



# De los nanómetros a los teravattios: Revoluciones pendientes para el cambio de modelo energético

**Prof. Pedro Gómez Romero**

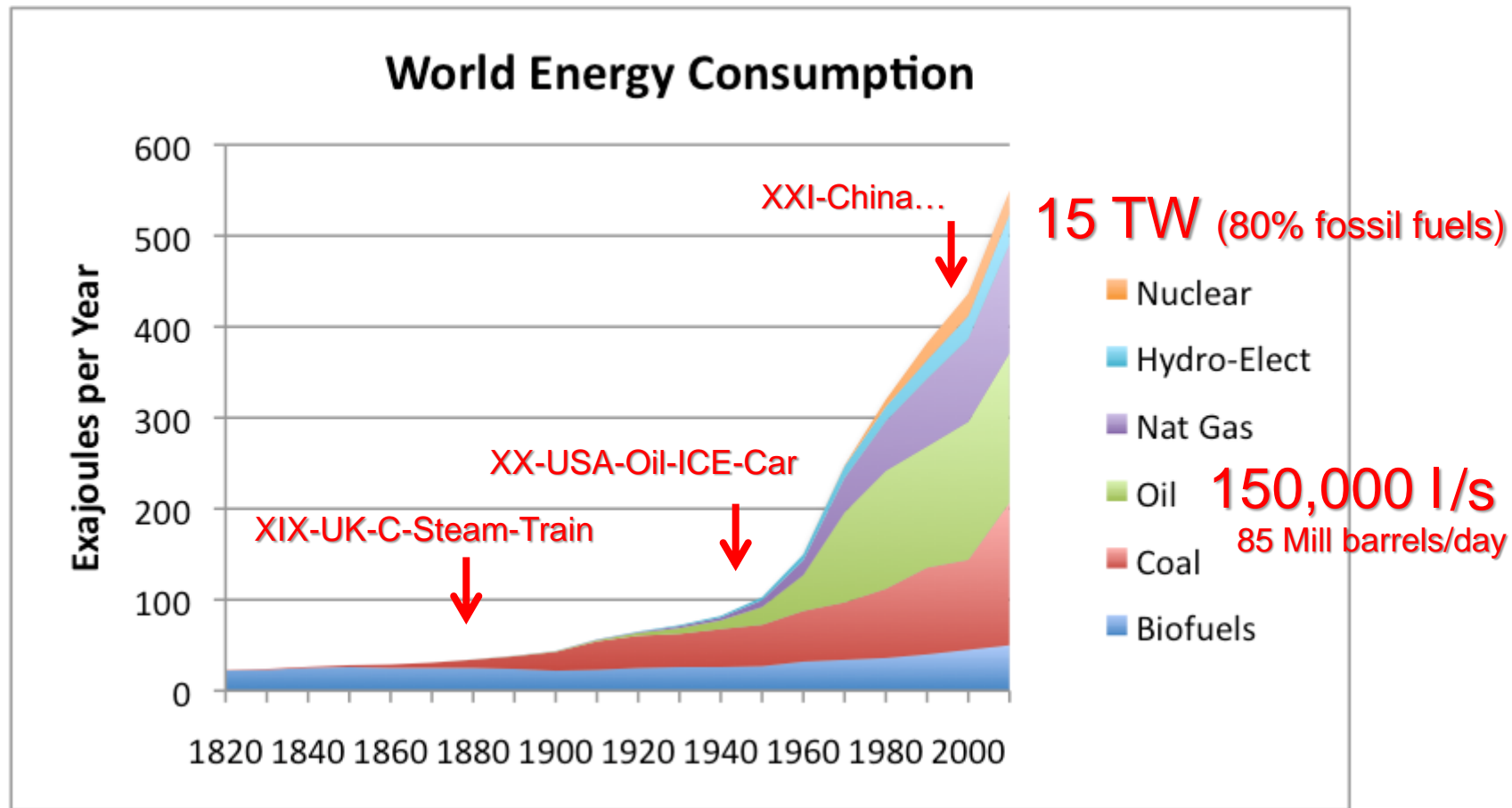
Institut Català de Nanociència i Nanotecnologia, ICN2 (CSIC-BIST), Bellaterra (Barcelona).  
Col·lectiu CMES per a Nou Model Energètic i Social Sostenible. 4 Sept 2017

**La huella de nuestra especie favorita**



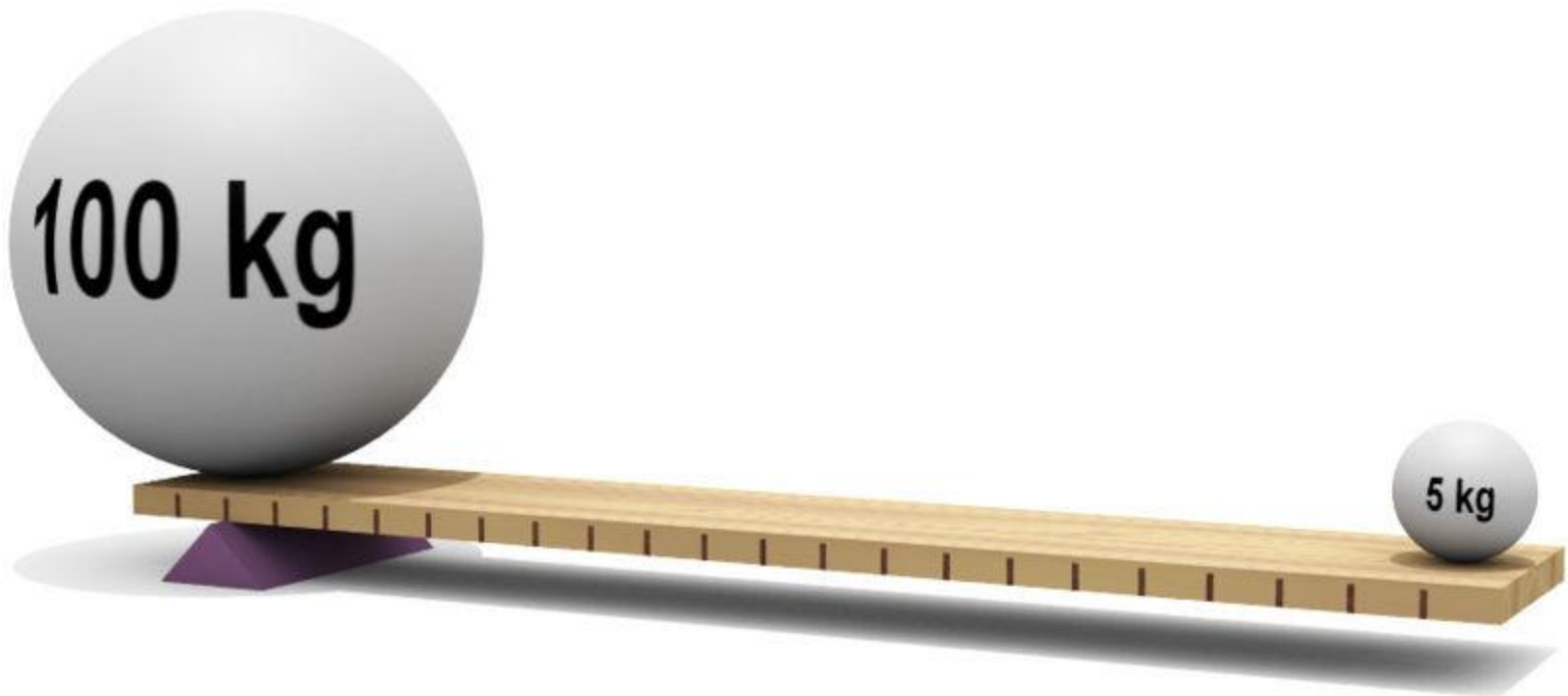
**una visión alienígena**

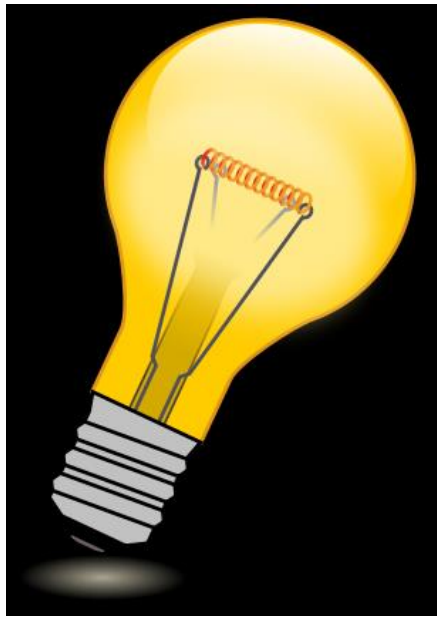
# Evolución del consumo global de energía... y de recursos



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

# ***La autoinsuficiencia humana***





**100 W**





**400 W**



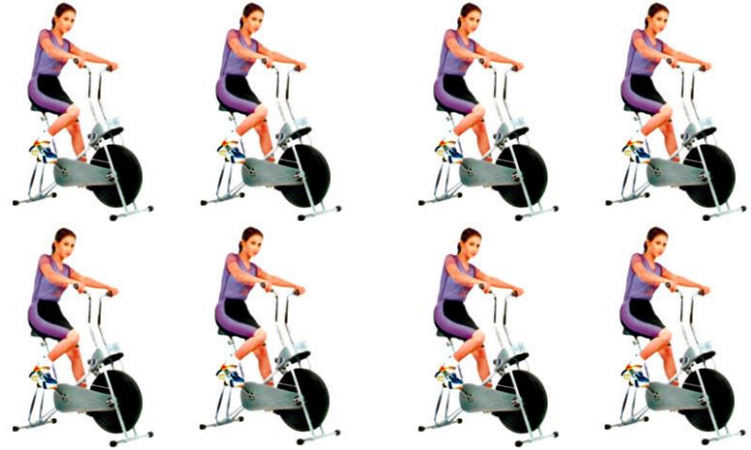
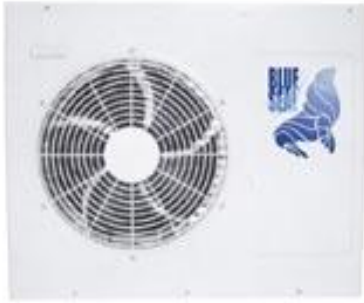


**1000 W**





2400 W





100CV 73600 W



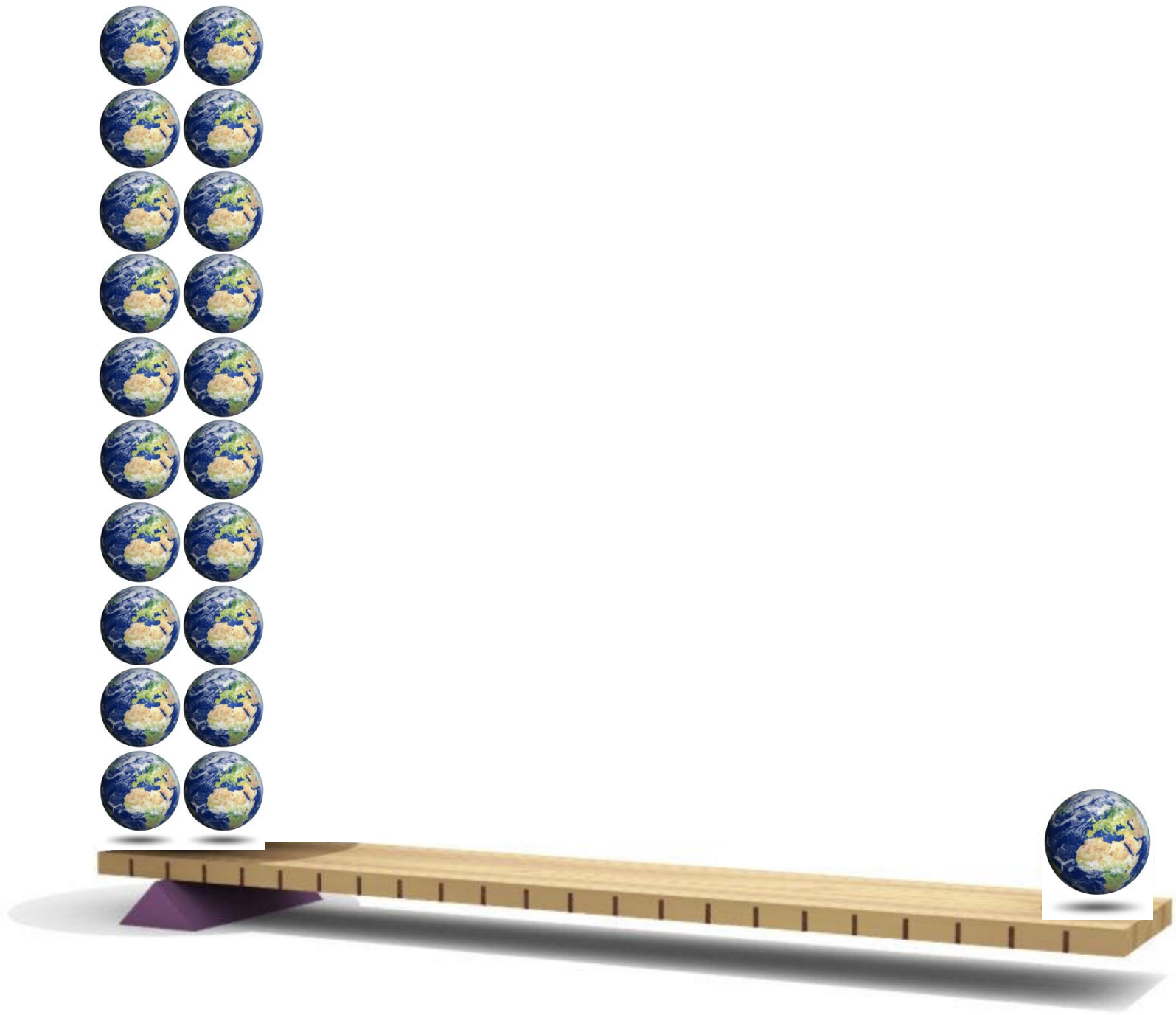
15TW = 15,000,000,000,000 vatios

100 vatios /humano

150,000,000,000 humanos

7,500,000,000 humanos/Tierra

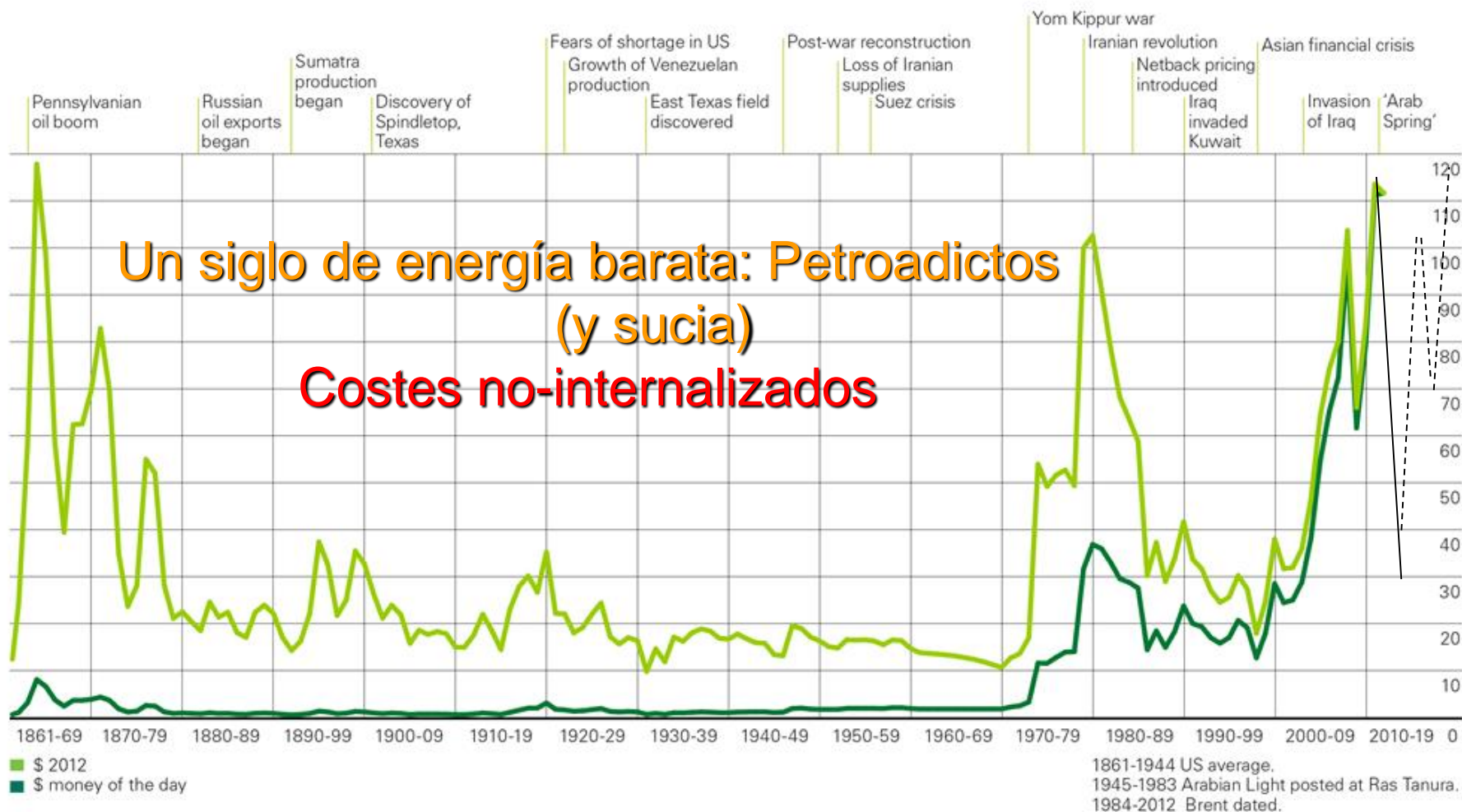
**20 Tierras**



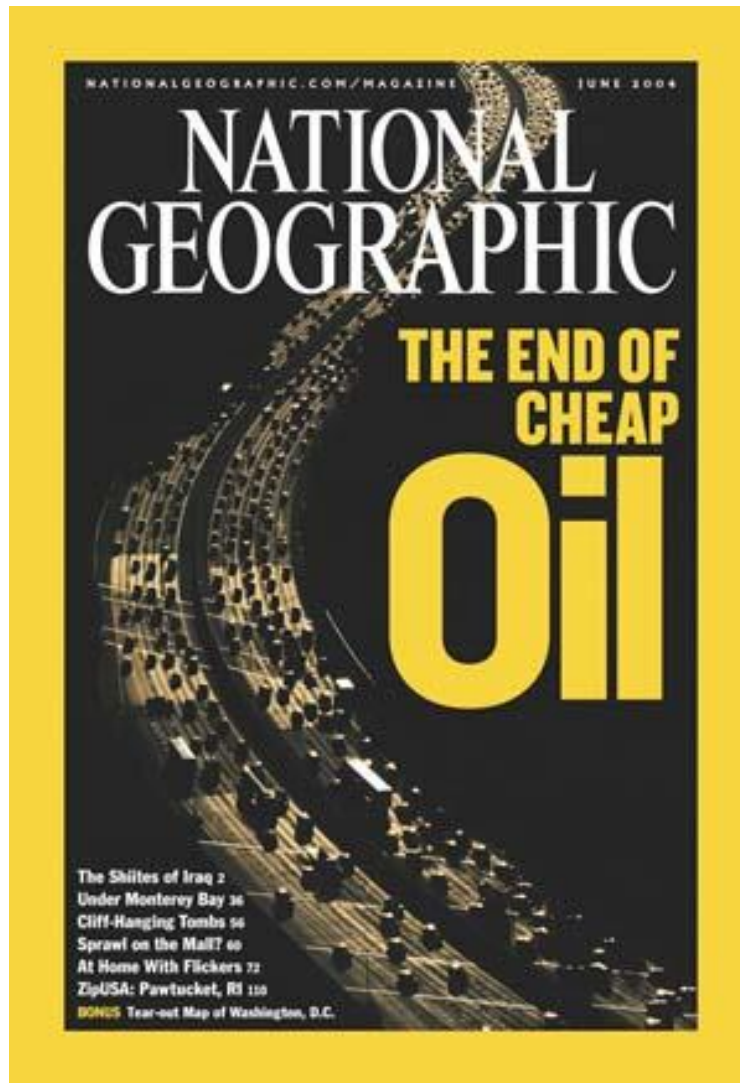
# Crude oil prices 1861-2012

US dollars per barrel, world events

## ¿Cómo hemos llegado a esto?





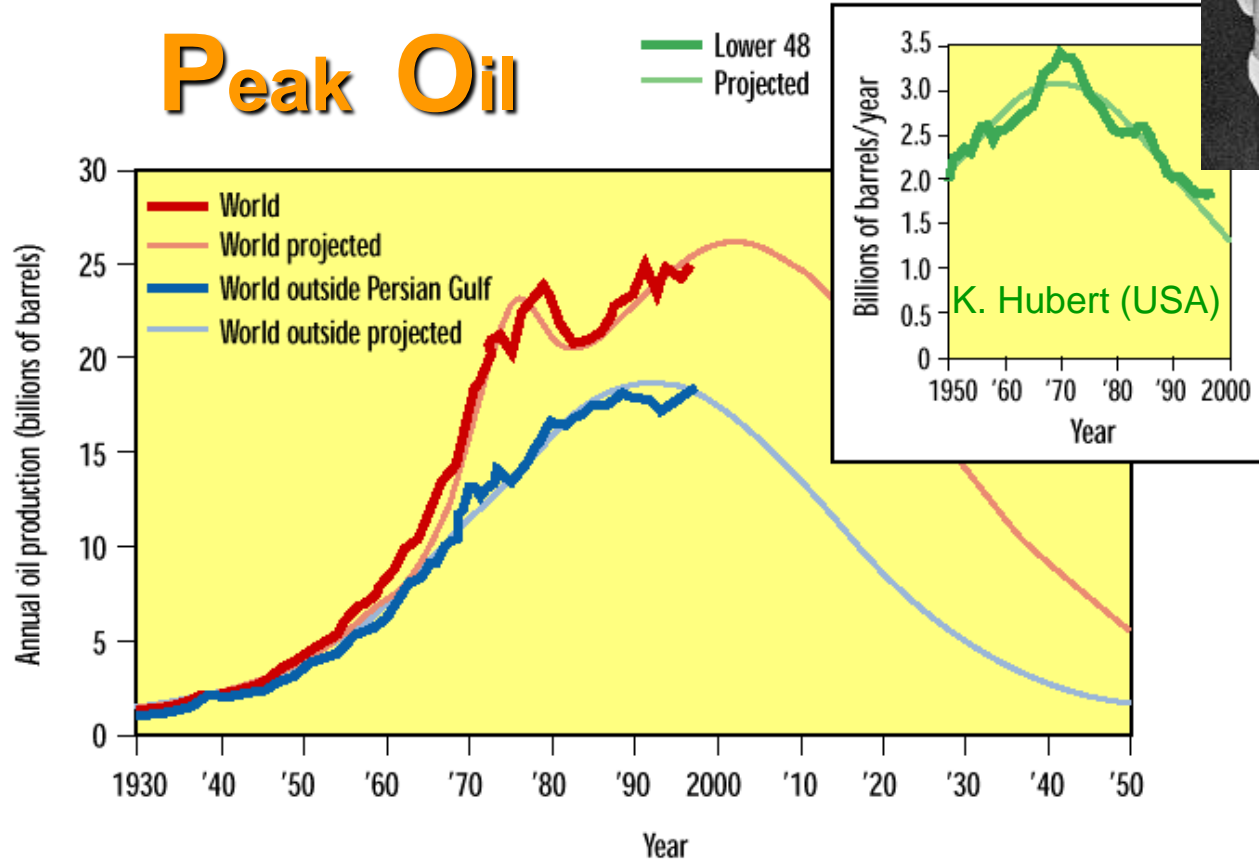


Junio 2004, Volumen 205, Numero 6


# Petróleo El pico de Hubbert



## Peak Oil



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



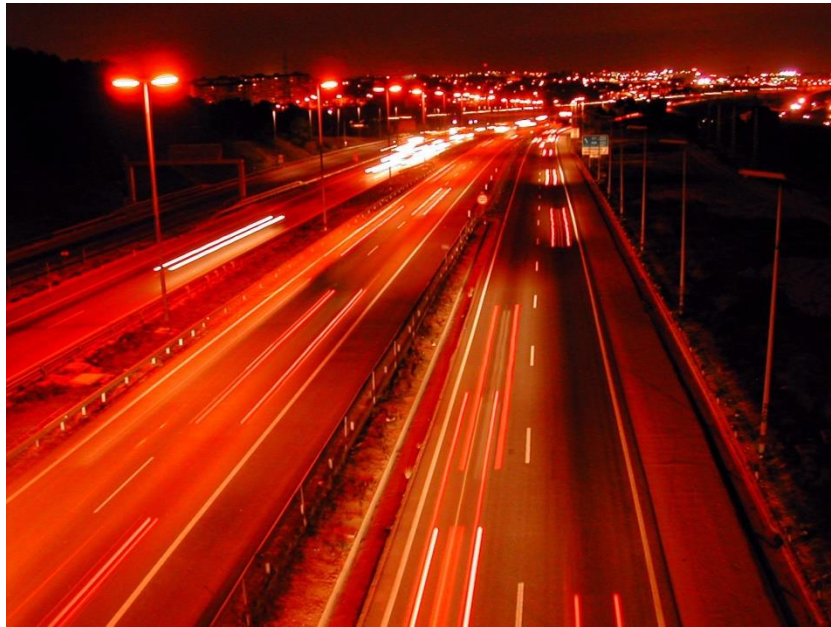
El *Fracking* NO anuncia el principio de una nueva era, sino el final de la era de los combustibles fósiles.

Brought to you by your Fracking Fossil Fuel Company



# Petróleo

Phase Out or Peak Oil



Esto ya ocurrió antes

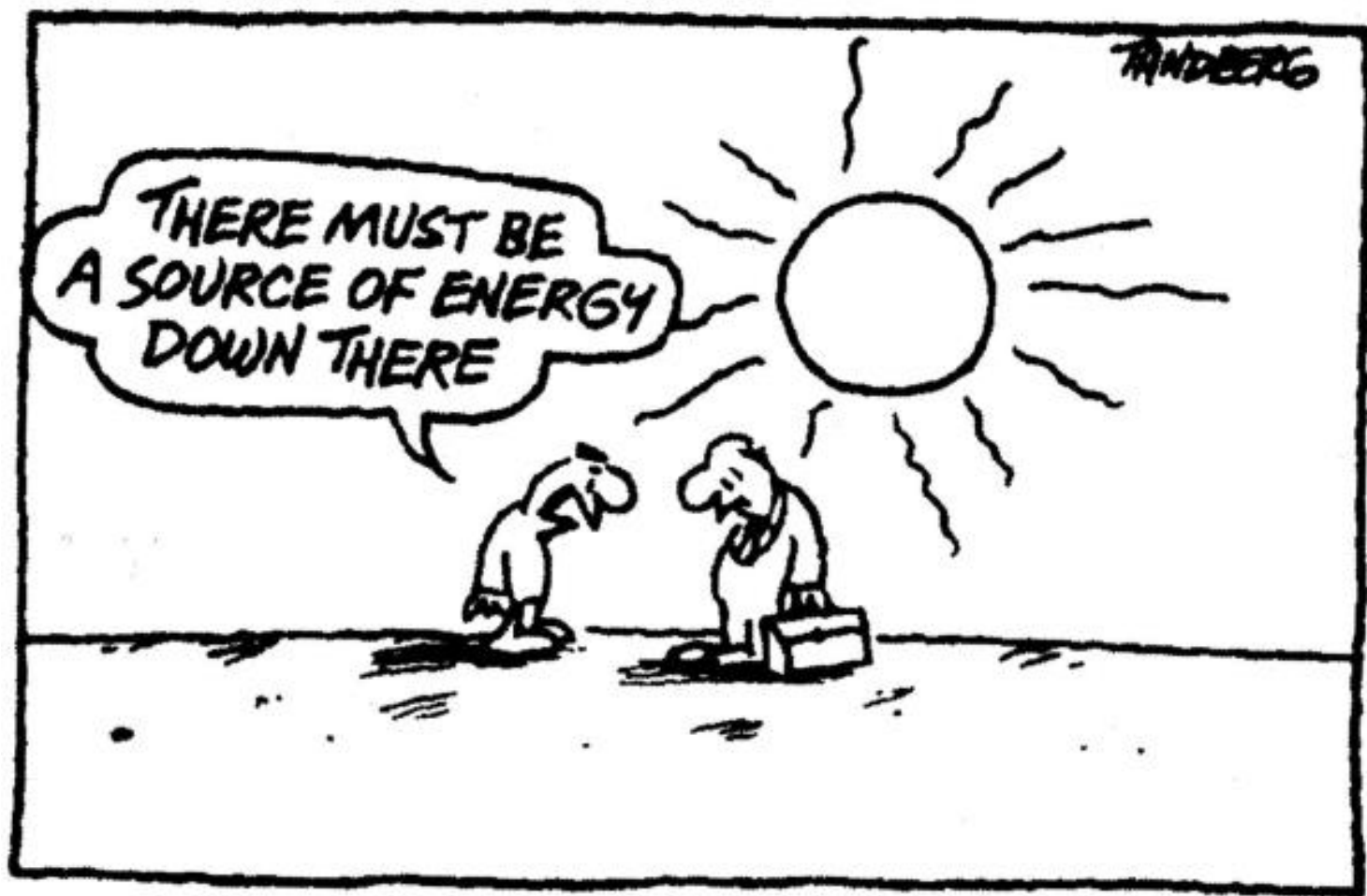
## The peak-buffalo story ( I mean...history )



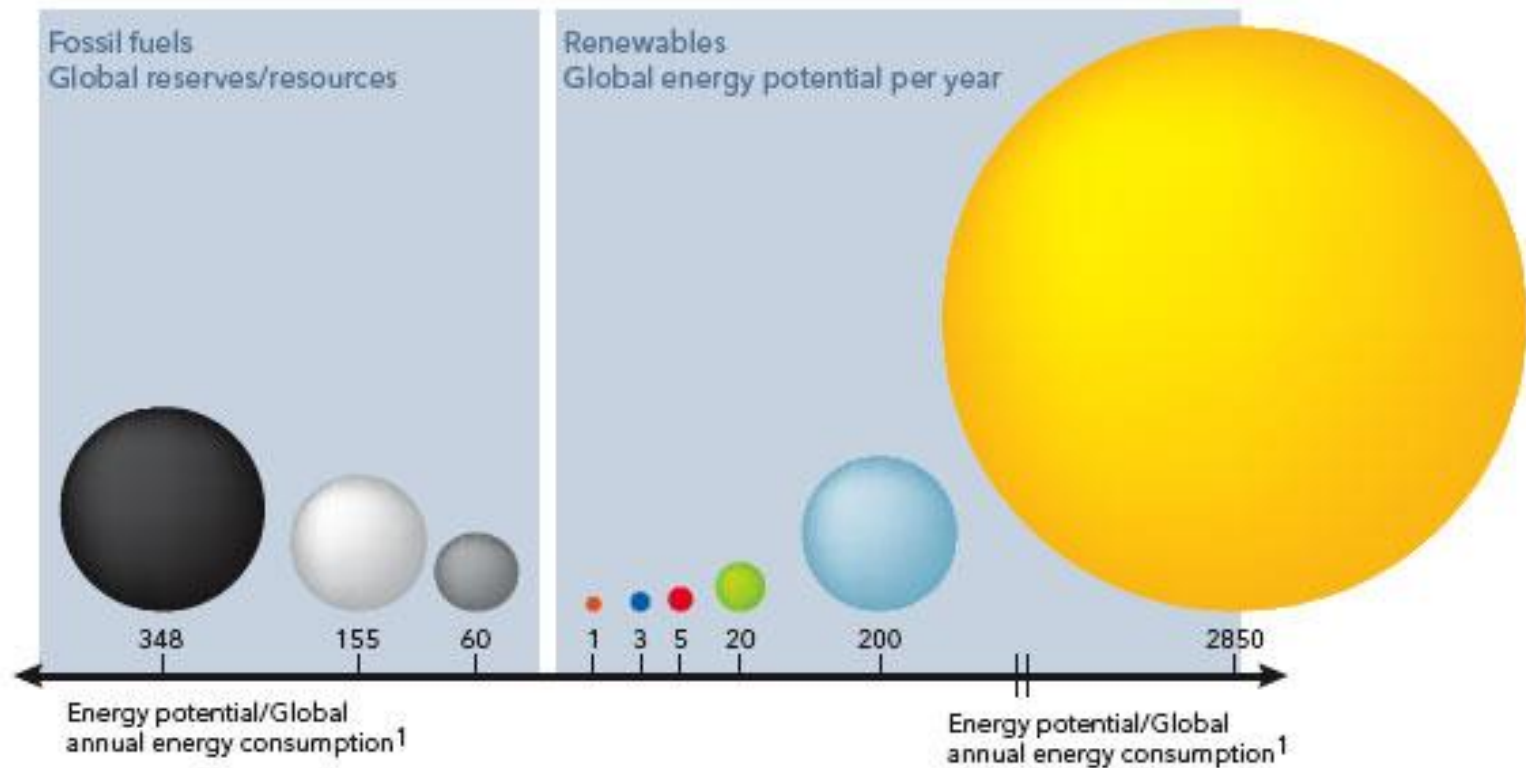
From buffalo-bullies ...to cow-boys

# ¿La solución al negro panorama de la energía?





# Fuentes primarias: ¿Sol arcaico o moderno?



	Energy potential Reserves/Resources <sup>2</sup>	Thereof conven- tionally utilisable <sup>2</sup>		Energy potential (amount of energy p. a.) <sup>2</sup>	technologically utilis- able (state of the art) <sup>2</sup>
■ Coal	~ 135.000 EJ		■ Solar radiation	~ 1.111.500 EJ	~ 1.482 EJ
■ Natural gas	~ 60.400 EJ	~ 12.000 EJ	■ Wind energy	~ 78.000 EJ	~ 195 EJ
■ Crude oil	~ 23.000 EJ	~ 9.800 EJ	■ Biomass	~ 7.800 EJ	~ 156 EJ
■ Global energy demand 2006: ~ 470 EJ			■ Geothermal	~ 1.950 EJ	~ 390 EJ
			■ Hydro/tide power	~ 1.170 EJ	~ 78 EJ

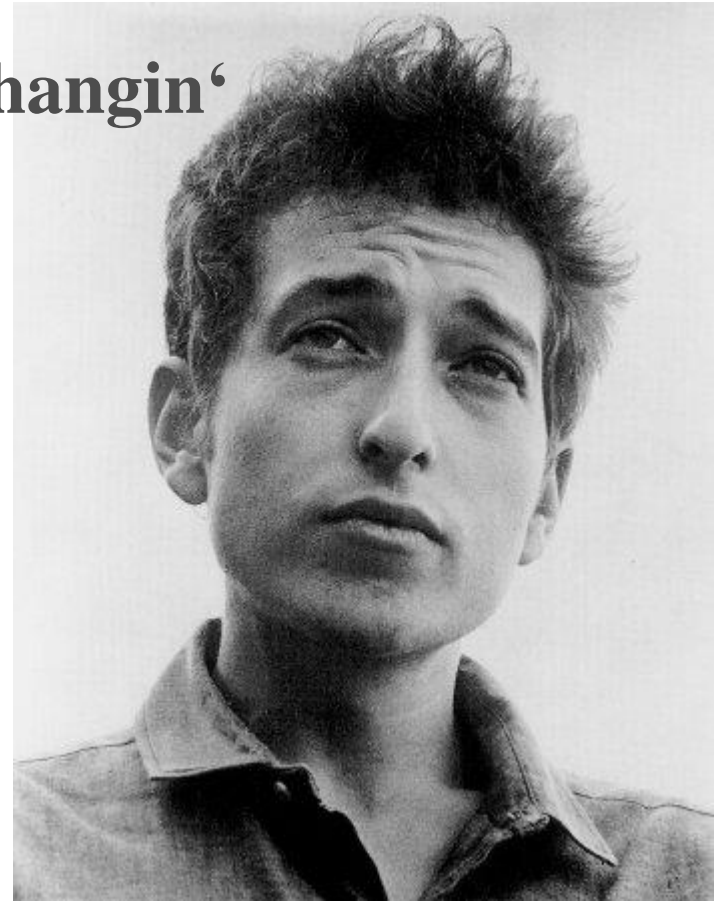
1 EJ = 1 exajoule or  $10^{18}$  joules or ~163 million barrels of oil.

Data source: German Federal Institute for Geosciences and Natural Resources

## **The Times They Are A-Changin'‘**

Come gather 'round people  
Wherever you roam  
And admit that the waters  
Around you have grown  
And accept it that soon  
You'll be drenched to the bone  
If your time to you  
Is worth savin'  
Then you better start swimmin'  
Or you'll sink like a stone  
For the times they are a-changin'

**1964**



**Robert Allen Zimmerman (1941-)  
Nobel Price in Literature, 2016**

**¡El futuro está aquí!**



parque eólico de Sisante  
(Iberdrola)



Huerto solar en Castilla La Mancha. Solaer

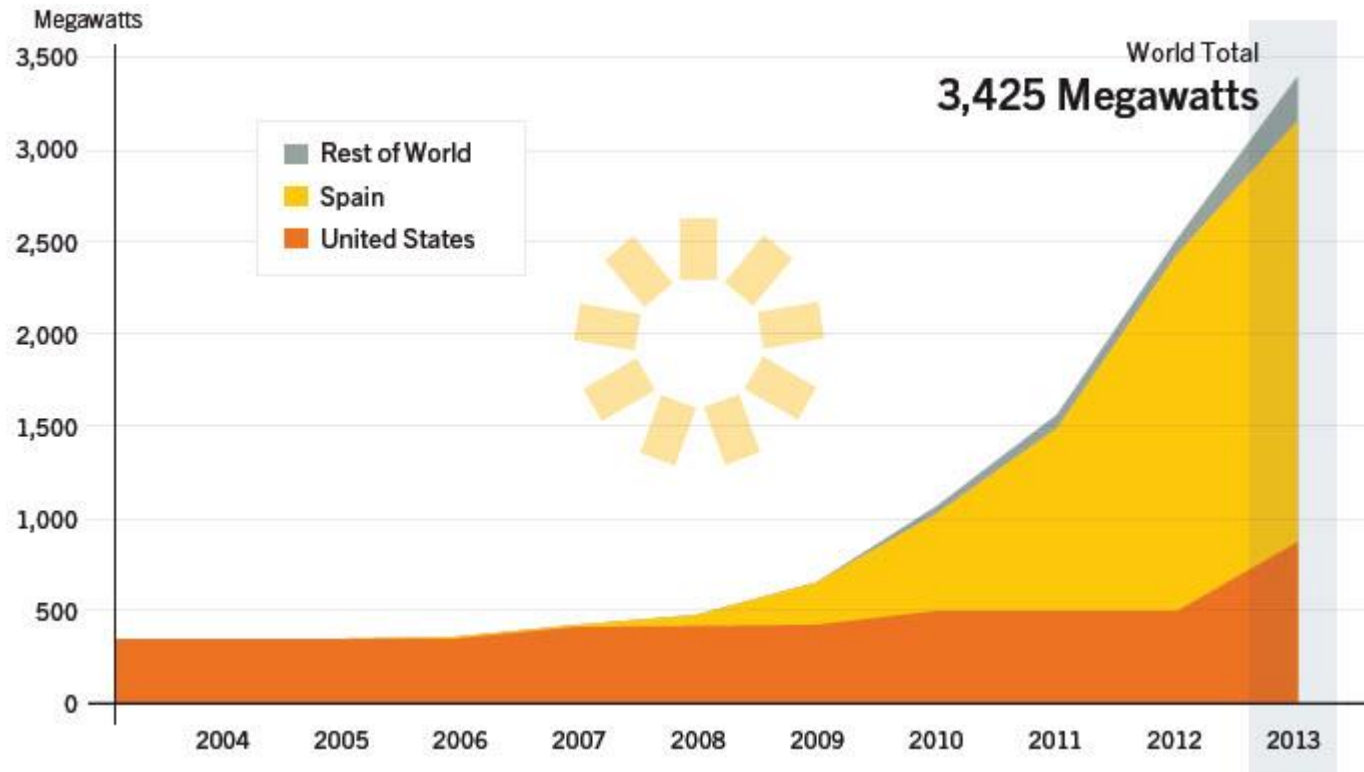
**¡El futuro está aquí!**



PS10 y PS20 centrales eléctricas Termosolares (Abengoa) en Sanlúcar (Sevilla)



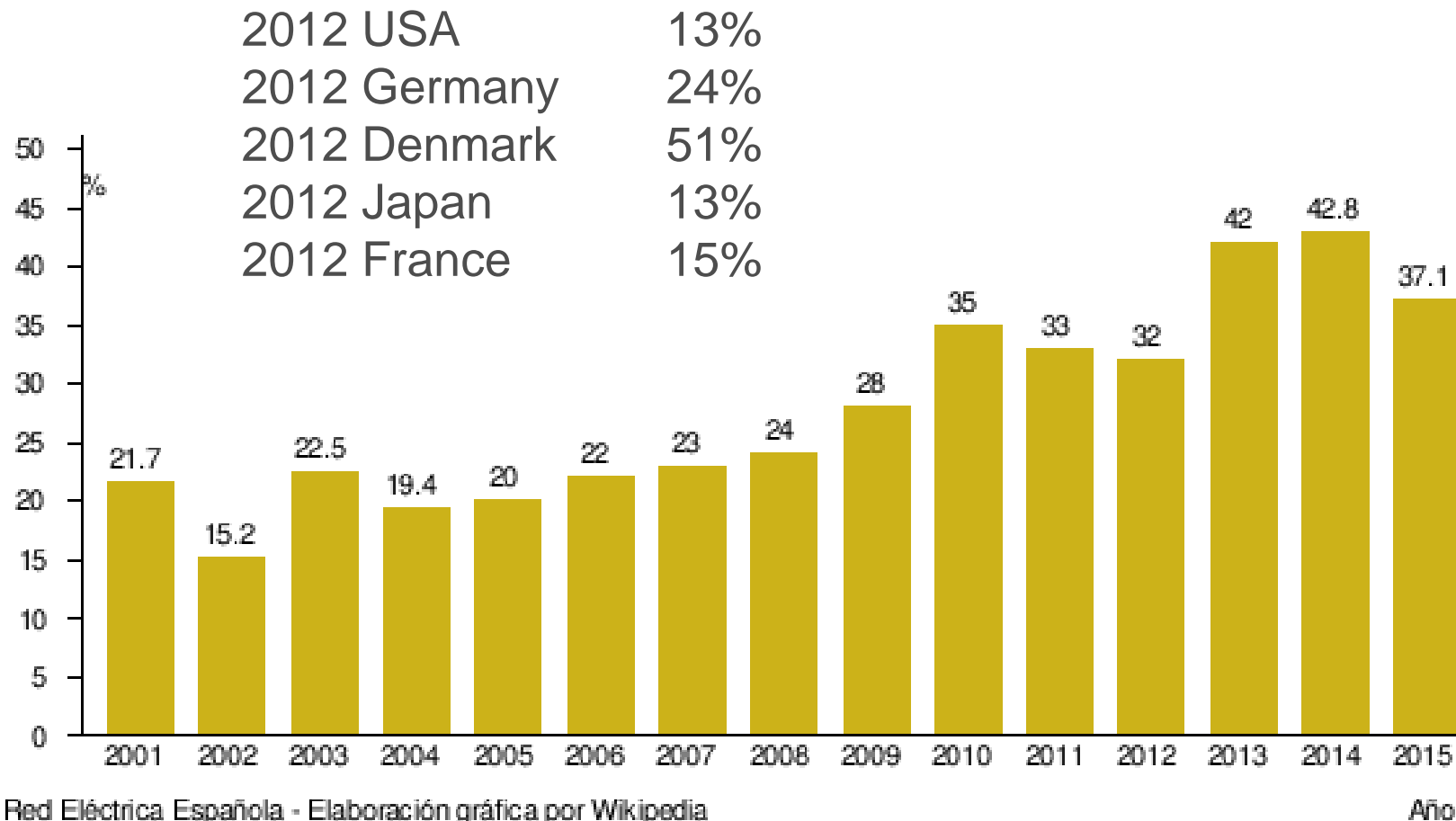
# España, la mayor potencia termosolar mundial



# The new Energy Landscape

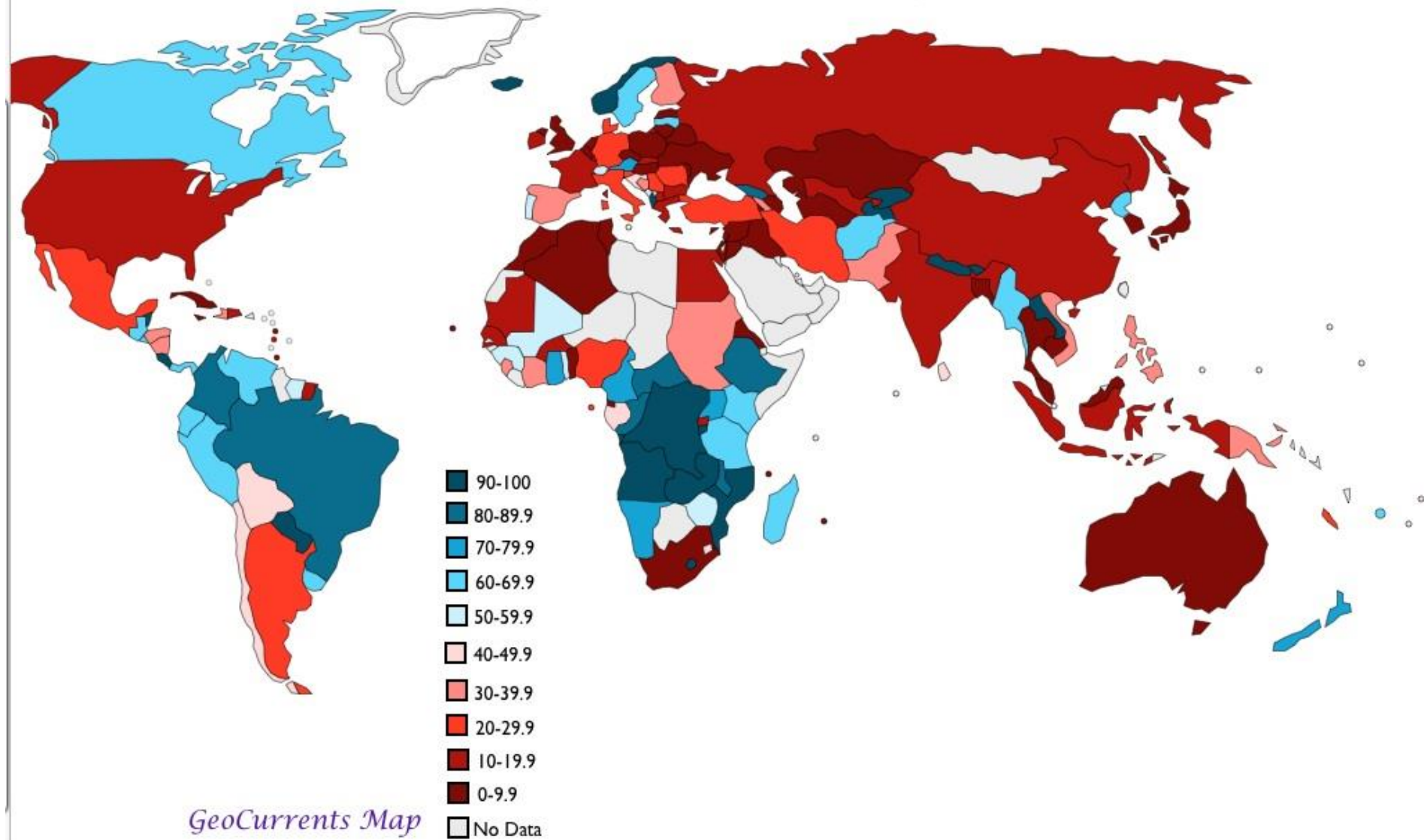


# Renewable electricity in Spain (%)



# 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)

# *pros y contras de las energías renovables*

## contras

Solar	NO funciona de noche
Eólica	NO funciona sin viento

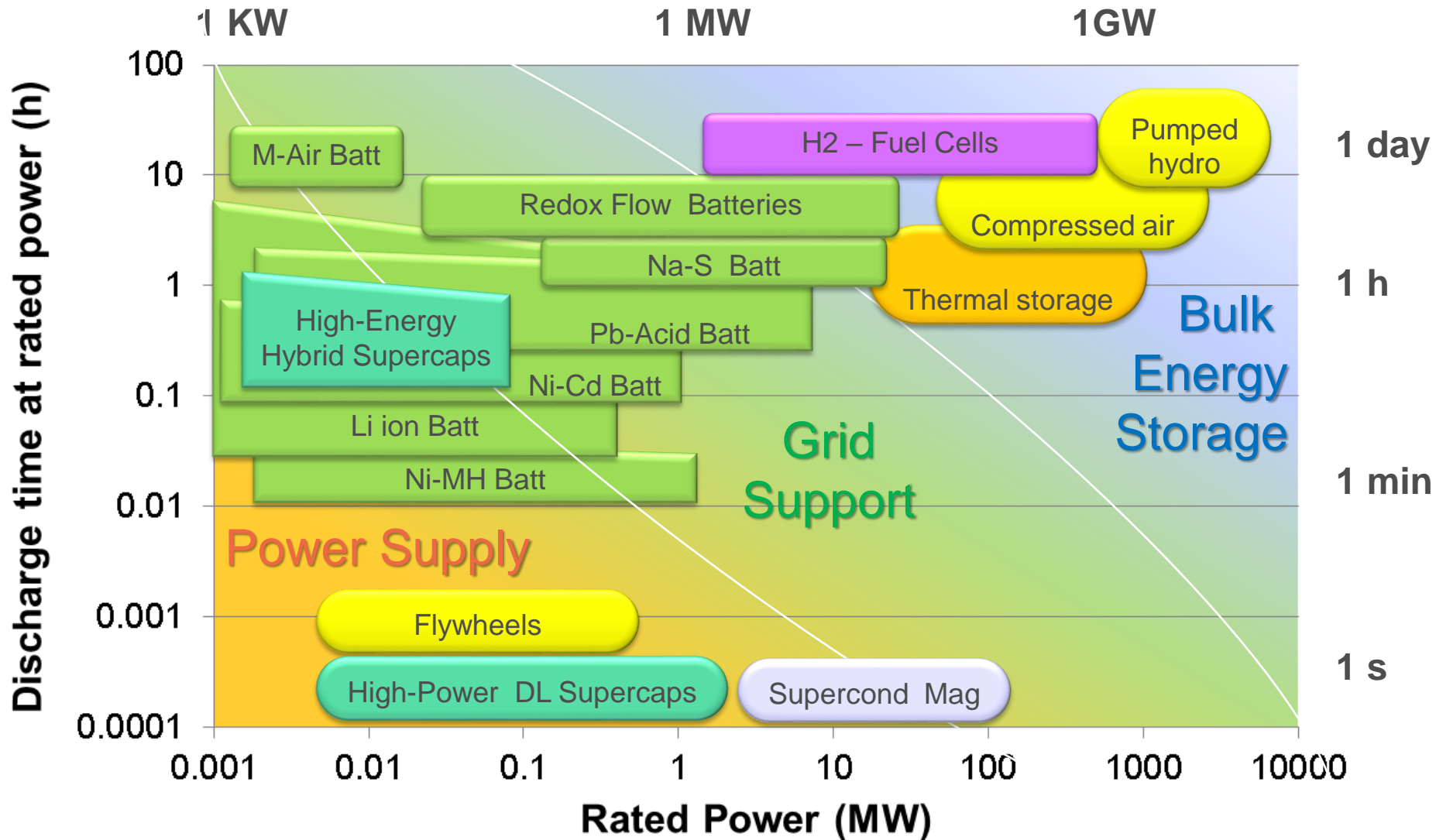
## pros

Solar	Funciona sin viento
Eólica	Funciona de noche

# Almacenamiento de energía eléctrica



# Sistemas de almacenamiento de energía



# Almacenamiento de energía: La Transición







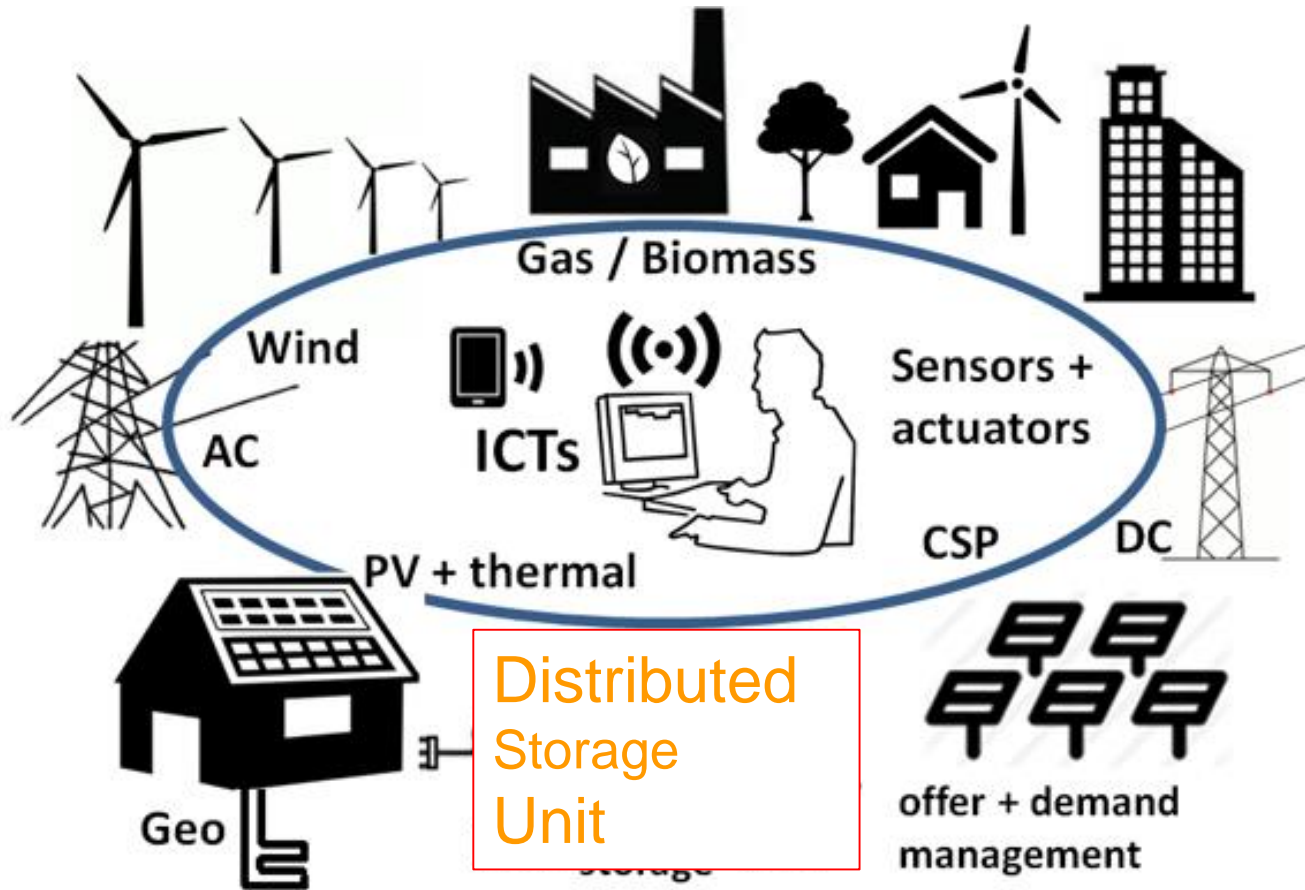
## Centralizada... o distribuida



A 32 MW fleet of batteries smooths the output from AES Corporation's wind farm in Laurel Mountain, W.Va. MRS Bulletin • Vol 37 • Nov 2012

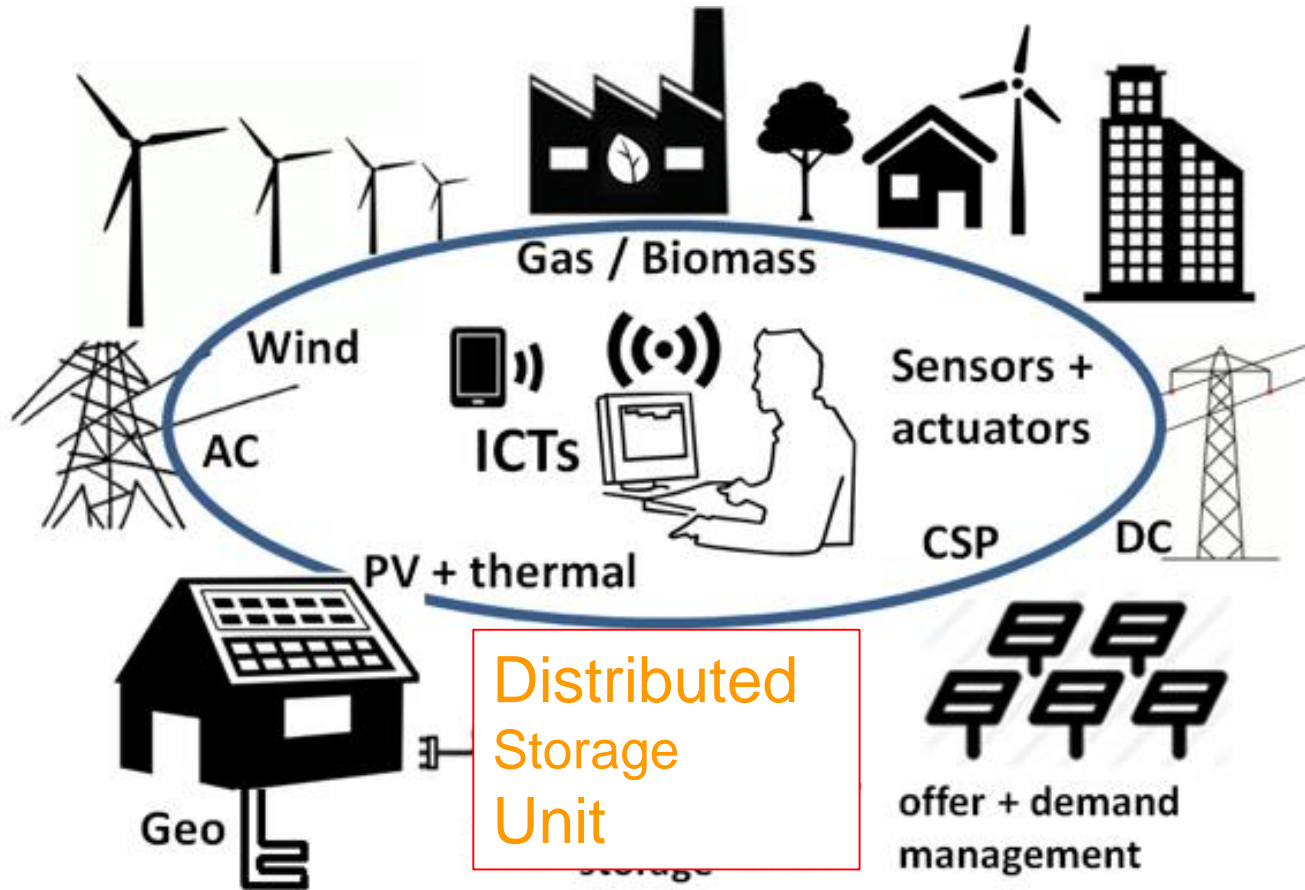
# Energía centralizada... o distribuida

## Smart Grids



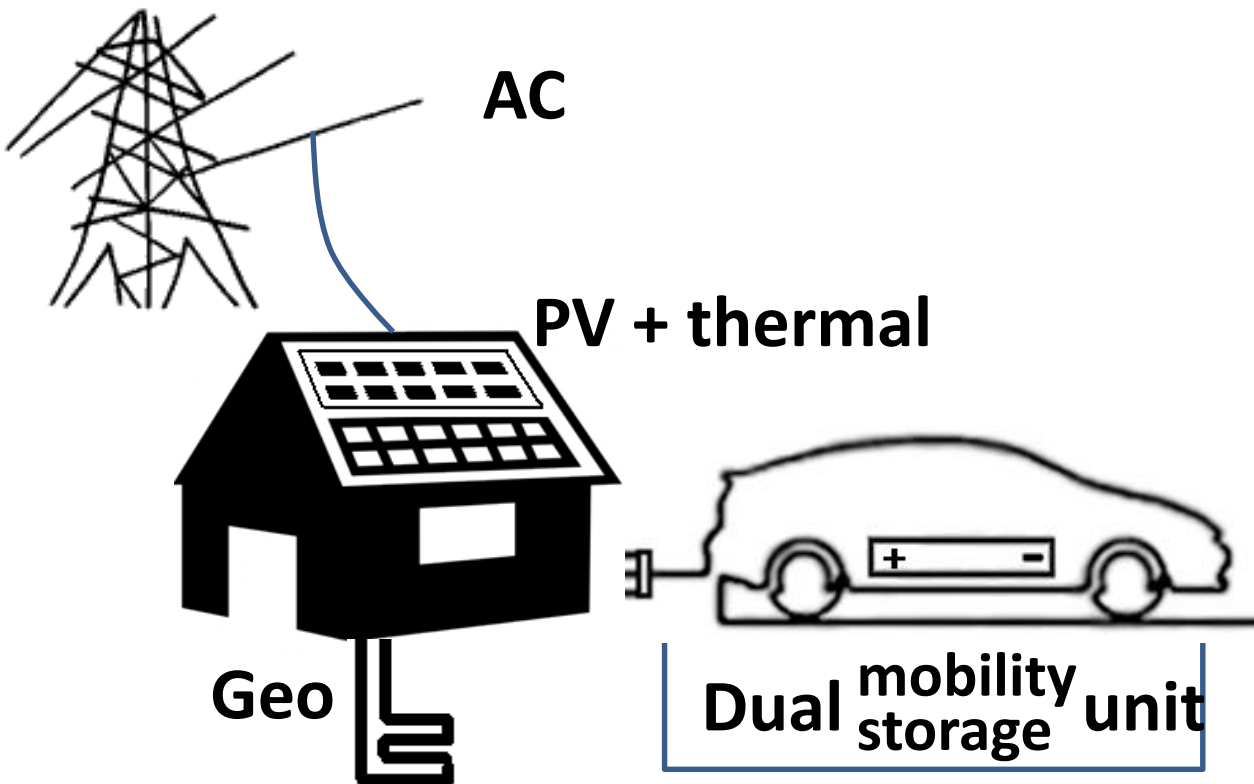
# Energía centralizada... Y distribuida

## Smart Grids



# Generación (y almacenamiento) distribuidos ¿Cuánto falta para el futuro?

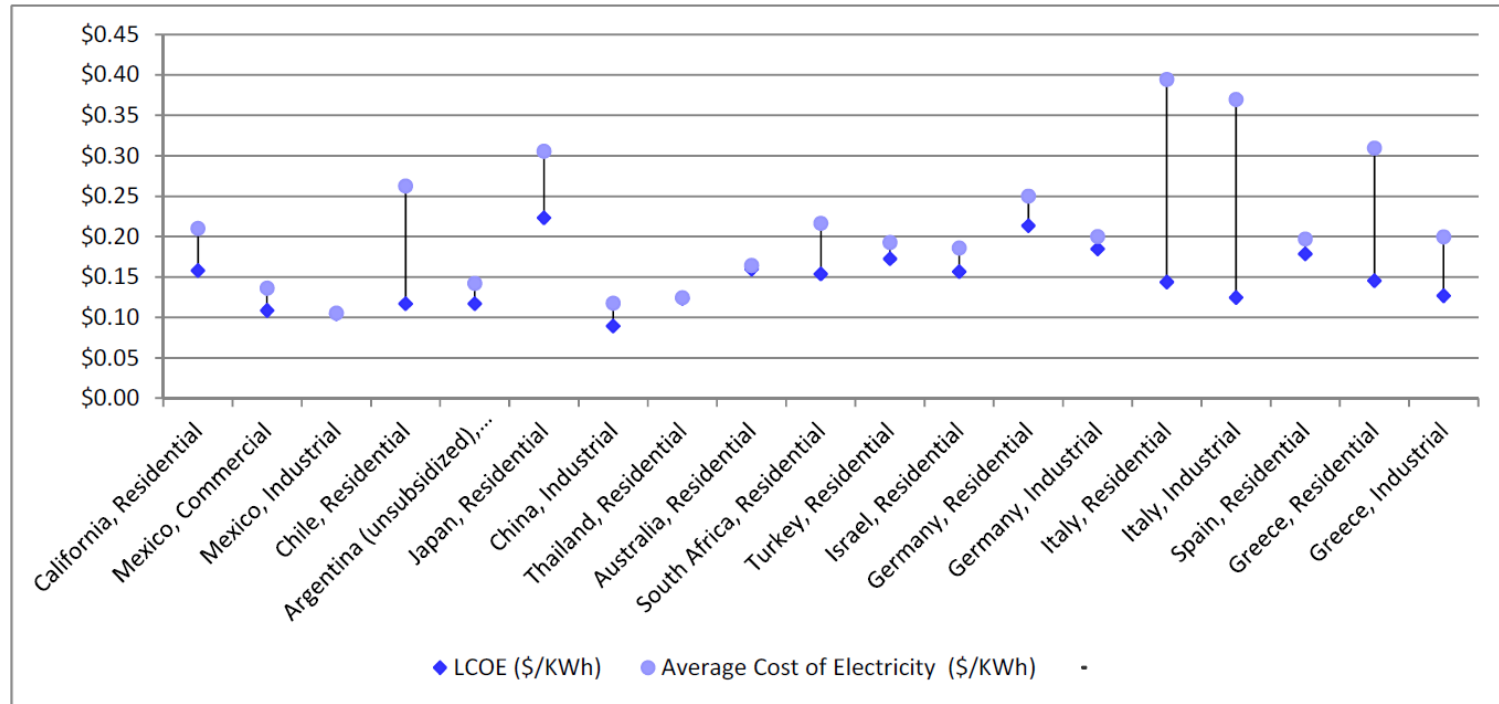
Paridad de red



# ¿son caras las renovables?

1) Solar is currently competitive without subsidies in at least 19 markets globally and we expect more markets to reach grid parity in 2014 as system prices decline further;

Figure 1: Markets at Grid Parity



Source: DB, BLS, Ontario Energy Board, Mexican Ministry of Energy, Chile Energy Group, Argentinean Secretary of Energy, NASA, Tepco, Chinese Economic Observer, Beijing International, Indian Central Regulatory Commission, Australia Power and Gas, Saudi Electric Company, Eksom, EuroStat

# ¿son caras las renovables? Paridad de Red

Solar\_-\_2014\_Outlook\_Let\_the\_Second\_Gold\_Rush\_Begin.pdf - Adobe Acrobat Pro

Archivo Edición Ver Ventana Ayuda

Crear

1 / 31 177%

Herramientas Comentario Compartir

**Deutsche Bank  
Markets Research**

North America  
United States  
Industrials  
Clean Technology

Industry  
**Solar**

Date  
6 January 2014

**Industry Update**

**2014 Outlook: Let the Second Gold Rush Begin**

**Demand Could Surprise to the Upside**  
While we have been generally constructive on the global demand outlook, we are raising our 2014 and 2015 demand expectations to ~46GW and ~56GW respectively. We believe upside demand surprises from the US, Japanese and Chinese markets could continue in 2014. We expect streamlined incentive programs in China, additional subsidy cut signals in end 2014, and decreasing financing constraints to act as catalysts for upside. Similar to the '05-07 capacity rush, we expect another gold rush by downstream installers to add recurring MW ahead of policy changes over the next 2-3 years. Moreover, we expect grid and financing constraints to improve from 2014.

**Supply Situation to Remain Tight**  
We expect global project finance focus to remain skewed towards downstream as opposed to upstream, which in our view could limit capacity

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**Top picks**

Trina Solar (TSL.N),USD15.35	Buy
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# ¿son caras las renovables? Paridad de Red

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4470 (1 de 13)

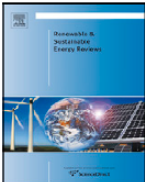
Herramientas Comentario Compartir

Renewable and Sustainable Energy Reviews 15 (2011) 4470–4482

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journal homepage: [www.elsevier.com/locate/rser](http://www.elsevier.com/locate/rser)

## A review of solar photovoltaic levelized cost of electricity

K. Branker<sup>a</sup>, M.J.M. Pathak<sup>b</sup>

<sup>a</sup> Department of Mechanical and Materials Eng  
<sup>b</sup> Department of Materials Science & Engineerin

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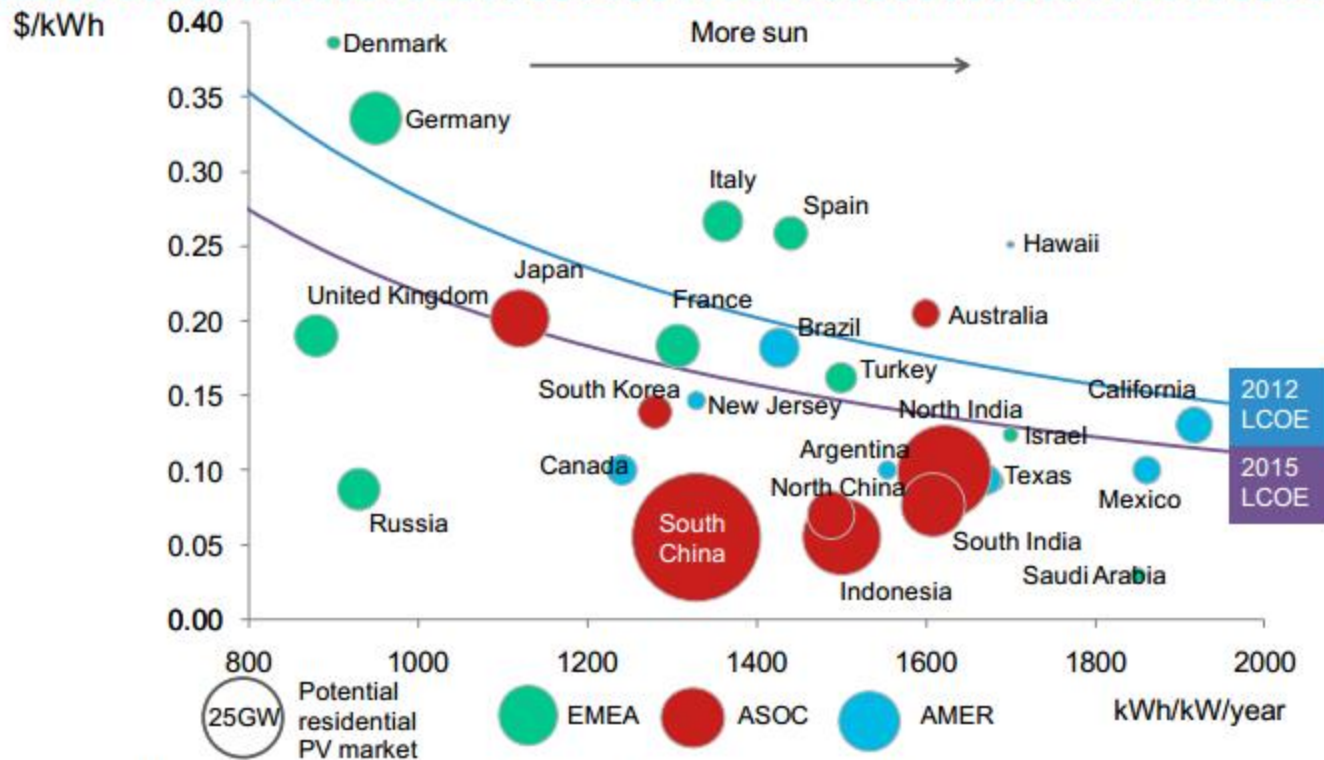
Keywords:  
Photovoltaic  
Levelized cost  
LCOE  
Grid parity  
Solar economics

Given the state of the art in the technology and favourable financing terms it is clear that PV has already obtained grid parity in specific locations and as installed costs continue to decline, grid electricity prices continue to escalate, and industry experience increases, PV will become an increasingly economically advantageous source of electricity over expanding geographical regions.



# ¿son caras las renovables? Paridad de Red

## RESIDENTIAL PV PRICE PARITY – RESIDENTIAL POWER PRICE VERSUS LCOE



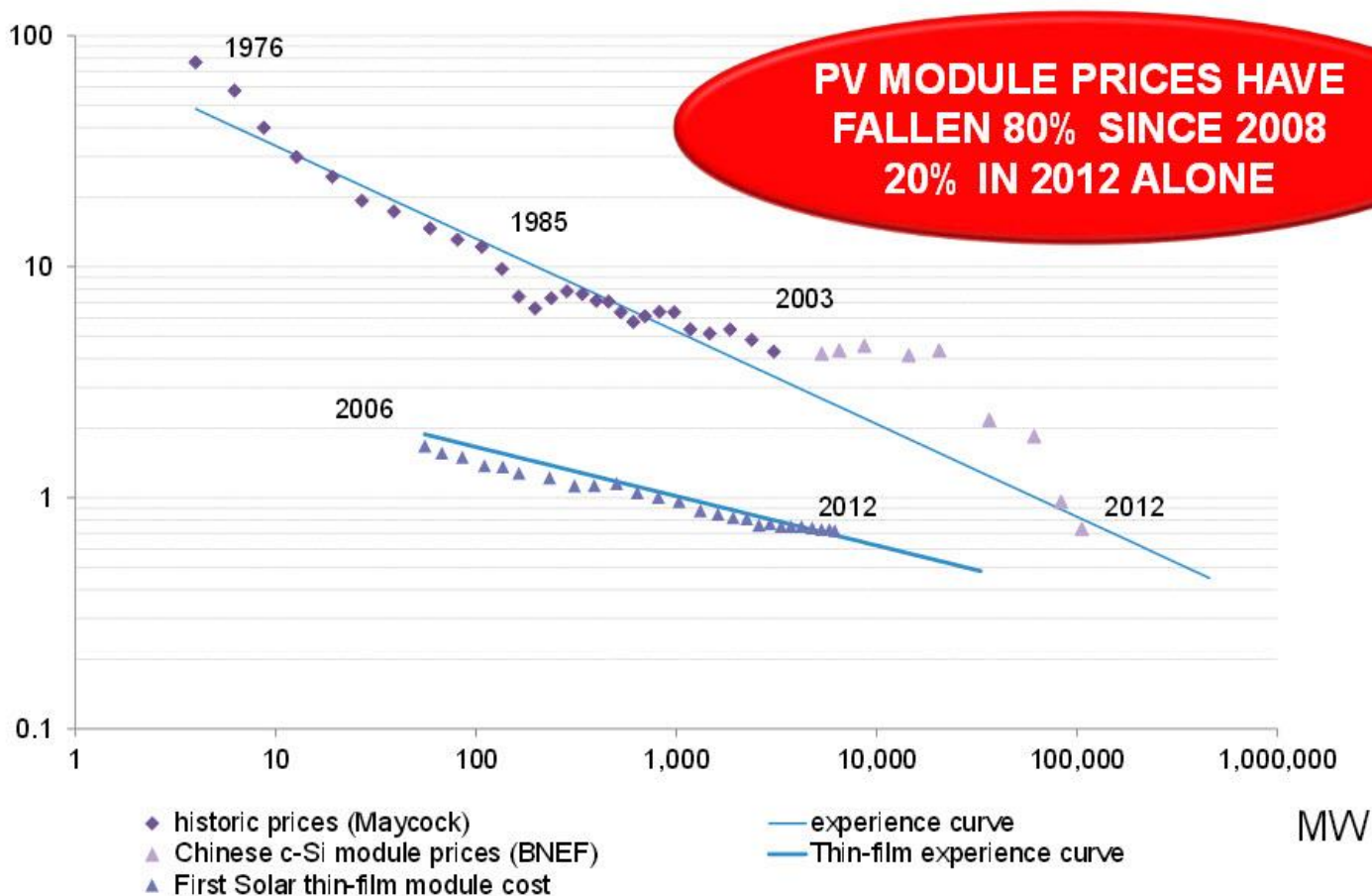
Note: LCOE based on 6% weighted average cost of capital, 0.7%/year module degradation, 1% capex as O&M annually. \$3.01/W capex assumed for 2012, \$2/W for 2015.

Source: Bloomberg New Energy Finance



# ¿son caras las renovables? Paridad de Red

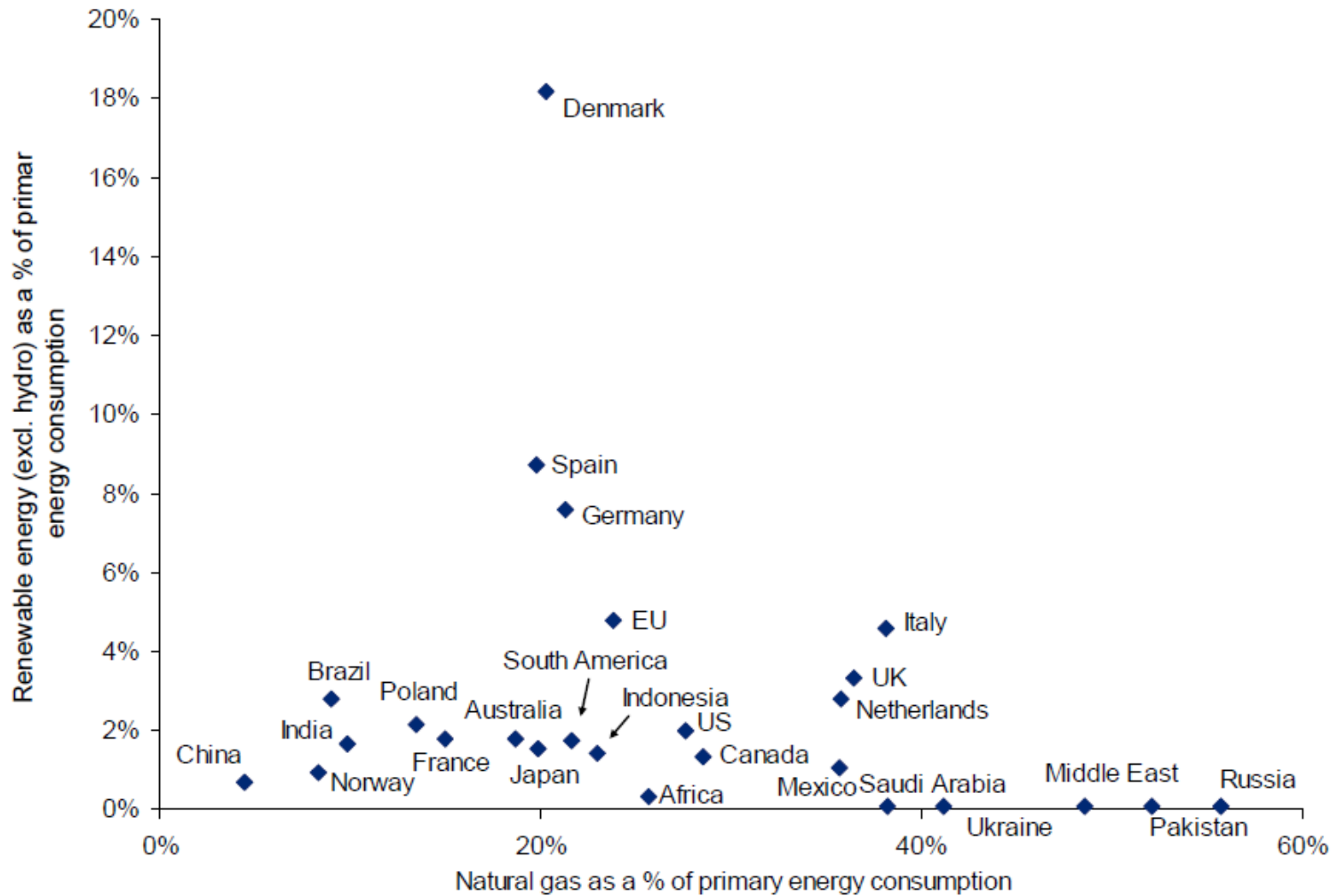
## PV EXPERIENCE CURVE, 1976-2012 2012 \$/W



Note: Prices inflation indexed to US PPI.

Source: Paul Maycock, Bloomberg New Energy Finance

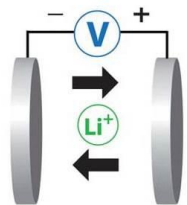
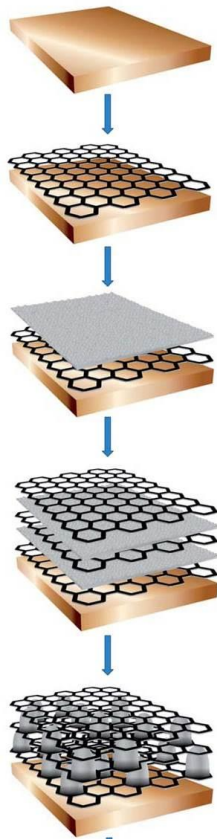
# La Contrarreforma en España



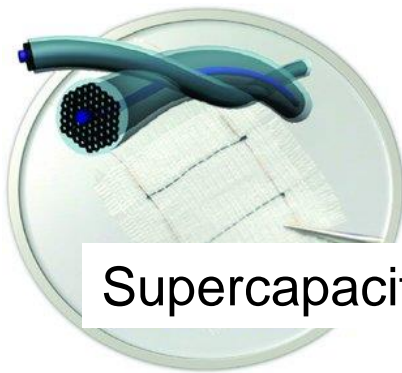
Source: BP Statistical Review, Citi Research

**la ciencia y la tecnología  
como palancas para el cambio  
del modelo energético**

# Grafeno para un futuro sostenible

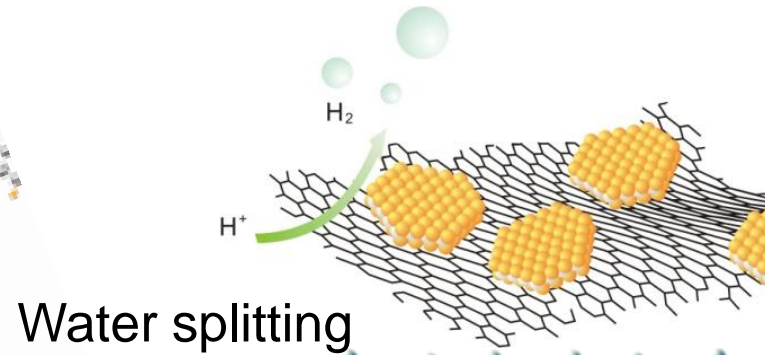
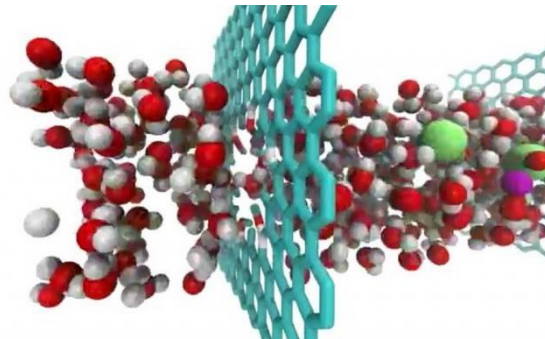


Batteries

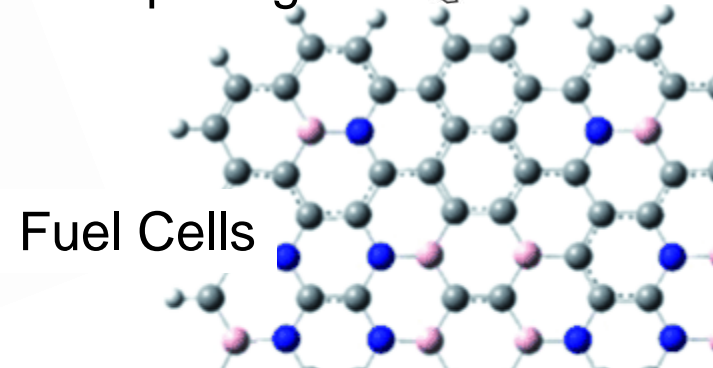


Supercapacitors

Desalination.  
Water purification

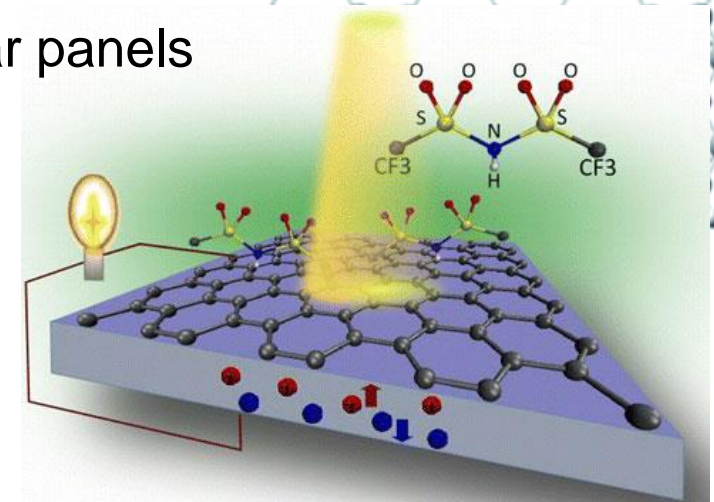


Water splitting

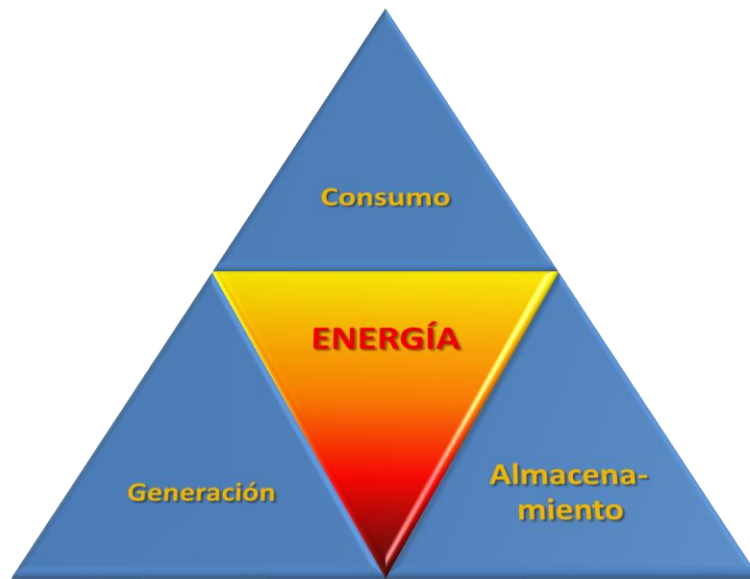


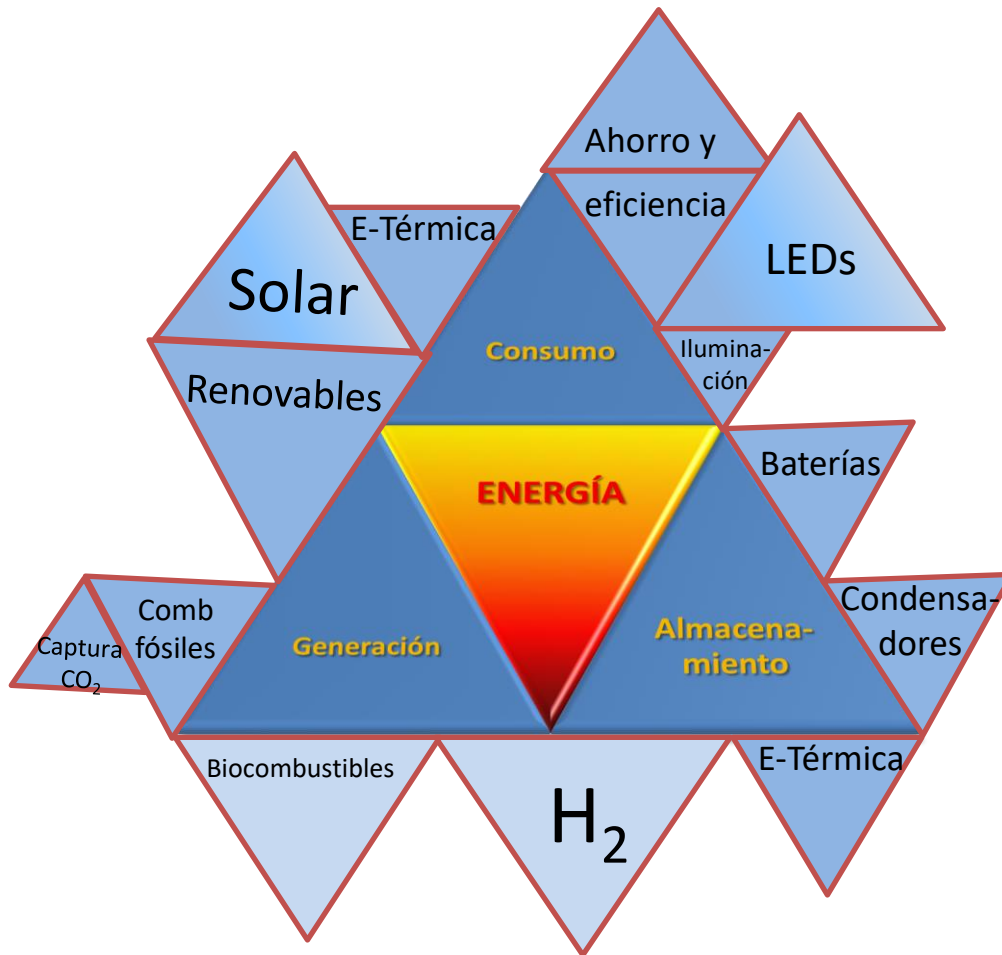
Fuel Cells

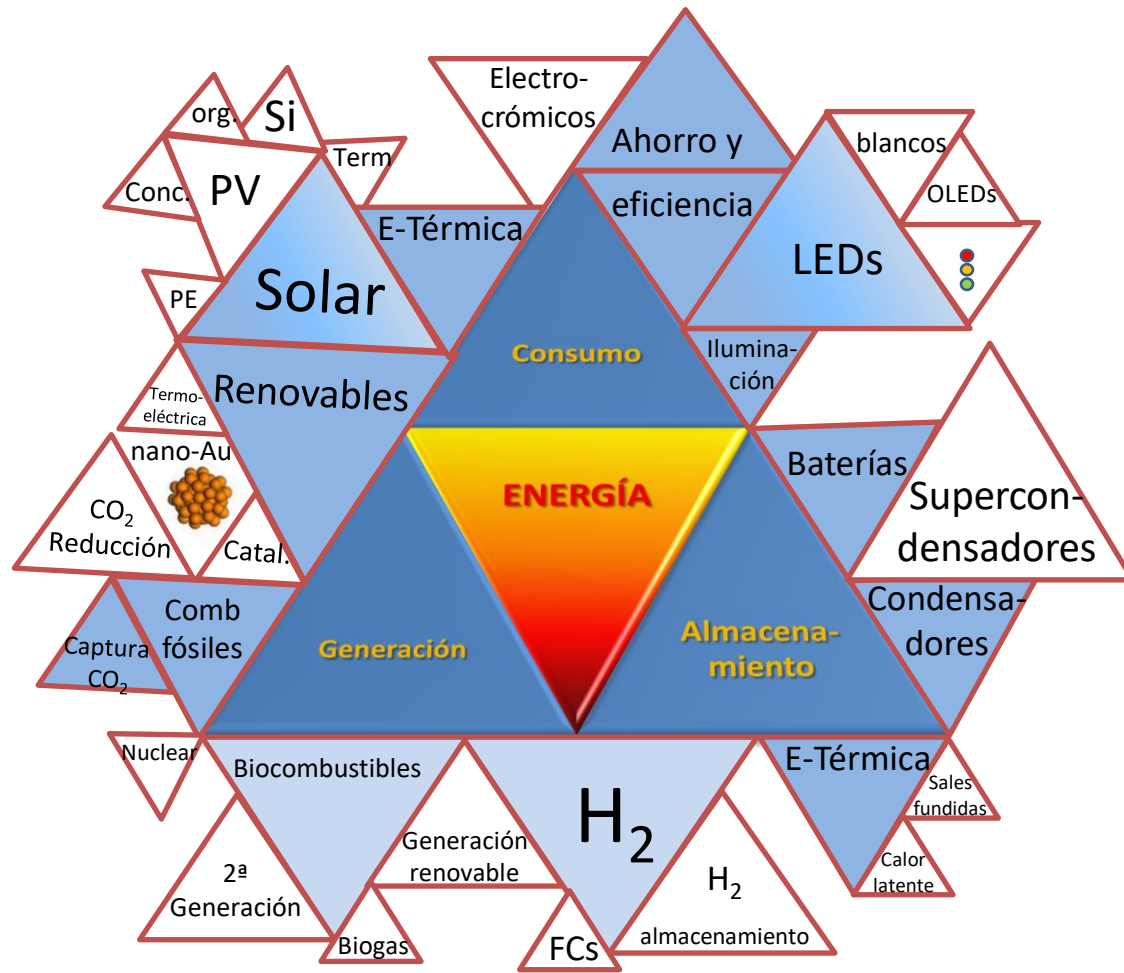
Solar panels



# Los nanomateriales al rescate de la energía

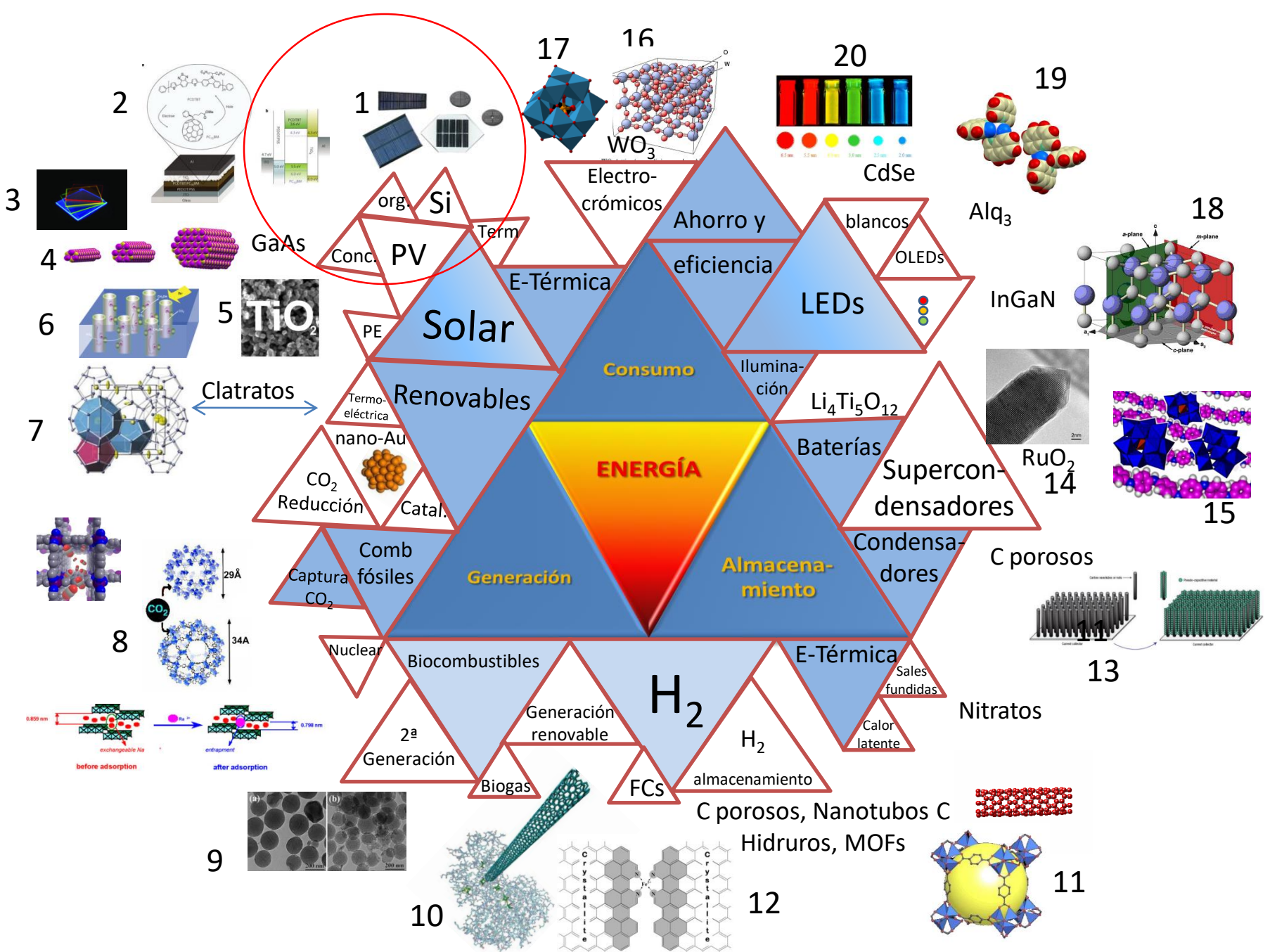












# Se busca: Silicio Solar barato

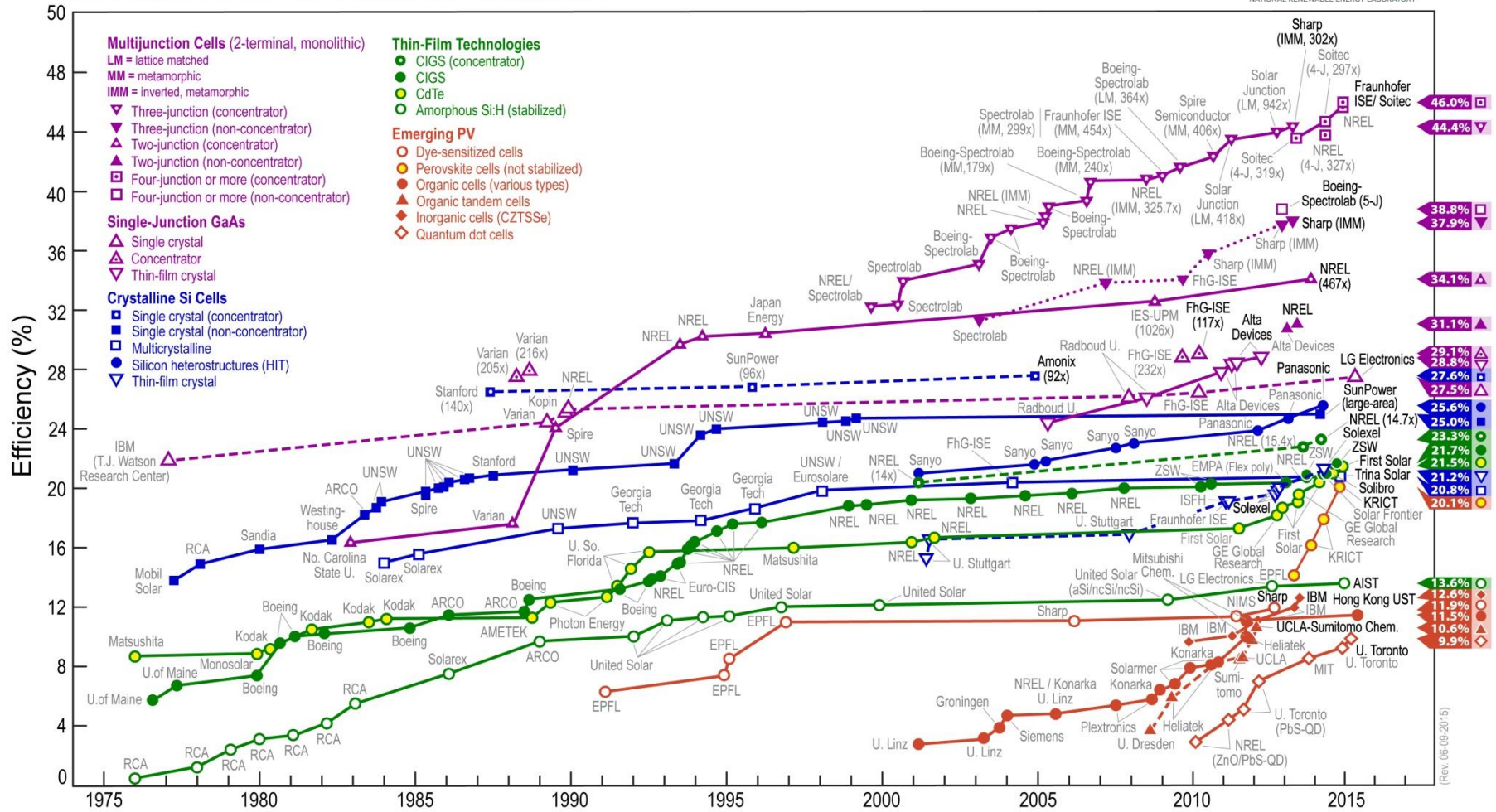
## Silicio 99.999%



# Eficiencias record Solar PV



## Best Research-Cell Efficiencies



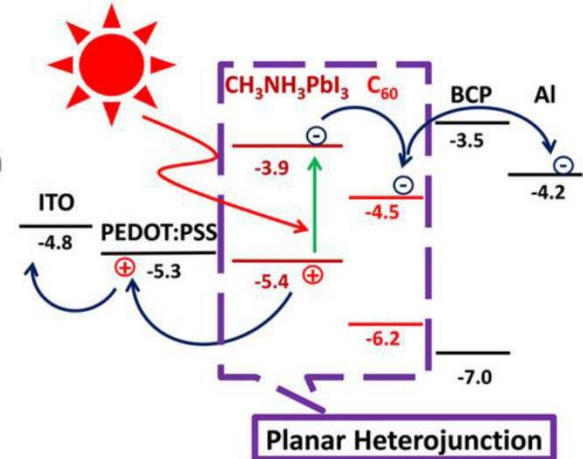
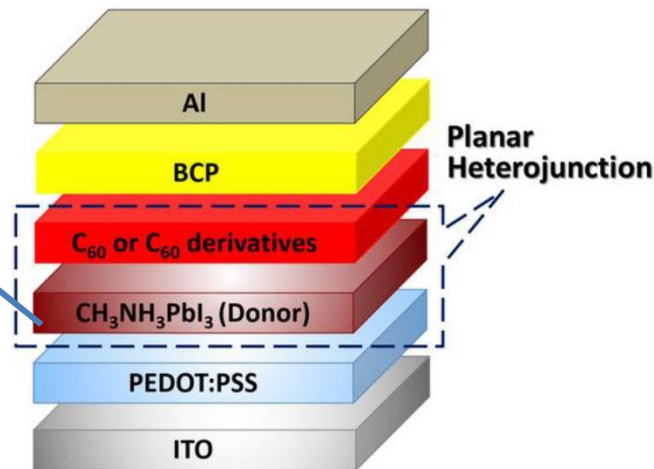
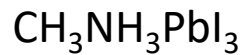
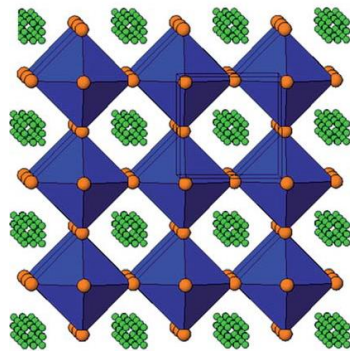
# Celdas solares basadas en perovskitas híbridas

Methylammonium Lead Iodide perovskite

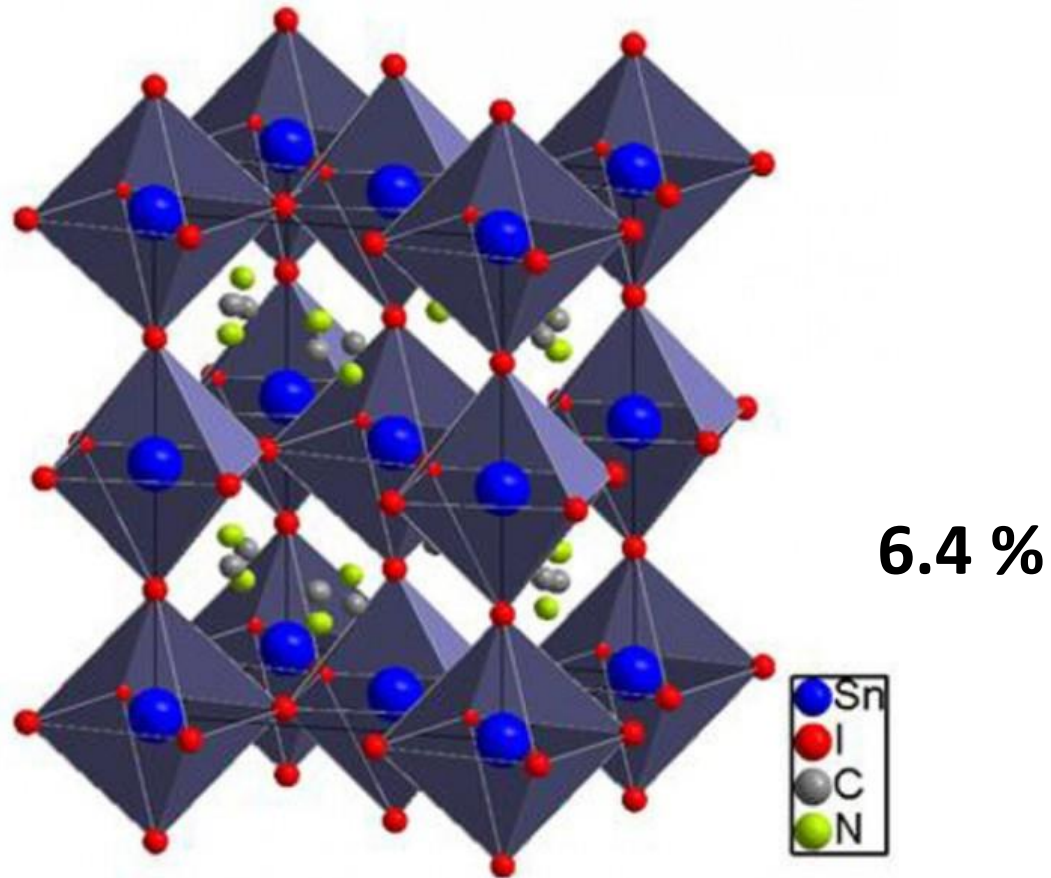
2009: 4.9%



2015: 20%



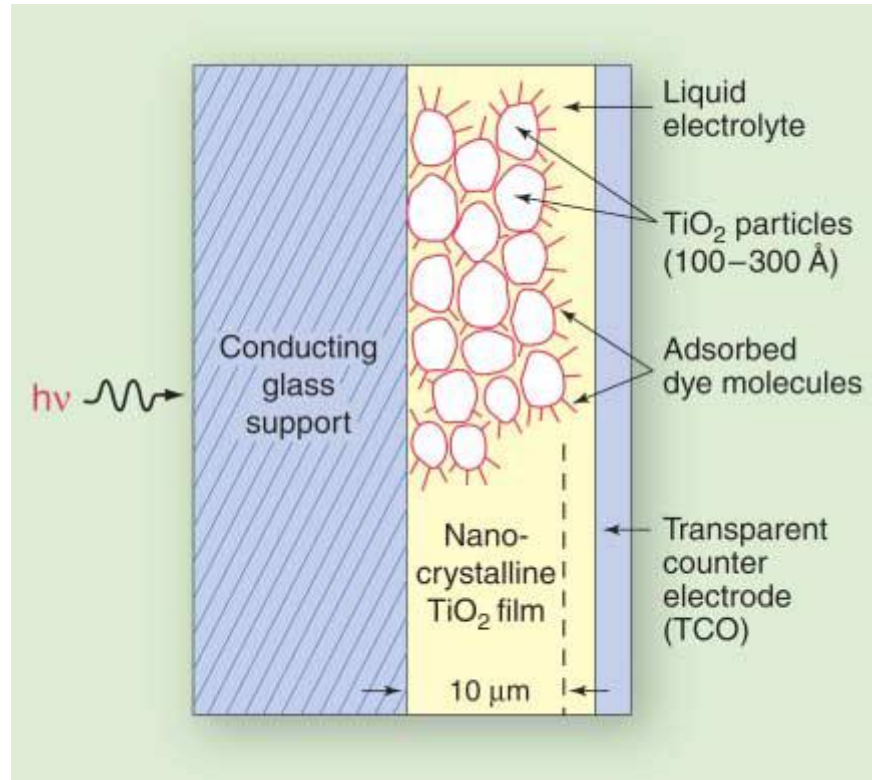
# Energía solar sin plomo



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

# Nano y Celdas Solares

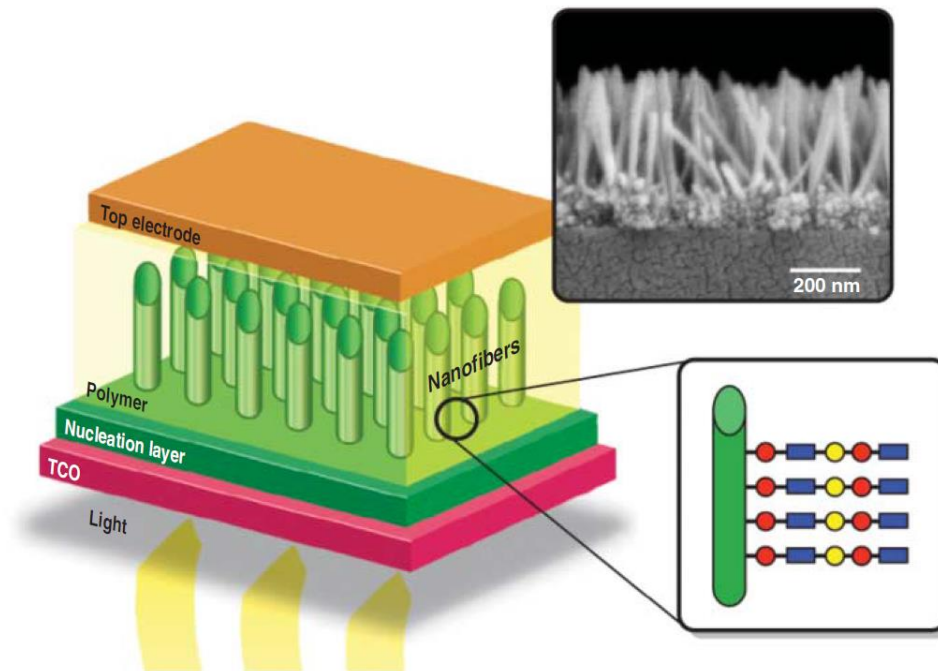
## Dye-Sensitized Solar Cells (Grätzel)



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



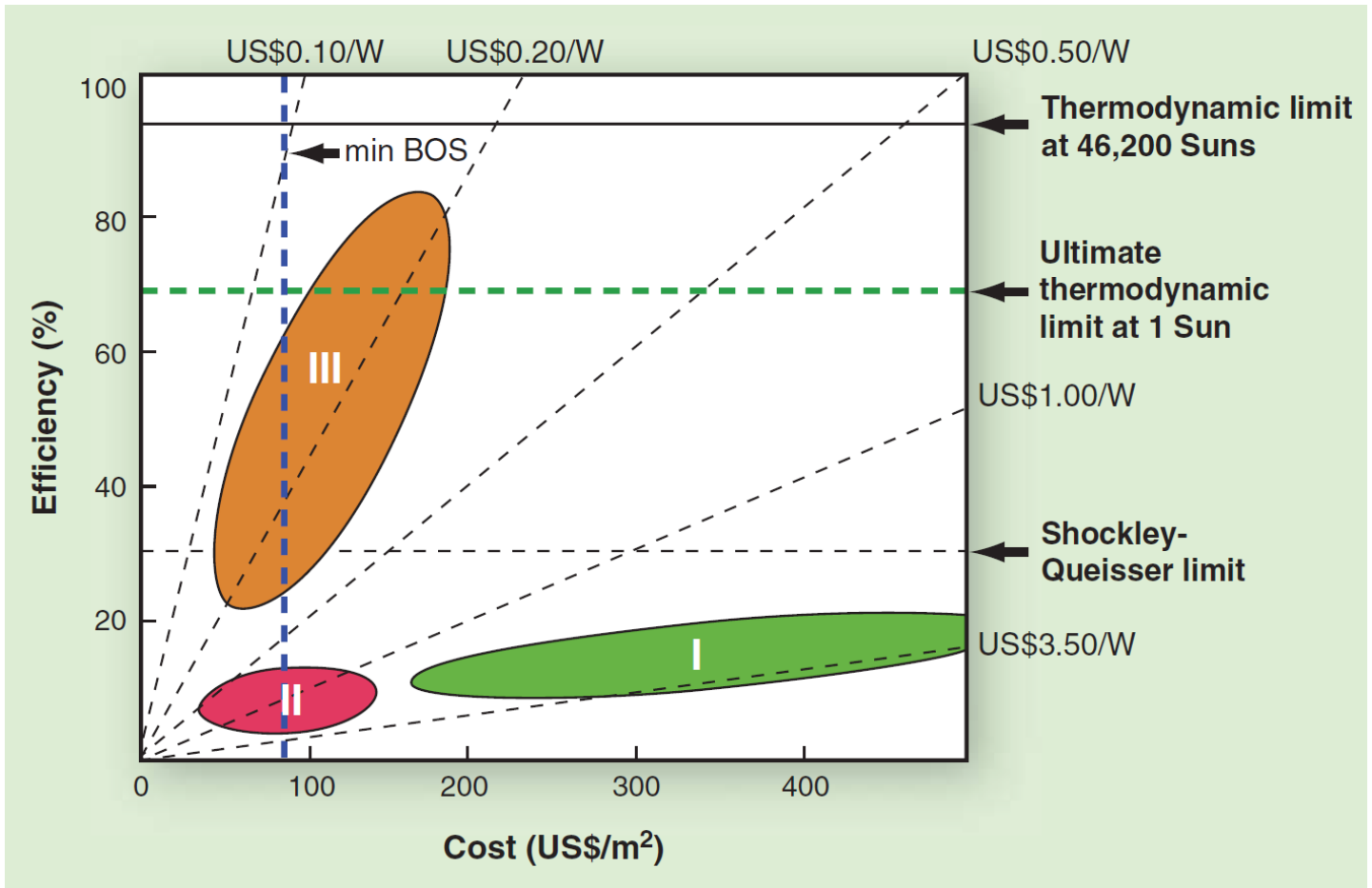
**Fig. 3.** Arrays of nanorods, illustrating an approach to orthogonalization of the directions of light absorption (down the length of the rods) and charge carrier collection (radially outward to the surface of the rods). [Adapted from (2)]

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



# Nano y Celdas Solares

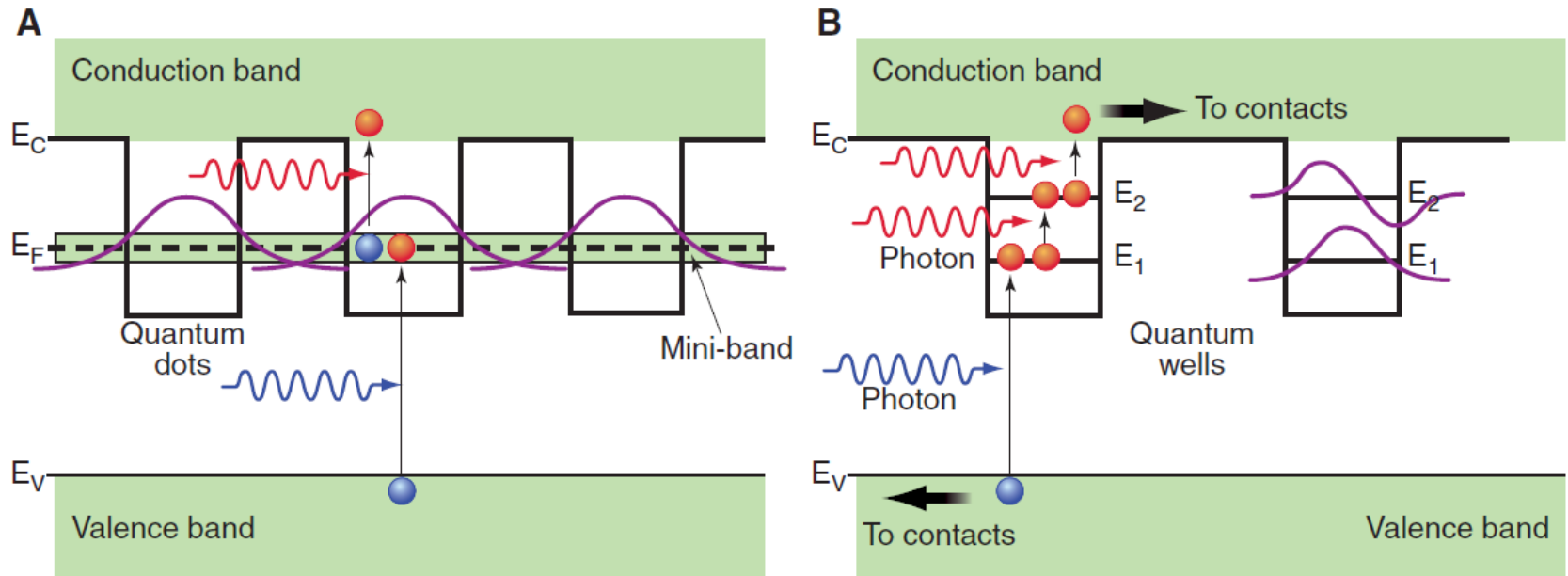
## Costes y eficiencias



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

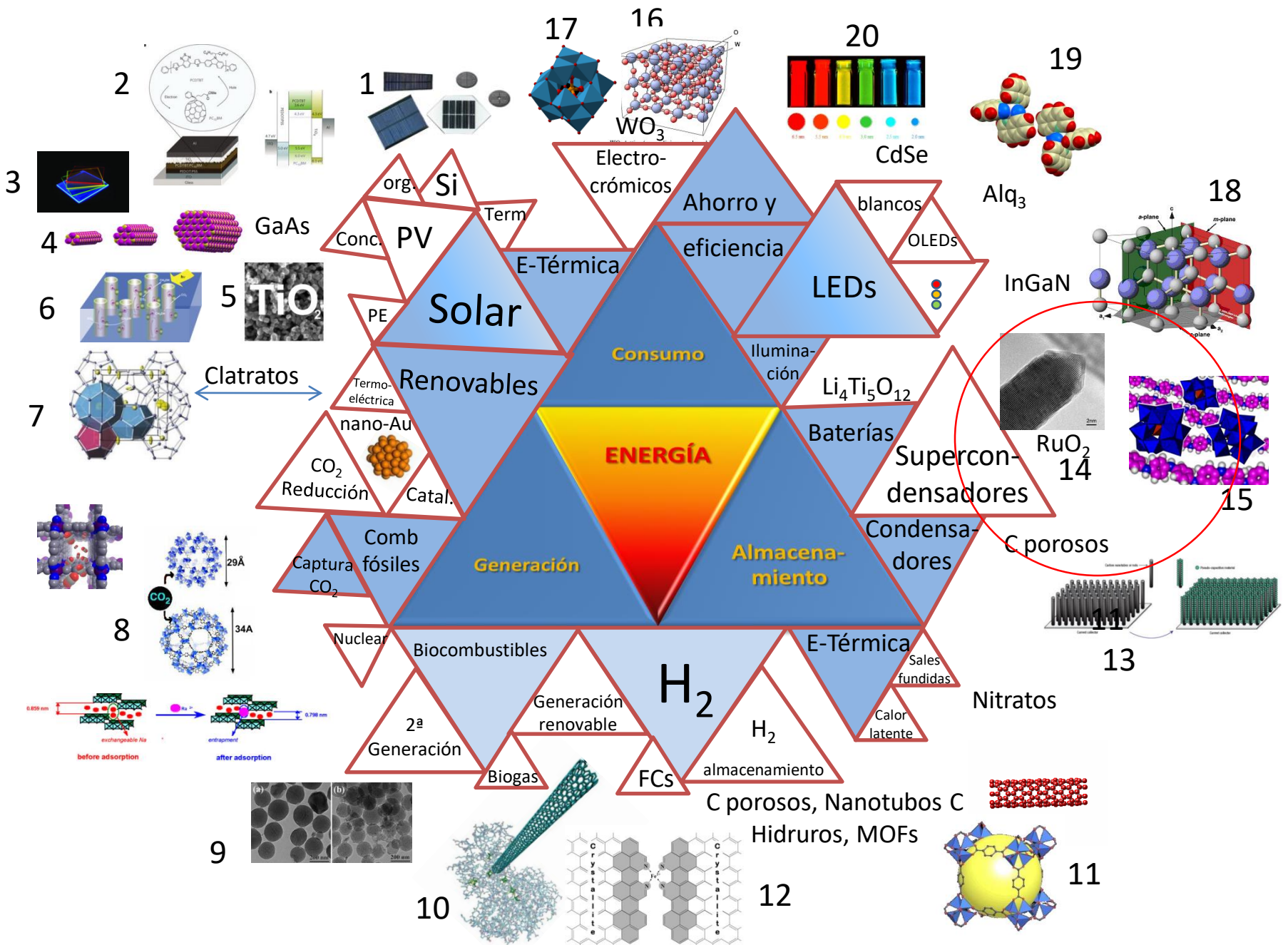
# Nano y Celdas Solares

## 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)



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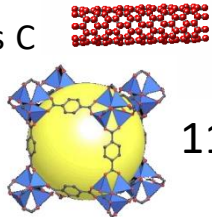
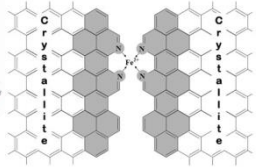
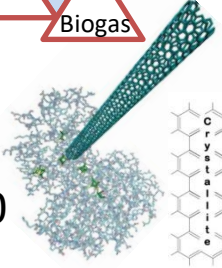
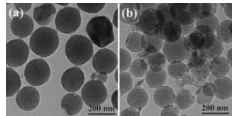
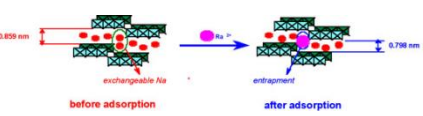
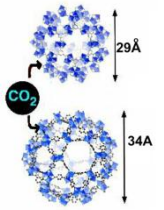
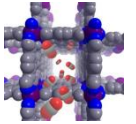
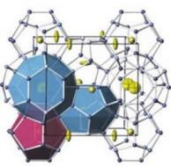
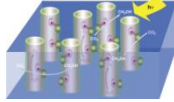
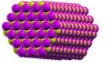
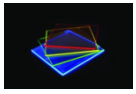
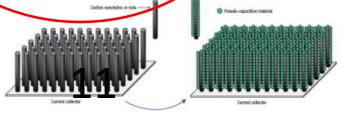
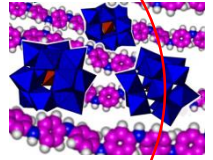
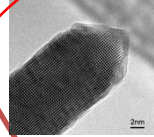
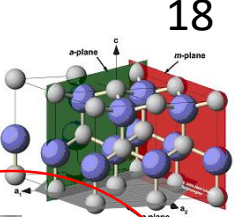
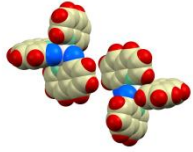
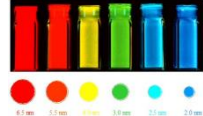
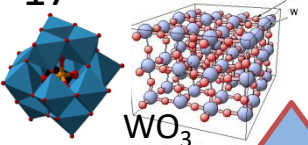
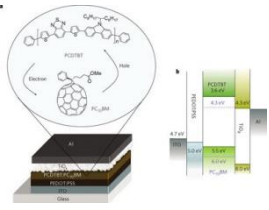
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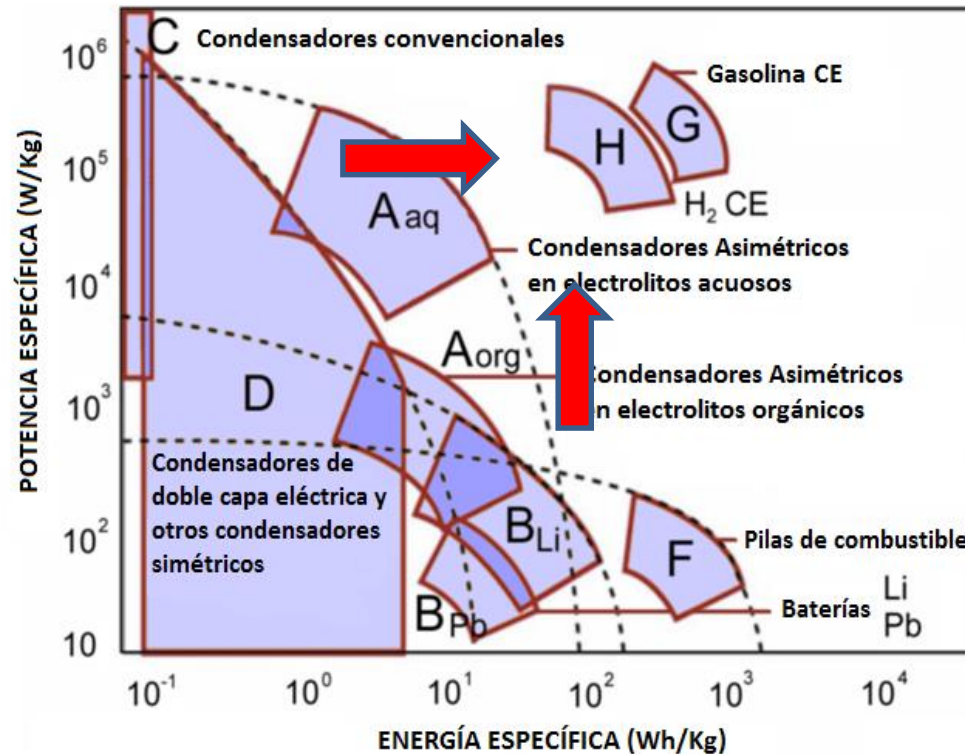
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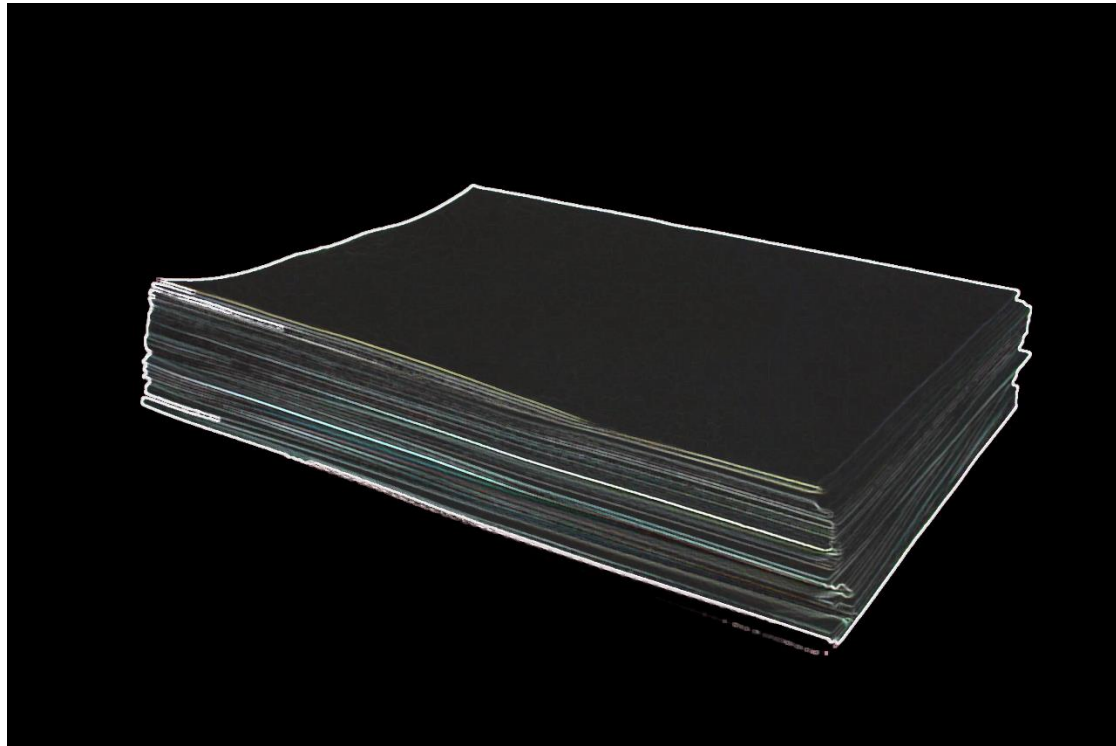


# Diagrama de Ragone.

## El tablero de ajedrez del almacenamiento de energía



# Batería de grafeno



# Batería de grafeno

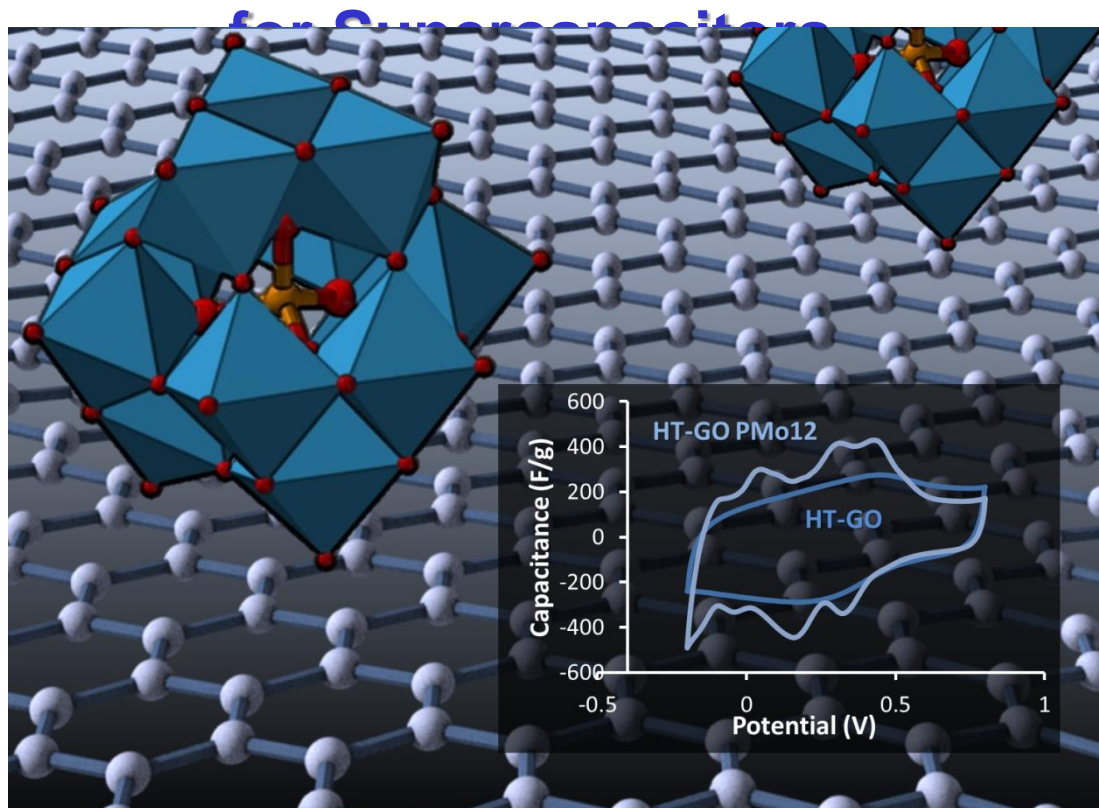


# Batería de grafeno



# Almacenamiento de energía híbrido

## Graphene-Polyoxometalate Hybrid Nanocomposite Material



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

SCIENTIFIC  
REPORTS



**OPEN**

SUBJECT AREAS:  
GRAPHENE  
BATTERIES

Received  
11 September 2014

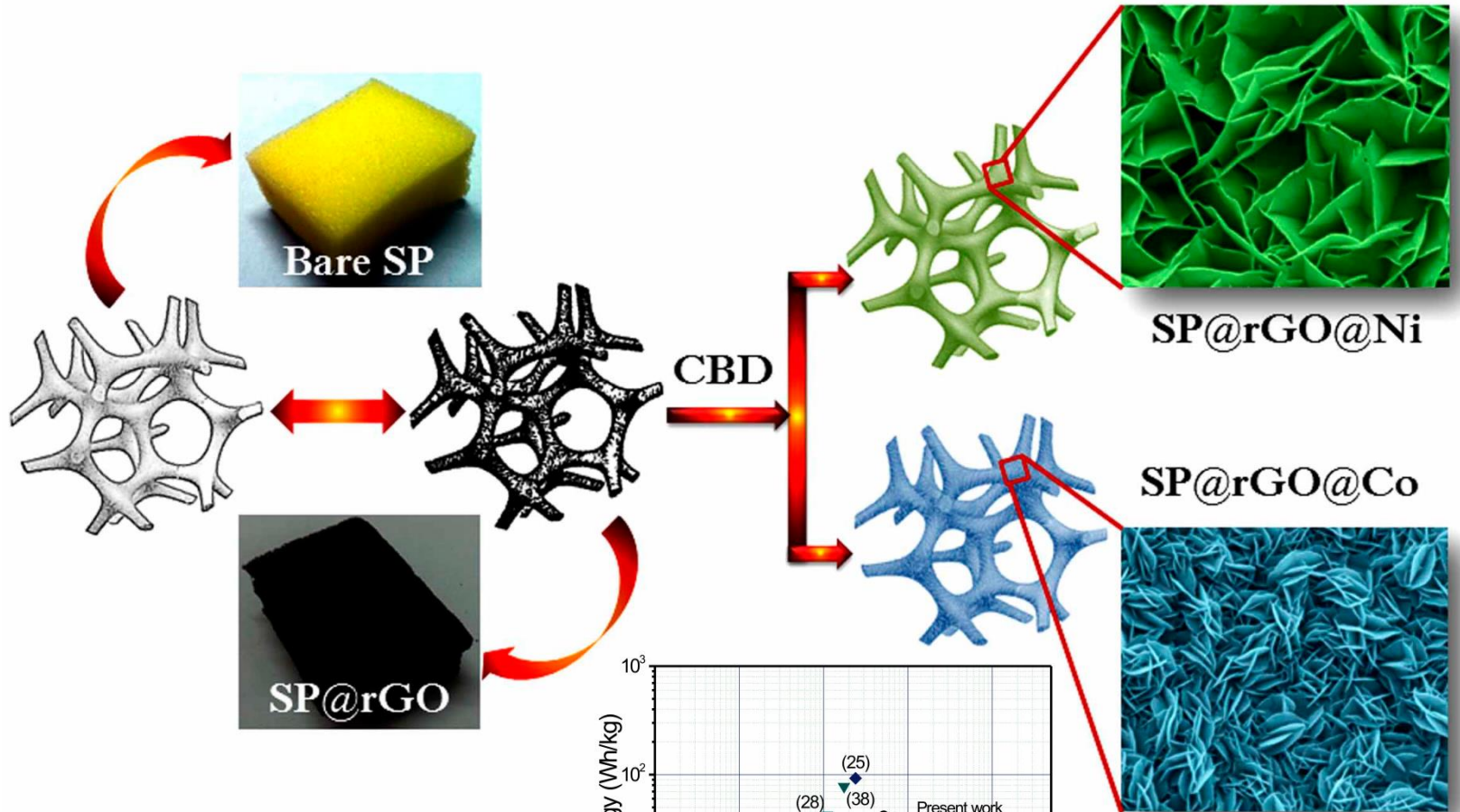
Accepted  
11 November 2014

Development of hybrid materials based on sponge supported reduced graphene oxide and transition metal hydroxides for hybrid energy storage devices

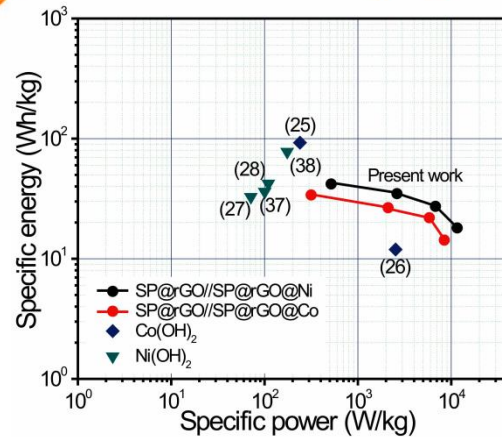
Deepak P. Dubal<sup>1,2</sup>, Rudolf Holze<sup>2</sup> & Pedro Gomez-Romero<sup>1,3</sup>

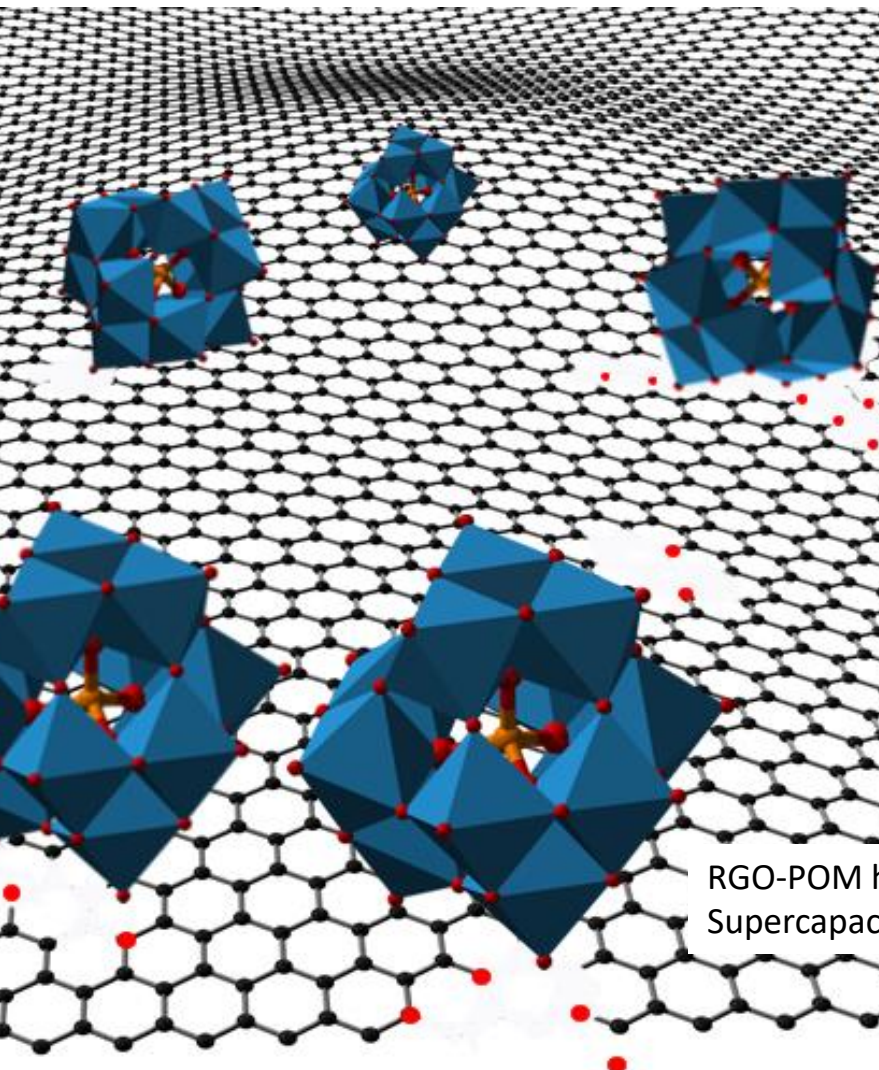
D. P. Dubal\*, R. Holze, P. Gomez-Romero\*.  
Scientific Reports (Nature pub. Group)  
**2014**, 4 : 7349

# Hybrid energy storage

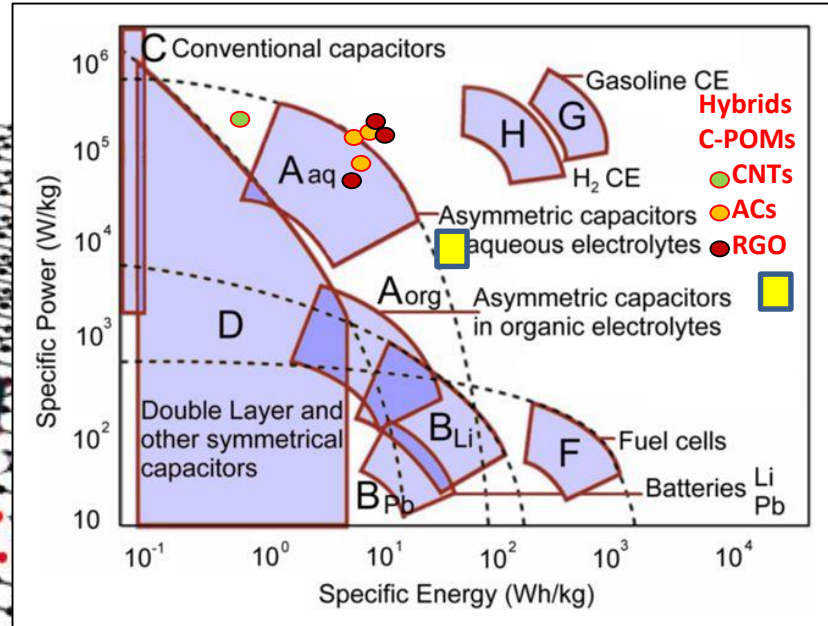


D. P. Dubal\*, R. Holze, P. Gomez-Romero\*.  
 Scientific Reports (Nature pub. Group)  
 2014, 4 : 7349

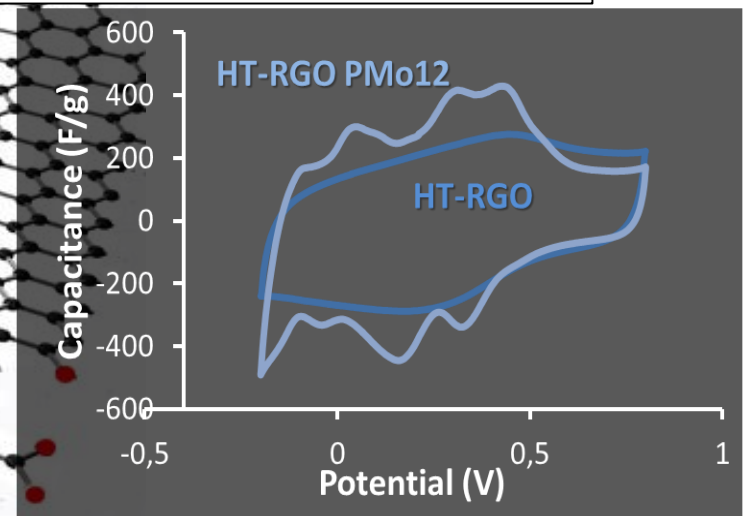




RGO-POM hybrid  
Supercapacitor electrode



RGO Ni(OH)<sub>2</sub>

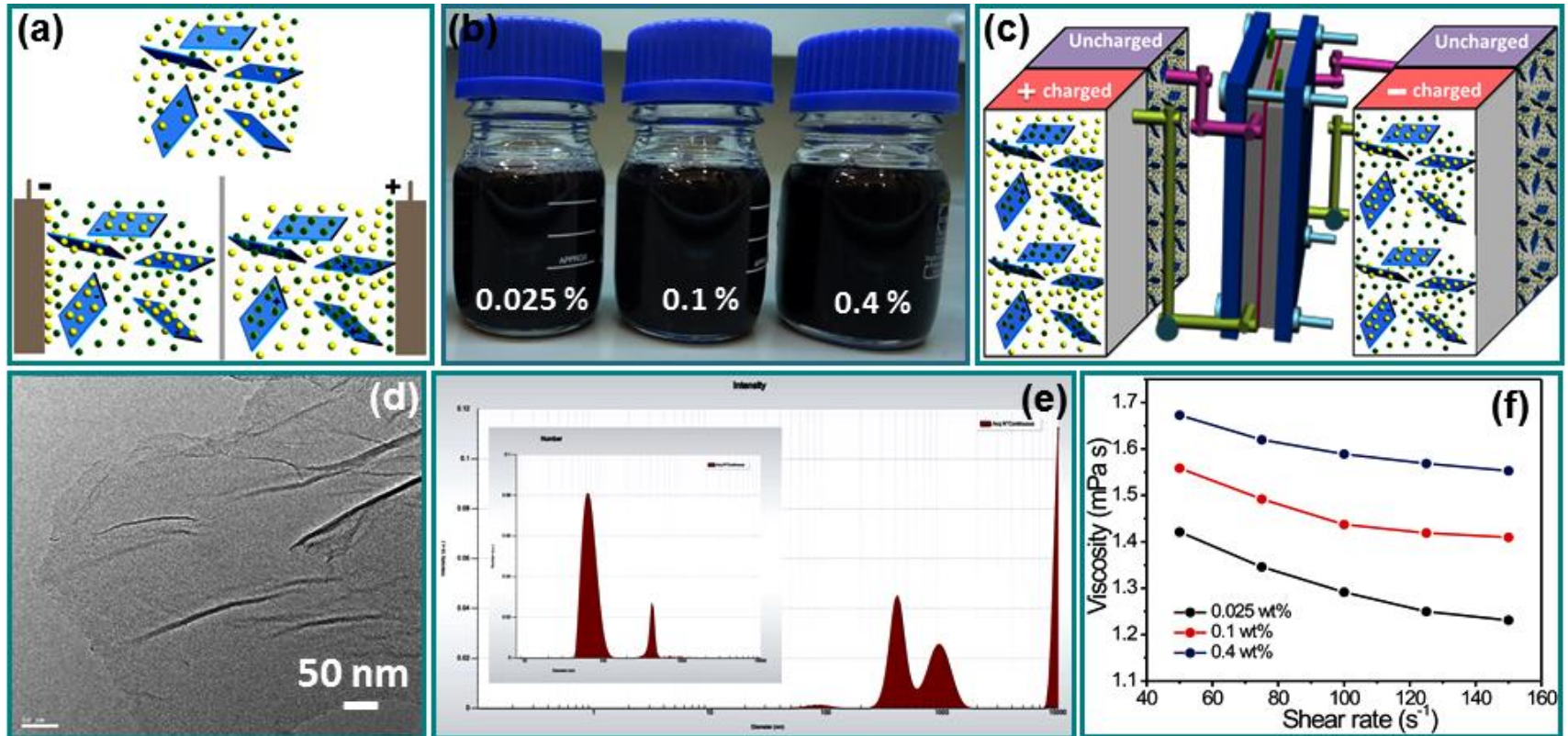


**Thermal**

**Electroactive**



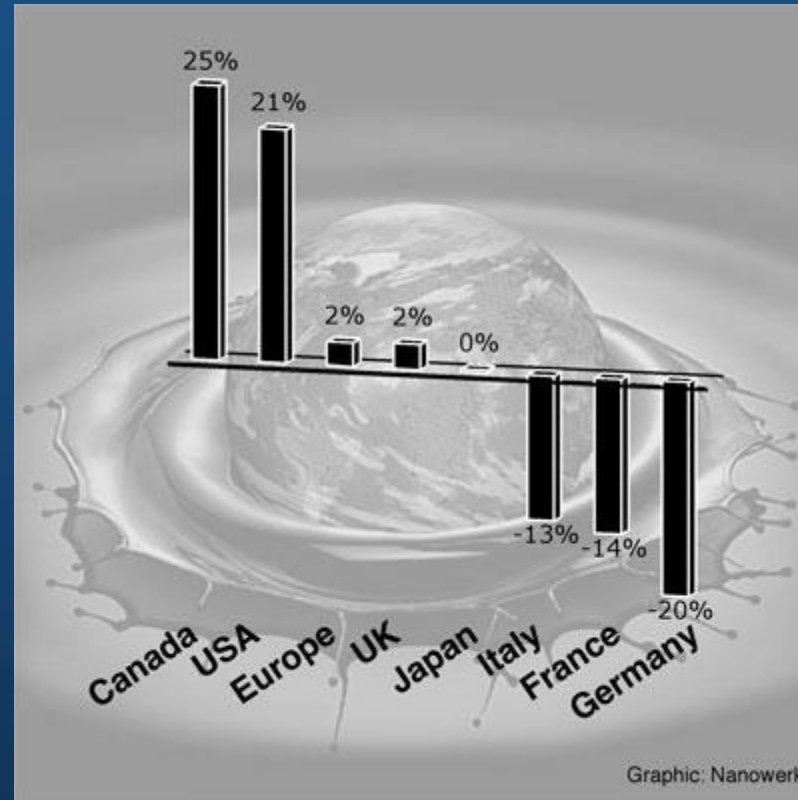
# Electroactive Nanofluids for New Flow Cell Concepts.



*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*

# Política y políticas

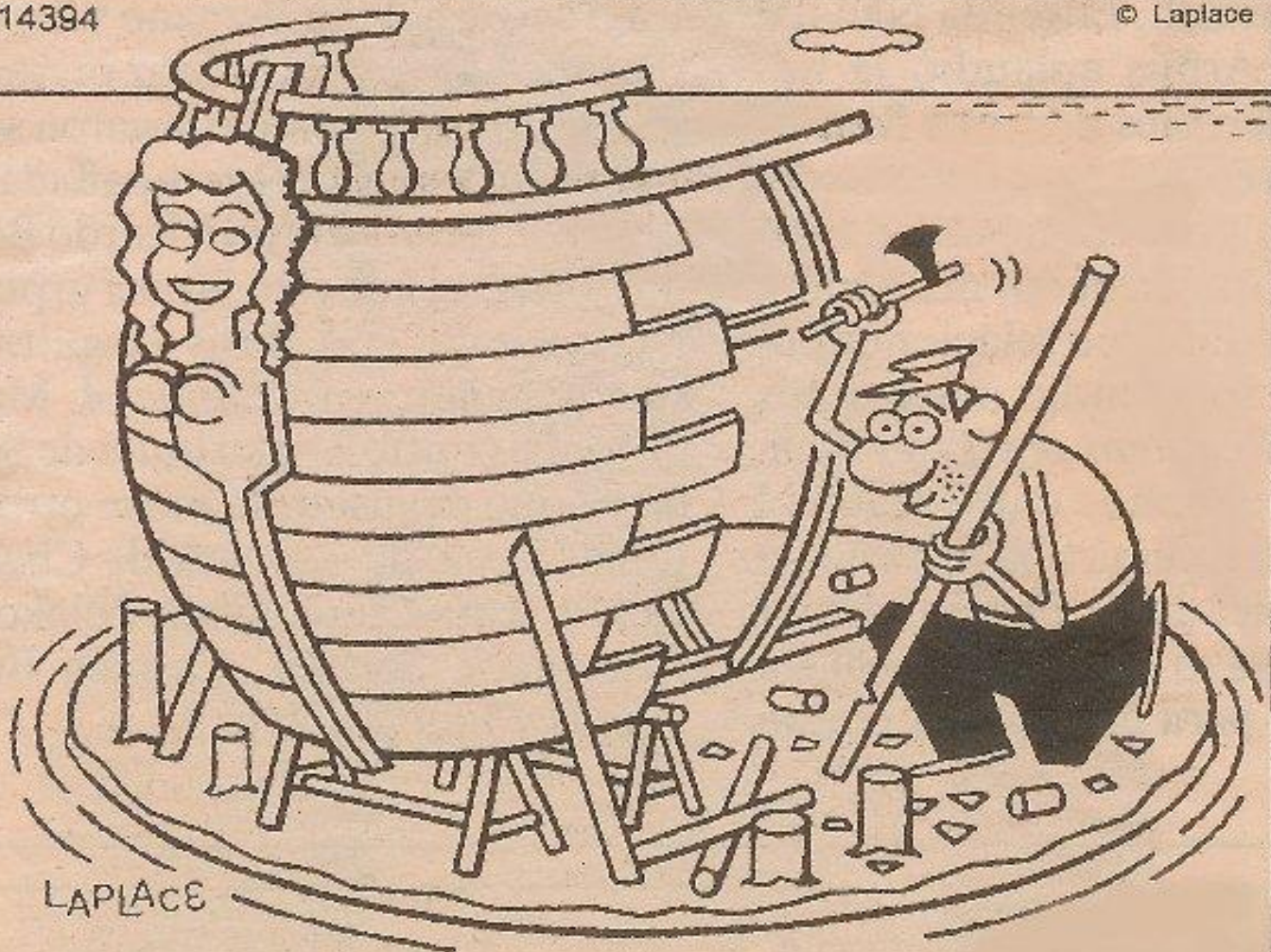
## Change in Petroleum Consumption for G7 Countries 1980-2007



Change in petroleum consumption for G7 countries on the basis of million barrels per day (G8 couldn't be compiled because data for Russia is only available from 1992, after breakup of the Soviet Union); All of Europe also shown in comparison. Data source: U.S. Department of Energy, [Energy Information Administration](#). Compilation and chart: Nanowerk)

14394

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LAPLACE



# En definitiva...

Se acabó la fiesta del malgasto de energía del primer mundo.

Urge una política proactiva para desarrollar/favorecer energías (y combustibles!) limpi@s, renovables capaces de alimentación masiva (2050, 28 TW)

Vamos a asistir a una Re-evolución tecnológica hacia un modelo sostenible de generación, almacenamiento y consumo, basada en revoluciones científicas:

- Biocombustibles de 2ª y 3ª generación

- H<sub>2</sub> Generación sostenible y almacenamiento eficiente

- Pilas de combustible baratas, sin Pt

- Si solar barato o materiales alternativos

- Baterías de alta densidad de potencia y recarga rápida

- Supercondensadores de alta densidad de energía

- LEDs blancos, brillantes y baratos

# Un planeta en busca de energía

Pedro Gómez Romero



II Edición del Premio de Ensayo  
Esteban de Terreros

EDITORIAL  
SÍNTESIS

¿Otras fuentes de energía?  
¿Y las nucleares?  
¿Energía de fusión?  
China, ¿fuente de soluciones?  
Economía o Medio Ambiente?  
Las facturas de la Tierra  
¿Y el agujero de ozono?  
¿Cabe esperar un milagro?

(Ed. Síntesis, 2007)



Gracias