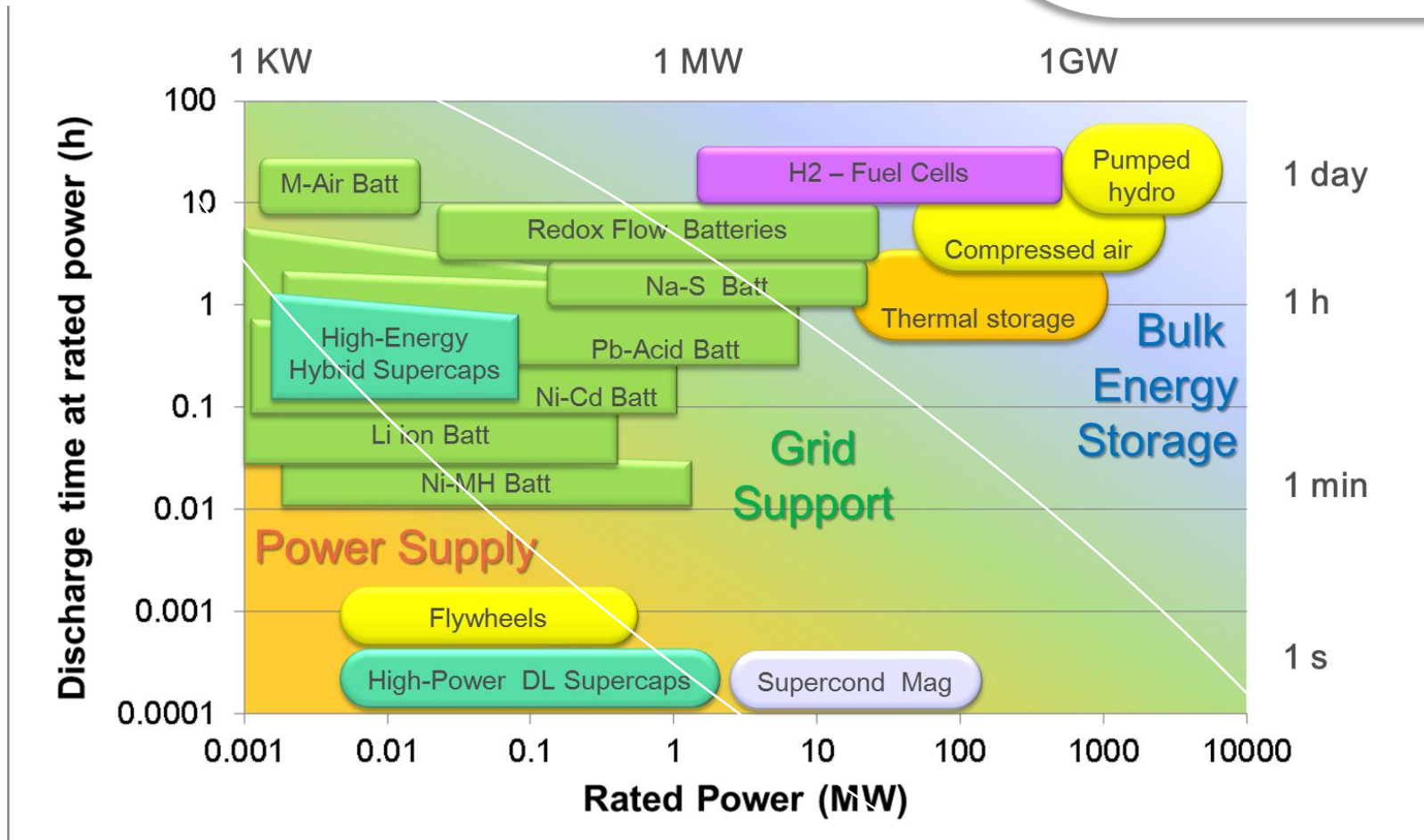


GeoCurrents Map

Data Source: [http://en.wikipedia.org/wiki/List\\_of\\_countries\\_by\\_electricity\\_production\\_from\\_renewable\\_sources](http://en.wikipedia.org/wiki/List_of_countries_by_electricity_production_from_renewable_sources)



# Energy storage systems



P. Gómez-Romero, D. Muñoz-Rojas Intro Chapter 1 “Energy in Transition”  
Materials for Sustainable Energy Applications (D. Muñoz-Rojas, X. Moya Eds.)  
Pan Stanford Pub **2016**

# Energy storage in transition



# Energy storage in transition

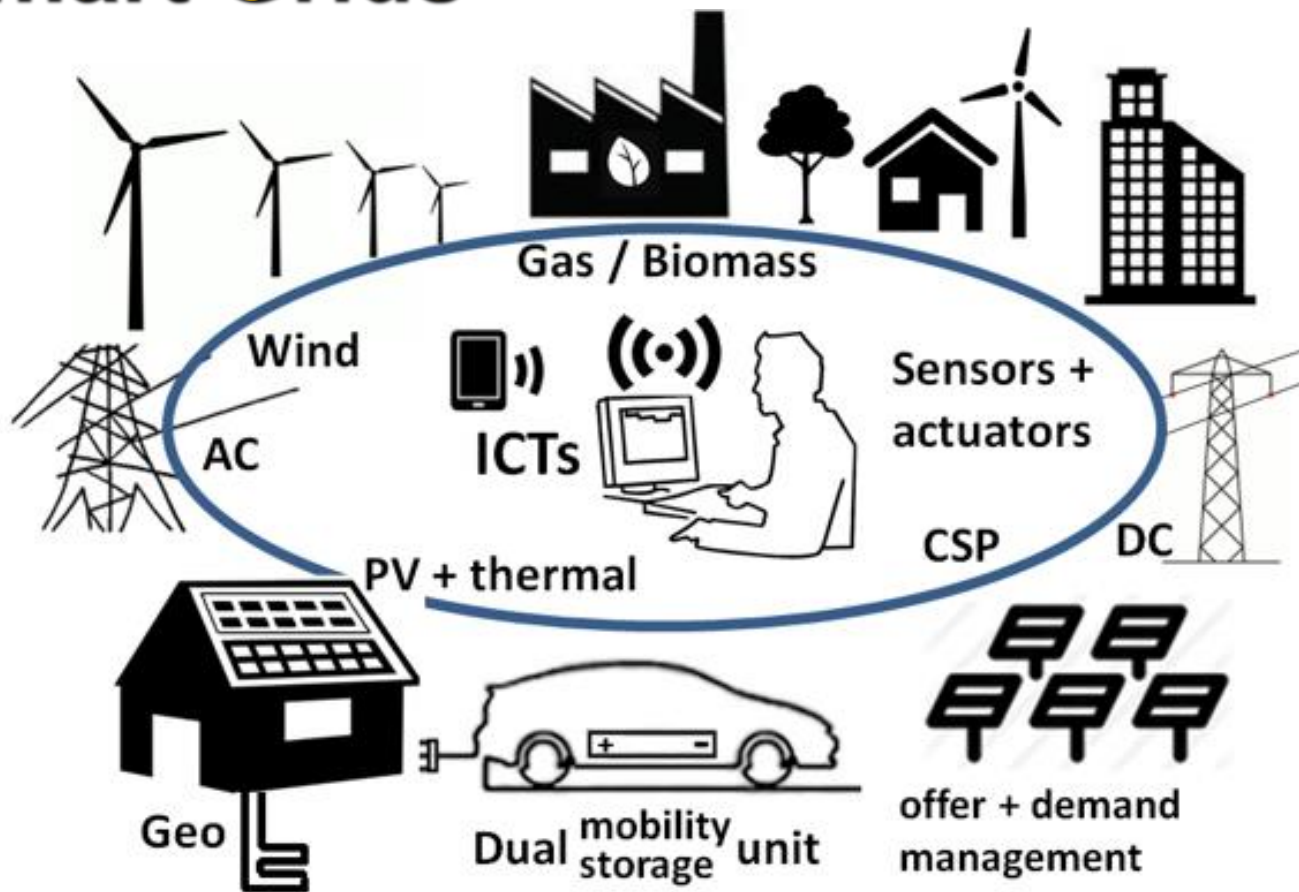


Towards flexible solid-state supercapacitors for smart and wearable electronics  
D. P. Dubal,\* N.R. Chodankar, D-H. Kim and P. Gomez-Romero\*  
Chemical Society Reviews, **2018**, 47(6), 2065-2129

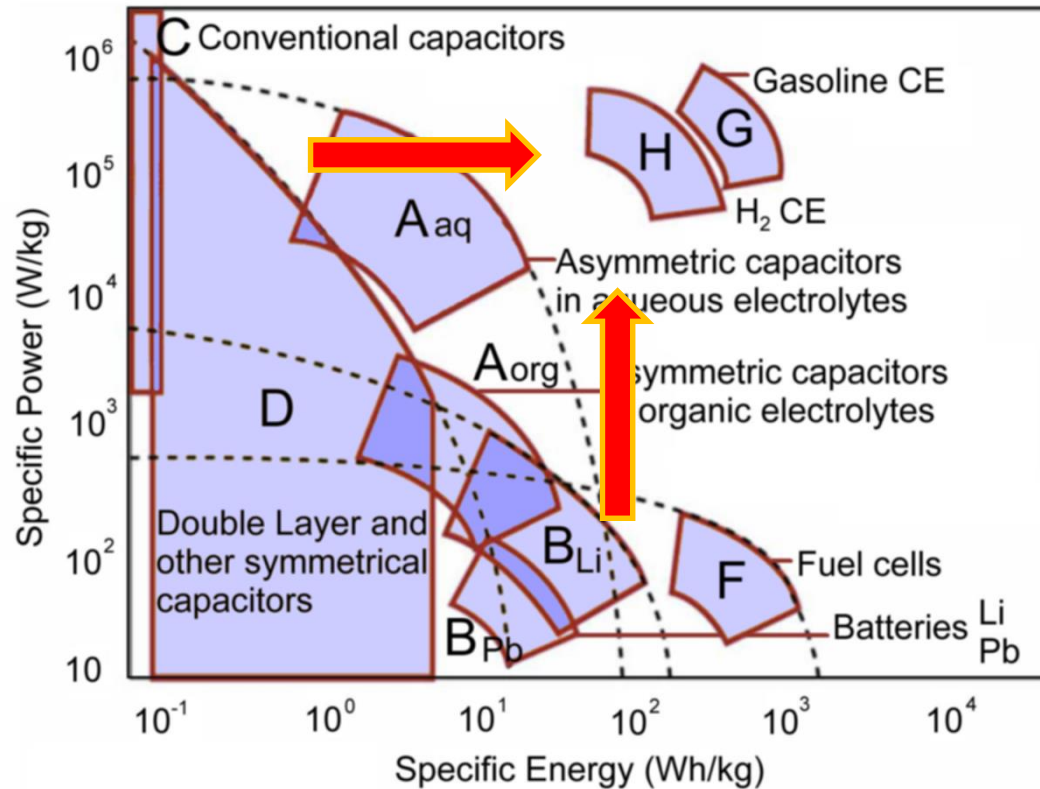
# Centralized AND Distributed Energy

## Smart Grids

## Internet of Things



# Ragone Plot: Energy vs. Power



Hybrid Energy Storage. The merging of battery and supercapacitor chemistries.

D. P. Dubal, O. Ayyad, V. Ruiz, and P. Gomez-Romero\* Chem.Soc.Rev. 44(7):1777-90 2015



# The NEO-Energy TEAM

[www.neoenergy.cat](http://www.neoenergy.cat)



Institut Català  
de Nanociència  
i Nanotecnologia



Prof. Pedro GOMEZ-ROMERO  
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Project Manager  
PhD Materials Science



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Beatriu de Pinos PostDoc.  
Dra en Quimica



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Doc Ind. PhD student  
Industrial Engineer



Mr. Daniel RUEDA-GARCÍA  
PhD Student  
Chemist.



Ms. Anukriti POKHRIYAL  
DOC-FAM PhD Student  
Elect Engineer.



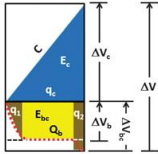
Mr. Junjie ZHU  
CSC PhD Student



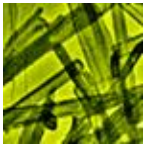
Mr. Aiman CHBANI  
Master Student  
Chemist.

# NEO-Energy Group.

## Active Research Lines

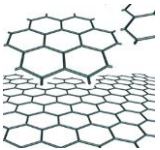


**Hybrid materials for Hybrid Energy Storage.** We work on batteries (high energy, poor power), we work on supercapacitors (high power, poor energy) Chem. Soc. Rev., **2018**, 47(6), 2065. AND we also work on hybrids for extra energy density with high power. Chem. Soc. Rev., **2015**, 44, 1777



### **Nano-Pipes. From polymers to carbons. From 1D to 2D materials.**

Novel Carbon Nanopipes (100 nm diameter) developed in our group could work as active encapsulating materials for the cathode in Li-S cells



### **New industrial Methods for the Fabrication of Graphene.**

Ease of preparation, eco-friendly methods with zero-waste- Trade secret.  
Electrochemical exfoliation (our style)



**Graphene secondary products: Nanofluids.** Made of graphene and different functional additives. Applications as Heat Transfer Fluids (HTFs) (in col. With prof. C. Sotomayor) and for Flow Cells. **Inks** for ink-jet or screen printing (in collaboration with prof. A. Merkoçi). **Graphene-Polymer** composites for **3D-printing**

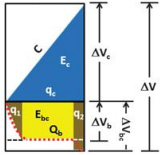


### **Graphene for energy storage in batteries and hybrid supercapacitors**

A Spin-off company with the mission to make energy-storage technology and products out of our knowledge and know-how in this field

# NEO-Energy Group.

## Active Research Lines



**Hybrid materials for Hybrid Energy Storage.** We work on batteries (high energy, poor power), we work on supercapacitors (high power, poor energy) Chem. Soc. Rev., **2018**, 47(6), 2065. AND we also work on hybrids for extra energy density with high power. Chem. Soc. Rev., **2015**, 44, 1777



**ICN2**<sup>R</sup>

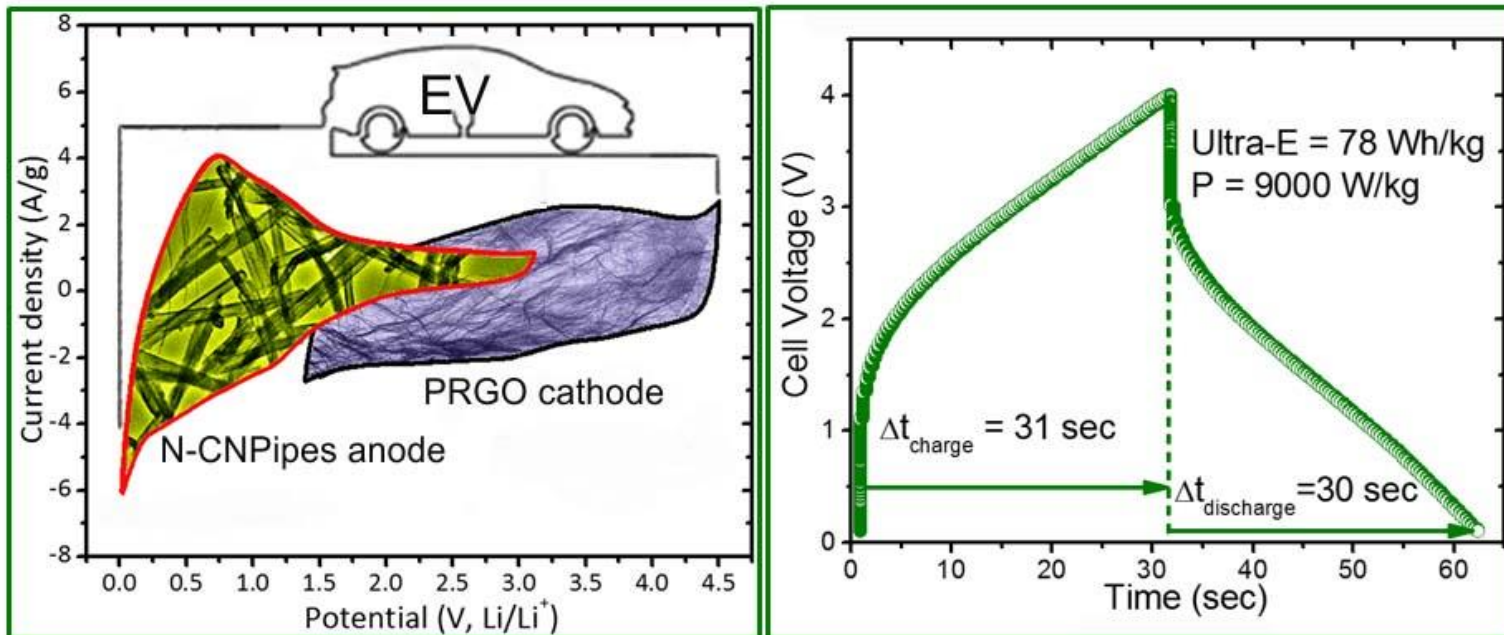
**Institut Català  
de Nanociència  
i Nanotecnologia**



**EXCELENCIA  
SEVERO  
OCHOA**

# Hybrid Device





Nanocarbon Li-Ion Capacitor:

Battery-like negative electrode + supercap-type positive electrode

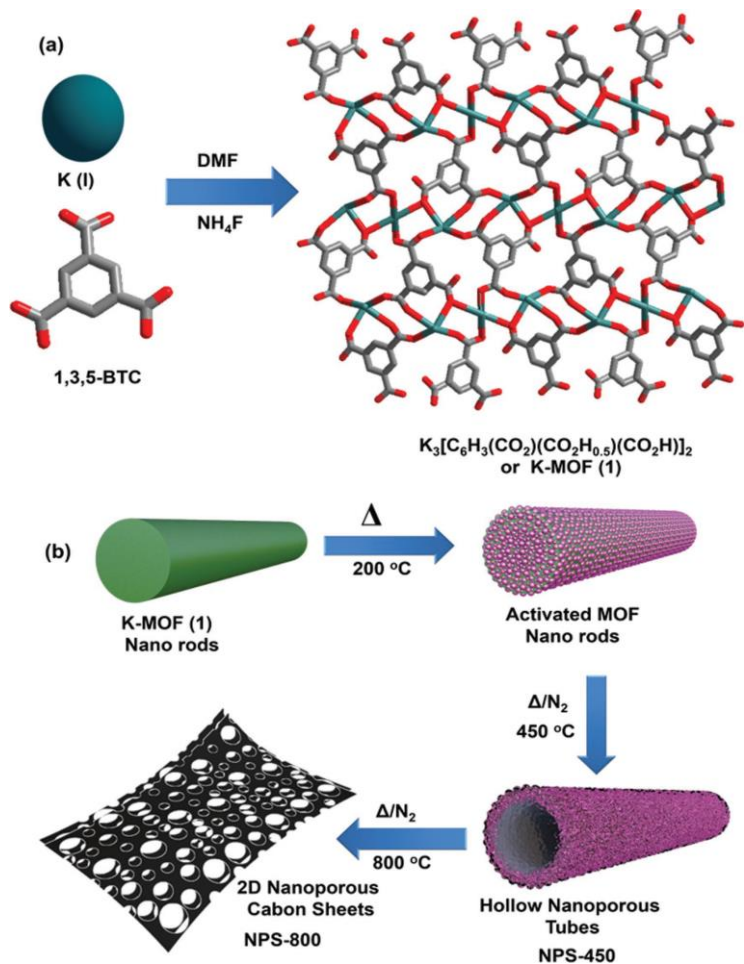
High energy and high power (fast charge) **SIMULTANEOUSLY**

All Nanocarbon Li-Ion Capacitor with High Energy and High Power Densities.

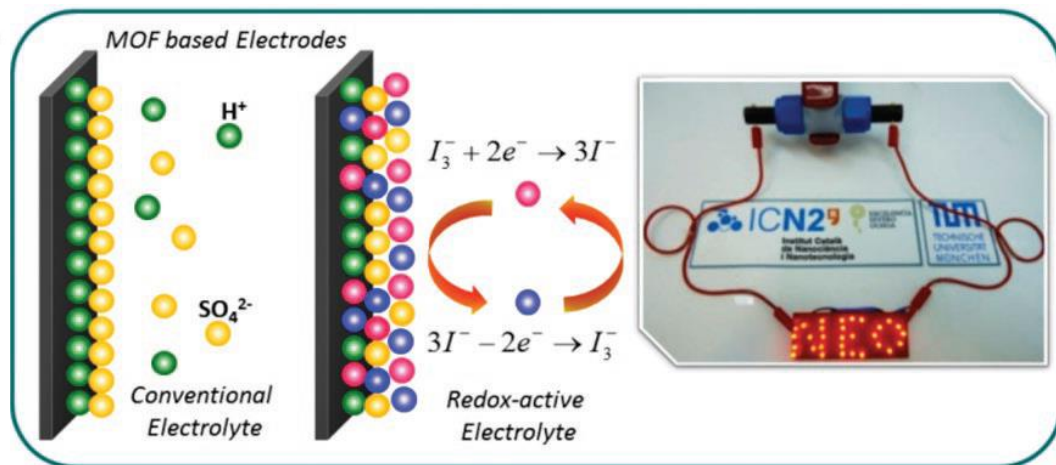
Deepak P. Dubal,\* Pedro Gomez-Romero\*\* *Materials Today Energy* **2018**, 8, 109-117

# Electrode-Electrolyte Hybridization

# 2D Nanoporous Carbon Sheets (from MOFs)



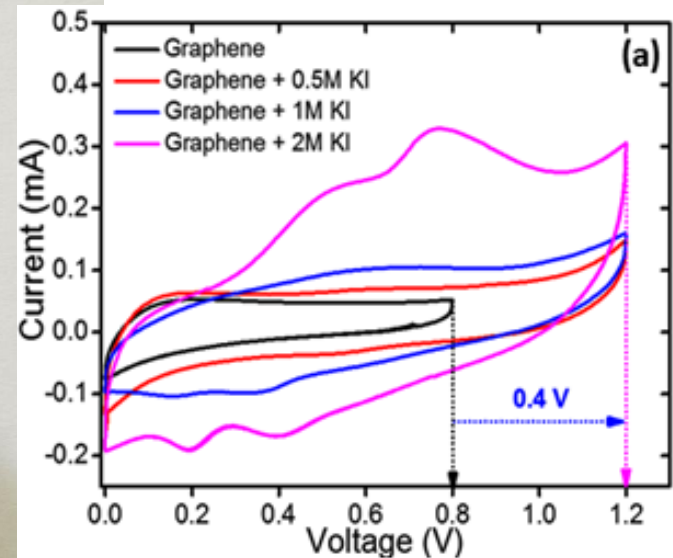
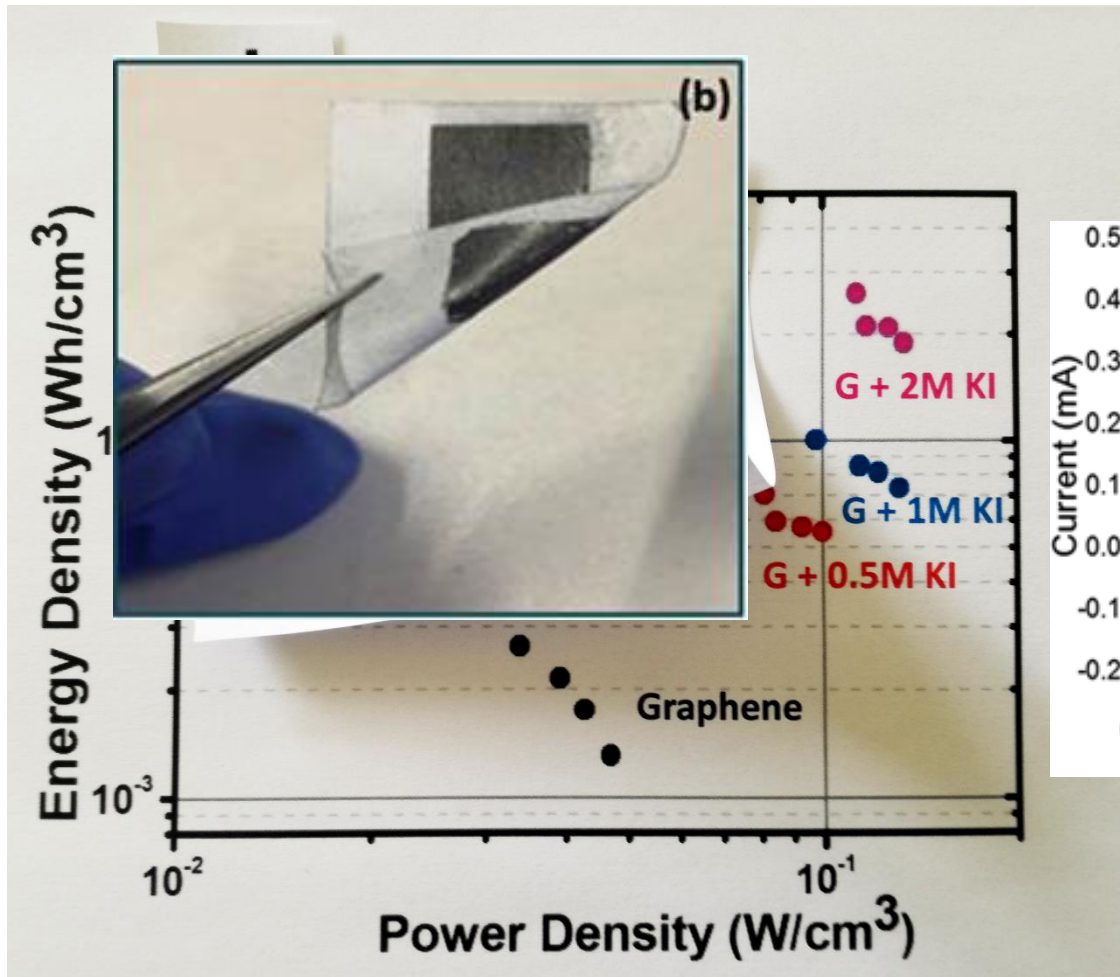
## Capacitive electrodes + Redox electrolytes



1200 m<sup>2</sup>/g

# Symmetric Graphene supercap printed on paper

## + KI

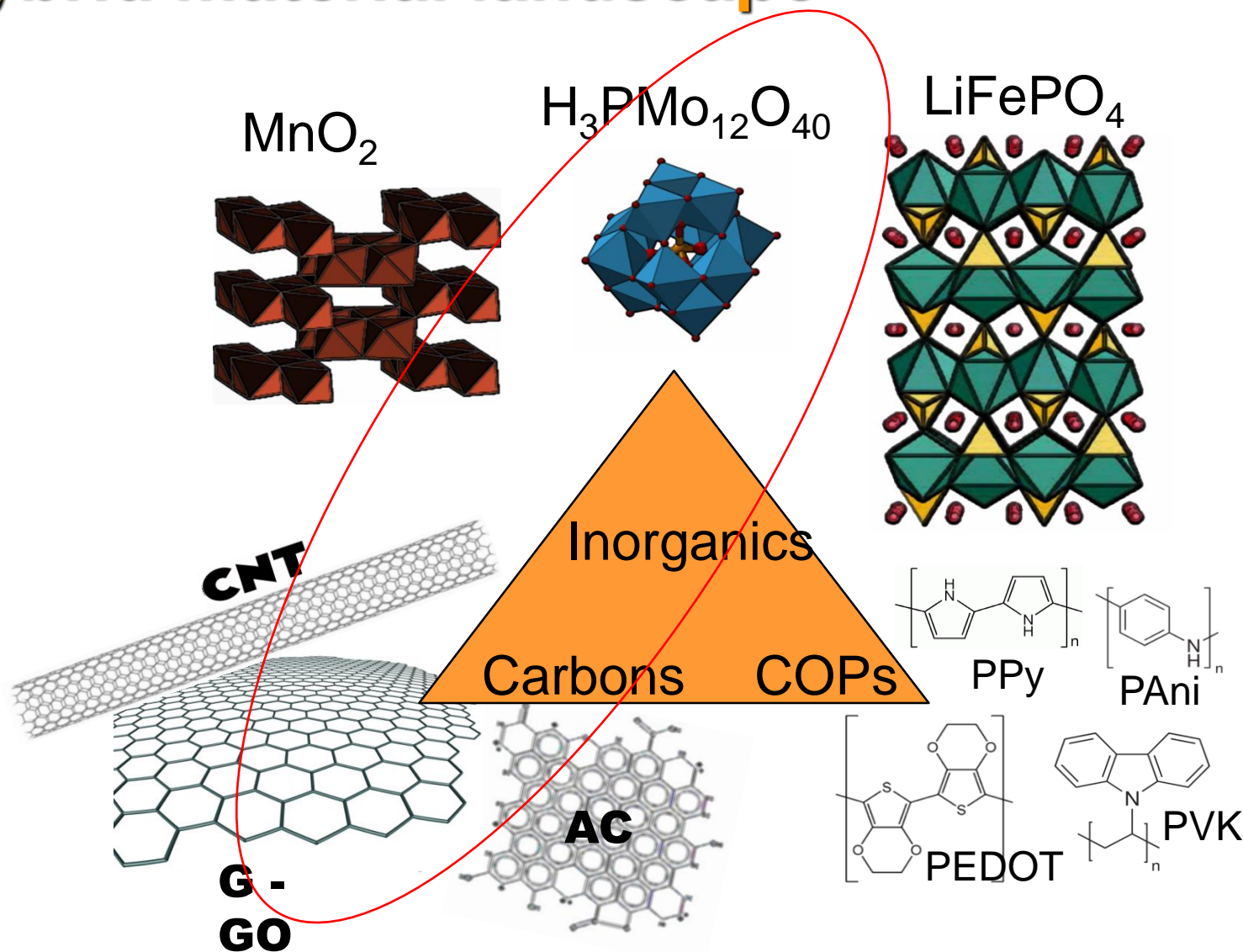


B Nagar, D. P. Dubal, L. Pires, A. Merkoçi and P. Gómez Romero\*  
*ChemSusChem* **2018**, 11(11), 1849-1856



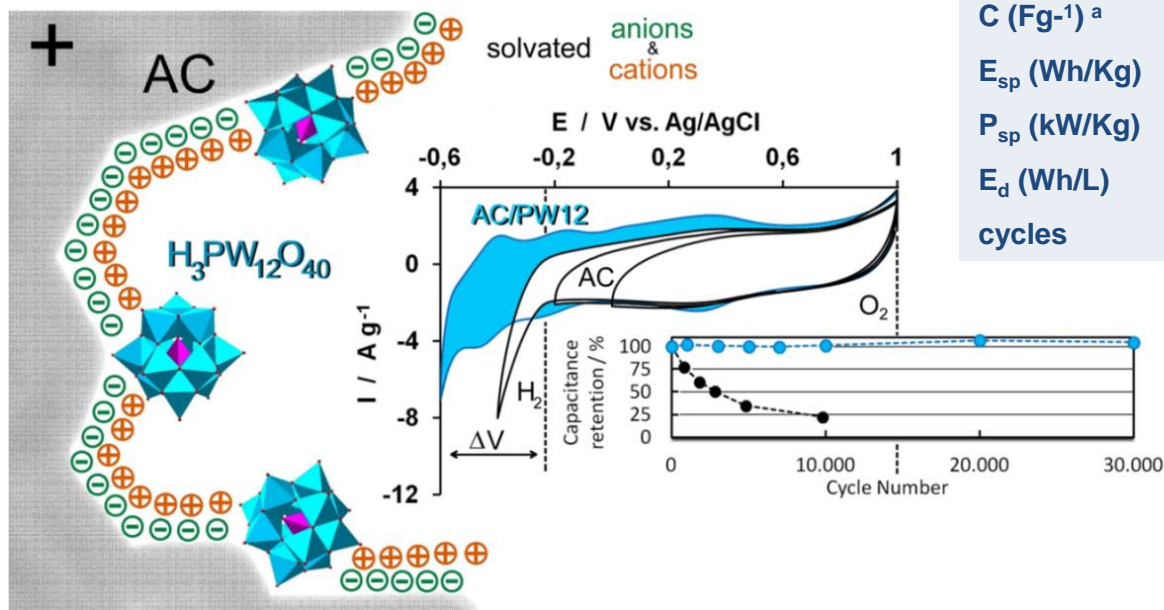
# Electrode Material Hybridization

# Our window to the hybrid material landscape



# Hybrid Energy Storage: Hybrid electrode materials

## Hybrid Activated Carbon- $\text{H}_3\text{PW}_{12}\text{O}_{40}$



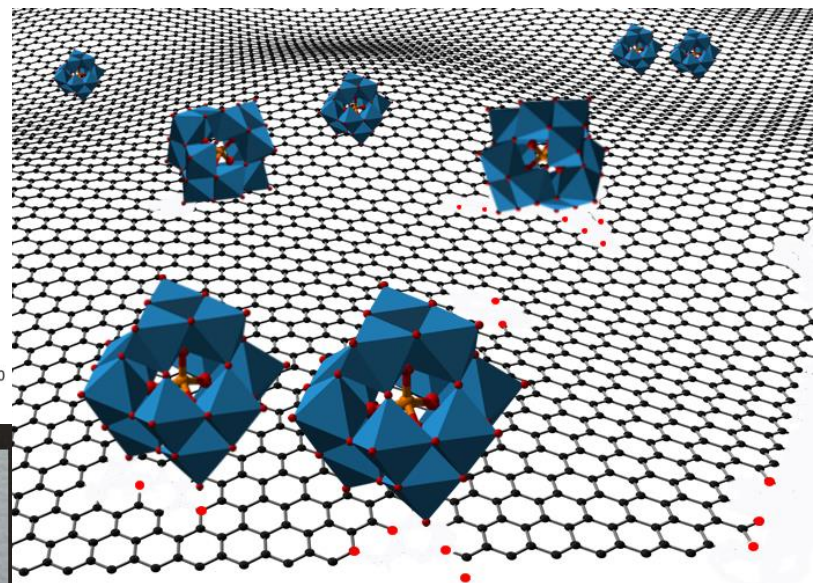
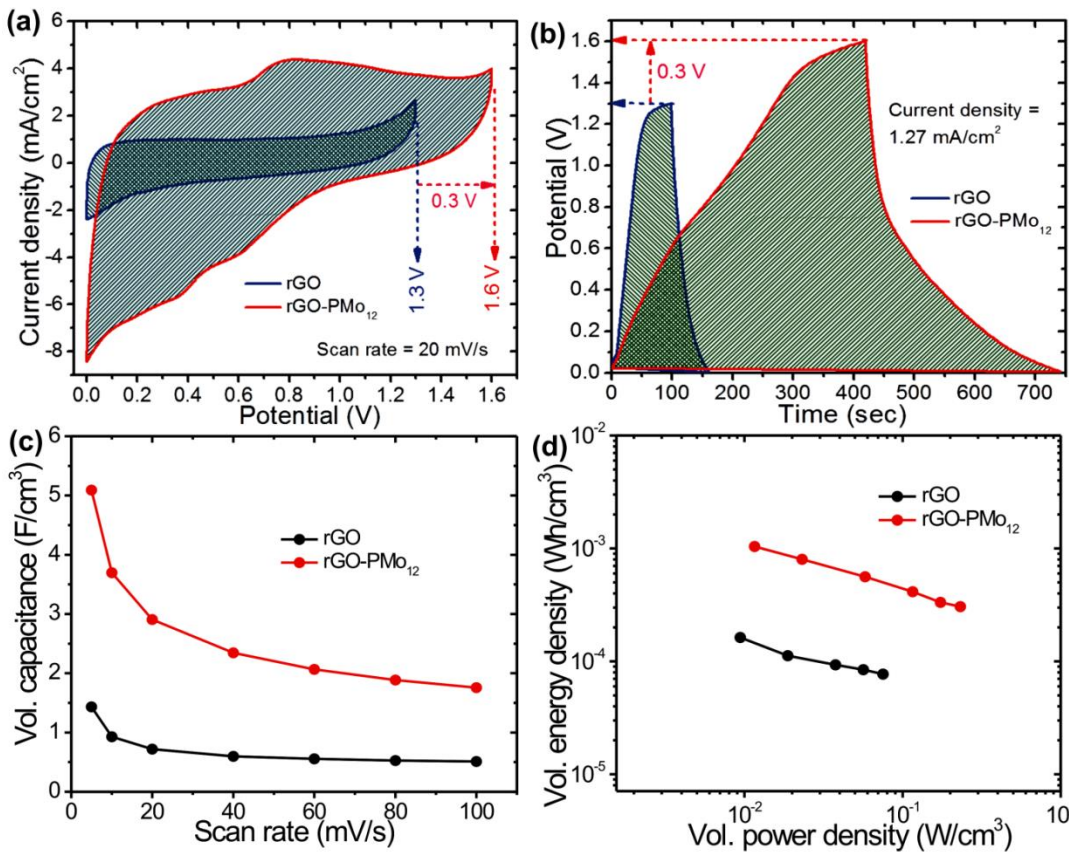
	AC	AC-PW12
C (Fg <sup>-1</sup> ) <sup>a</sup>	185	254
E <sub>sp</sub> (Wh/Kg)	4.05	4.96 (1.6 A/g)
P <sub>sp</sub> (kW/Kg)	45	115
E <sub>d</sub> (Wh/L)	1.55	2.32
cycles	10,000	> 30,000 (6 A/g)

1.6V  
in 1M H<sub>2</sub>SO<sub>4</sub> !

# Hybrid Graphene Polyoxometalate Electrodes

## Hybrid Energy Storage: Hybrid electrode materials + Electroactive electrolyte

### rGO / H3PMo12O40 / HQ



31 LEDs powered with a single rGO-PMo<sub>12</sub> symmetric cell with 0.2 M HQ doped polymer gel electrolyte.  
 30 s charge 2 min lit



# NEO-Energy Group. Active Research Lines



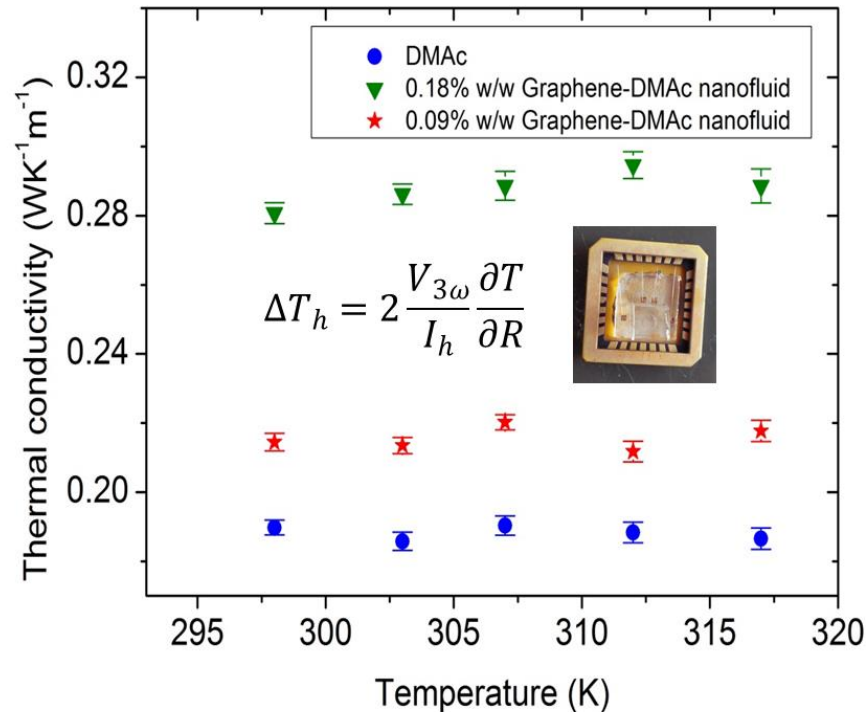
## Graphene secondary products:

**Nanofluids.** Made of graphene and different functional additives. Applications as Heat Transfer Fluids (HTFs) (in col. With prof. C. Sotomayor) and for Flow Cells.

**Inks** for ink-jet or screen printing (in collaboration with prof. A. Merkoçi).

**Graphene-Polymer** composites for **3D-printing** (col. With EURECAT)

# Graphene Nanofluids as Heat Transfer Fluids



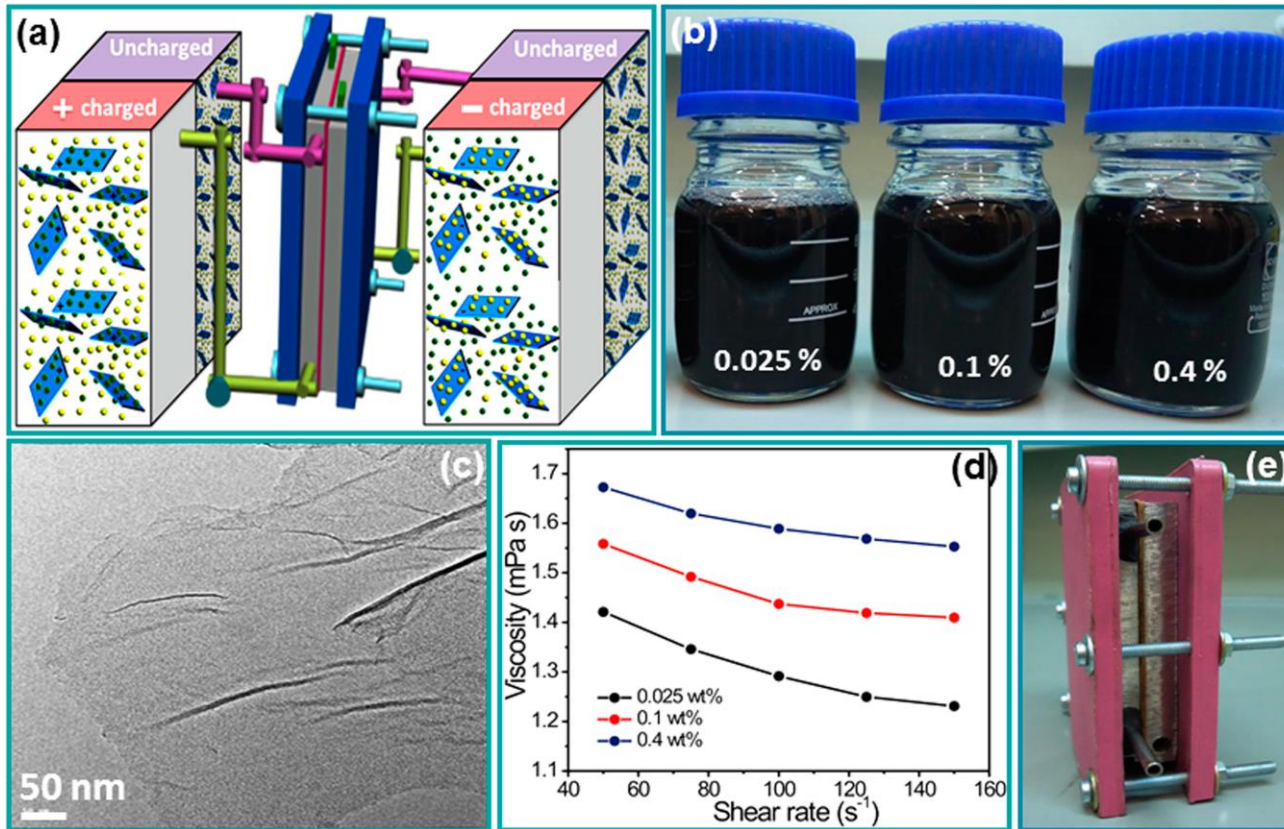
3-omega measurements.  
Novel approach for thermal conductivity in liquids (colaboration with Prof. C. Sotomayor's and Prof. P Ordejón's groups at ICN2)

Less than 1% graphene in a perfectly stable solution (left) leads to a 50% improvement

Mechanisms behind the enhancement of thermal properties of graphene nanofluids

M. R. Rodríguez-Laguna, A. Castro-Alvarez, M. Sledzinska, J. Maire, F. Costanzo, B. Ensing, P. Ordejón, C. M. Sotomayor-Torres, P. Gómez-Romero and E. Chávez-Ángel *Nanoscale*, **2018**, 10, 15402-15409

# Electroactive Graphene Nanofluids for New Flow Cell Concepts.

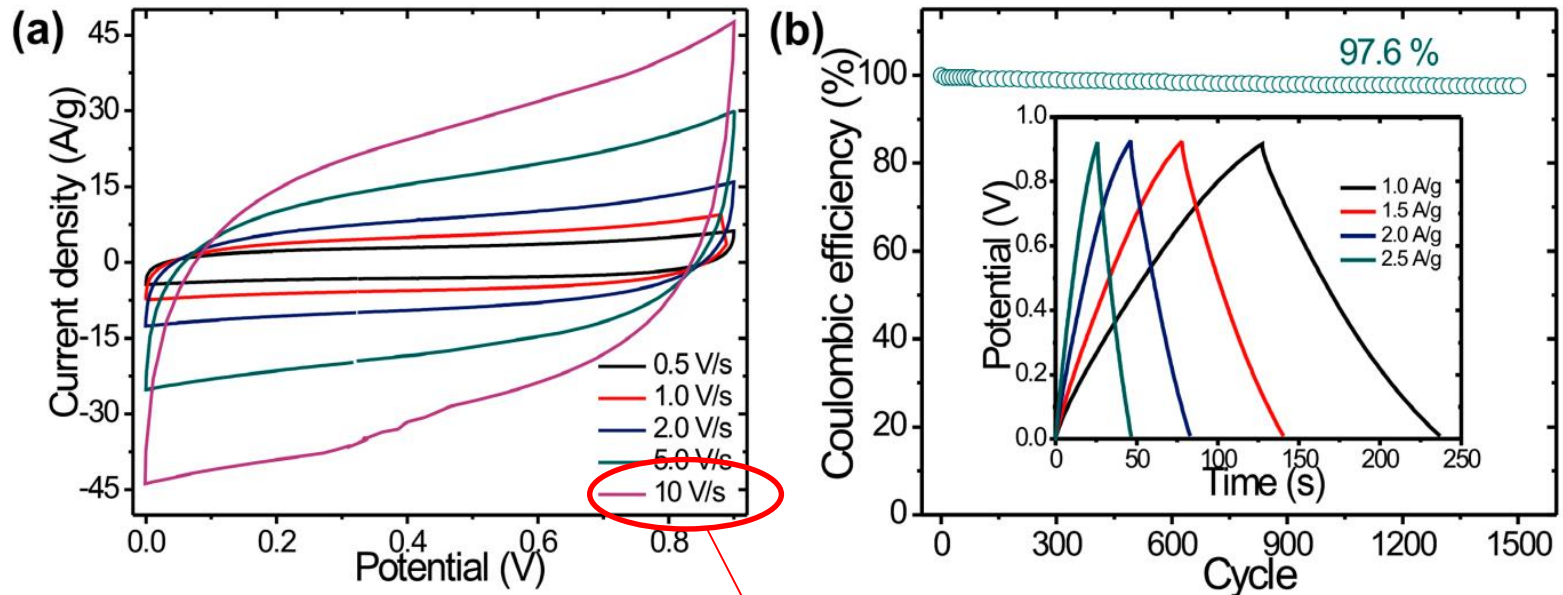


*D. P. Dubal, D. Gomez, P. Gómez-Romero, Patent ES1641.1064. "Electroactive nanofluids on graphene-based materials for energy storage in flow cells." 20-05-2015*

Electroactive Graphene Nanofluids for Fast Energy Storage.

D.P. Dubal and P. Gomez-Romero 2D-Materials **2016**, 3, 031004

# Electroactive Graphene Nanofluids for New Flow Cell Concepts.

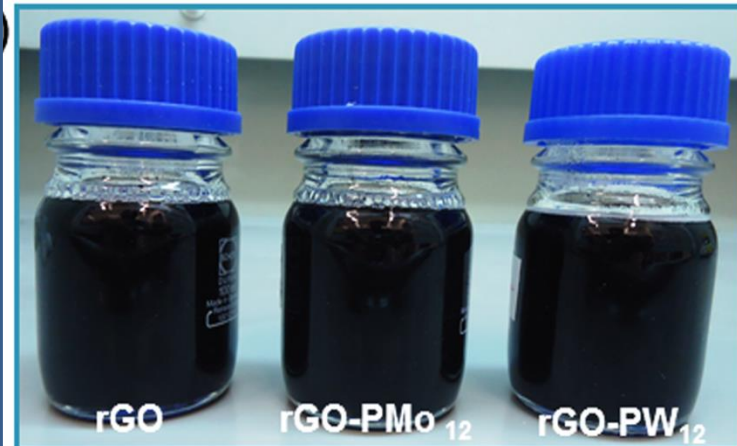
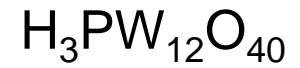
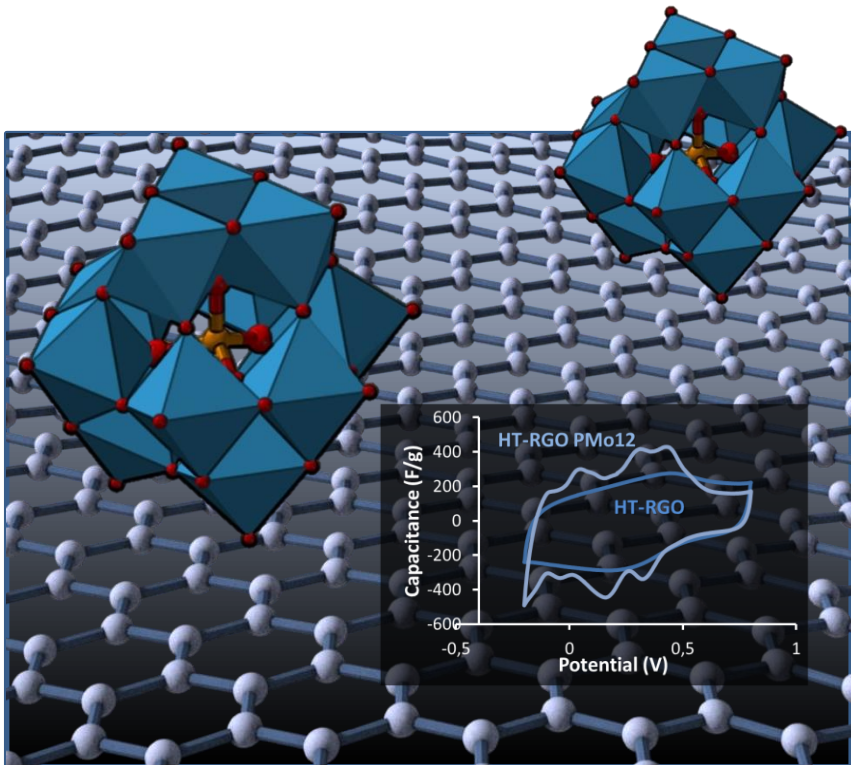


ultrafast  
electrochemical  
response

Electroactive Graphene Nanofluids for Fast Energy Storage.

D.P. Dubal and P. Gomez-Romero 2D-Materials **2016**, 3, 031004

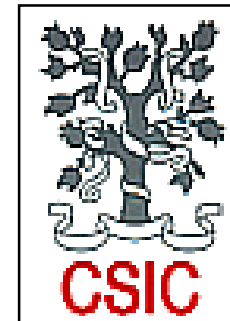
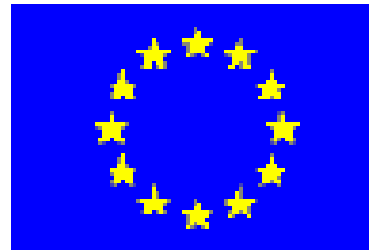
# Hybrid Electroactive Graphene Nanofluids for New Flow Cell Concepts.





# NEO-Energy Lab

Prof. Pedro Gómez-Romero



Generalitat  
de Catalunya



## NEO-Energy Group @ ICN2 May 2019



Dani Rueda, Verónica Fabián, Bhawna Nagar, Pedro Gómez, Raúl Benages, Carlos Marchante, Rocío Rodríguez, Jun-Jie Zhu



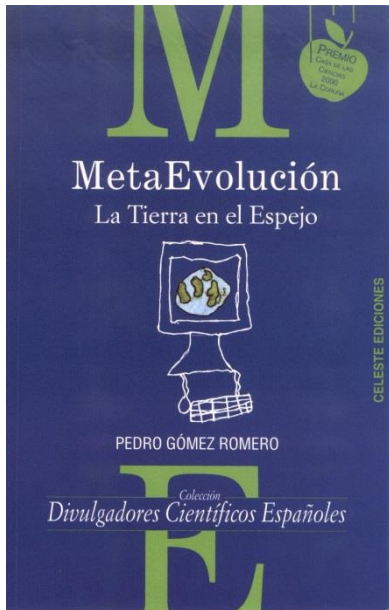


Gracias  
... for your attention!

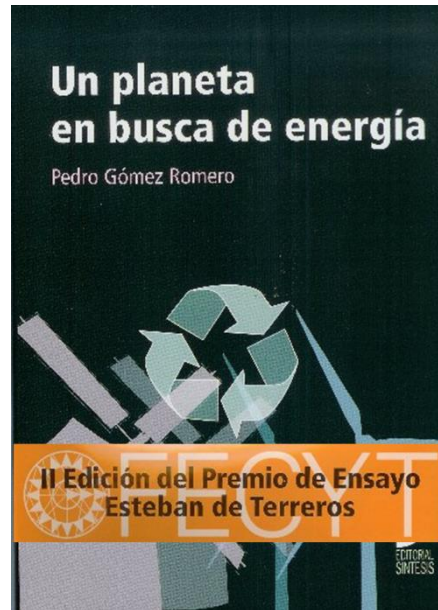


QUESTIONS

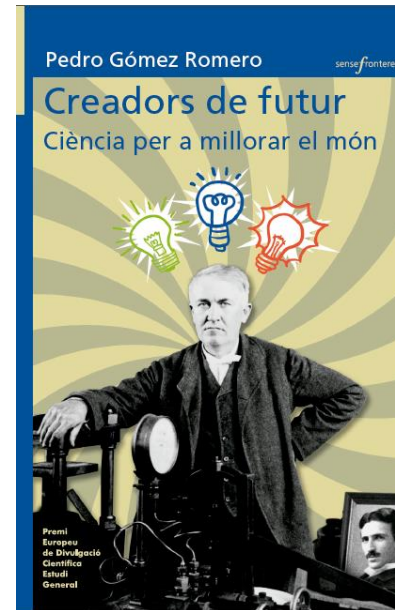
# NEO-Energy Group. Social communication of science



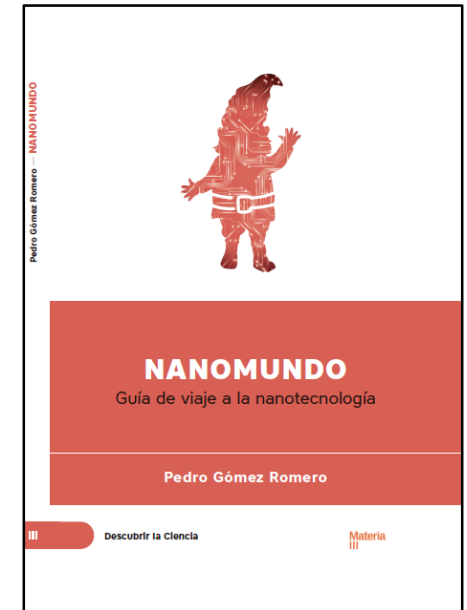
Celeste, 2001



Síntesis, 2007



Bromera, 2016



Materia/EP, 2016