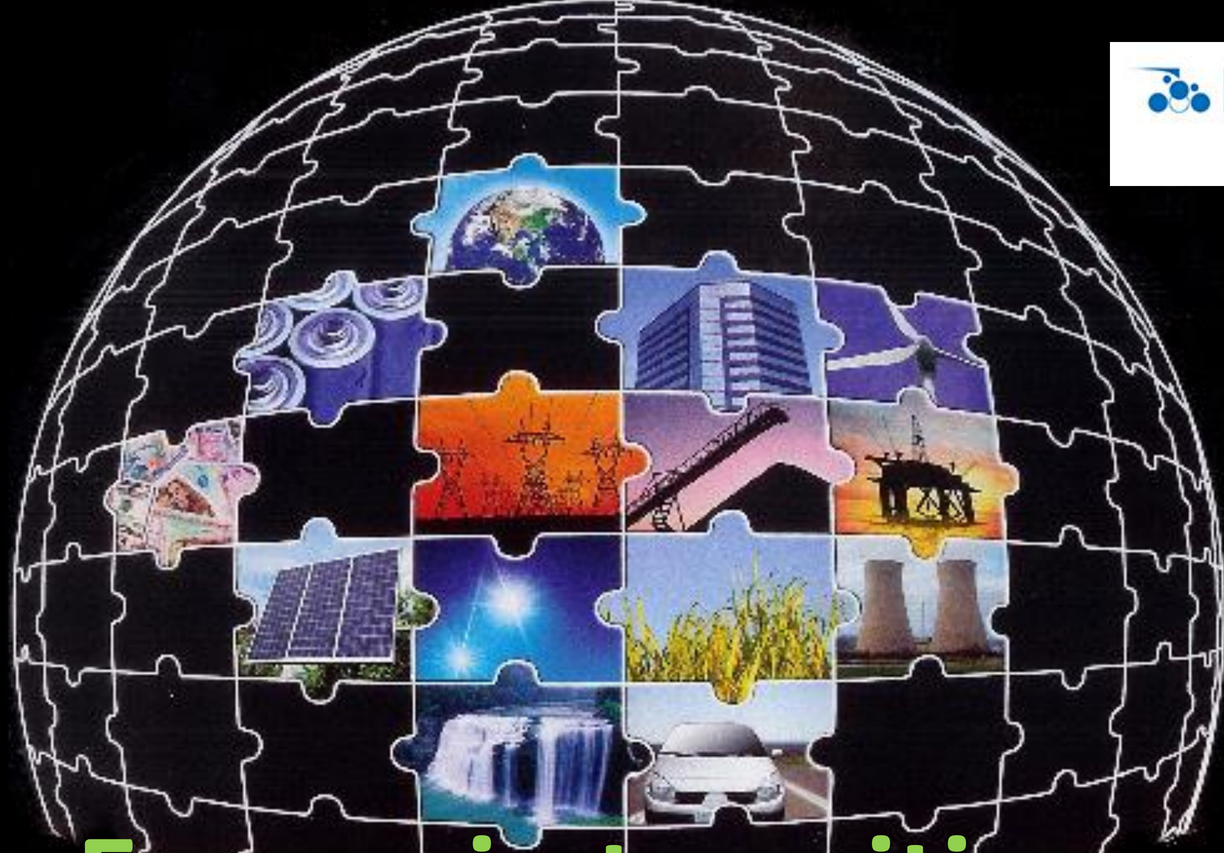


Energy in transition.

A case for Science, Technology and Society

Prof. Pedro Gómez-Romero

Institut Catalá de Nanociència i Nanotecnologia, ICN2 (CSIC-BIST),Bellaterra (Barcelona)

pedro.gomez@icn2.cat

SEVERO OCHOA SUMMER SCHOOL IN MATERIALS FOR ENERGY

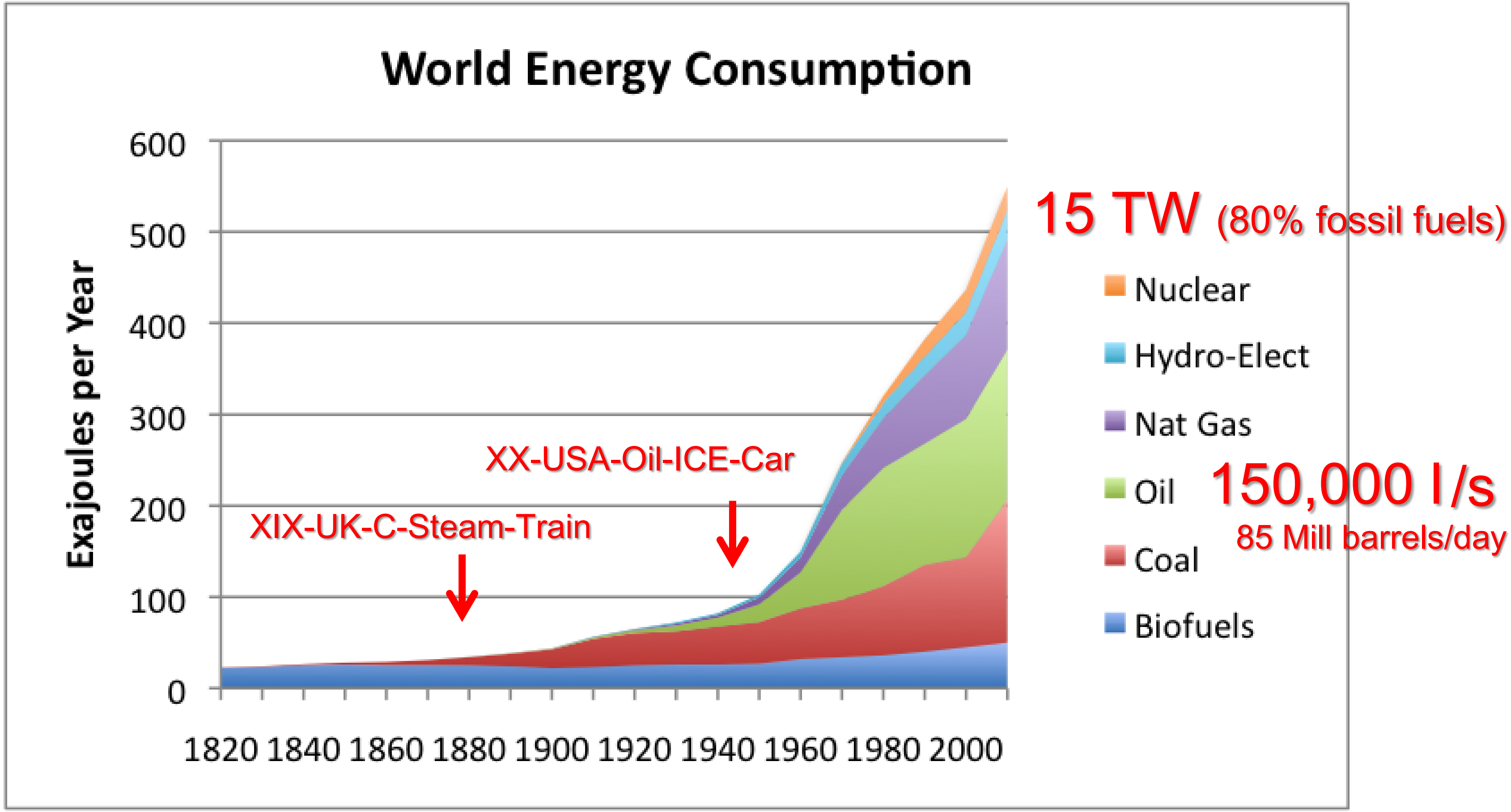
ICMAB, Bellaterra, 17-20 Sep 2018

MATENER2018

The energy conundrum

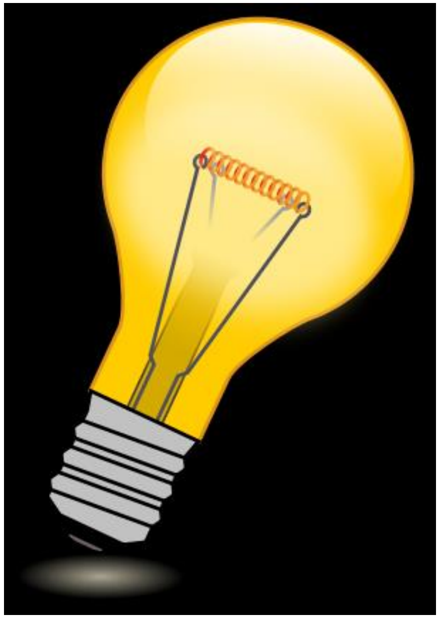
an alien point of view

Energy Evolution. The past



Based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects together with BP Statistical Data for 1965 and subsequent

Human power vs. human needs
A story of self(in)sufficiency



20th Century light bulb

100 W

20th Century CRT TV

400 W




1000 W


2400W

100CV 73600 W

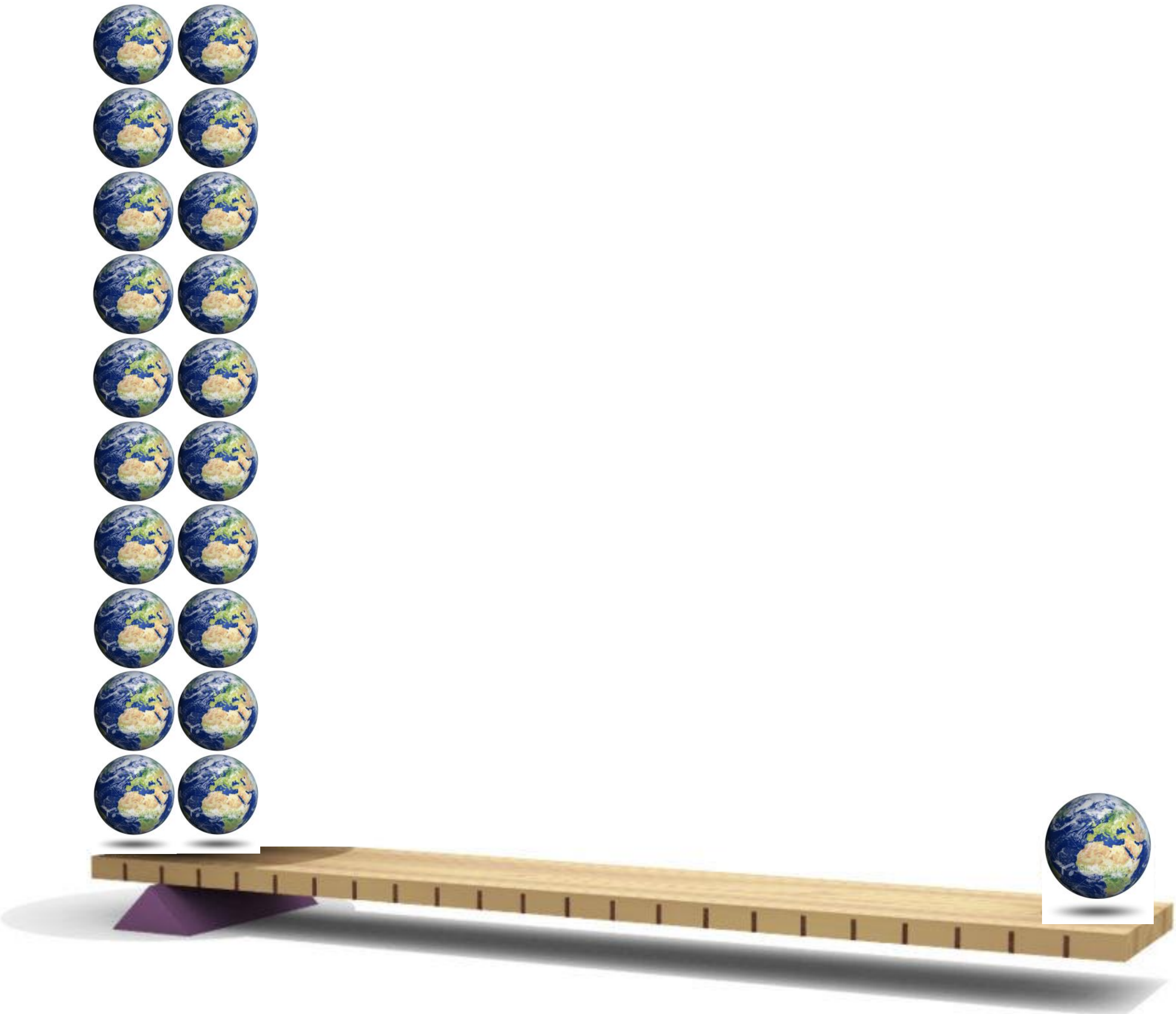
15TW = 15,000,000,000,000 watts

100 watts/human

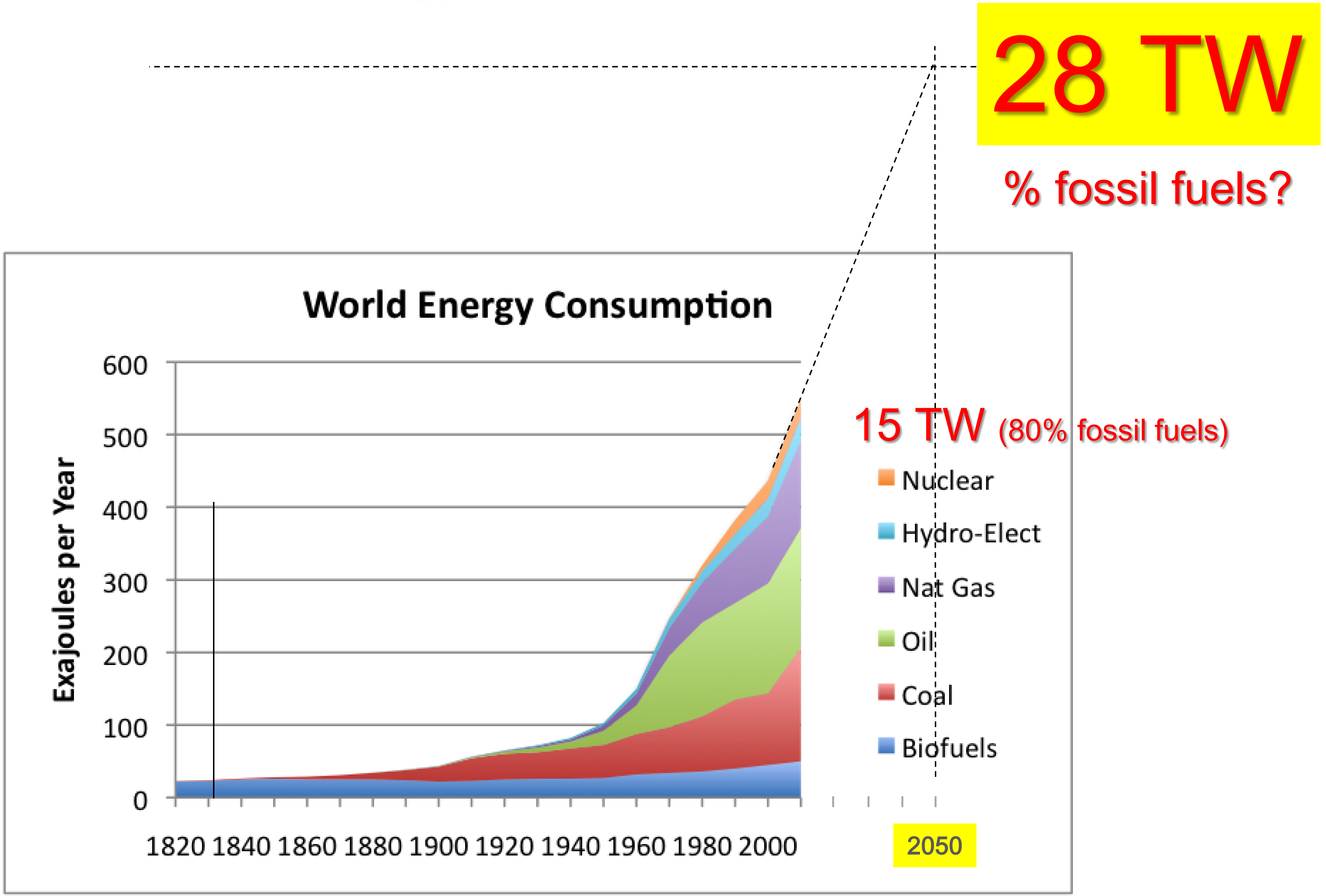
150,000,000,000 humans

7,300,000,000 humans/Earth

20 planet Earths

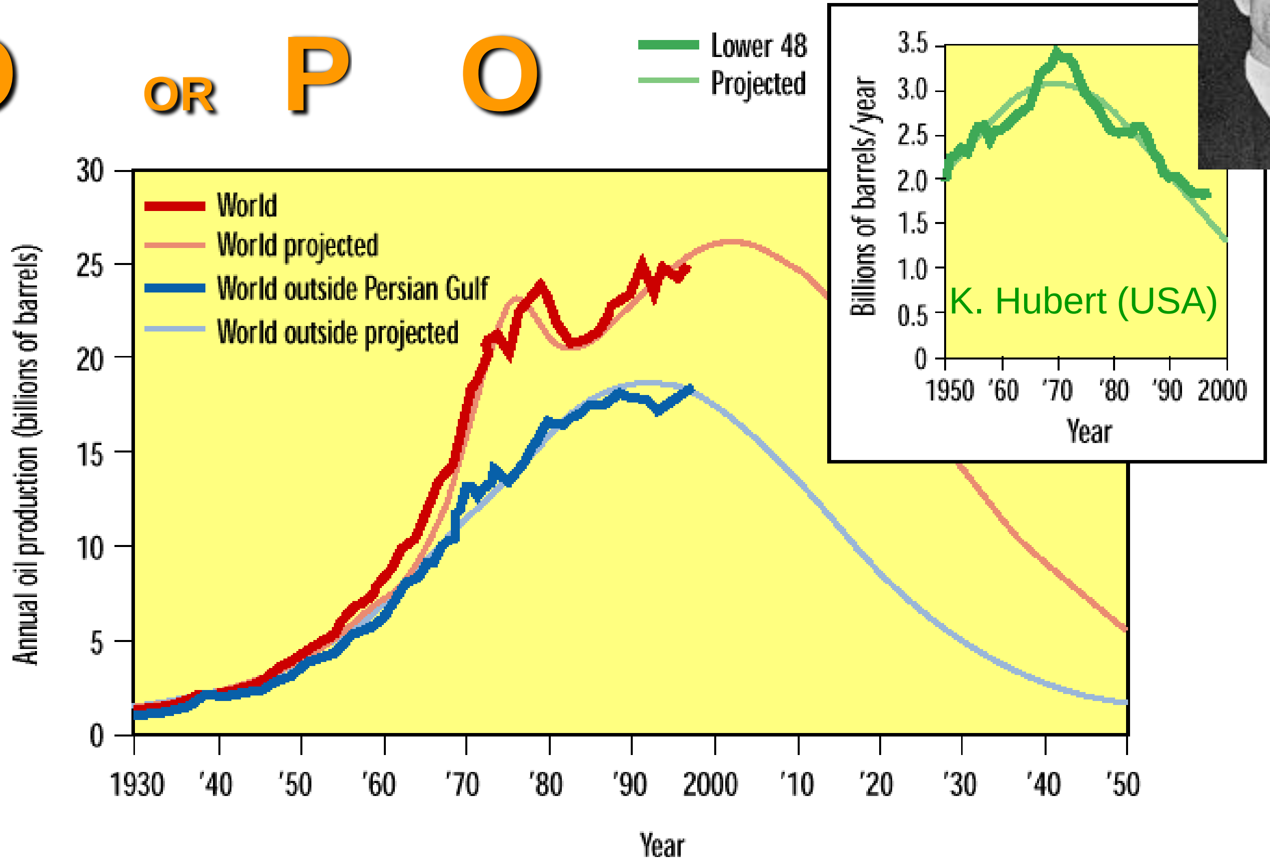


Energy Evolution. The future?

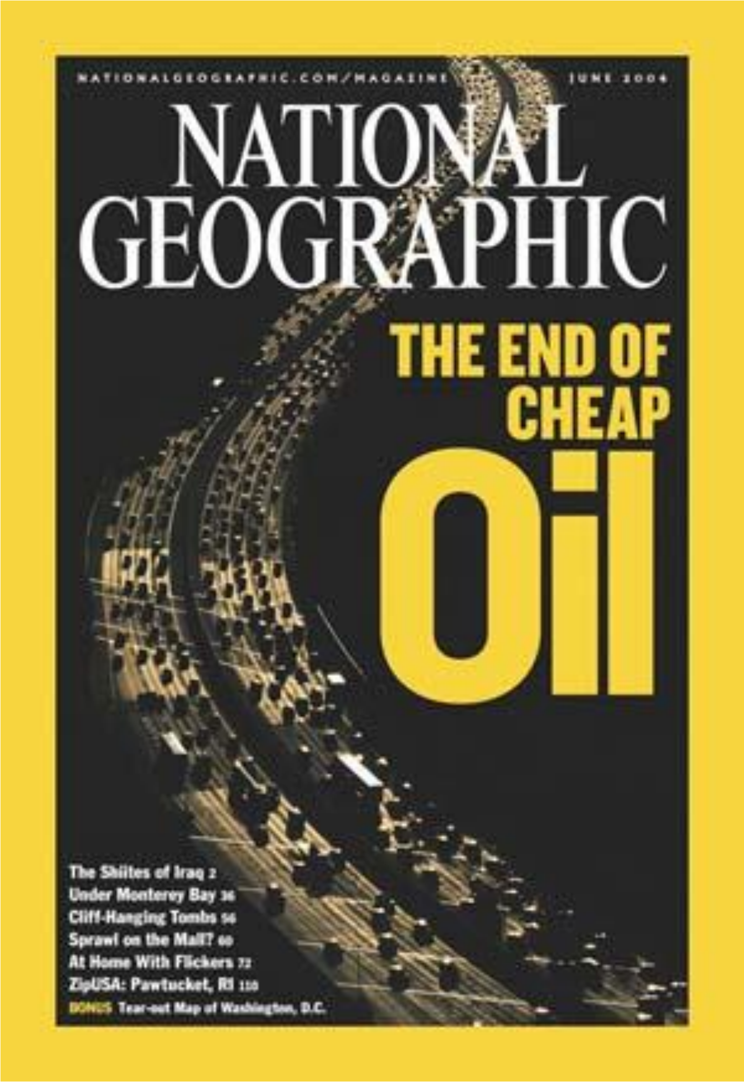


Hubbert's Peak Oil

P O OR P O



C. Campbell & J. Laherrere, Scientific American, March 1998
See also Science, vol. 281, Aug. 21,1998, p.1128



Junio 2004, Volumen 205, Numero 6

Deepwater Horizon oil spill. 2010

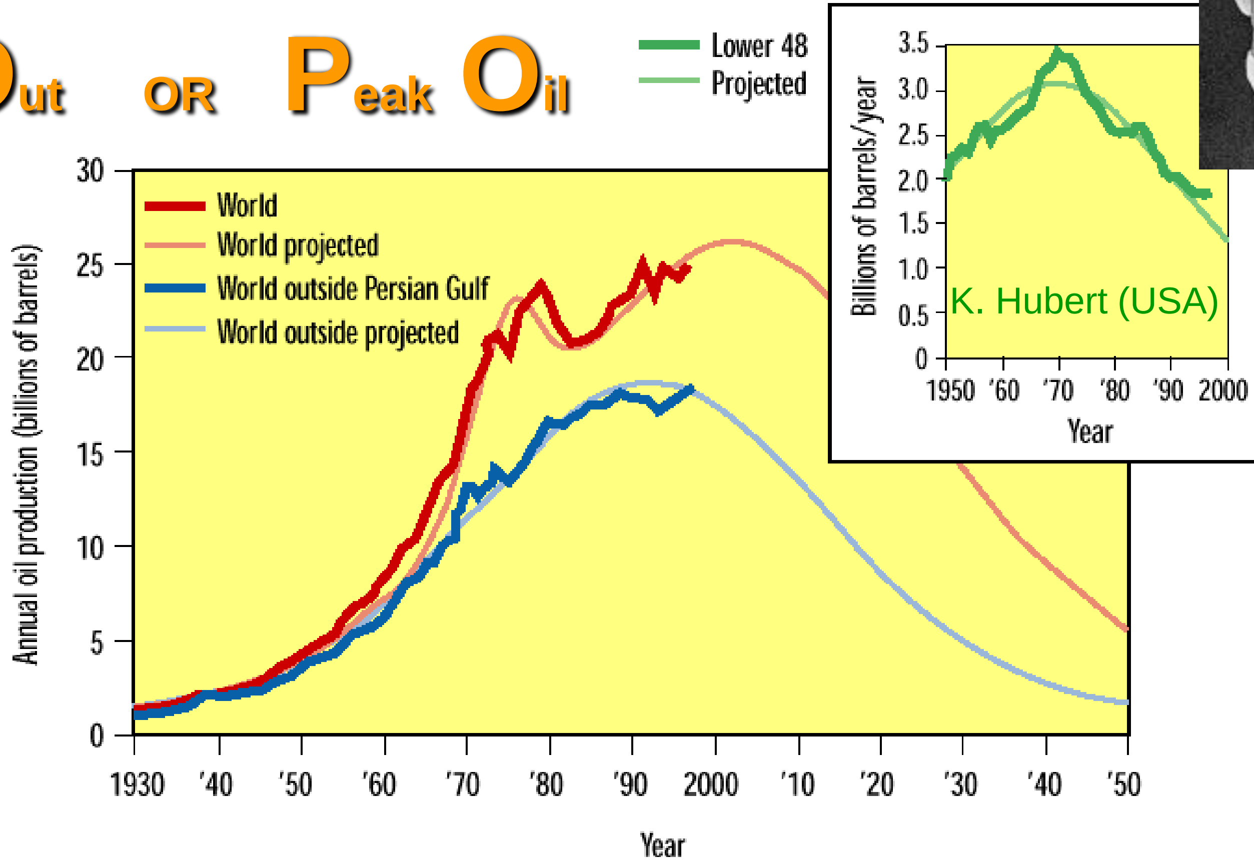
largest marine oil spill in history,

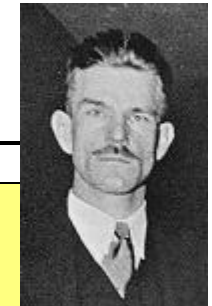
Who is to blame?


¡PETRÓLEO NO!
¡GASOLINA SÍ!

Hubbert's Peak Oil

Phase Out OR Peak Oil





C. Campbell & J. Laherrere, Scientific American, March 1998
See also Science, vol. 281, Aug. 21,1998, p.1128

It has happened before

The peak-buffalo story (I mean…history)

From buffalo-bullies …to cow-boys

From gatherers to farmers
A historical perspective

Kiss good bye your "primary" fuel
and

pick your favorite energy vectors

Bio-vectors: Biofuels
Biodiesel (20% bio 80% diesel), (oileaginous)
Bioethanol (Gasoline)(carbohydrates) (Brazil)

Electro-vectors: Batteries. Supercaps / Electric Vehicle

Chem-vectors: H_2 Fuel Cells, CO_2 red. products, solar fuels

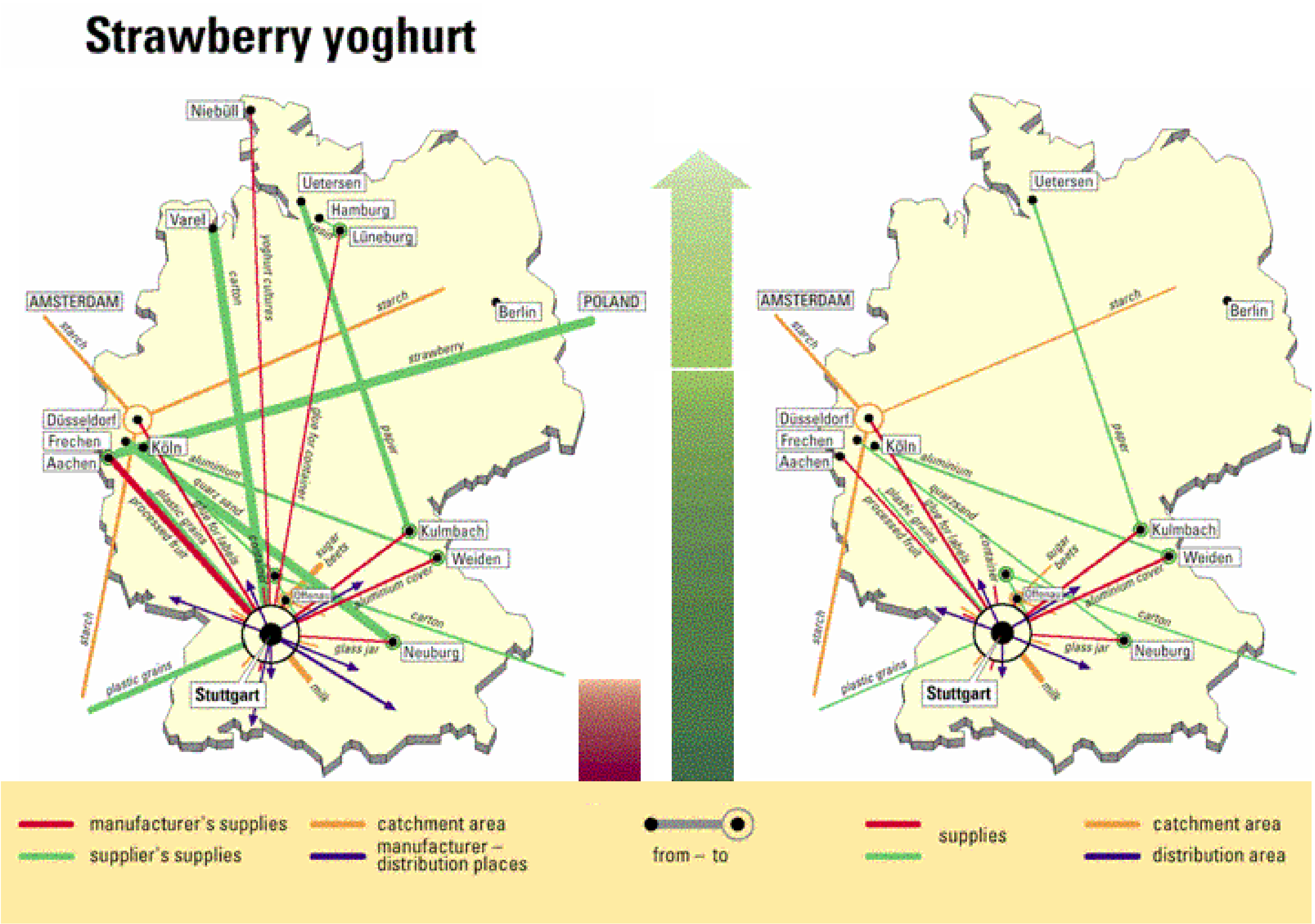
How to change? What to change?

CLEANER
fuels
vectors

RENEWABLE
energy sources

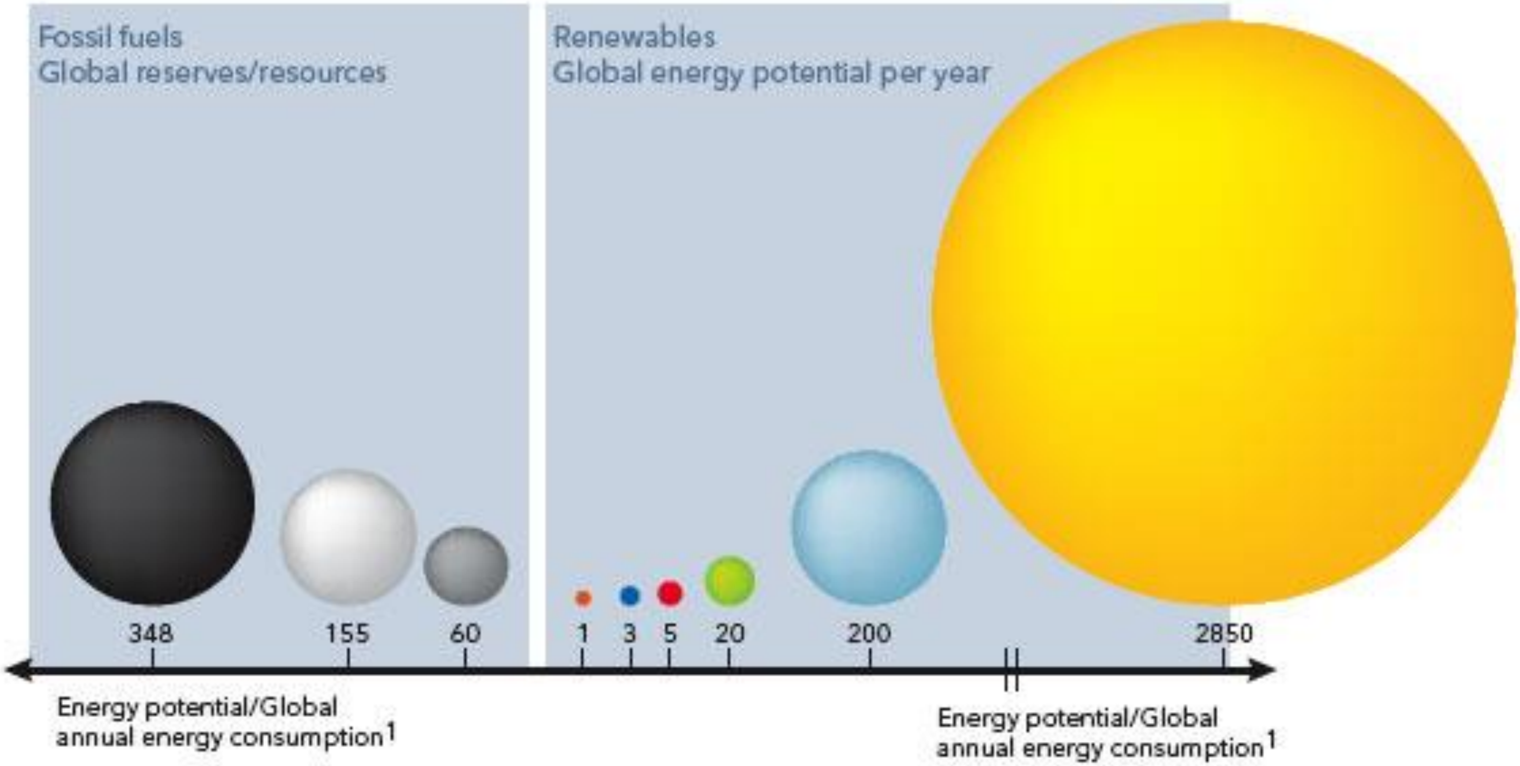
ENERGY
EFFICIENCY &
CONSERVATION

Eficiencia energética / Cadena de suministro



Fuente: E.U. von Weizsäcker. "China: Building a Resource-Efficient Society" Beijing, 25 June, 2005

Primary sources: archaic or present-time Sun?



	Energy potential Reserves/Resources[2]	Thereof conventionally utilizable[2]
Coal	~ 135.000 EJ	
Natural gas	~ 60.400 EJ	~ 12.000 EJ
Crude oil	~ 23.000 EJ	~ 9.800 EJ

Global energy demand 2006: ~ 470 EJ

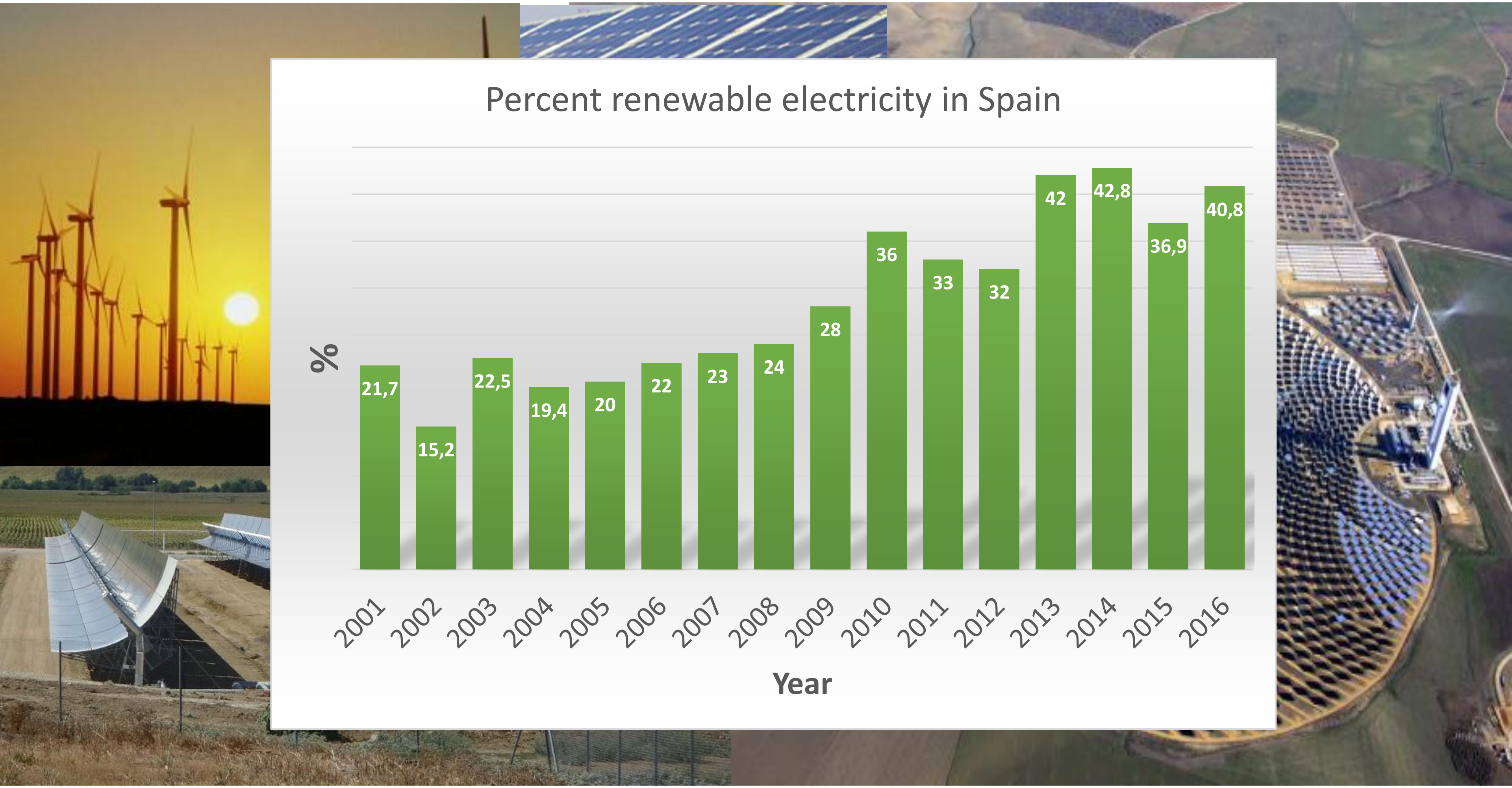
	Energy potential (amount of energy p. a.)[2]	technologically utilizable (state of the art)[2]
Solar radiation	~ 1.111.500 EJ	~ 1.482 EJ
Wind energy	~ 78.000 EJ	~ 195 EJ
Biomass	~ 7.800 EJ	~ 156 EJ
Geothermal	~ 1.950 EJ	~ 390 EJ
Hydro/tide power	~ 1.170 EJ	~ 78 EJ

1 EJ = 1 exajoule or 10^{18} joules or ~163 million barrels of oil.
Data source: German Federal Institute for Geosciences and Natural Resources

The new Energy Landscape

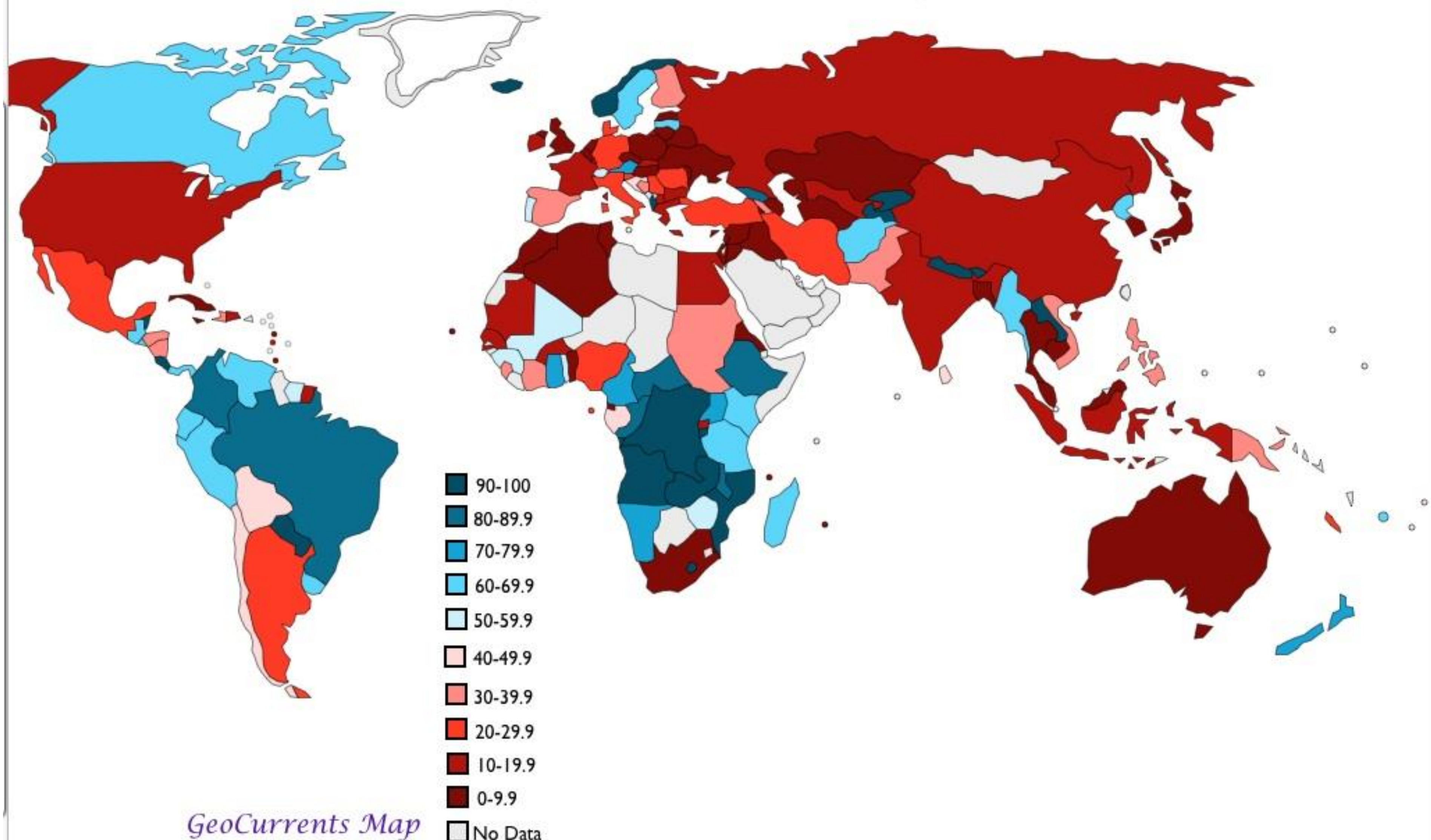
Institut Català de Nanociència i Nanotecnologia

EXCELENCIA SEVERO OCHOA



Percentage of Electricity Generation from Renewable Sources

(Hydro, Geothermal, Solar, Biomass, Wind)



Data Source: http://en.wikipedia.org/wiki/List_of_countries_by_electricity_production_from_renewable_sources

pros and cons of renewable energies

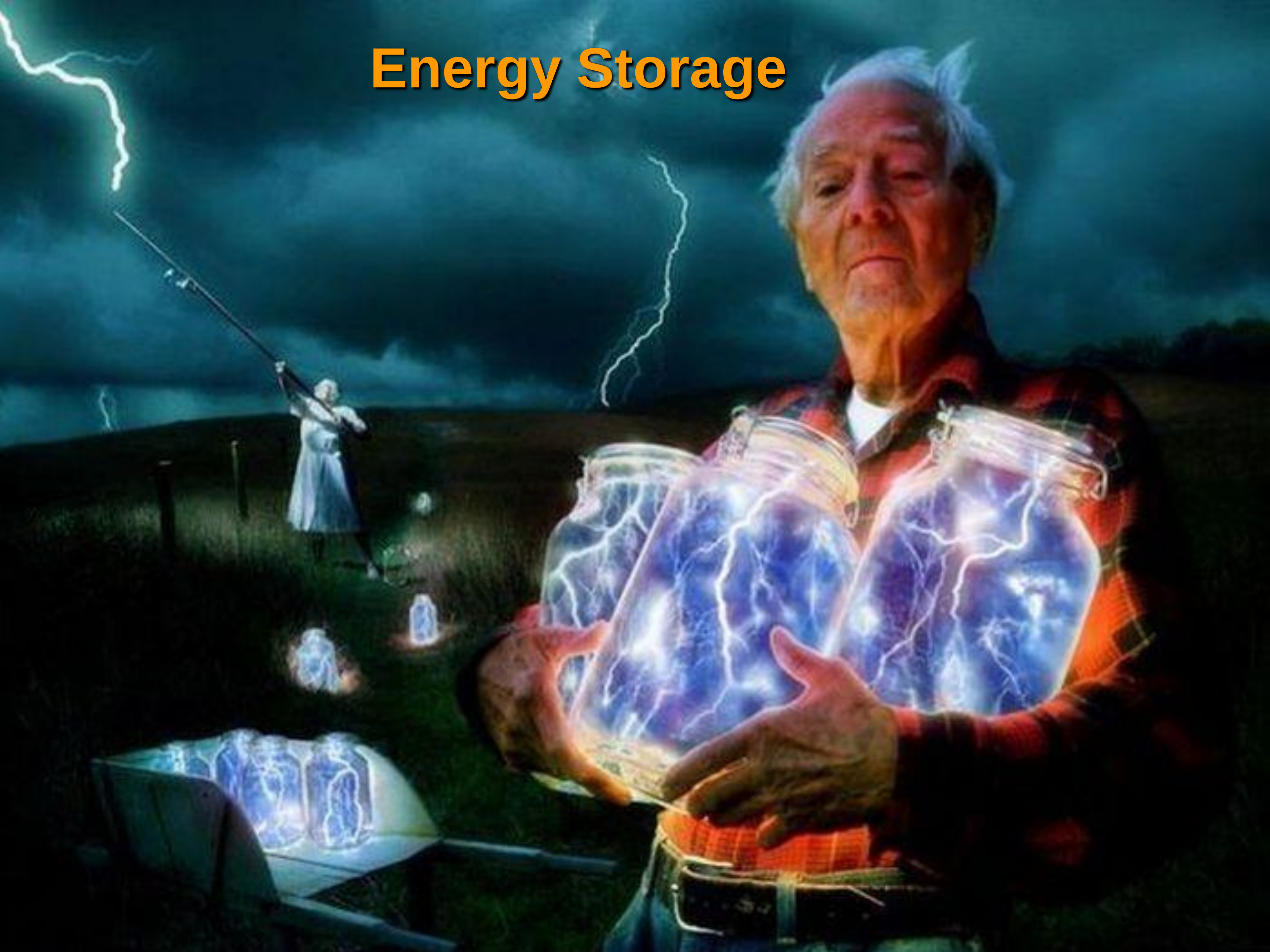
cons

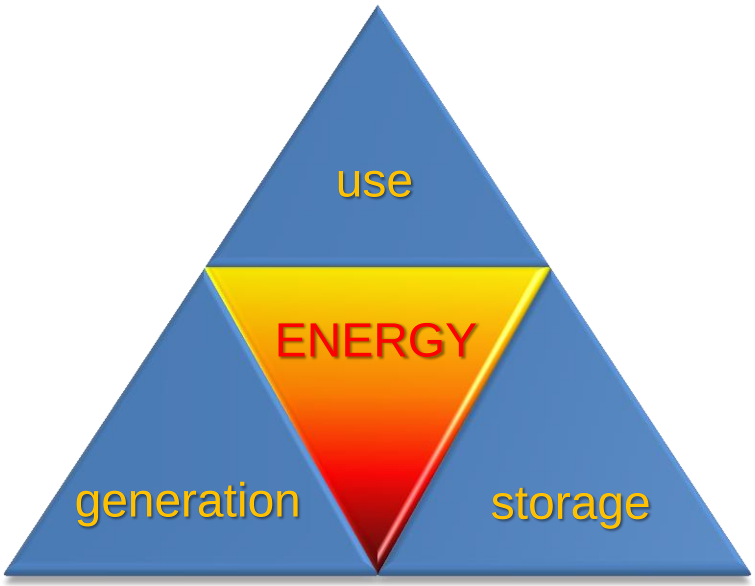
Solar	Does NOT work at night
Wind	Does NOT work in the absence of wind

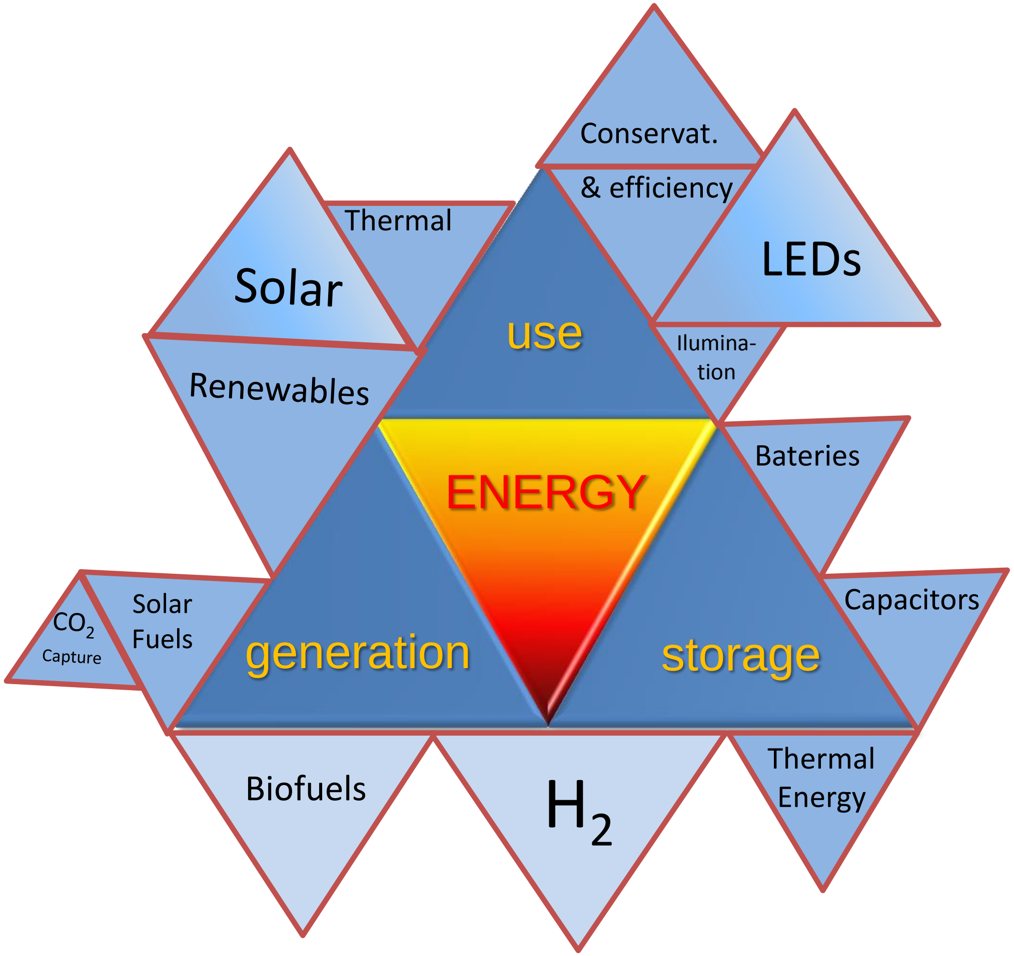
pros

Solar	It DOES work in the absence of wind
Wind	It DOES work at night

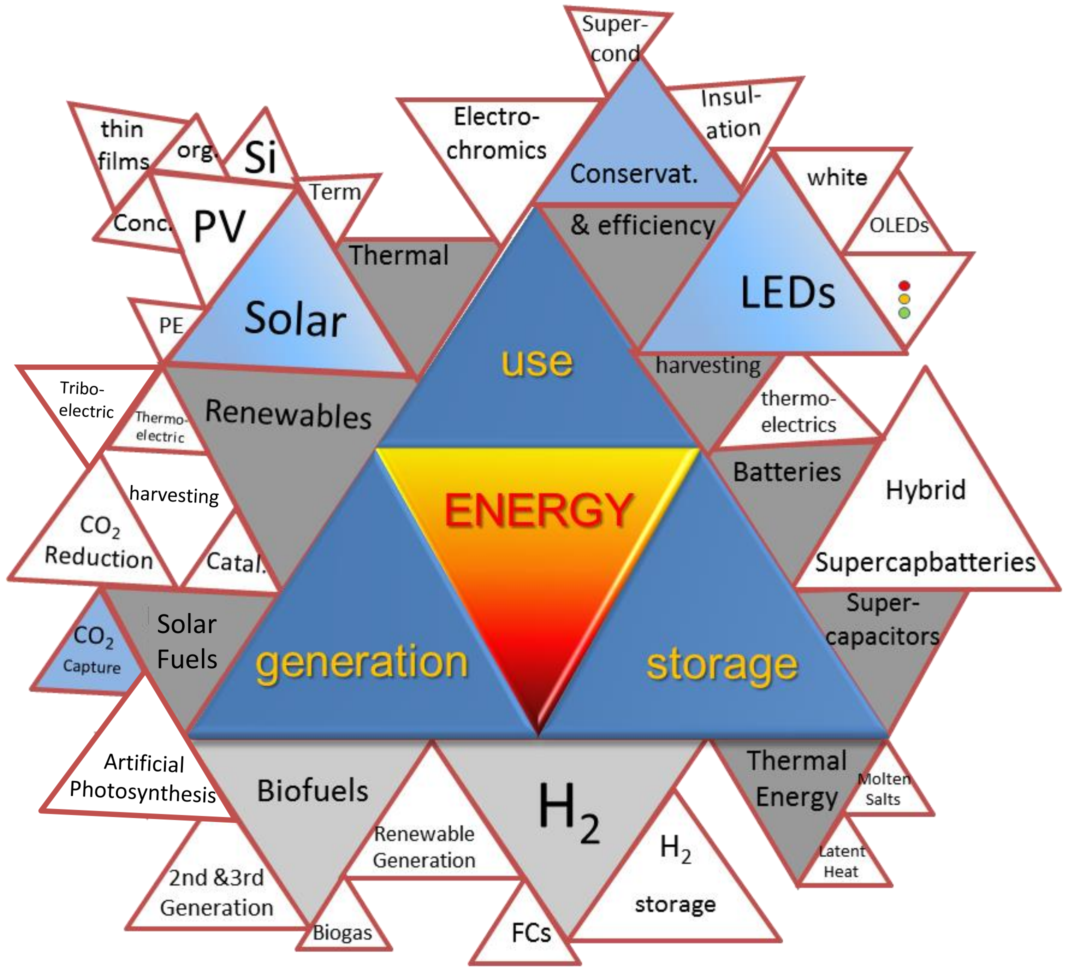
Energy Storage




use
ENERGY
generation
storage



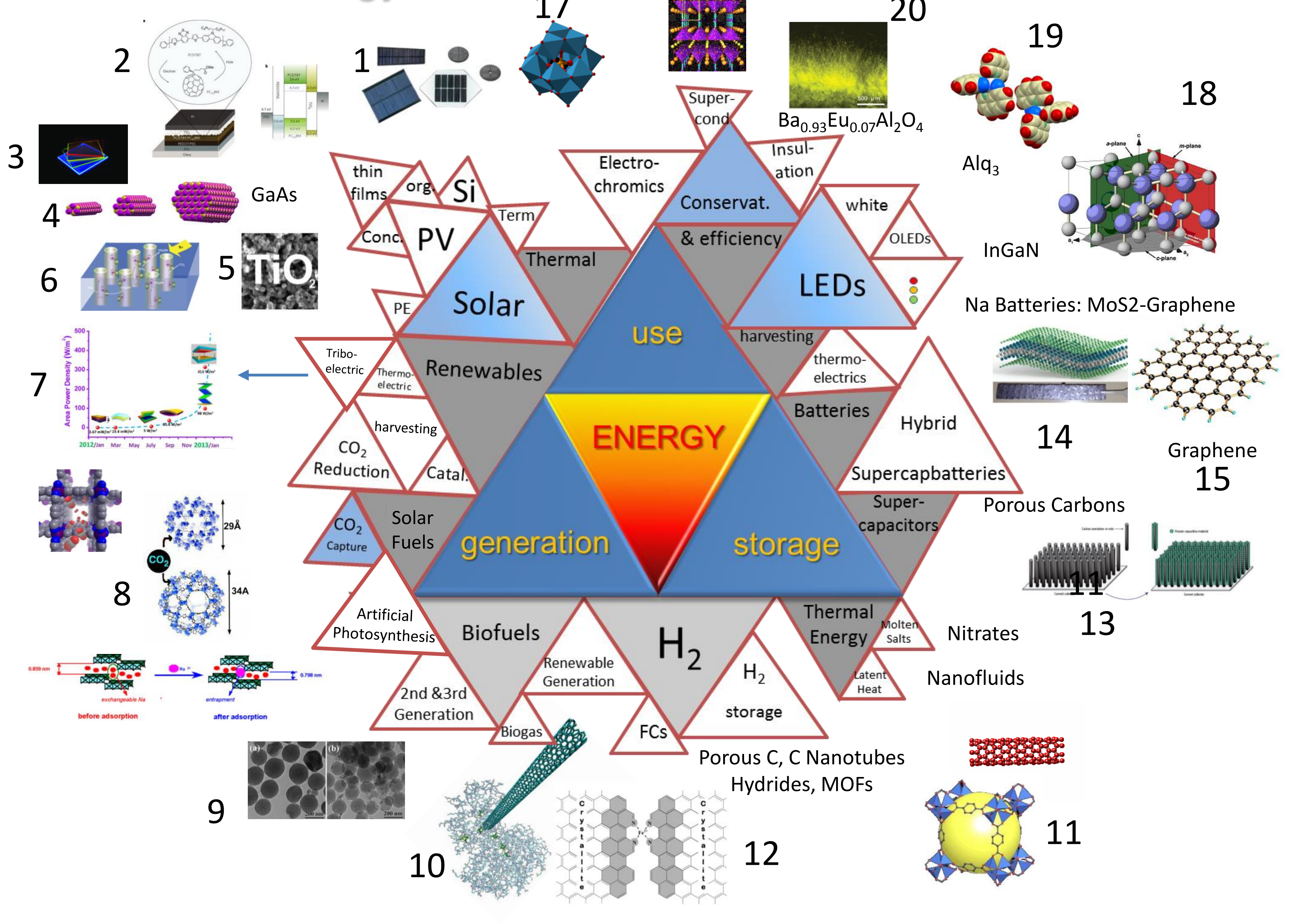
Conservat.
& efficiency
LEDs
Thermal
Solar
use
Ilumina-
tion
Renewables
ENERGY
Bateries
Capacitors
CO_2
Capture
Solar
Fuels
generation
storage
Biofuels
H_2
Thermal
Energy



ENERGY
use
generation
storage
Super-
cond
Electro-
chromics
Conservat.
& efficiency
Insul-
ation
white
OLEDs
LEDs
harvesting
thermo-
electrics
Batteries
Hybrid
Supercapbatteries
Super-
capacitors
Thermal
Energy
Molten
Salts
Latent
Heat
H2
storage
FCs
H2
Renewable
Generation
Biofuels
Biogas
2nd &3rd
Generation
Artificial
Photosynthesis
CO2
Capture
Solar
Fuels
CO2
Reduction
Catal.
harvesting
Tribo-
electric
Thermo-
electric
Renewables
PE
Solar
PV
Conc.
thin
films
org.
Si
Term
Thermal

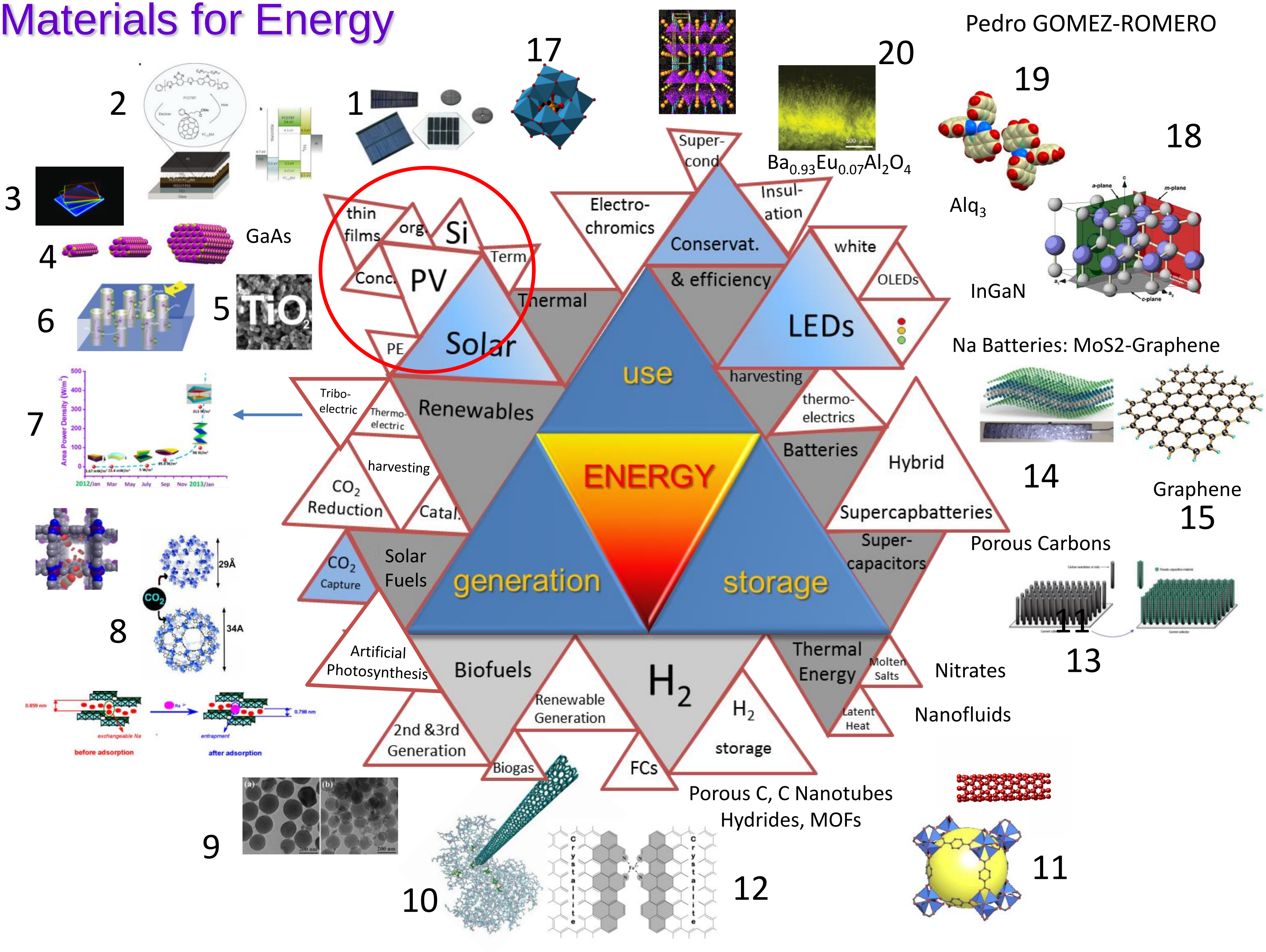
Materials for Energy

Pedro GOMEZ-ROMERO

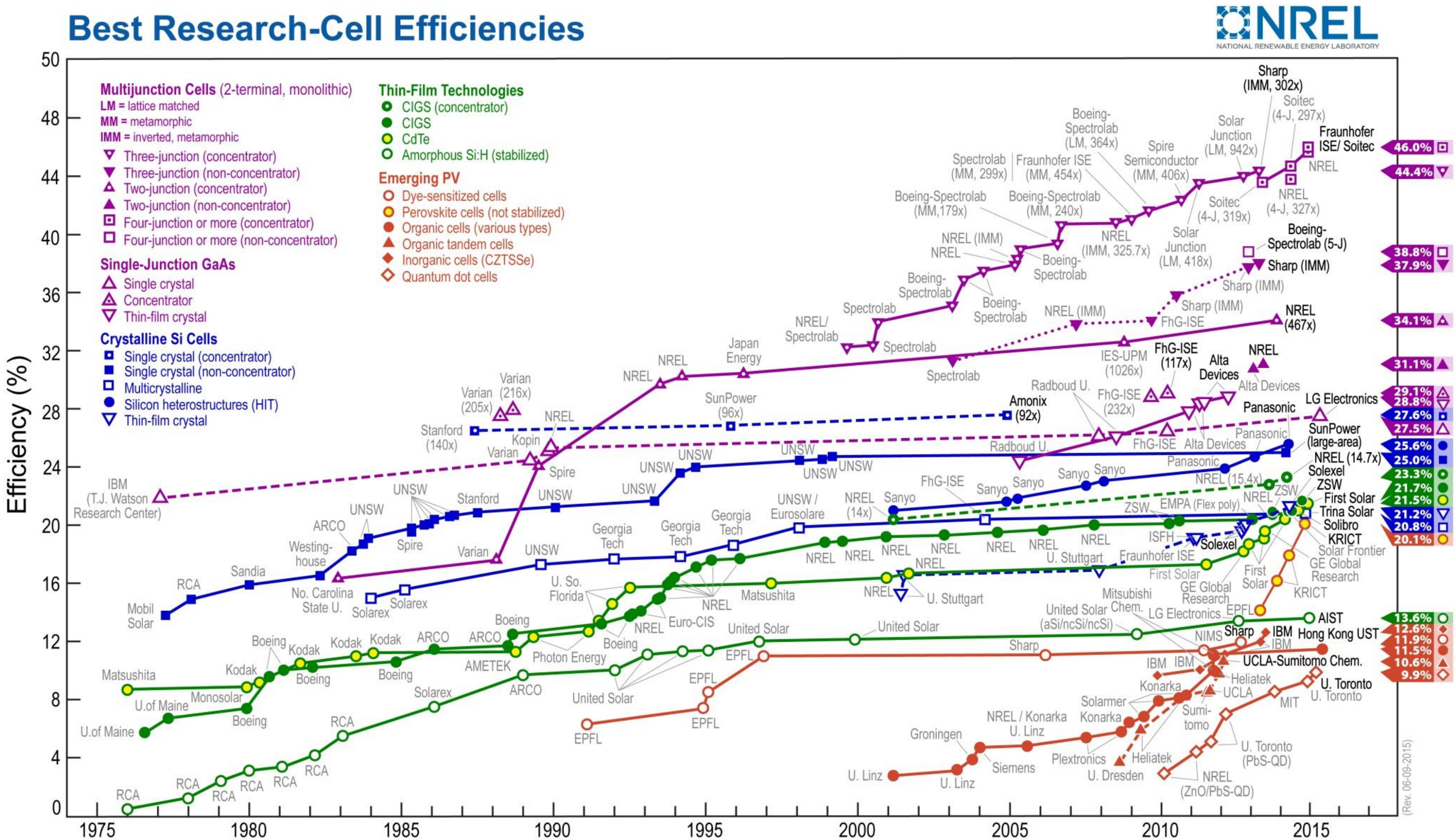


Materials for Energy

Pedro GOMEZ-ROMERO



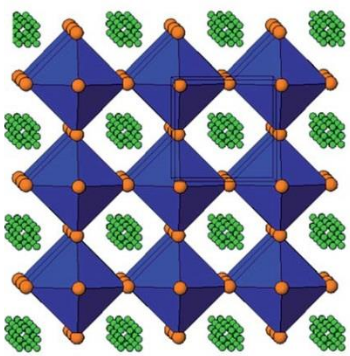
Eficiencias record Solar PV



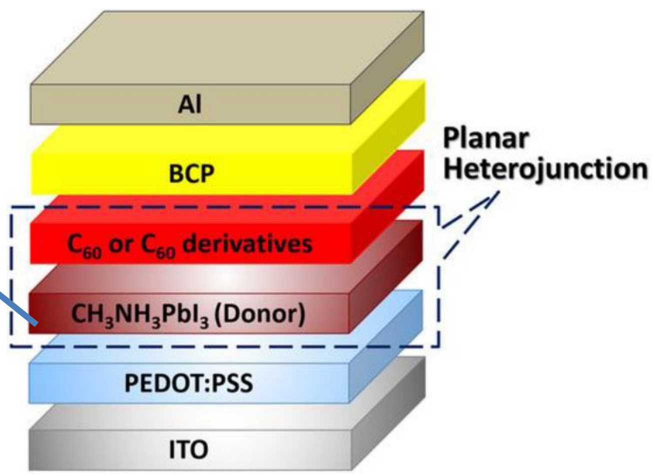
Hybrid Perovskites for Solar PV Cells

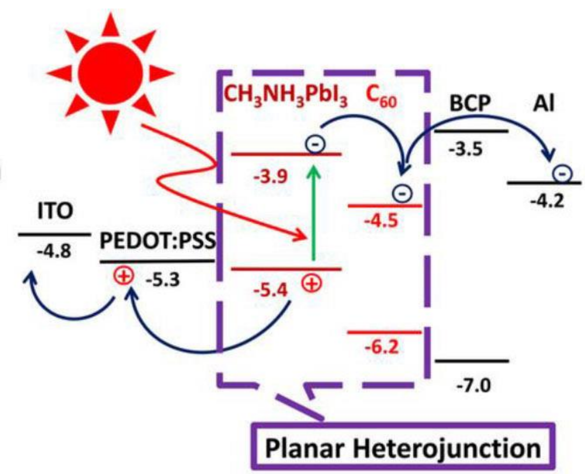
Methylammonium Lead Iodide perovskite

2009: 4.9% → 2015: 20%



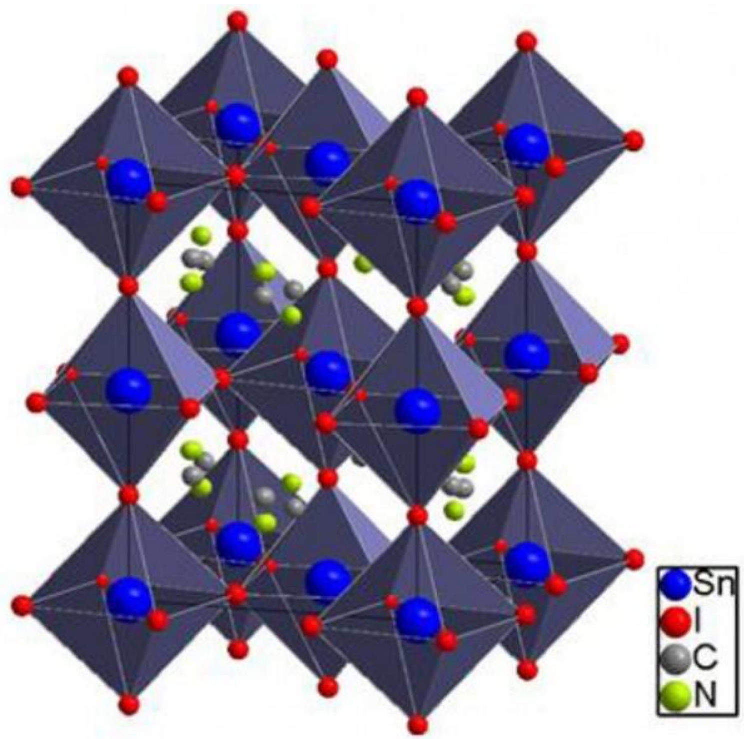
$CH_3NH_3PbI_3$





A. Kojima, K. Teshima, Y. Shirai, T. Miyasaka, J. Am. Chem. Soc., 131 (2009) 6050

Lead-free Solar Cells



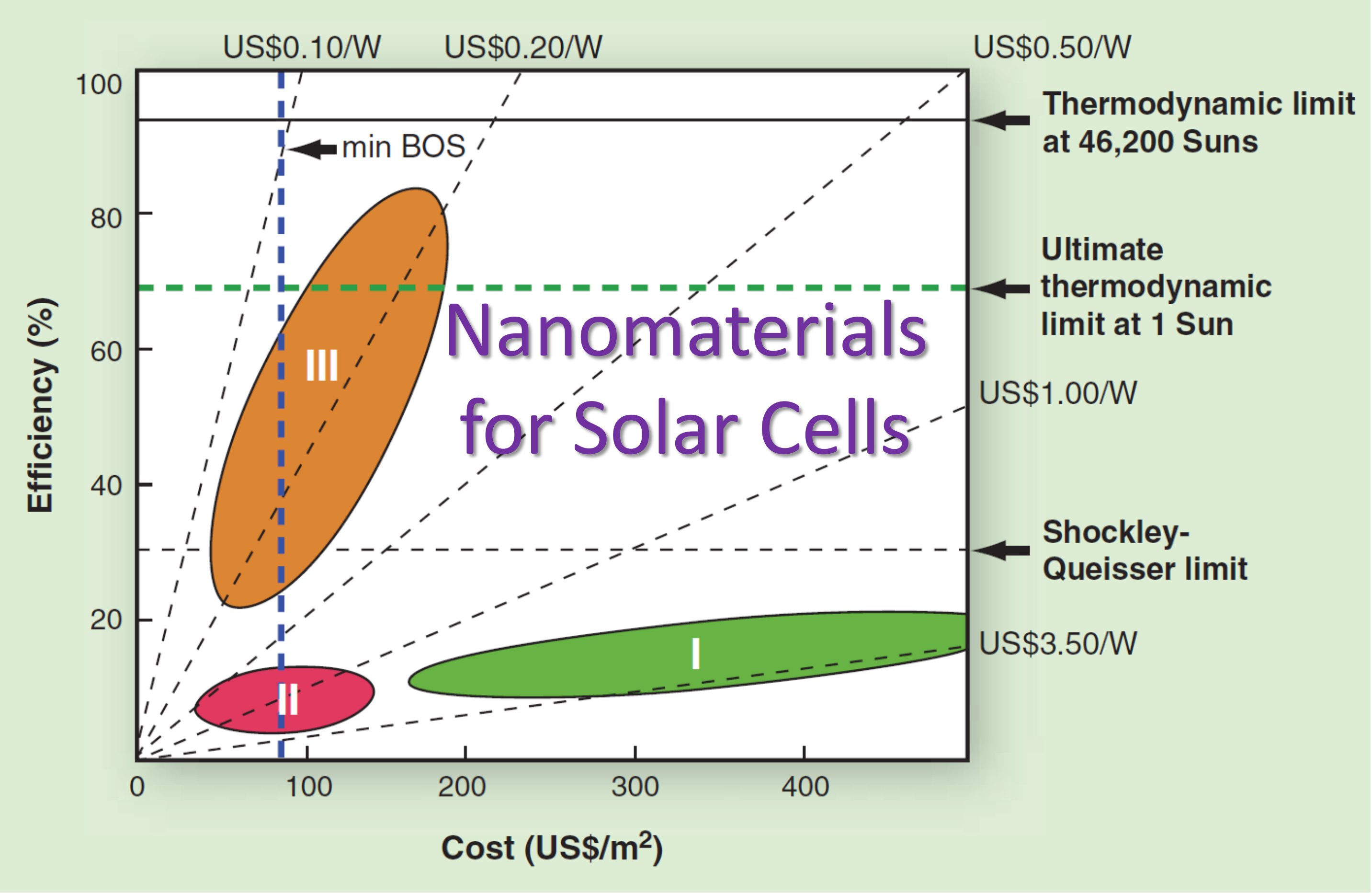
6.4 %

Lead-free organic–inorganic tin halide perovskites for photovoltaic applications
Nakita K. Noel et al. Energy Environ. Sci., **2014**, 7, 3061-3068

Conducting tin halides with a layered organic-based perovskite structure
David Mitzi *et al., Nature* **1994,** 369, 467-469 (1994)

From Materials to Nanomaterials

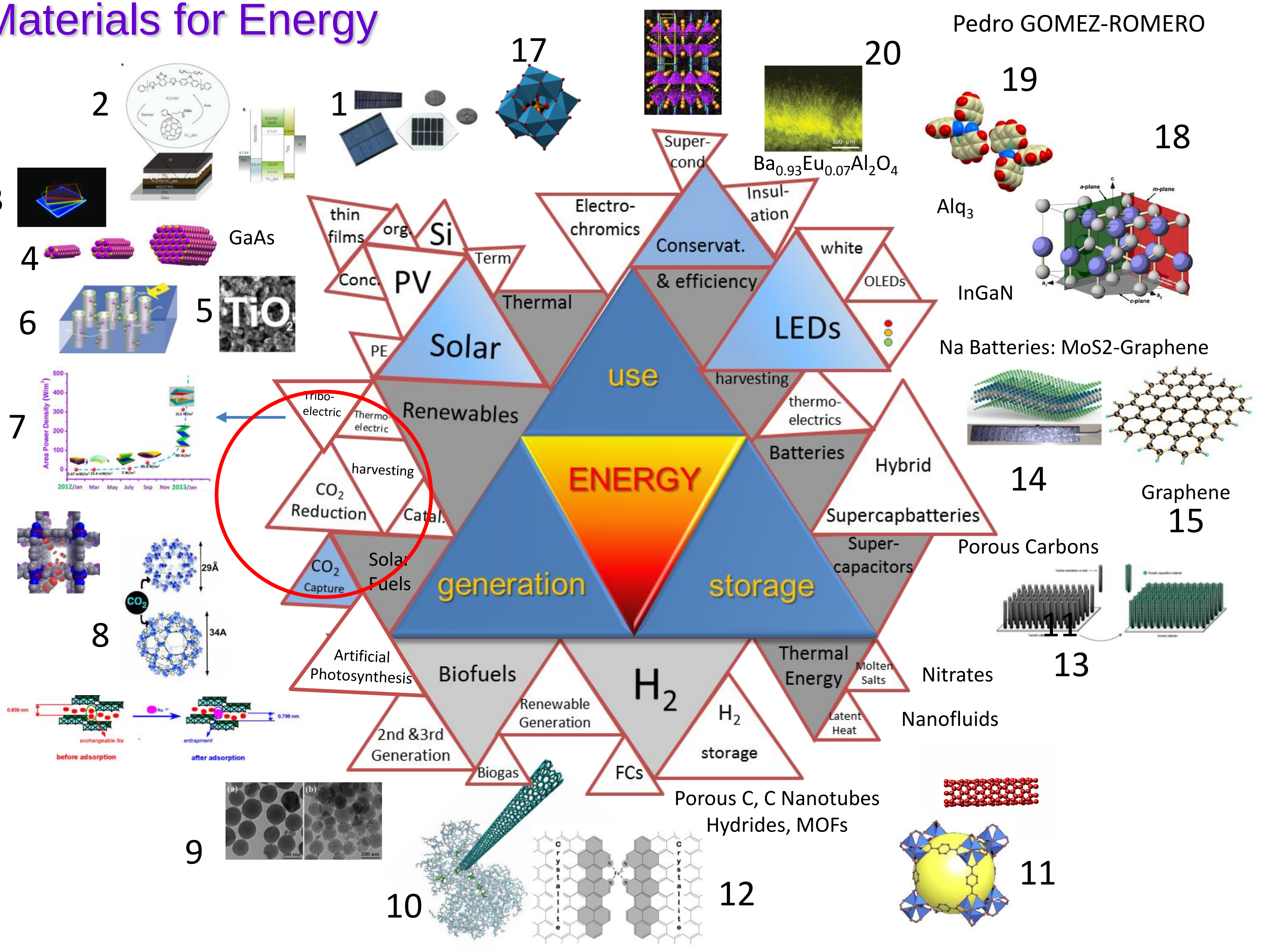
Intrinsic changes in properties



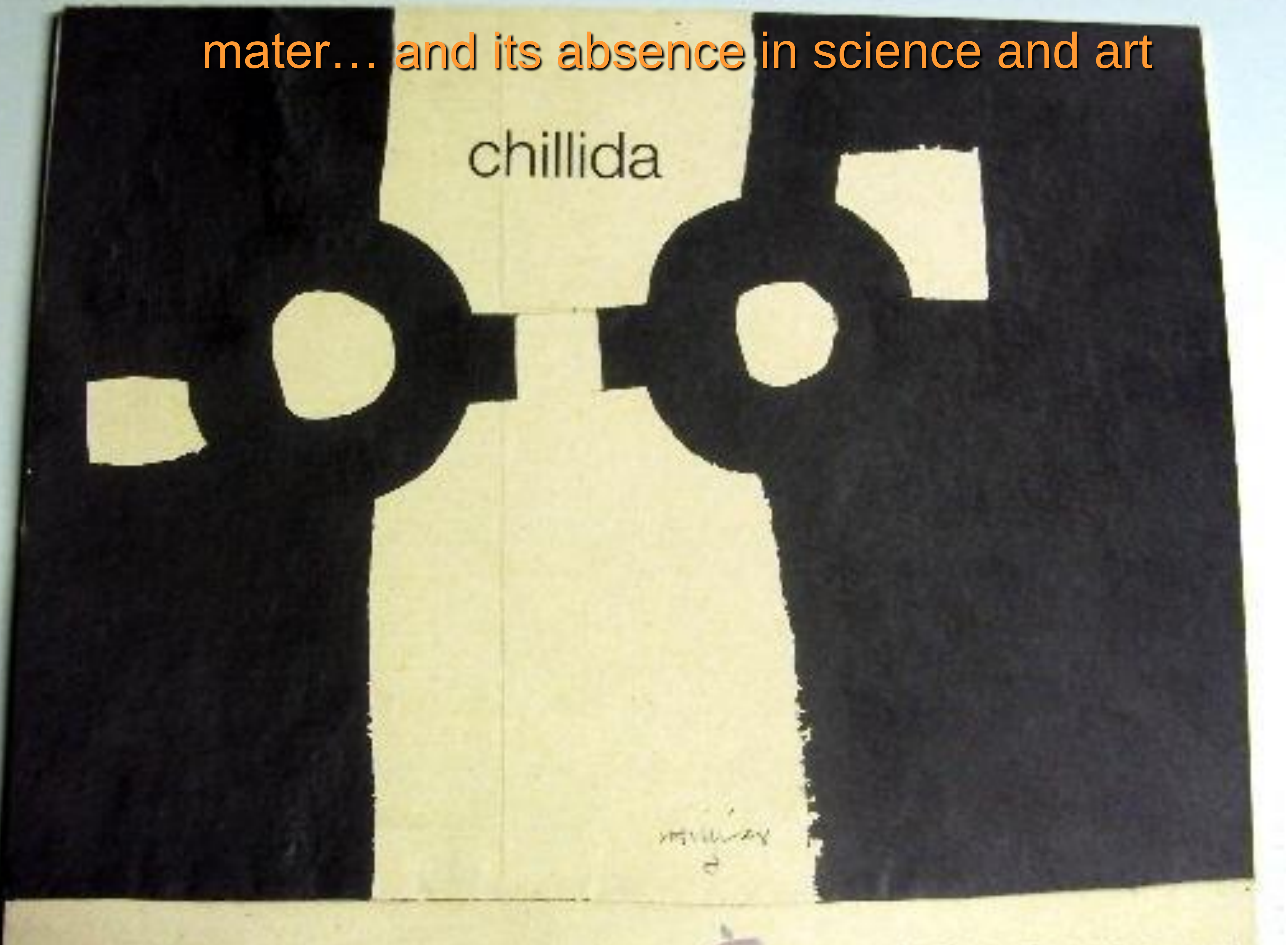
Nathan S. Lewis, et al. Toward Cost-Effective Solar Energy Use. Science 315, 798 (2007)

Materials for Energy

Pedro GOMEZ-ROMERO

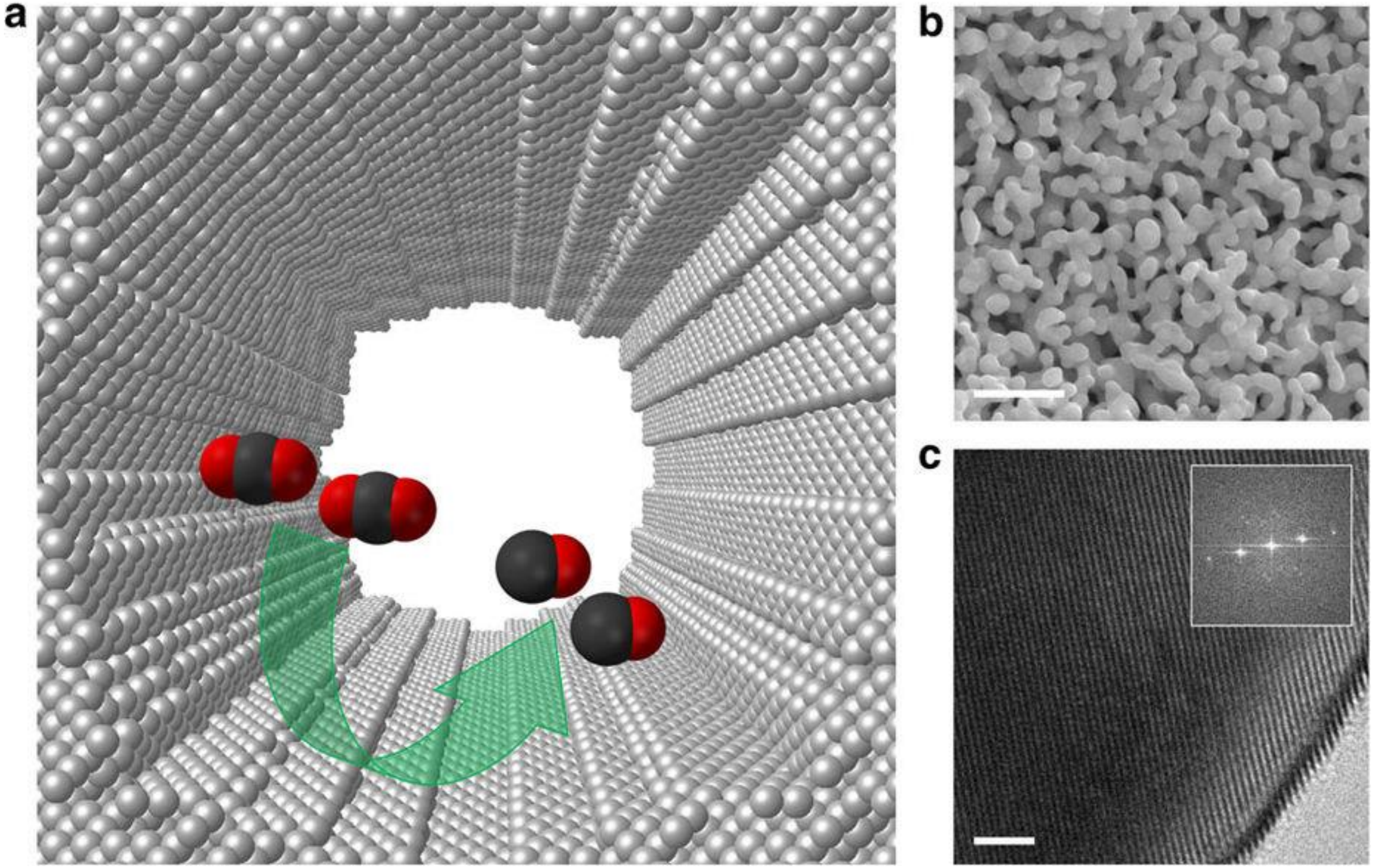


mater… and its absence in science and art



Nano and Catalysis

CO_2 Electroreduction to CO by nanopores in de-alloyed Ag from AgAl

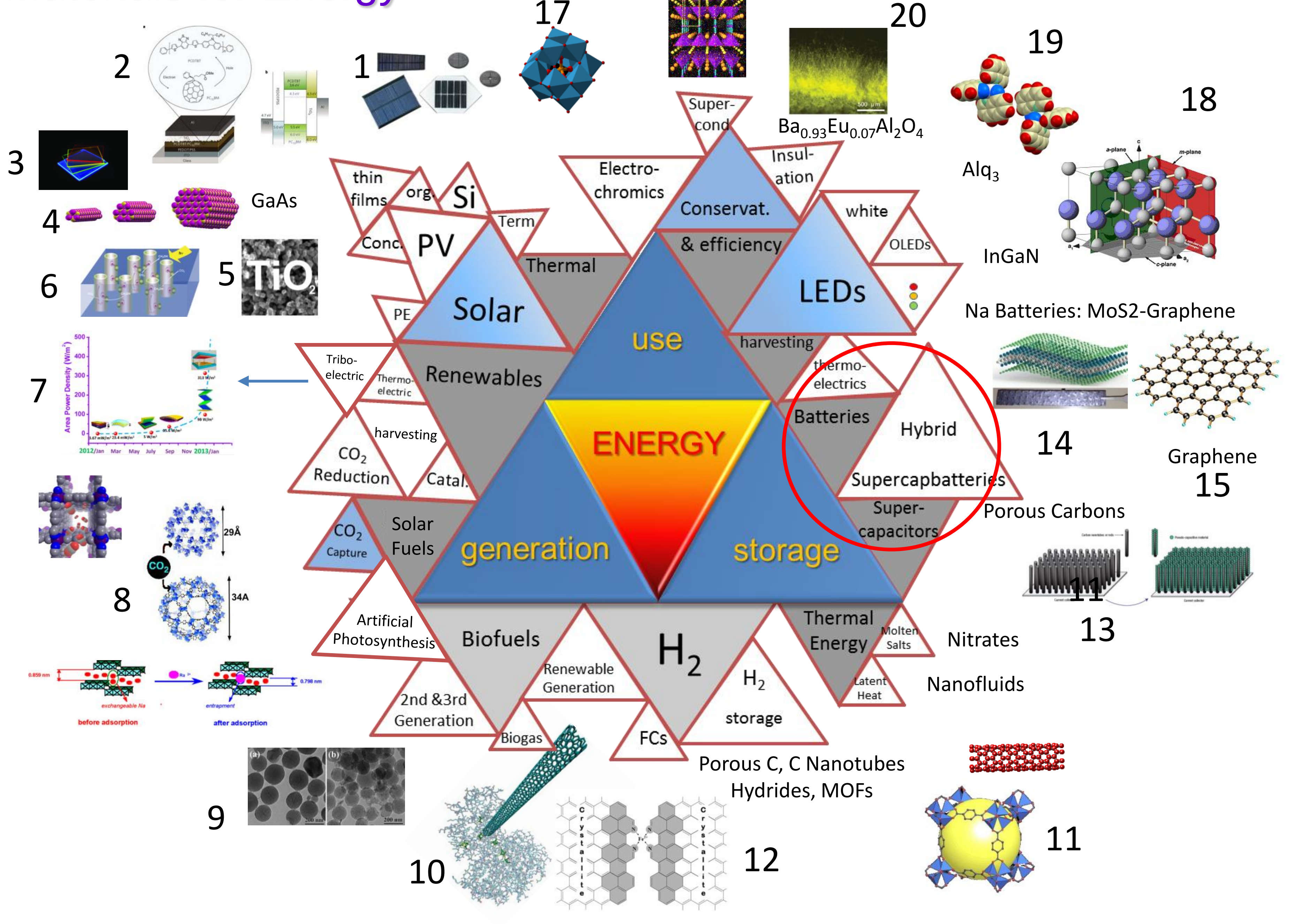


activity three orders of magnitude higher than that of the polycrystalline counterpart at a moderate overpotential of <500 mV.

Qi Lu et al. *Nature Communications* **5**: 3242 (2014)

Materials for Energy

Pedro GOMEZ-ROMERO

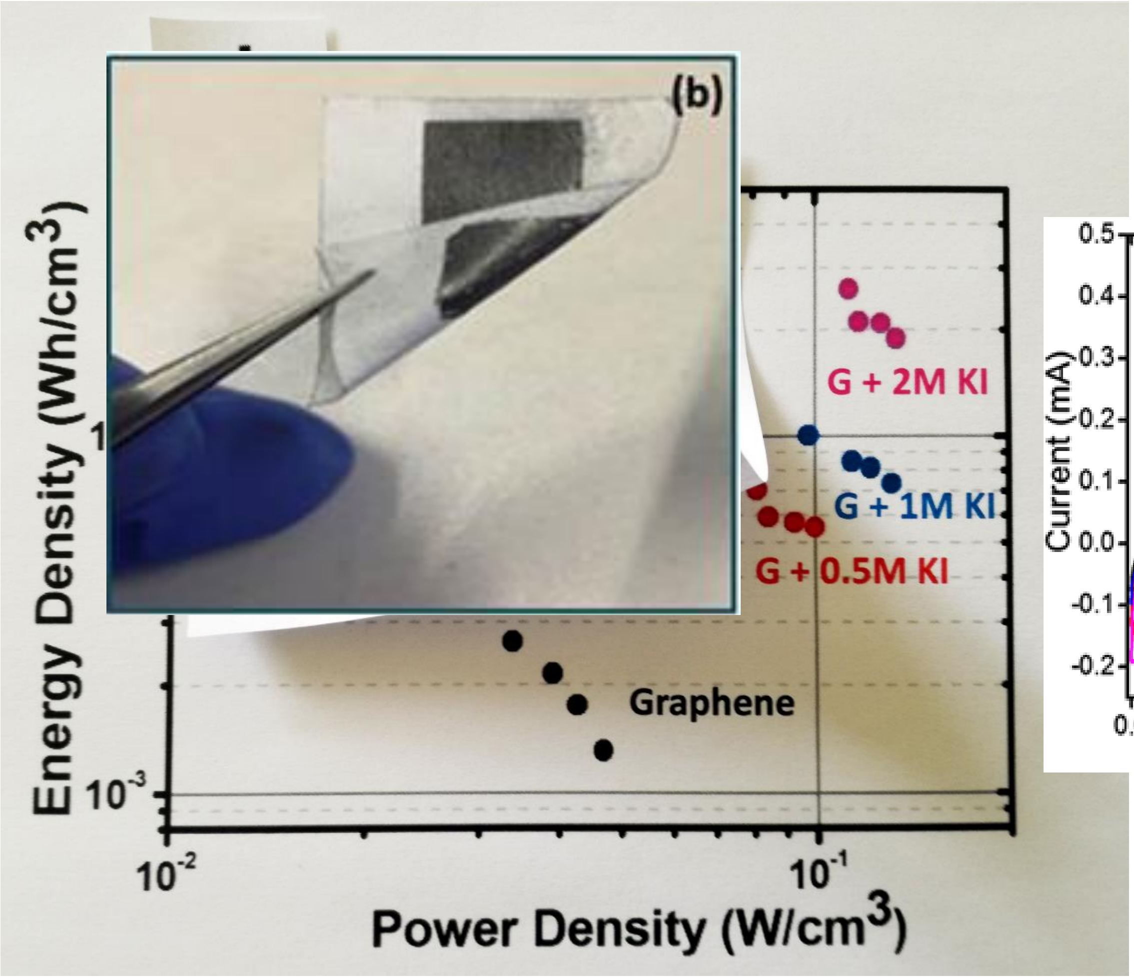


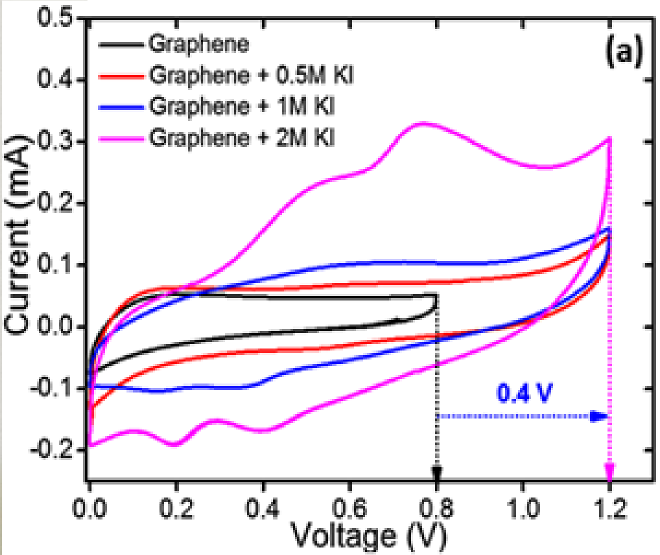
Energy storage in transition

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

Symmetric Graphene supercap printed on paper

+ KI





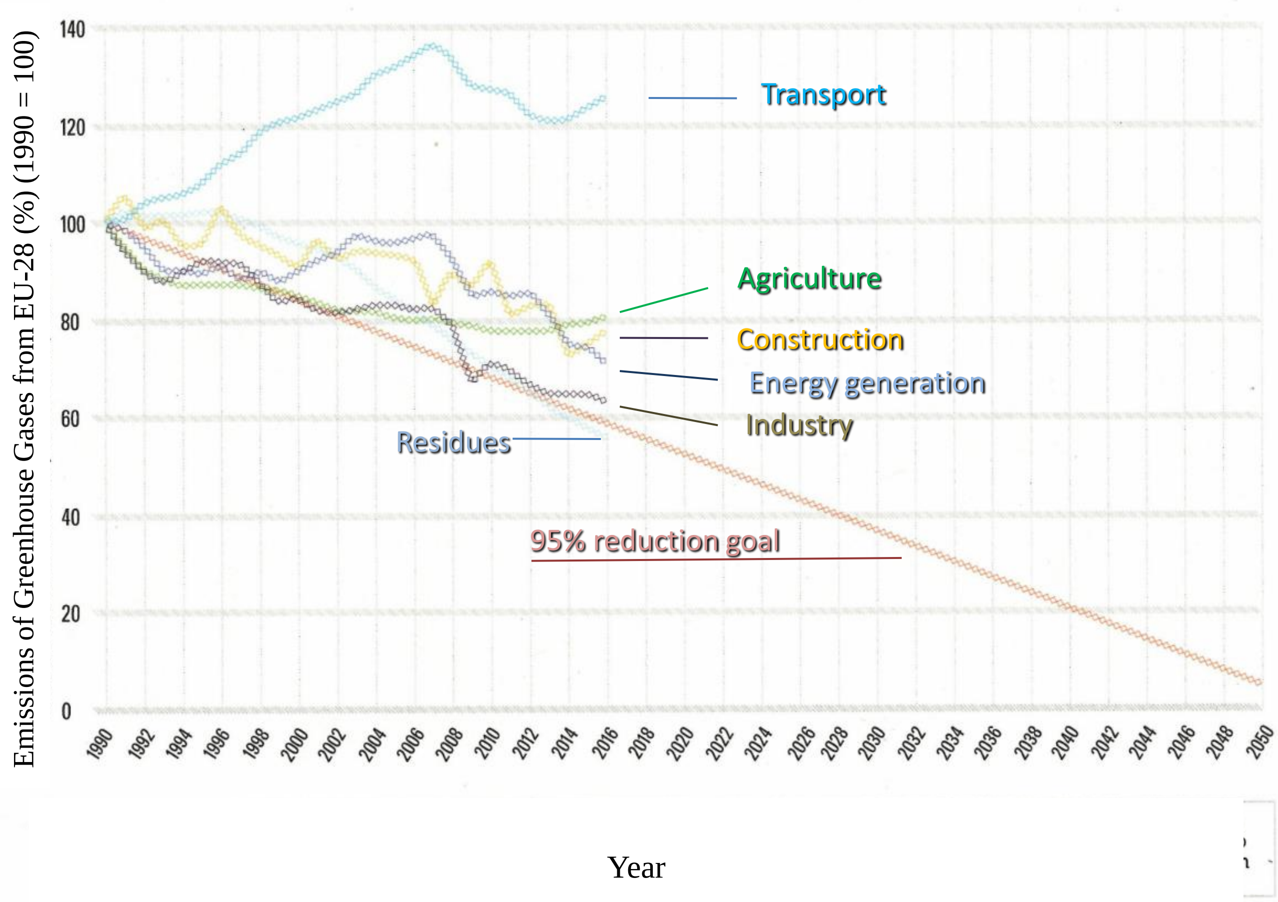
1 M H_2SO_4 electrolyte

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

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

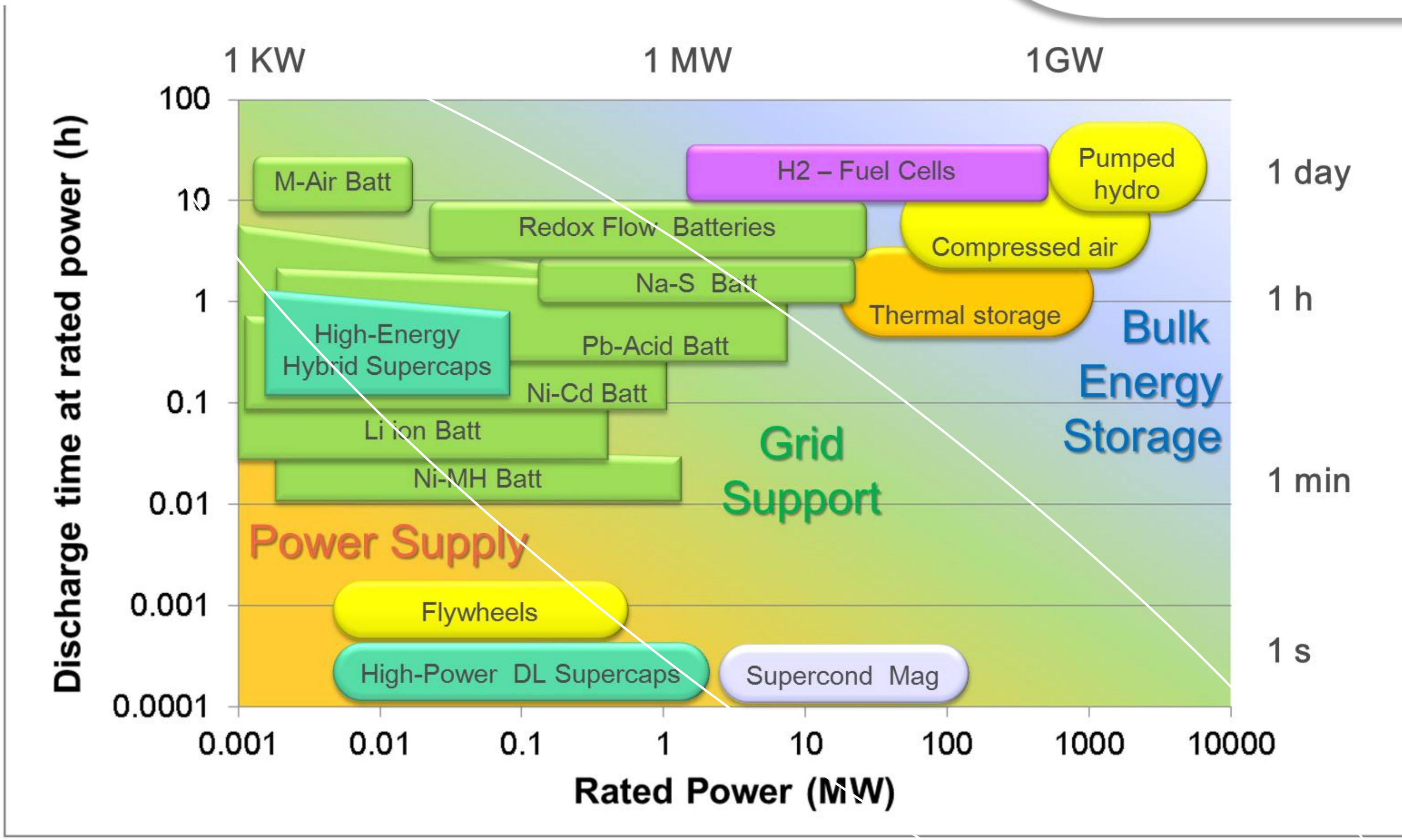
Which sector is not reducing emissions in Europe (yet)?



Source: Transport and Environment. From: Ballena Blanca, revista de medioambiente y economía, Nº 13, Dic 2017


PLUG-IN
HYBRID

Energy storage systems



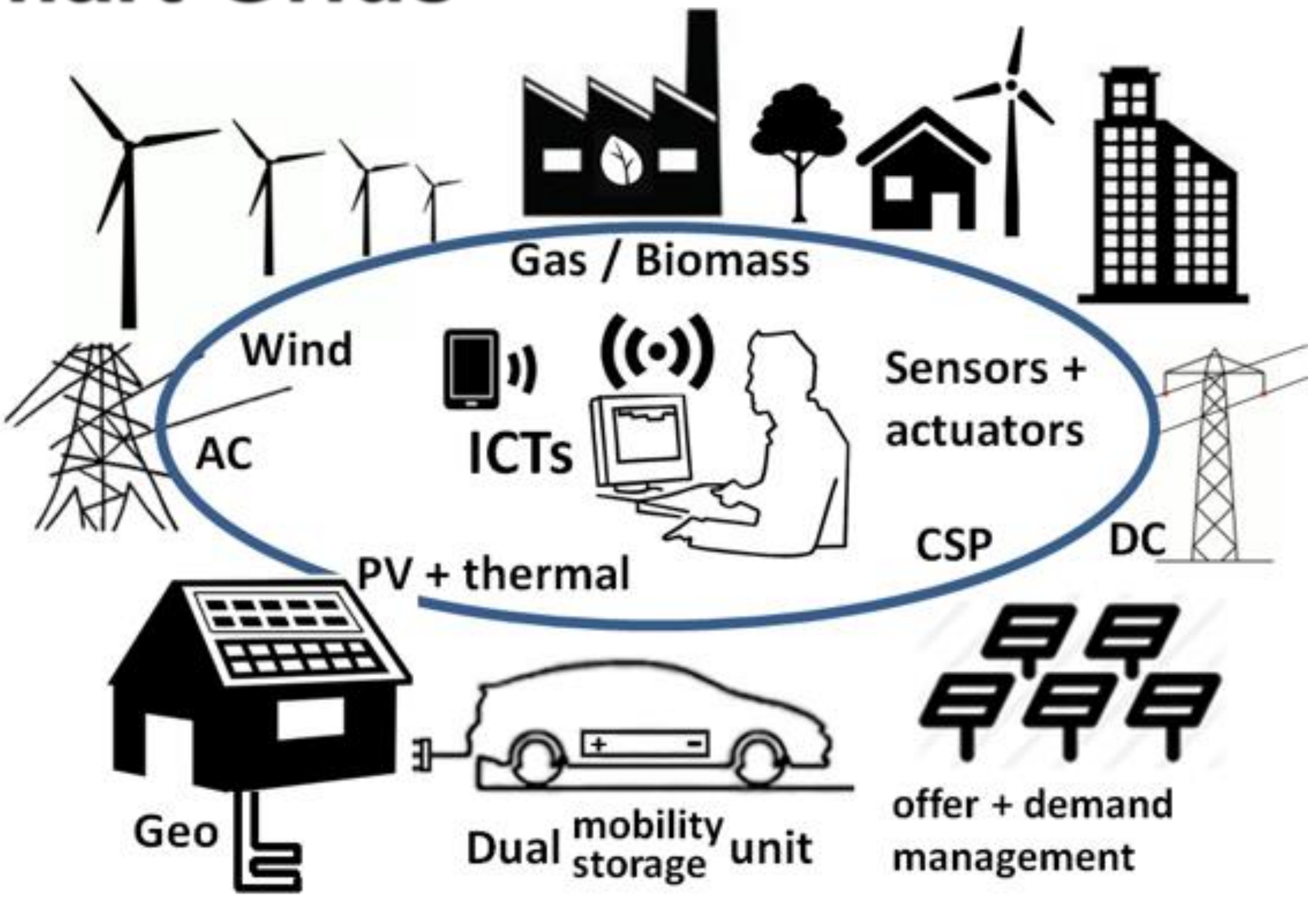
P. Gómez-Romero, D. Muñoz-Rojas Intro Chapter 1 “Energy in Transition” Materials for Sustainable Energy Applications (D. Muñoz-Rojas, X. Moya Eds.) Pan Stanford Pub **2016**

Instalación Hidroeólica de El Hierro

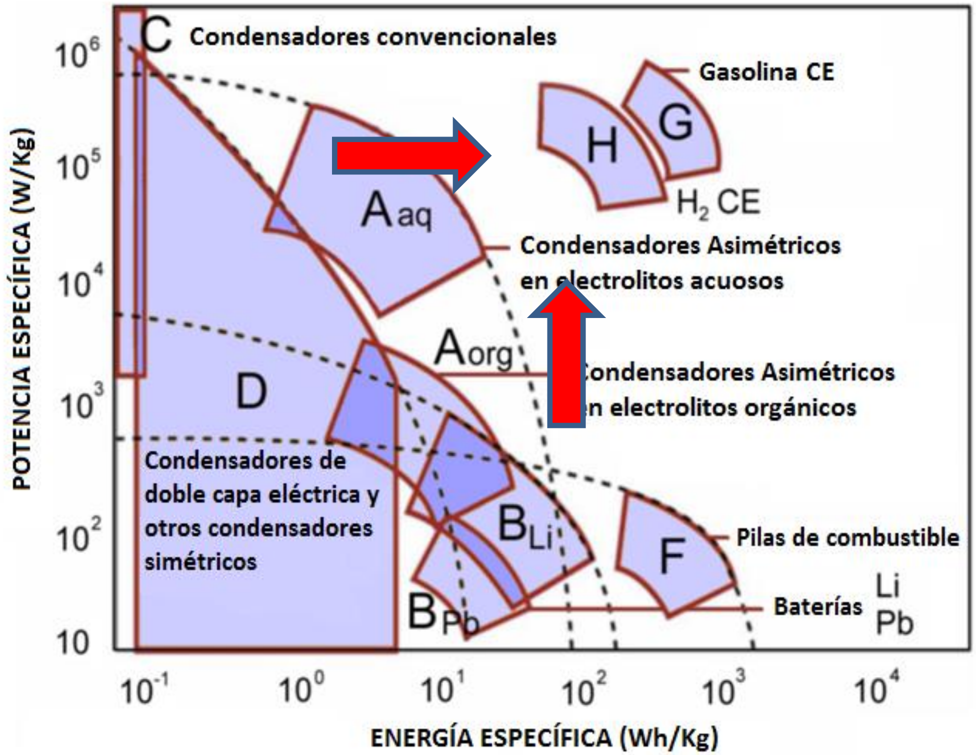
Centralized AND Distributed Energy

Smart Grids

Internet of Things

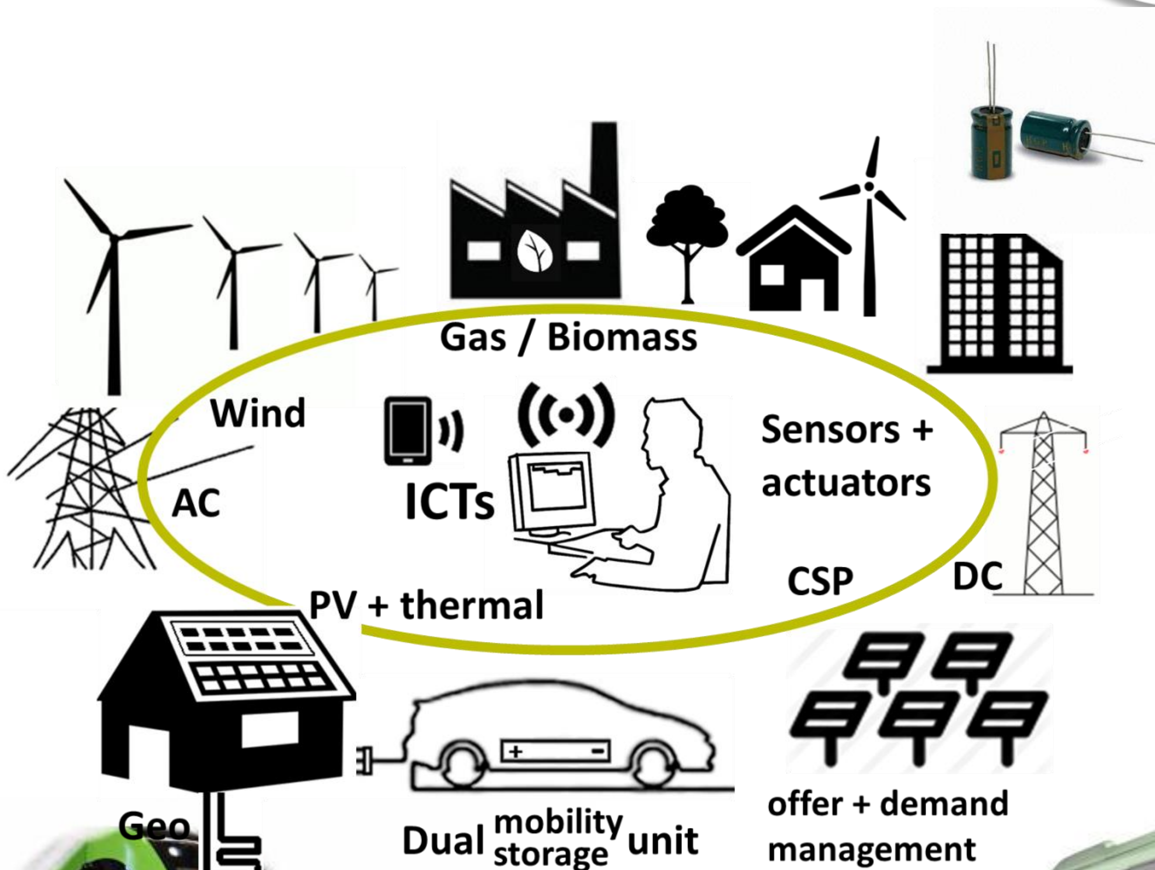


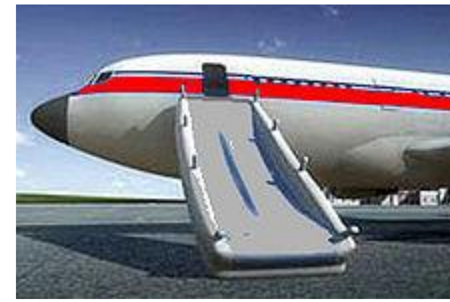
Energy vs. Power
Batteries vs. Supercapacitors



D. P. Dubal, V. Ruiz, O. Ayyad and P. Gomez-Romero, Chem. Soc. Rev, 2015

Supercapacitors applications





Hybrid approaches

Hybrid devices

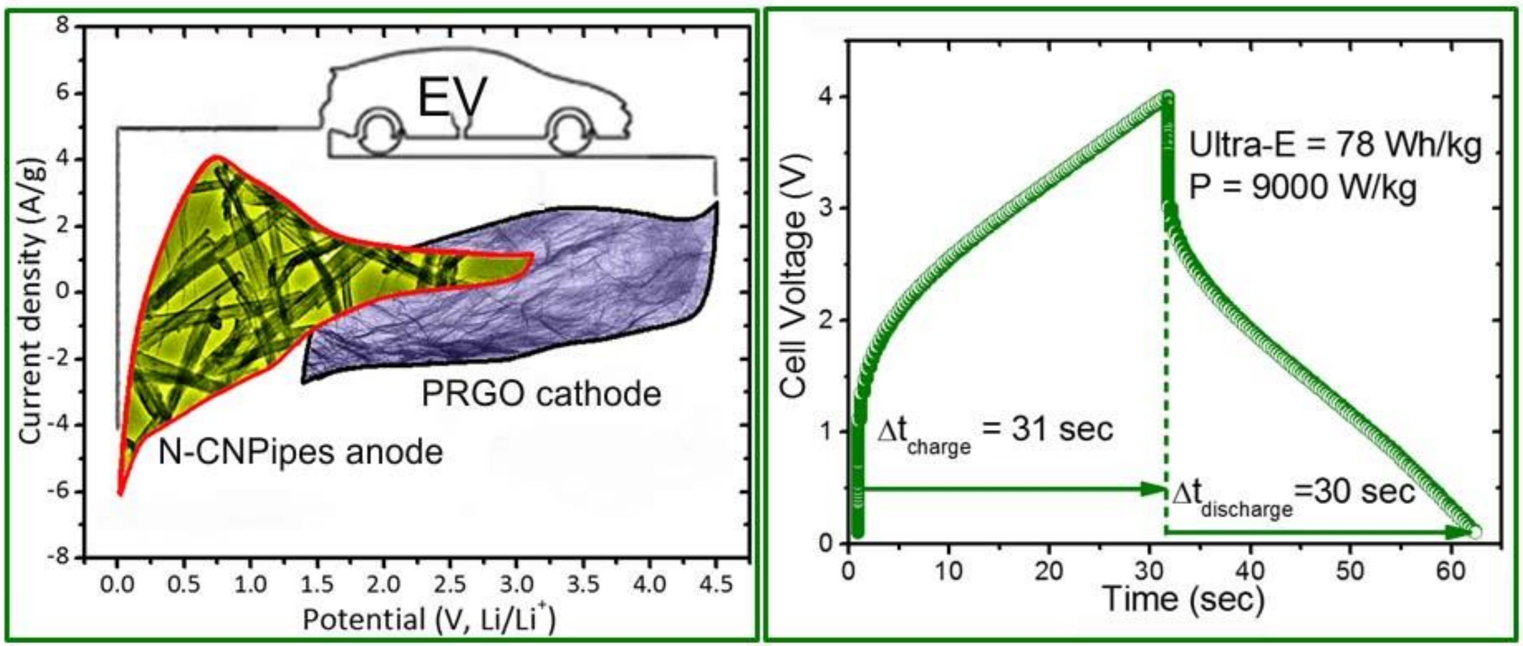
Electrode - Electrode
Electrode - Electrolyte

Hybrid materials

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**

Hybrid Device

Hybrid Energy Storage
Hybrid devices:
Nanocarbon Li-Ion Capacitor

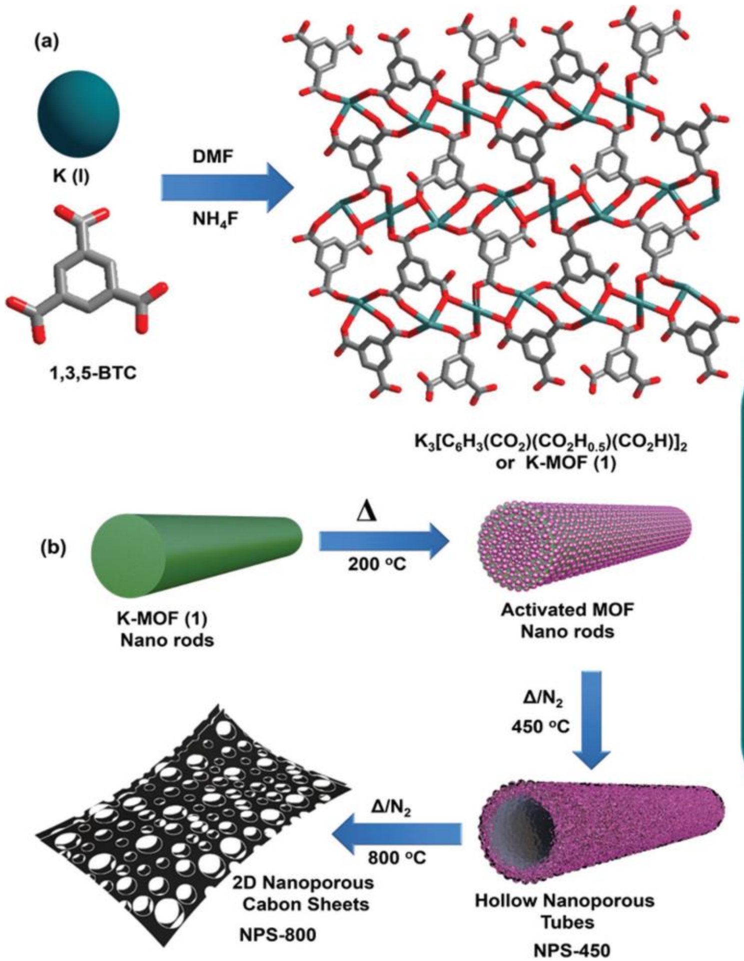


Nanocarbon Li-Ion Capacitor:
Battery-like negative electrode + supercap-type positive electrode
High energy and high power (fast charge) SIMULTANEOUSLY

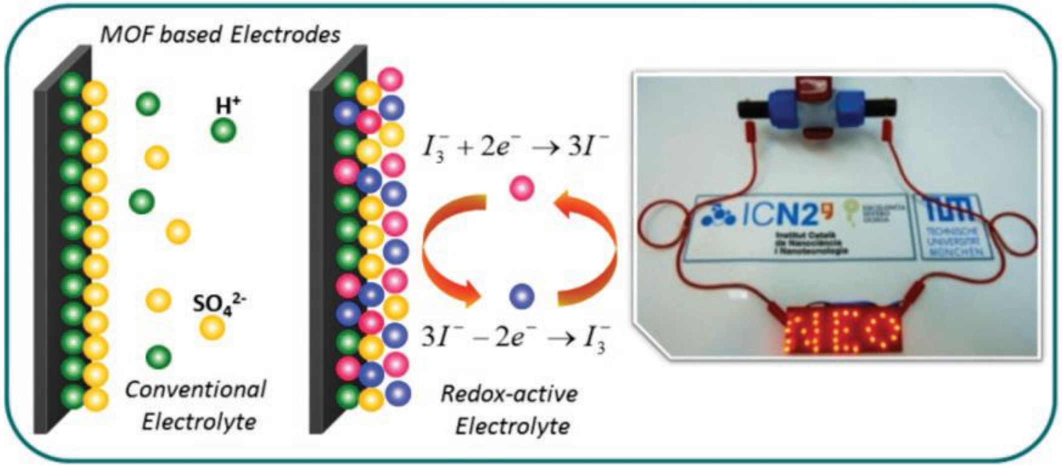
All Nanocarbon Li-Ion Capacitor with High Energy and High Power Densities.
Deepak P. Dubal,* Pedro Gomez-Romero** Materials Today Energy **2018**, 8, 109-117

Electrode-Electrolyte Hybridization

2D Nanoporous Carbon Sheets



Capacitive electrodes + Redox electrolytes

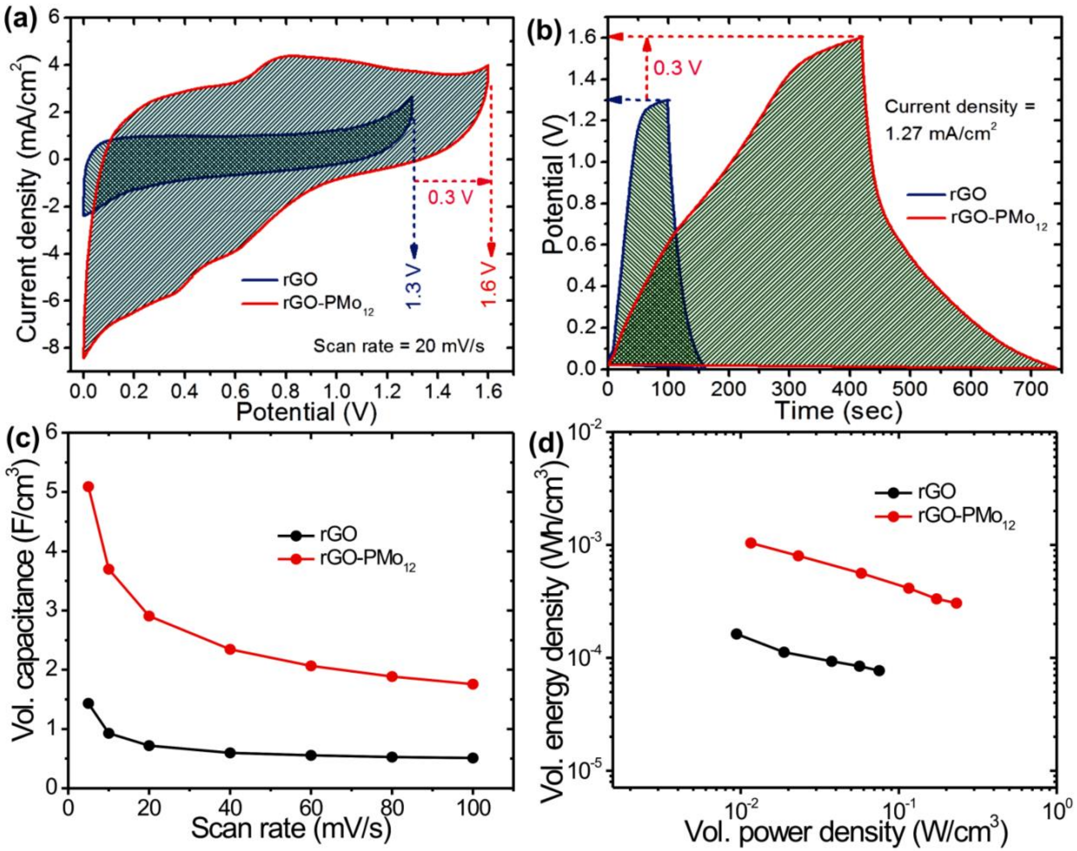


1200 m^2/g

K. Jayaramulu, D. P. Dubal, B. Nagar, …R Fischer P Gomez-Romero Adv Mater **2018**

Electrodes Material Hybridization

Hybrid Graphene Polyoxometalate Electrodes

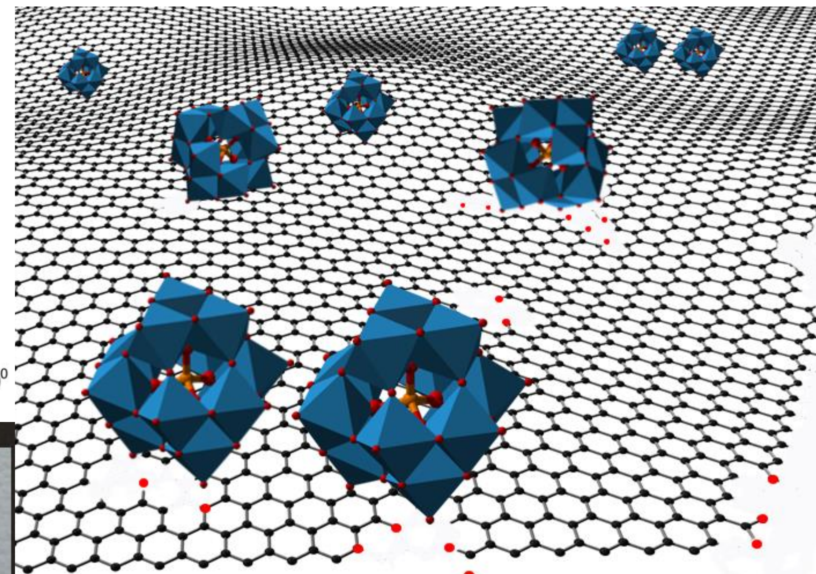


Hybrid Energy Storage:

Hybrid electrode materials

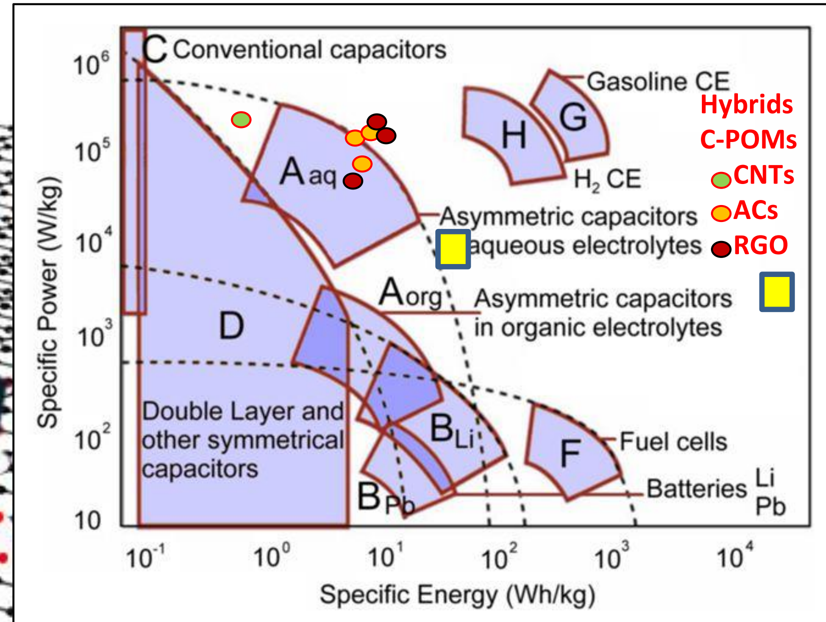
+ Electroactive electrolyte

rGO / H3PMo12O40 / HQ

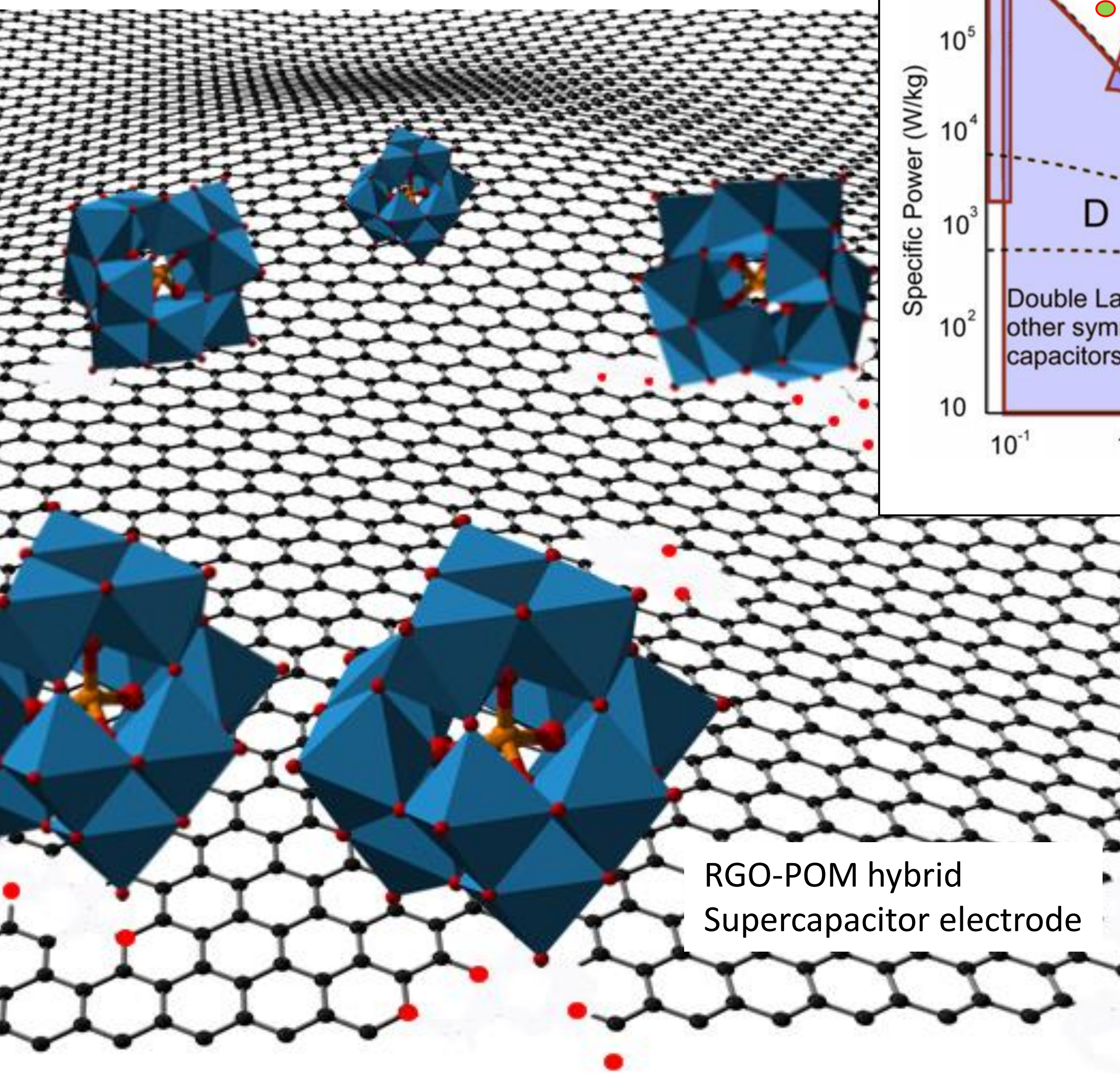


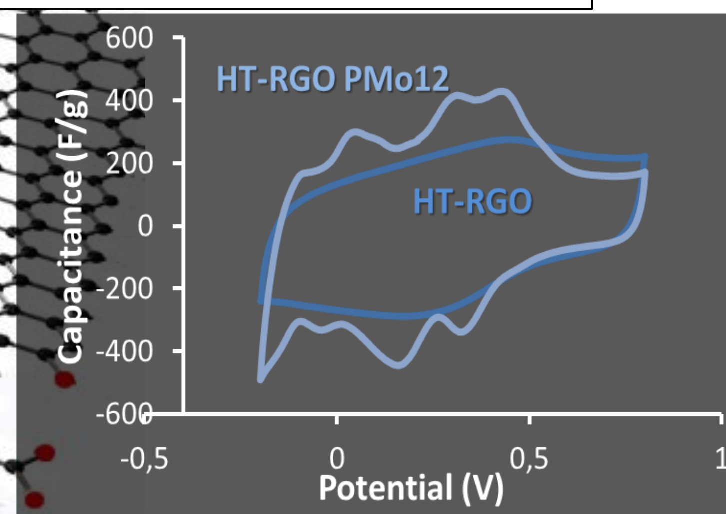
31 LEDs powered with a single rGO-PMo$_{12}$ symmetric cell with 0.2 M HQ doped polymer gel electrolyte.
30 s charge 2 min lit

D.P. Dubal ... P. Gomez-Romero Journal of Materials Chemistry A, 2015, 3(46), 23483

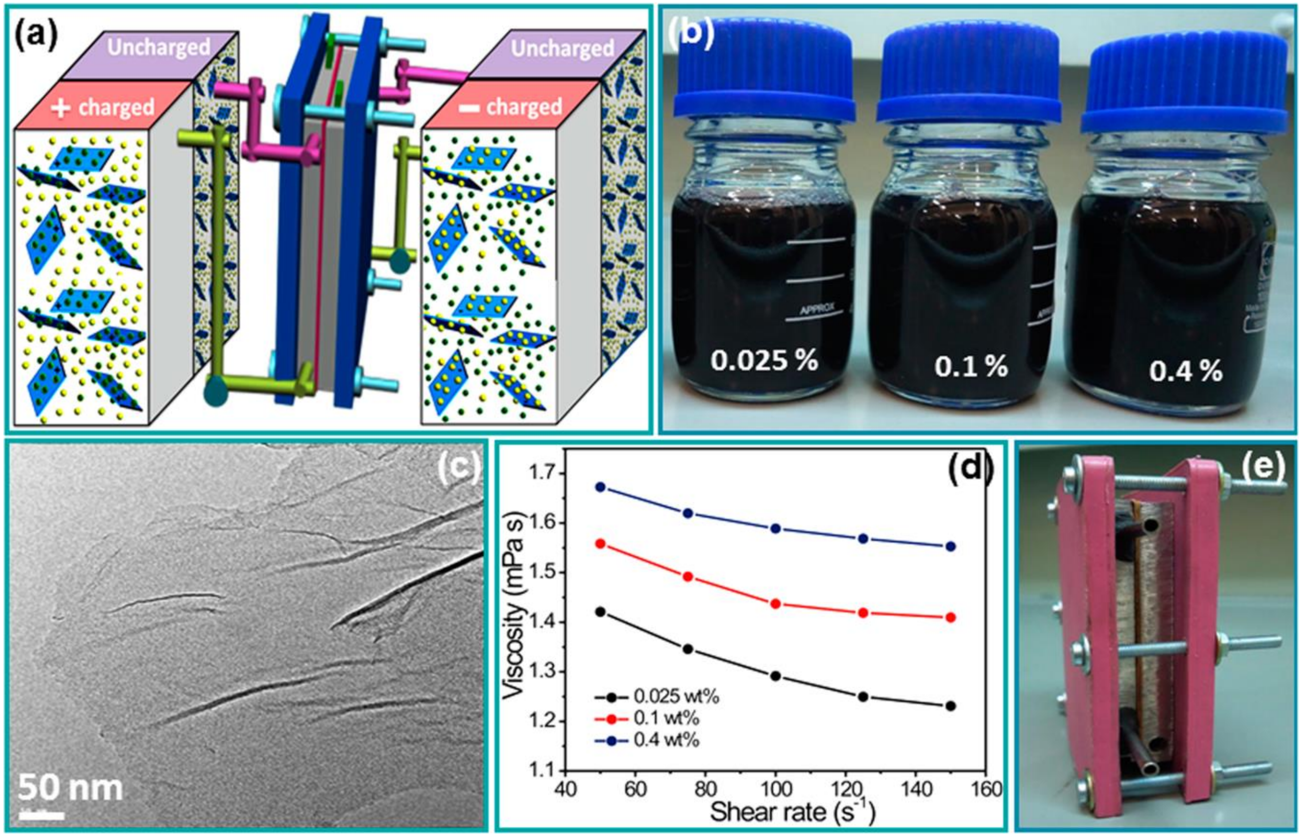

Specific Power (W/kg)
Specific Energy (Wh/kg)
10^6
10^5
10^4
10^3
10^2
10
10^{-1}
10^0
10^1
10^2
10^3
10^4
C Conventional capacitors
Gasoline CE
H
G
H_2 CE
A_{aq}
Asymmetric capacitors aqueous electrolytes
A_{org}
Asymmetric capacitors in organic electrolytes
D
Double Layer and other symmetrical capacitors
B_{Li}
B_{Pb}
F
Fuel cells
Batteries Li Pb
Hybrids
C-POMs
CNTs
ACs
RGO

rGO $Ni(OH)_2$


RGO-POM hybrid
Supercapacitor electrode


HT-RGO PMo12
HT-RGO
Capacitance (F/g)
600
400
200
0
-200
-400
-600
-0,5
0
0,5
1
Potential (V)

Electroactive Graphene Nanofluids for New Flow Cell Concepts.



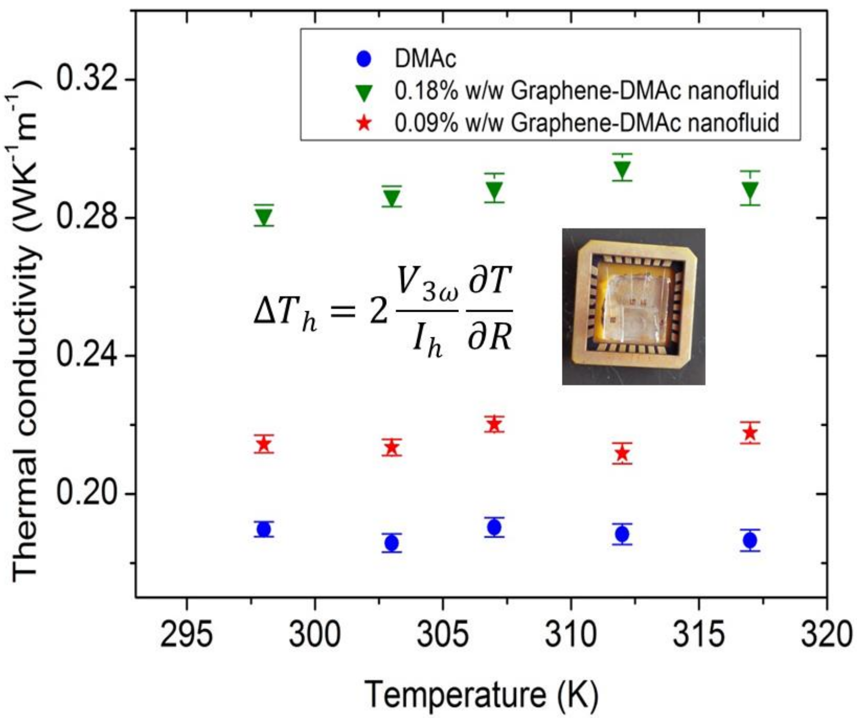
D. P. Dubal, D. Gomez, P. Gómez-Romero, Patent ES1641.1064. "Electroactive nanofluids on graphene-based materials for energy storage in flow cells." 20-05-2015

Electroactive Graphene Nanofluids for Fast Energy Storage.

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

Graphene Nanofluids as Heat Transfer Fluids

ICN2
Institut Català de Nanociència i Nanotecnologia
EXCELENCIA SEVERO OCHOA



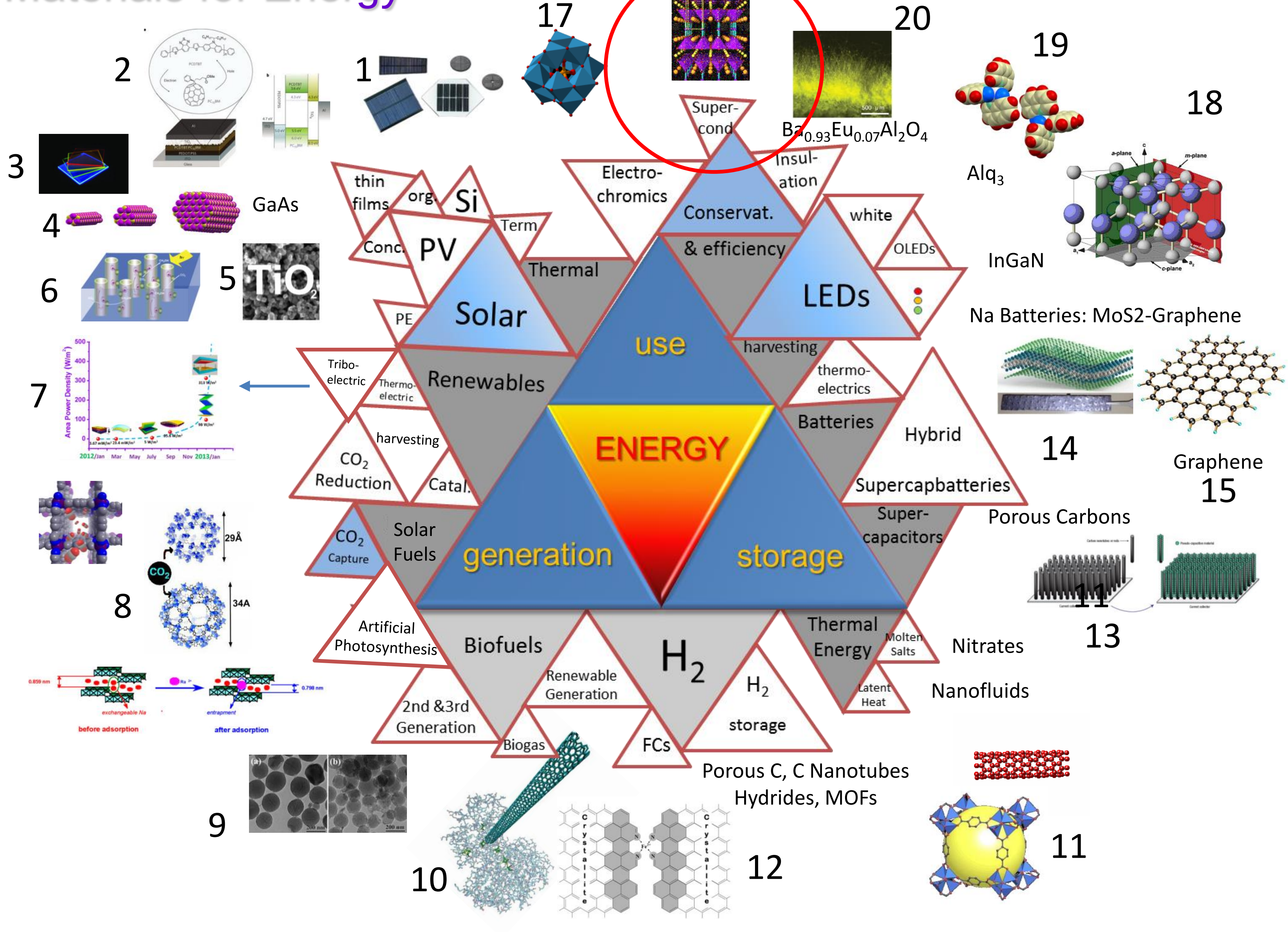
3-omega measurements. Novel approach for thermal conductivity in liquids (colaboration with Prof. C. Sotomayor's and Prof. P Ordejon's groups at ICN2)

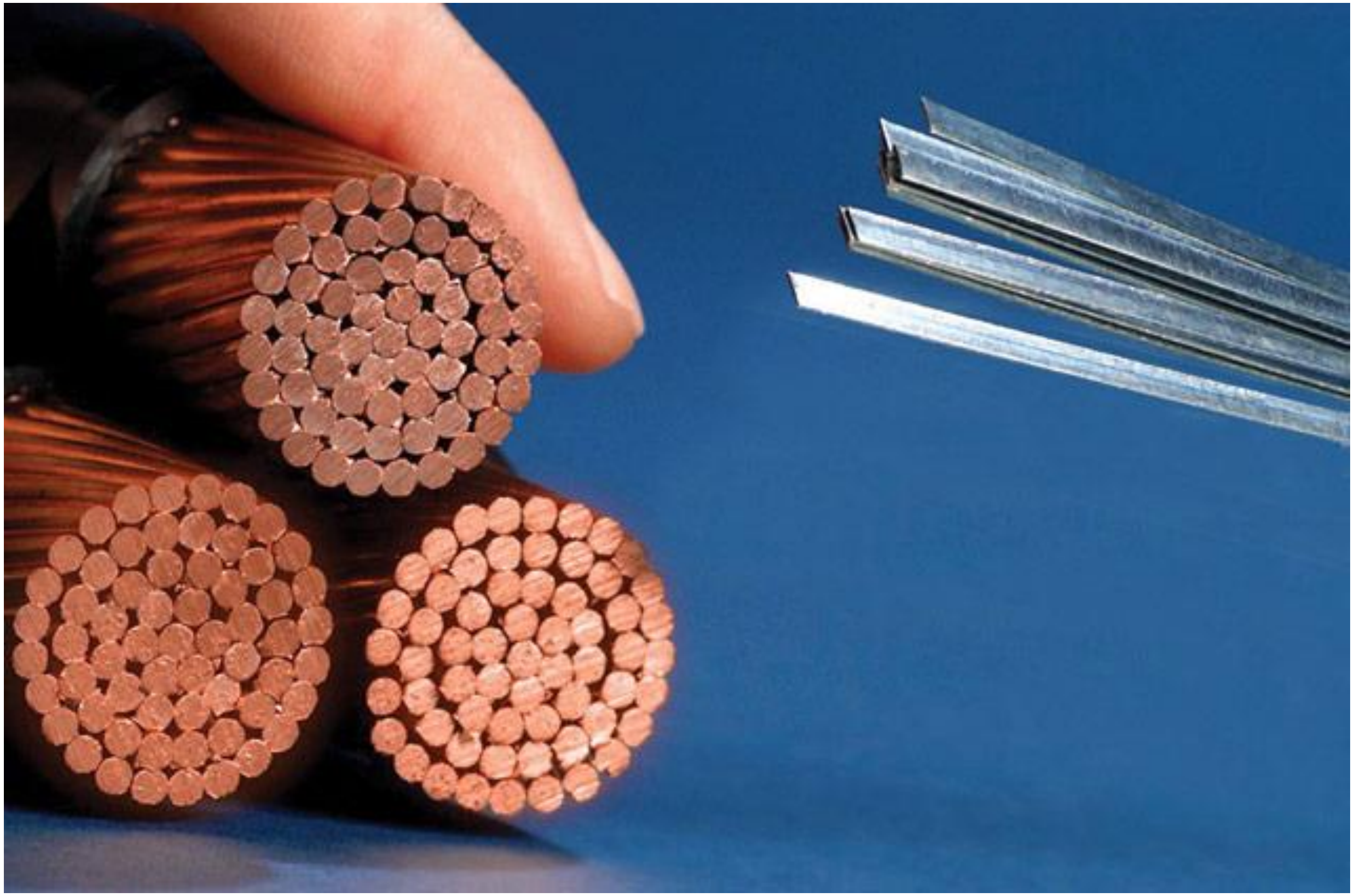
Less than 1% graphene in a perfectly stable solution (left) leads to a 50% improvement

Graphene acting as an accelerating centre for thermal waves in organic 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

Materials for Energy

Pedro GOMEZ-ROMERO

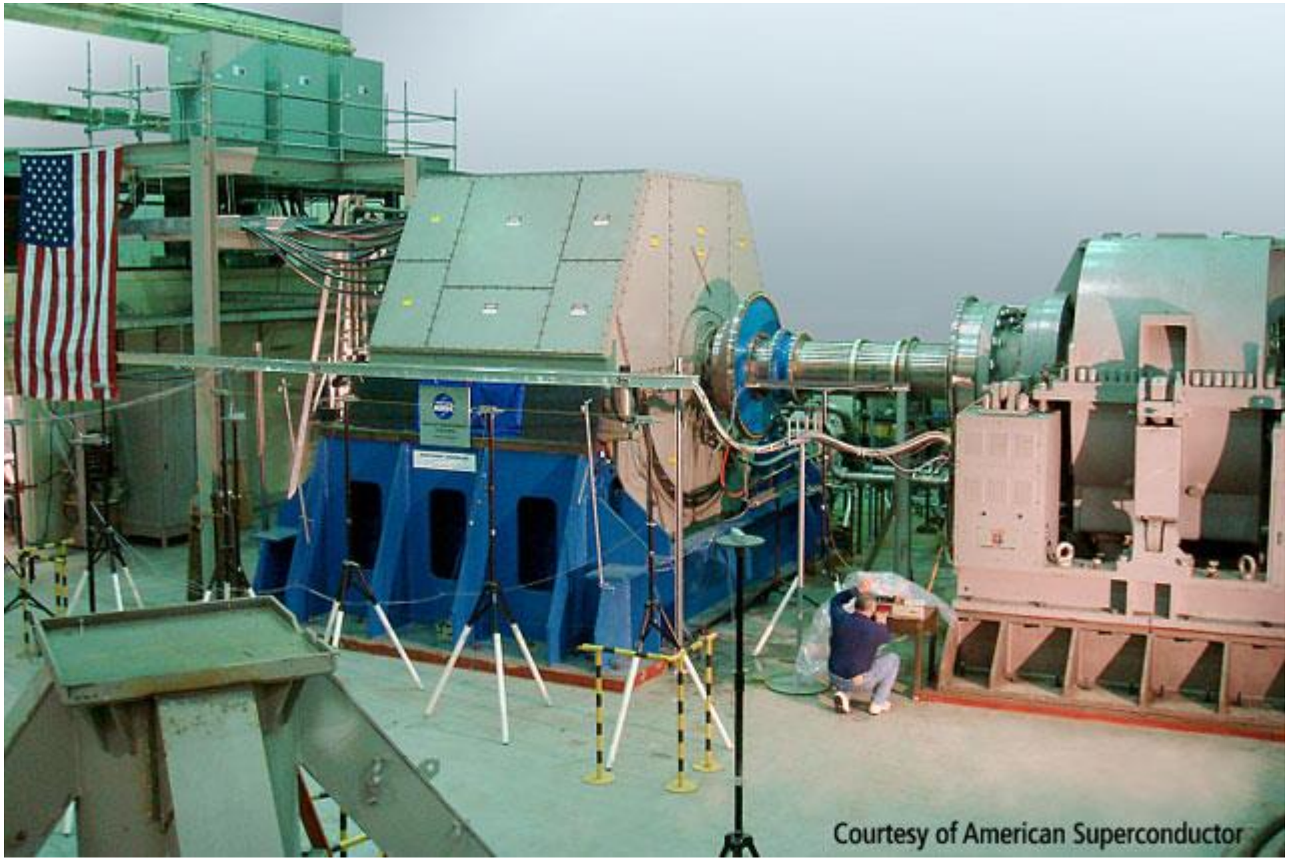




HTSC wires conduct more than 100 times the current of equivalent sized copper wire.

As a result, the few Amperium wires pictured on the right are able to carry as much power as all of the copper on the left. (Courtesy of American Superconductor)

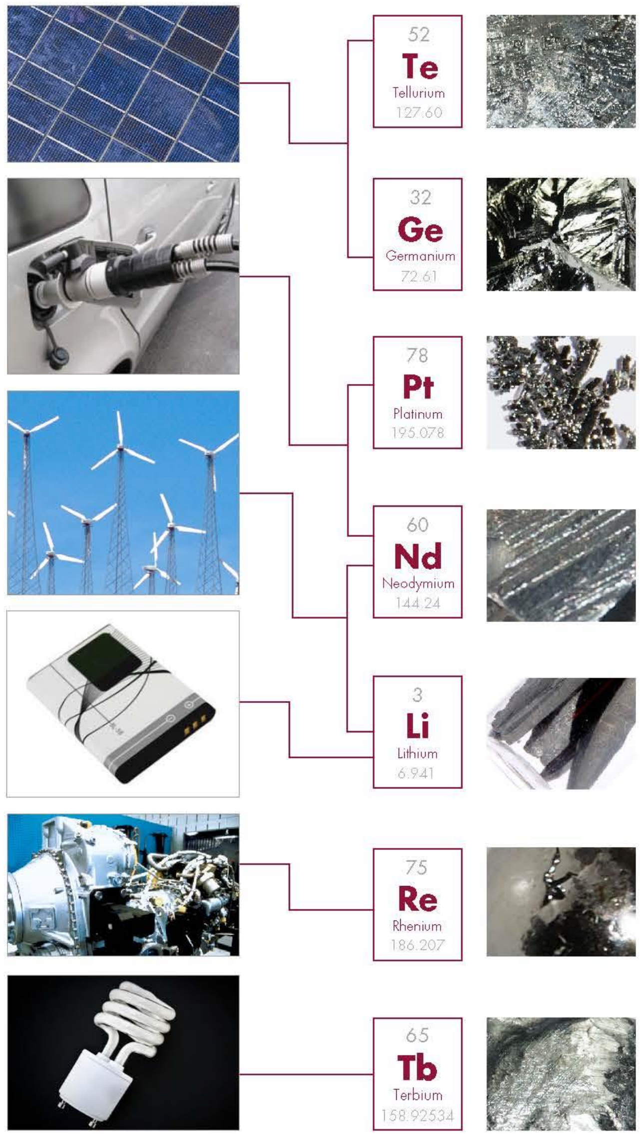
2008. world's first HTS power transmission cable system. Long Island April 2008. At full capacity, the 138 kV system is capable of carrying 574 megawatts of power



2009. World's first 36.5 MW (49,000 hp) superconductor ship propulsion motor by AMSC and Northrop Grumman for the U.S. Navy
the motor is 1/3 the size and weight of a conventional 36.5 MW

HTS in rotors rather than copper
enables the generator to be much smaller, lighter, more efficient and less expensive than conventional large-scale wind turbine generators.
Titan generators are direct drive. No need for a gearbox, which tends to be the most maintenance intensive wind turbine component. AMSC expects to license SeaTitan wind turbines and Titan generators to multiple manufacturers around the world by the end of 2010

Energy Critical Elements



TELLURIUM—brittle, silvery-white metallic element used in solar panels

GERMANIUM— hard, grayish-white element with metallic luster; used in solar panels

PLATINUM—silvery-white, lustrous, ductile and malleable; used in pollution control devices for cars, and in fuel cells

NEODYMIUM—bright, silvery rare-earth metal element; used in wind turbines and hybrid cars

LITHIUM—a soft, silver-white metallic element; used in wind turbines and lithium-ion batteries in hybrid cars

RHENIUM—silvery-white metal with one of the highest melting points of all elements; used to make advanced turbines and jet engine parts

TERBIUM—a soft, silvery-white rare earth metal; used along with its fellow rare earth europium in compact fluorescent light bulbs to provide an acceptable color balance

Chemistry. Nanocrystal nucleation and growth

Fundamental research at pof P. Alivisatos’ laboratory. CdSe-CdS core shell NP

NanoSys Quantum Dot Technology from P. Alivisatos CdSe-CdS core shell nanoparticles

Getting away from *Toxic Tech*

ALIEN, our future material(s)

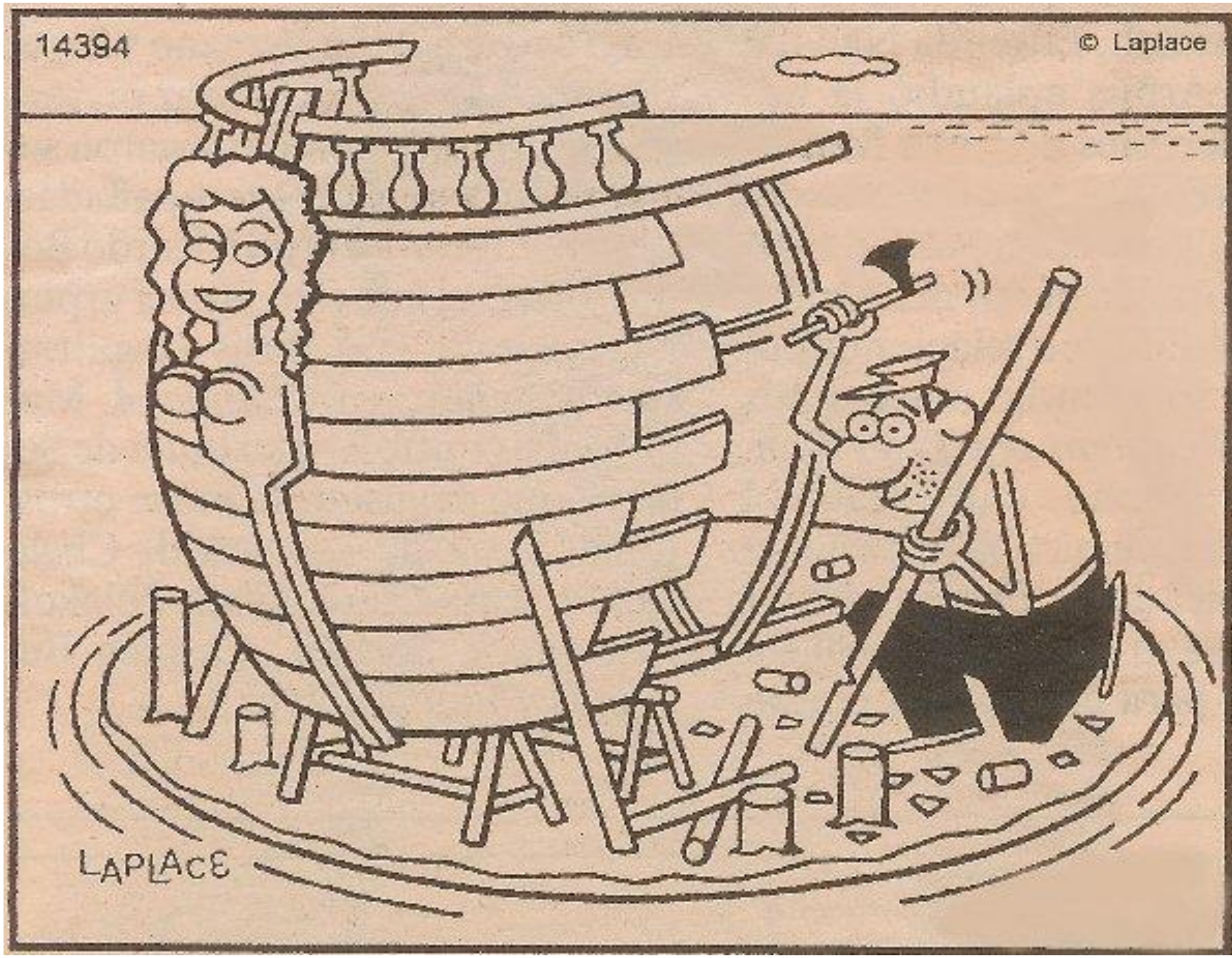
Abundant

Lower costs

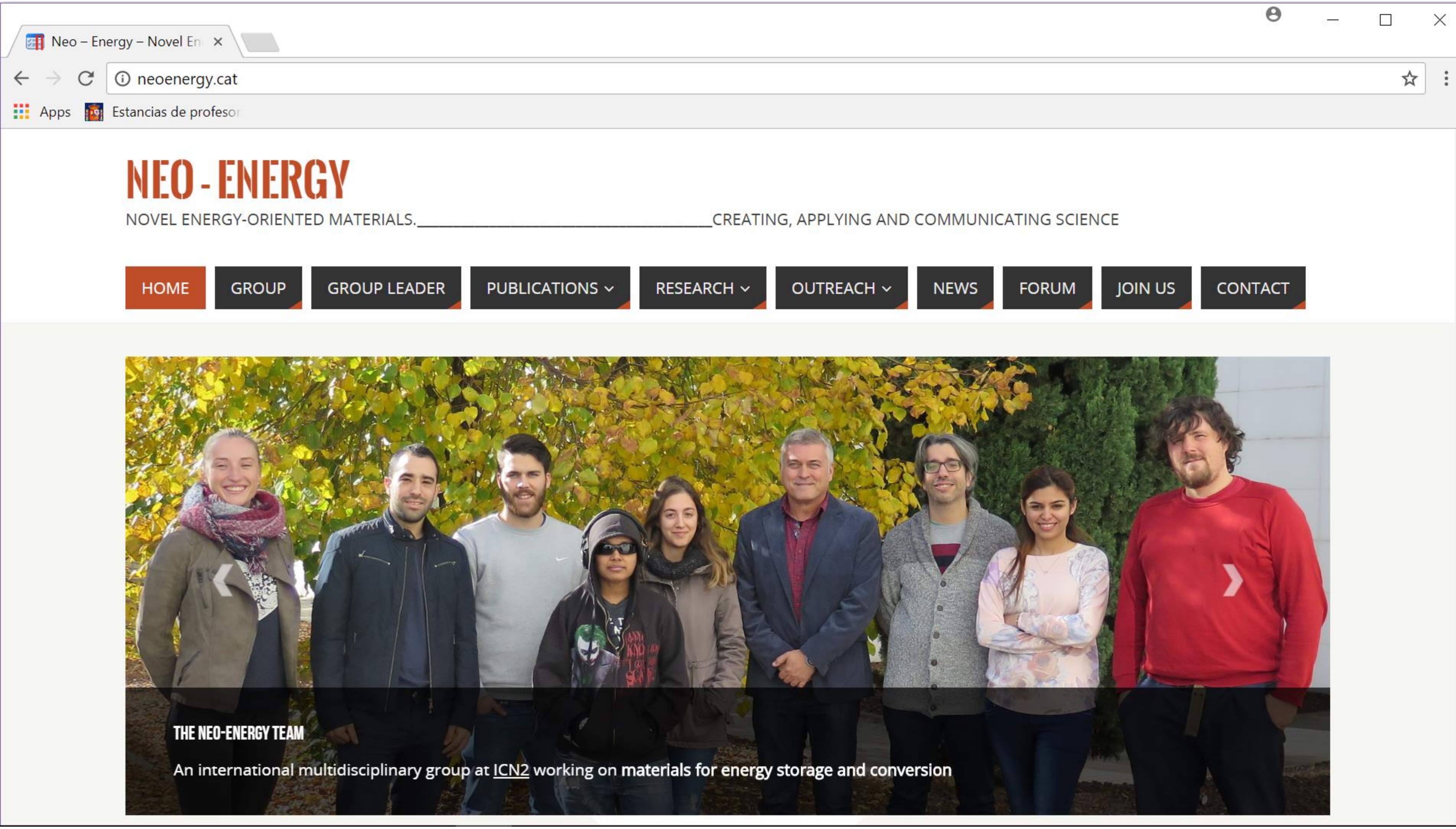
I mproved performance

Environmentally friendly

New props tricks and apps


14394
© Laplace
LAPLACE

The NEO-Energy Group

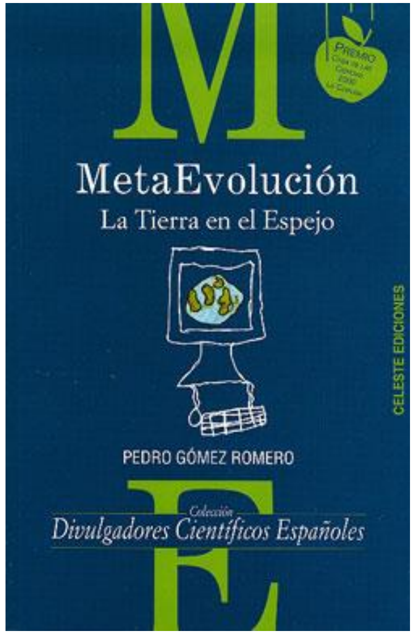


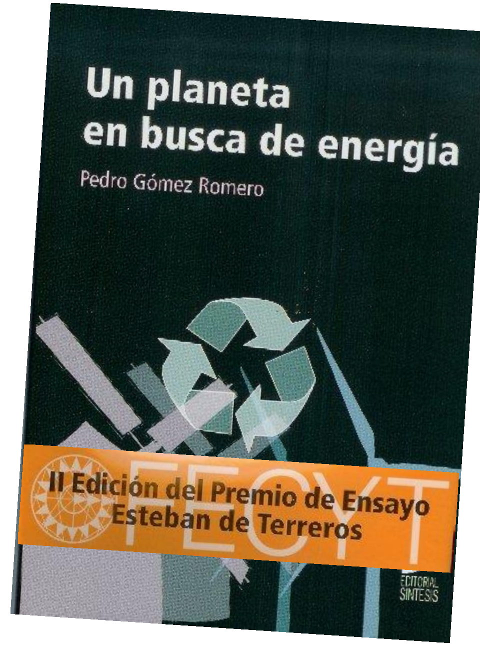
www.neoenergy.cat


neoenergy.cat
Gracias


QUESTIONS

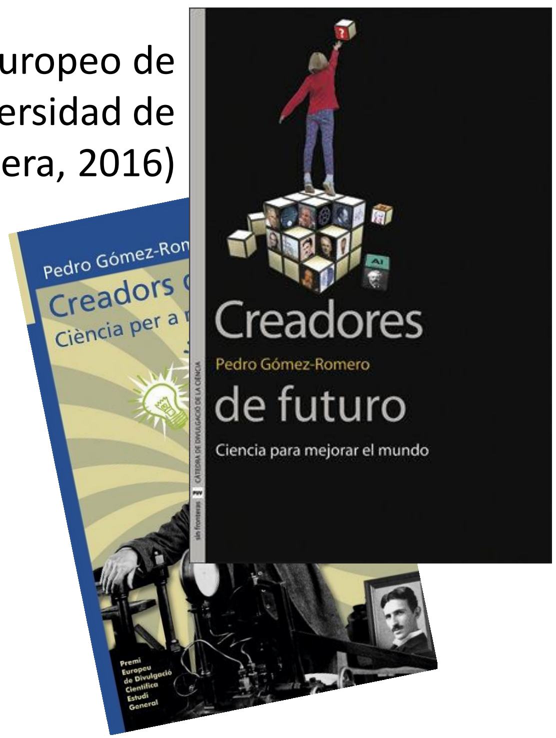
Premio Casa de las Ciencias de Divulgación 2000 (Celeste, 2001).

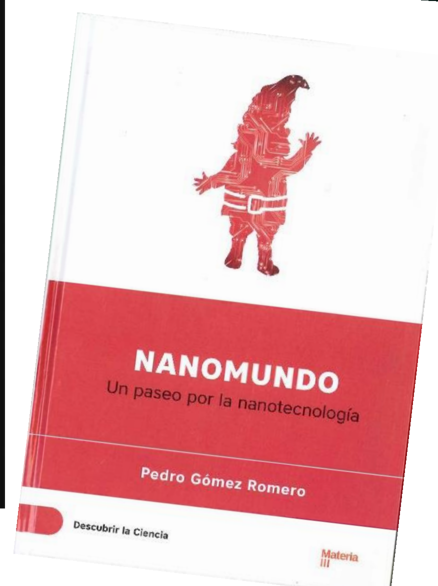




Premio Internacional de Ensayo “Esteban de Terreros”
(Editorial Síntesis, 2007)

Premio Europeo de Divulgación Universidad de Valencia (Ed. Bromera, 2016)





Editorial Materia/El País
(Nov 2016)

NEO-Energy Lab

Prof. Pedro Gómez-Romero

ICN2
Institut Català de Nanociència i Nanotecnologia
EXCELENCIA SEVERO OCHOA

MINISTERIO DE CIENCIA E INNOVACIÓN

CSIC

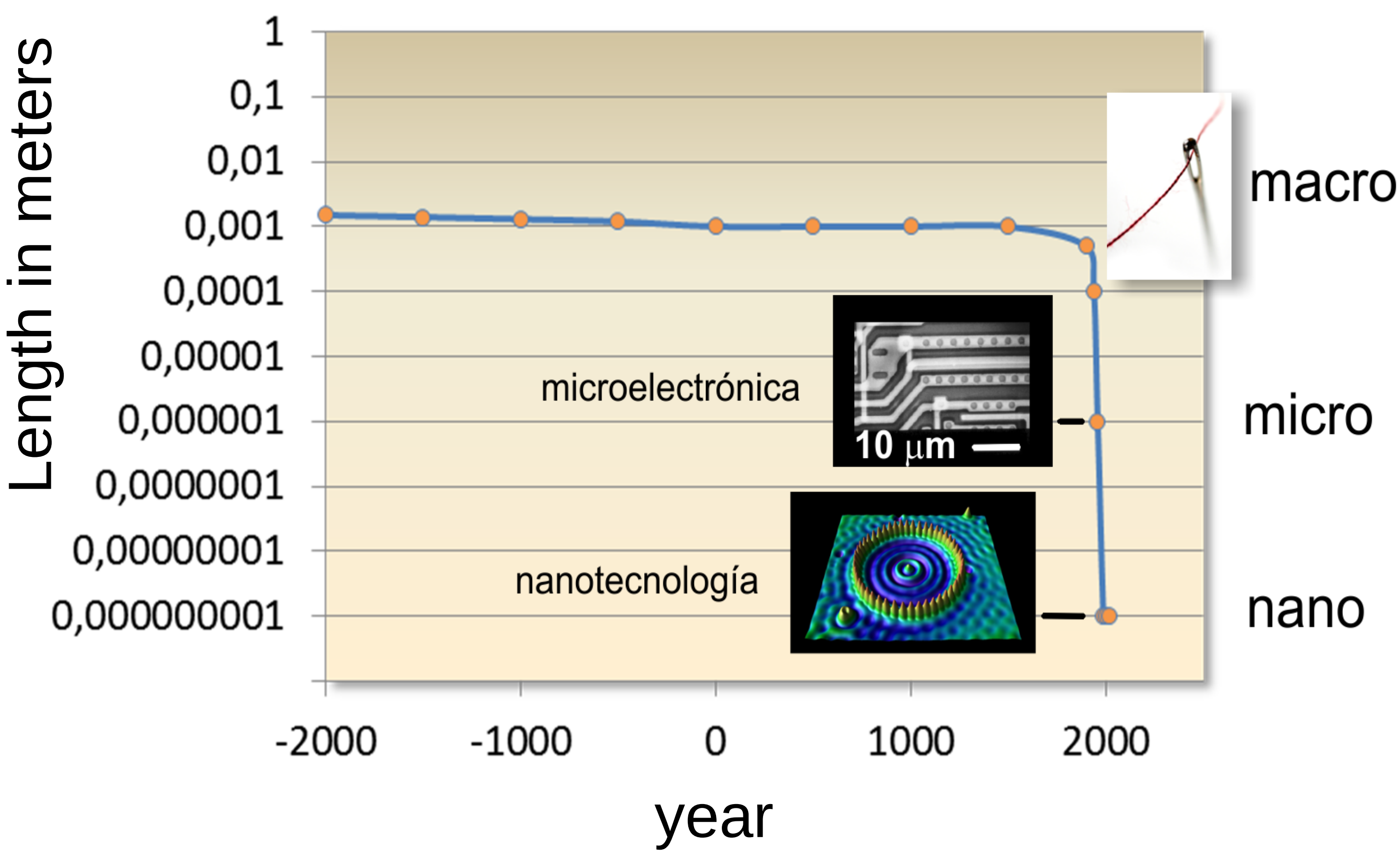
NATO OTAN

Generalitat de Catalunya

EARTHDAS

Nano-Science and Nano-Technology. Much more than just fashion

Length of the smallest object made by humans



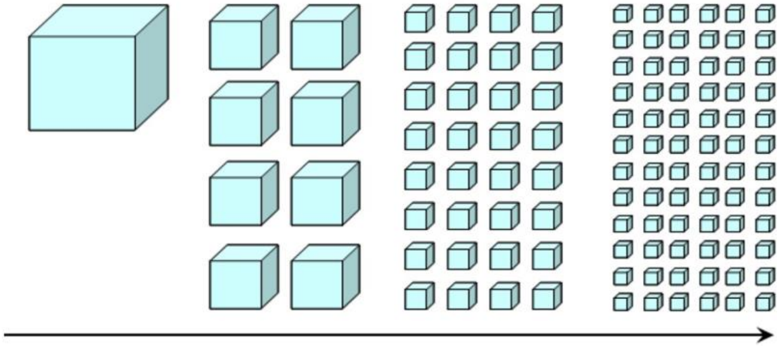
Source: P. Gómez Romero. “Nanomundo.Un paseo por la Nanotecnología” Materia/El País 2016

From Materials to Nanomaterials

Extrinsic changes in properties

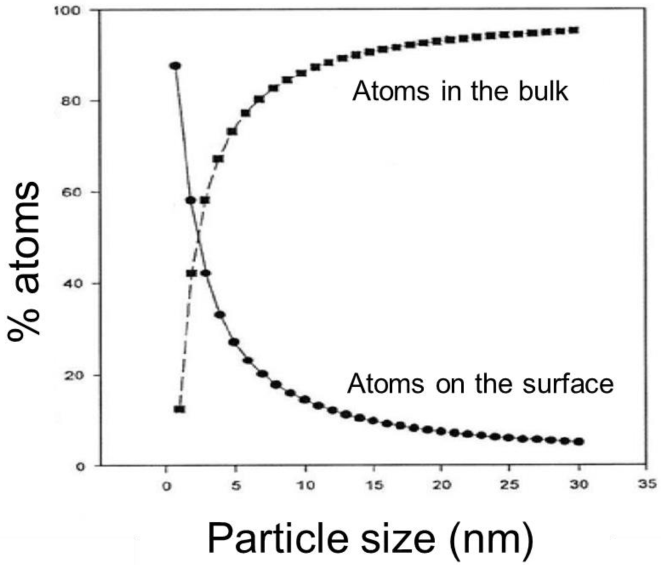
From Materials to Nanomaterials

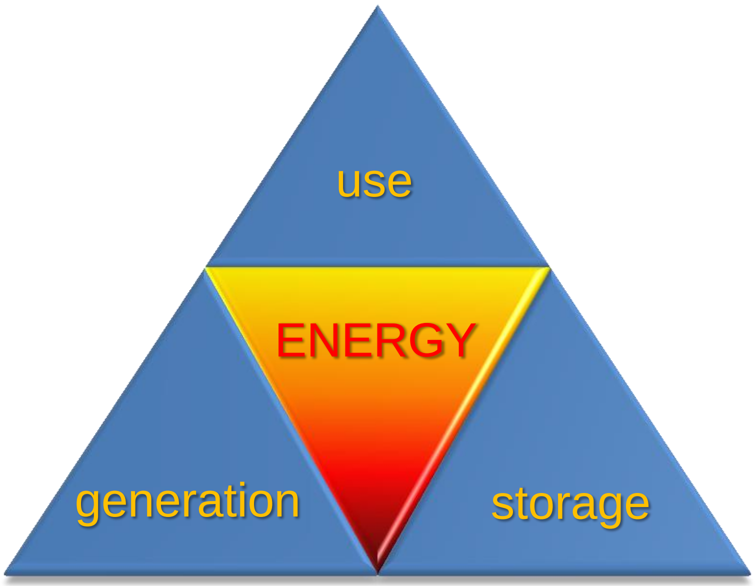
Extrinsic changes in properties

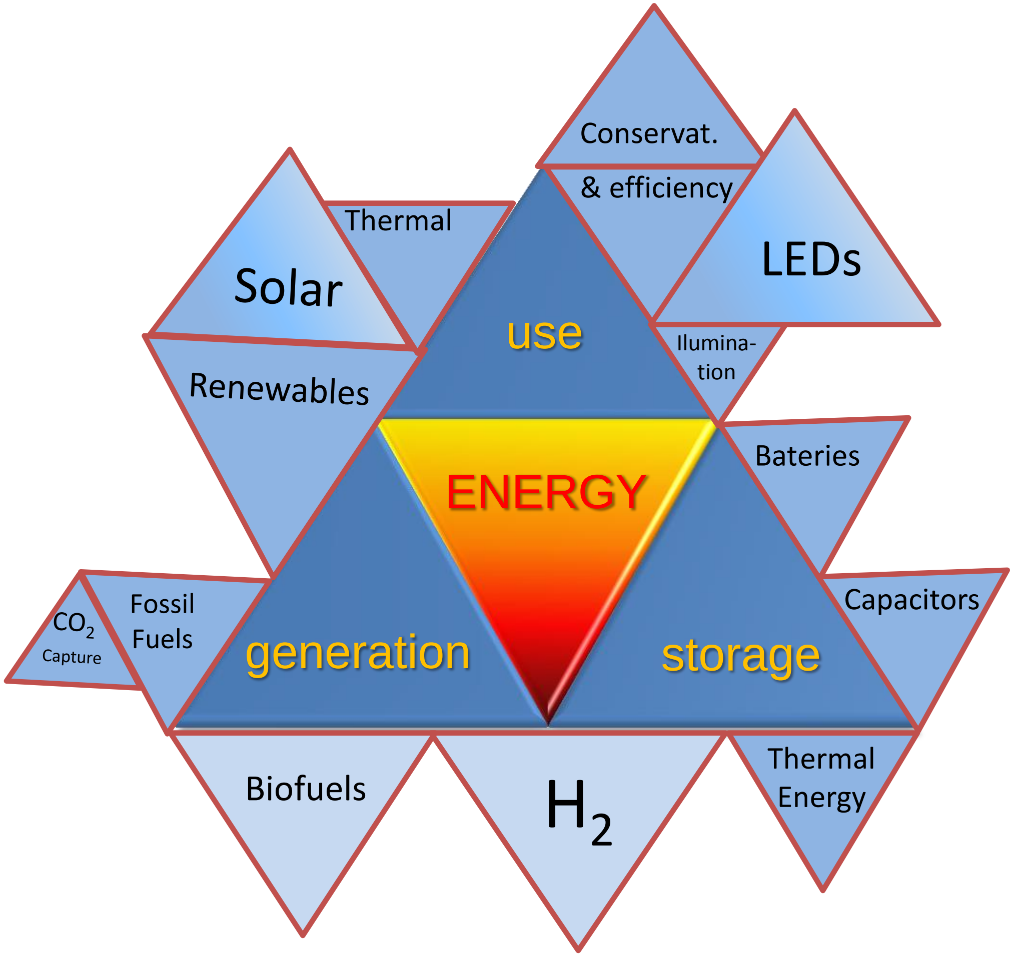


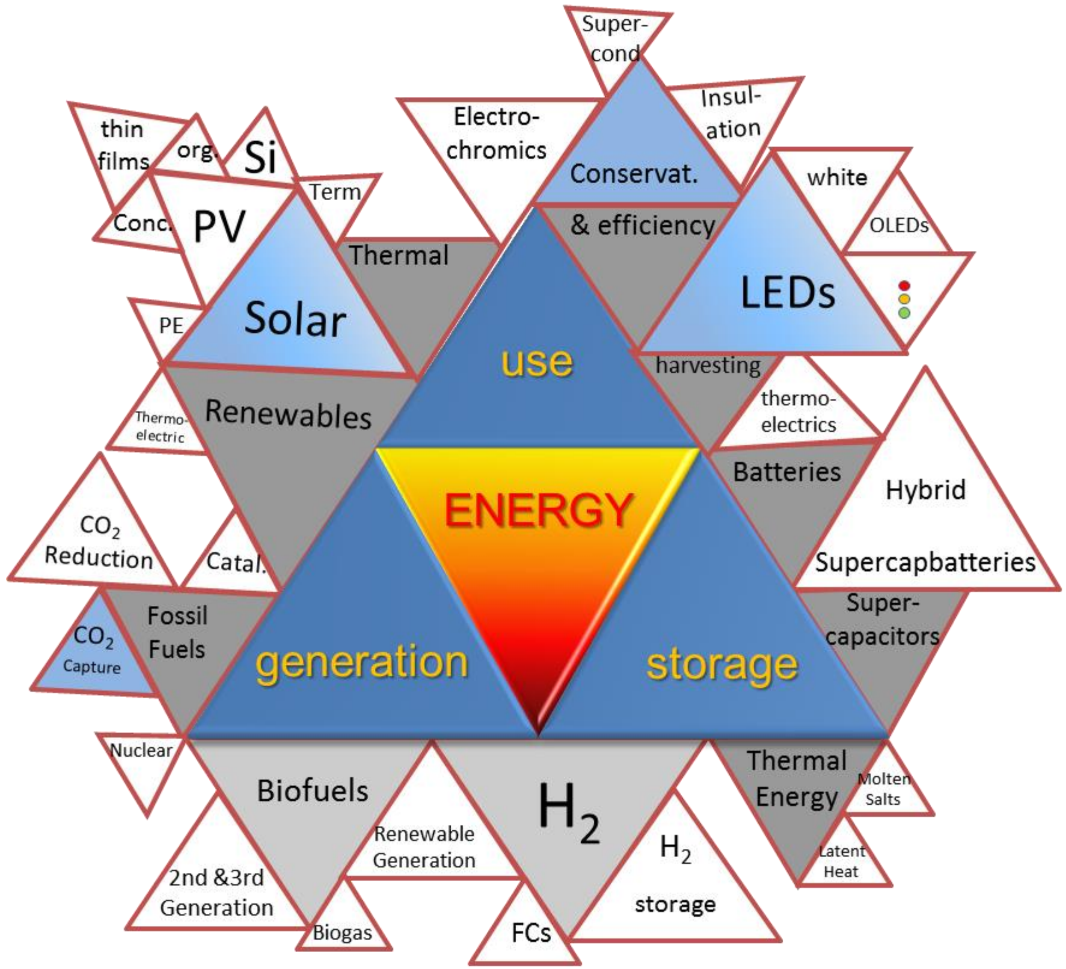
1cube
1m
6 m^2

10^{27}cubes
1nm
$6 \cdot 10^9 m^2$ (6000 Km^2)




use
ENERGY
generation
storage

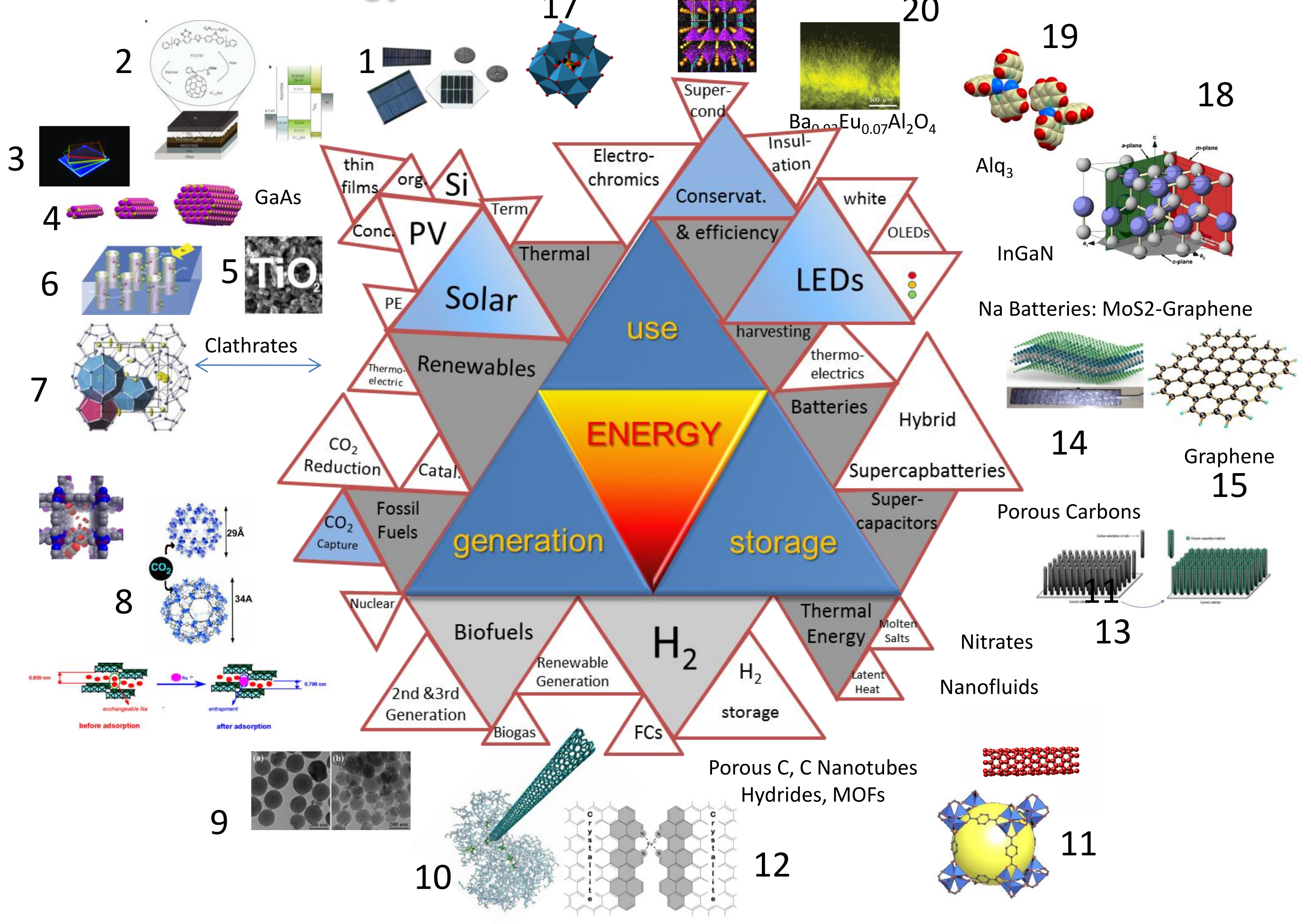

Conservat.
& efficiency
LEDs
Thermal
Solar
use
Illumina-
tion
Renewables
ENERGY
Bateries
Capacitors
Fossil
Fuels
CO_2
Capture
generation
storage
Biofuels
H_2
Thermal
Energy



Super-
cond
Electro-
chromics
Insul-
ation
Conservat.
& efficiency
thin
films
org.
Si
Conc.
PV
Term
Thermal
white
OLEDs
LEDs
Solar
PE
use
harvesting
thermo-
electrics
Renewables
Thermo-
electric
Batteries
Hybrid
ENERGY
CO_2
Reduction
Catal.
Supercapbatteries
Super-
capacitors
Fossil
Fuels
CO_2
Capture
generation
storage
Nuclear
Thermal
Energy
Molten
Salts
Biofuels
H_2
Renewable
Generation
H_2
storage
Latent
Heat
2nd &3rd
Generation
Biogas
FCs

Materials for Energy

Pedro GOMEZ-ROMERO



1. CUESTIÓN DE ENERGÍA

Una introducción fundamental a la cuestión de la energía.

Termodinámica: Energía frente a Entropía

Biosíntesis
Crecimiento celular
Respiración
Movimiento
Comunicación
Defensa

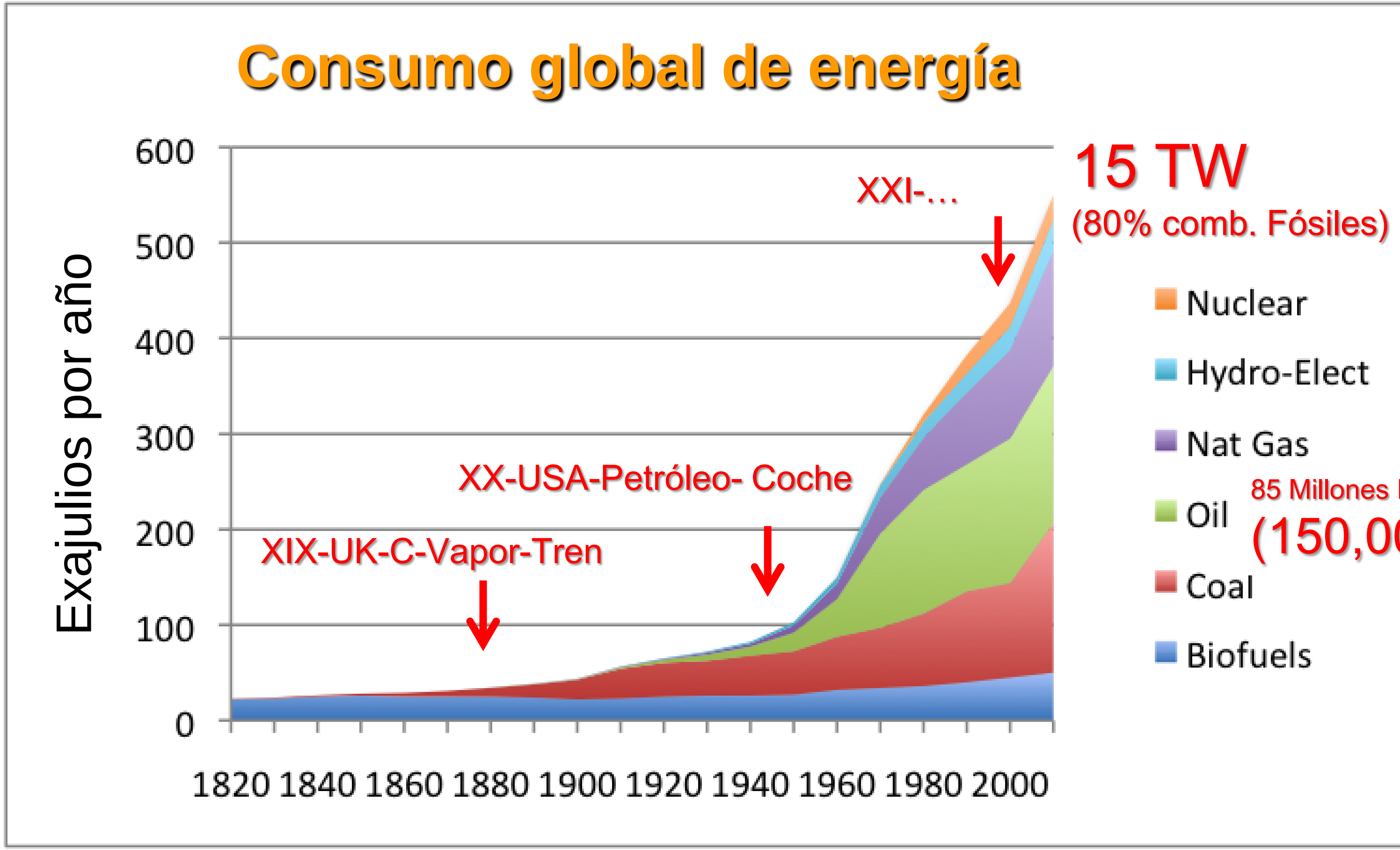
Energía somática

2,000 Kcal/persona·día

Extracción de recursos
Fabricación / manufactura
Construcción
Transporte
Comunicación
Defensa

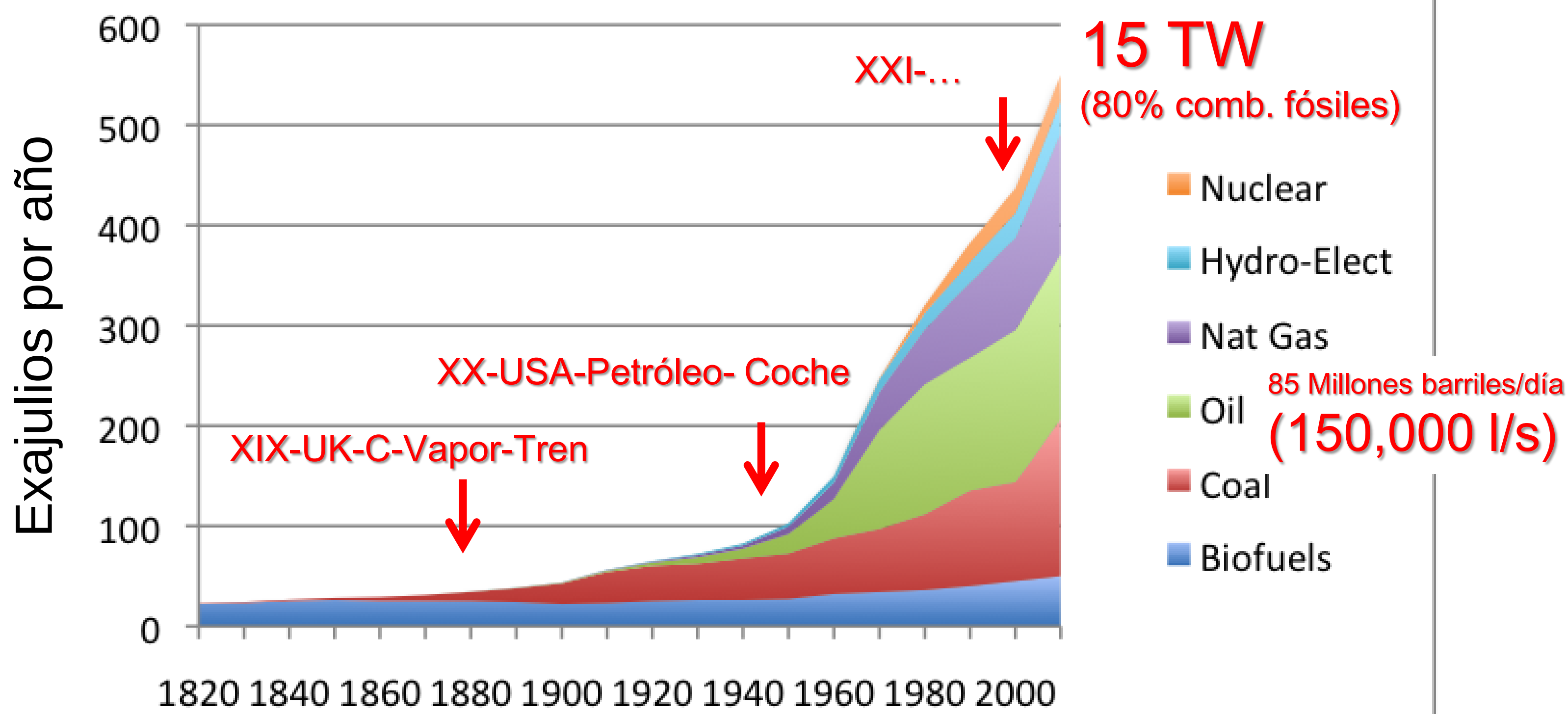
Energía exosomática

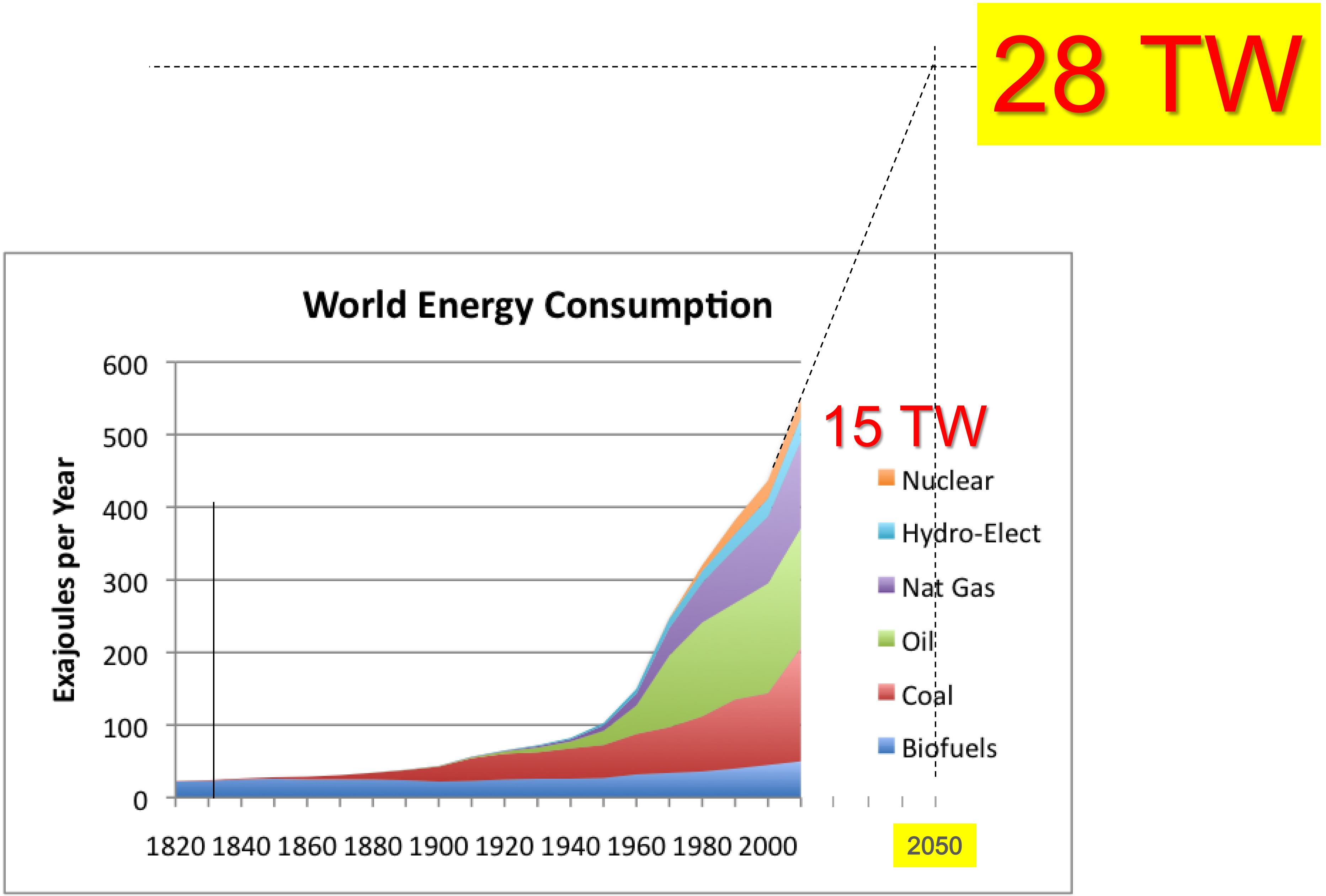
200,000 Kcal/persona·día



Based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects together with BP Statistical Data for 1965 and subsequent

Consumo global de energía





28 TW
World Energy Consumption
15 TW
Exajoules per Year
600
500
400
300
200
100
0
1820 1840 1860 1880 1900 1920 1940 1960 1980 2000
2050
Nuclear
Hydro-Elect
Nat Gas
Oil
Coal
Biofuels

De recolectores a agricultores.

Una perspectiva histórica

Adios a los combustibles "primarios"

elige un vector energético

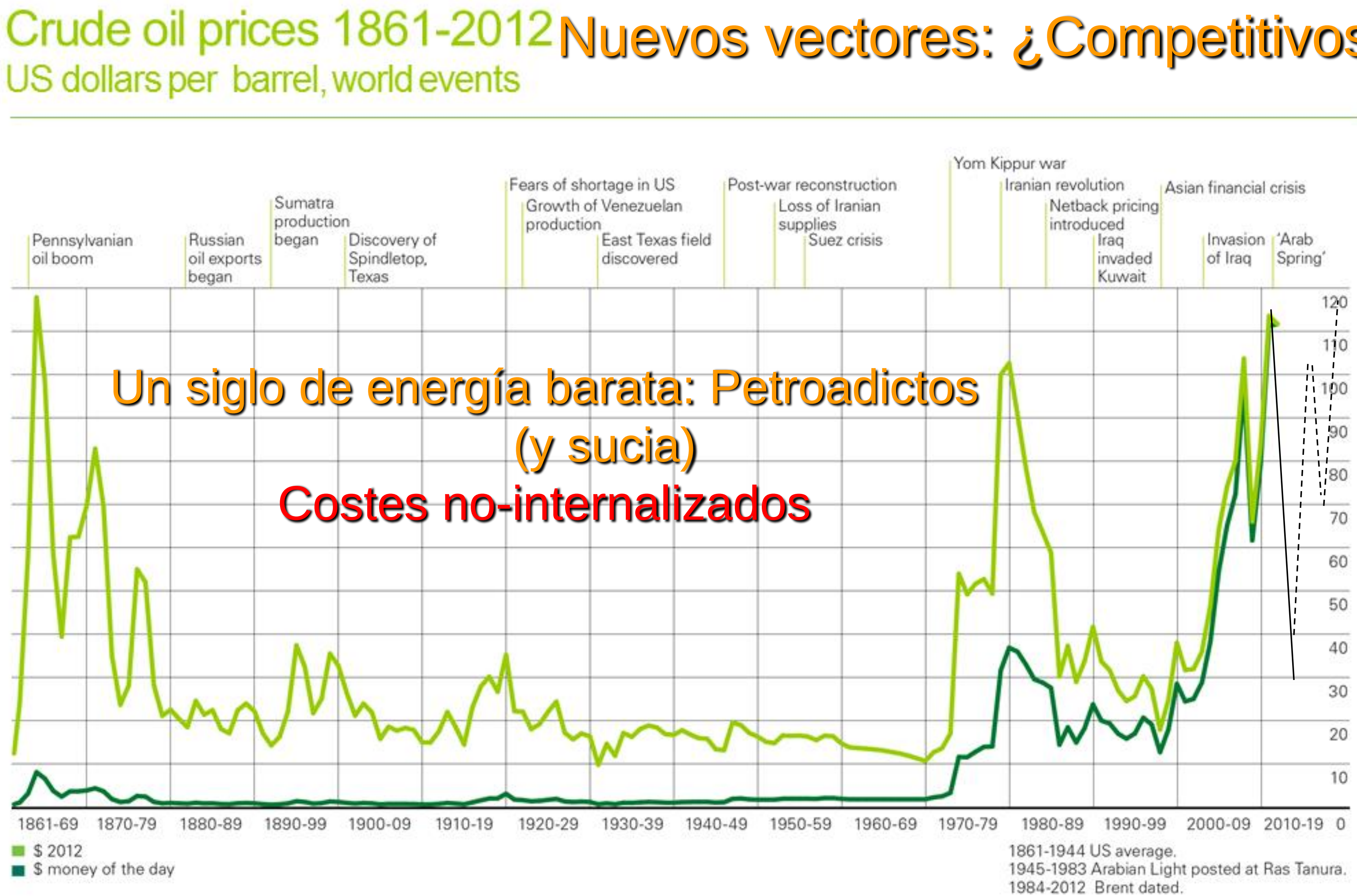
Vector

Bio: Biocombustibles
Biodiesel (20% bio 80% diesel), (oleaginosas)
Bioetanol (con Gasolina)(carbohidratos/azúcares)

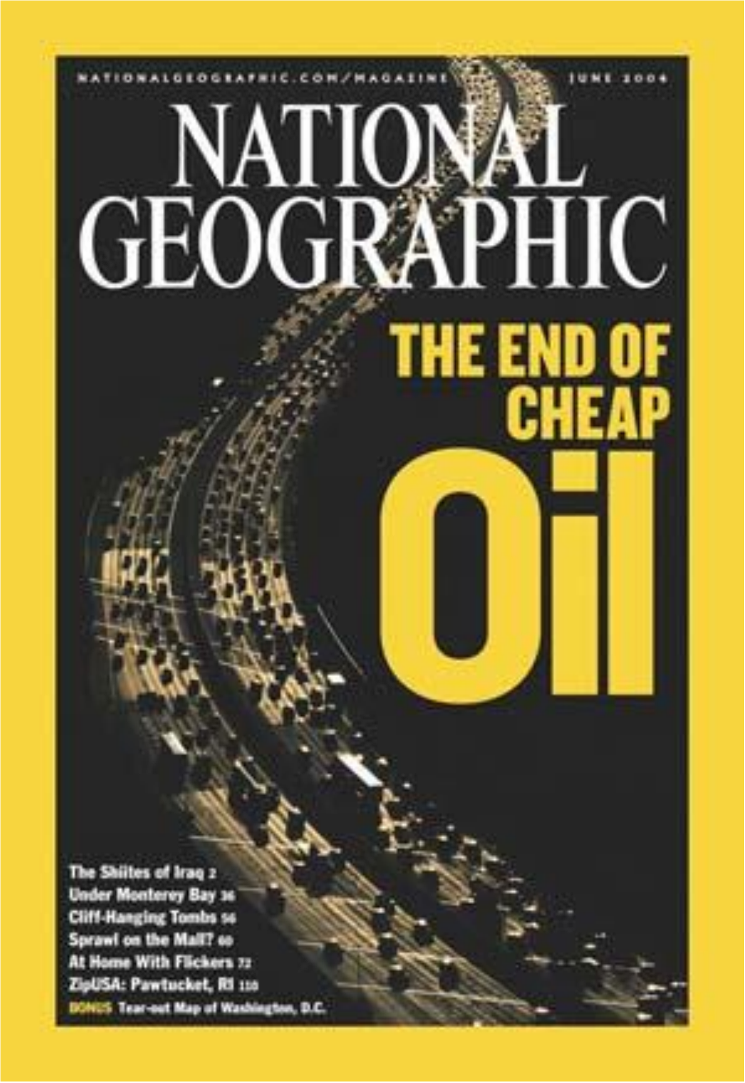
Elect: Baterías recargables para Vehículos Eléctricos

Quim: Pilas de Hidrógeno (Pilas de Combustible)
H_2... El combustible del futuro?

Nuevos vectores: ¿Competitivos?

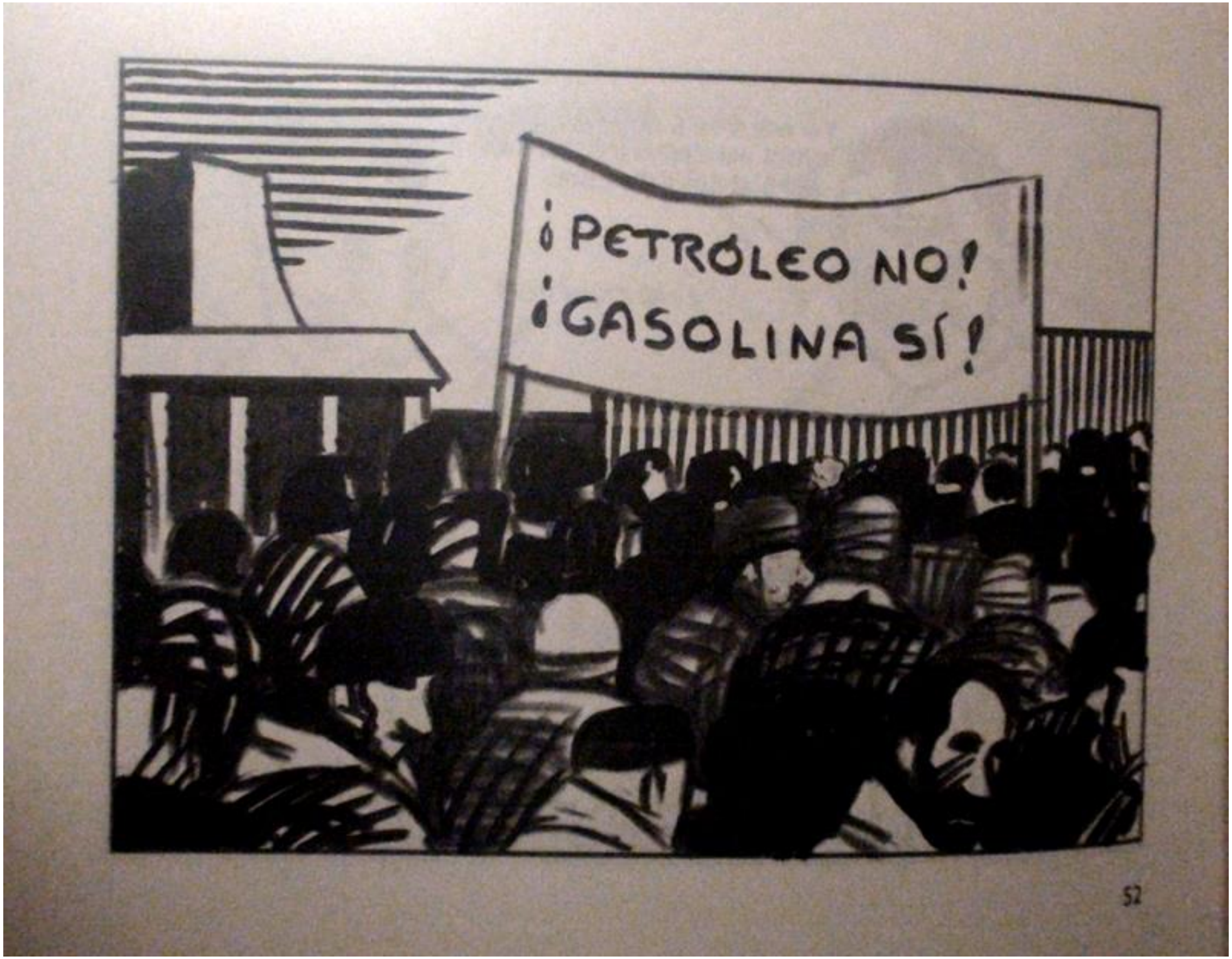


BP Statistical Review of World Energy 2013



Junio 2004, Volumen 205, Numero 6


Houston
New Orleans
BP / Deepwater Horizon Spill
Jacksonville
Tampa
Miami
Havana
SKYTRUTH
263 mi
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image NASA
© 2010 Google
© 2010 Europa Technologies
©2009 Google


¡PETRÓLEO NO!
¡GASOLINA SÍ!
52

¿La solución al negro panorama de la energía?

Combustibles más LIMPIOS vectores

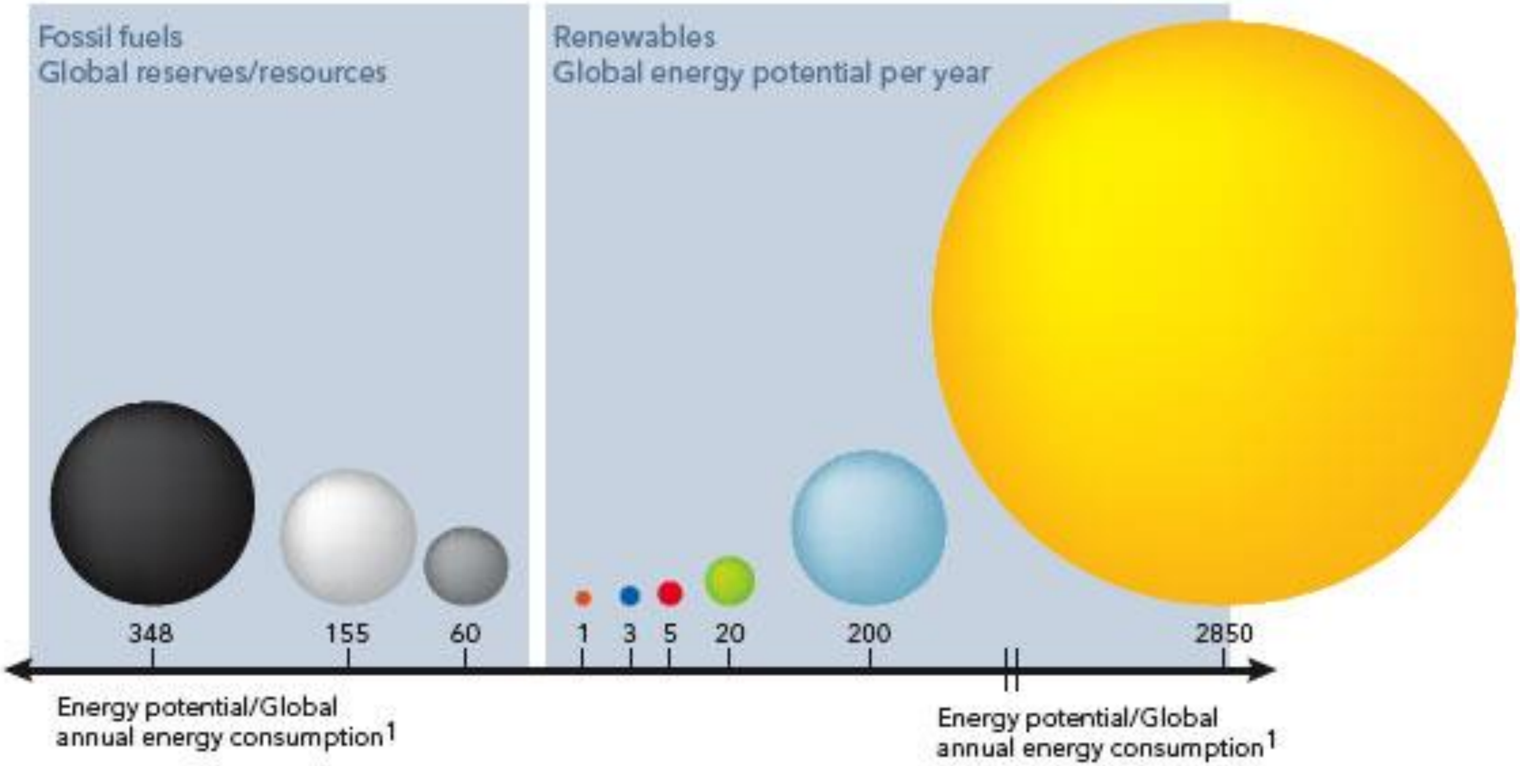
fuentes RENOVABLES de energía primaria

AHORRO Y EFICIENCIA ENERGÉTICOS

¿La solución al negro panorama de la energía?

fuentes
RENOVABLES
de energía primaria

Fuentes primarias: ¿Sol arcaico o moderno?



	Energy potential Reserves/Resources[2]	Thereof conventionally utilizable[2]
Coal	~ 135.000 EJ	
Natural gas	~ 60.400 EJ	~ 12.000 EJ
Crude oil	~ 23.000 EJ	~ 9.800 EJ

[1]Global energy demand 2006: ~ 470 EJ

	Energy potential (amount of energy p. a.)[2]	technologically utilizable (state of the art)[2]
Solar radiation	~ 1.111.500 EJ	~ 1.482 EJ
Wind energy	~ 78.000 EJ	~ 195 EJ
Biomass	~ 7.800 EJ	~ 156 EJ
Geothermal	~ 1.950 EJ	~ 390 EJ
Hydro/tide power	~ 1.170 EJ	~ 78 EJ

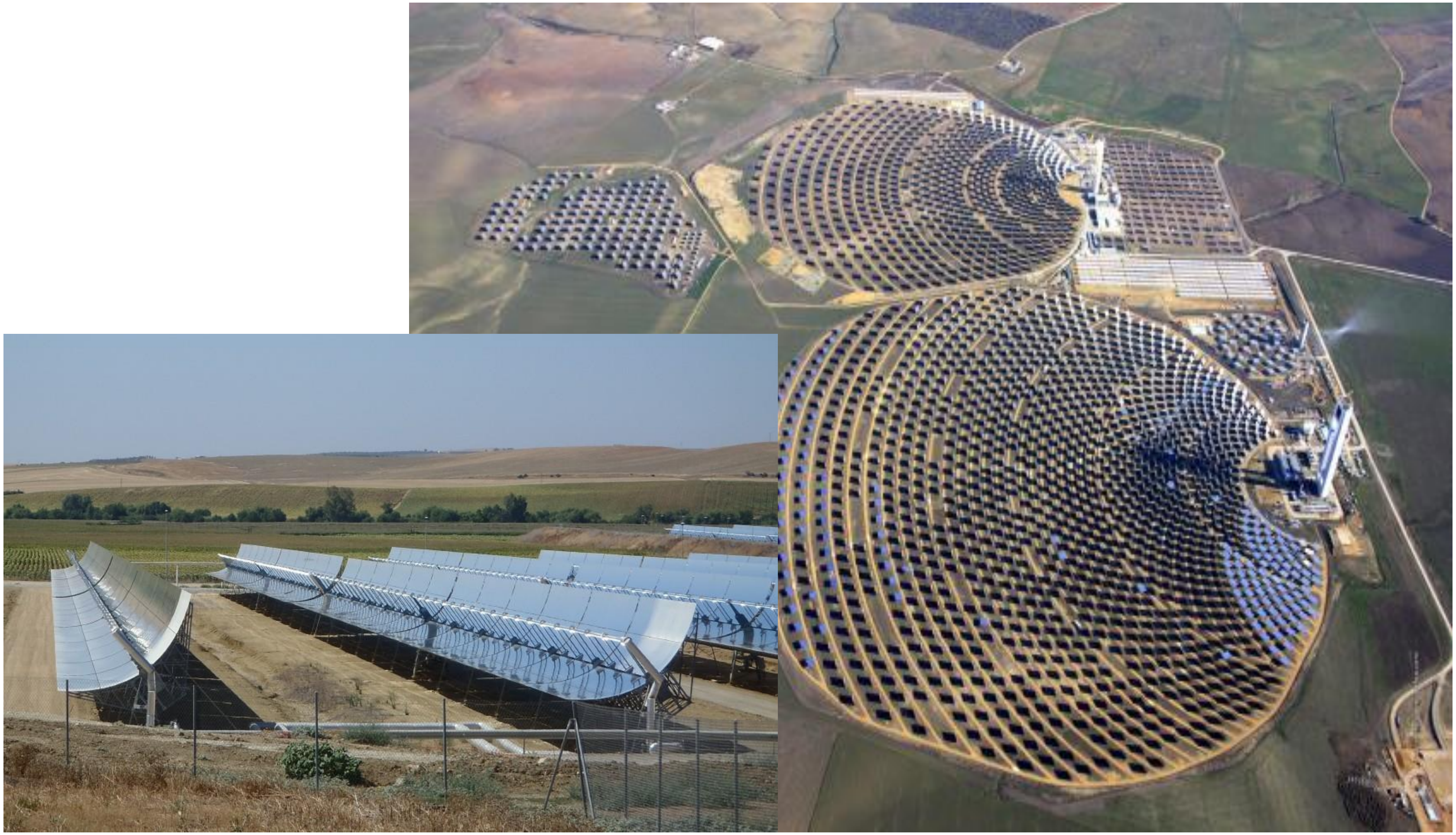
1 EJ = 1 exajoule or 10^{18} joules or ~163 million barrels of oil.
Data source: German Federal Institute for Geosciences and Natural Resources

El nuevo paisaje de la energía

Wind power at Sisante
La Mancha
Spain

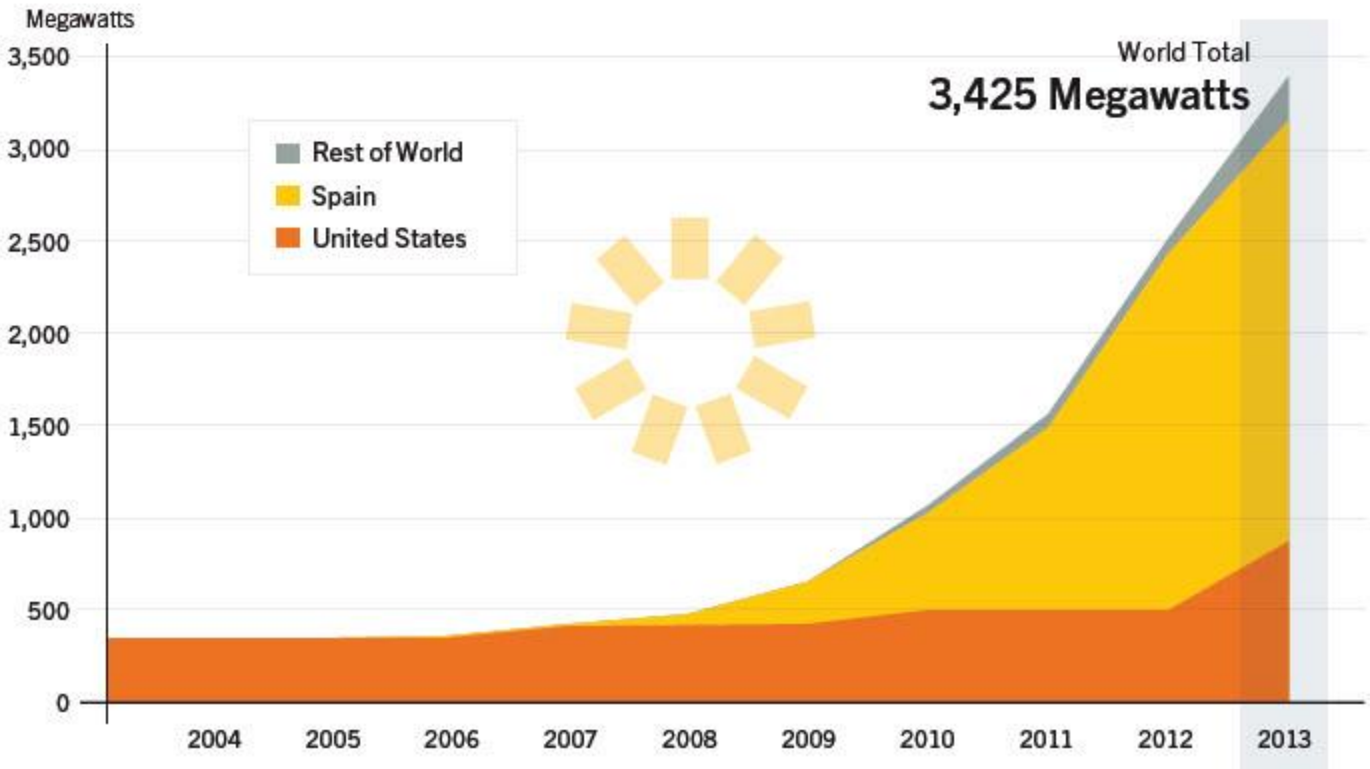
Solar PV crop in Castilla La Mancha (Solaer)

El nuevo paisaje de la energía



Pioneer thermosolar power plant. Sanlucar (Sevilla) Spain (Abengoa)

España, potencia mundial en energía solar térmica de concentración (CSP).

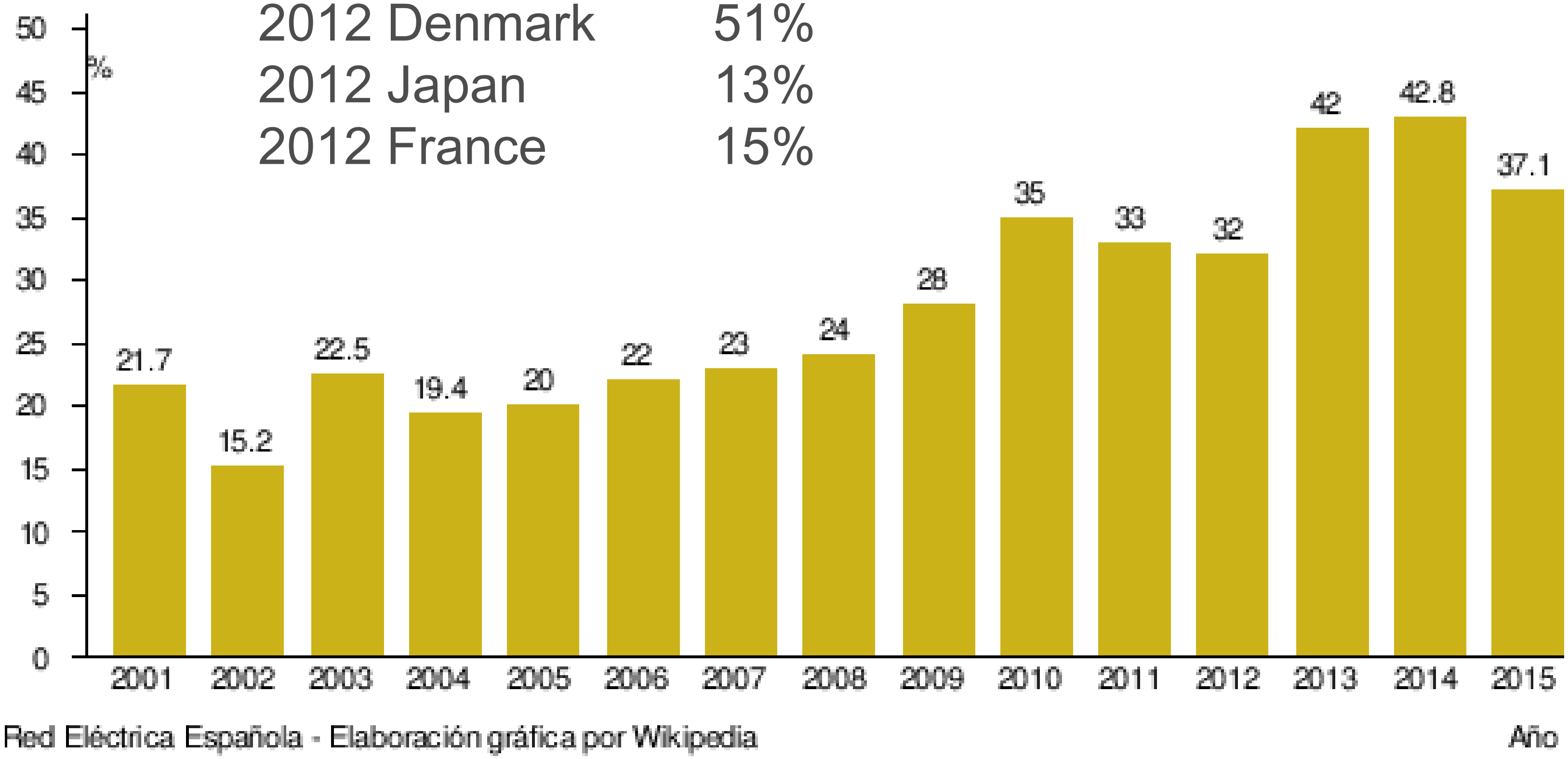


http://cleanleap.com/02-market-and-industry-trends/concentrating-solar-thermal-power-csp

El nuevo paisaje de la energía

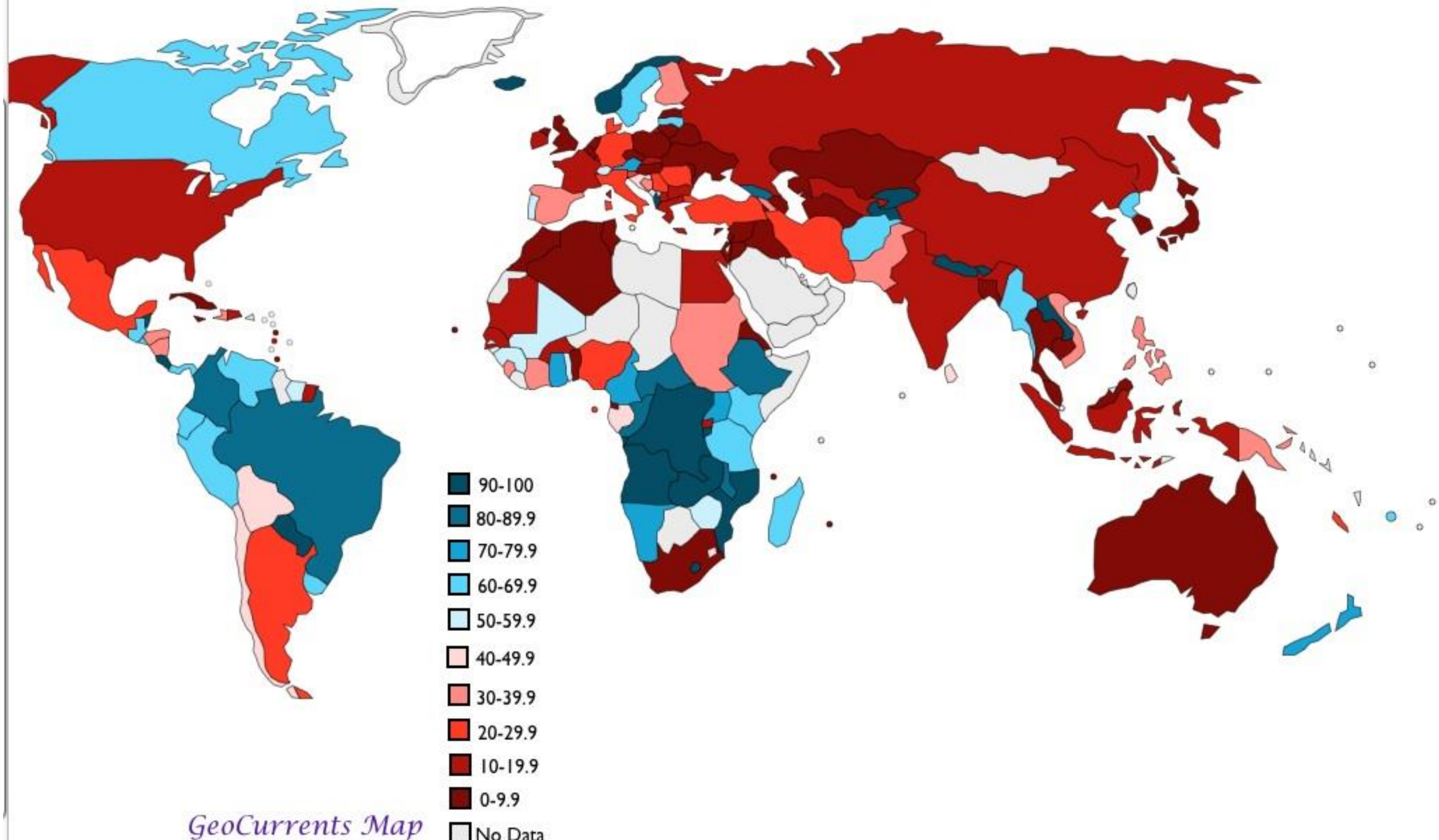
Renewable electricity in Spain (%)

2012 USA	13%
2012 Germany	24%
2012 Denmark	51%
2012 Japan	13%
2012 France	15%



Percentage of Electricity Generation from Renewable Sources

(Hydro, Geothermal, Solar, Biomass, Wind)



Data Source: http://en.wikipedia.org/wiki/List_of_countries_by_electricity_production_from_renewable_sources

¿La solución al negro panorama de la energía?

Combustibles más LIMPIOS vectores

De recolectores a agricultores

Adios a los combustibles "primarios"

elige un vector energético

Vector

Bio: Biocombustibles
Biodiesel (20% bio 80% diesel), (oleaginosas)
Bioetanol (con Gasolina)(carbohidratos/azúcares)

Elect: Baterías recargables para Vehículos Eléctricos

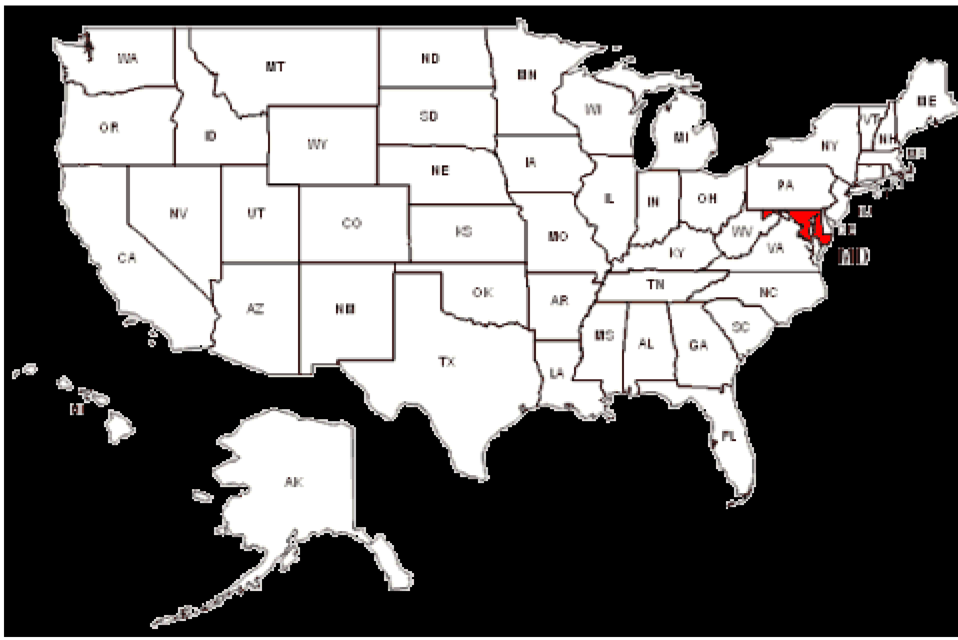
Quim: Pilas de Hidrógeno (Pilas de Combustible)
H_2... El combustible del futuro?

Biocombustibles

Biocombustibles


Biocombustibles 2G

DOE: aprox. 40000 Km^2
Suficientes para sustituir
Todo el petróleo consumido
en USA por algas



Biocombustibles 3G

De recolectores a agricultores

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H_2... El combustible del futuro?

H_2 ¿El combustible del futuro?

Honda FCX 2005
Hydrogen car

13 August 2004

Revoluciones pendientes:

- Generación H_2 renovable
- Almacenamiento eficaz
- Pilas de Combustible mejoradas

Tipos de aplicaciones

Generación local estacionaria

Off-grid and emergency power

PEM FC

Transporte

Honda FCX 2005

Coche de hidrógeno

Miniaturización

Pilas de combustible para

ordenadores portátiles

20h de autonomía.

De recolectores a agricultores

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elige un vector energético

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Quim: Pilas de Hidrógeno (Pilas de Combustible)
H_2... El combustible del futuro?

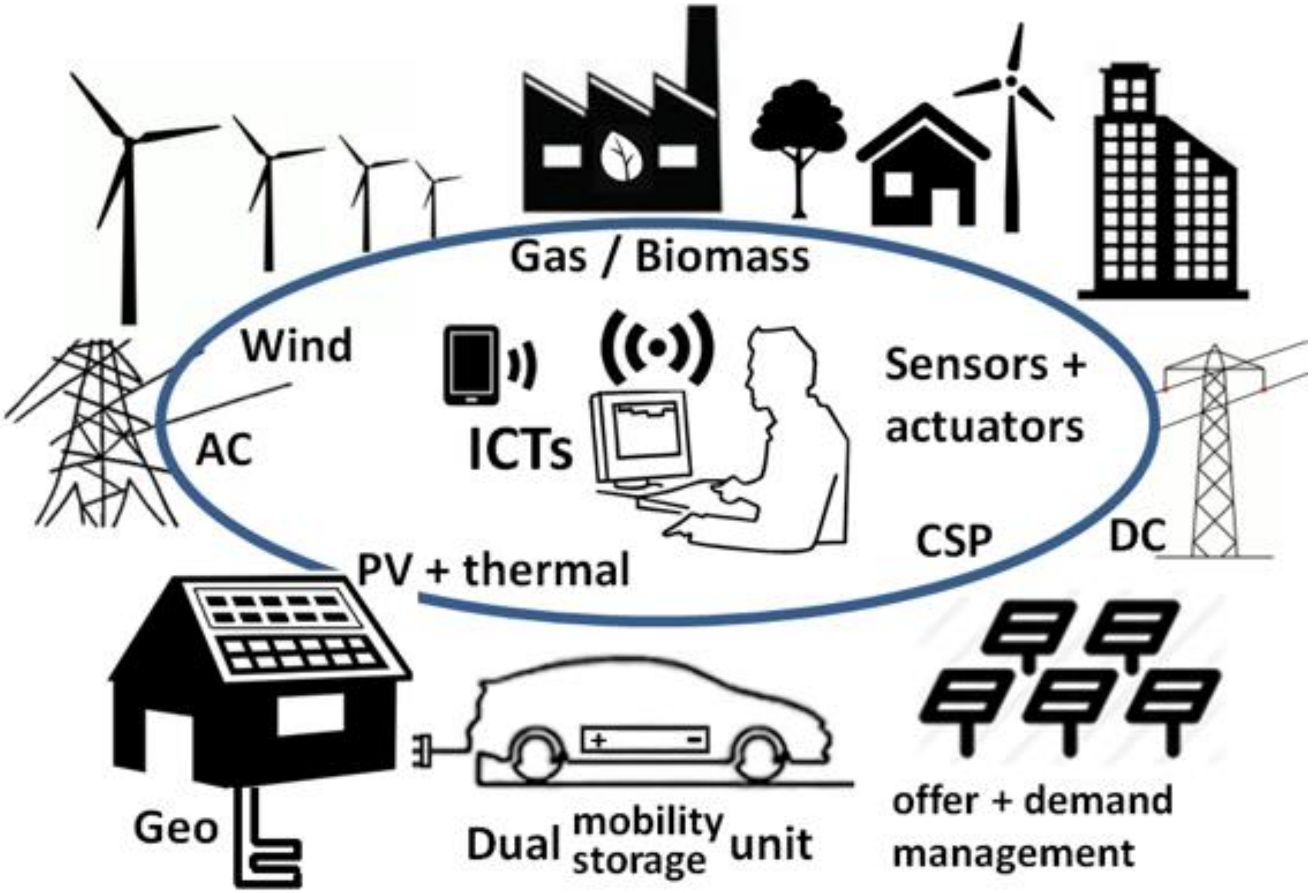
Energía Centralizada… o Distribuída

Largest Stationary Battery System.
Power Back-up, Fairbanks (AK, USA)

46 MW
1370 NiCd cells
2000 m2
1300 T
7 min elec. Fairbanks

Energía Centralizada… o Distribuída

Smart Grids



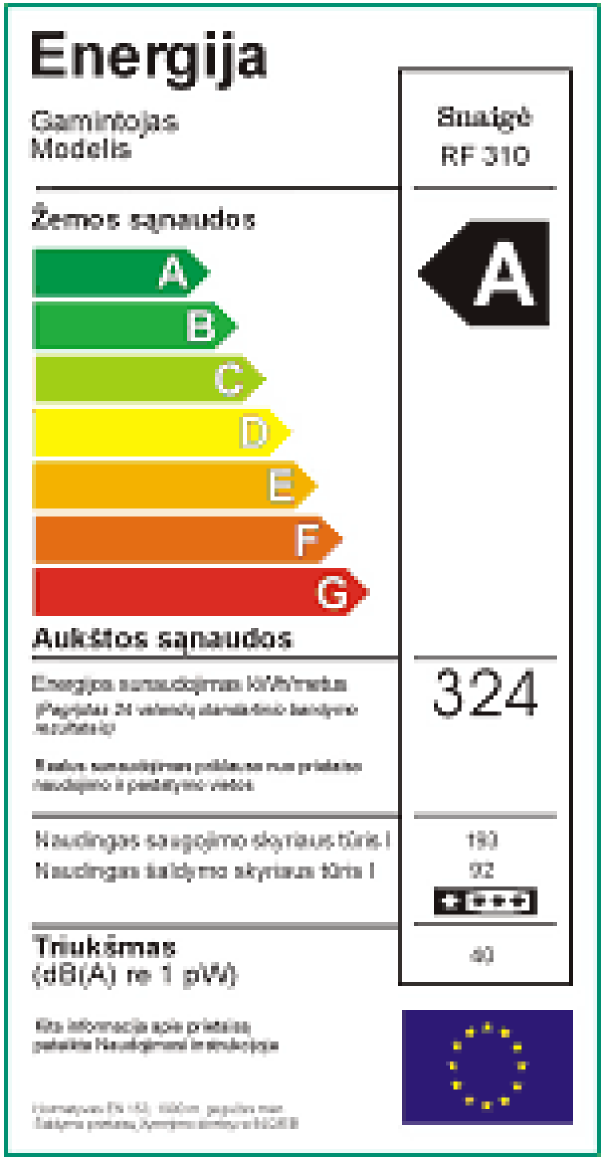
¿puede haber algo más sostenible?

Claude Guillot, (1673-1722) **The Two Coaches** (ca. 1710)   Musée Louvre, Paris

¿La solución al negro panorama de la energía?

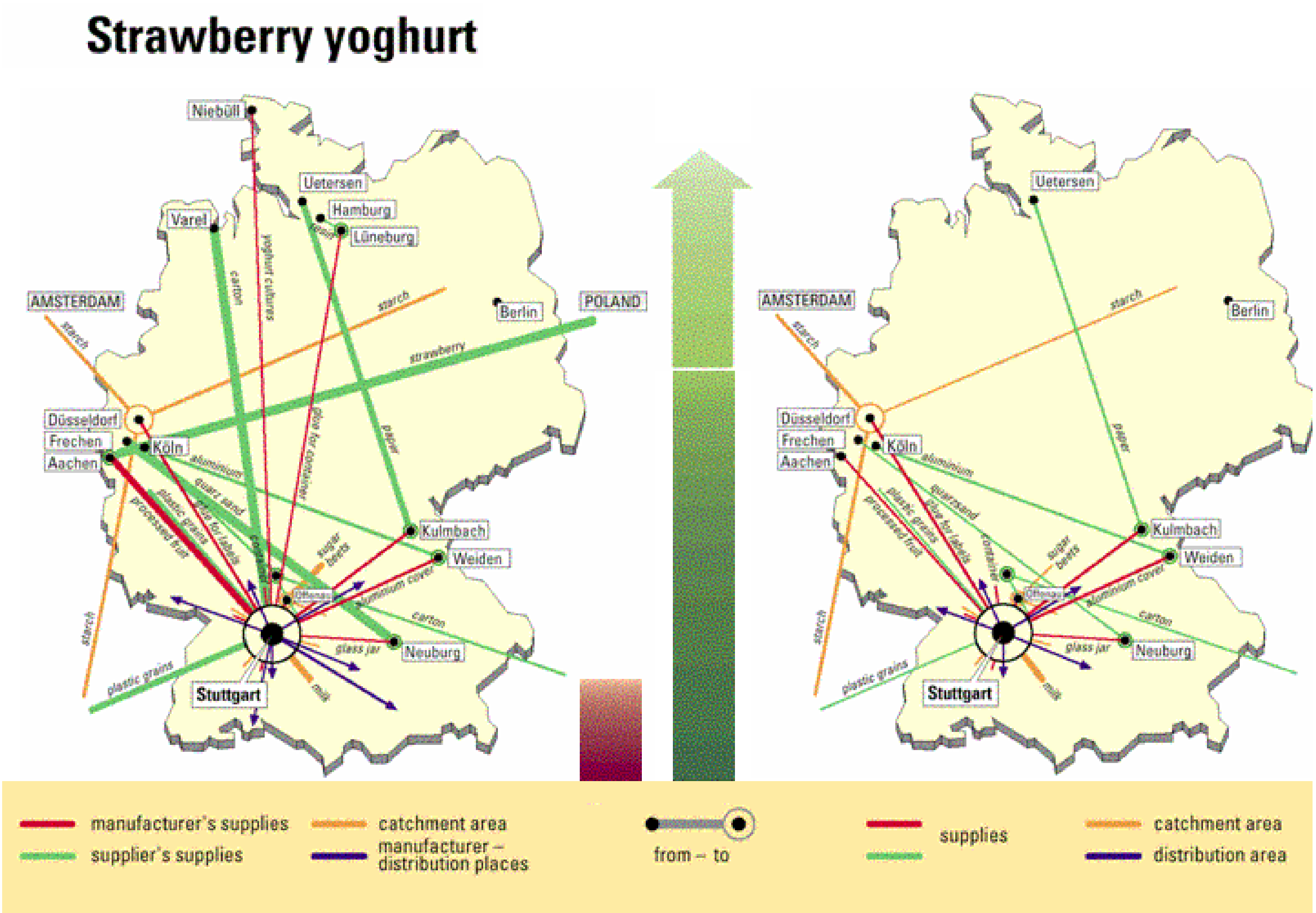
AHORRO
Y
EFICIENCIA ENERGÉTICOS

Eficiencia y ahorro energéticos



Frigo tipo A vs. tipo D
Se amortiza en ≈3 años

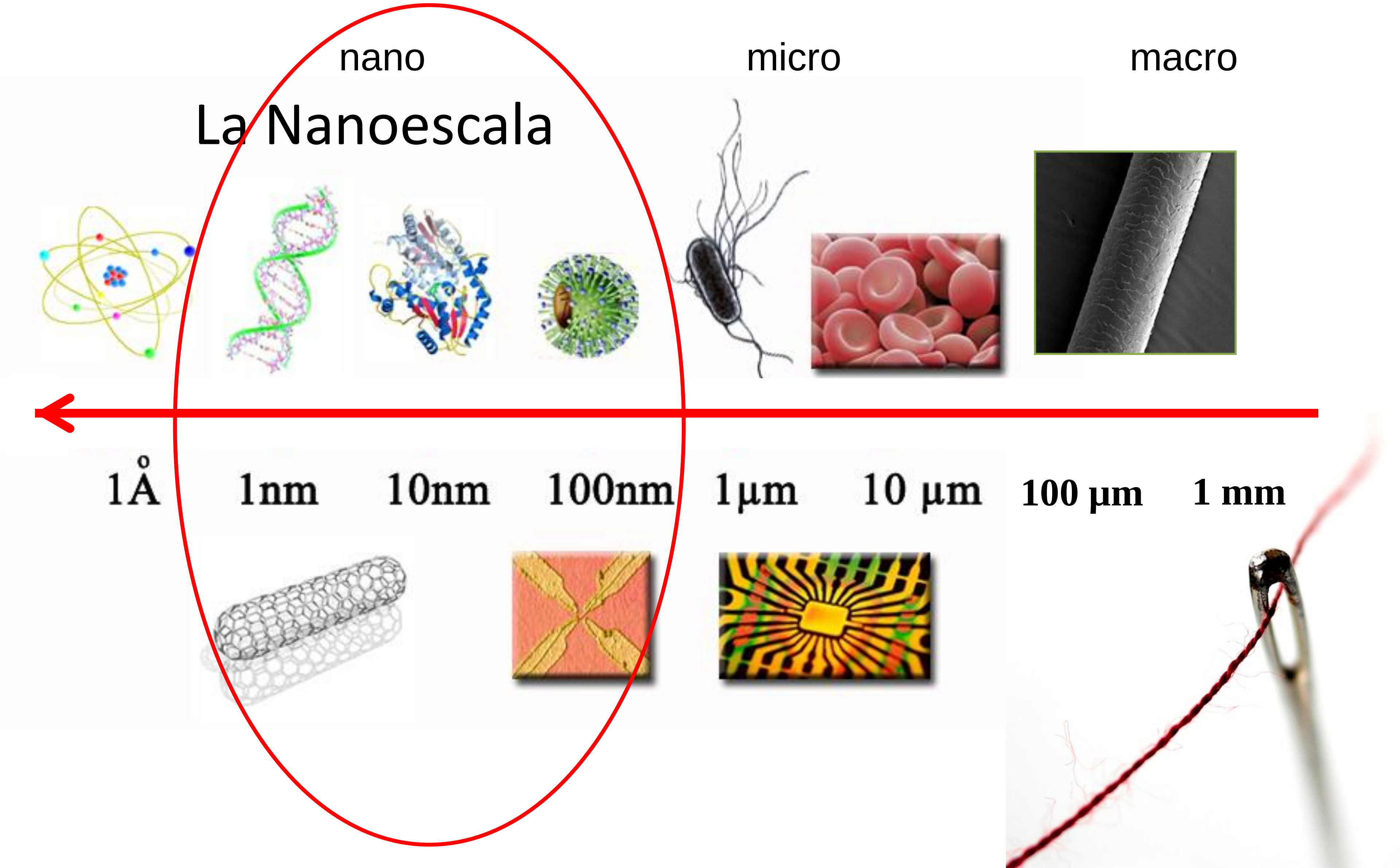
Eficiencia energética / Cadena de suministro



Fuente: E.U. von Weizsäcker. "China: Building a Resource-Efficient Society" Beijing, 25 June, 2005

la nanotecnología como motor de cambio del modelo energético

2. NANOCIENCIA Y NANOTECNOLOGÍA



2. NANOCIENCIA Y NANOTECNOLOGÍA

Temas de investigación transversales en Nanociencia

- Catálisis por parte de materiales en la nanoescala
- Uso de interfases para manipular energy carriers
- Relaciones entre estructura y función en la nanoescala
- Ensamblado y arquitectura de estructuras en la nanoescala
- Teoría, modelado y simulación de la nanociencia de la energía
- Métodos de síntesis escalables

Nanoscience Research for Energy Needs. Report of the March 2004 National Nanotechnology Initiative Grand Challenge Workshop. Second Edition, June 2005

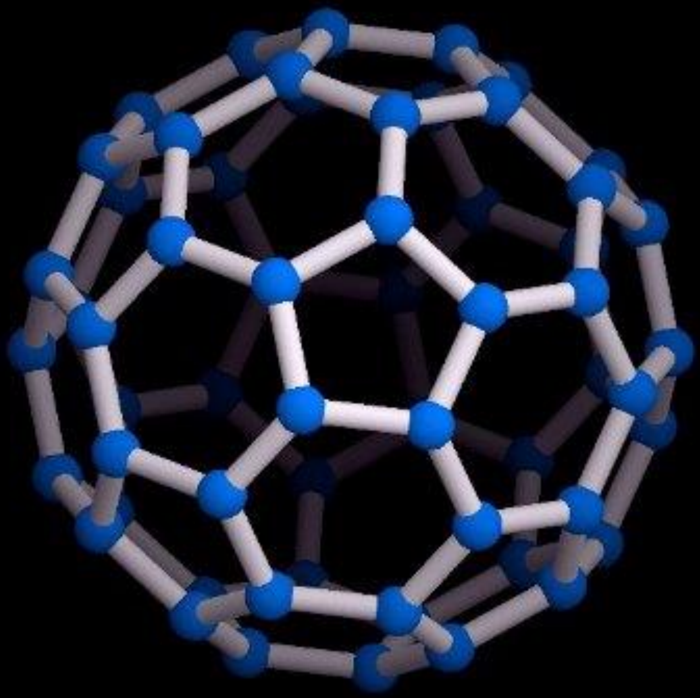
El principio de la nanotecnología moderna

o

Cómo ganar el premio Nobel con un balón de fútbol

Kroto, Curl and Smalley
Fullereno, 1985. Premio Nobel de Química 1996

Por su descubrimiento de los fullerenos



nanobalón

1nm = 0.000000001 m

Nano mundo

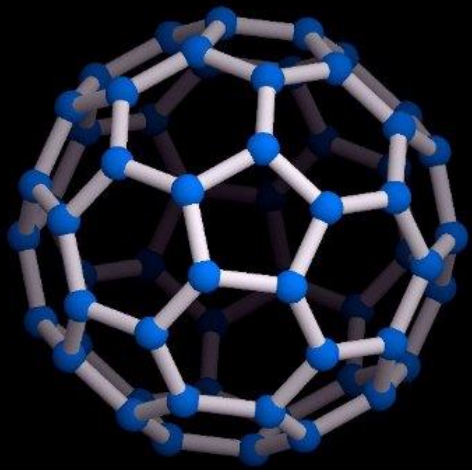
1nm = 0.000000001 m

mundo humano

1 m

Giga mundo

1Gm = 1,000,000,000 m



4 x

nanobalón

1nm = 0.000000001 m

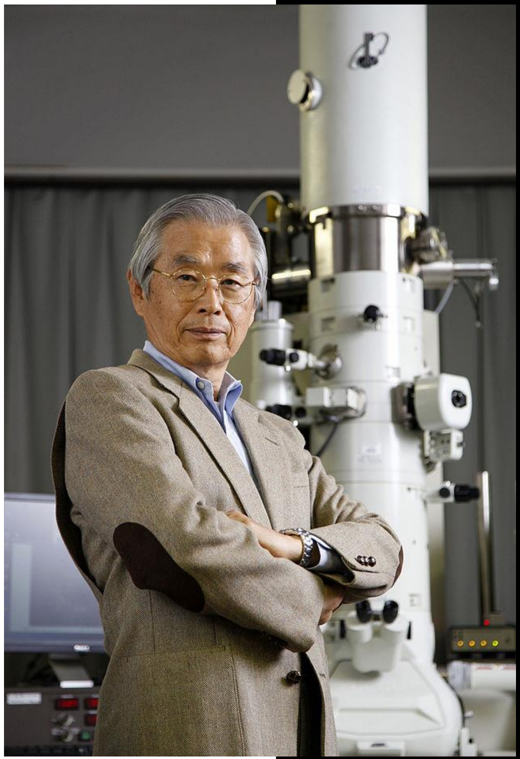
balón

0.22 m

4 x Tierra

4 x 12,700,000 m

diámetros



Sumio Iijima
1991

Carbon Nanotubes

University of Manchester
2010 Nobel Prize in Physics

"for groundbreaking experiments regarding the two-dimensional material graphene".

We have been able to prepare graphitic sheets of thicknesses down to a few atomic layers (including single-layer graphene), to fabricate devices from them, and to study their electronic properties. Despite being atomically thin, the films remain of high quality, so that 2D electronic transport is ballistic at submicrometer distances. No other film of similar thickness is known to be even poorly metallic or continuous under ambient conditions. Using FLG, we demonstrate a metallic field-effect transistor in which the conducting channel can be switched between 2D electron and hole gases by changing the gate voltage.

Our graphene films were prepared by mechanical exfoliation (repeated peeling) of small mesas of highly oriented pyrolytic graphite (*15*). This approach was found to be highly reliable and allowed us to prepare FLG films up to 10 μm in size. Thicker films ($d \geq 3$ nm) were up to 100 μm across and visible by the naked eye. Figure 1 shows examples of the prepared films, including single-layer graphene [see also (*15*)]. To study their electronic properties, we processed the films into multiterminal Hall bar devices placed on top of an oxidized Si substrate so that a gate voltage V_g could be applied. We have studied more than 60 devices with $d < 10$ nm. We focus on the electronic properties of our thinnest (FLG) devices, which contained just one, two, or three atomic layers (*15*). All FLG devices exhibited essentially identical electronic properties characteristic for a 2D semimetal, which differed from a more complex (2D plus 3D) behavior observed for thicker, multilayer graphene (*15*) as well as from the properties of 3D graphite.

In FLG, the typical dependence of its sheet resistivity ρ on gate voltage V_g (Fig. 2) exhibits a sharp peak to a value of several kilohms and decays to ~100 ohms at high V_g (note that 2D resistivity is given in units of ohms rather than ohms × cm as in the 3D case). Its conductivity $\sigma = 1/\rho$ increases linearly with V_g on both sides of the resistivity peak (Fig. 2B). At the same V_g where ρ has its peak, the Hall coefficient R_H exhibits a sharp reversal of its sign (Fig. 2C). The observed behavior resembles the ambipolar field effect in semiconductors, but there is no zero-conductance region associated with the Fermi level being pinned inside the band gap.

Our measurements can be explained quantitatively by a model of a 2D metal with a small overlap $\delta\varepsilon$ between conductance and valence bands (*15*). The gate voltage induces a surface charge density $n = \varepsilon_0 \varepsilon V_g / te$ and, accordingly, shifts the position of the Fermi energy ε_F. Here, ε_0 and ε are the permittivities of free space and SiO_2, respectively; e is the electron charge; and t is the thickness of our SiO_2 layer (300 nm). For typical $V_g = 100$ V, the formula yields $n \approx 7.2 \times 10^{12}$ cm^{-2}. The electric field doping transforms the shallow-overlap semimetal into either completely electron or completely hole conductor through a mixed state where both electrons and holes are present (Fig. 2). The three regions of electric field doping are clearly seen on both experimental and theoretical curves. For the regions with only electrons or holes left, R_H decreases with increasing carrier concentration in the usual way, as $1/ne$. The resistivity also follows the standard dependence $\rho^{-1} = \sigma = ne\mu$ (where μ is carrier mobility). In the mixed state, σ changes little with V_g, indicating the substitution of one type of carrier with another, while the Hall coefficient reverses its sign, reflecting the fact that R_H is proportional to

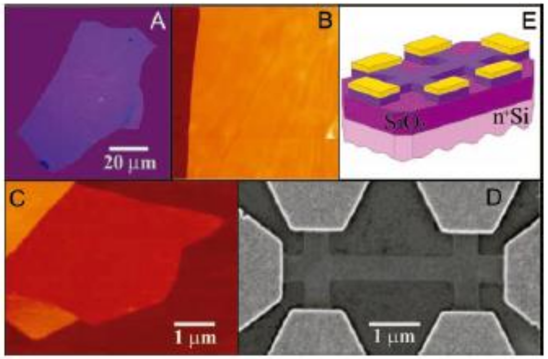


Fig. 1. Graphene films. (**A**) Photograph (in normal white light) of a relatively large multilayer graphene flake with thickness ~3 nm on top of an oxidized Si wafer. (**B**) Atomic force microscope (AFM) image of 2 μm by 2 μm area of this flake near its edge. Colors: dark brown, SiO_2 surface; orange, 3 nm height above the SiO_2 surface. (**C**) AFM image of single-layer graphene. Colors: dark brown, SiO_2 surface; brown-red (central area), 0.8 nm height; yellow-brown (bottom left), 1.2 nm; orange (top left), 2.5 nm. Notice the folded part of the film near the bottom, which exhibits a differential height of ~0.4 nm. For details of AFM imaging of single-layer graphene, see (15). (**D**) Scanning electron microscope image of one of our experimental devices prepared from FLG. (**E**) Schematic view of the device in (D).

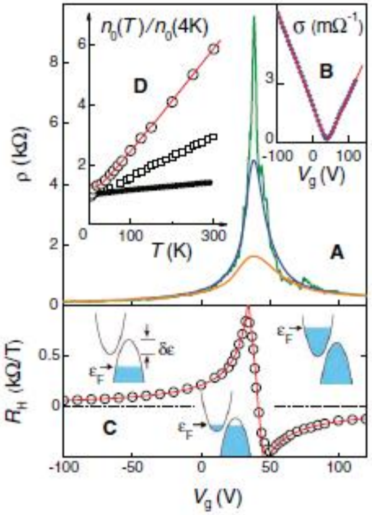
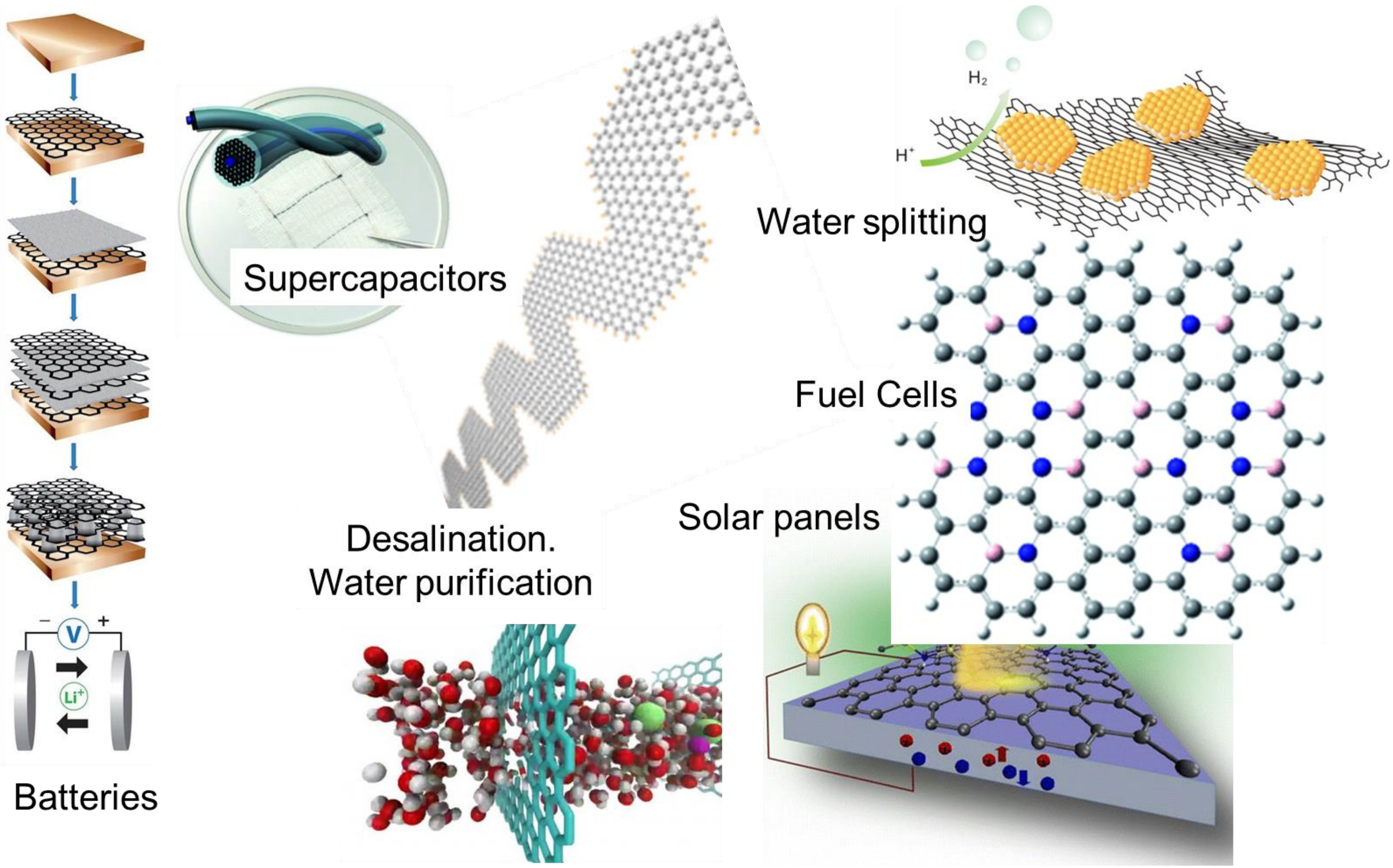


Fig. 2. Field effect in FLG. (**A**) Typical dependences of FLG's resistivity ρ on gate voltage for different temperatures (T = 5, 70, and 300 K for top to bottom curves, respectively). (**B**) Example of changes in the film's conductivity $\sigma = 1/\rho(V_g)$ obtained by inverting the 70 K curve (dots). (**C**) Hall coefficient R_H versus V_g for the same film; T = 5 K. (**D**) Temperature dependence of carrier concentration n_0 in the mixed state for the film in (A) (open circles), a thicker FLG film (squares), and multilayer graphene ($d \approx 5$ nm; solid circles). Red curves in (B) to (D) are the dependences calculated from our model of a 2D semimetal illustrated by insets in (C).

Grafeno para un futuro sostenible



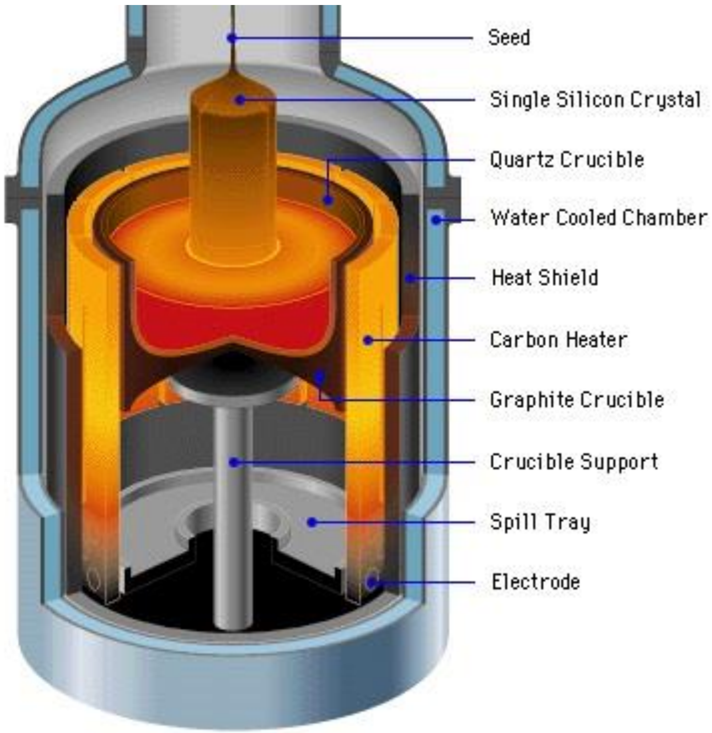
3. NANOMATERIALES PARA CONVERSIÓN DE ENERGÍA

Lo que en términos de ingeniería se conoce como generación:

- Conversión fotovoltaica
- Energía Solar Térmica
- Hidrógeno y pilas de combustible

Se busca: Silicio Solar barato

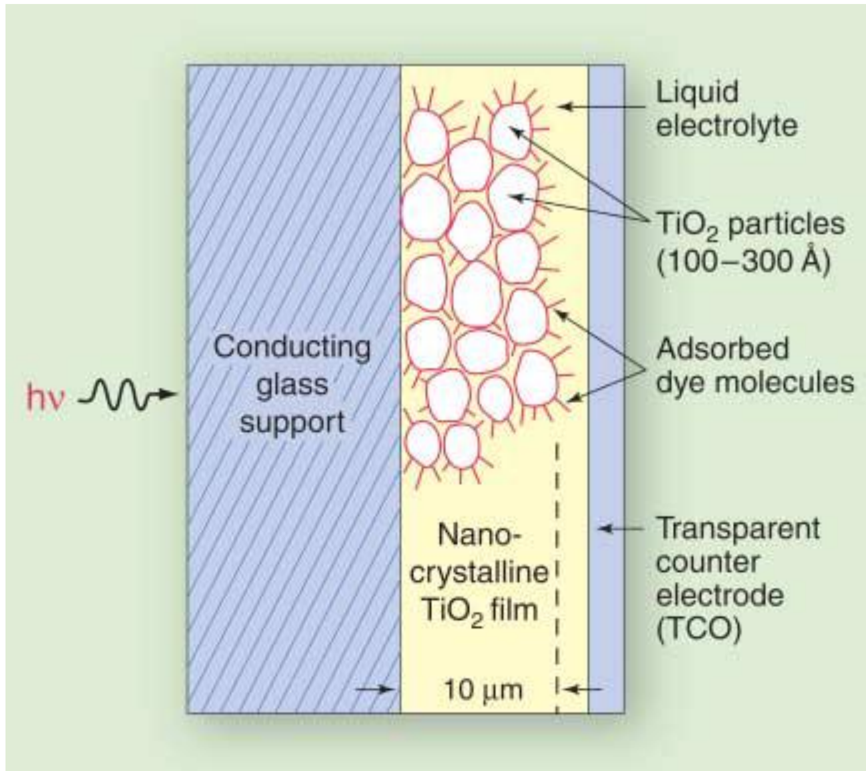
Silicio 99.999%



15% eficiencia

Nano y Celdas Solares

Dye-Sensitized Solar Cells (Grätzel)



Nathan S. Lewis, et al. Toward Cost-Effective Solar Energy Use. Science 315, 798 (2007)

Nano y Celdas Solares

Nanoestructura para “ortogonalizar” la absorción y la separación de carga

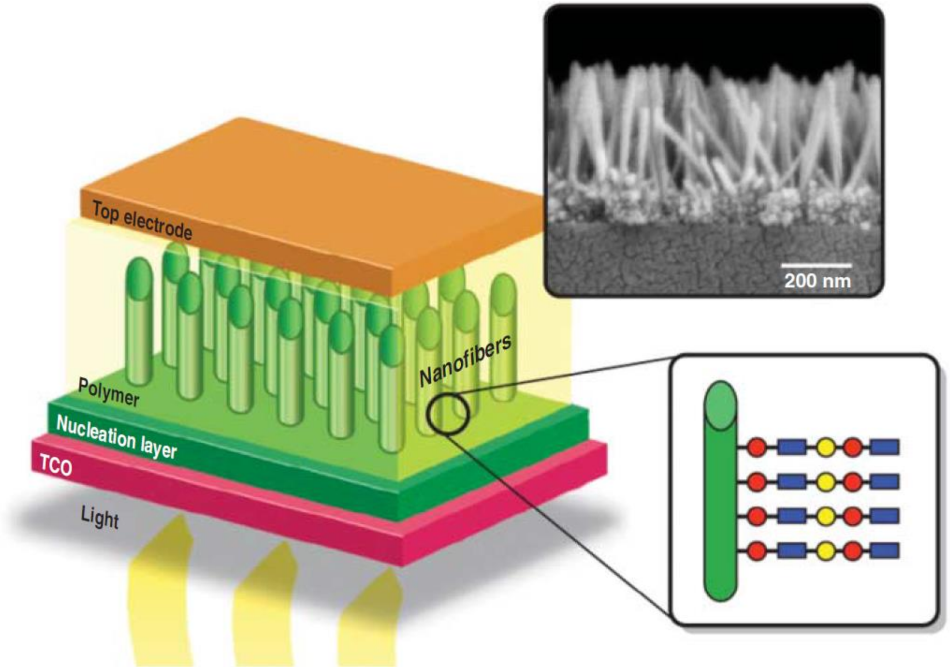
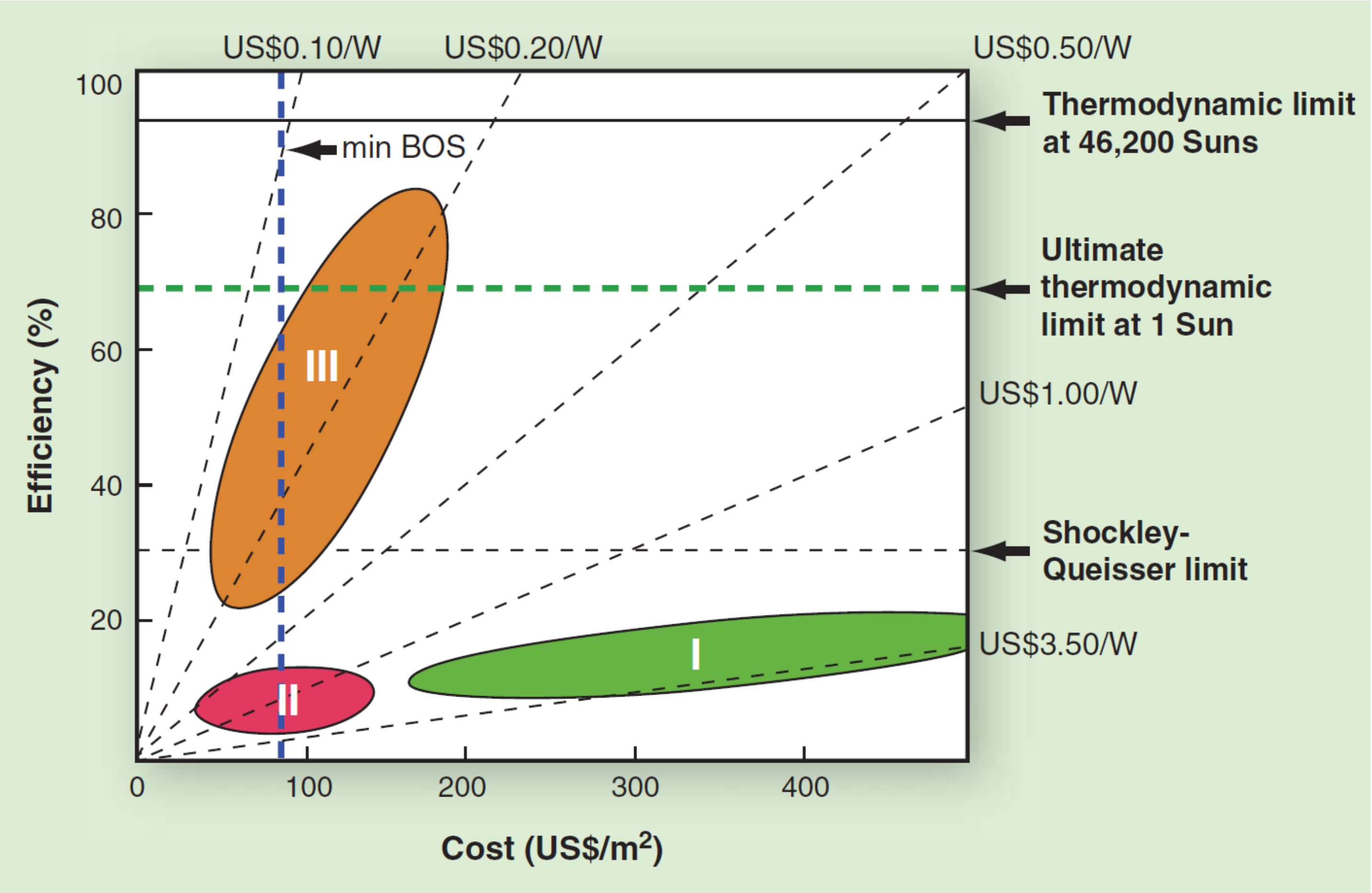


Fig. 3. Arrays of nanorods, illustrating an approach to orthogonalization of the directions of light absorption (down the length of the rods) and charge carrier collection (radially outward to the surface of the rods). [Adapted from (*2*)]

Nathan S. Lewis, et al. Toward Cost-Effective Solar Energy Use. Science 315, 798 (2007)

Nano y Celdas Solares

Costes y eficiencias



Nathan S. Lewis, et al. Toward Cost-Effective Solar Energy Use. Science 315, 798 (2007)

Nano y Celdas Solares

La importancia de ser nano

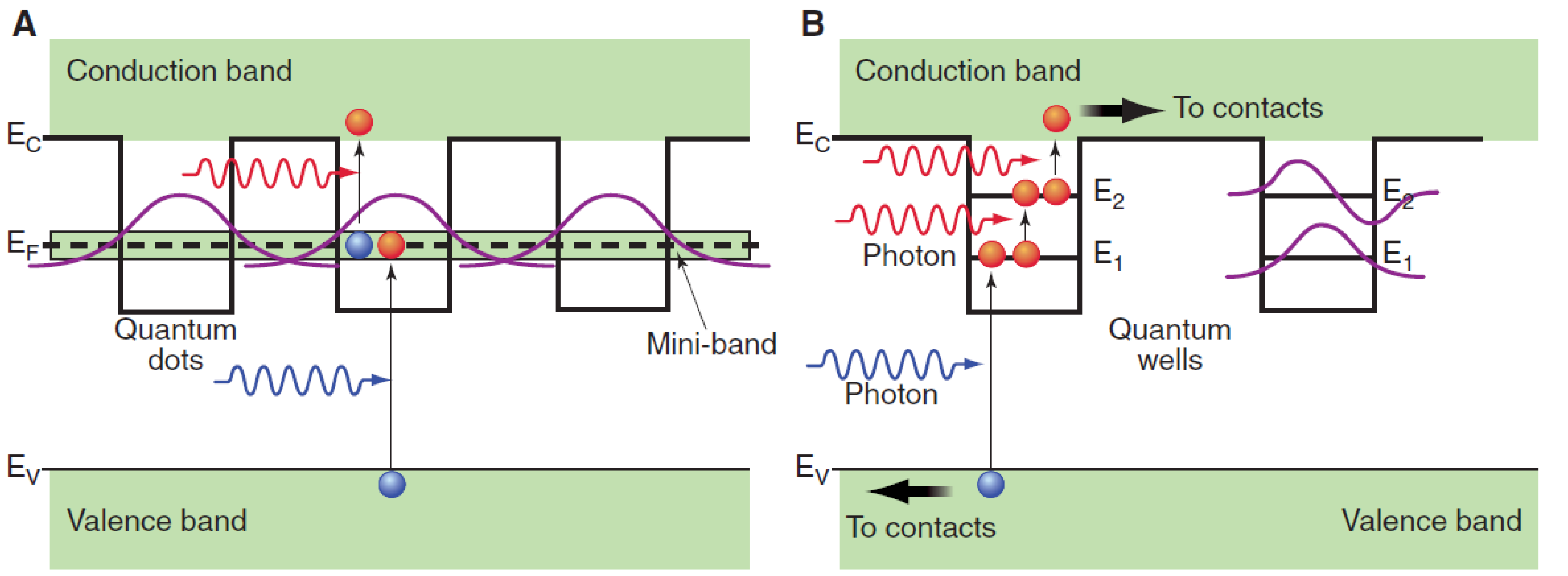


Fig. 2. Possible methods of circumventing the 31% efficiency limit for thermalized carriers in a single–band gap absorption threshold solar quantum conversion system. (**A**) Intermediate-band solar cell; (**B**) quantum-well solar cell. [Adapted from (*2*)]

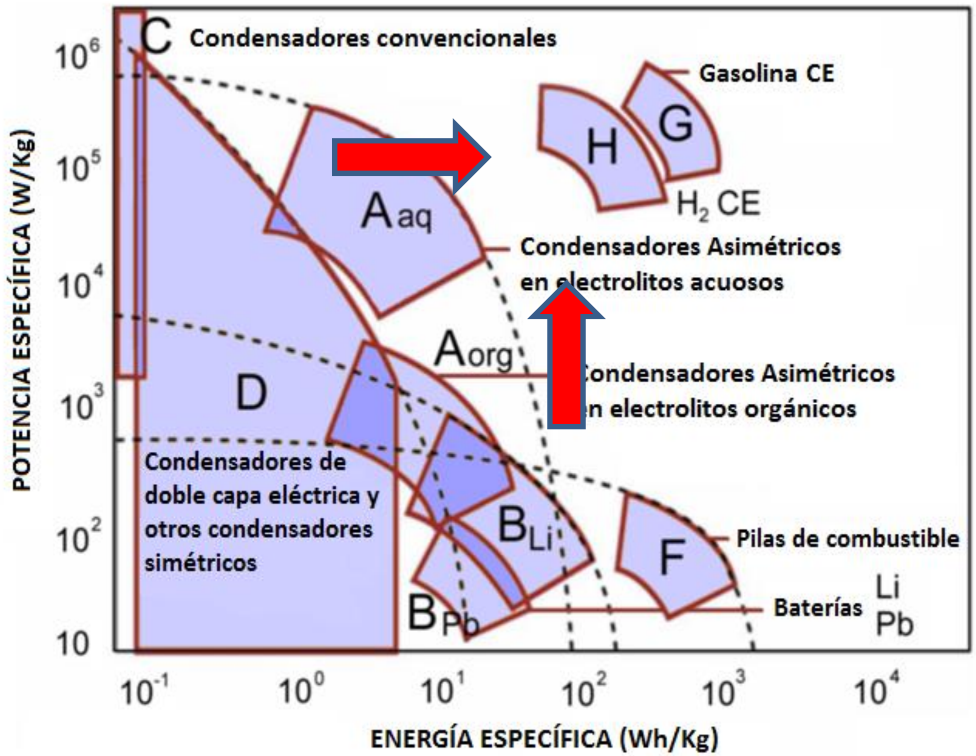
Nathan S. Lewis, et al. Toward Cost-Effective Solar Energy Use. Science 315, 798 (2007)

3. NANOMATERIALES PARA ALMACENAMIENTO DE ENERGÍA

Un campo tradicionalmente desatendido (excepto aplicaciones nicho) y actualmente en despegue:

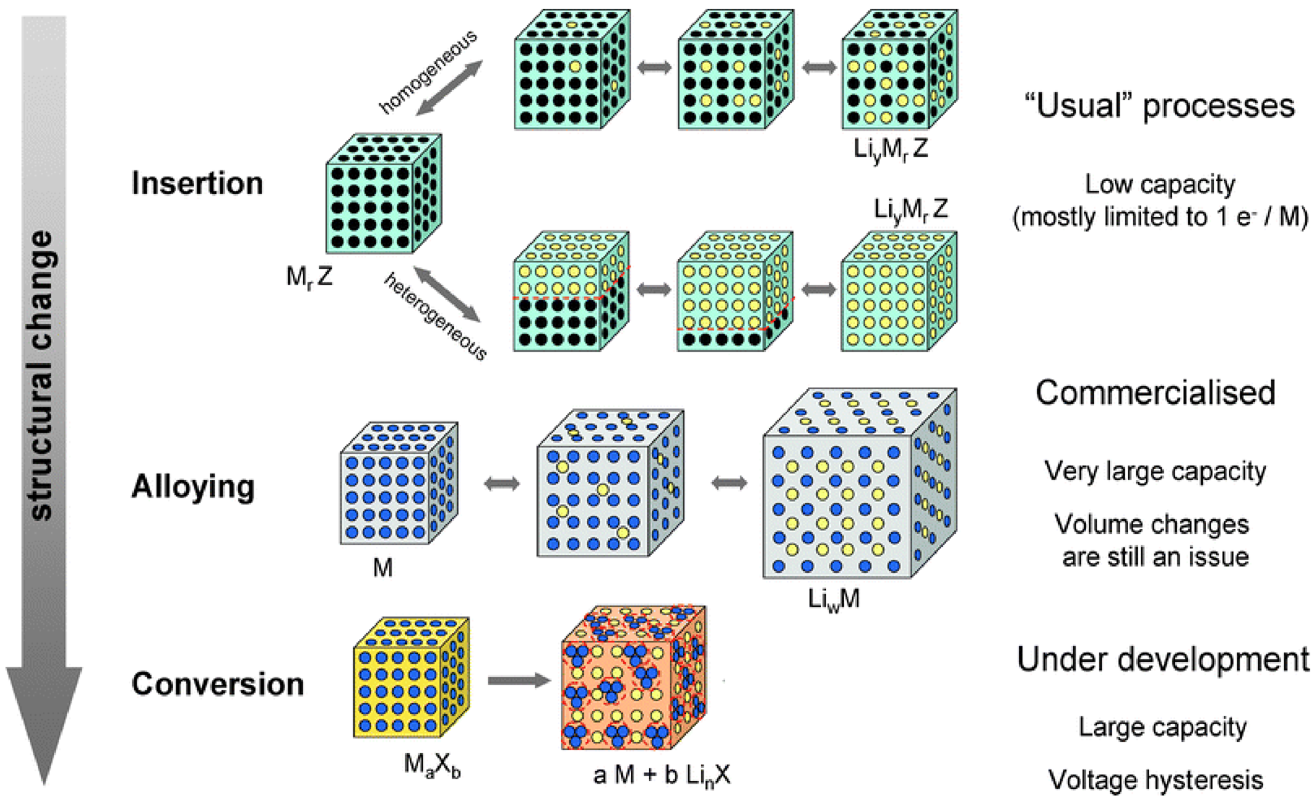
- Baterías… de litio, de ¿sodio?
- Supercondensadores
- Dispositivos Híbridos (Supercapbatteries)

Diagrama de Ragone.
El tablero de ajedrez del almacenamiento de energía



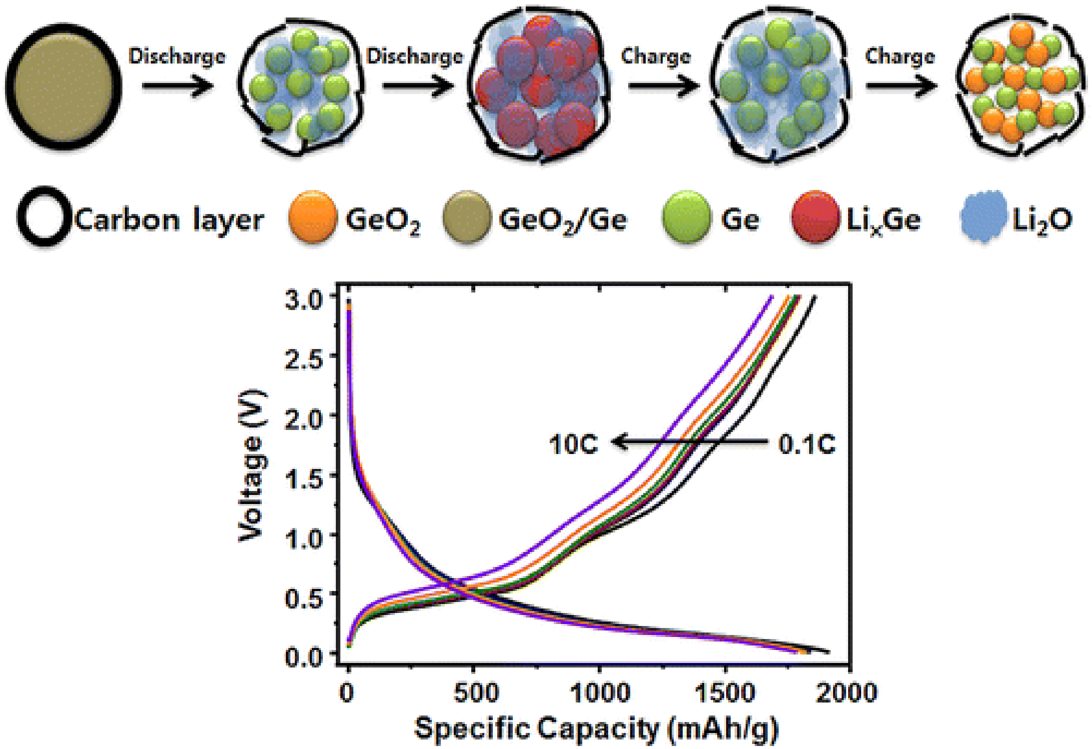
Hybrid Energy Storage. The merging of battery and supercapacitor chemistries.
D. P. Dubal, O. Ayyad, V. Ruiz, and P. Gomez-Romero* Chemical Society Reviews, **2015,** 44, 1777.

Baterías
Tipos de materiales



Recent advances in rechargeable battery materials: a chemist's perspective
M. Rosa Palacín Chem. Soc. Rev., 2009,38, 2565-2575

Nuevos materiales
Ejemplo de ánodo de conversión en baterías de Li



Prof Z. Guo y col. Self-Assembled Germanium/Carbon Nanostructures as High-Power Anode Material for the Lithium-Ion Battery. Angew. Chem. Int. Ed. 2012, 51(23), 5657

¿baterías más rápidas?

Electrodos nanoestructurados
Microestructura fractal

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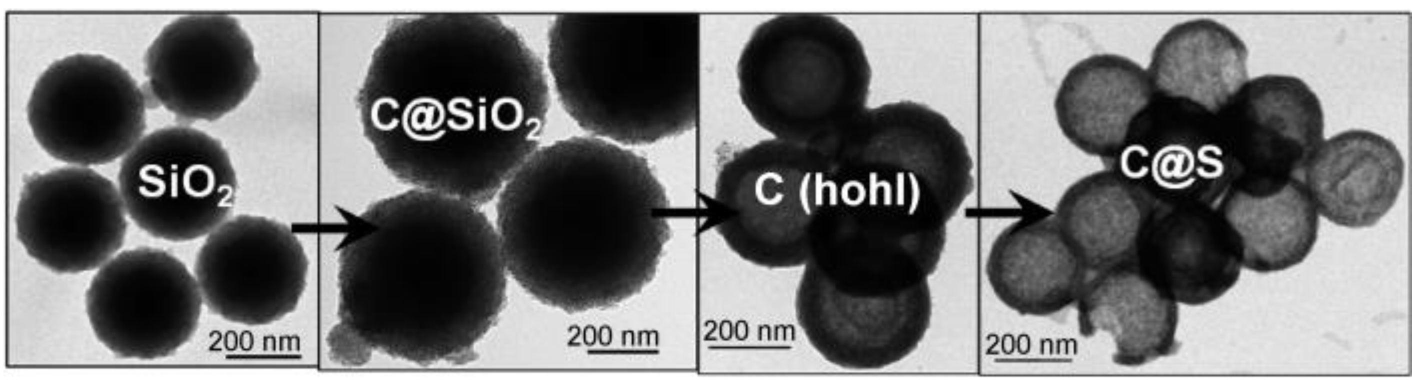
i Nanotecnologia
EXCELENCIA
SEVERO
OCHOA

New (nano)solutions for old battery chemistries

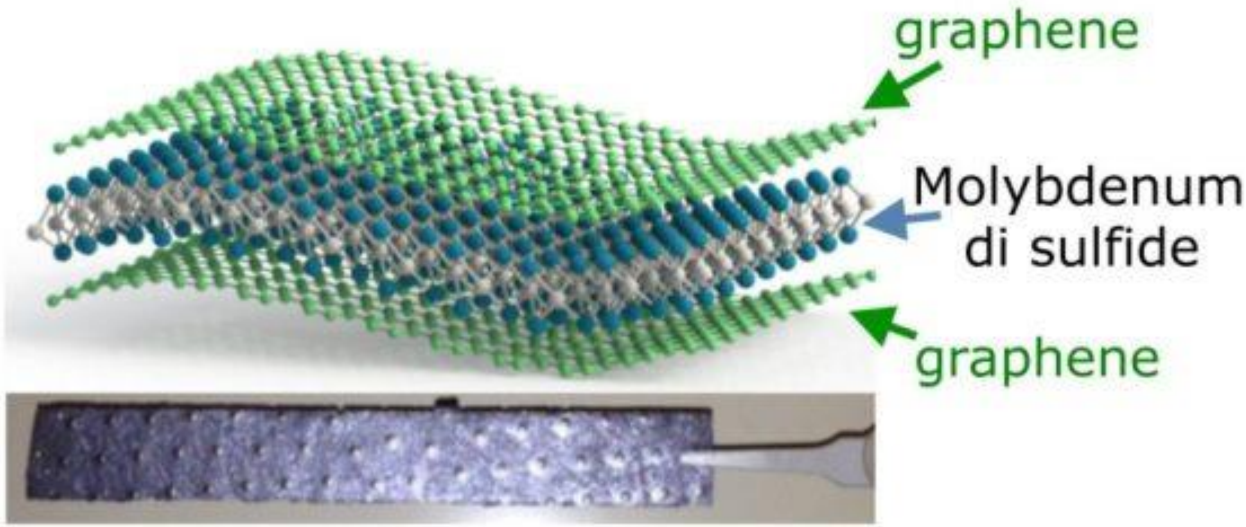
Cathode material	Specific capacity (mAh/g)	Cell voltage (V)	Specific energy (Wh/kg)
LiFePO4	140	3.3	578
LiCoO2	160	3.7	580
LiMn2O4	130	3.9	592
S	1670	2.1	2600

New Composite Cathode Materials for Li/S Batteries: A Review
A. Fedorková*, R. Oriňáková, O. Čech, M. Sedlaříková *Int. J. Electrochem. Sci.,* 8 **(2013)** 10308 - 10319



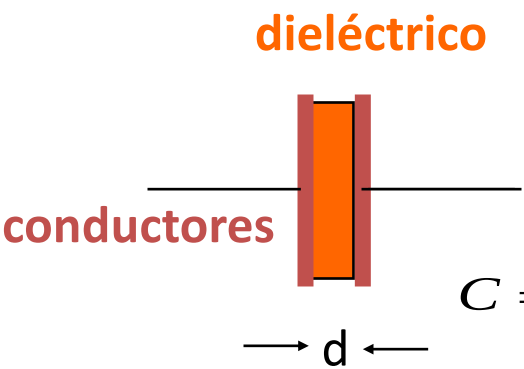
N. Jayaprakash, J. Shen, S. S. Moganty, A. Corona, L. A. Archer, *Angew. Chem.,* 123 (2011) 6026.

De baterías de Litio… a baterías de Sodio.



Lamuel David , Romil Bhandavat , and Gurpreet Singh *
MoS_2/Graphene Composite Paper for Sodium-Ion Battery Electrodes
ACS Nano, 2014, 8 (2), pp 1759–1770

Condensadores (sin súper)



Capacidad

Area

$$C = \frac{q}{V} \qquad C = \frac{A\varepsilon\varepsilon_0}{d}$$

Permitividad en el vacío

8.854 E-12 F/m ---> Pico Faradios

Aumentar A
disminuir d

Supercondensadores

Doble capa eléctrica (d Å)

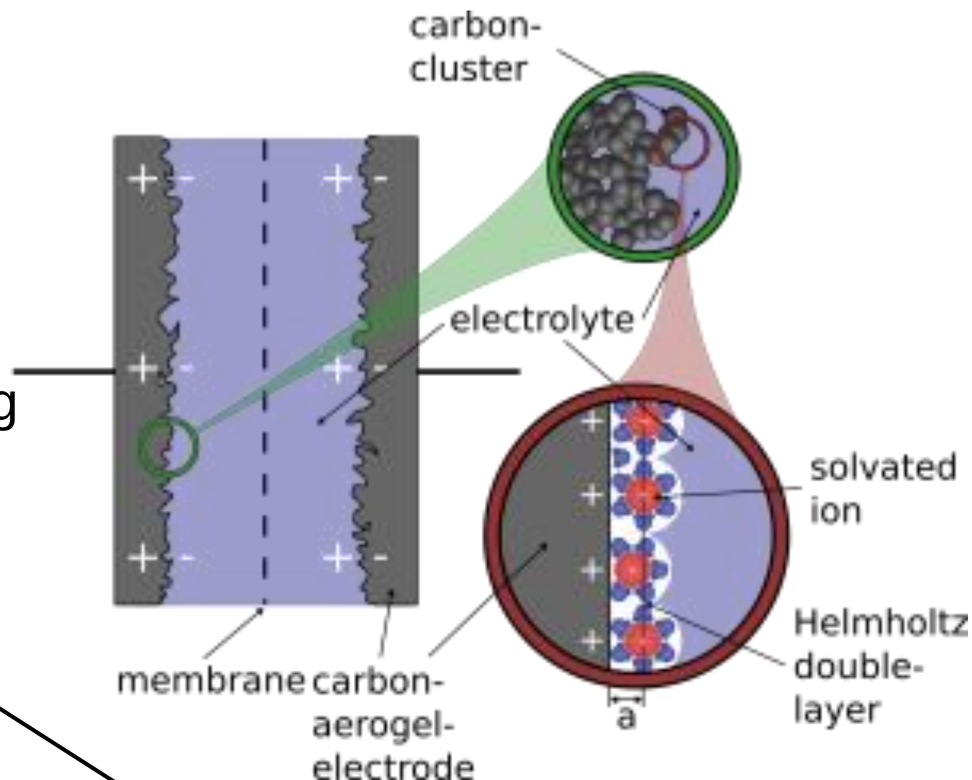
Supercondensadores de Doble Capa

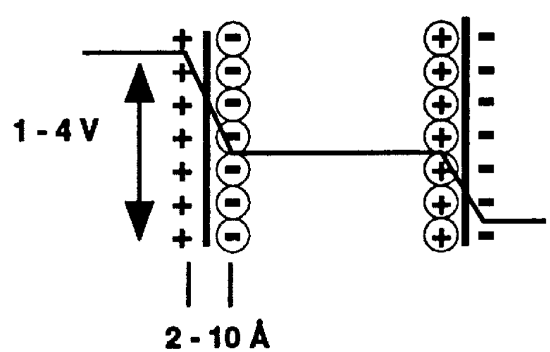
Capacitance

Farads

Area
$10^3\ m^2/g$

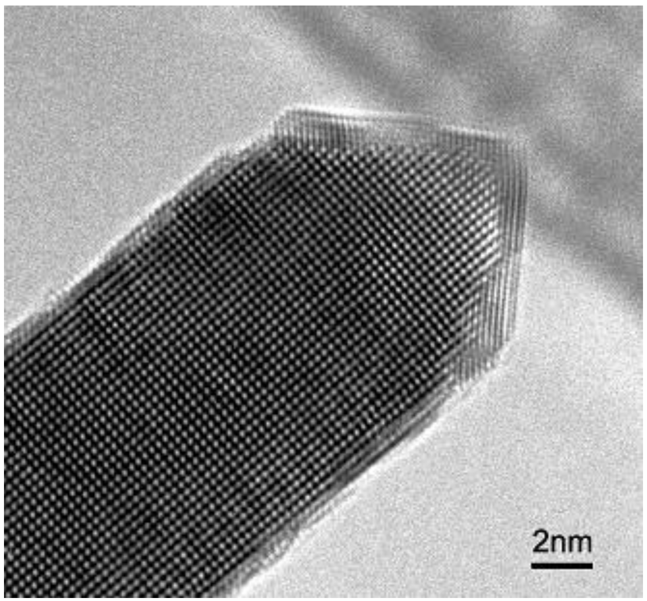
$$C = \frac{q}{V} \qquad C = \frac{A\varepsilon\varepsilon_0}{d}$$





Supercondensadores electroquímicos

$2RuO_2 + 2H^+ + 2e^- \leftrightarrow Ru_2O_3 + H_2O$



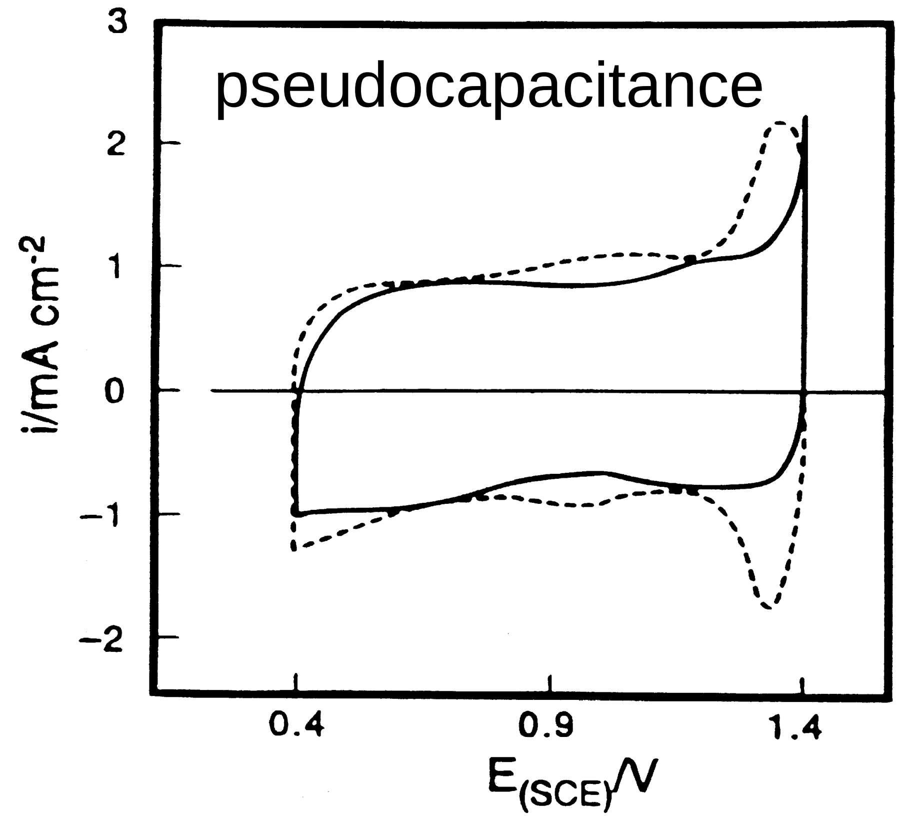
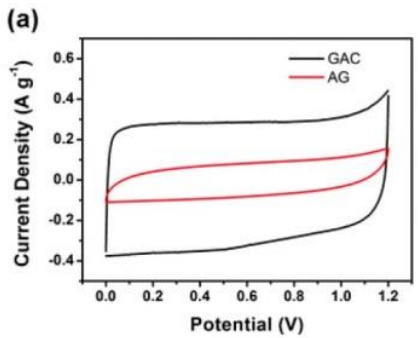
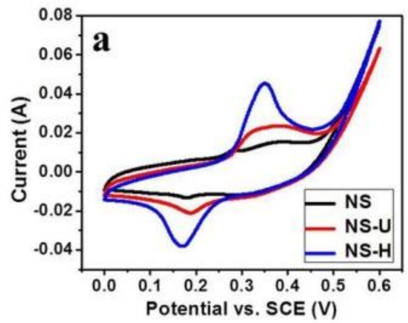


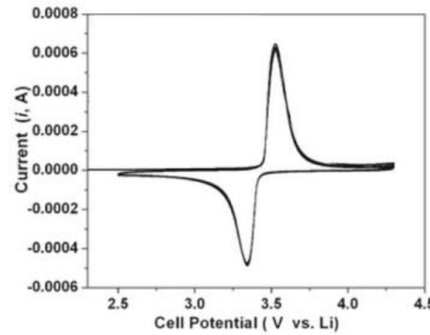
Fig. 5. Typical voltammetric curves at 20 mV s^{-1} of a RuO_2 electrode between 0.4 and 1.4 V (RHE) in 1 mol dm^{-3} solutions (–) $HClO_4$ and (– – –) KOH. (From Ref. 9.)

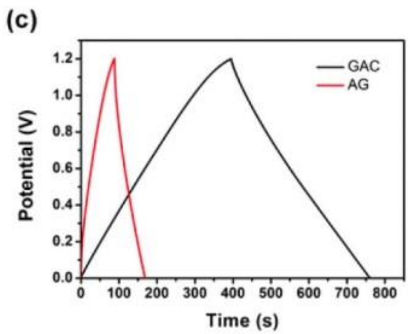
Trasatti 1971
Conway 1975-1980

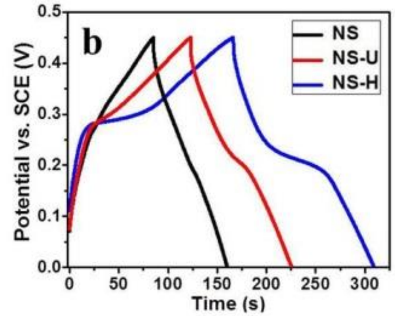
Supercondensadores vs. baterías

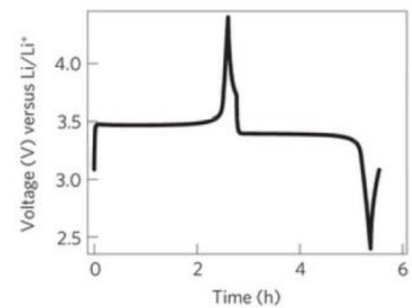












carbon-based EDLC supercapacitors

Co_3O_4 pseudocapacitor

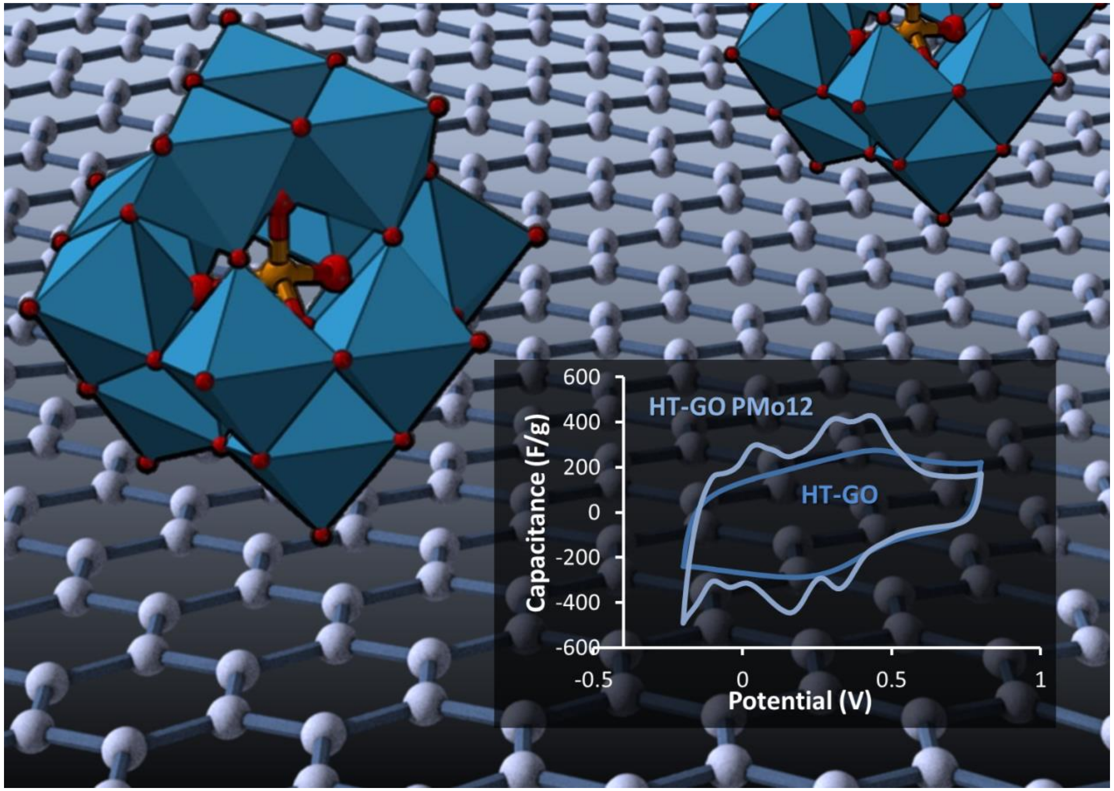
$LiFePO_4$ (vs. Li) battery

…pero NO un mecanismo híbrido

Hybrid Energy Storage. The merging of battery and supercapacitor chemistries.
D. P. Dubal, O. Ayyad, V. Ruiz, and P. Gomez-Romero* Chemical Society Reviews, **2015,** 44, 1777.

Almacenamiento de energía híbrido

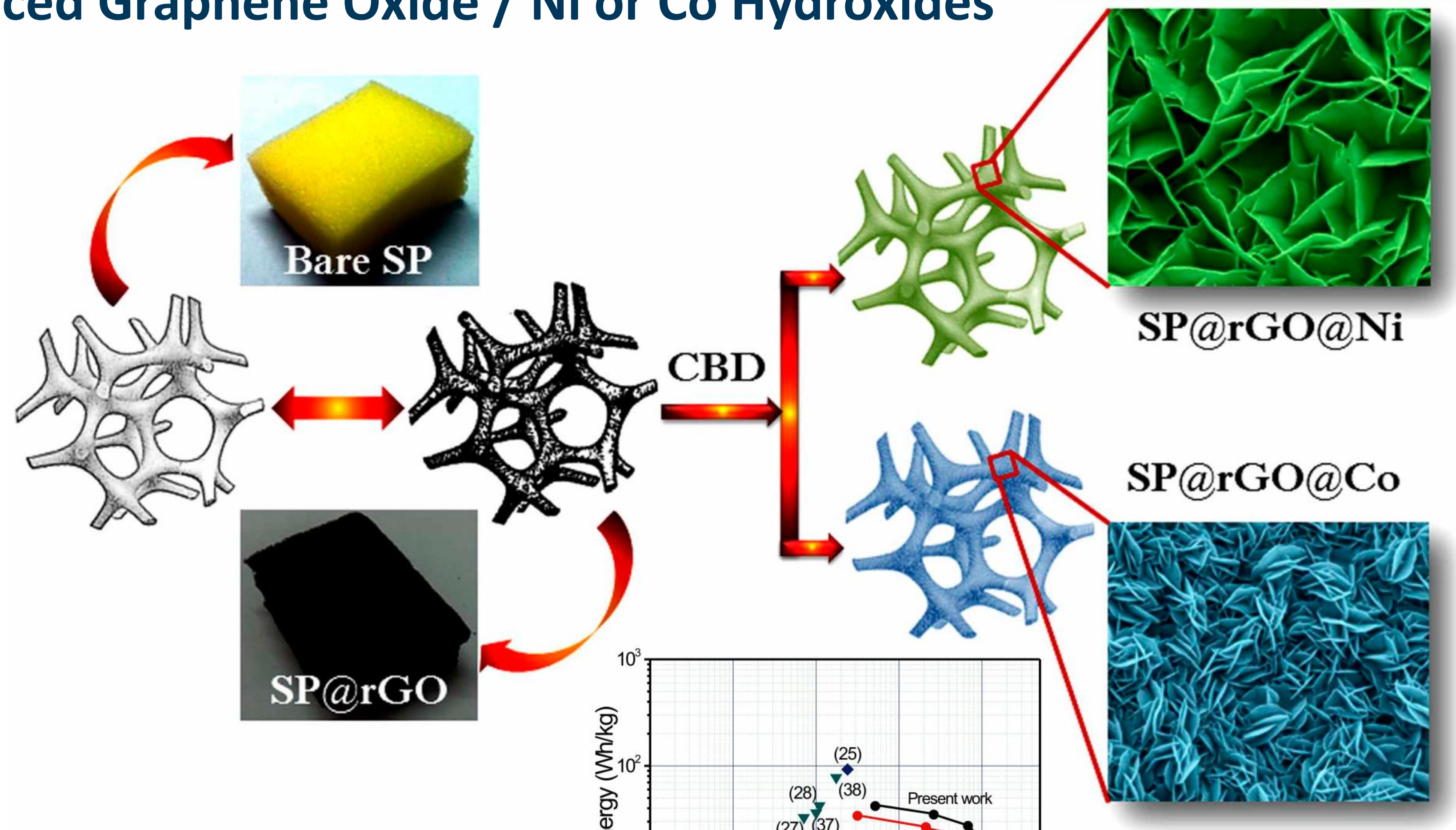
Graphene-Polyoxometalate Hybrid Nanocomposite Material for Supercapacitors

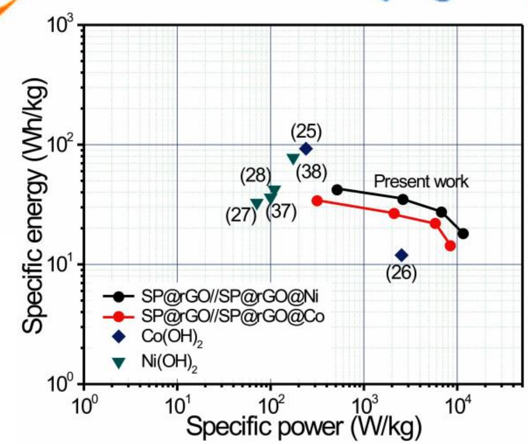


Stable Graphene-Polyoxometalate Nanomaterials for Application in Hybrid Supercapacitors.
J. Suarez-Guevara, V. Ruiz,, P. Gomez-Romero Phys.Chem.Chem.Phys., 2014, 16 (38), 20411.

Hybrid Energy Storage:

Reduced Graphene Oxide / Ni or Co Hydroxides

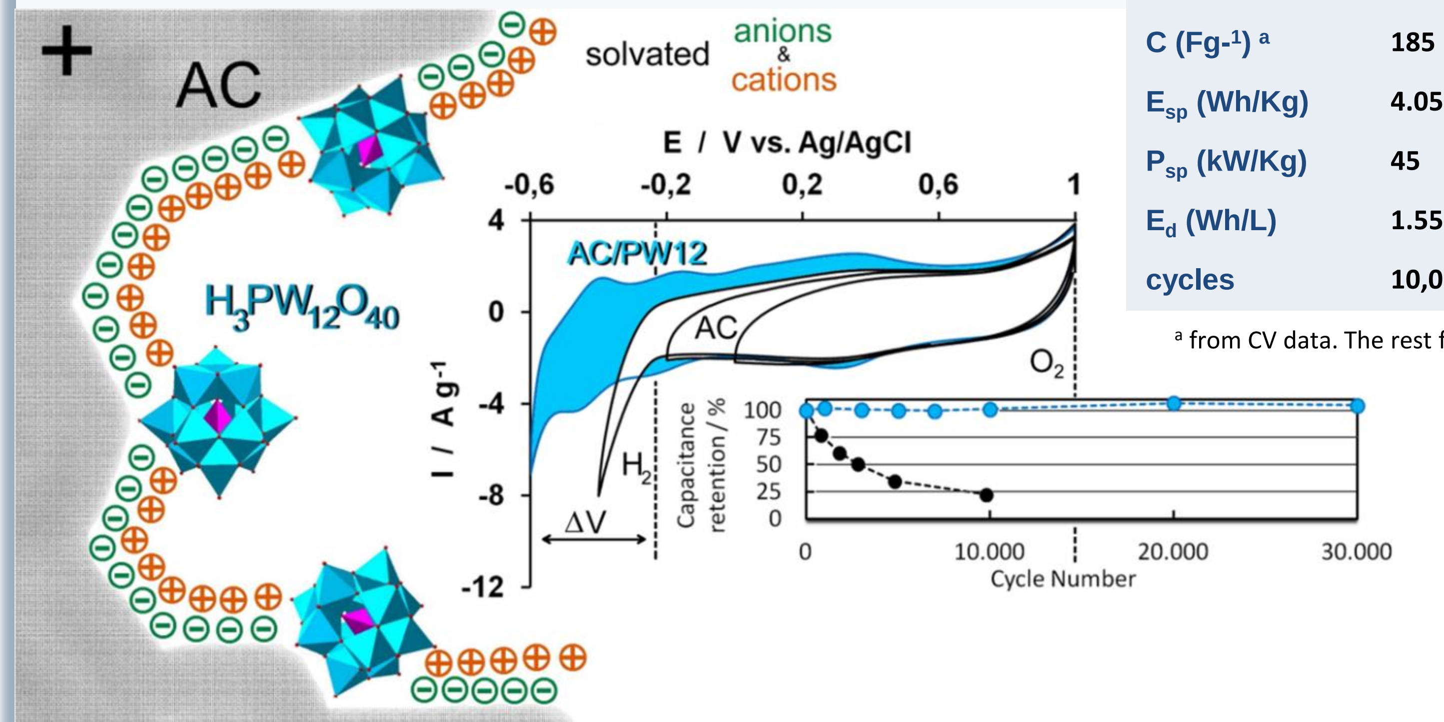




D. P. Dubal*, R. Holze, P. Gomez-Romero*
Scientific Reports **2014**, 4 : 7349

Hybrid Energy Storage

Activated Carbon (AC) - $PW_{12}O_{40}$ Hybrid



	AC	AC-PW12
C (Fg^{-1}) [a]	185	254
E_{sp} (Wh/Kg)	4.05	4.96 (1.6 A/g)
P_{sp} (kW/Kg)	45	115
E_d (Wh/L)	1.55	2.32
cycles	10,000	> 30,000 (6 A/g)

[a] from CV data. The rest from charge-discharge data

Hybrid Electrodes Based on Polyoxometalate-Carbon Materials for Electrochemical Supercapacitors
V. Ruiz, J. Suárez-Guevara, P. Gomez-Romero. Electrochemistry Communications **2012**, 24, 35-8

Hybrid Energy Storage: High Voltage Aqueous Supercapacitors based on Activated C-Phosphotungstate Hybrid Materials.
J. Suárez-Guevara, V. Ruiz, P. Gomez-Romero J. Mater. Chem. A, **2014**, 2 (4), 1014-1021

NEO-Energy
Novel Energy-Oriented Materials

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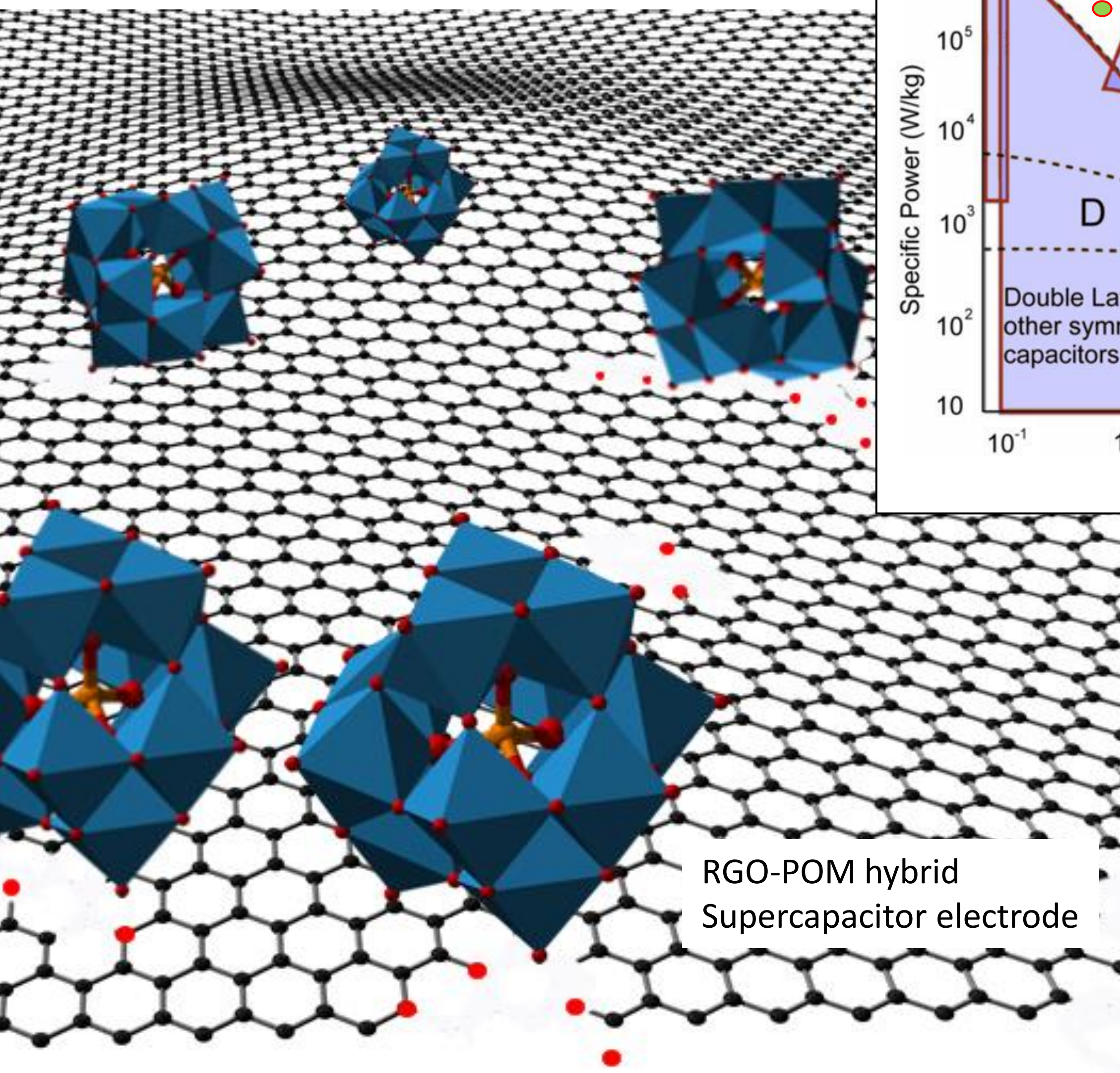
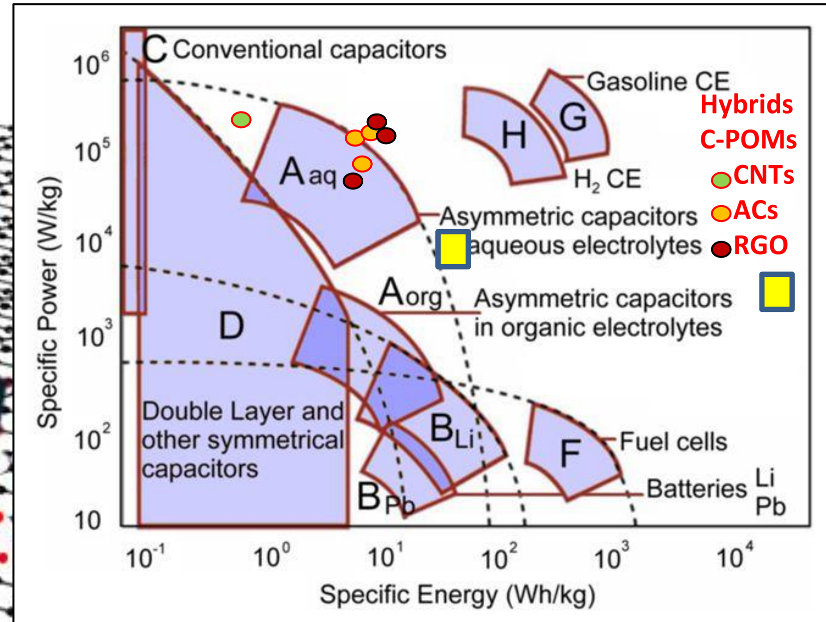
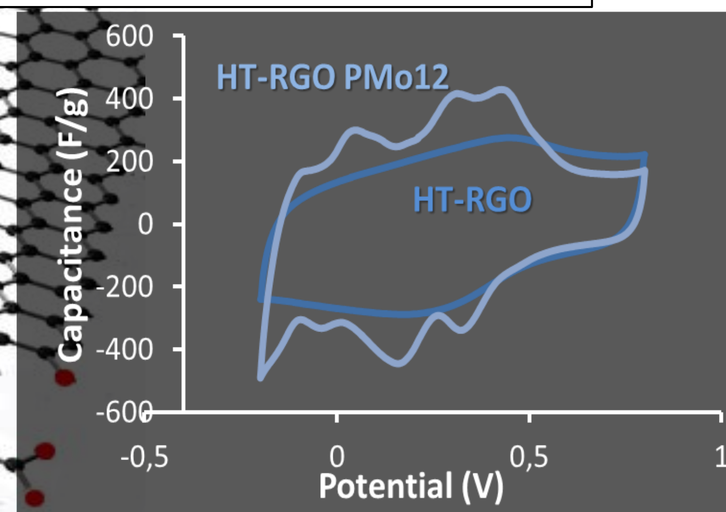
EXCELENCIA SEVERO OCHOA







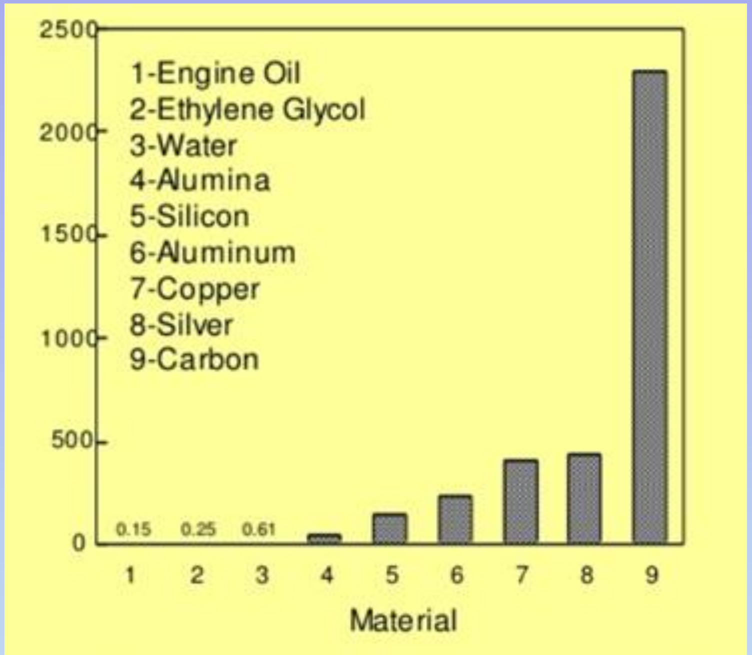
RGO-POM hybrid
Supercapacitor electrode

Nanofluids: size matters

dispersions of nanoparticles in base fluids

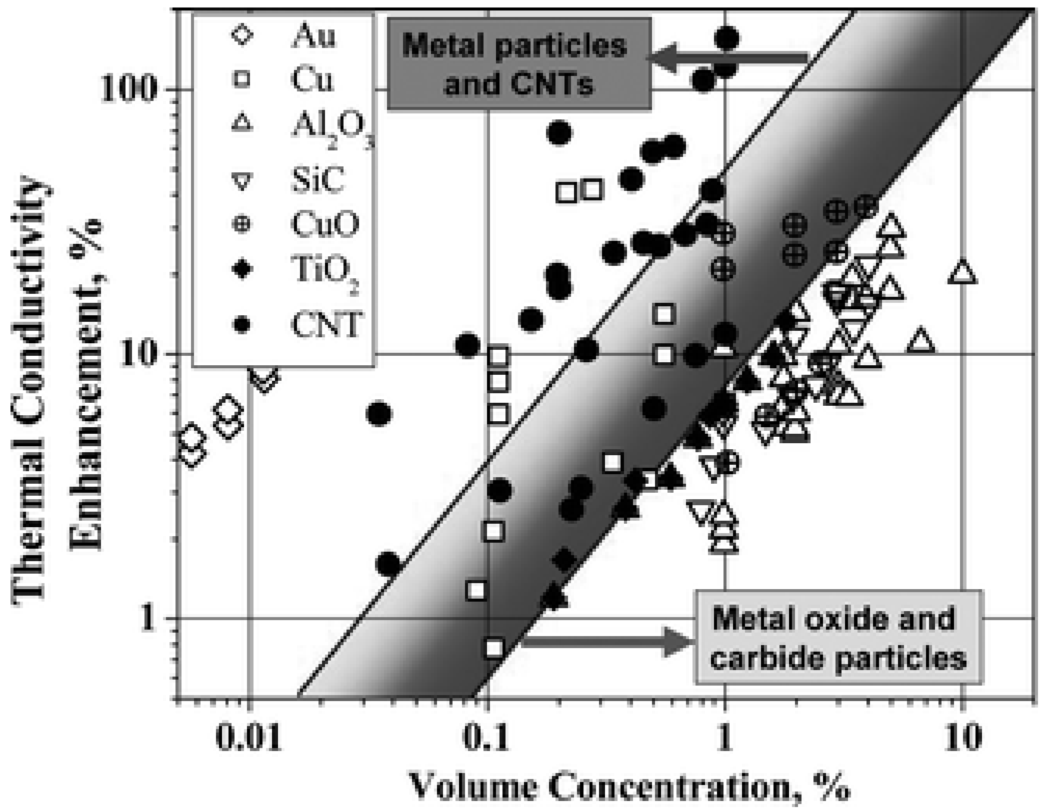
Thermal Nanofluids concept

- Conventional Heat transfer Fluids (HTFs) have poor thermal conductivity compared to solids
- Fluids containing microparticles lead to engineering problems (precipitation, clogging…)
- Nanofluids provide enhanced performance from dispersed solid nanoparticles without those problems



Termal conductivity of solids:
Orders of magnitud larger than
Those of conventional HTFs

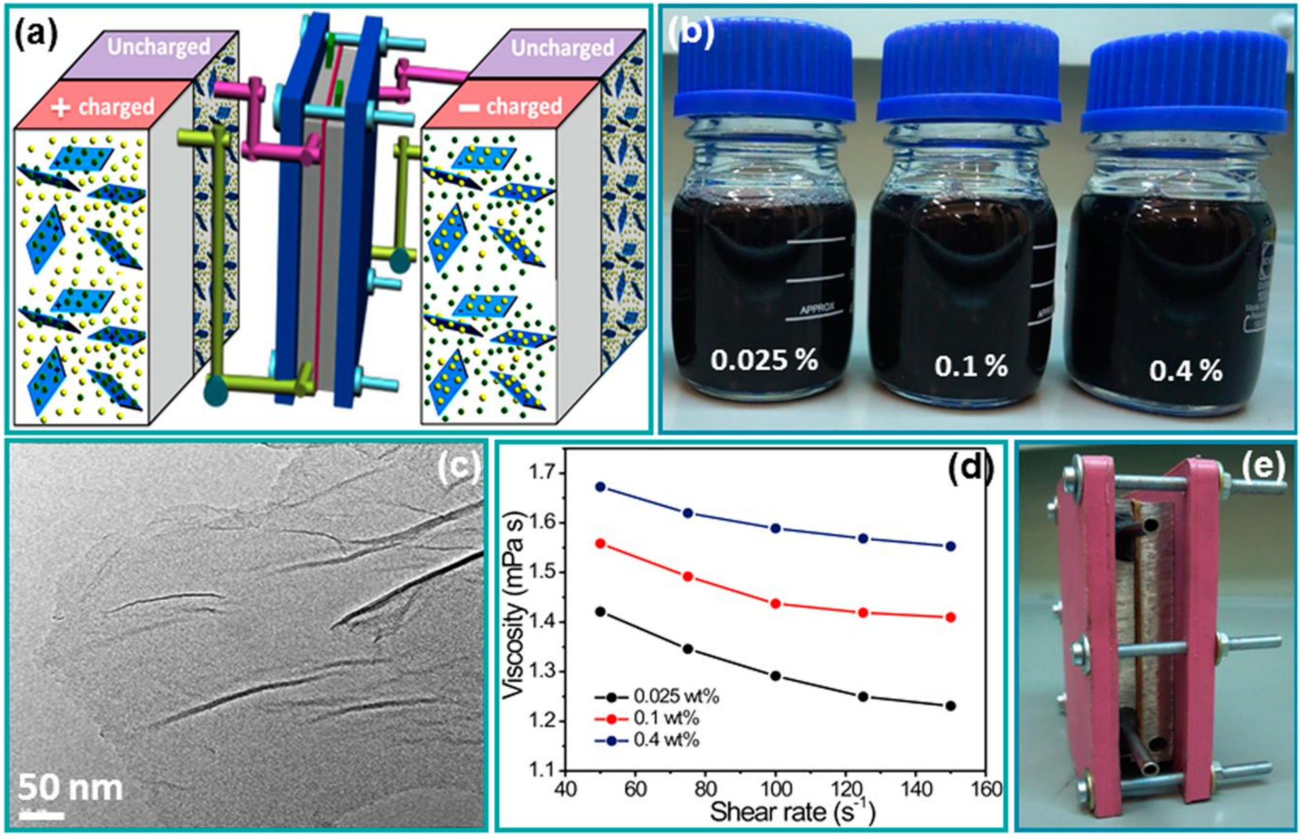
Thermal Nanofluids Performance



The mechanism of heat transfer in nanofluids: state of the art (*review*). Part 1. Synthesis and properties of nanofluids V.I. Terekhov, S.V. Kalinina, and V.V. Lemanov. *Thermophysics and Aeromechanics*, *2010*, *Vol. 17*, *No. 1, 1-14*

Electroactive Nanofluids for New Flow Cell Concepts.

ICN2 Institut Català de Nanociència i Nanotecnologia
EXCELENCIA SEVERO OCHOA



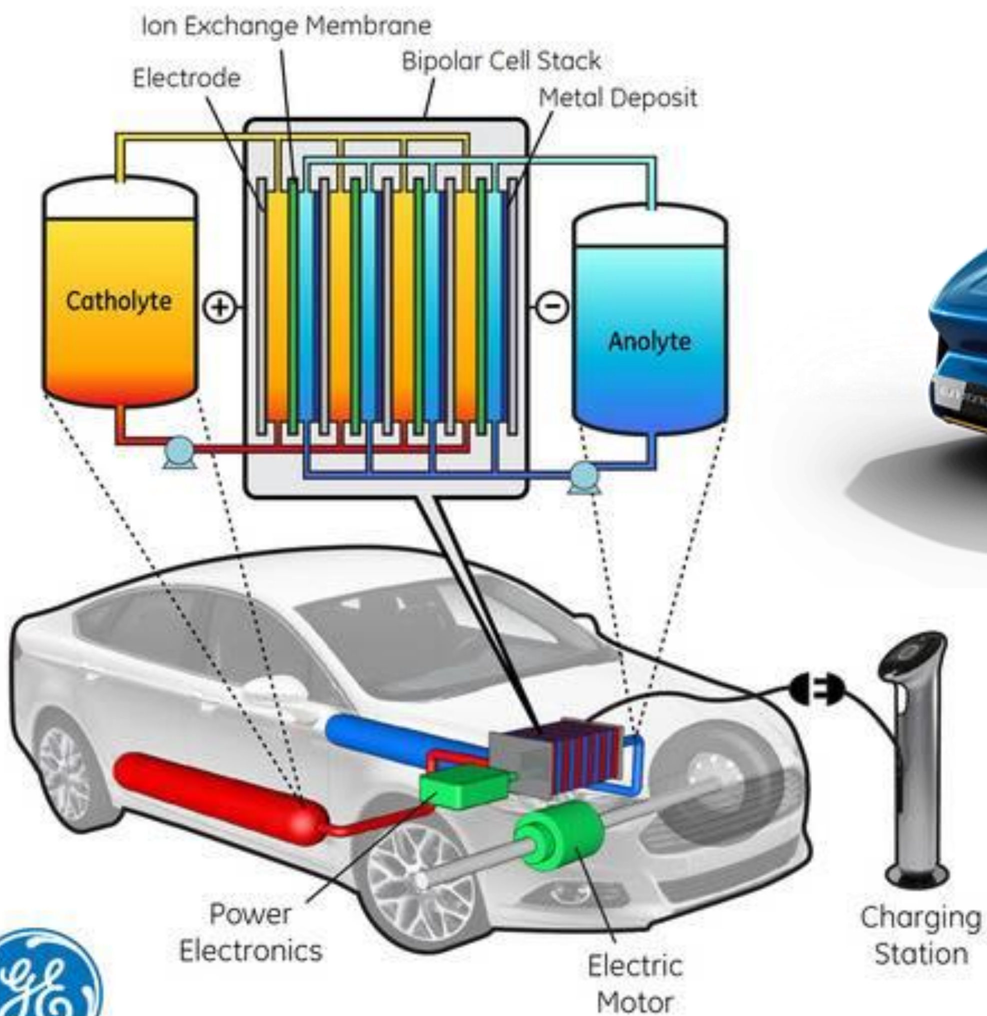
D. P. Dubal, D. Gomez, P. Gómez-Romero, Patent ES1641.1064. "Electroactive nanofluids on graphene-based materials for energy storage in flow cells." 20-05-2015

Electroactive Graphene Nanofluids for Fast Energy Storage.

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

Prototype Electric vehicles with Flow technology

Early Model of Water-Based Flow Battery Designed For Use in Electric Vehicles



Quantino

250-liter tanks to hold liquids that flow past an electrochemical cell

Flowing liquid is undisclosed

http://arpa-e.energy.gov/?q=slick-sheet-

News

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Videos
Fact Sheets, Brochures and Reports
Summer Science Writing Internship

ARPA-E awards IIT-Argonne team $3.4 million for breakthrough battery technology

AUGUST 30, 2013

Tweet Tweet Share Email Print

CHICAGO – Carlo Segre, Duchossois Leadership Professor of Physics at Illinois Institute of Technology, has received a $3.4 million award from the U.S. Department of Energy's Advanced Research Projects Agency (ARPA-E) to develop a breakthrough battery technology that may more than double the current range of electric vehicles (EV), increase safety, reduce costs and simplify recharging.

Segre and his collaborators John Katsoudas, also of IIT, and Elena Timofeeva, Dileep Singh and Michael Duoba of Argonne National Laboratory will develop a prototype for a rechargeable "nanoelectrofuel" flow battery that may extend the range of EVs to at least 500 miles and provide a straightforward and rapid method of refueling. Current EV ranges are 100-200 miles, with recharging taking up to eight hours.

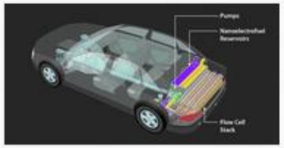
Flow batteries, which store chemical energy in external tanks instead of within the battery container, are generally low in energy density and therefore not used for transportation applications. The IIT-Argonne nanoelectrofuel flow battery concept will use a high-energy density "liquid" with battery-active nanoparticles to dramatically increase energy density while ensuring stability and low-resistance flow within the battery.

"I am delighted by this award, not only because of the

Researchers (left to right) Dileep Singh, Carlo Segre, Mike Duoba, John Katsoudas, Elena Timofeeva, and Chris Pelliccione stand by one of the plug-in electric vehicles they hope to revolutionize with the IIT-Argonne "nanoelectrofuel" flow battery technology they are developing. Click to enlarge.

CONTACT US

For more information, contact Angela Hardin at (630-252-5501; media@anl.gov) or Patricia Cronin at (312-567-3132; cronin@iit.edu).



The Illinois Insitute of Technology will share $3.4 million to develop a prototype of their "nanoelectrofuel" flow battery. Funding for the prototype project comes from

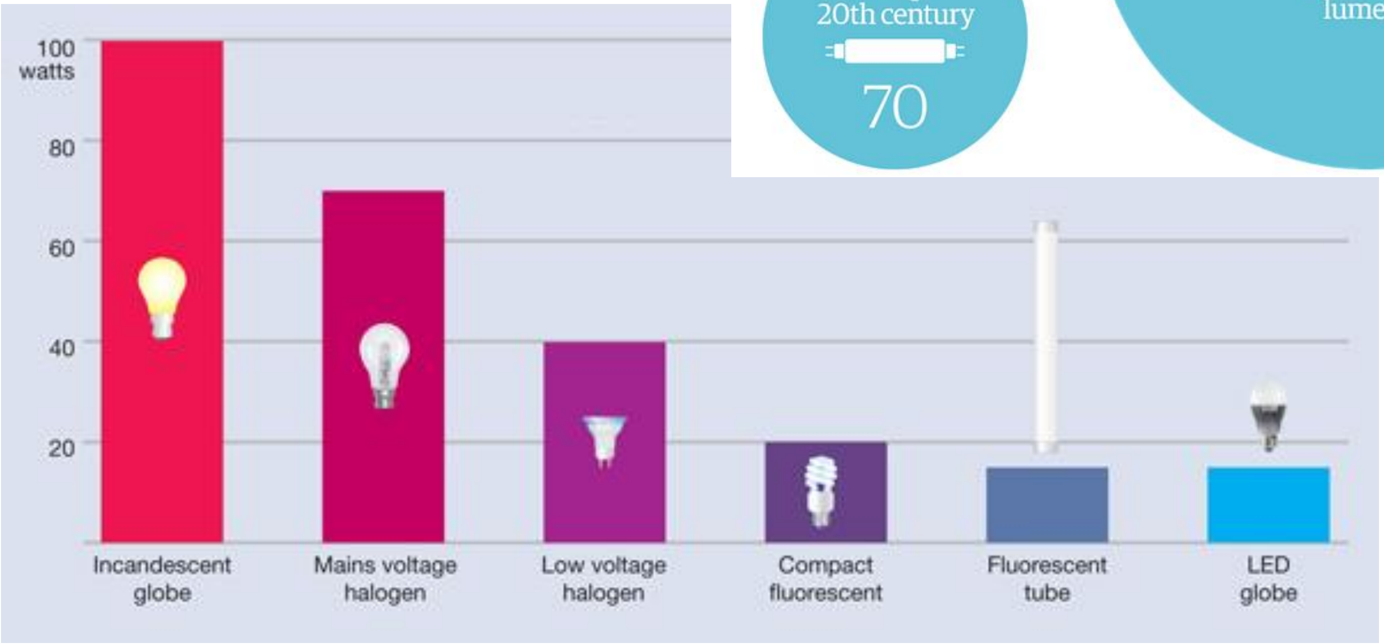
3. NANOMATERIALES PARA EFICIENCIA ENERGÉTICA

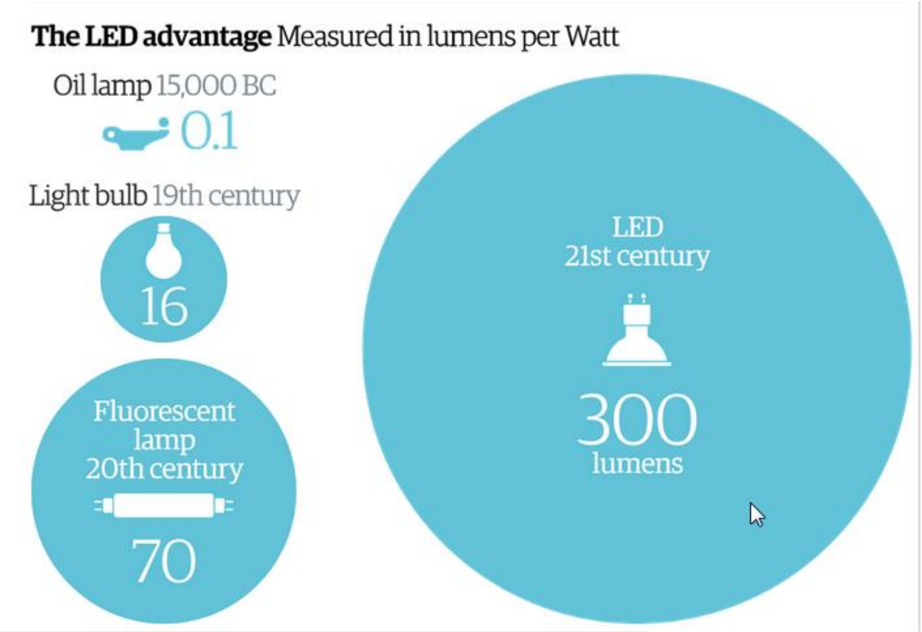
Otro campo ignorado por la industria del sector (excepto aplicaciones nicho) y actualmente en despegue:

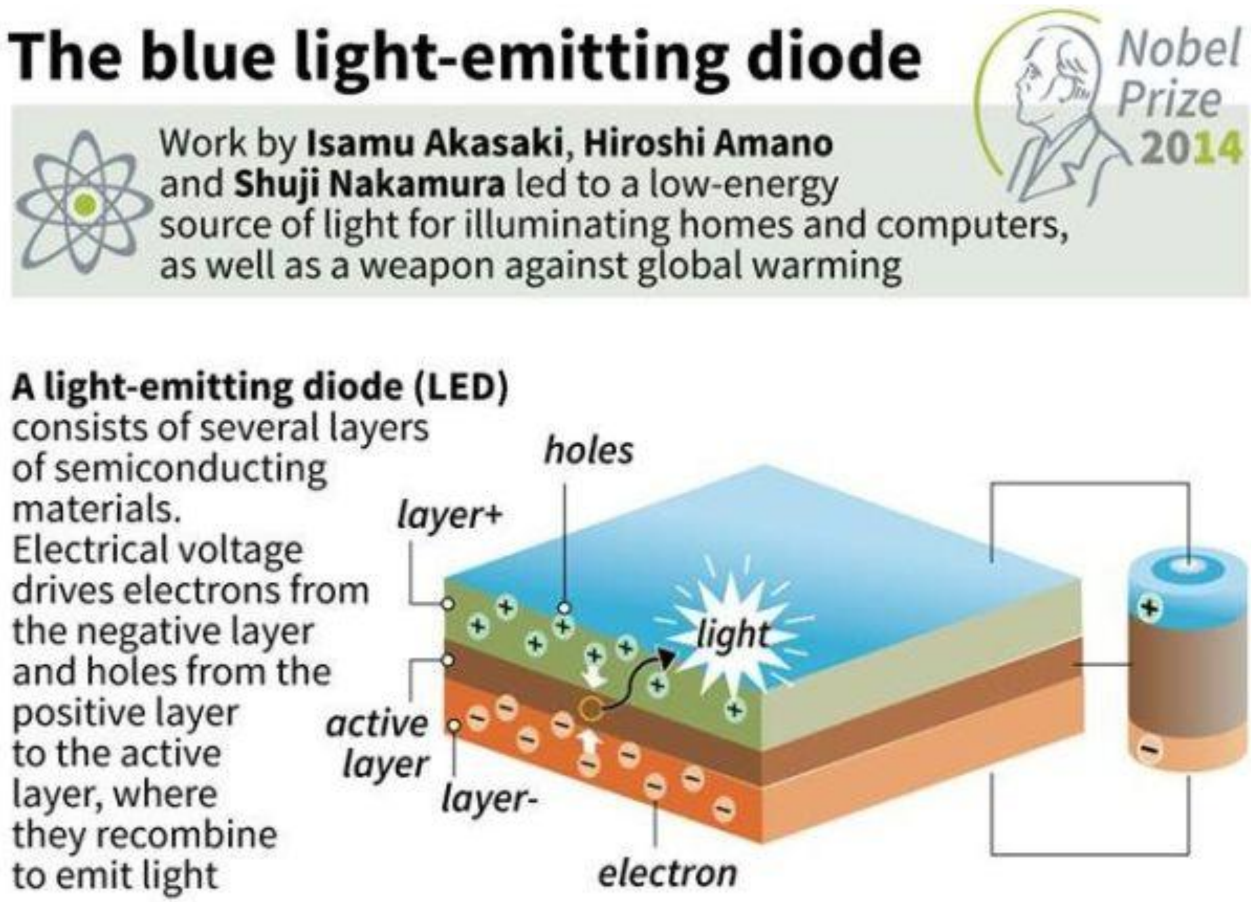
- LEDs
- OLEDs
- OLEDs poliméricos

Evolución tecnológica de la iluminación

LEDs
Blancos
Brillantes
Baratos, y…

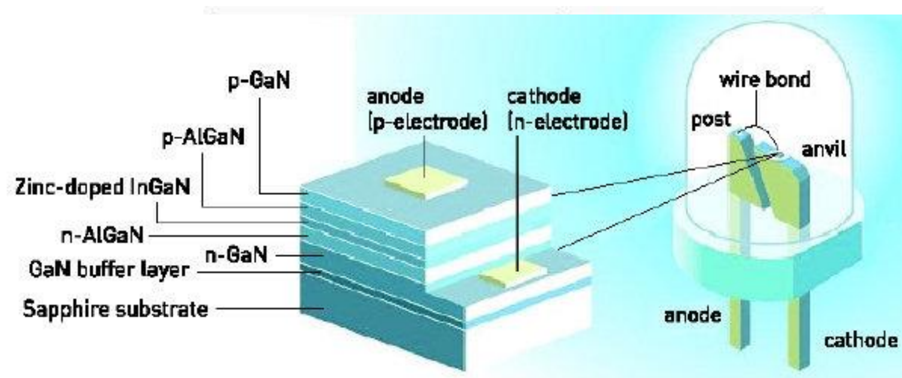

100
watts
80
60
40
20
Incandescent globe
Mains voltage halogen
Low voltage halogen
Compact fluorescent
Fluorescent tube
LED globe


The LED advantage Measured in lumens per Watt
Oil lamp 15,000 BC
0.1
Light bulb 19th century
16
Fluorescent lamp 20th century
70
LED 21st century
300
lumens

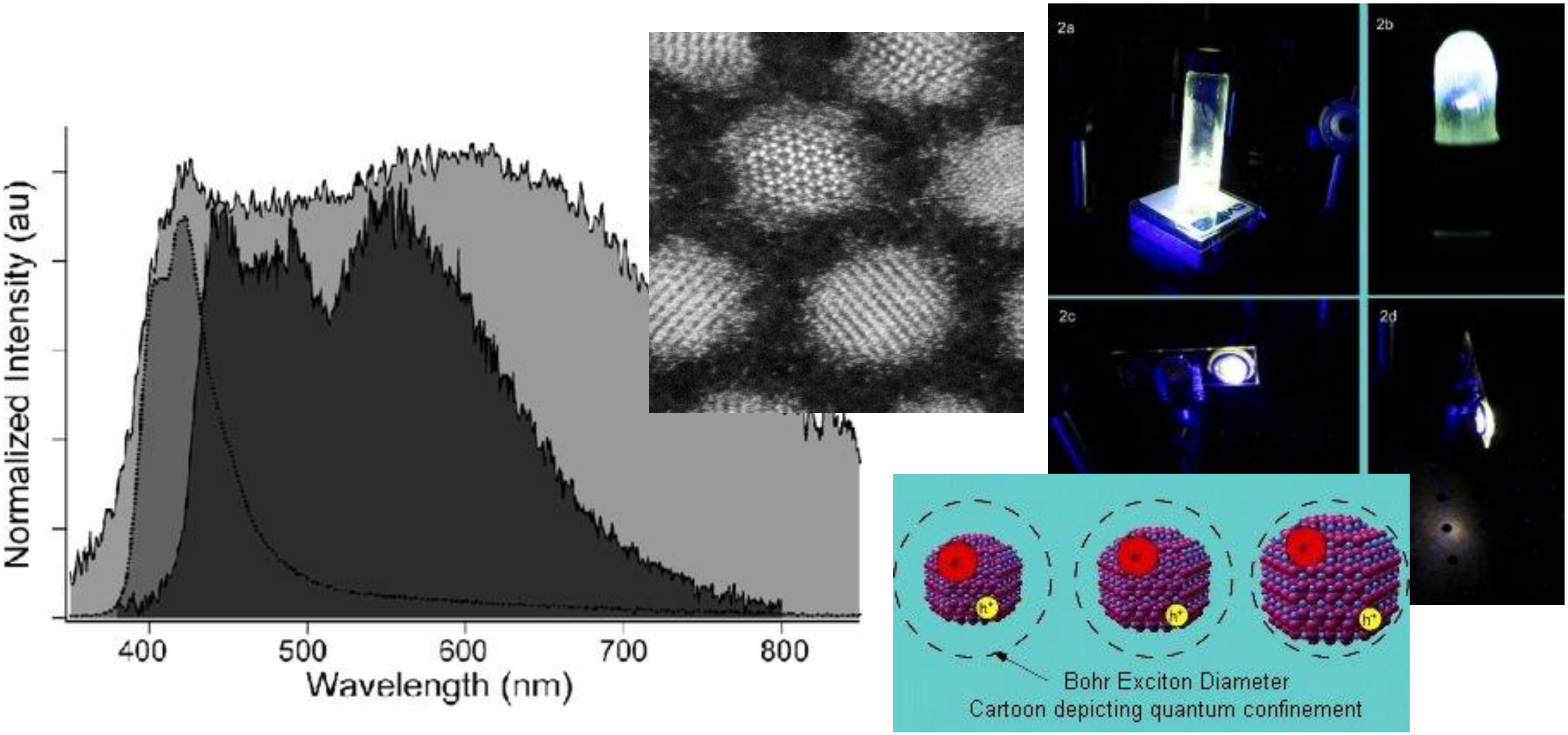


GaN → efficient blue LEDs

InGaN quantum wells

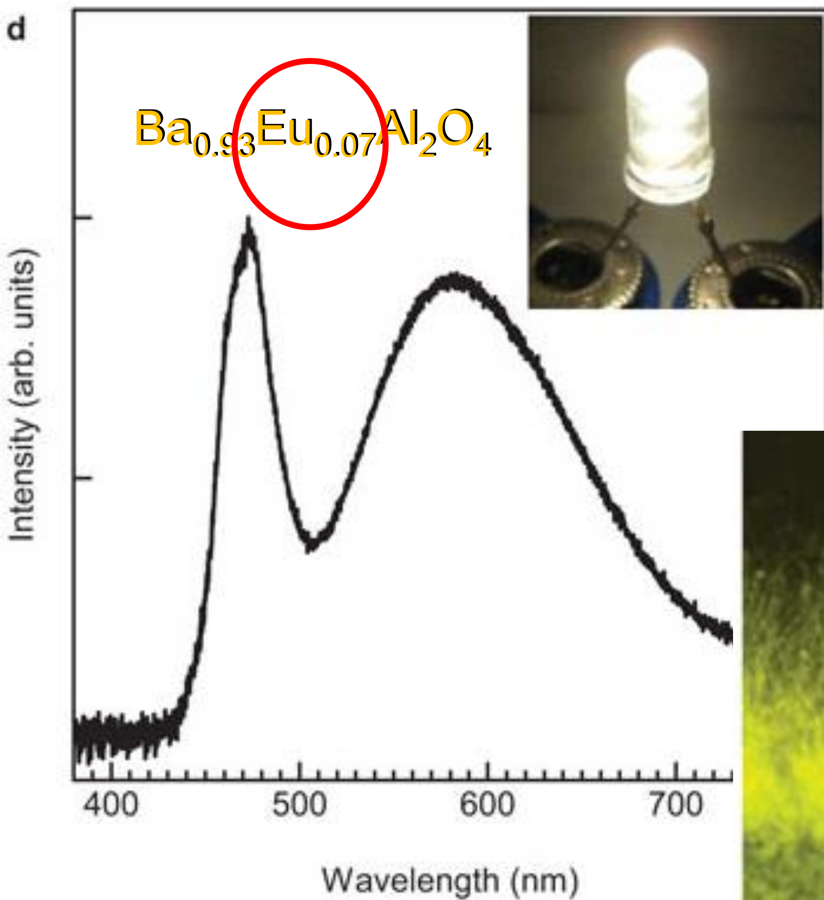


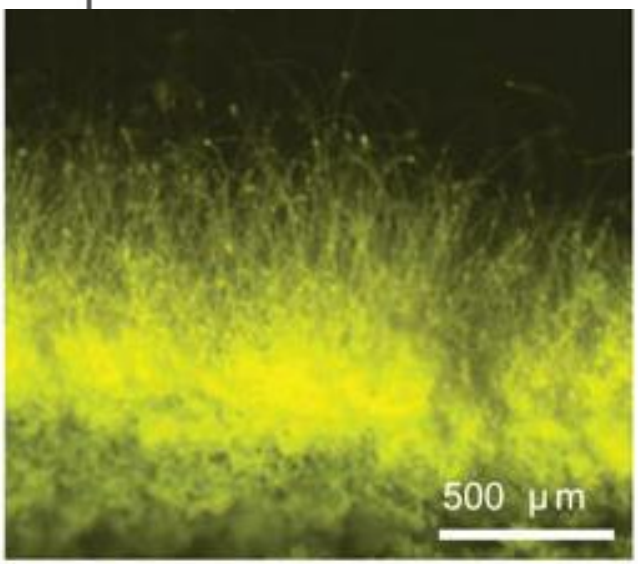
¿LEDs or Fluorescencia?



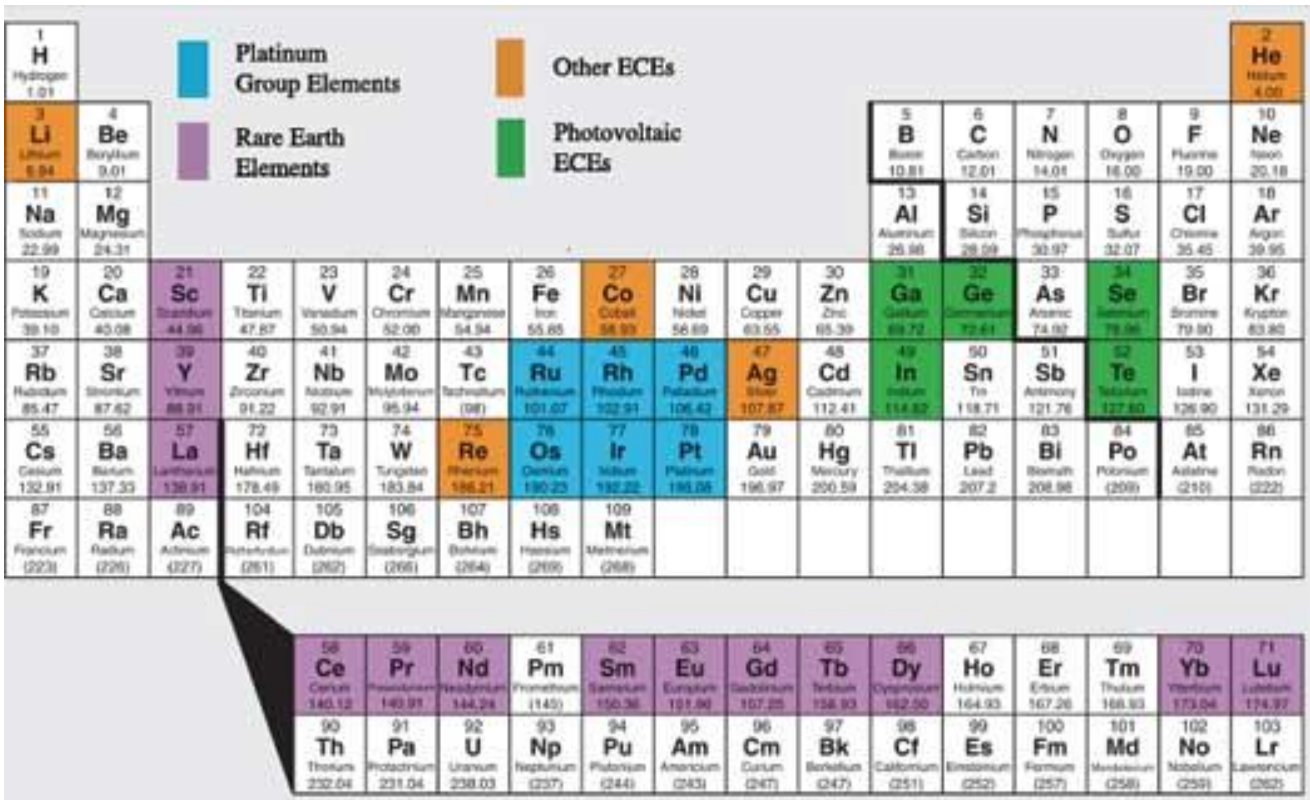
White Light-Emitting Diodes Based on Ultrasmall [CdSe Nanocrystal] Electroluminescence
Michael A. Schreuder et al. (Sandra Rosenthal) N*ano Lett.*, 2010, 10 (2), pp 573–576

Inorganic LEDs





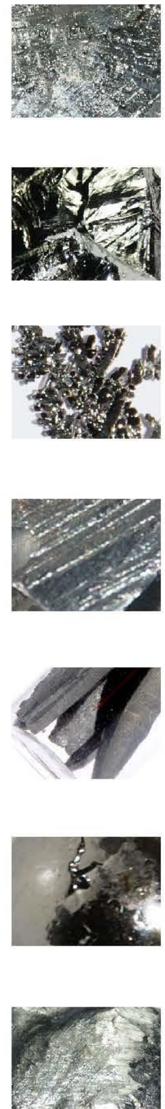
Energy Critical Elements



Energy Critical Elements: Securing Materials for Emerging Technologies
APS-MRS. R. Jaffe et al., 2011

Energy Critical Elements

52 **Te** Tellurium 127.60



TELLURIUM—brittle, silvery-white metallic element used in solar panels

32 **Ge** Germanium 72.61

GERMANIUM— hard, grayish-white element with metallic luster; used in solar panels

78 **Pt** Platinum 195.078

PLATINUM—silvery-white, lustrous, ductile and malleable; used in pollution control devices for cars, and in fuel cells

60 **Nd** Neodymium 144.24

NEODYMIUM—bright, silvery rare-earth metal element; used in wind turbines and hybrid cars

3 **Li** Lithium 6.941

LITHIUM—a soft, silver-white metallic element; used in wind turbines and lithium-ion batteries in hybrid cars

75 **Re** Rhenium 186.207

RHENIUM—silvery-white metal with one of the highest melting points of all elements; used to make advanced turbines and jet engine parts

65 **Tb** Terbium 158.92534

TERBIUM—a soft, silvery-white rare earth metal; used along with its fellow rare earth europium in compact fluorescent light bulbs to provide an acceptable color balance

ALIEN, our future material(s)

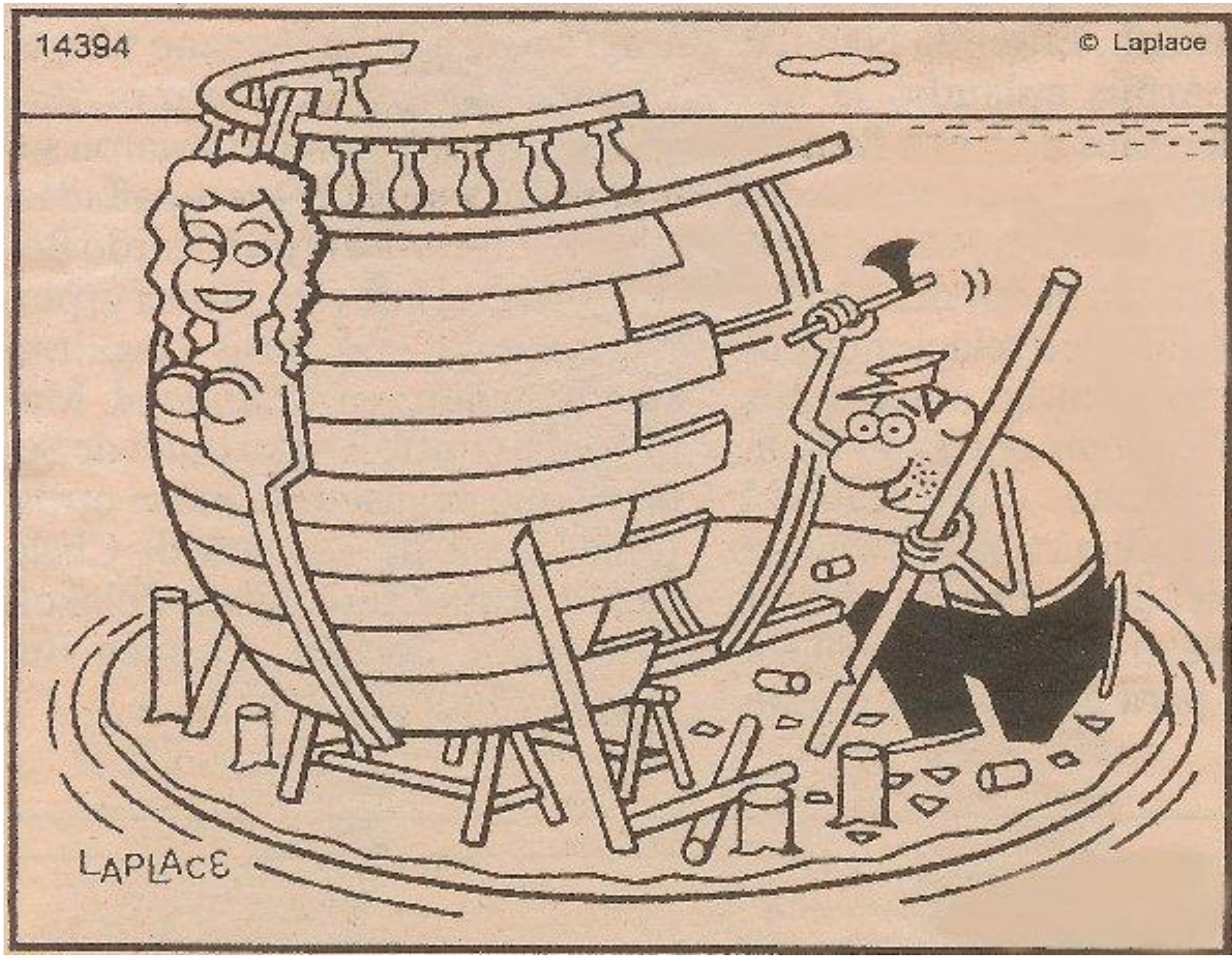
Abundant

Lower costs

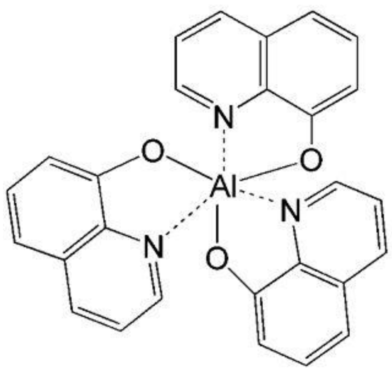
I mproved performance

Environmentally friendly

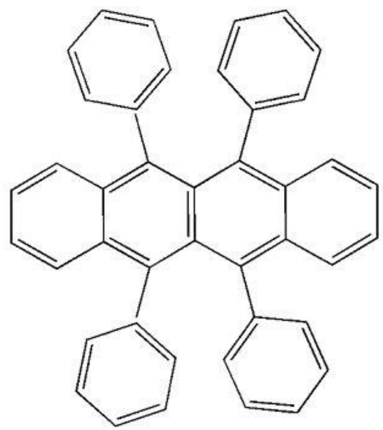
New props tricks and apps


14394
© Laplace
LAPLACE

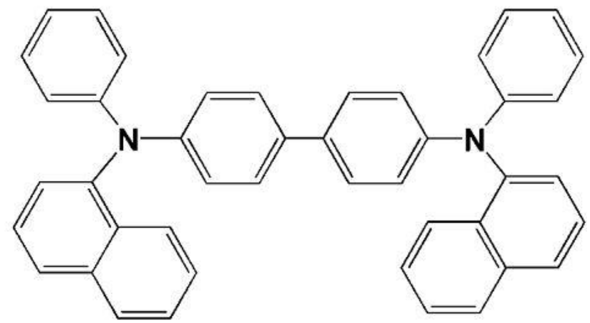
LEDs Orgánicos (OLEDs)



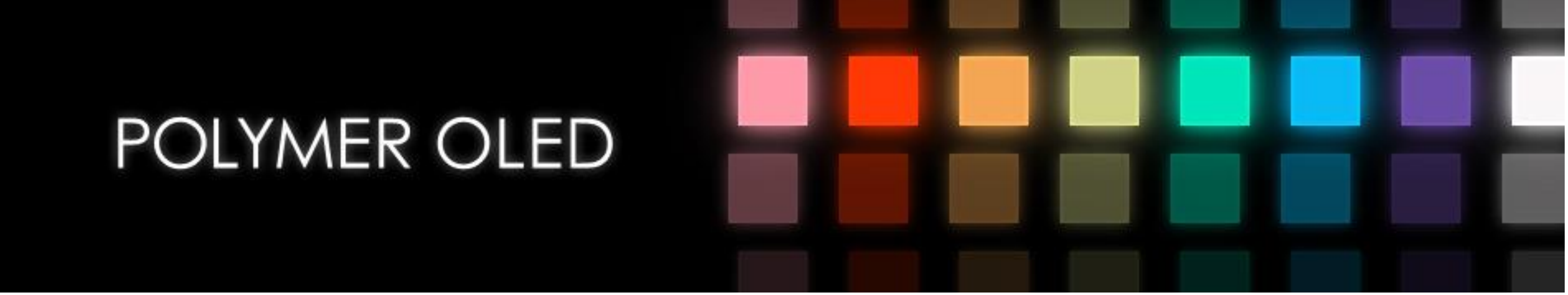
Alq_3

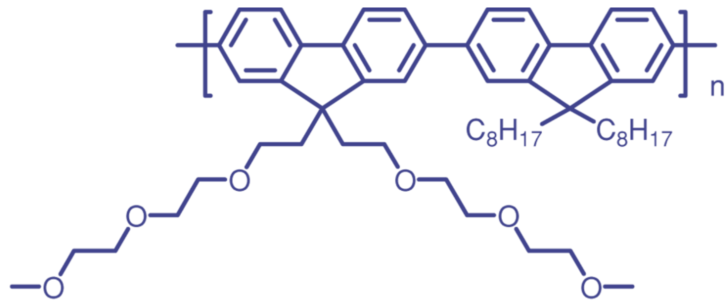


rubrene

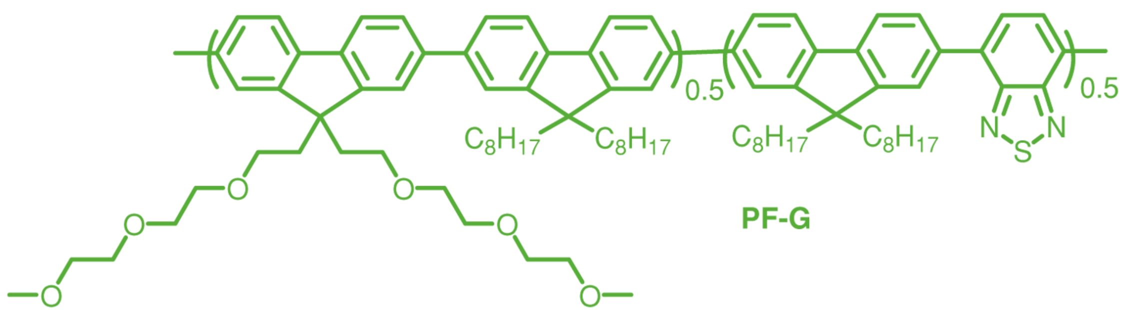


α-NPD

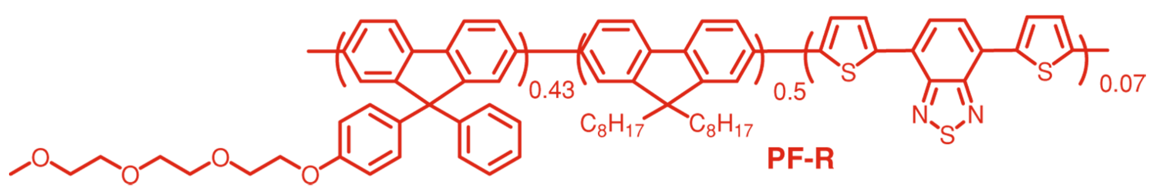




PF-B

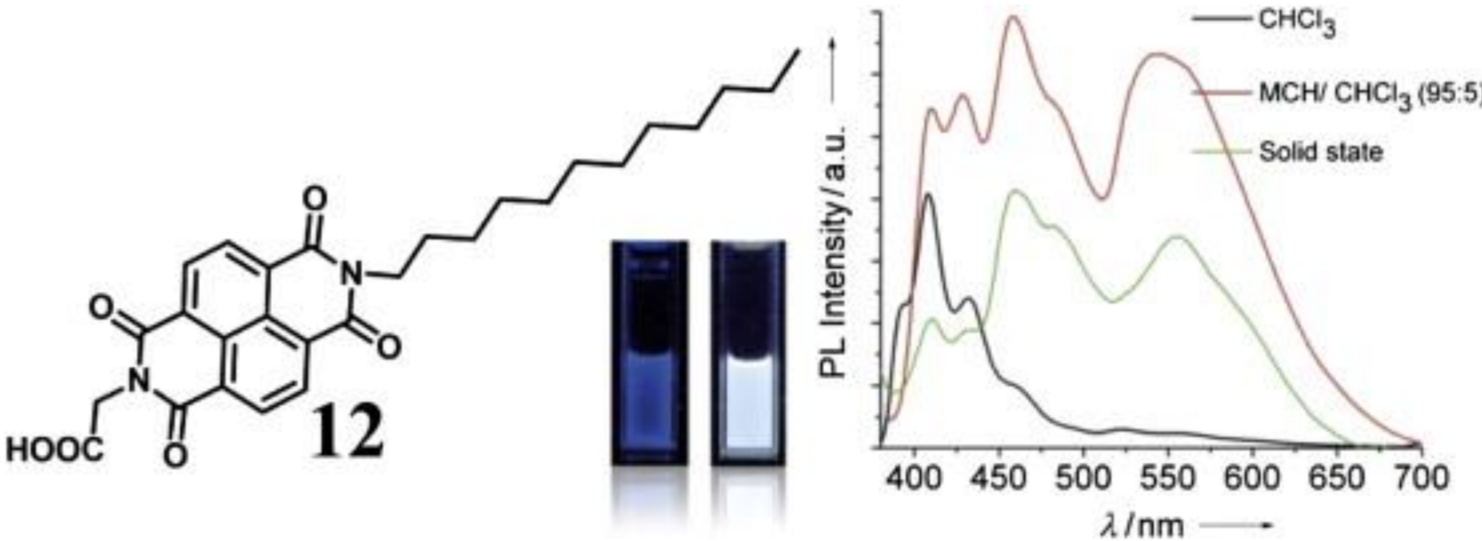


PF-G



PF-R

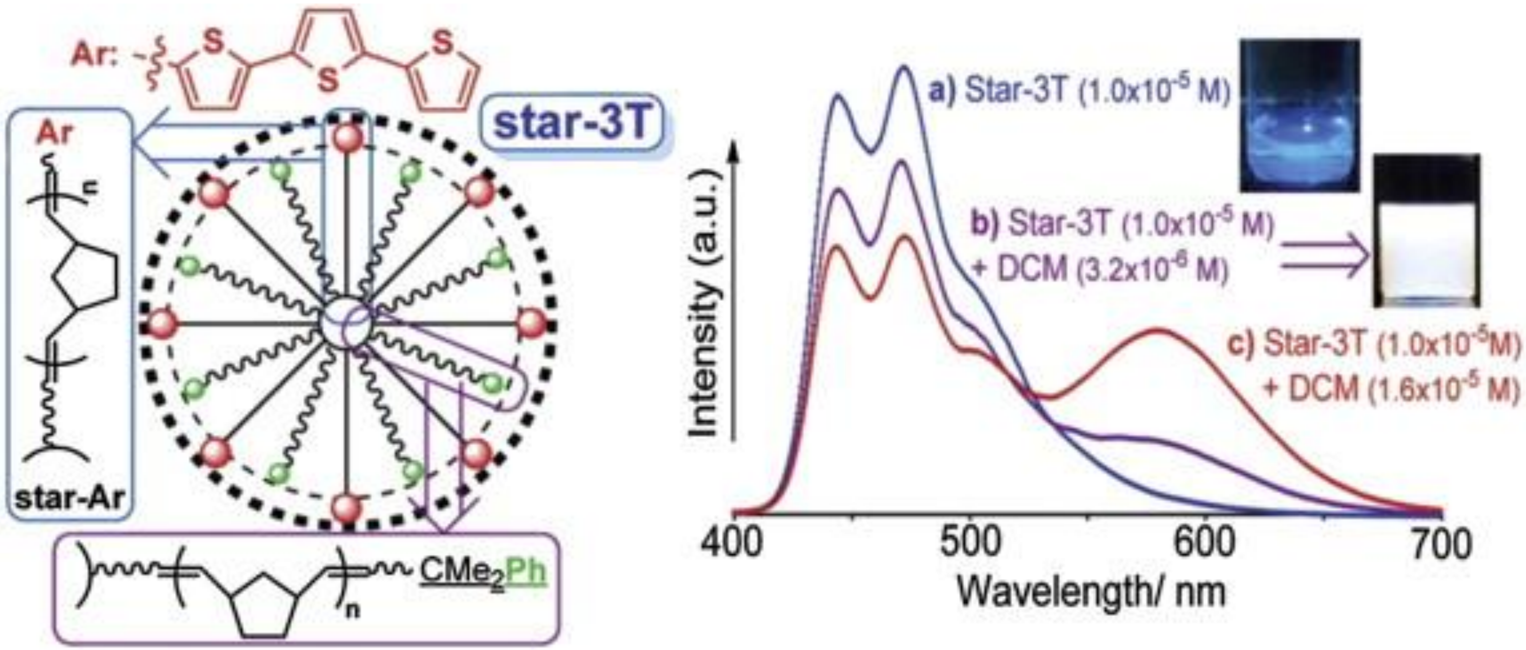
LEDs Orgánicos (OLEDs)



Molecular formula of **12** (left). Photographs of **12** in $CHCl_3$ and $MCH/CHCl_3$ (95:5) solutions (middle). Emission spectra of **12** in different conditions upon excitation at 340 nm (right). Adapted with permission from reference 33. Copyright 2012, John Wiley and Sons

S. Mukherjee, P. Thilagar "Organic white-light emitting materials" Dyes and Pigments, Volume 110, 2014, 2 - 27

LEDs Orgánicos (OLEDs)



Left; Schematic representation of the star shape structure of the **star-3T** polymer. Right; fluorescence spectra of **star-3T** upon addition of **DCM** in THF at 25 °C with excitation at 380 nm. Adapted with permission from reference 76. Copyright 2012, American Chemical Society. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

S. Mukherjee, P. Thilagar "Organic white-light emitting materials" Dyes and Pigments, Volume 110, 2014, 2 - 27

Conclusión...

Vamos a asistir (estamos ya asistiendo) a una Re-evolución tecnológica hacia un modelo sostenible de generación, almacenamiento y consumo de energía, basada en revoluciones científicas en las que los nanomateriales tendrán mucho que aportar:

Biocombustibles de 2ª y 3ª generación
H_2 Generación sostenible y almacenamiento eficiente
Pilas de combustible baratas, sin Pt
Si solar barato / materiales alternativos / Nanopartículas
Baterías de alta densidad de potencia y recarga rápida
Supercondensadores de alta densidad de energía
LEDs blancos, brillantes y baratos


QUESTIONS

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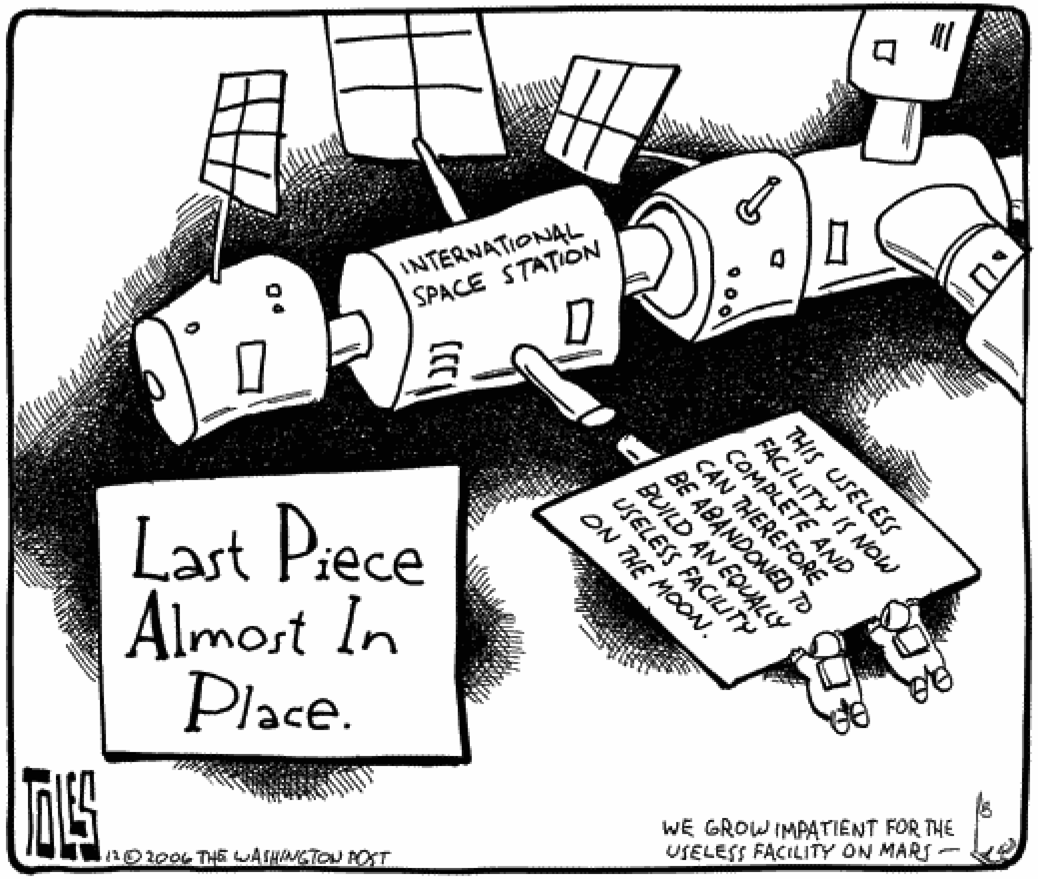

Will you prefer **war** as a technology booster?
If yes… In your own backyard or in someone else’s