ENERGY FOR THE 21st CENTURY: WHERE WE ARE, WHERE WE SHOULD GO

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EuCheMS

Società Chimica Italiana

CONSIGLIO NAZIONALE DEI CHIMICI

Chemistry for the Future of Europe - Energy, Food, Environment

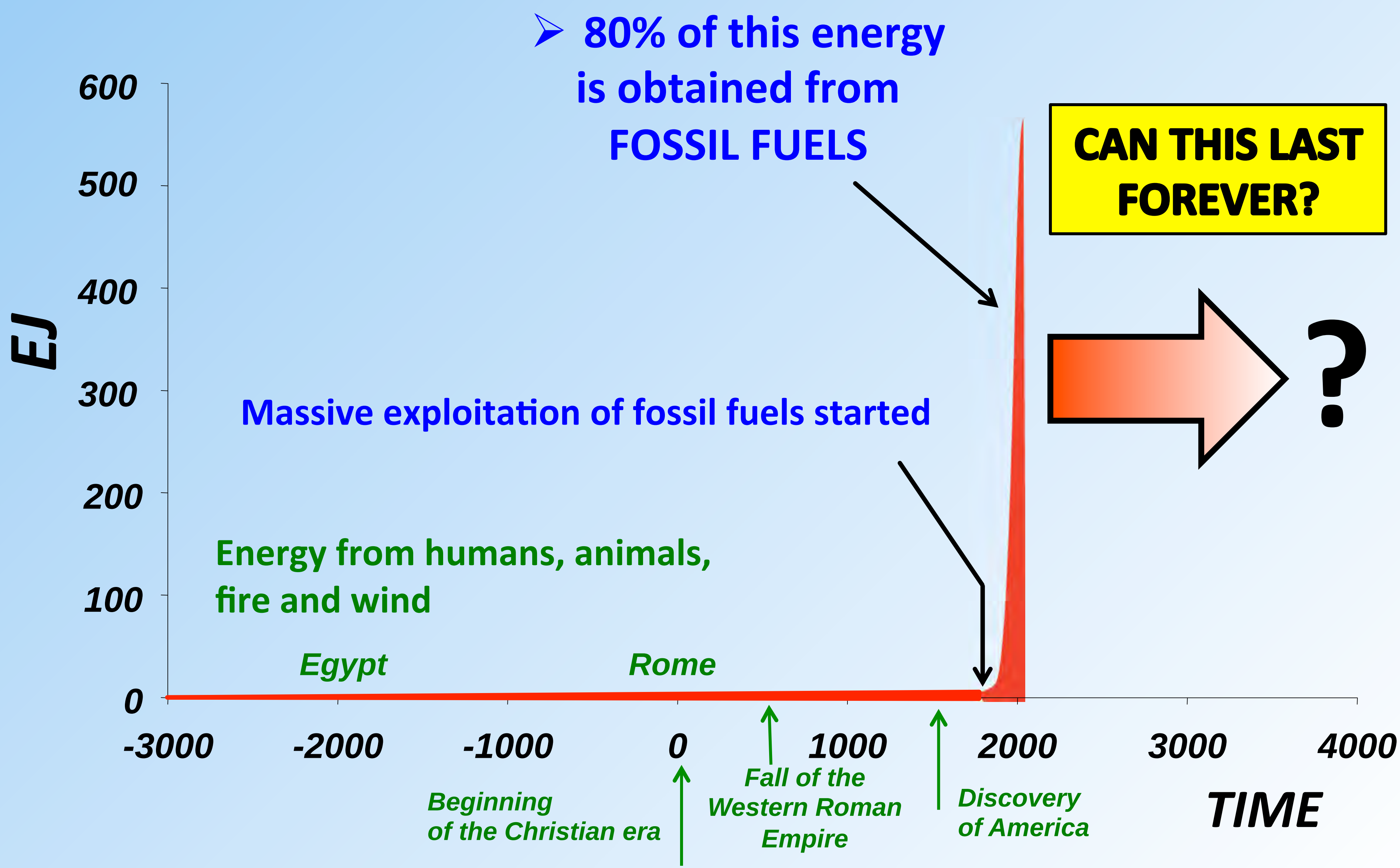
University La Sapienza – Rome

November 25, 2014

OUTLINE

- **PART I: The present situation**
- **PART II: The perspectives**
- **PART III: Reflections on Europe**

THE ENERGY TIMELINE



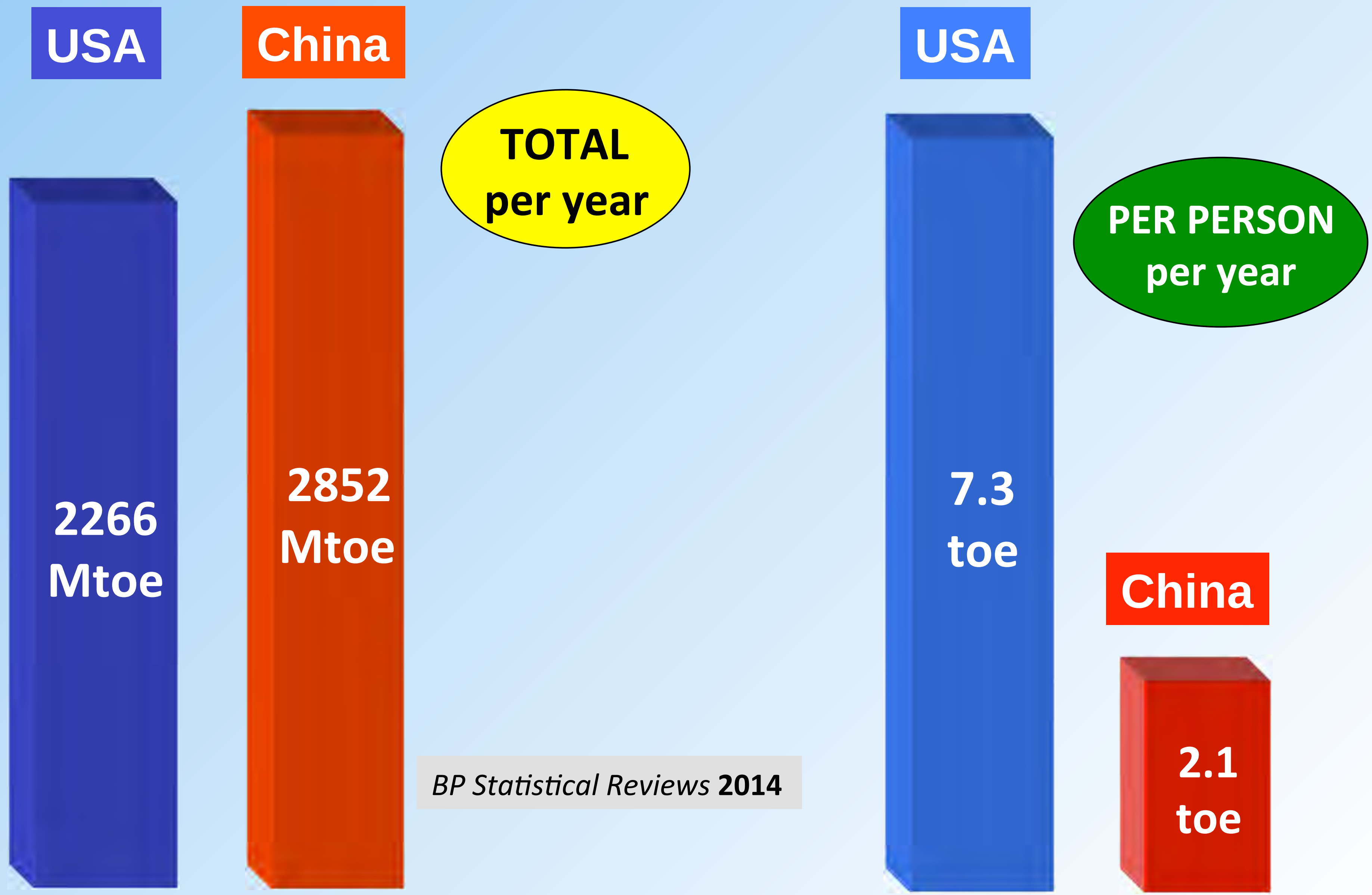
RUNNING TOO FAST: rate of consumption of fossil fuels

Consumption of fossil CARBON: ≈ 10 Gt/y

Amount of "paleobiomass" needed : ≈ 50 000 Gt

This amounts to about 500 years of photosynthesis

The consumption race: USA vs. China



World oil reserves, top 10 countries

	Gigabarrels	%
Venezuela	298.3	17.7
Saudi Arabia	265.9	15.8
Canada	174.3	10.3
Iran	157.0	9.3
Iraq	150.0	8,9
Kuwait	101.5	6.0
Un. Arab Emirates	97.8	5.8
Russia	93.0	5.5
Libya	48.5	2.9
USA	44.2	2.6

62.0 %

BP Statistical Reviews, **2014**

Consequence : The most dangerous place on Earth
THE STRATEGIC ENERGY ELLIPSE

16 countries, 70% of conventional OIL and GAS reserves

ENERGY is embodied everywhere

Steel

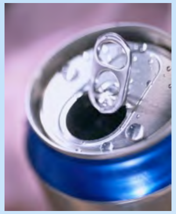
0.4*

Plastics

2.5*

Aluminum

4.2*

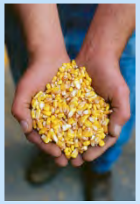


Motor vehicles

2.4*

Wheat, corn fruit

0.1*



Rice

0.25*

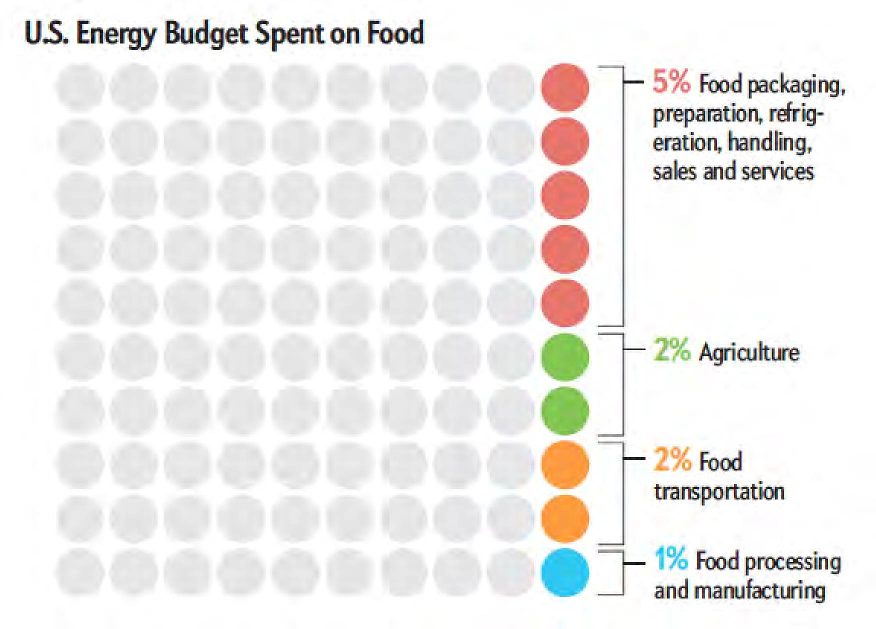
Greenhouse vegetables

1*

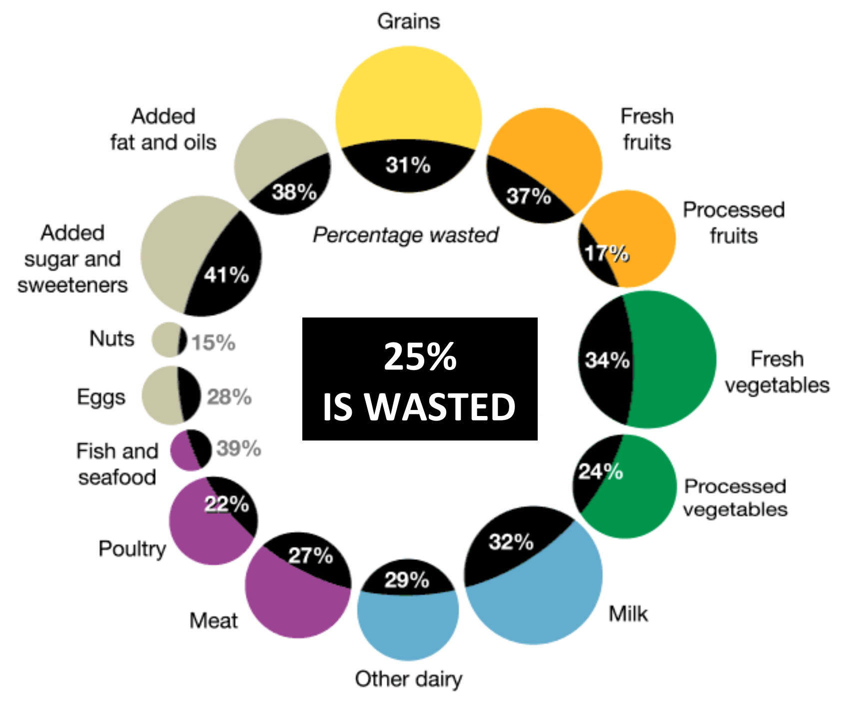
***toe/t**

ENERGY is also wasted everywhere

10 % of U.S. energy is used to make food available



M. E. Webber, *Sci. Am.* January **2012**, 64



National Geographic Magazine, November **2014**
The Future of Food Features

2.5% of U.S. energy supply is wasted in food loss

Food wasted yearly by an average U.S. family

CREDIT: National Geographic Magazine, November **2014**

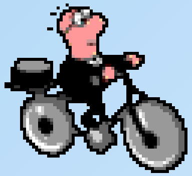
ENERGY production requires huge amounts of WATER: the case of Europe

"The total abstraction of freshwater across Europe is around 288 km^3/year* and represents, on average, 5 300 m^3 per capita/year. Overall, 44 % of the total abstracted is for energy production, 24 % for agriculture, 21 % for the public water supply and 11 % for industry"

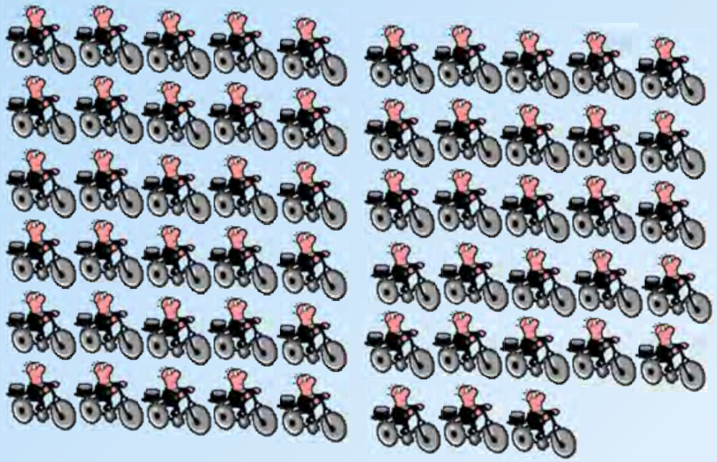
* Approx. SIX Garda Lakes

European Environment Agency, *Water resources across Europe. Confronting water scarcity and drought*, **2009**

QUANTIFYING OUR FOSSIL FUEL BONANZA
THE “ENERGY SLAVE” POWER UNIT:
STEADY 80 W FOR 8 HOURS



This guy is your hypothetical slave



THE AVERAGE EU CITIZEN HAS 58 ENERGY SLAVES WORKING 24/7 AND NO HOLIDAYS

IS ENERGY REALLY EXPENSIVE?
Mmm .. let's make a quick calculation

EU AVERAGE HOUSEHOLD
ELECTRICITY CONSUMPTION

3500 kWh

EU AVERAGE ELECTRICITY
CONSUMPTION FOR LIGHTING

14%

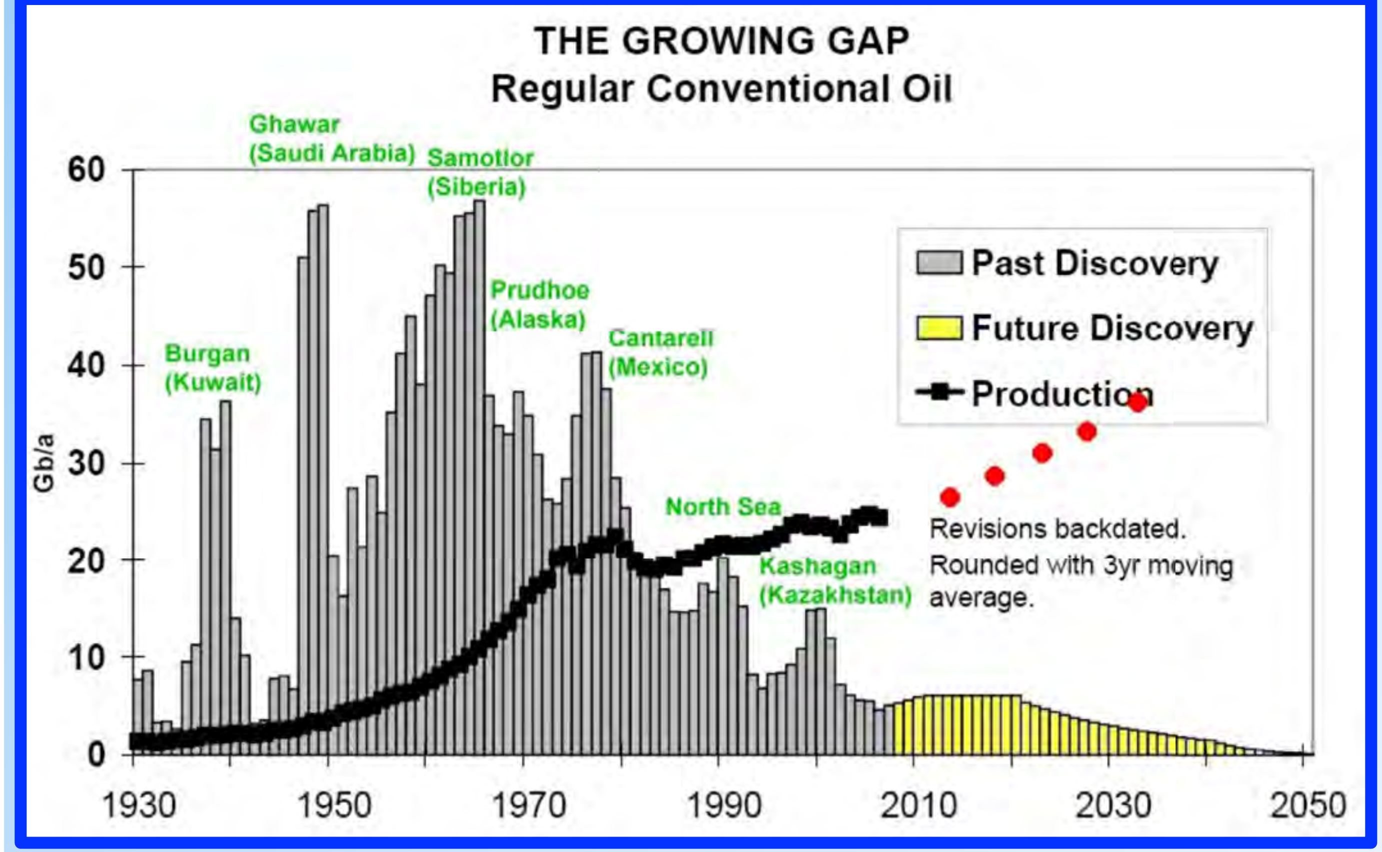
490 kWh

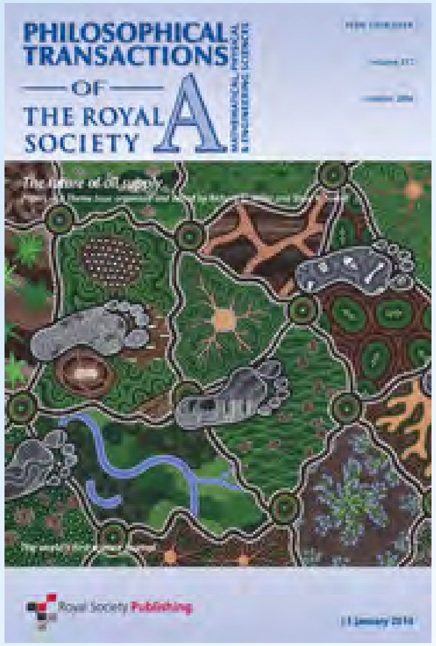
98 €

490 kWh = 766 people for 10 h

230.000 € (at 30 €/h)

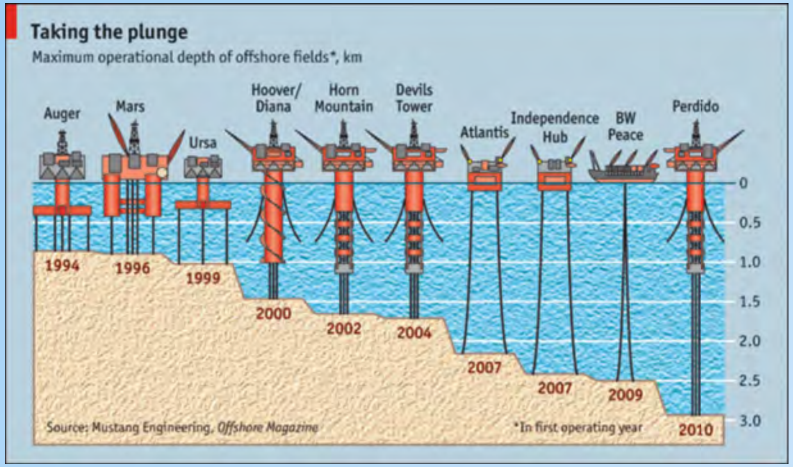
The dwindling resource: CONVENTIONAL OIL discoveries vs. production, historical





The future of oil supply - Special Issue - January 2014

Entering the era of "extreme" oil & gas

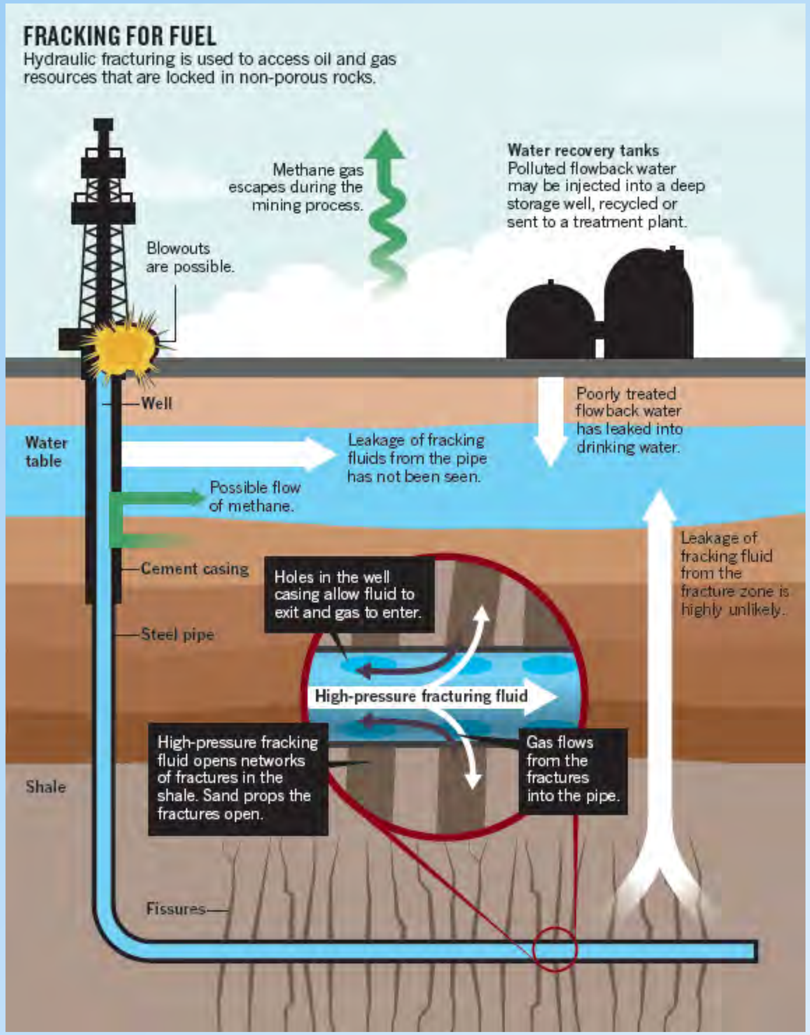


C&EN, Feb 14, **2011**

Deep see and Arctic drilling

Unconventional hydrocarbons:
- Tar sands,
- Shale oil & gas

"FRACKING" FOR SHALE OIL & GAS:
Associated Risks and Problems



Nature **2011**, *477*, 271

Groundwater Contamination

Science **2014**, *344*, 1468
PNAS **2013**, *110*, 11250
Nature **2013**, *498*, 415

Induced Seismicity

Science **2013**, *341*, 142
U.S. NAS Report **2012**, *ISBN 978-0-309-25367-3*

Methane release in the atmosphere

PNAS **2014**, *111*, 6237
Nature **2012**, *482*, 139

Quickly declining rate of production

Nature **2012**, *494*, 307

Poor EROI

Environ. Sci. Tech. **2013**, *47*, 5459

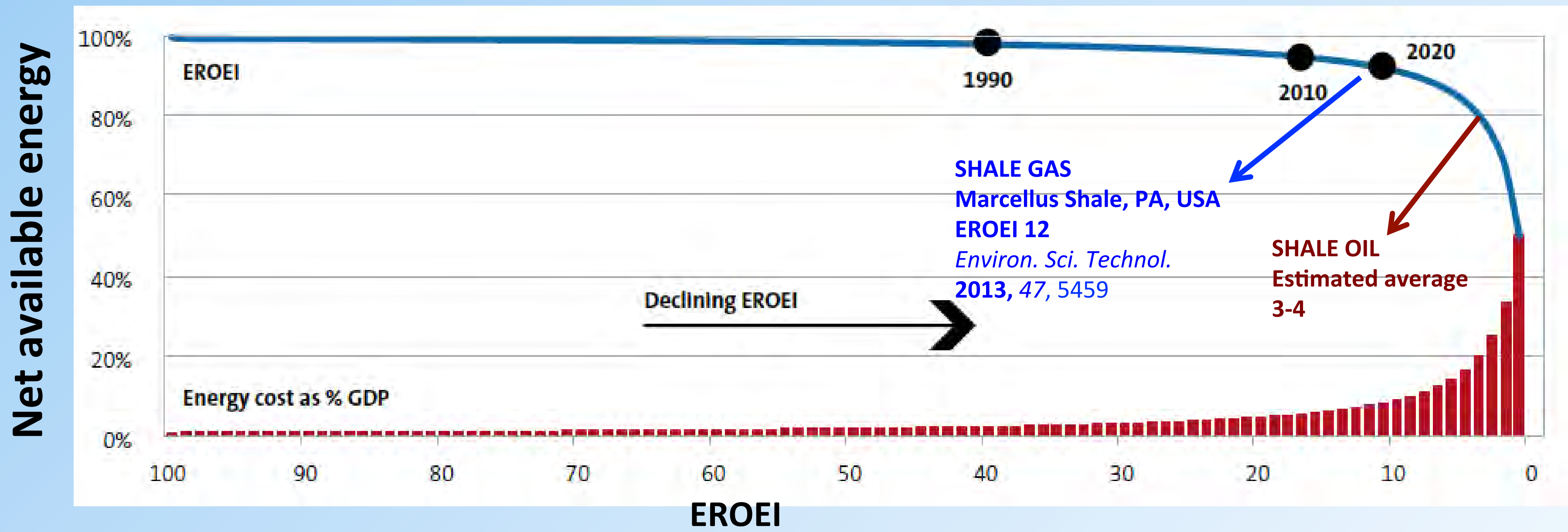
Key concept: IT TAKES ENERGY TO GET ENERGY
(ENERGY RETURN ON ENERGY INVESTMENT: EROEI)

ENERGY INVESTMENT →

EXAMPLE: EROEI U.S. oil

1950	1970	Today
100	30	< 10

APPROACHING THE EROEI CLIFF?



Some financial analysts estimate that with EROEI below ≈ 10 the world economy is poised to collapse

Perfect Storm - Energy, Finance and the End of Growth
Tullet Prebon Report, **2013**

SHALE OIL AND GAS: THE NEXT BUBBLE?

Newsweek

Is the U.S. Fracking Boom a Bubble?

July 14, 2014

Bloomberg

Drillers Piling Up More Debt Than Oil Hunting Fortunes in Shale

September 8, 2014

The Telegraph

Shale gas: 'The dotcom bubble of our times'

Comment: output from shale wells declines so quickly that they will never be profitable – when investors realise this, the industry will collapse, writes Tim Morgan

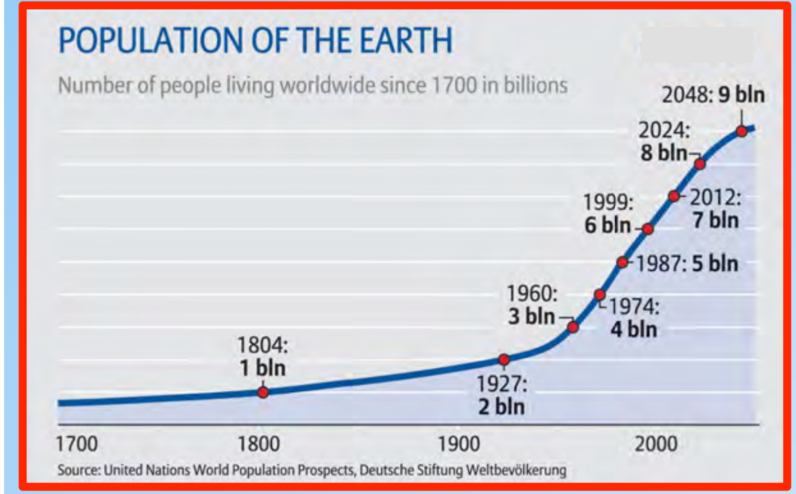
August 04, 2014

Il Sole 24 ORE

Crollo del petrolio e debito spazzatura,
la bolla dello shale oil rischia di esplodere

November 12, 2014

OTHER (SOME) RELATED BIG ISSUES



Trend: + 80 million/year, + 220 000/day

GLOBAL WARMING

http://climate.nasa.gov/sof/

ENVIRONMENTAL DEGRADATION

PO VALLEY
October 30, 2014

http://earthobservatory.nasa.gov

THE PERFECT STORM?

The last 80 years: the fossil fuel age

BUT … CONVENTIONAL HYDROCARBONS WILL BE VIRTUALLY IMPOSSIBLE TO REPLACE

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How many renewable/perennial alternatives do we have??



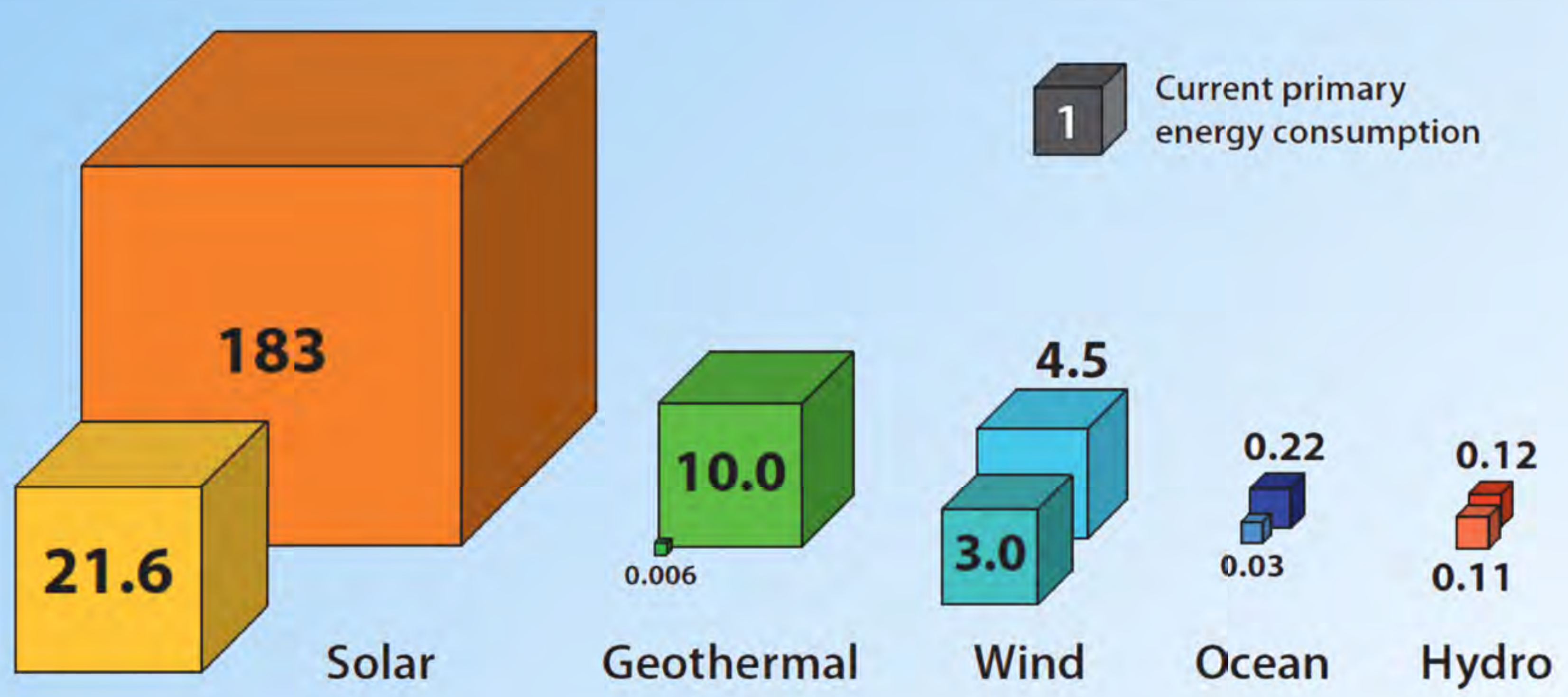

GEOTHERMAL

GRAVITATIONAL

SOLAR

(DIRECT and INDIRECT)

Do we have enough? YES, INDEED



SMALLER CUBES: Amount that is technically, economically and ecologically exploitable NOW

N. Armaroli, V. Balzani
Energy for a Sustainable World, Wiley-VCH, ***2011***

LET'S BE PRACTICAL: WHAT DO WE NEED?

Share of Final Energy Consumption in the Affluent World

~ 25 %

ELECTRICITY

~ 75 %

FUELS (heat, transport)

WE HAVE 2 OBJECTIVES … WELL … 3

1) Produce **ELECTRICITY**

2) Produce **FUELS**

3) Reduce **CONSUMPTION**, increase **EFFICIENCY**

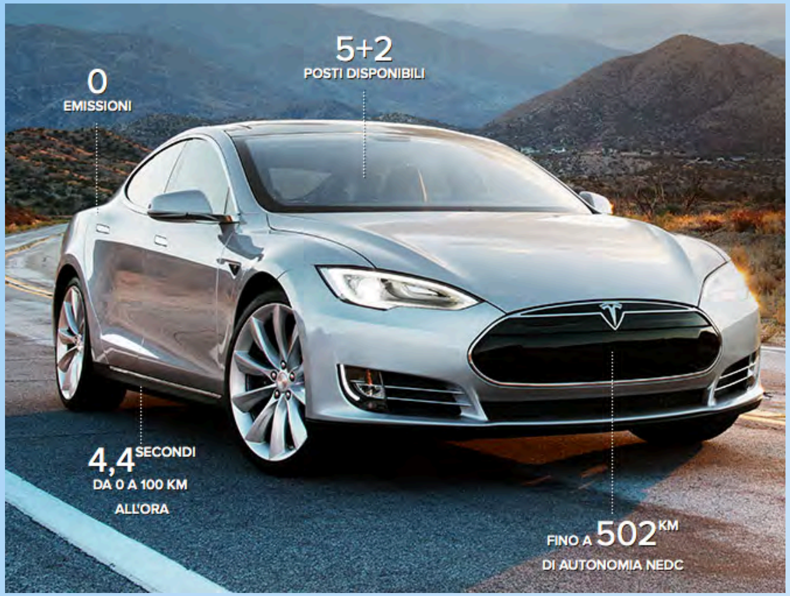
a) Target ELECTRICITY

The most mature renewable technologies are electric:

INCREASE THE SHARE OF ELECTRICITY IN FINAL USE

Energy Environ. Sci. **2011**, *4*, 3193-3222

HOW MUCH ELECTRICITY TO POWER e-CARS?



CONSUMPTION: 0.18 kWh/km

15 000 km/year: 2700 kWh

= MY HOUSEHOLD CONSUMPTION (5 people)

In Italy: 37 million cars

Average mileage: 12000 km/year

If electric they'd consume: 80 TWh

(luxury, not economy car!)

Italy, 2013: 112 TWh from RENEWABLES (ca. 40% of total cons.)

47%

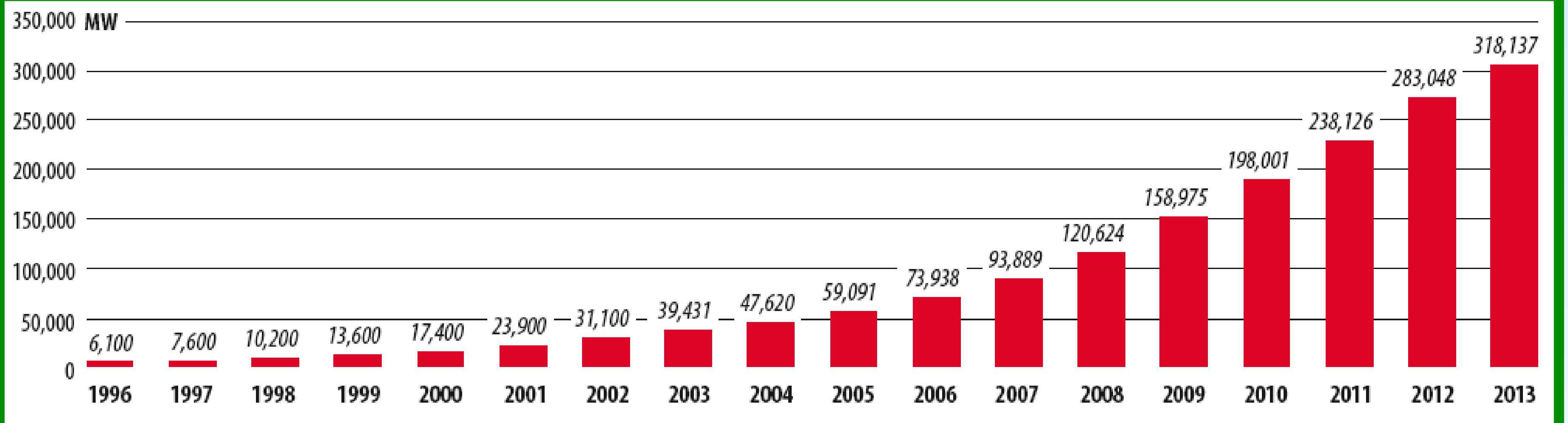
19%

15%

14%

5%

World development of WIND ENERGY, 1996-2013

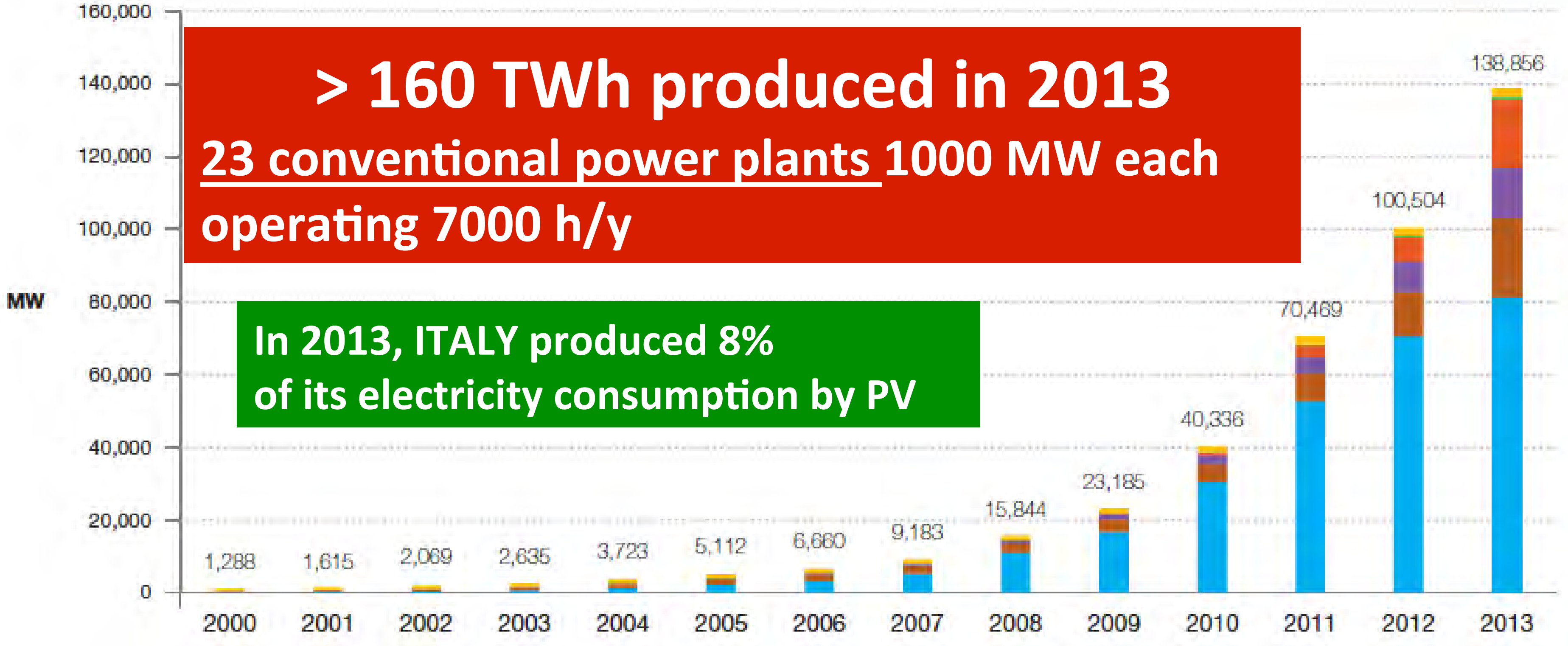


2013: 596 TWh, 3.3% of world electricity

85 conventional power stations 1000 MW 7000 h/y

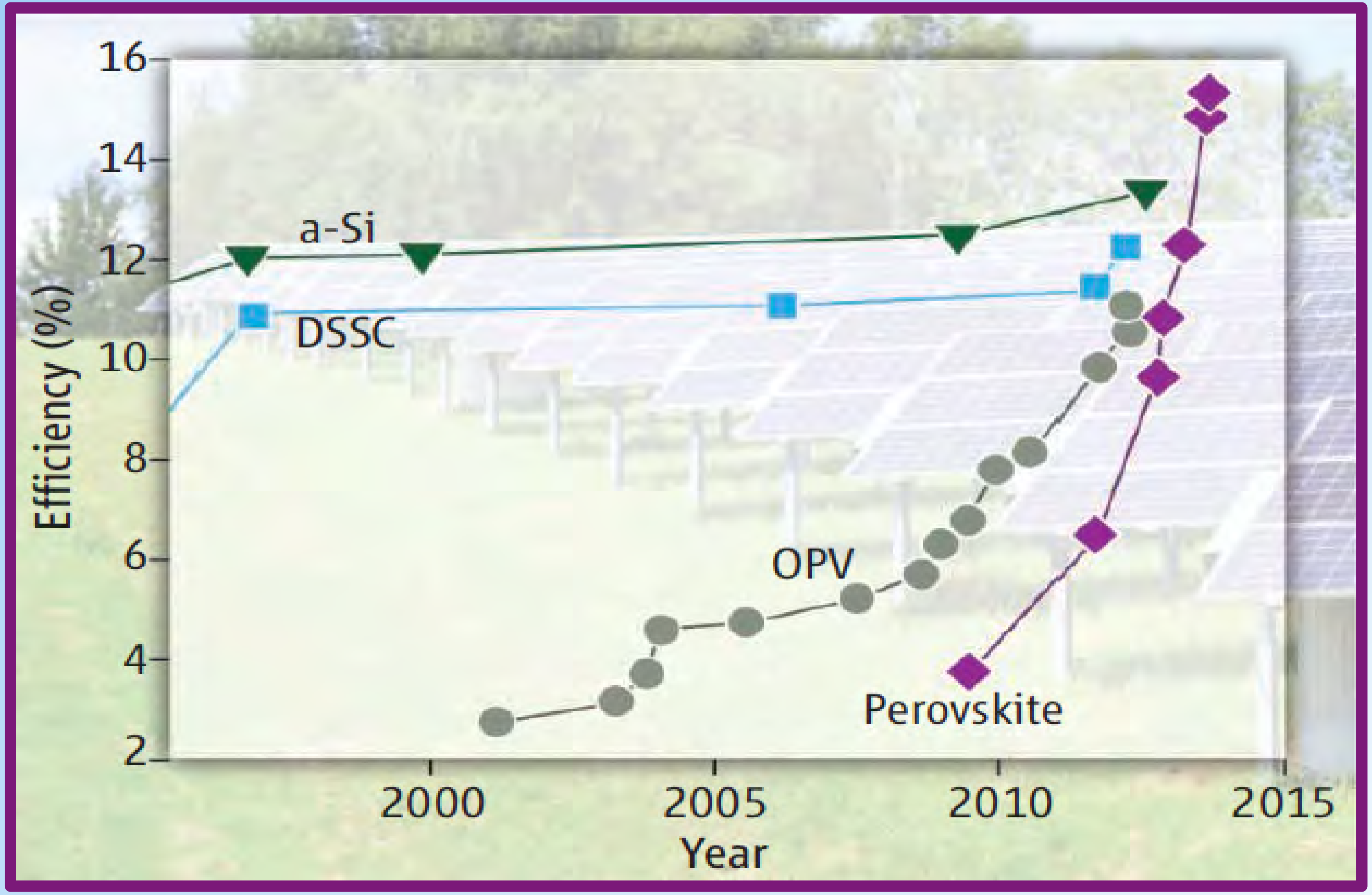
GWEC – Global Wind Energy Council, **2014**

World development of PV ELECTRICITY, 2000-2013



EPIA Report, **2014**

Potential competitors for crystalline silicon?



Perovskite-Based Solar Cells: $(CH_3NH_3)MX_{3\text{-}X}Y_X$ (M = Pb/Sn ; X,Y = I/Br/Cl)

Science **2013**, *342*, 317

BIGGEST CHALLENGES for intermittent renewable electricity

1) **OVERCAPACITY** (installed capacity 2/3/4 x compared to conventional technologies)

2) **STORAGE**: peak production is often too large

3) **ELECTRIC GRID**: to be completely reshaped (*smart grid*)

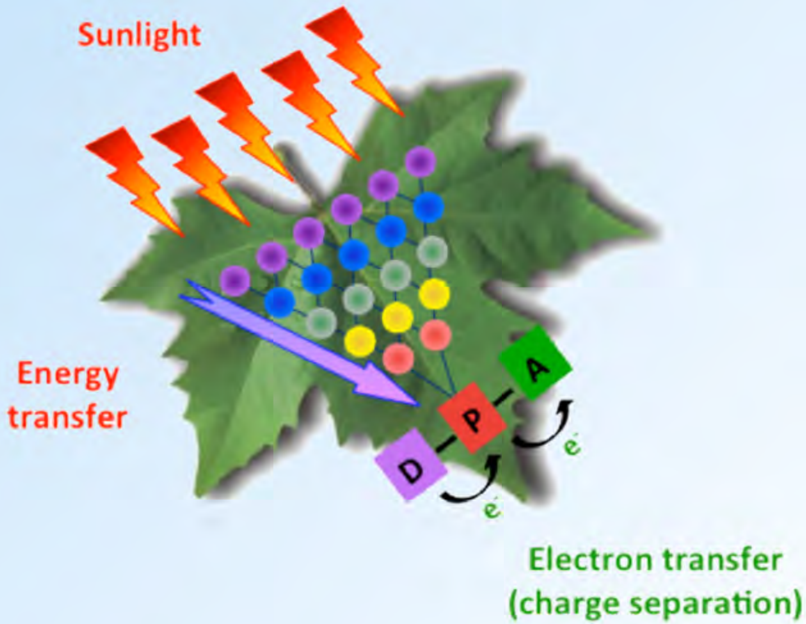
b) Target FUELS

FROM THE EXPLOITATION

of naturally occurring (fossil) fuels

TO THE MANUFACTURING

of artificial fuels

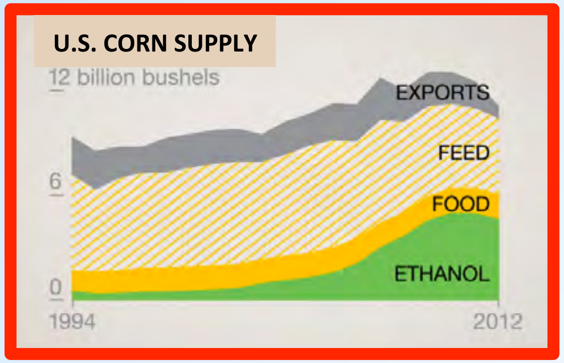


Harvesting solar energy through natural photosynthesis: BIOFUELS (4% of world's transportation fuels - 23% in Brazil)

BIOETHANOL for petrol engines
(from corn, sugarcane,
sugar beet, sorghum)

1ST
GENERATION

BIODIESEL for diesel engines
(from vegetal oils: rape,
sunflower, soybean, palm, etc.)



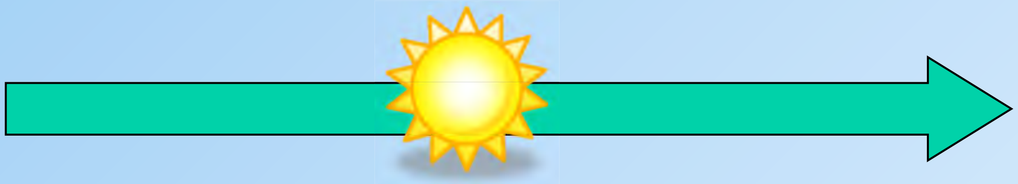
BIOETHANOL from non edible
cellulosic materials and
non food crops

2ND
GENERATION

COMING UP

3^{RD} GENERATION SOLAR FUELS: ARTIFICIAL PHOTOSYNTHESIS

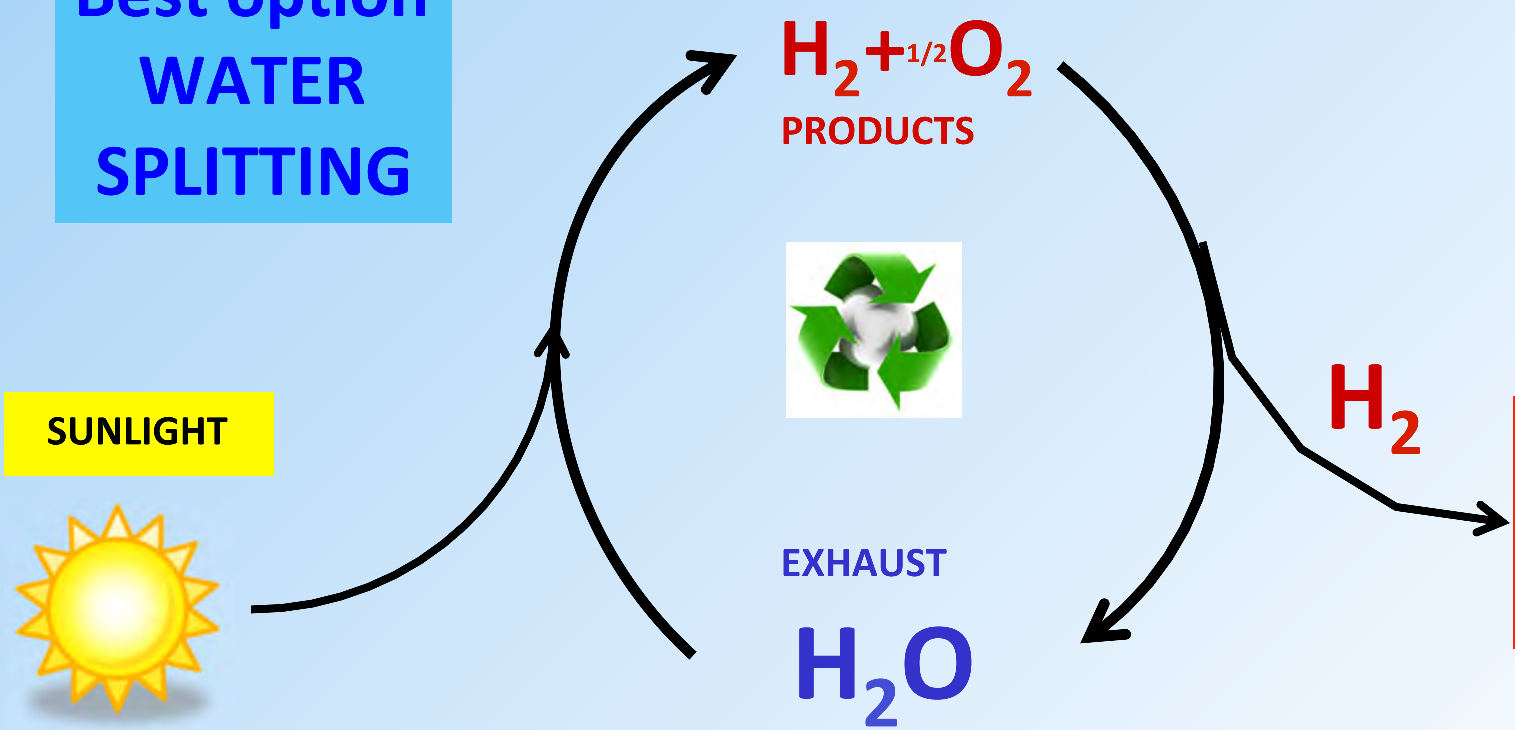
H_2O, CO_2



H_2, CH_3OH, etc.

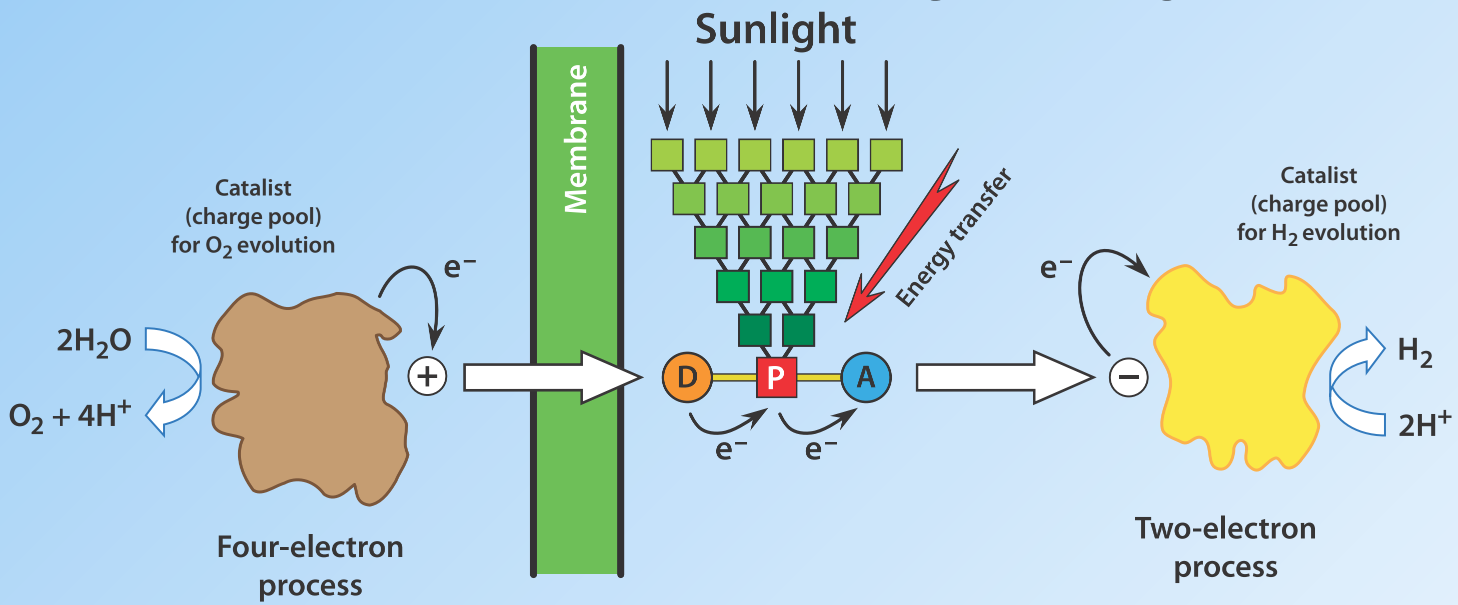
ARTIFICIAL
MATERIALS, PROCESSES, SYSTEMS

Best option
WATER SPLITTING



- FUEL
(I.C.E., FUEL CELLS)
- CHEMICAL
(COMBIN. WITH CO_2)

WATER SPLITTING - key components



1) Antenna (energy transfer)

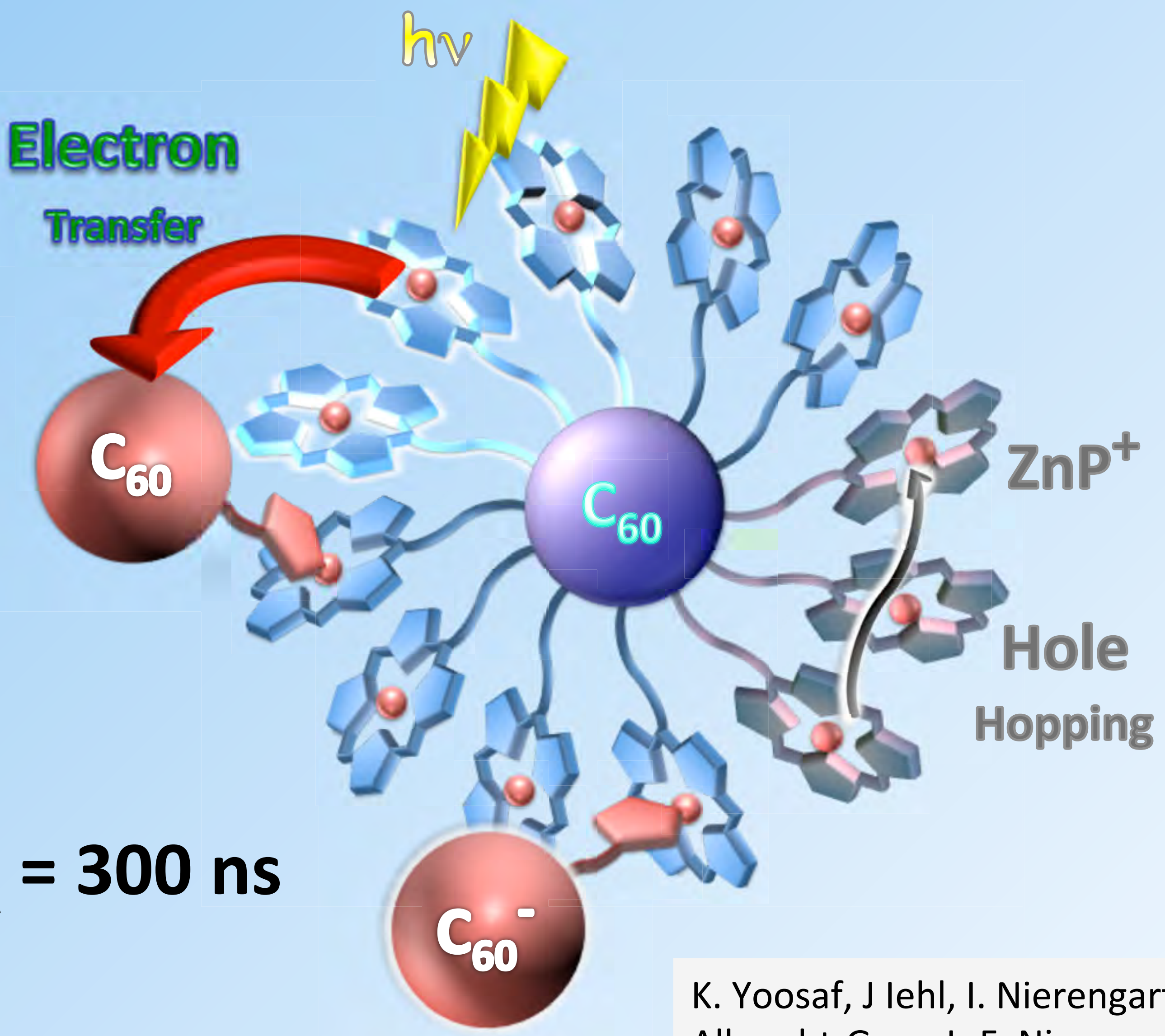
2) Charge separation unit (electron transfer)

3) Catalyst for H_2 evolution

4) Catalyst for O_2 evolution

5) Membrane separating the two processes

A supramolecular model photosynthetic antenna/CS unit



τ_{CR} = 300 ns

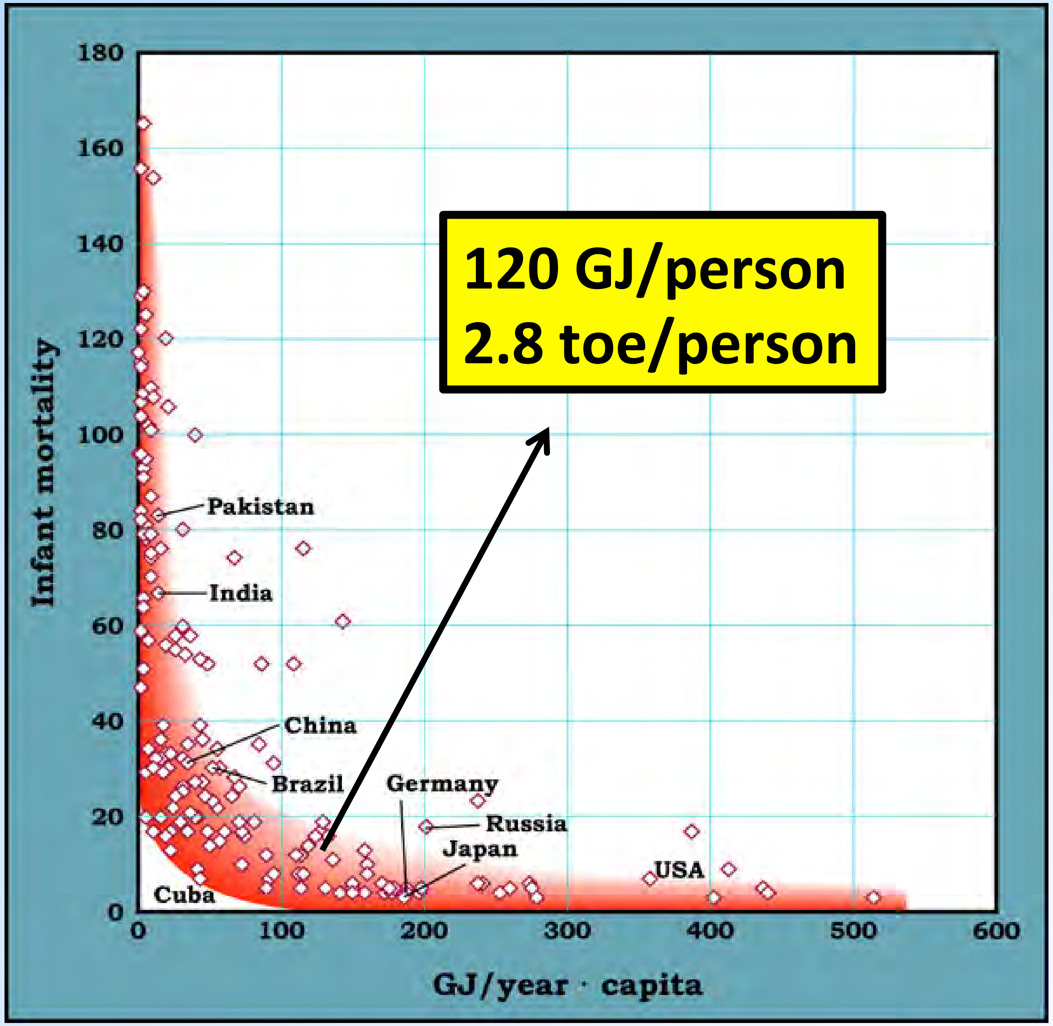
K. Yoosaf, J Iehl, I. Nierengarten, M. Hmadeh, A.-M. Albrecht-Gary, J.-F. Nierengarten, N. Armaroli
Chem. Eur. J. **2014**, *20*, 223-231

c) Target REDUCED CONSUMPTION and INCREASED EFFICIENCY

Reducing consumption: HOW MUCH?

Infant mortality

A parameter strictly related to the quality of life



Credit: Prof. Vaclav Smil, Univ. of Manitoba, CANADA

Energy consumption: an ideal path to 2050

	Mtoe / country	toe / pers
Canada	333	9.4
USA	2 266	7.3
France	248	3.8
EU	1 760	3.5
Italy	159	2.6
TARGET 2050	25 000	2.8
China	2 852	2.1
WORLD 2013	12 730	1.8
Brazil	284	1.4
India	595	0.5
Ethiopia	3	0.03

2050
9 billion

2013
7.2 billion

Elaborated from *Eurostat, PRB, and BP Statistical Reviews* **2014**

What would you do with 0.03 toe/y of energy?

Improving EFFICIENCY: lighting

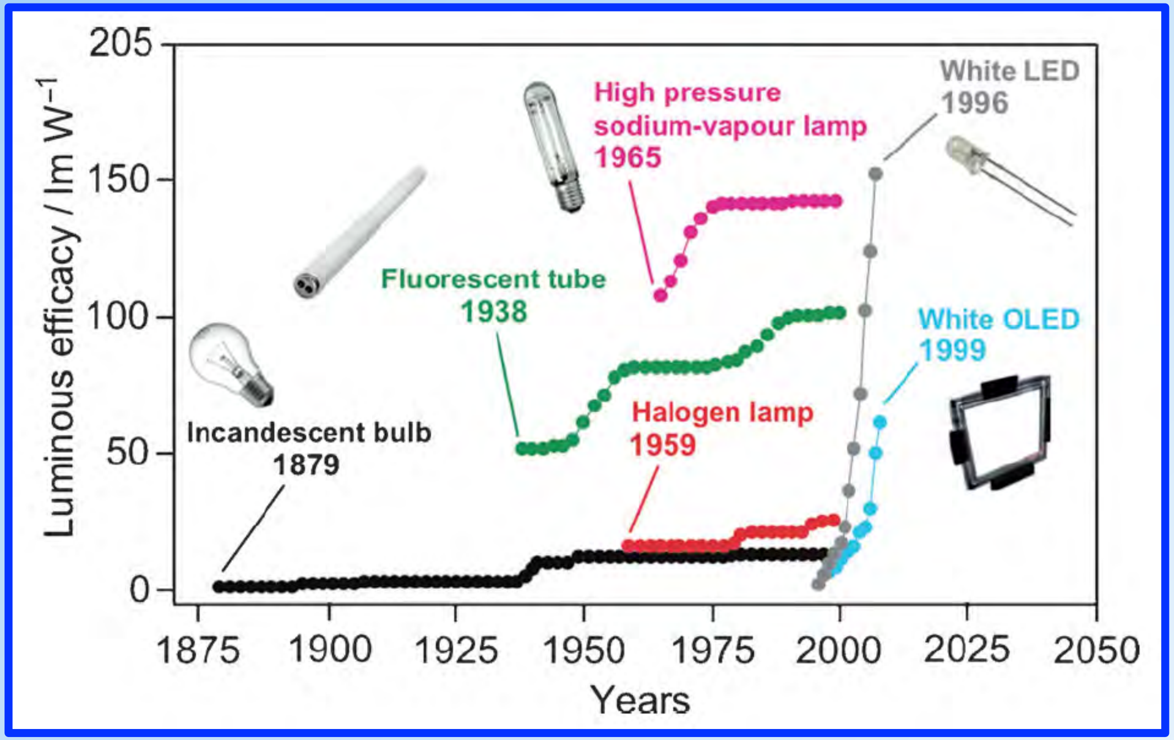
95%

40%

22%

Overall Efficiency < 10%

Ongoing epochal change in lighting



"OLD" TECHNOLOGIES

hot lighting

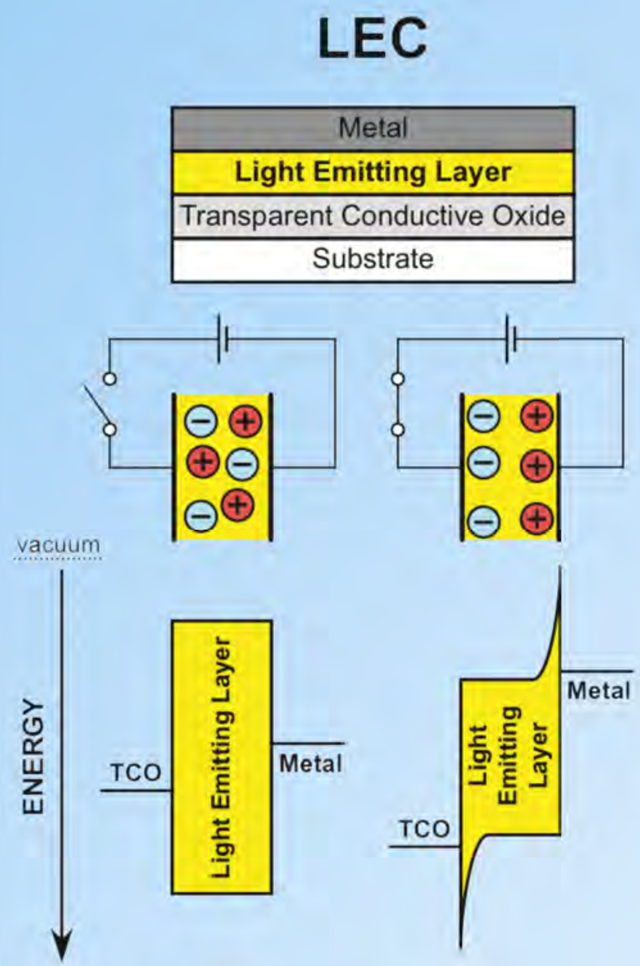
Light is an indirect effect

LED and OLED

cold lighting

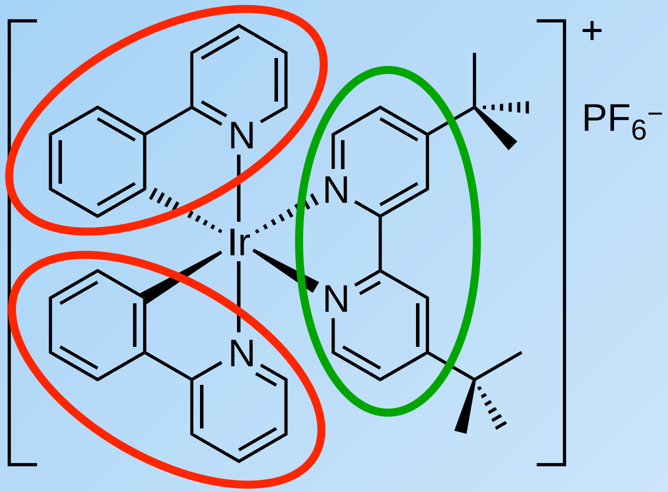
Materials/molecules are the very emitters

A simpler design concept than OLEDs:
LIGHT EMITTING ELECTROCHEMICAL CELL (LEC)



- ✓ <u>ionic</u> **metal complexes**
- ✓ **few layers**
- ✓ **easy processability**

Mostly investigated iTMCs for LECs: Ir(III)

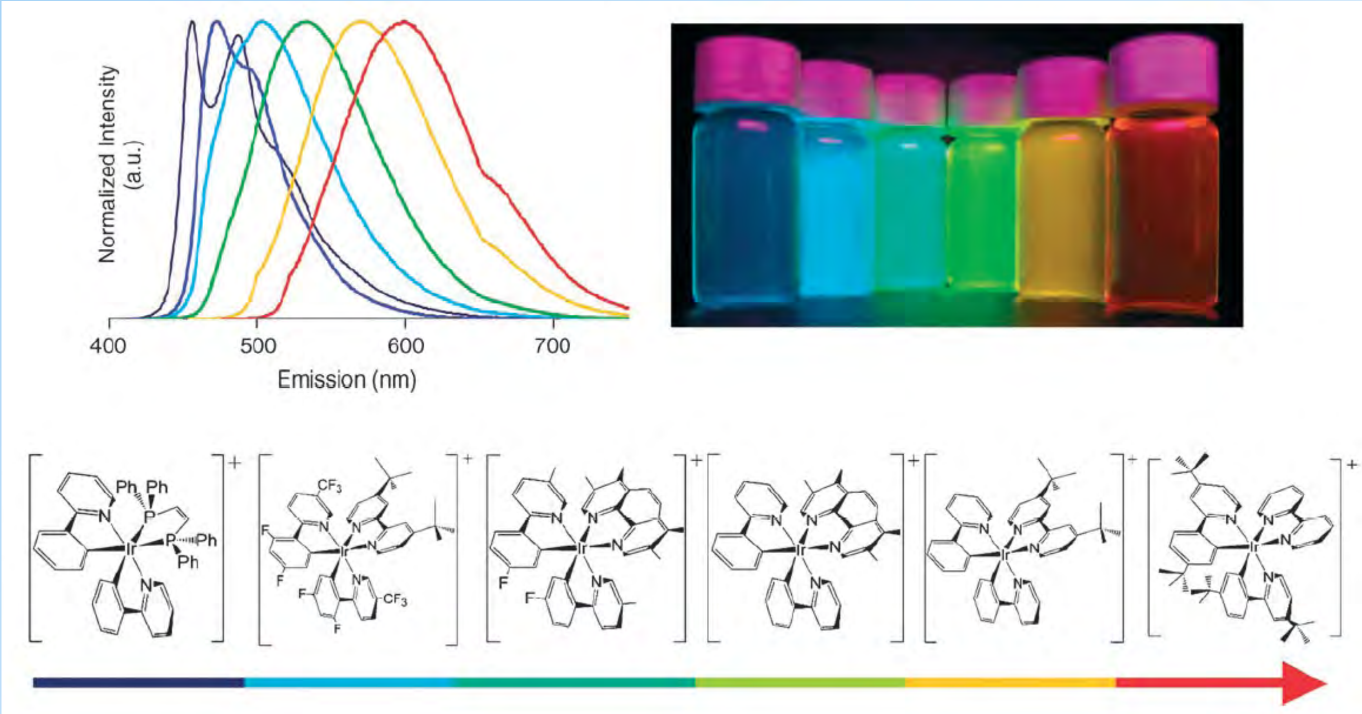


Cyclometallating C-N ligands

“Ancillary” N-N ligand

R. D. Costa, E. Ortì, H. J. Bolink, F. Monti, G. Accorsi, N. Armaroli
Angew. Chem. Int. Ed. **2012**, *51*, 8178–8211

Ir(III) complexes
emission from blue to red by ligand design



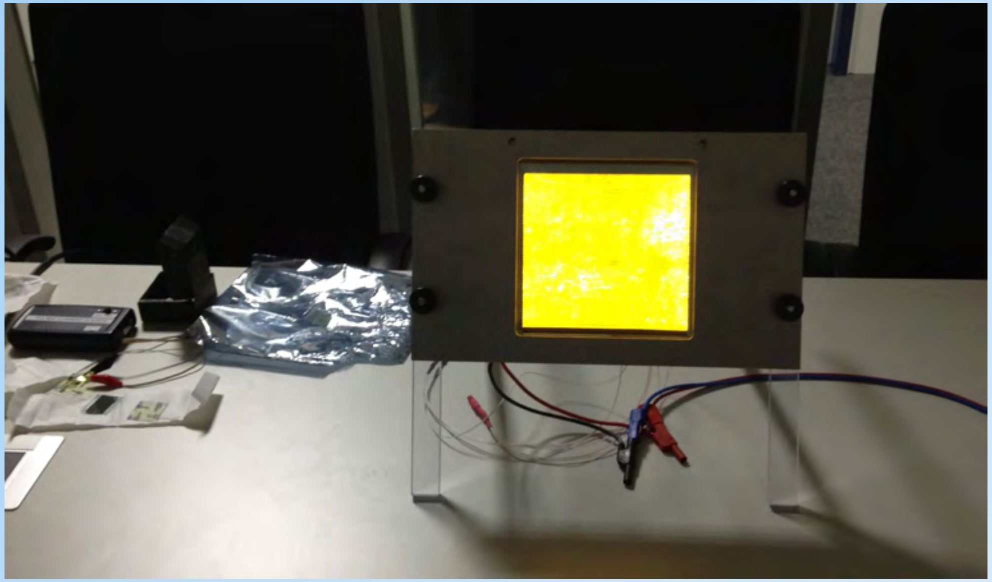
Chem. Eur. J. **2006**, *12*, 7977

Luminescence always stems from the lowest TRIPLET excited state

HOMO-LUMO energy tuning allows colour change

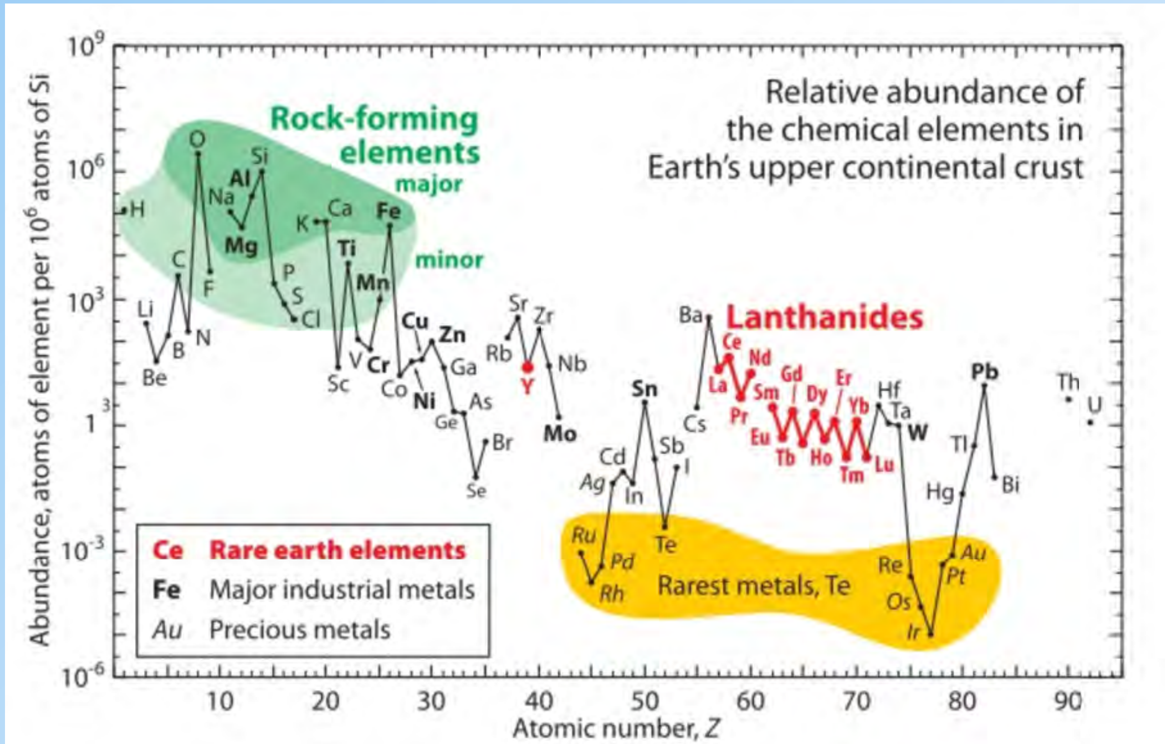
LEC demonstrator

RESEARCH FOR **LOW COST**
FLEXIBLE LIGHTING SOLUTIONS



Size: 210 cm^2
Brightness: 1150 cd/m^2
Efficacy: 4.5 lm/w

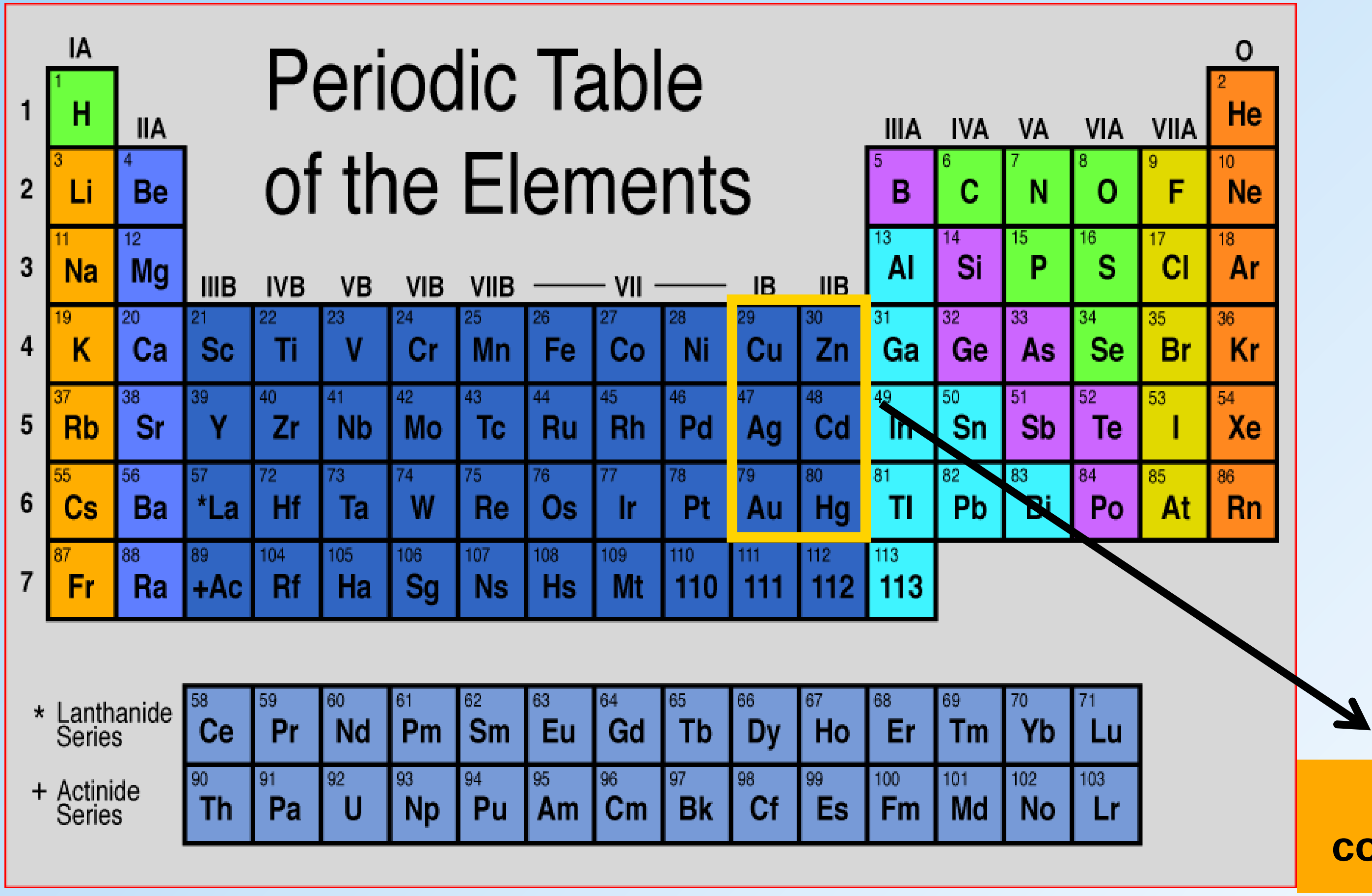
Iridium is great, but there is a problem



The rarest element on Earth's crust …

World Iridium production is around 4 t/y
(≈ 6 x10^{-4} g/person)

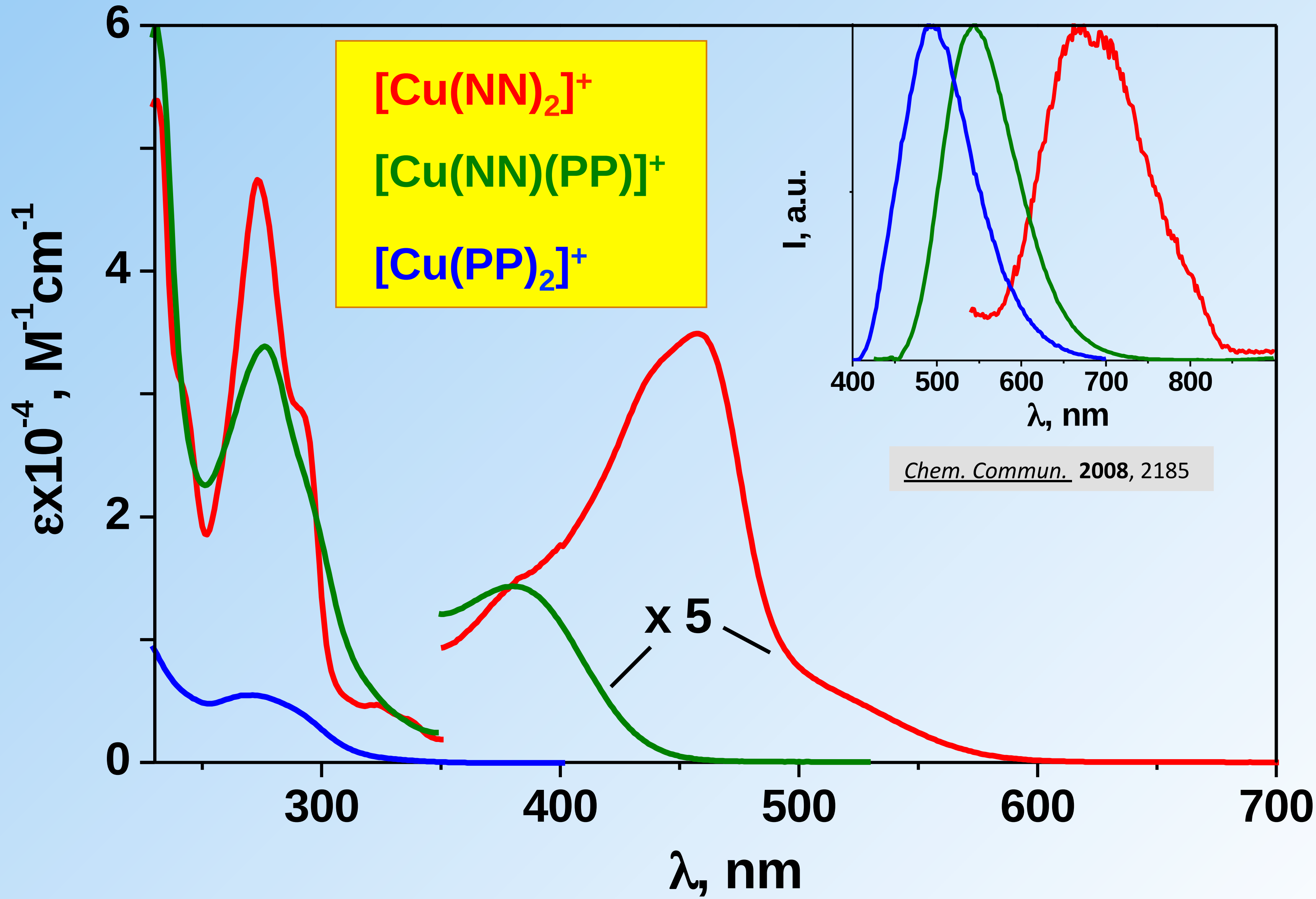
Possible alternatives to Ir(III) complexes



d^{10} complexes

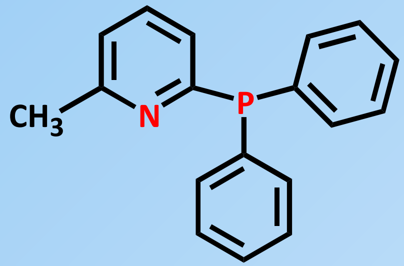
A. Barbieri, G. Accorsi, N. Armaroli *Chem. Commun.* **2008**, 2185-2193 (Feature Article)

Color tuning with tetrahedral Cu(I) complexes

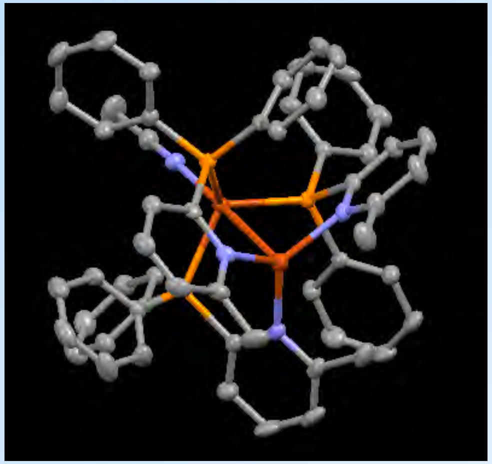


Chem. Commun. **2008**, 2185

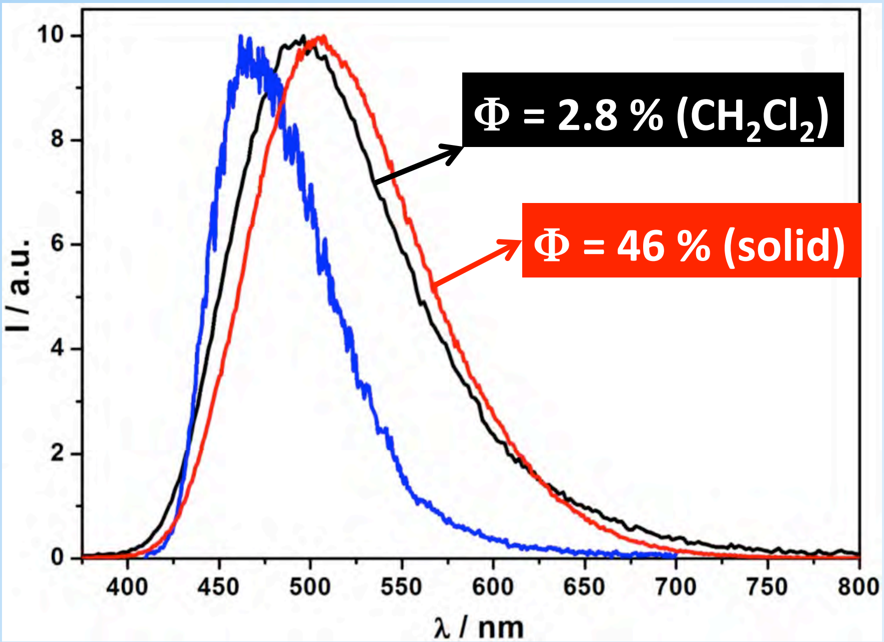
Recent example 1 - dinuclear cluster-like Cu(I) complexes



+ $Cu(CH_3CN)_4BF_4$ →



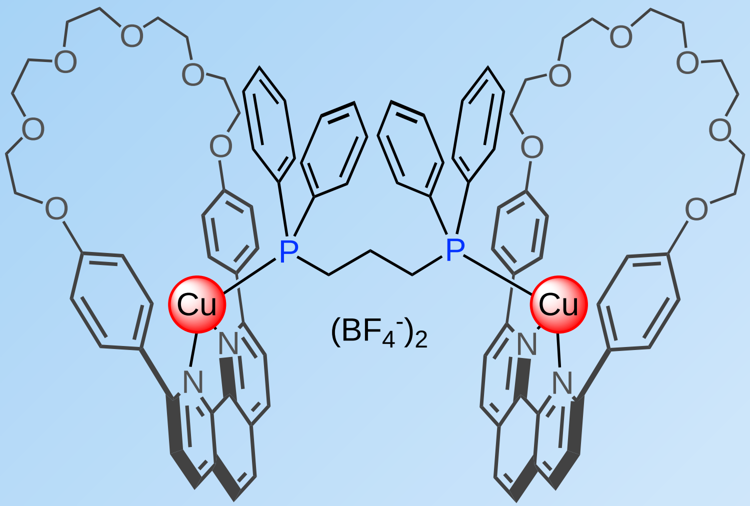
3 eq.   2 eq.



Chem. Commun. **2013**, *47*, 859

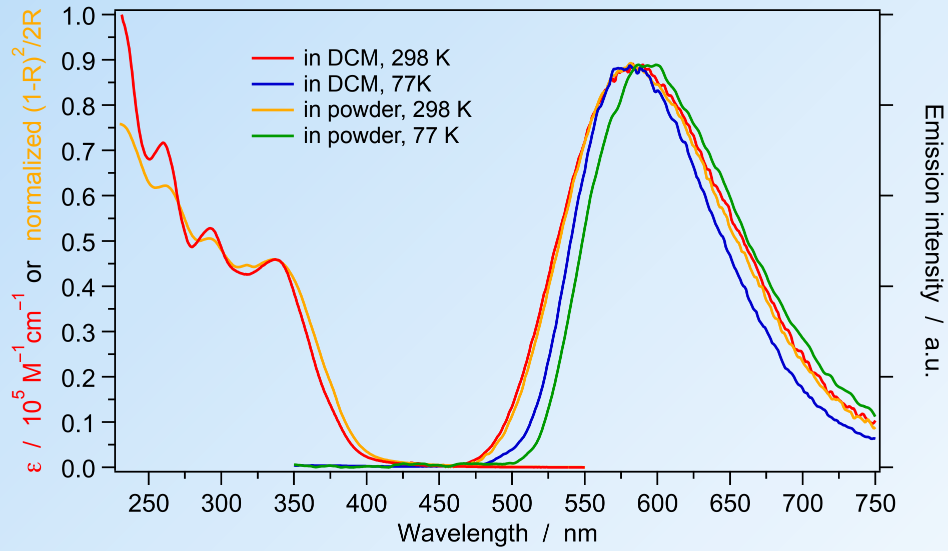
Recent example 2 - dinuclear pseudorotaxane Cu(I) complexes

$[Cu(NN)(PP)]^+$

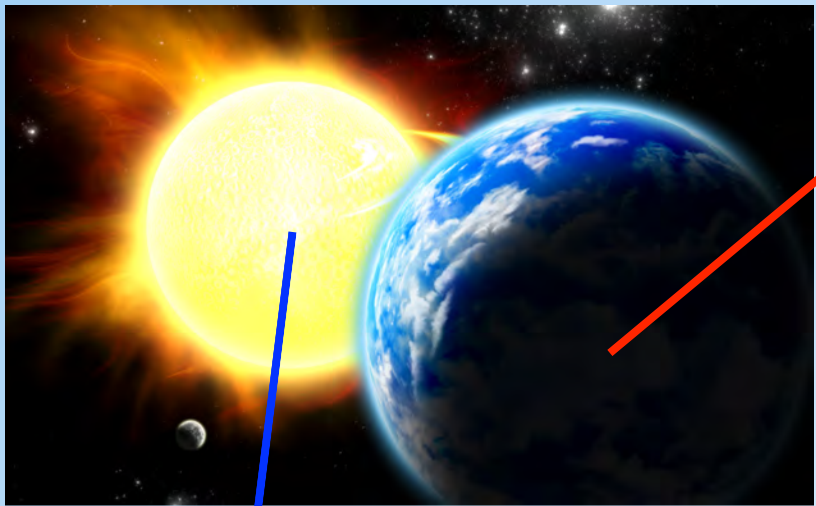


TRIGONAL GEOMETRY

Chem. Eur. J. **2014**, *20,* 12083



PERENNIAL ENERGY IS OVERABUNDANT …
… AND HUMAN INGENUITY TOO …
… BUT RESOURCES OF PLANET EARTH ARE LIMITED



THE CONVERTERS OF SOLAR ENERGY ARE MADE OF “TERRESTRIAL” MATERIALS, HENCE THEY ARE AVAILABLE IN LIMITED AMOUNTS

“EXTRATERRESTRIAL” INPUT AMOUNTING TO THOUSANDS OF TIMES OUR NEEDS

RARE ELEMENTS IN ENERGY TECHNOLOGIES:
Some examples

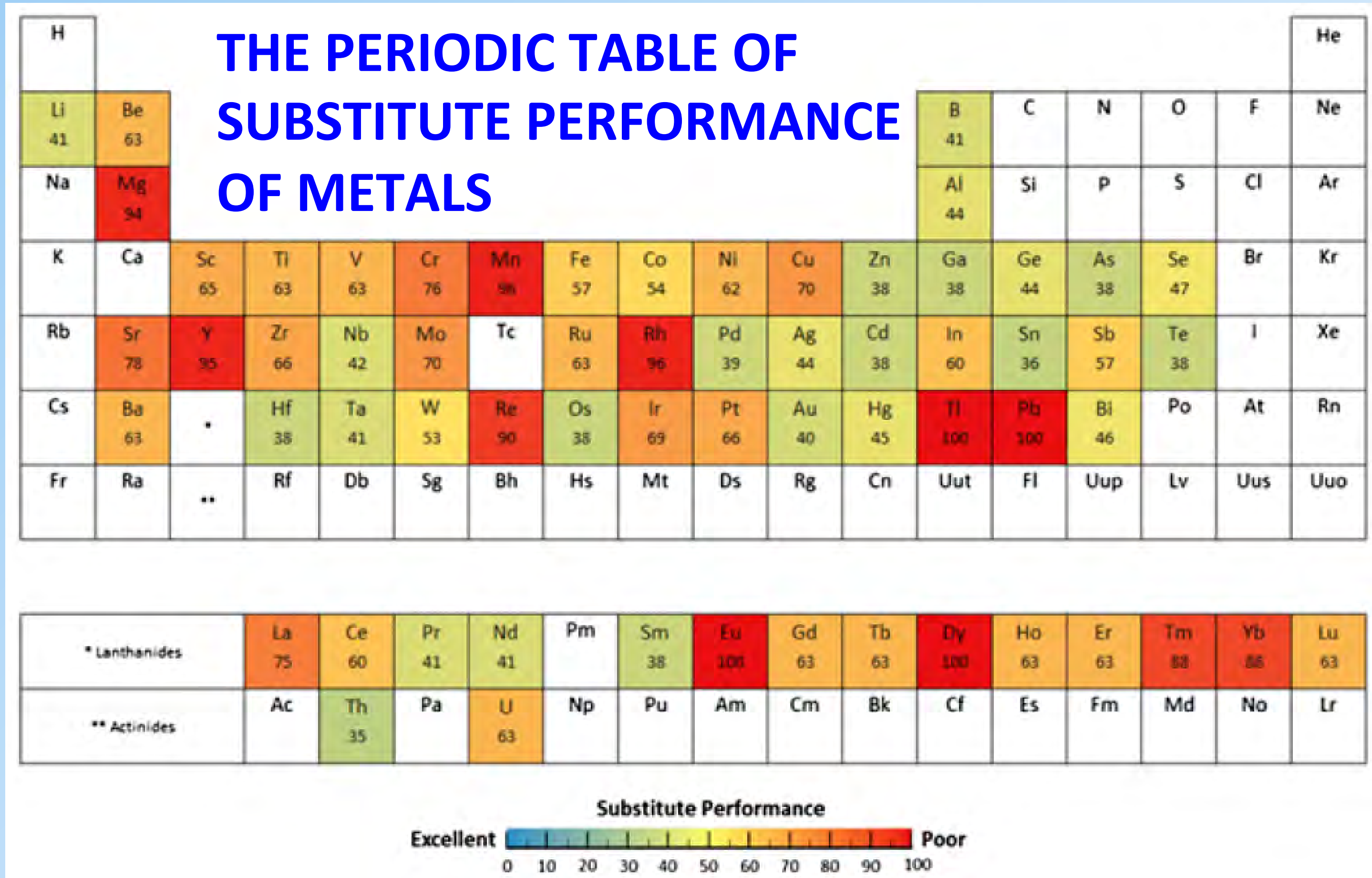
THIN FILM PV PANELS:
Indium, Gallium, Tellurium

Neodymium, Praseodymium, Dysprosium

- Neodymium, Praseodymium Dysprosium
- Lanthanum, Cerium; Lithium

Europium, Terbium, Yttrium, Cerium

REPLACEMENT IS OFTEN NOT POSSIBLE (YET)

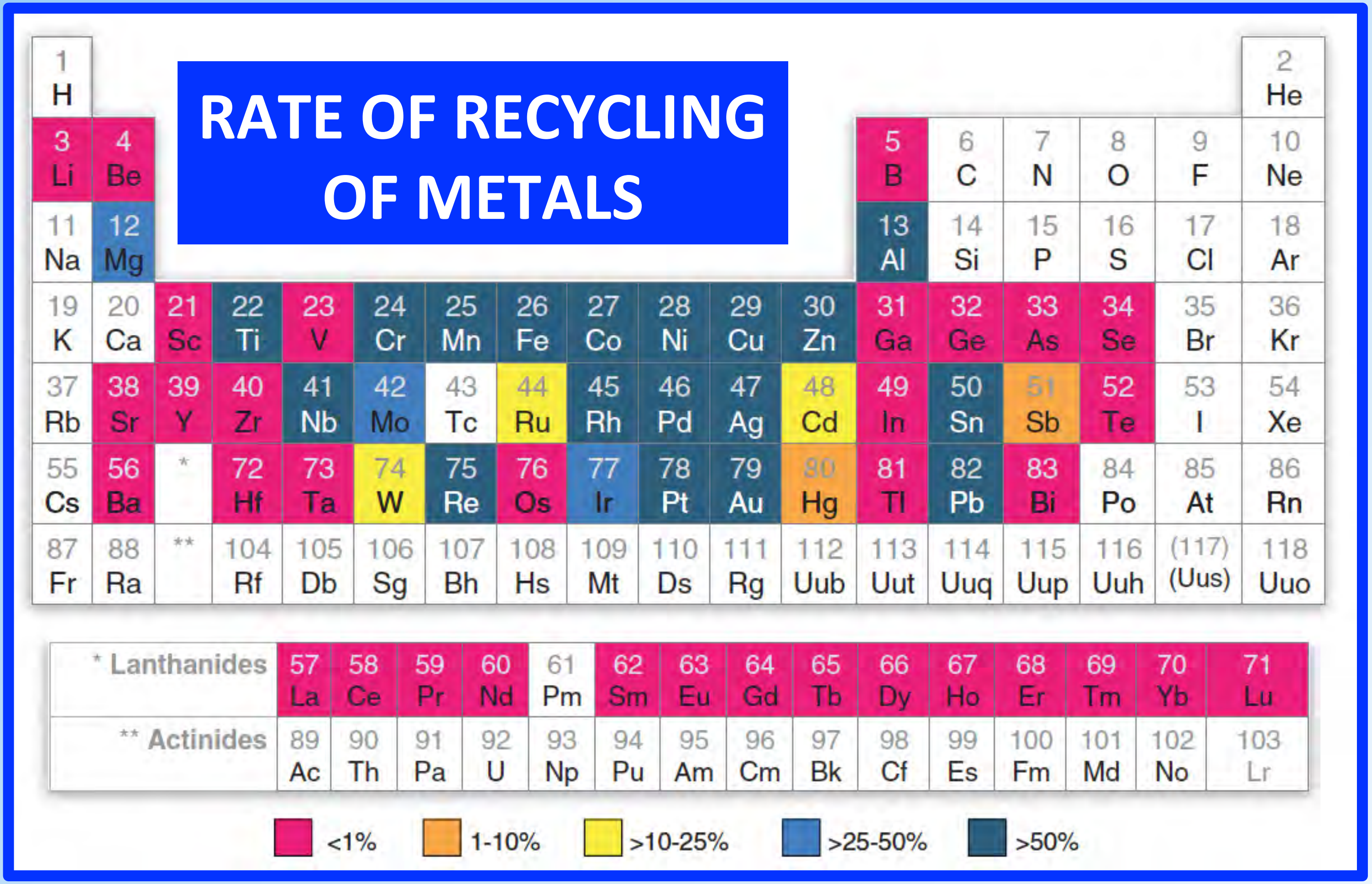


0 : exemplary substitutes exist for all major uses

100 : no substitute with adequate performance exists for any of the major uses

Graedel et al. *PNAS* , DOI: 10.1073/pnas.1312752110

THE ONLY SOLUTION: RECYCLING



Science **2012**, *337*, 690

PRESENT RECYCLING RATES ARE TOTALLY UNACCEPTABLE

OUTLINE

- **PART I: The present situation**
- **PART II: The perspectives**
- **PART III: Reflections on Europe**

THE ENERGY TRANSITION IS AN EXTRAORDINARY OPPORTUNITY FOR EUROPE

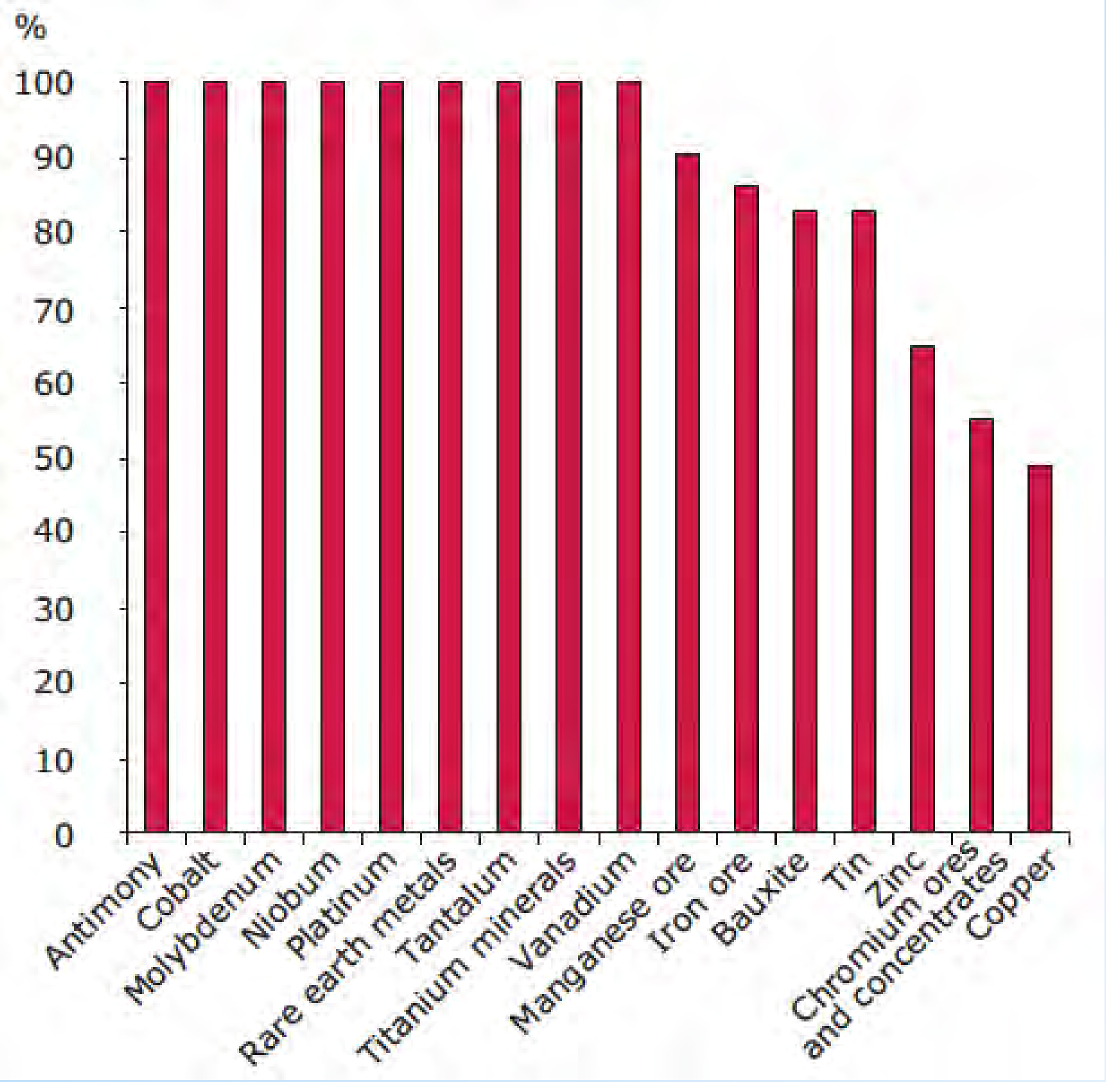
EU: RESERVES OF CONVENTIONAL ENERGIES

We own only 0.4, 0.8, 6.1 % of the world's proved reserves of oil, gas and coal and we have virtually no uranium reserves*

We enjoy the best quality of life on Earth BUT our enviable prosperity is based on energy resources coming FROM OTHER CONTINENTS

*BP Statistical Review of World Energy, **2014**

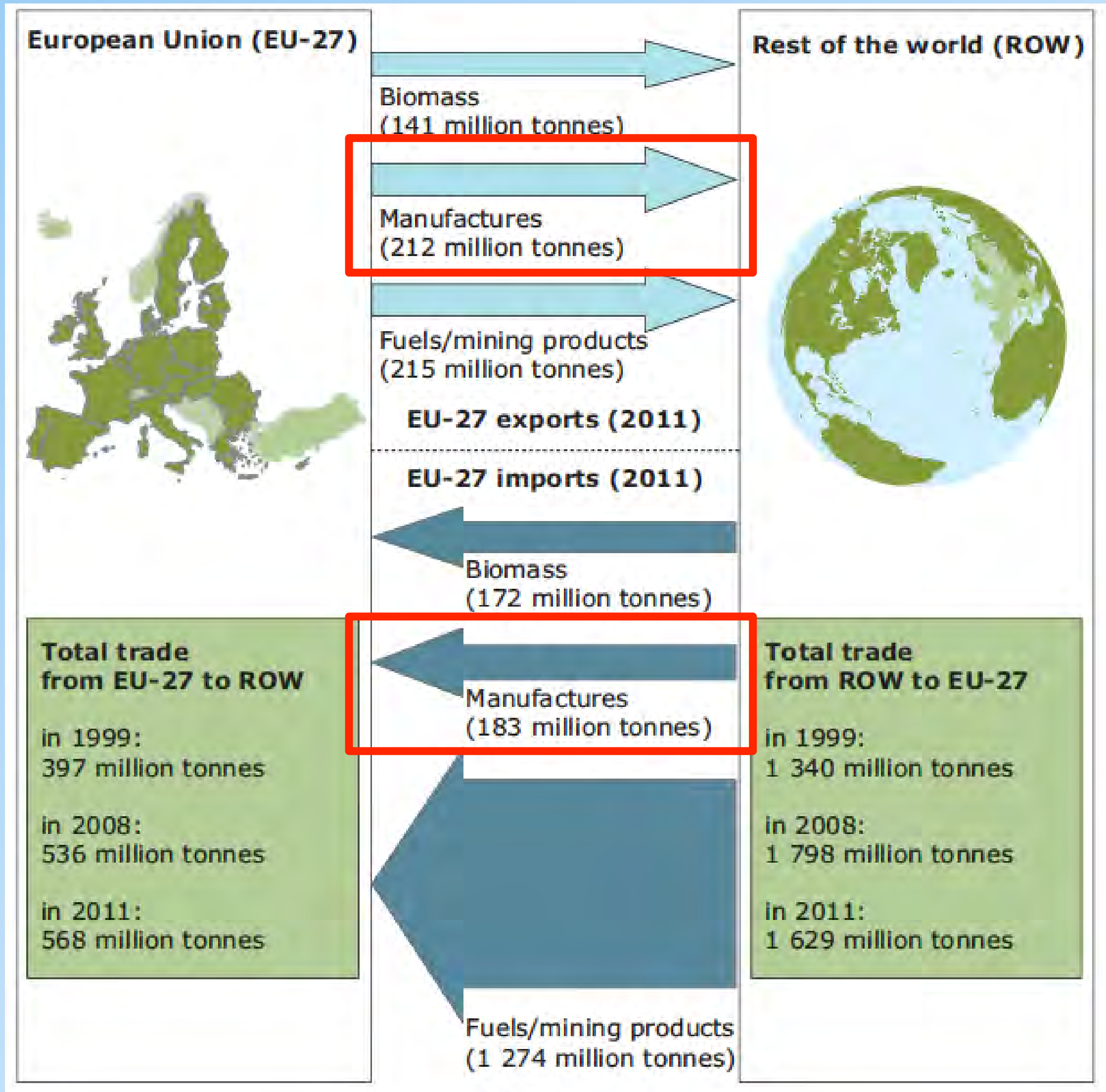
EU-27 : IMPORT OF METALS



WE ALMOST TOTALLY DEPEND ON IMPORTS

Material Resources and Waste – Update 2012, EEA **2012**

EU: IMPORT-EXPORT OF MATERIALS



WE HAVE STILL AN ADVANTAGE ON HIGH ADDED VALUE MANUFACTURING

Material Resources and Waste – Update 2012, EEA **2012**

FOSSILS vs. RENEWABLES: THE KEY DIFFERENCE

FOSSIL FUELS

THEY ARE "STUFF"
Either you have or you don't have

RENEWABLE ENERGY TECHNOLOGIES

THEY ARE MANUFACTURING AND KNOWLEDGE

WHERE WE SHOULD (POSSIBLY) GO

Increase public awareness: we are facing the toughest and most uncertain challenge ever faced by mankind

Abandon fossil fuels before they will abandon us

Stop the suicidal policy of cutting fund to education and research

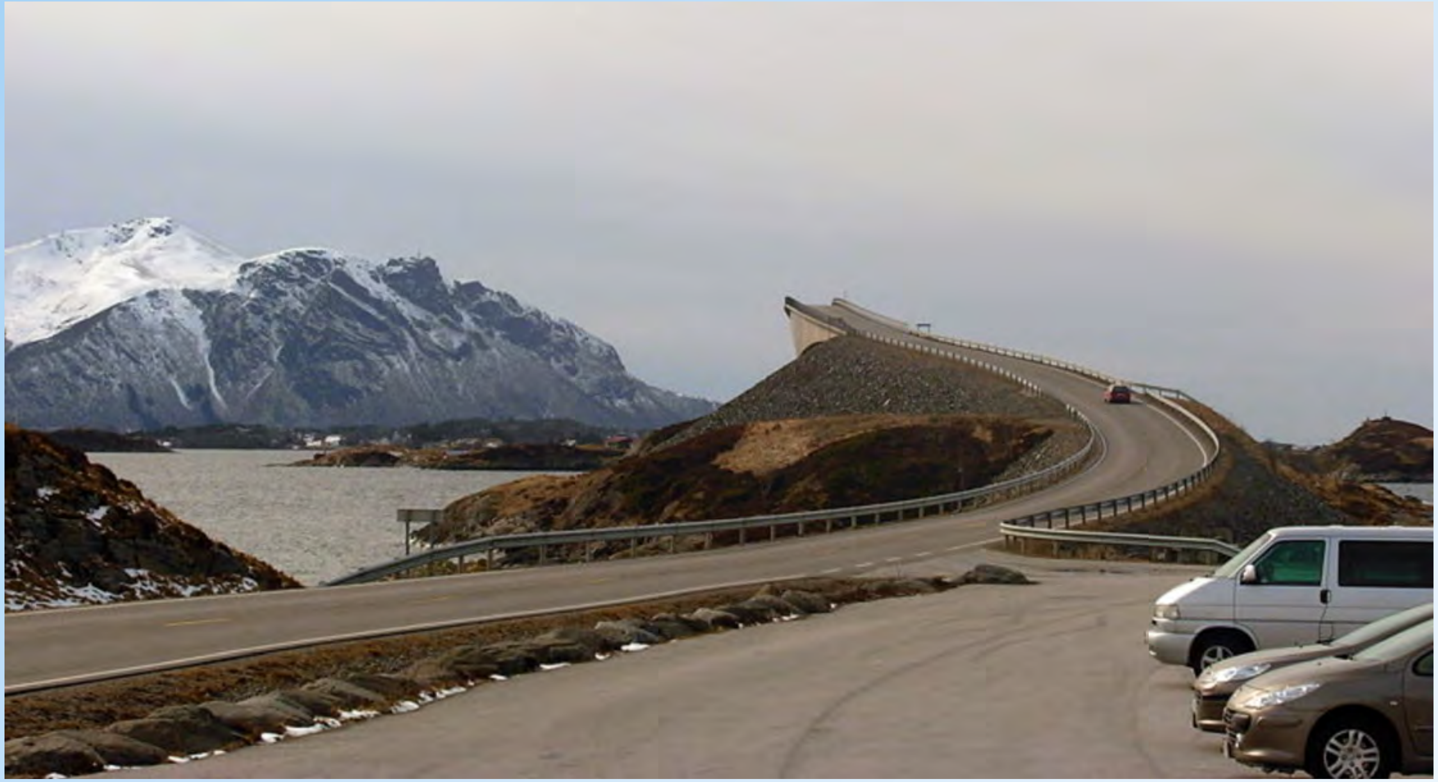
Favour the energy transition with adequate legislation

Stop weakening the commitment to decarbonization (as done recently ...)

Realize that energy transition is a huge opportunity , perhaps the only opportunity to save the EU economy

CONVENTIONAL RECIPIES TO REVIVE OUR ECONOMY HAVE FAILED FOR YEARS
WE ENTERED A NEW HISTORICAL PHASE
THE FOSSIL FUEL AGE IS IN ITS FINAL STAGE

WHAT IS DESPERATELY MISSING:
A bridge between scientists and decision makers



WE ARE IN A HURRY

Without a bridge between knowledge and decision

THE ENERGY, CLIMATE AND RESOURCE CRISES CAN OVERWHELM US

THE ENERGY TRANSITION: CHALLENGES AND SOLUTIONS

CHALLENGES

Perennial energy sources

Energy efficiency

Energy convers. & storage

Critical materials

…

SOLUTIONS

Artificial Photosynthesis, …

New Materials (e.g. for lighting)

Batteries, Fuel cells, Hydrogen

Recycling, Replacement

…

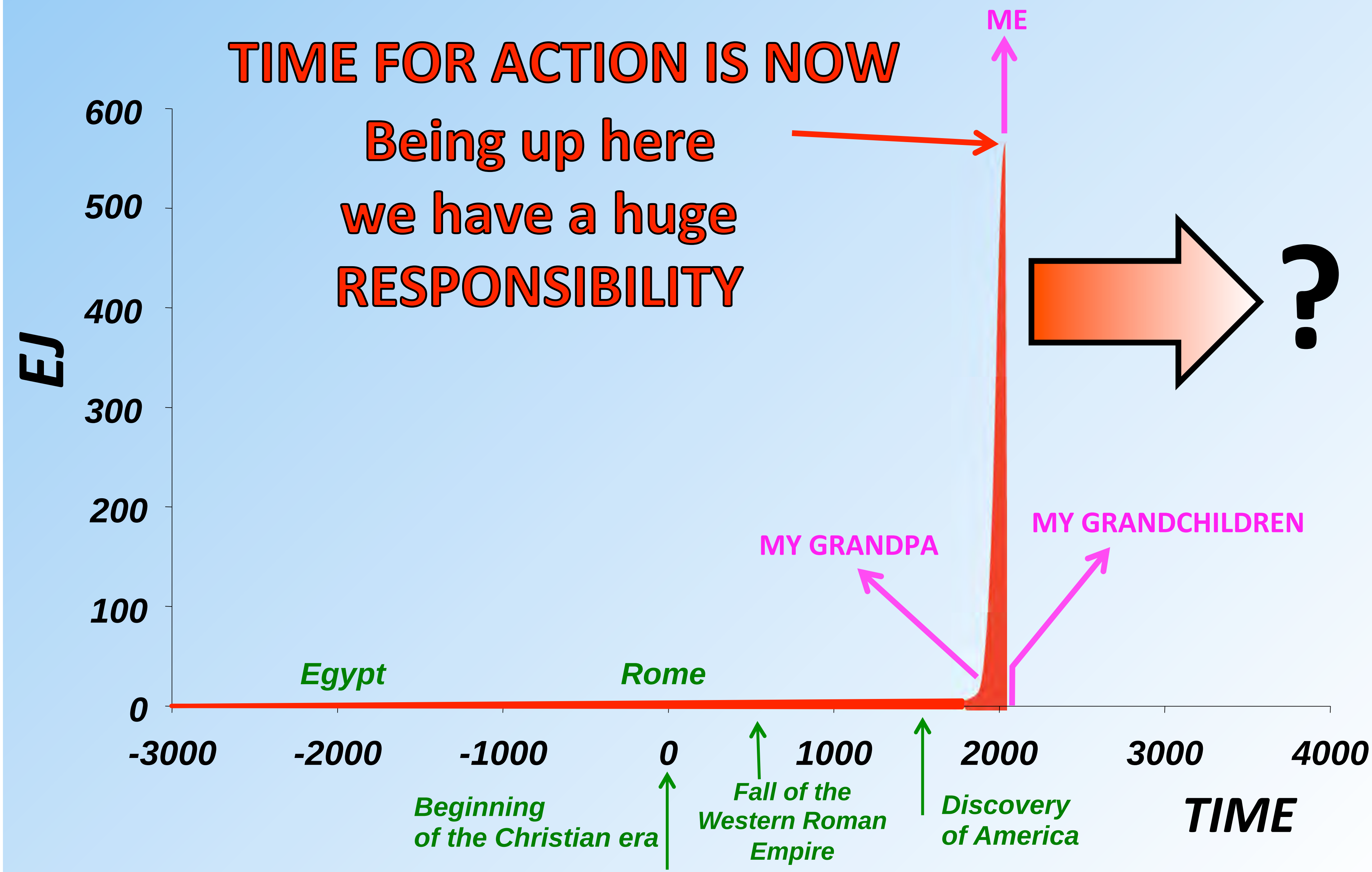
CHEMISTRY

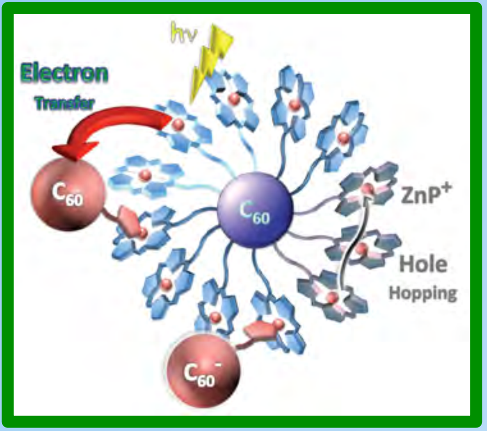
BUT LET'S NOT LOOSE THE SENSE OF OUR LIMITS

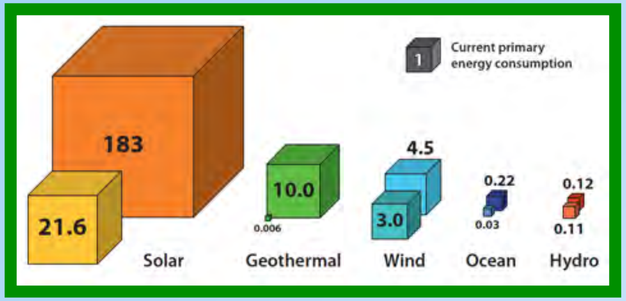
Cleaning operations on the Louisiana coasts (USA), after the disaster of the Deepwater Horizon oil spill

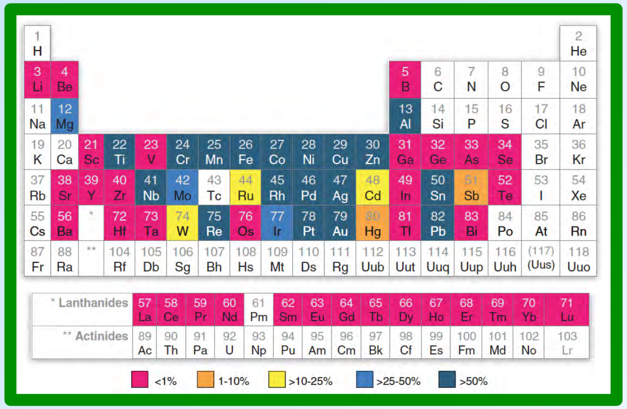
Science & Technology are NOT the solutions to all of our problems

THE ENERGY TIMELINE









A politician looks at the next election.
A statesman looks at the next generation

Alcide De Gasperi

Italian Prime Minister, 1946-1953

Founding father of the EU