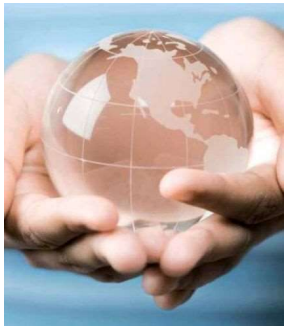


NANOTECHNOLOGIES IN ENERGETICS

(tendencies and hopes)

Norbert Kroo
Wigner Research Center of Physics and
Hungarian Academy of Sciences

„Humboldt Kollege” Conference, 15.09.2022

Probably the greatest challenge of the next decades:

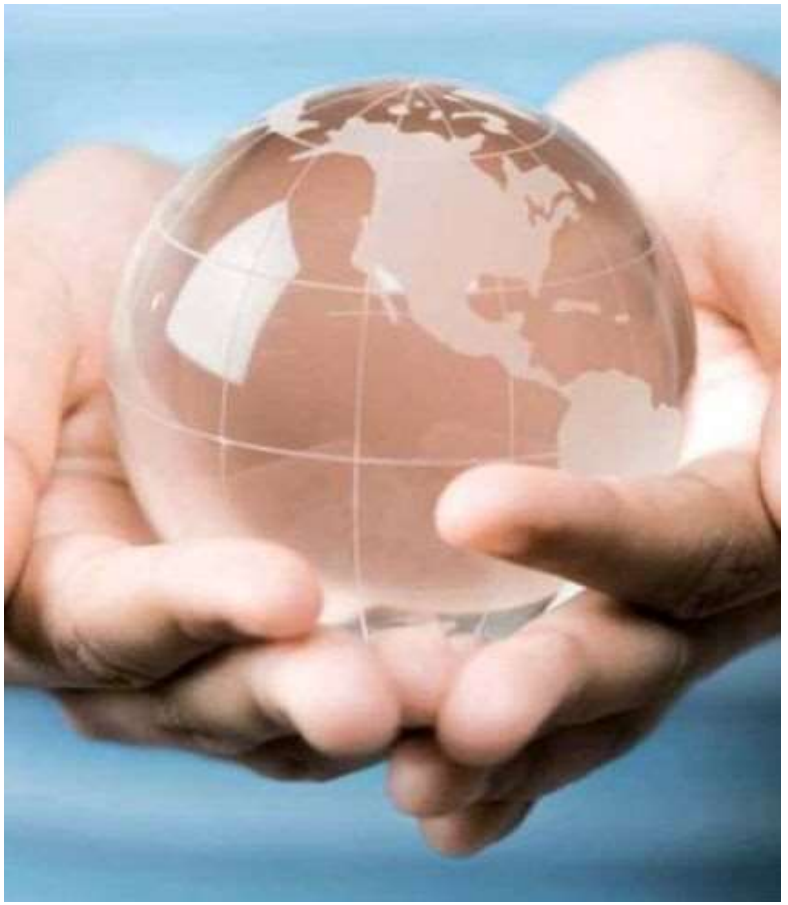
SECURE ENERGY FOR 10¹º HUMANS

At 2050 minimum 10 Terawatt additional energy sources will be necessary.

And for global prosperity this energy should be cheap.

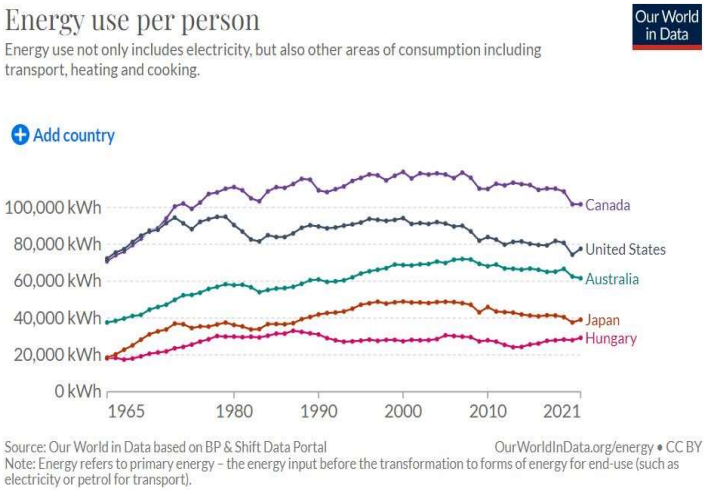
WITH THE PRESENT TECHNOLOGIES THIS IS IMPOSSIBLE

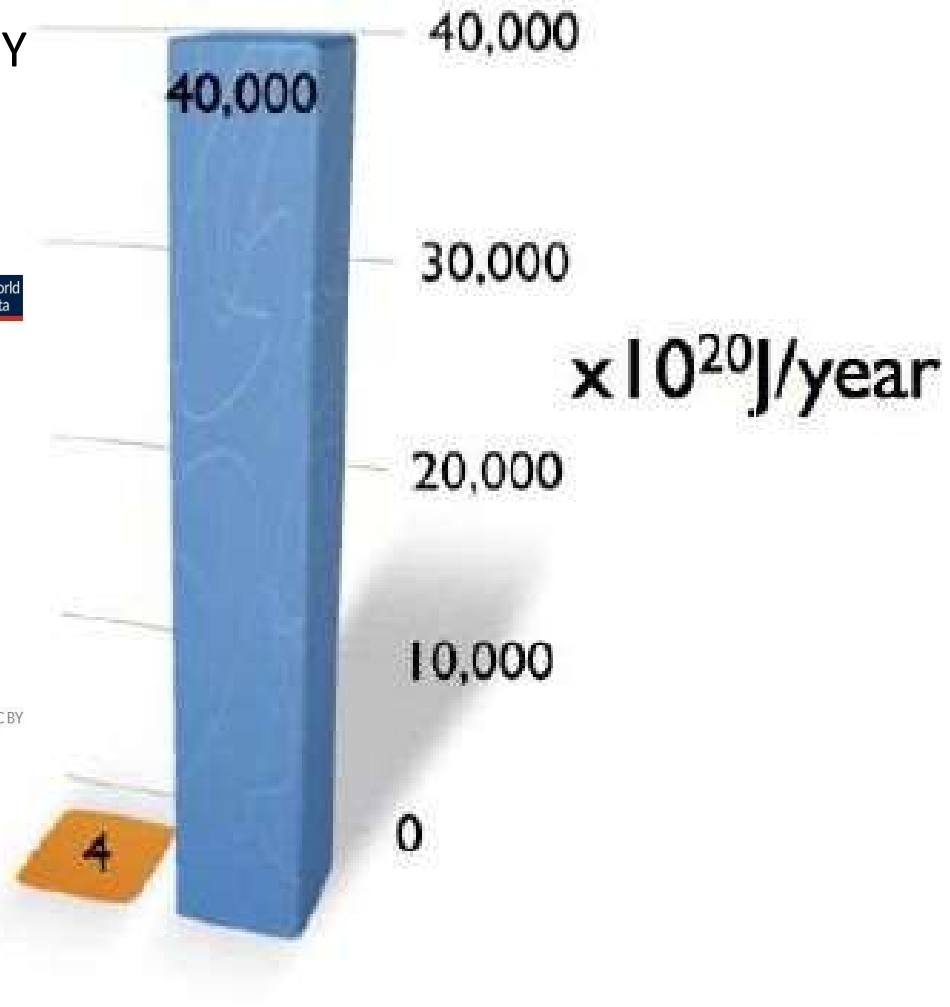
AND THE PRESENT ENERGY CRYSIS?
(uncertainties and risks)



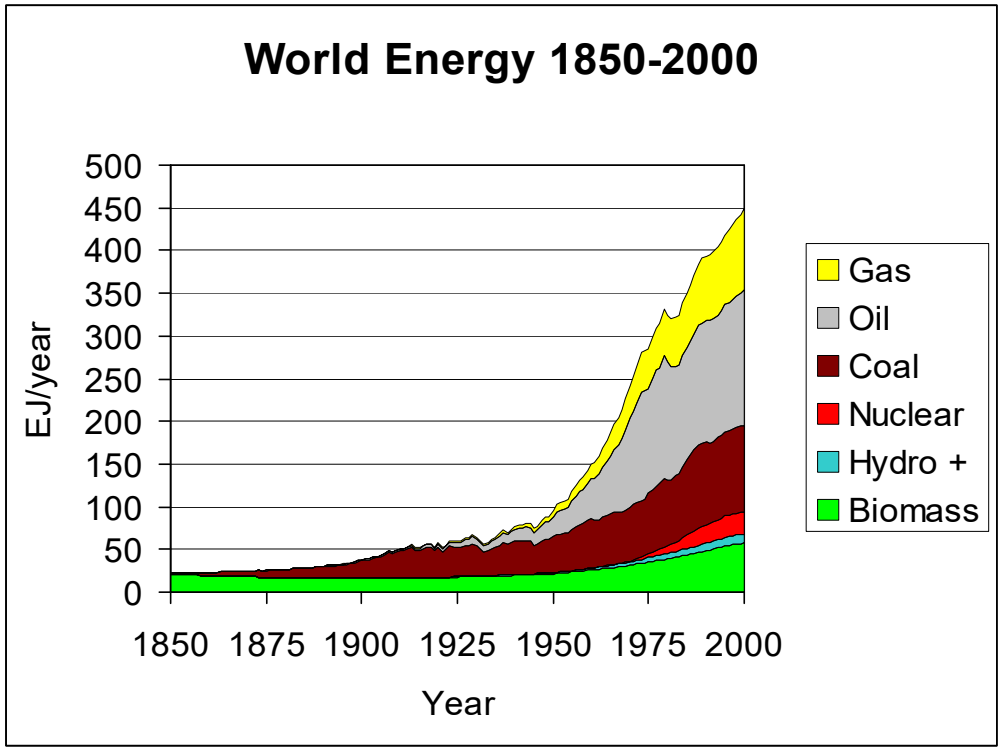
ENERGY OPTIMALIZATION

ABUNDANT ENERGY
„RESERVES”

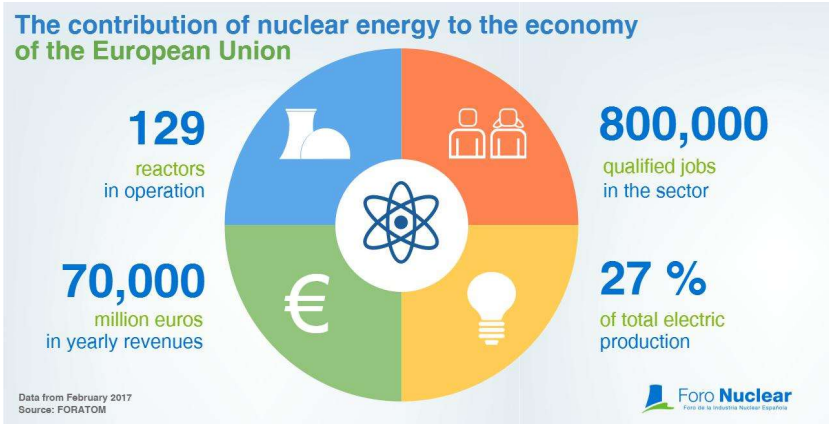


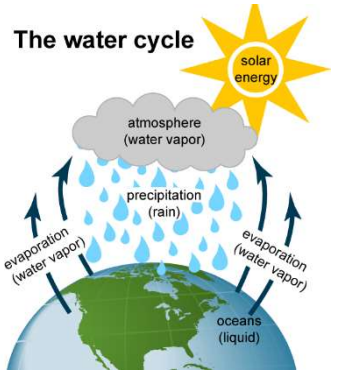


The solar energy flux is 10,000 times our consumption



20 fold growth between 1850 and 2000 .
The share of fossile ones in 2000: 80% .

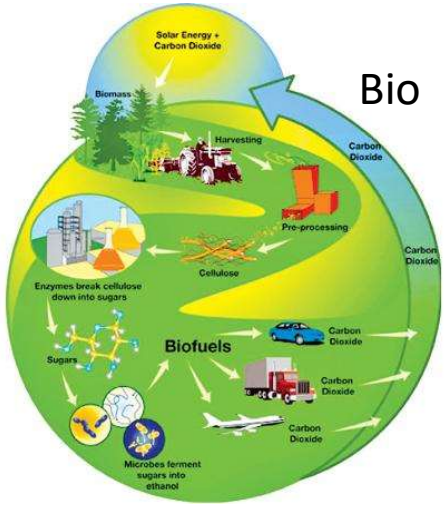




Hydro

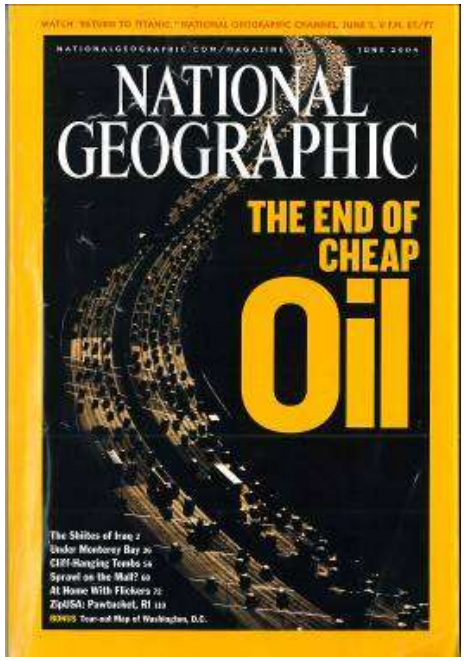
Wind

Solar

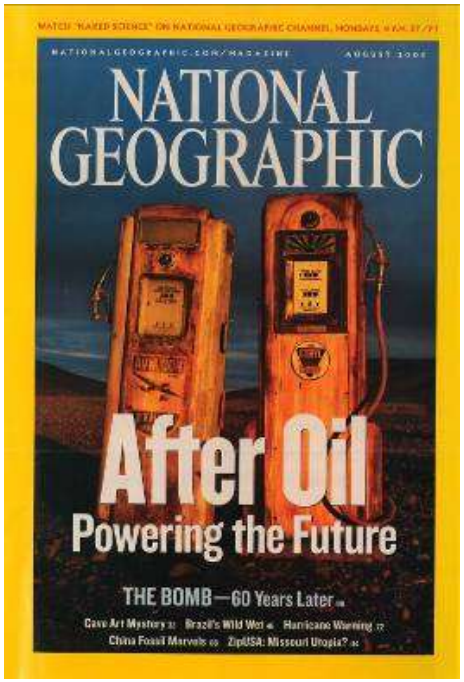


Bio

My hope is that the oil age will come to the end not because there is no more oil, like the stone age has not been finished because all the stones have been consumed.

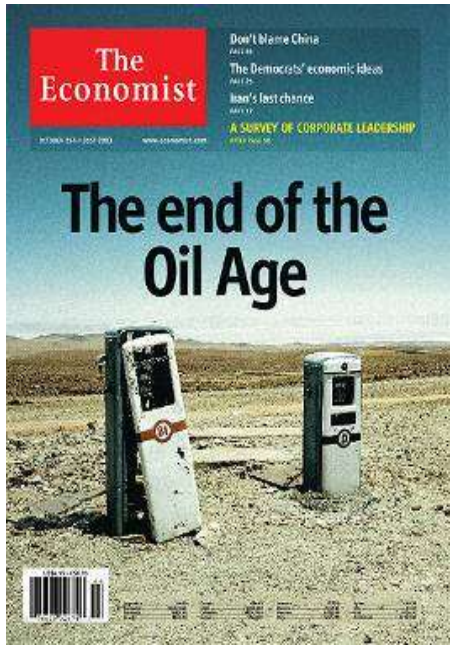


2004 June



2005 August

2005 May

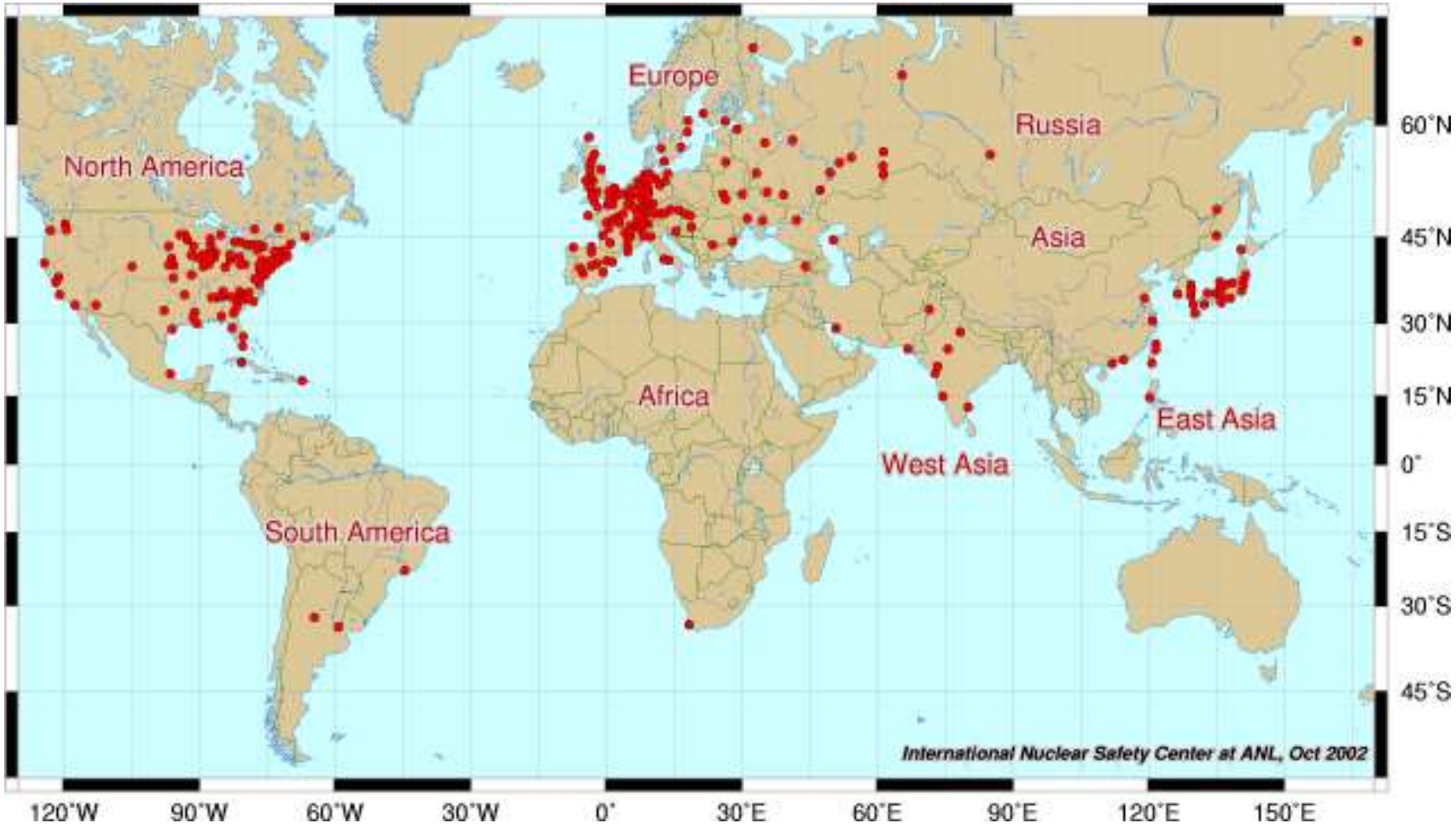


2003 October

NUCLEAR POWER STATIONS

(one of the first energetic uses based on the $E = mc^2$ rule)

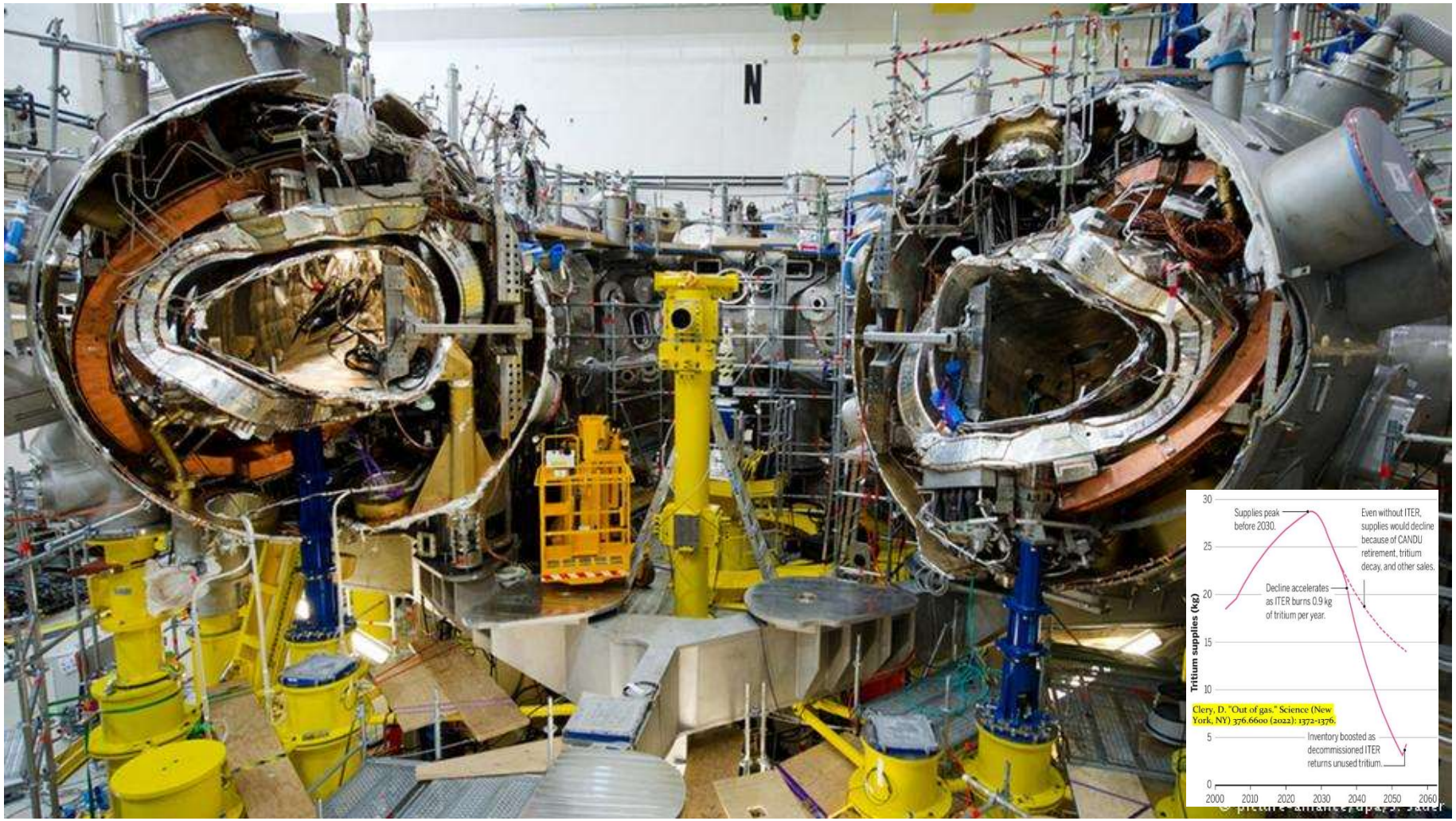
THE RADIOACTIV WASTE PROBLEM!



INCREASING ROLE

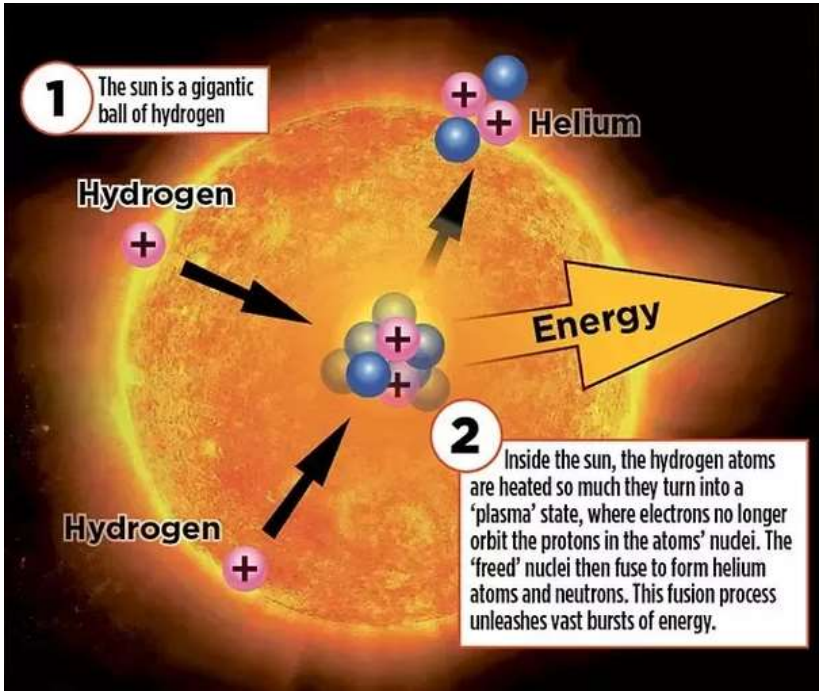
Future: fusion (?) ITER under construction:

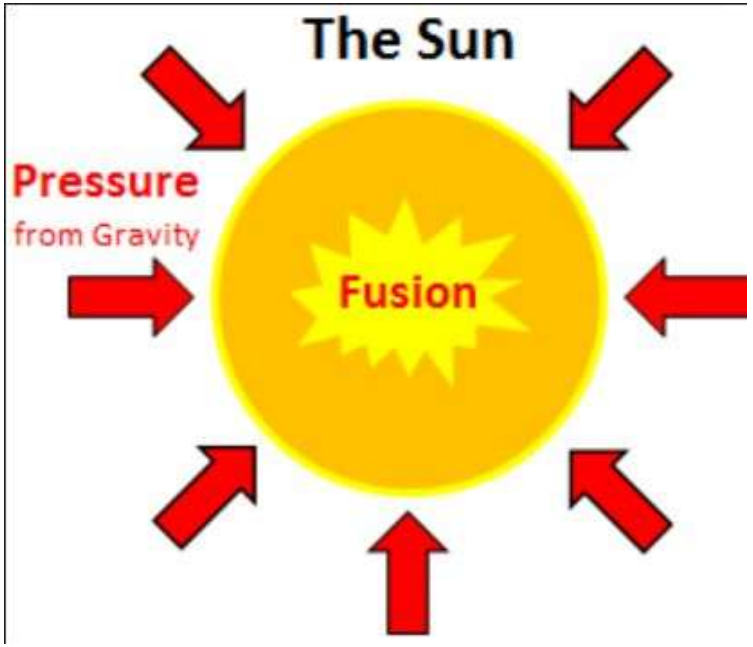
THE MAGNETIC CONFINEMENT FUSION REACTOR (ITER): (inside view)

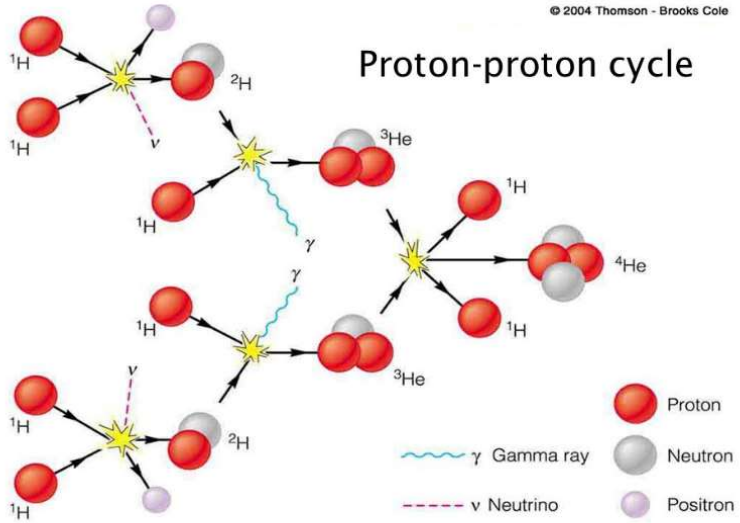


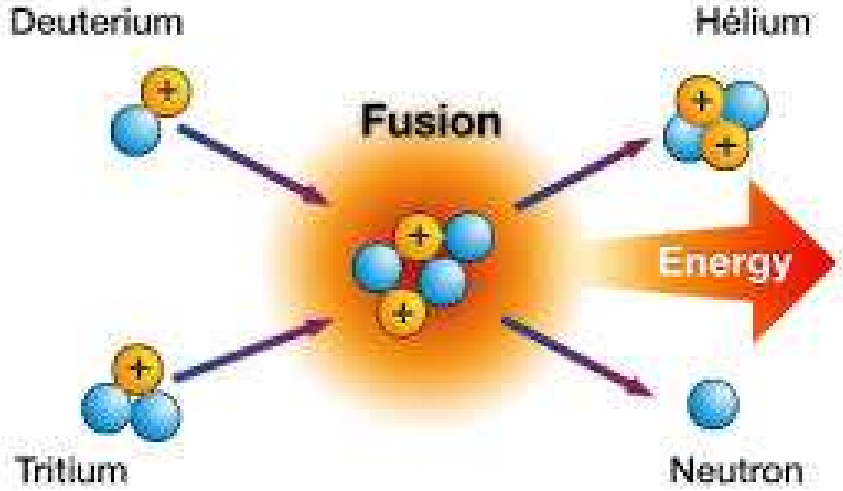
Problems: costs; size; tritium supply (?); construction materials; delay; etc.

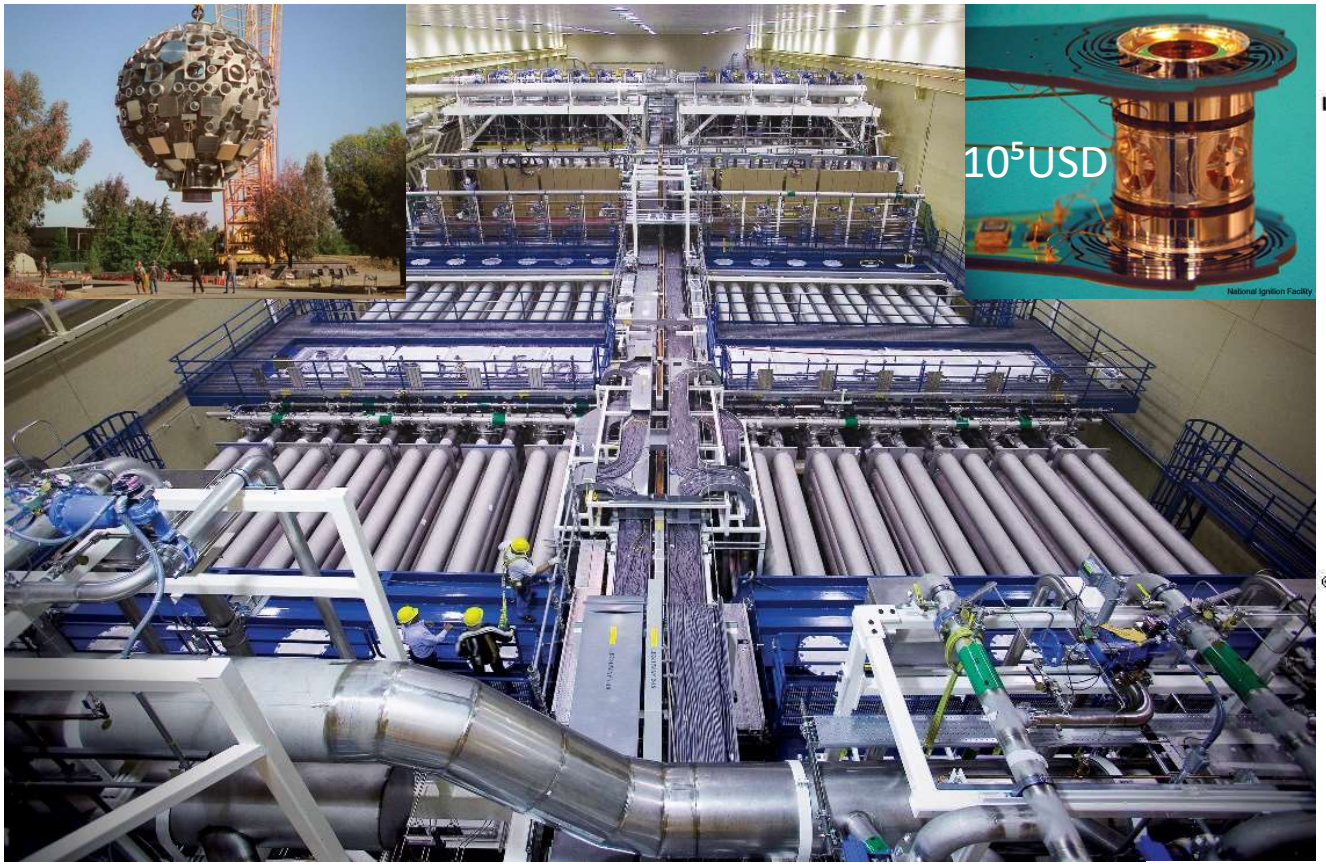
INERTIAL FUSION

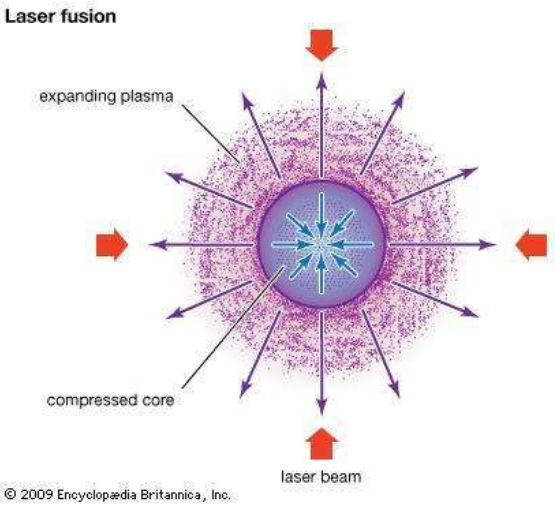












Long laser pulses (~50ns)
Raileigh-Taylor instability
Complicated target construction
Enormous laser energy (400/1.8MJ)

Problems of inertial fusion

- High requirements on irradiation symmetry
- Insufficient laser repetition rate
- Very precise injection system is needed
- The target position has to be tracked in order to ensure required irradiation precition

TO COMBINE 2 DIFFERENT (e.g. fusion and nano-) TECHNOLOGIES TO REACH FUSION AT THESE ULTRAHIGH EM FIELDS?

TOWARD THE NANOWORLD

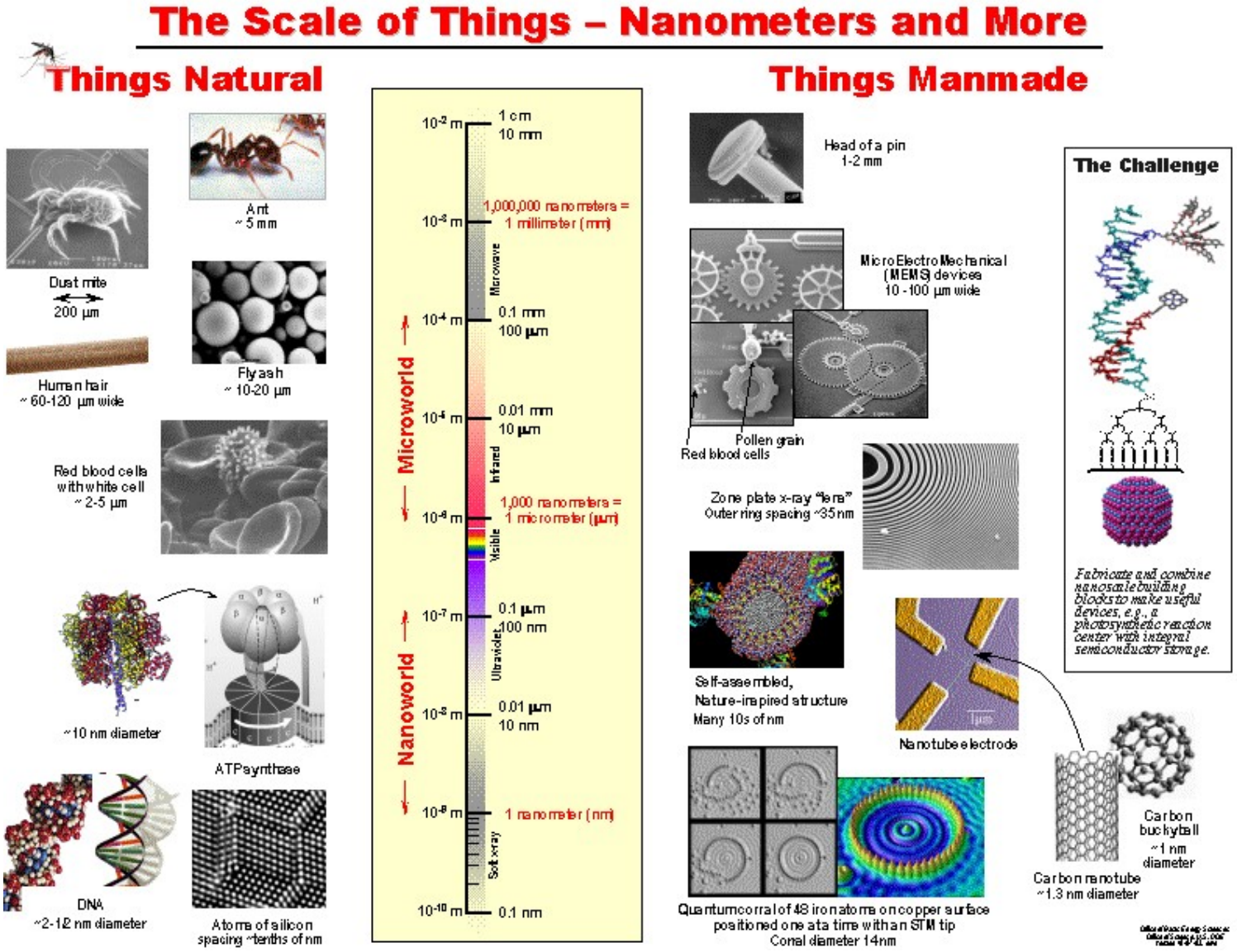
(ANALOGIES FROM NATURE)

VISUAL

OPTICAL MICROSCOPE

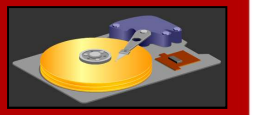
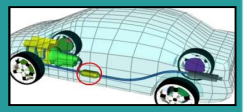
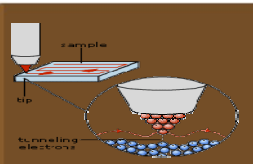
SCATTERING (RÖNTGEN, ELECTRON, NEUTRON)

NEAR FIELD MICROSCOPE, AFM, STM



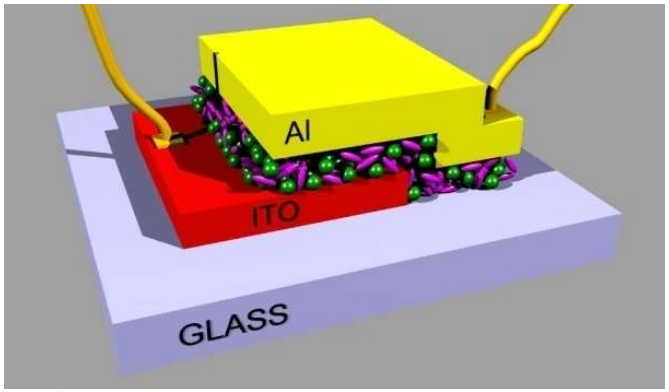
Nanotechnology Applications

- **Expected to impact upon virtually all technological sectors as an "enabling" or "key" technology**

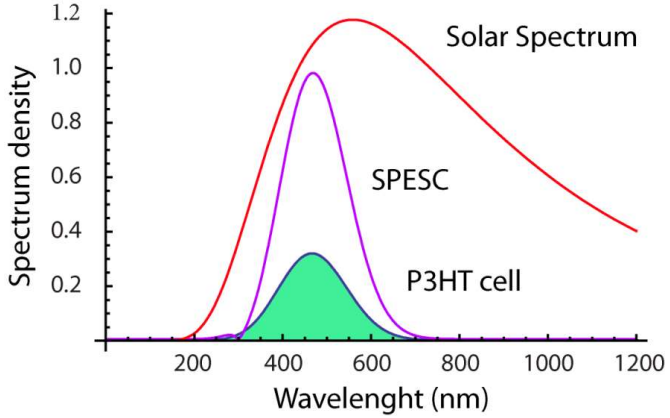
Medicine and Health	Information Technology	Energy Production / Storage	Materials Science	Food, Water and the Environment	Instruments
 Drug delivery	 GMR Hard Disk	 Hydrogen Fuel Cells	 Lightweight and strong	 Remediation methods	 Tunneling microscopy

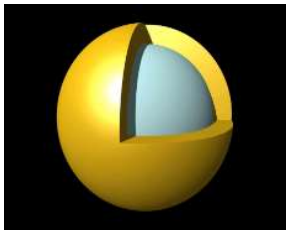
Some potential new energy technologies

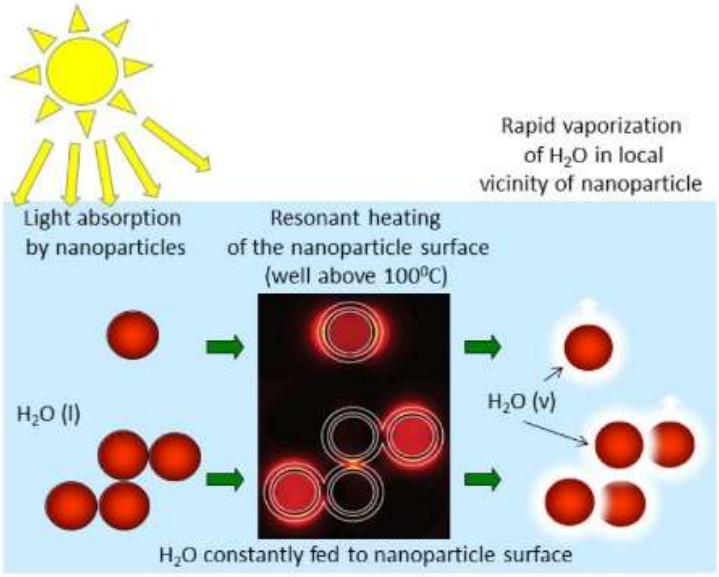
(involving nanotechnologies)



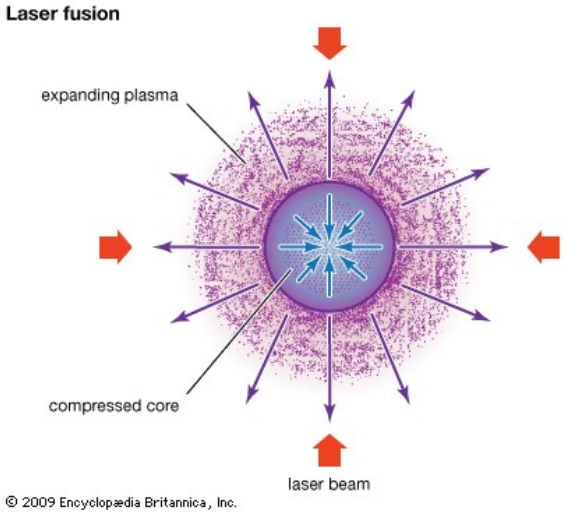
P3HT Cell efficiency = 6%
SPESC (P3HT) efficiency = 17.5%

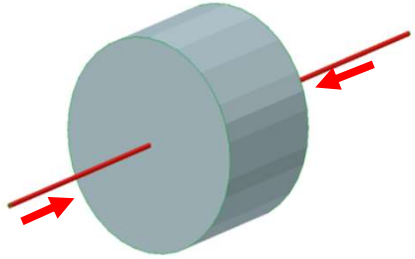






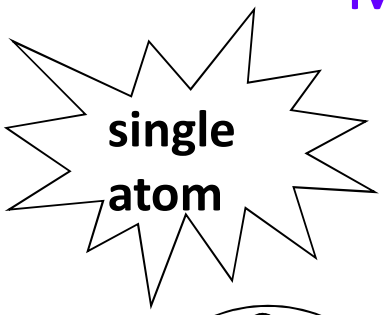
?



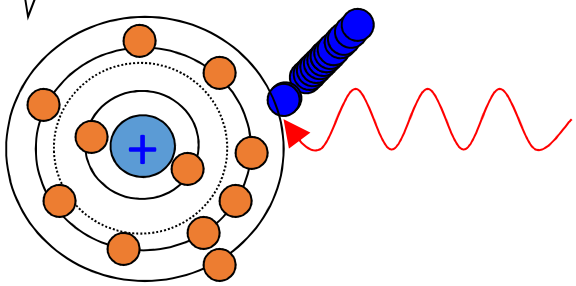


Toward our proposal

Matter under extreme conditions (extremely high intensities)

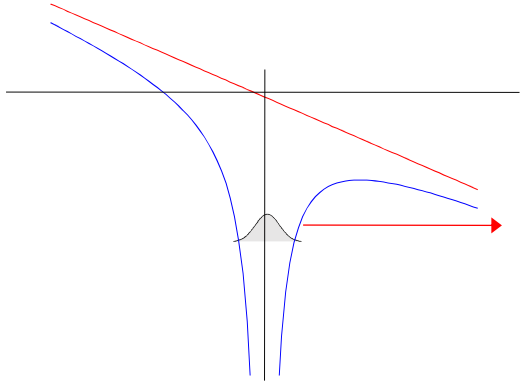


$I = 10^{16}$ W cm^{-2} → E ~ 10^9 V/cm

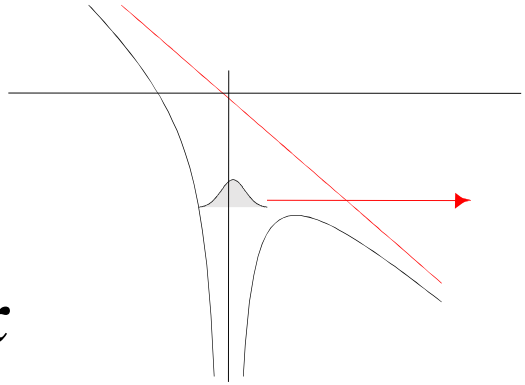


High intensity
Photoeletric Effect

Rapid ionization of valence electrons



$$V = -\frac{q}{x} \pm E.x$$



Tunnelling

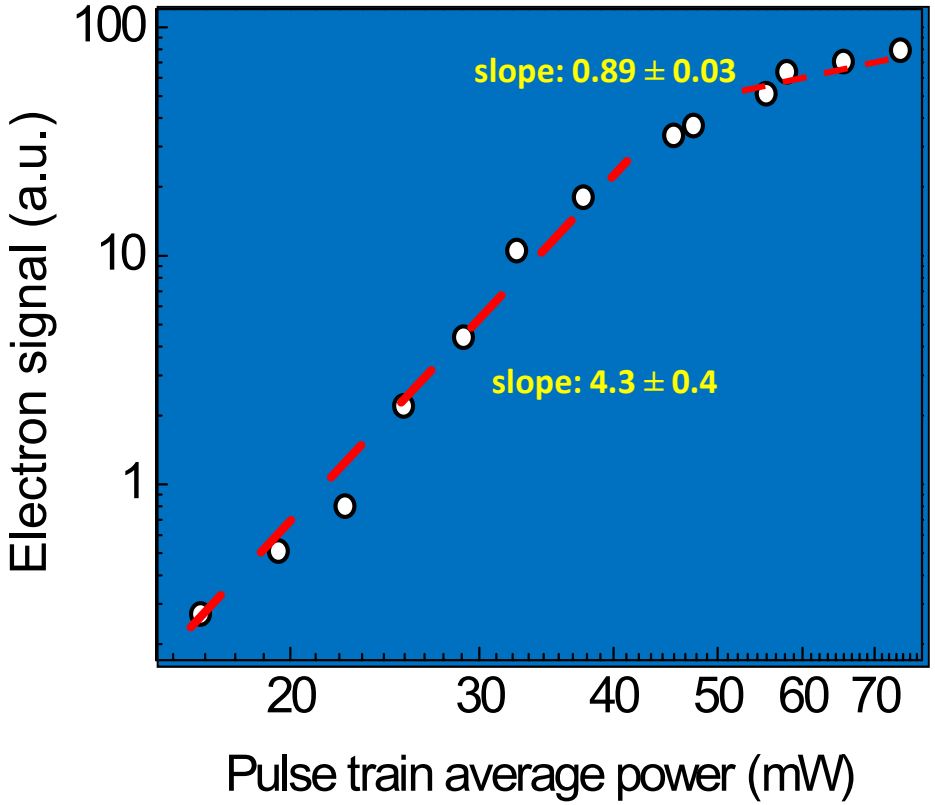
10^{14} - 10^{15} W cm^{-2}

Over the barrier

> 10^{15} W cm^{-2}

Each atom loses at least one electron. Some can lose as many as 6 !

MULTIPHOTON ELECTRON EMISSION FROM GOLD



PLASMONIC ENHANCEMENT!

Multiphoton ⟹ tunneling transition at ~4×10^{10} W/cm^2 incident intensity, ~5.5×10^{8} V/m field

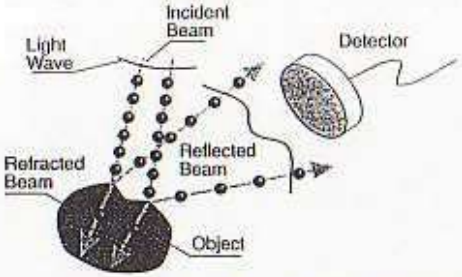
Keldysh-gamma γ=31

→ indication of well-known field enhancement of surface plasmonic fields

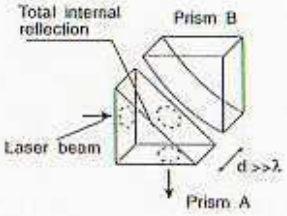
$$\gamma^2 = \frac{W}{2U_p} = \left(\frac{\omega\sqrt{2mW}}{eE_l} \right)^2$$

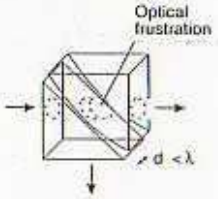
W: work function, E_l: laser field strength

THE OPTICAL NEAR FIELD

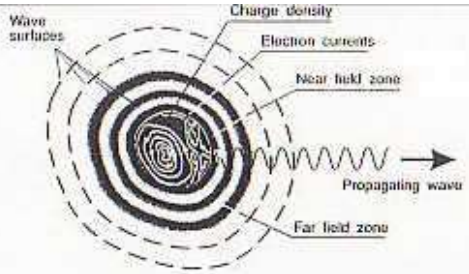


Schematic of the interaction between an object and a light beam. In first approximation, the light beam can be considered as projectiles launched against a target (the object) and then reflected towards the detector. This interpretation is primitive but provides the basis for the understanding of the notion of image.

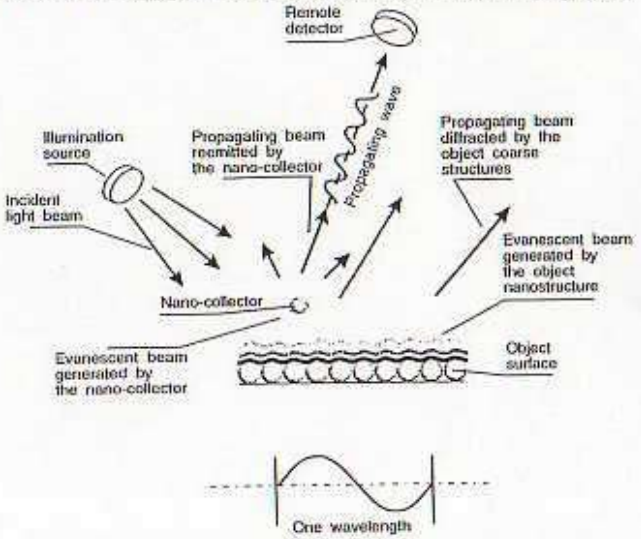




The famous experiment of Newton. A light beam is projected onto a prism. As expected, the beam is internally and totally reflected on the larger side of the prism. If a second prism is brought to the first one, no effect is detected unless the distance between the two prisms becomes smaller than a fraction of a micron. The light beam then seems to be captured by the second prism, frustrating the total reflection. The beam intensity transmitted through the second prism depends exponentially on the distance *d*.



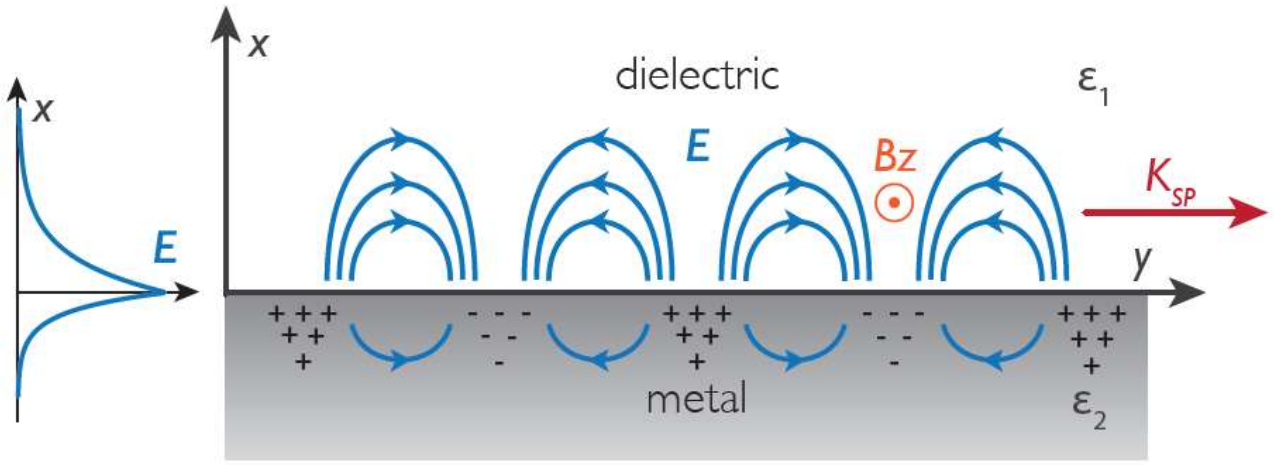
Field emitted from an object. The electron currents (in the case of conducting materials) and the charge densities inside the object induce an electromagnetic field radiating from the surface. Far away from the surface the field has the well known structure of propagating waves. Very close to the object (the region of the question mark), the field has a more complex structure since it is composed of propagating and non-radiating components.



Sketch of near field detection. Step 1: generation of the object near field by the illumination process. A light source illuminates an object represented as composed of discrete components. These components are excited by the incident field and re-emit light. The waves associated to the reflected beam are composed of evanescent waves confined on the object surface and of propagating waves. If the periodic structures of the object are smaller than the wavelength (it is the case of the figure), the reflected field, far away from the object, does not contain any information on the fine structure of the object. Step 2: detection of the near field. For detecting the subwavelength object information, a small scattering centre (the nano-collector) is brought close enough to the object surface. The near field lying on the surface will excite the scattering centre which will re-emit light. The re-emitted light is again composed of evanescent waves (non-detectable) and propagating ones which can propagate far away to the remote detector.

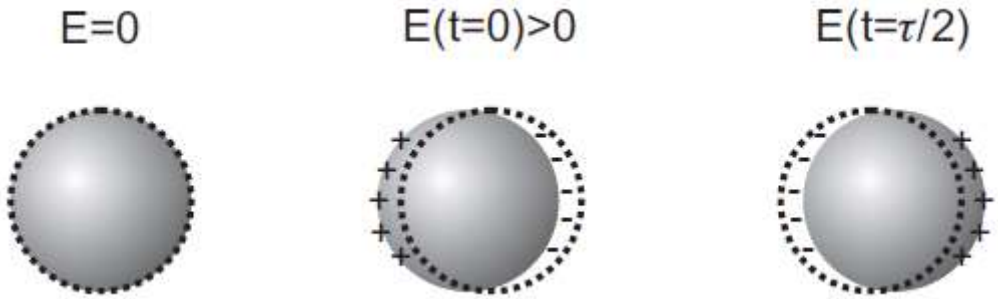
A SPECIAL NEAR FIELD: SURFACE PLASMONS

a.



SPP

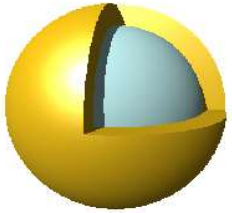
b.



LSPP

Two examples with Ti:Sa lasers: λ=800nm (1.55eV)

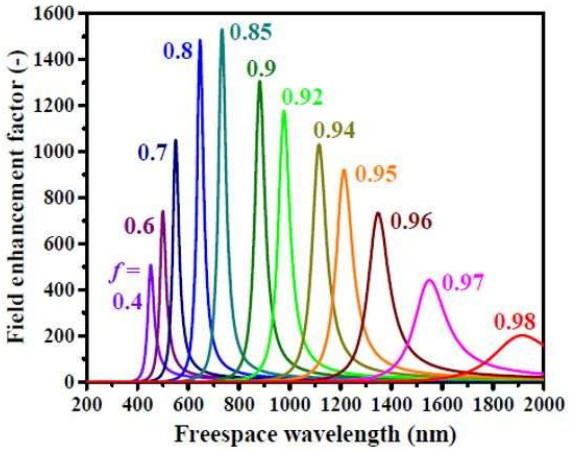
OUR PROPOSAL: localized plasmons (LSPP):



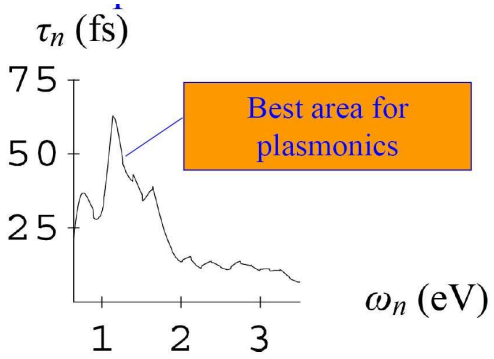
NANOSHELL (nx10nm)

NANOROD (~85x25nm)

Used at present

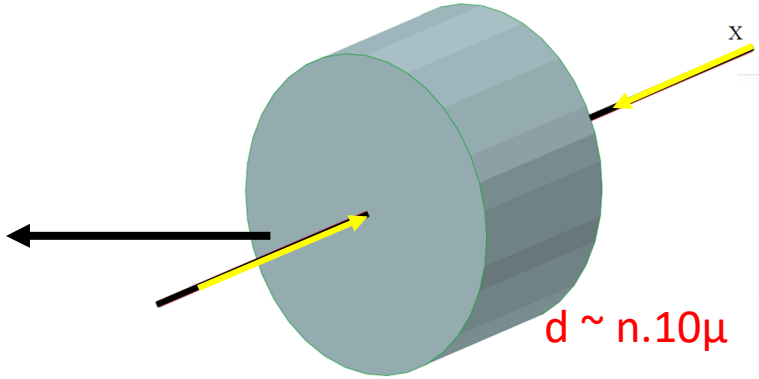


λ = 800nm

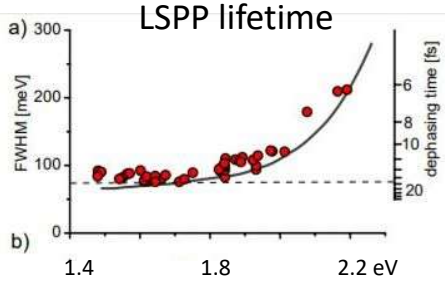


n.10µ

NANOPARTICLES IN THE FUSION MATERIAL



d ~ n.10µ



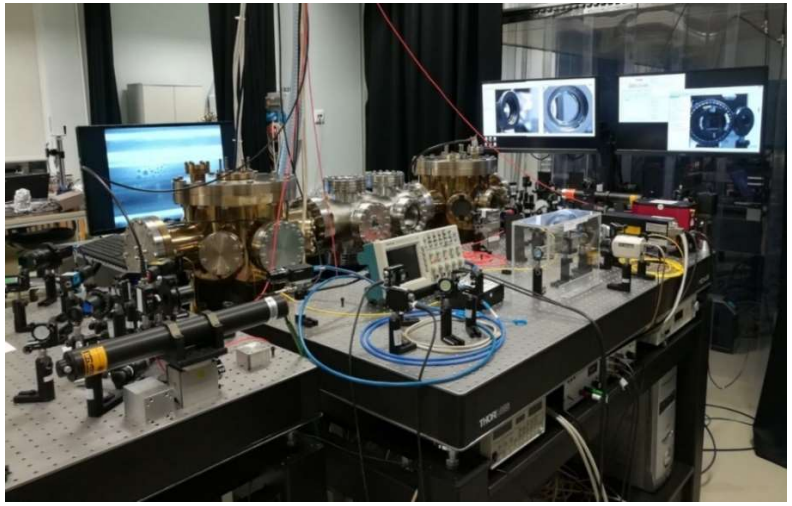
FEMTOSECOND LASER PULSES
HIGH REPETITION FREQUENCY
LIGHT SPEED: NO TIME FOR INSTABILITIES,ONLY TWO BEAMS, VOLUME IGNITION

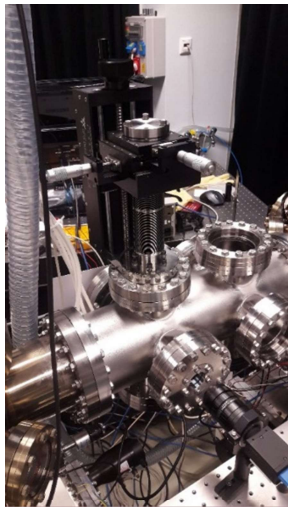
Modelling with a polymer (UDMA) with gold nanoparticles (at present nanorods)

Extreme Light Infrastructure (ELI-ALPS) – Szeged, HU

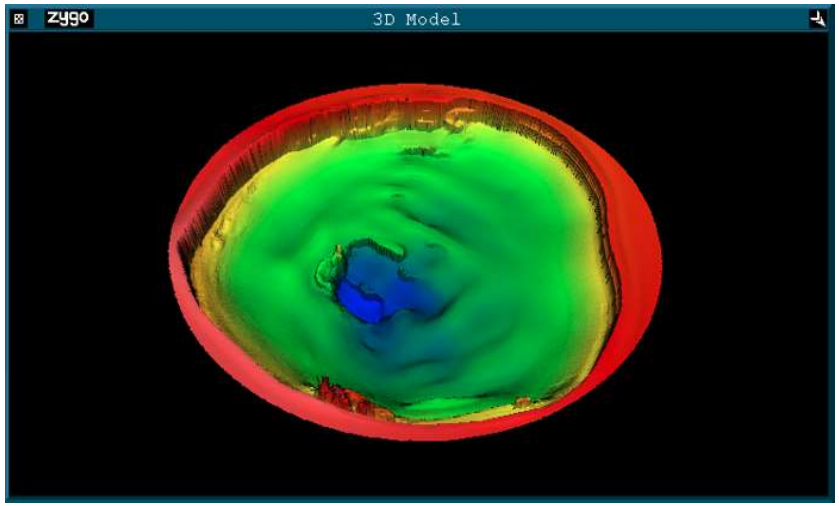
ELI-ALPS Szeged:
Also attosec laser pulses

2PW extreme laser pulse energy;
10Hz/1Hz, <10fs, 30 J, 10^{12} contrast

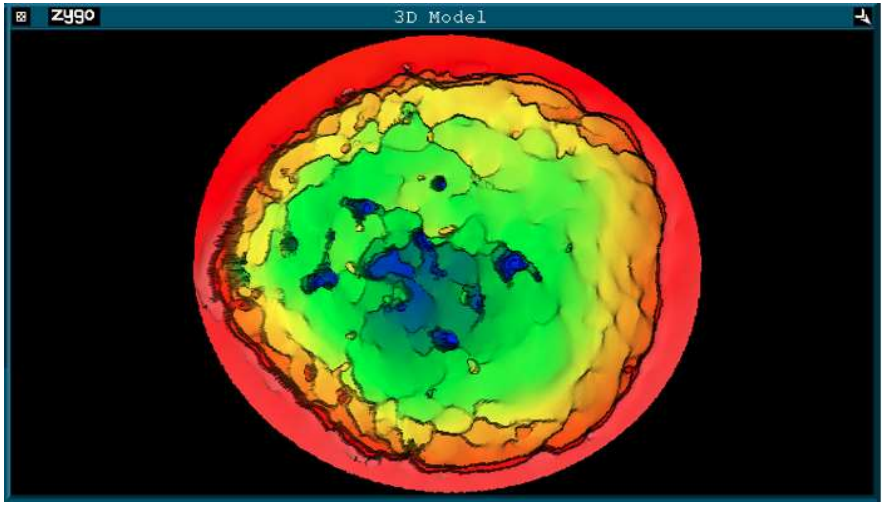


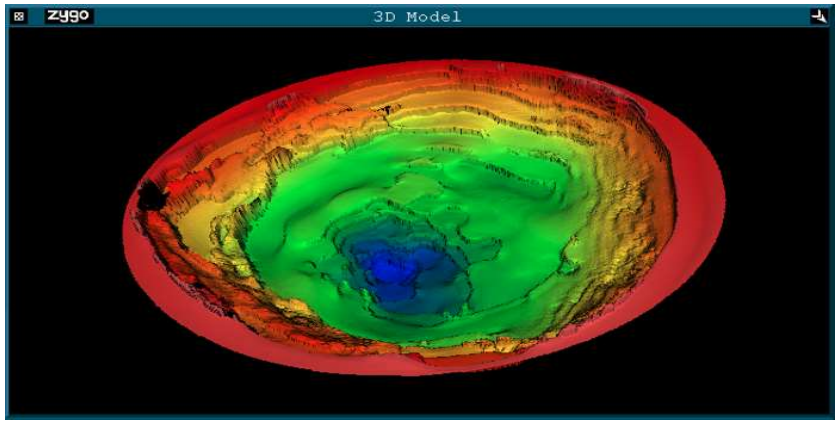


Ti::Sa laser:
800nm, 40fs
Max 30mJ
~10^{17} W/cm^2
Contrast ~ 10^6

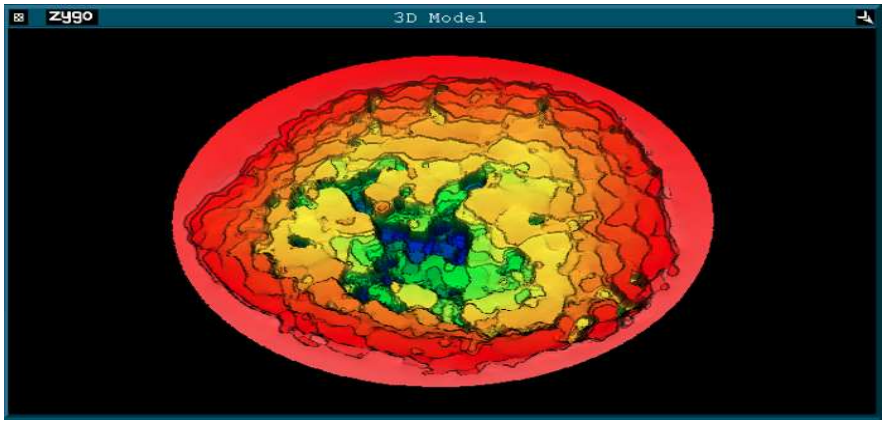

zygo
3D Model

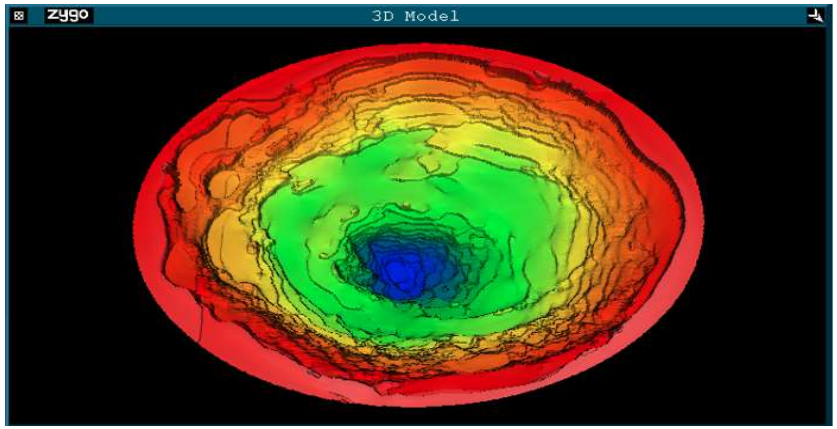
1mJ


zygo
3D Model

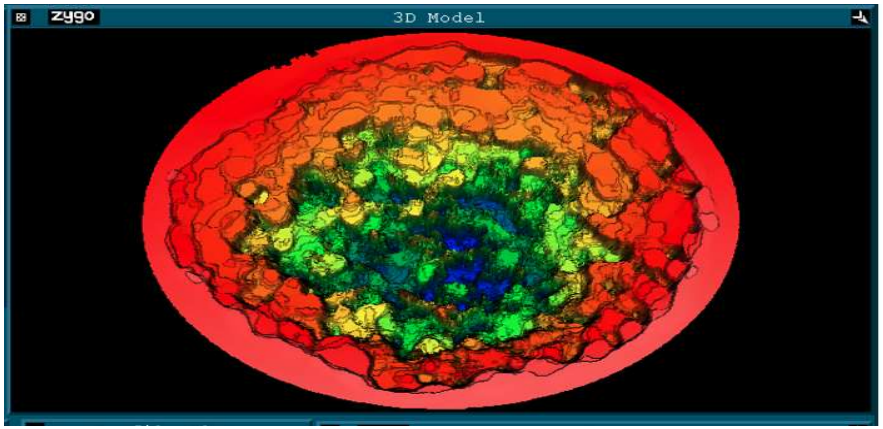

zygo
3D Model

5mJ

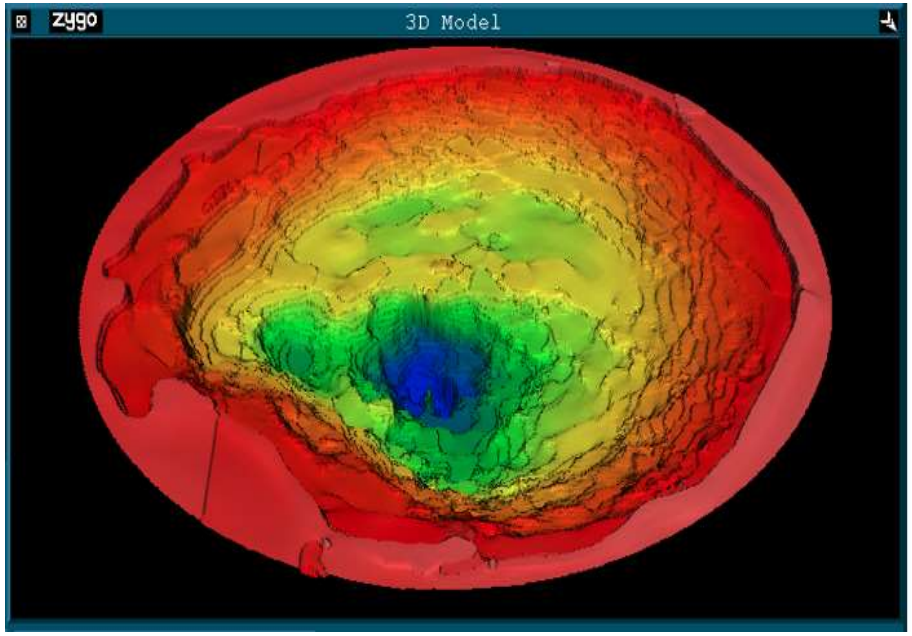

zygo
3D Model

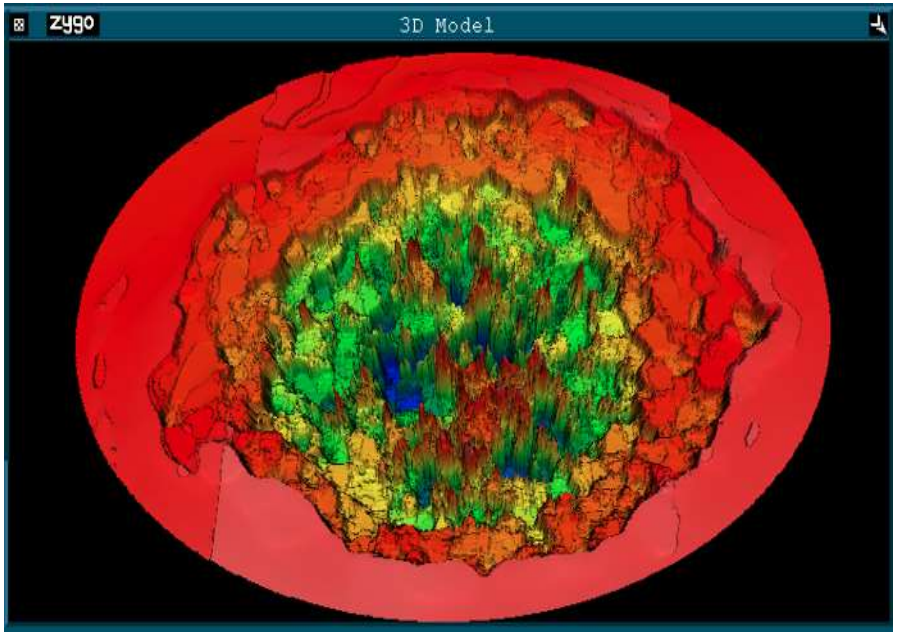

zygo
3D Model

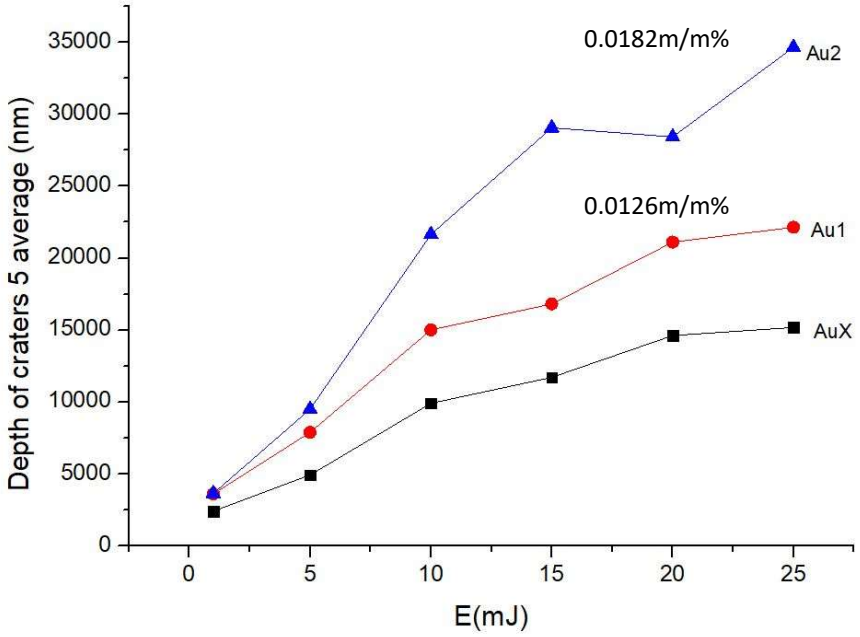
15mJ

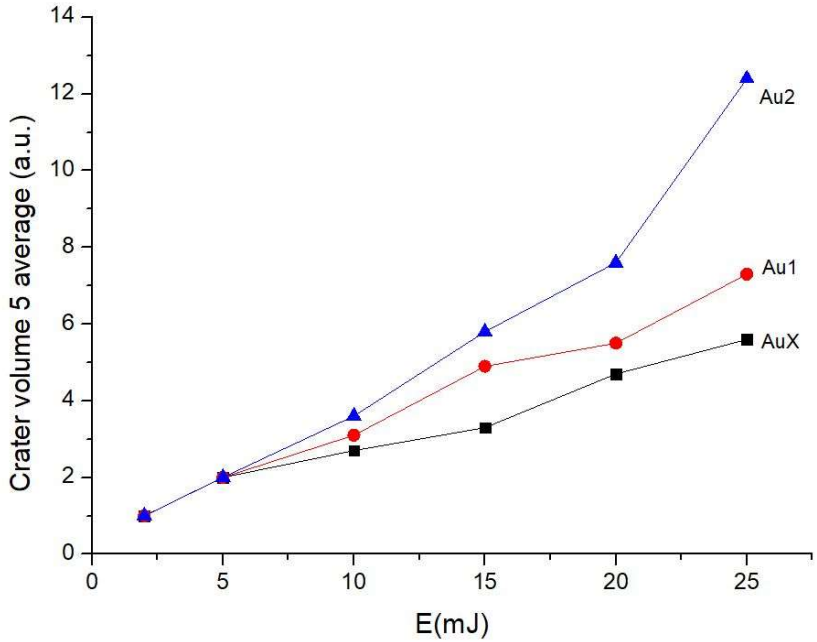

zygo
3D Model

DIAGNOSIS METHOD No.1: CRATER PARAMETERS

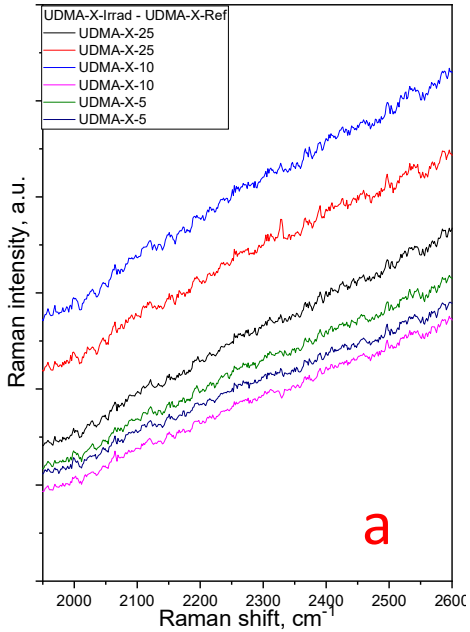


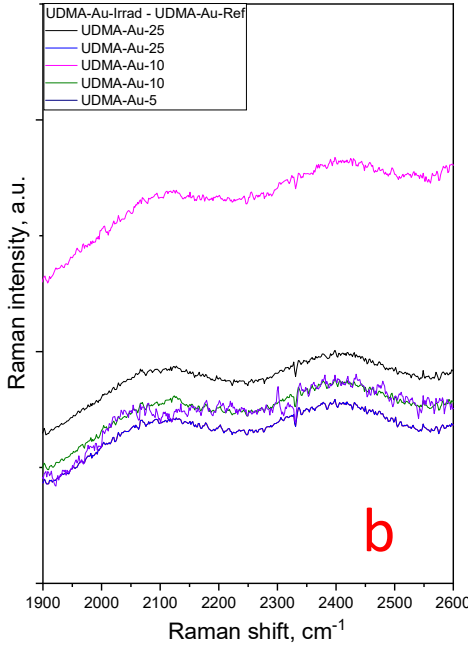


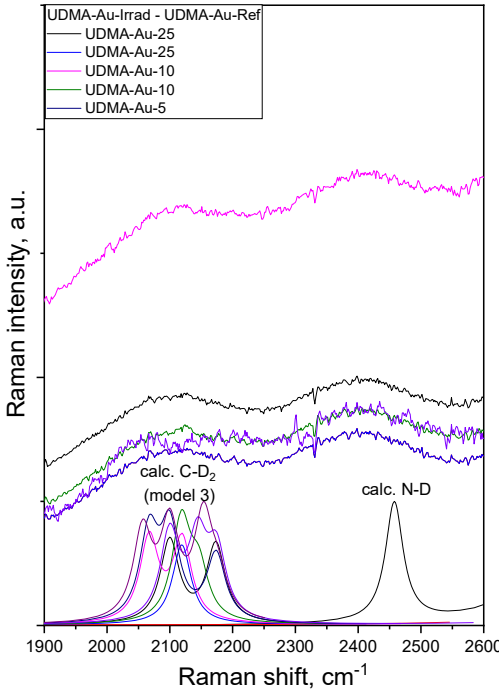


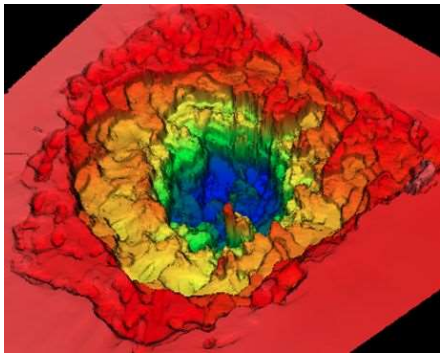


DIAGNOSIS METHOD No2 :Raman scattering from the crater surface

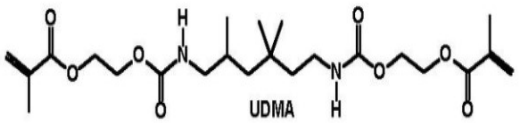


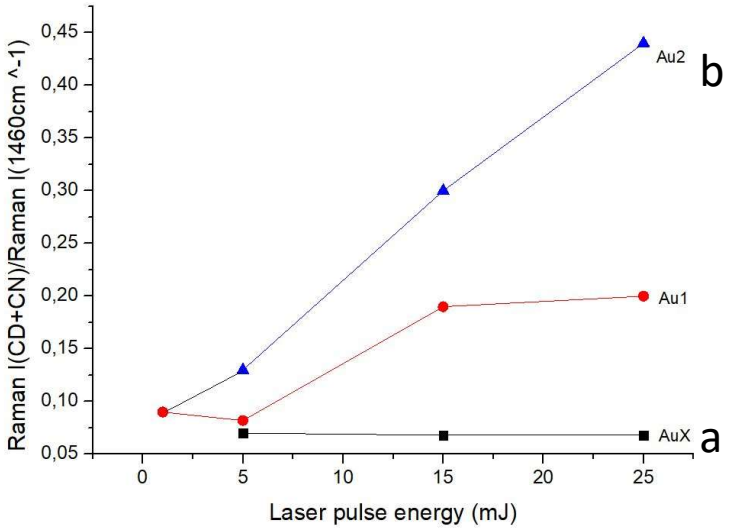






$I_{laser} > 10^{16}$ W/cm²





DIAGNOSIS No3: LIBS analysis of the laser plume plasma

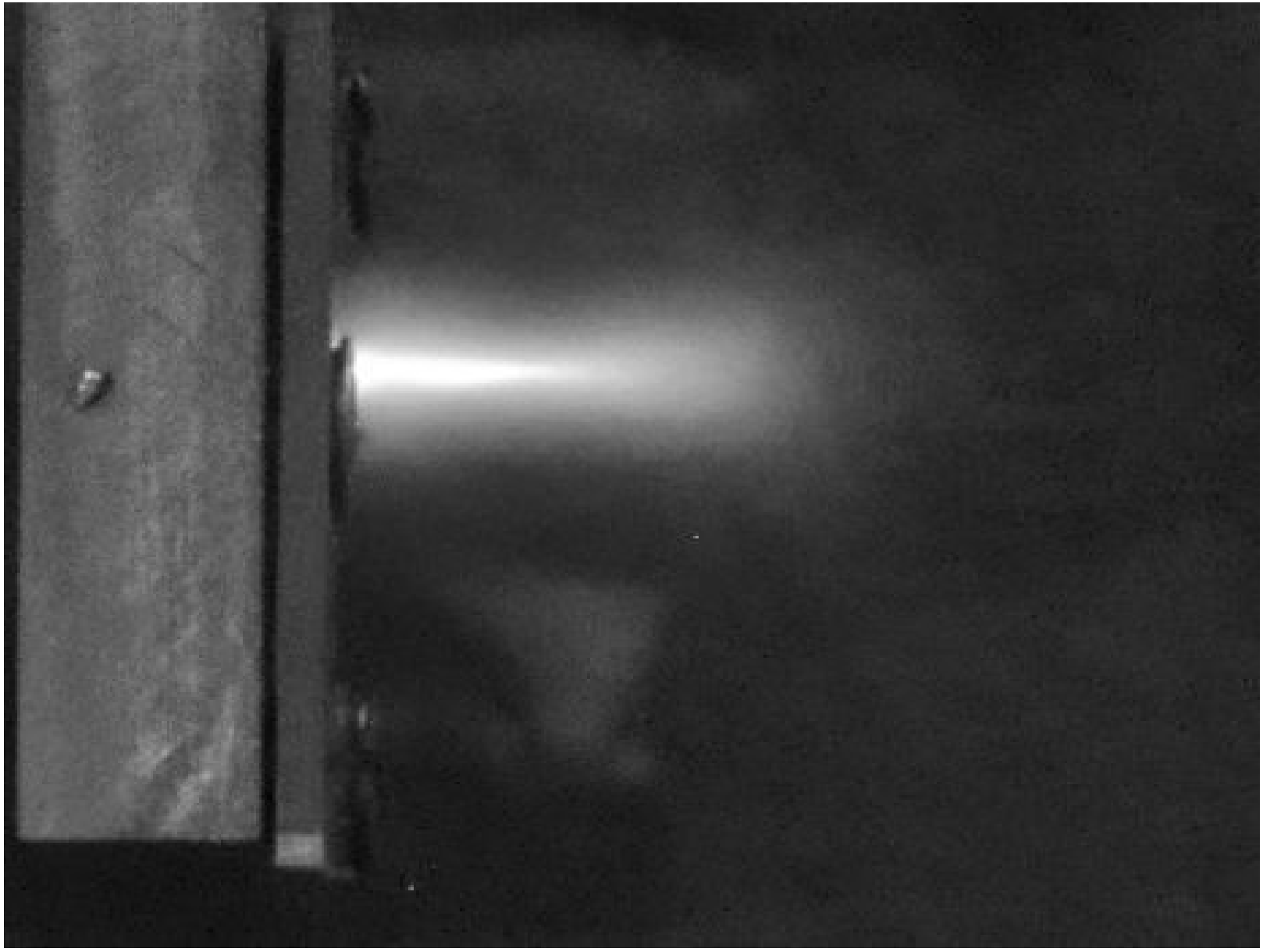
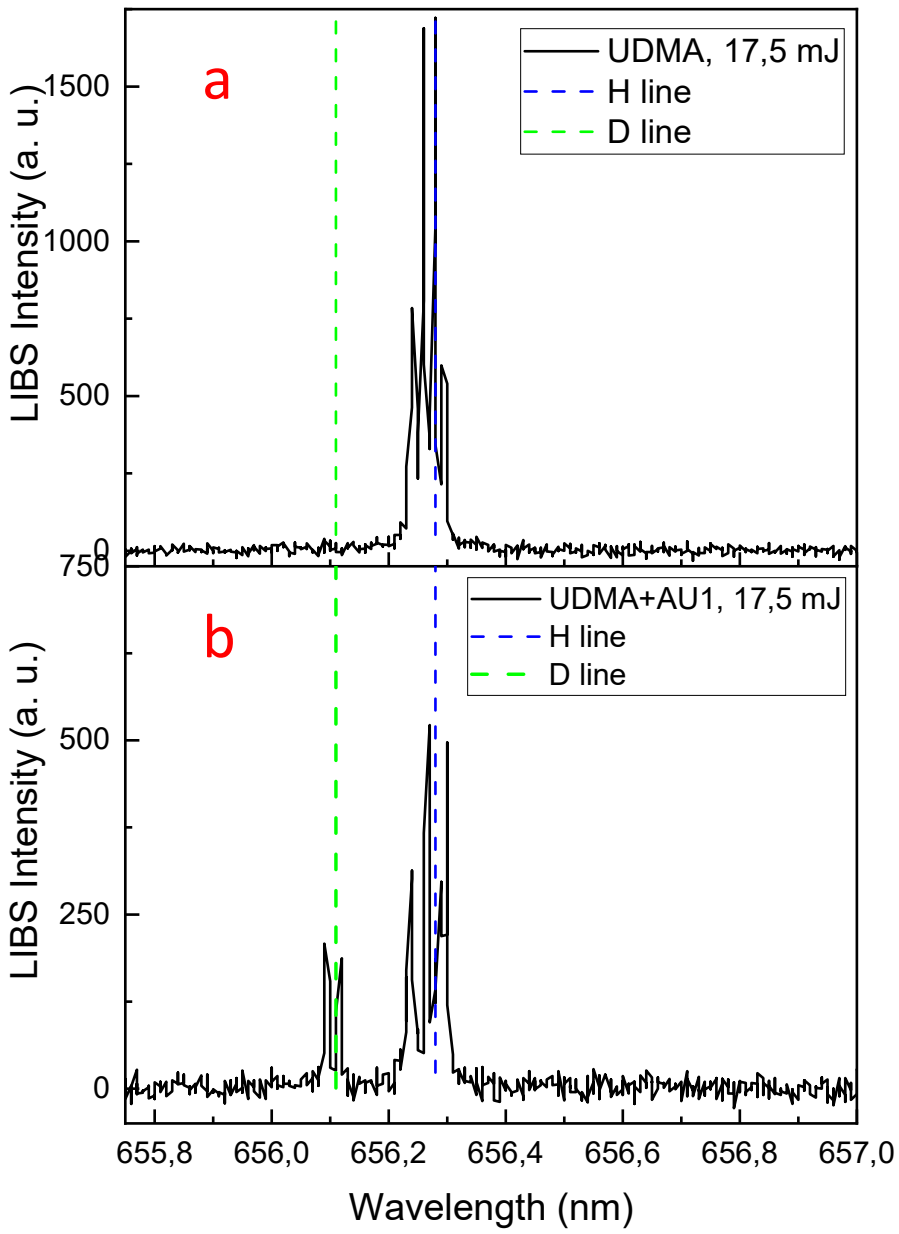
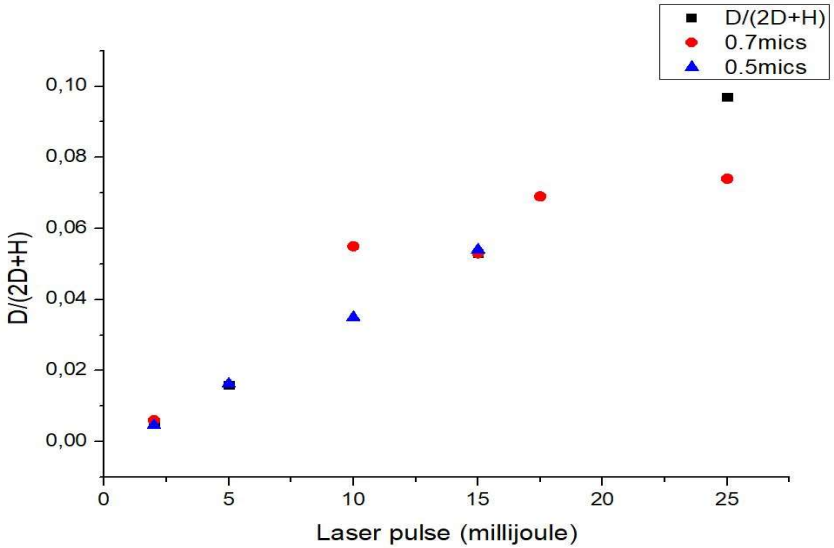


PHOTO OF A LASER SHOT INDUCED PLASMA PLUME





D/(2D+H): 6.8% ??

2D+H is the total number of hydrogen atoms before the transmutation process

Number of deuterium atoms per 17.5mJ shots: ~1.76×10^{15} ??

Renewable energy resources? Substituted!

Only the Sun and radioactivity. The difference is only the time-delay of using the „stored” energy.

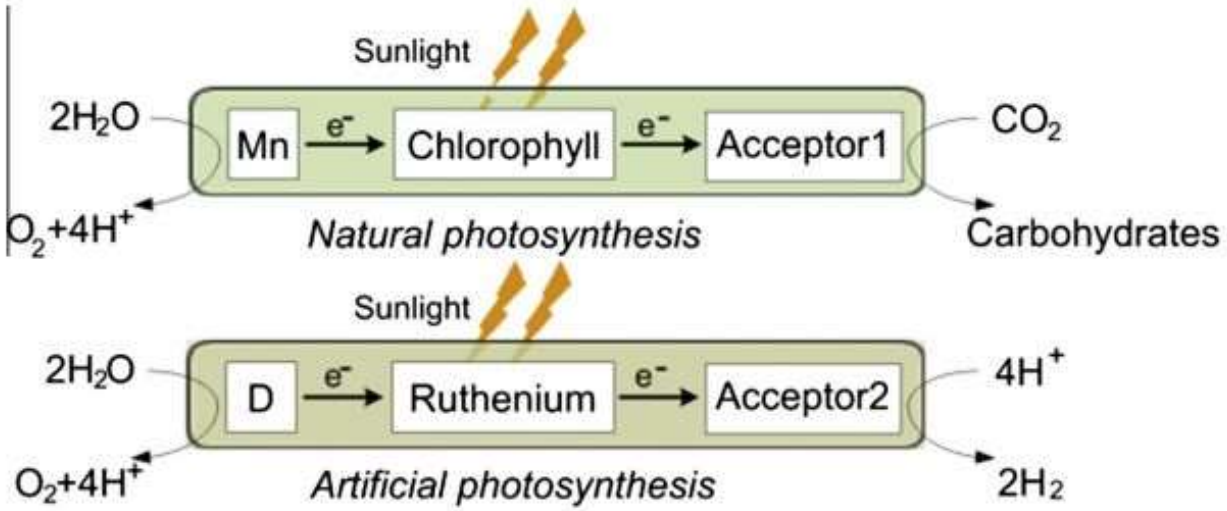
Sustainability.

Entropy „production”

Energy generation (to release it) and storage.

Ideologically byased conclusions.

Copy ideas from Nature (e.g. photosynthesis)



Different shorter and „longer” time energy storage solutions

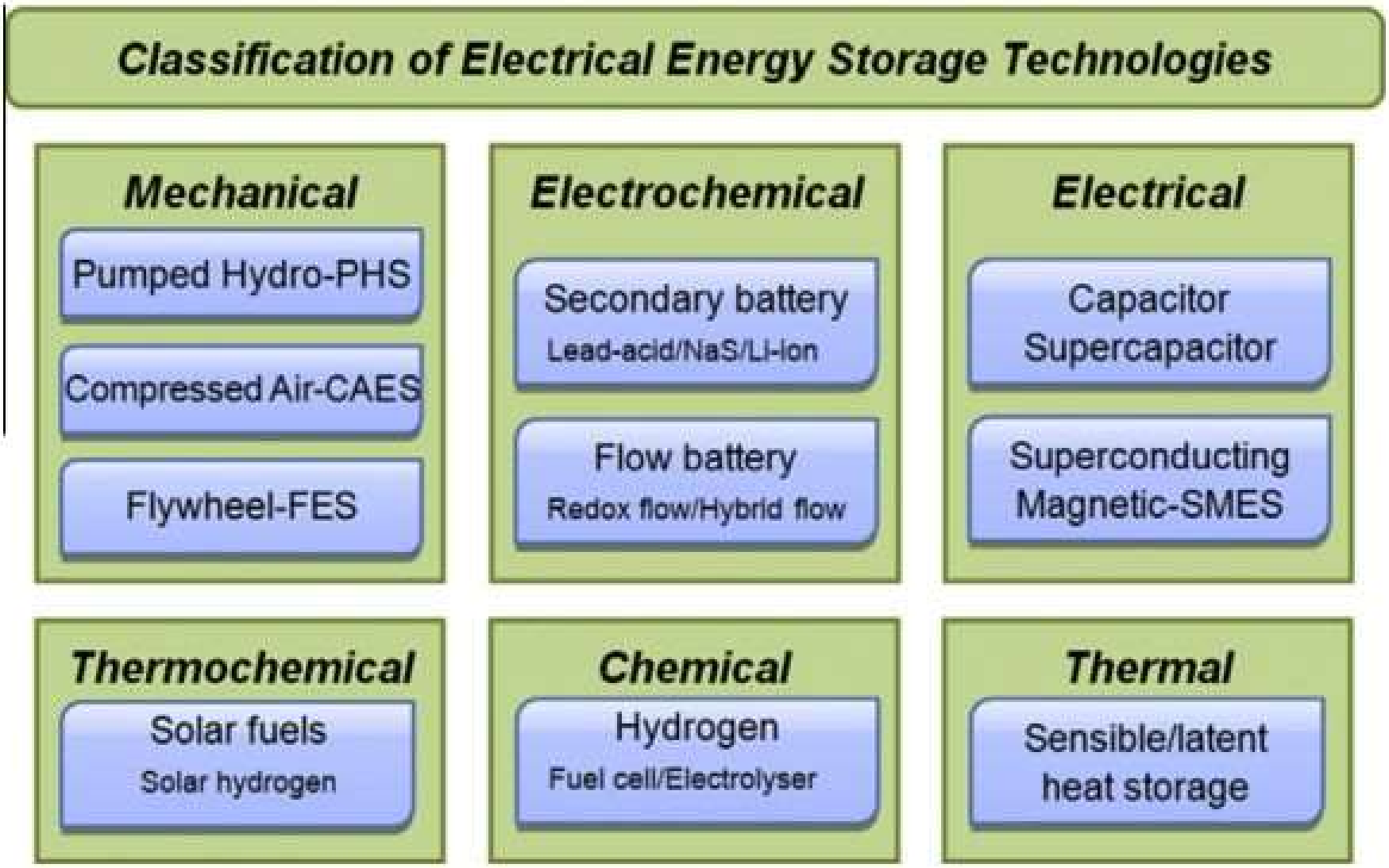
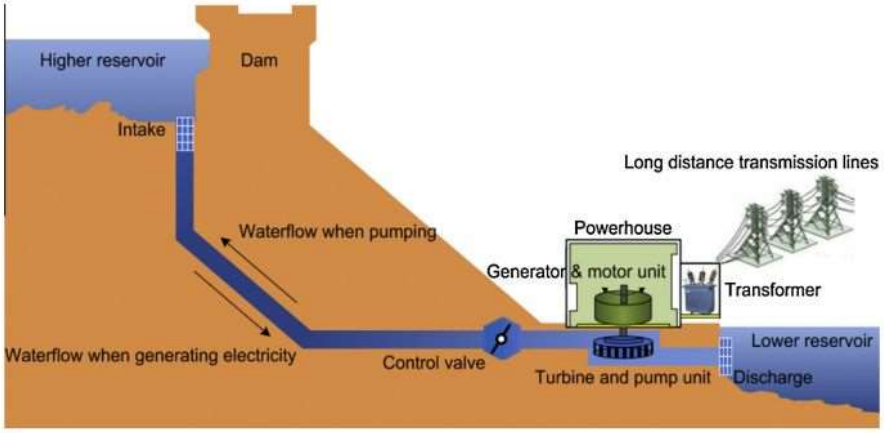
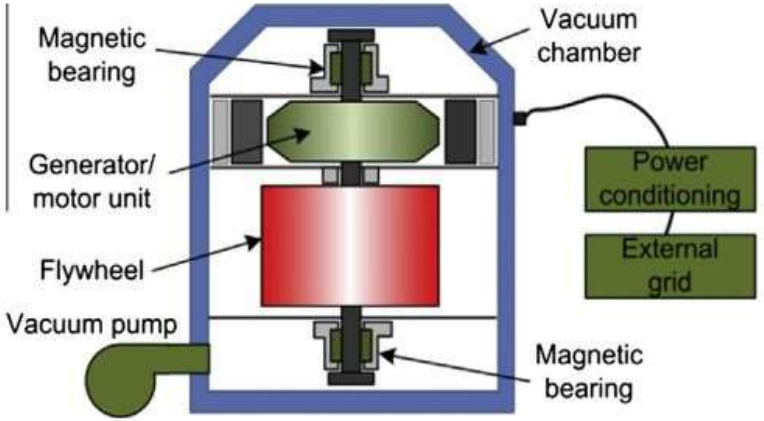


Fig. 3. Classification of EES technologies by the form of stored energy.

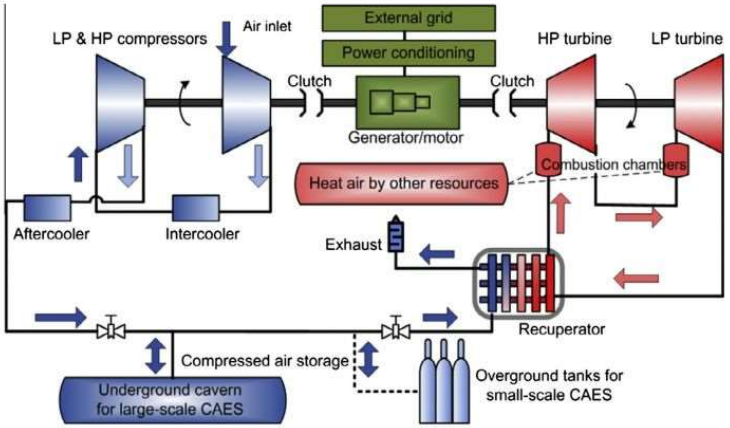
PROMPT ENERGY STORAGE 1.



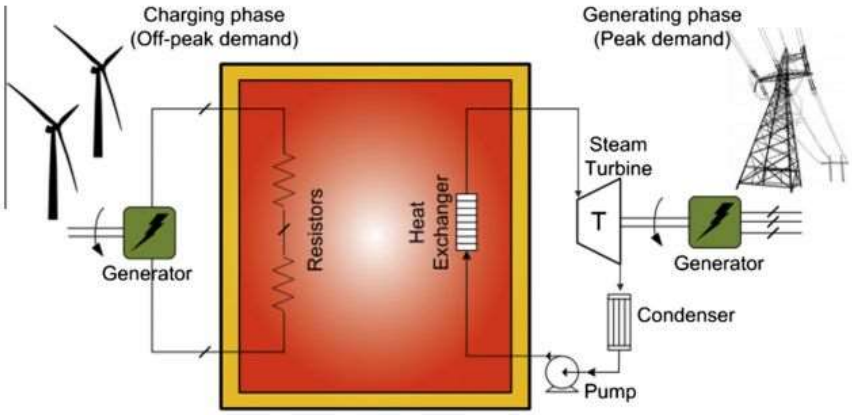
Hydro



Flywheel



Compression air



Heat storage from wind power generation

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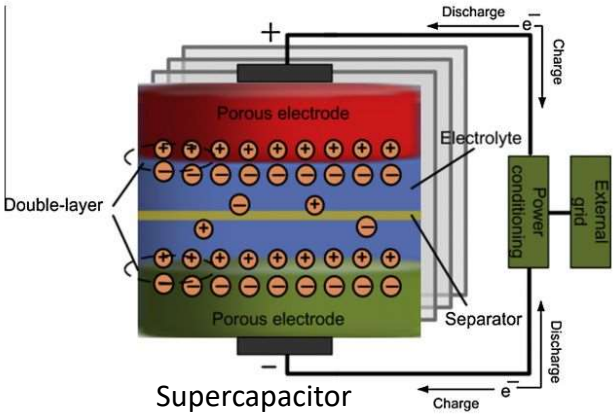
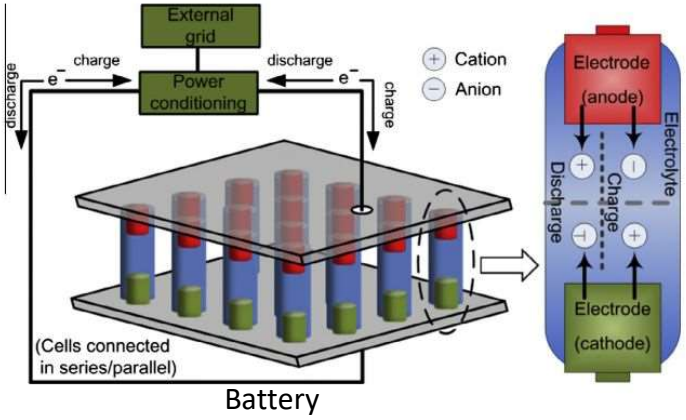
Volume 137, 1 January 2015, Pages 511-536

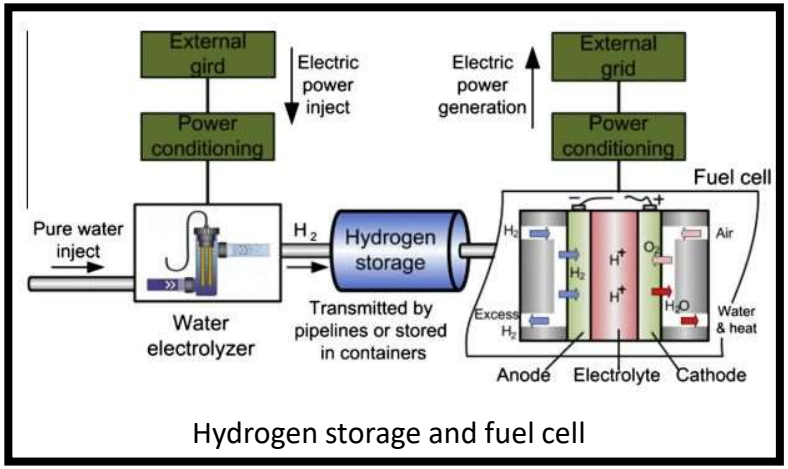
PROMPT ENERGY STORAGE 2.



Supercapacitor

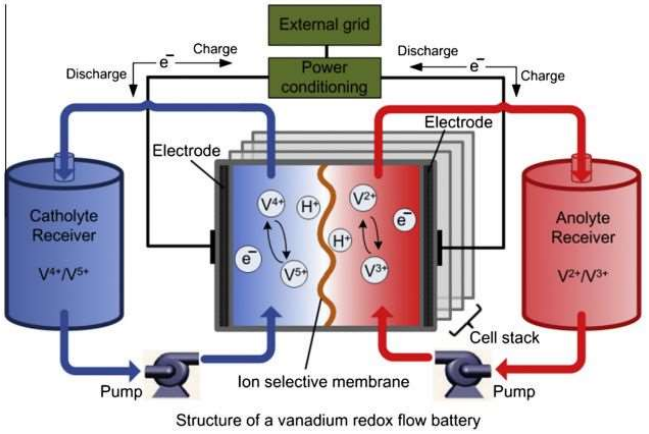


Battery



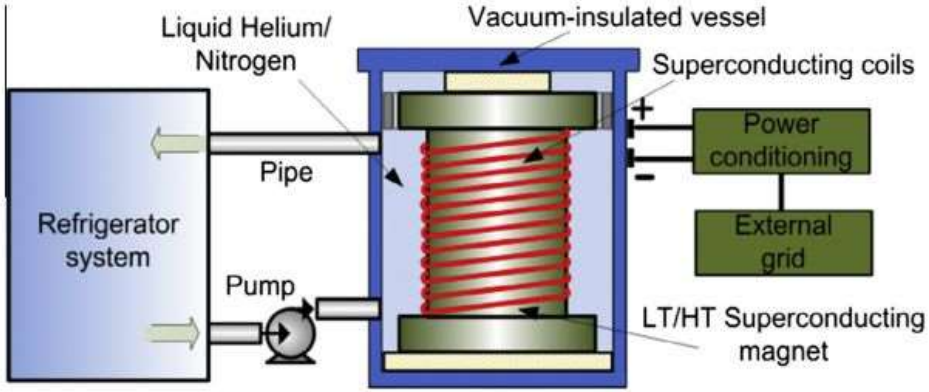
Hydrogen storage and fuel cell

!



Structure of a vanadium redox flow battery

Vanadium redox flow

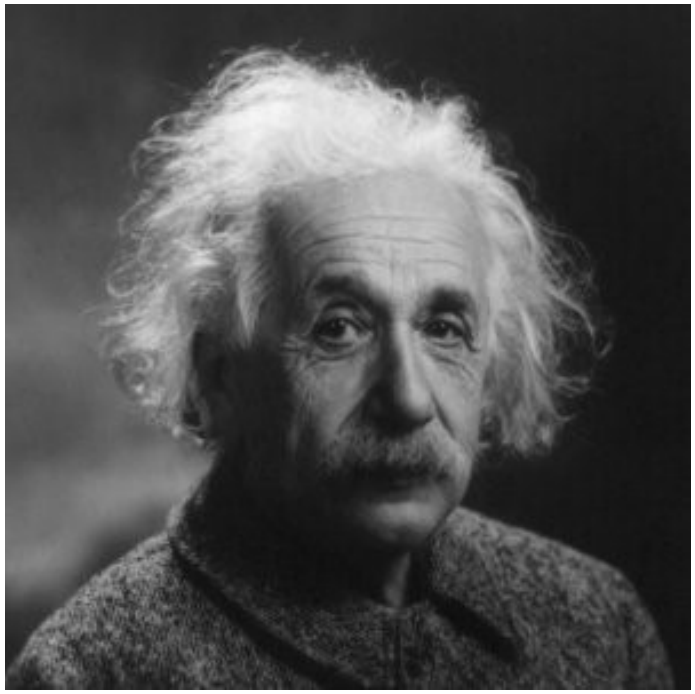


Superconducting magnetic energy

X.Luo at al. Applied Energy Volume 137, 1 January 2015, Pages 511-536

THE ADVICE OF ALBERT EINSTEIN FOR THE FUTURE:

THE PROBLEMS WE ARE FACING TODAY CAN NOT BE SOLVED WITH THE SAME WAY OF THINKING BY WHICH WE CREATED THEM.



THIS IS WHY CREATIVE SCIENTIFIC THINKING IS THE KEY TO OUR FUTURE

THANKS FOR YOUR ATTENTION