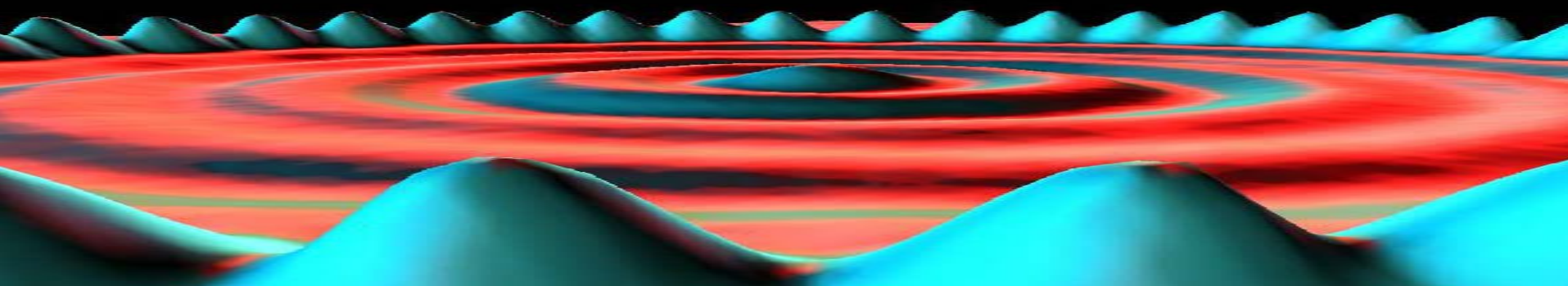
Return to Session

Jean-Claude Boudenot
Thales Research & Technology

XXISt century : The century of Nanoconvergence

From data storage to power cables



Nanotechnology is not new !

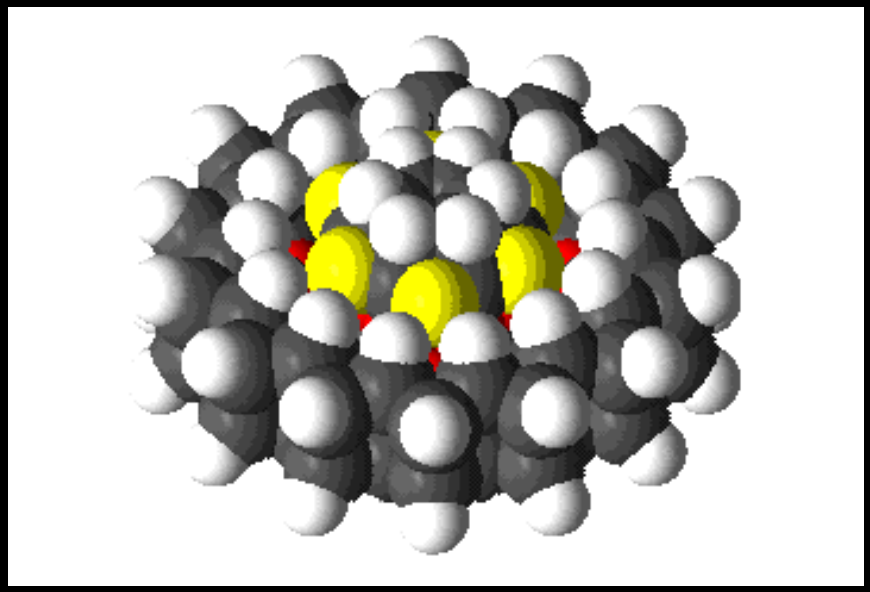
Lycurgus' cup, Roman Empire IV^{E} Century, British Museum

Transmitted light = red ; reflected light = green
(40 nm particles in the glass)

What is nanotechnology ?

Convergence between technology, physics, chemistry and biology

Exploit the specific properties of the world at atomic scale (mesoscopic and quantum effects)



If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering

Neal Lane, Former Assistant to the US President for Science and Technology

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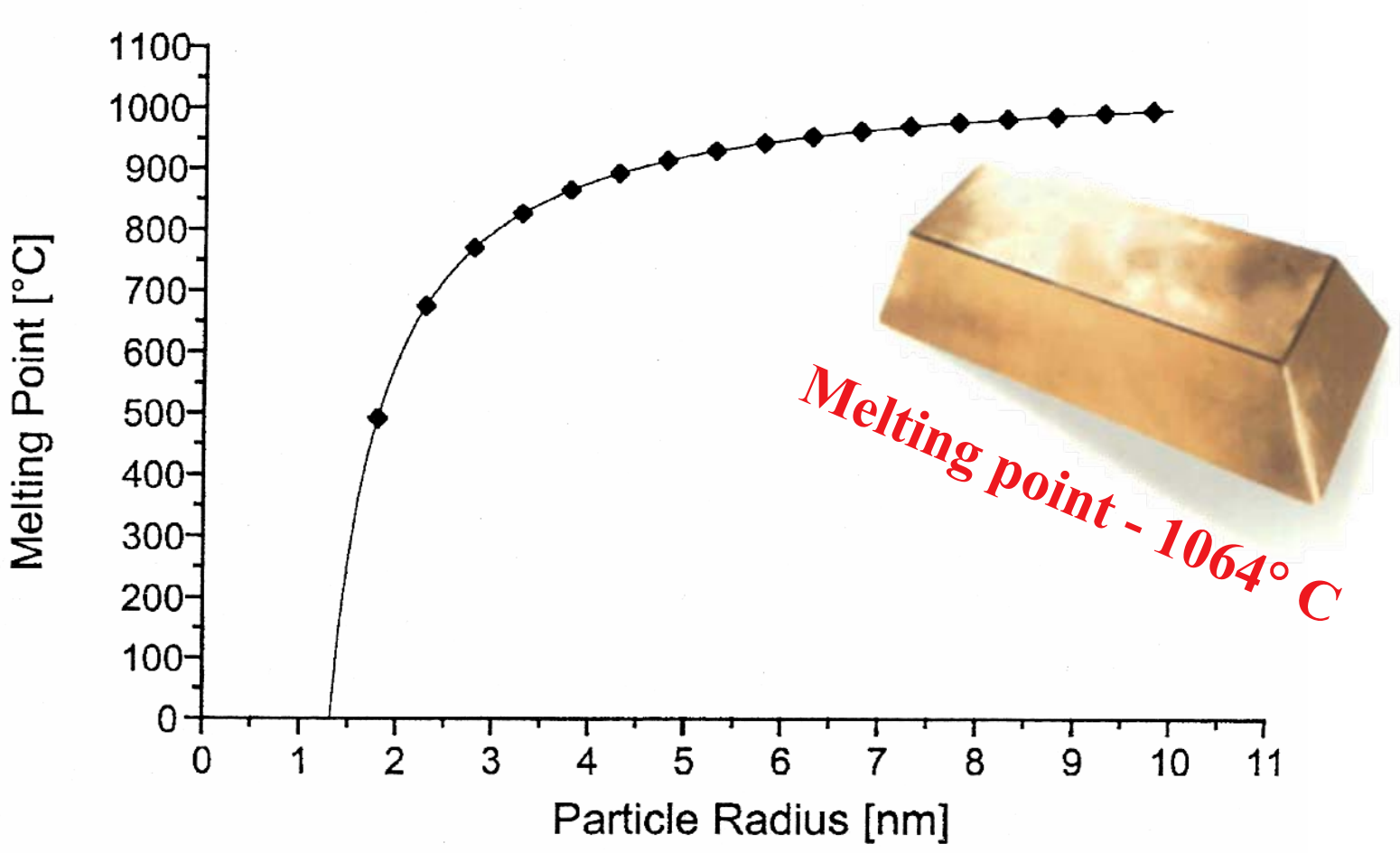
Melting point depends on the size !



Source: K.J. Klabunde, 2001

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OUTLINE

- Computing and Data Storage
- Materials and Manufacturing
- Health and Medicine
- Energy and Environment
- Transportation
- Security
- Carbon nanotubes, the way to transport electricity

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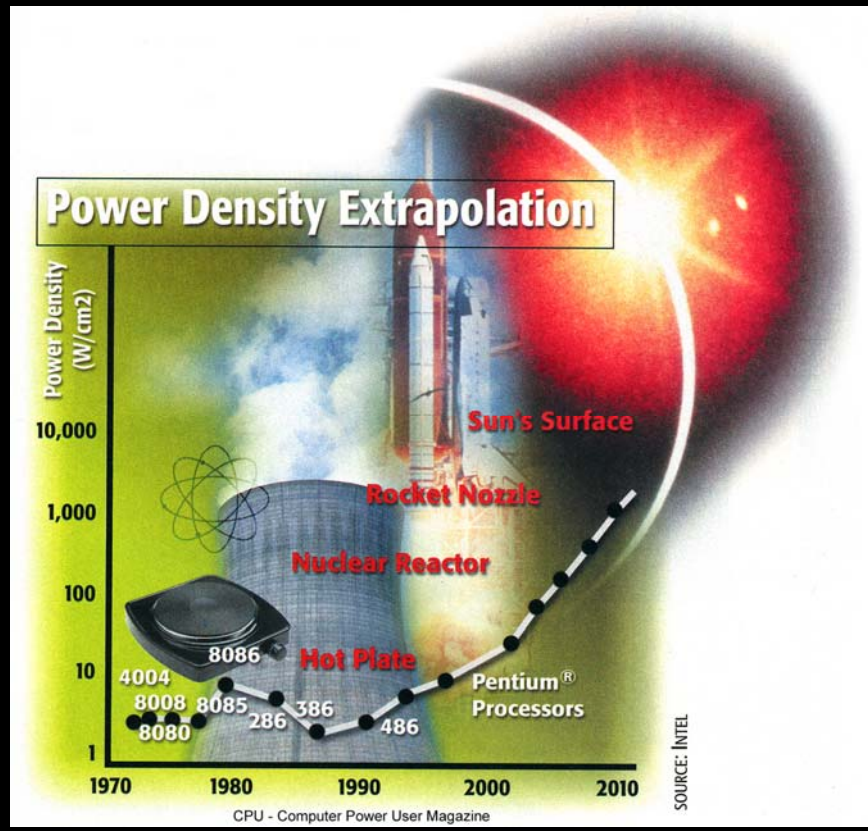
OUTLINE

- **Computing and Data Storage**
- Materials and Manufacturing
- Health and Medicine
- Energy and Environment
- Transportation
- Security
- Carbon nanotubes, the way to transport electricity

Computing & Data storage

- Processors performance X 10^6 (Gflops -> Pflops)
- Small mass storage devices → multi-tera bit levels
- Smart nanosensors: collecting, processing and communicating massive amounts of data with minimal size, weight, and power consumption
- Higher transmission frequencies : more efficient utilization of optical spectrum to provide at least 10 times the current bandwidth
- Quantum computing



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Data storage capacity

Current data storage density ~ 10^9 bits/cm^2

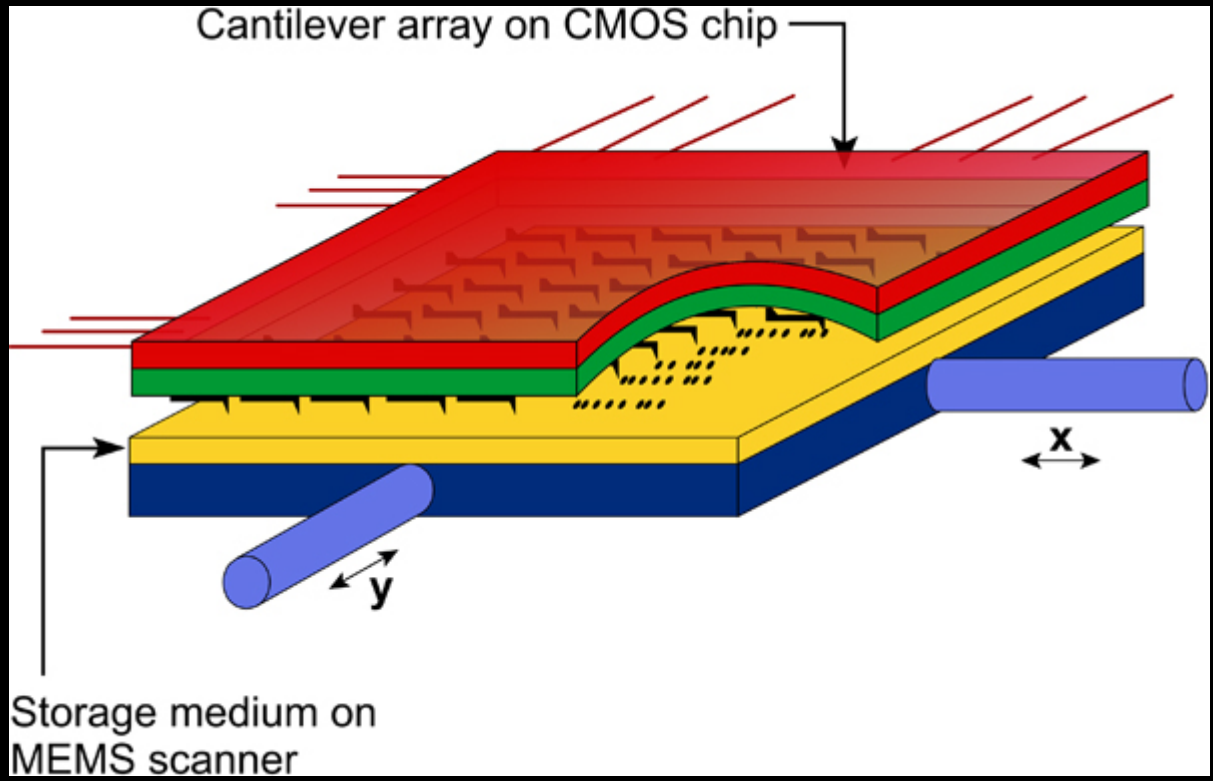
1 bit ~ 100 atoms (at the best)

Theoretical data storage capacity = X 1000 (10^{12} bits/cm^2)

3D => Data storage capacity could be ~ 10^{16} bits/cm^3

(10^{12} bits/cm^2 x 10^4/cm)

IBM Millipede



Combine the advantage of the hard disk (storage capacity, target ~ 1 Tbit /in²) and the advantage of DRAM (speed access)

Principle: nanometric holes on the surface of an thermo active polymer

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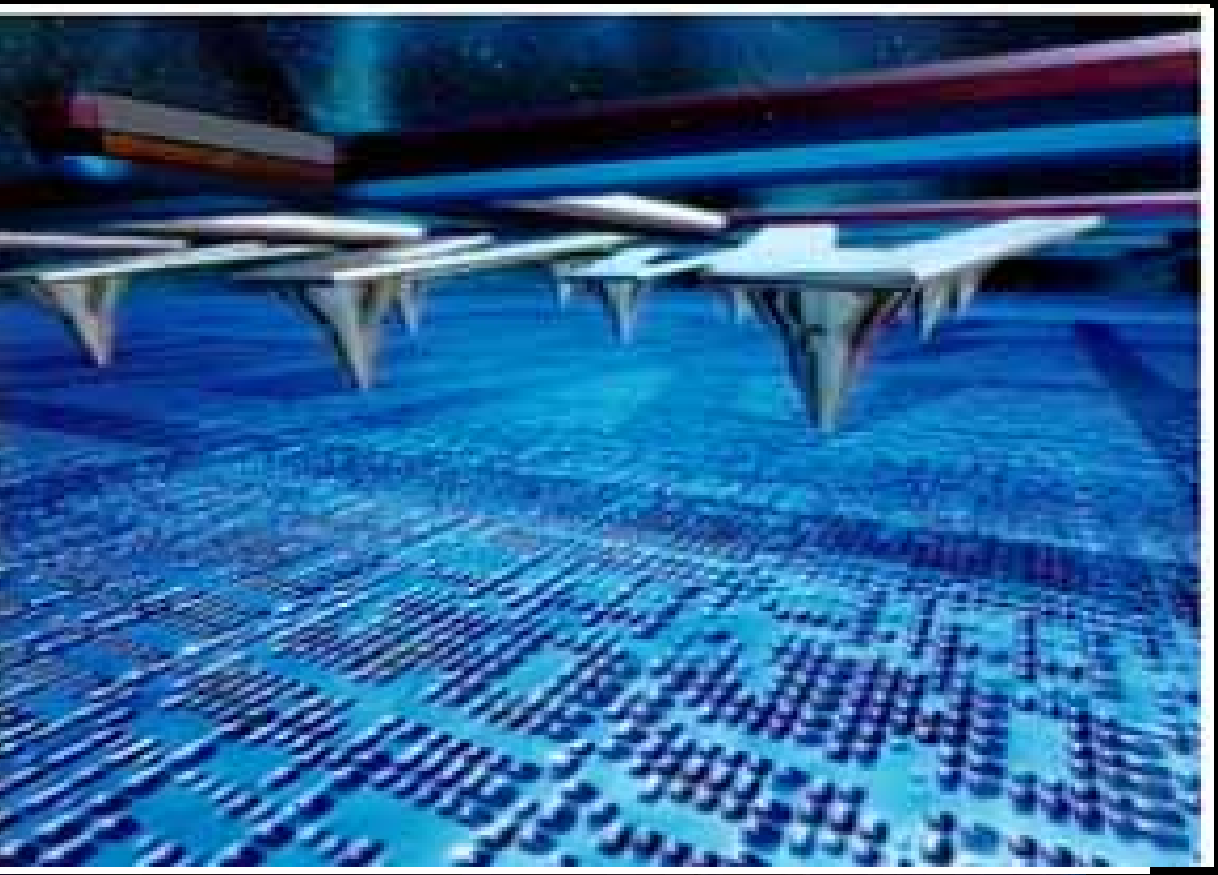
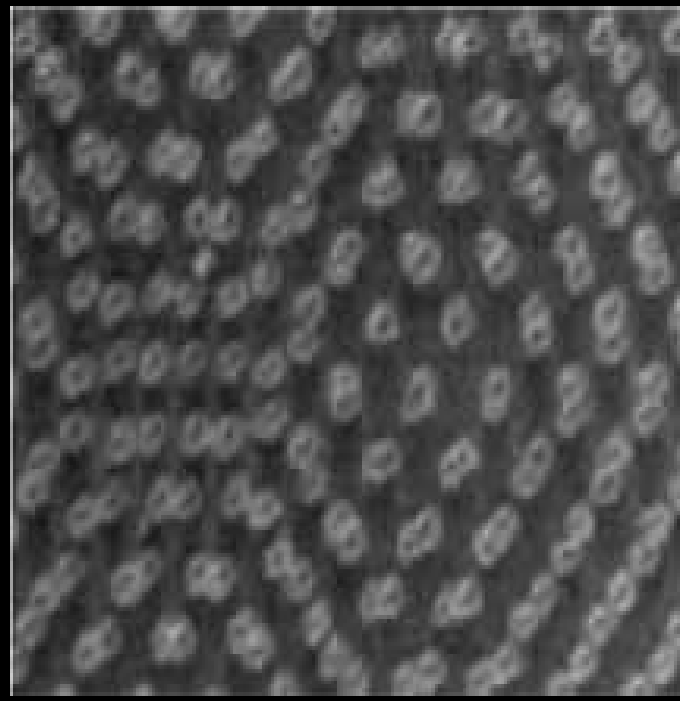
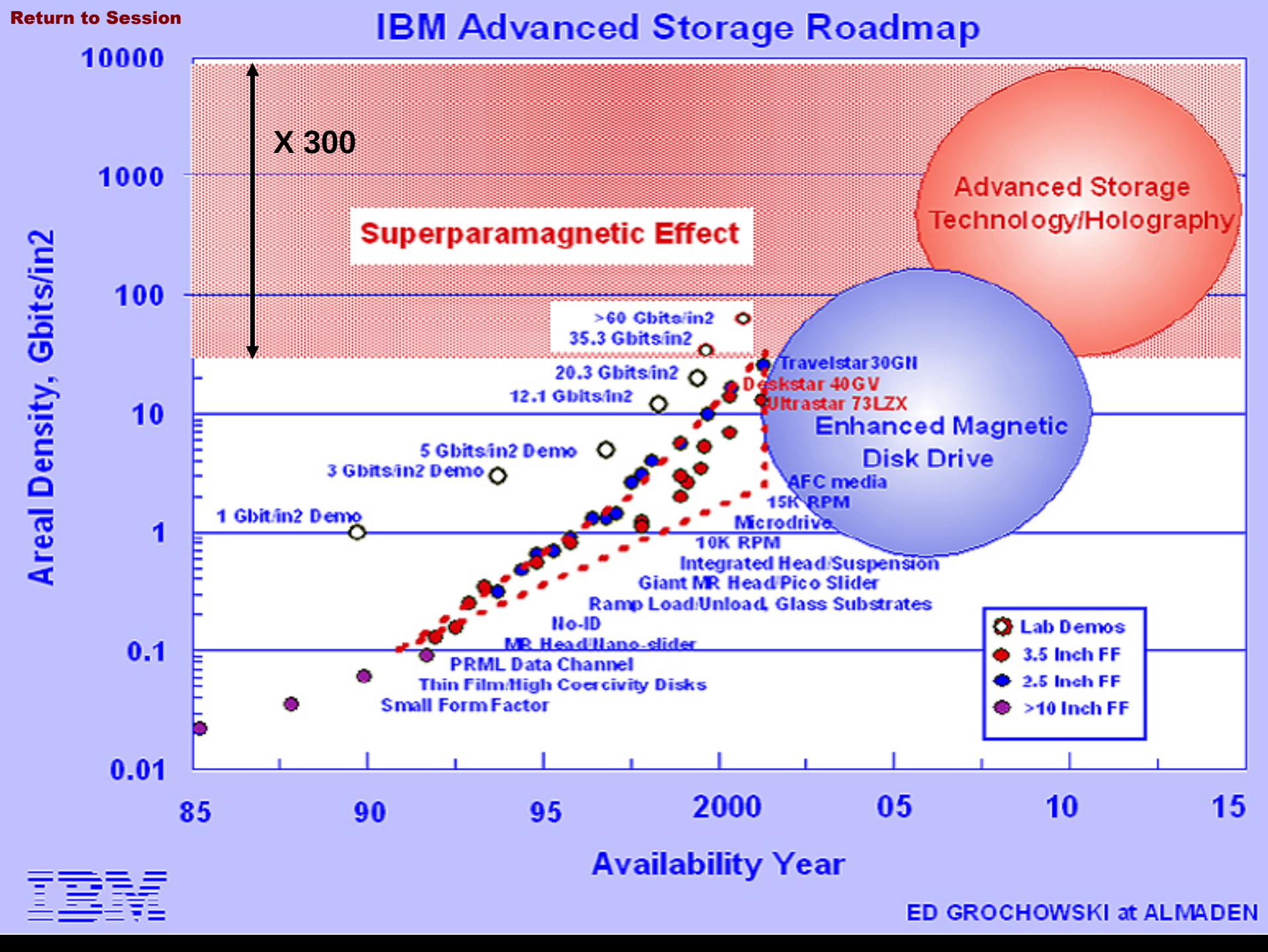
IBM Millipede

3.10^{10} bits / cm^2

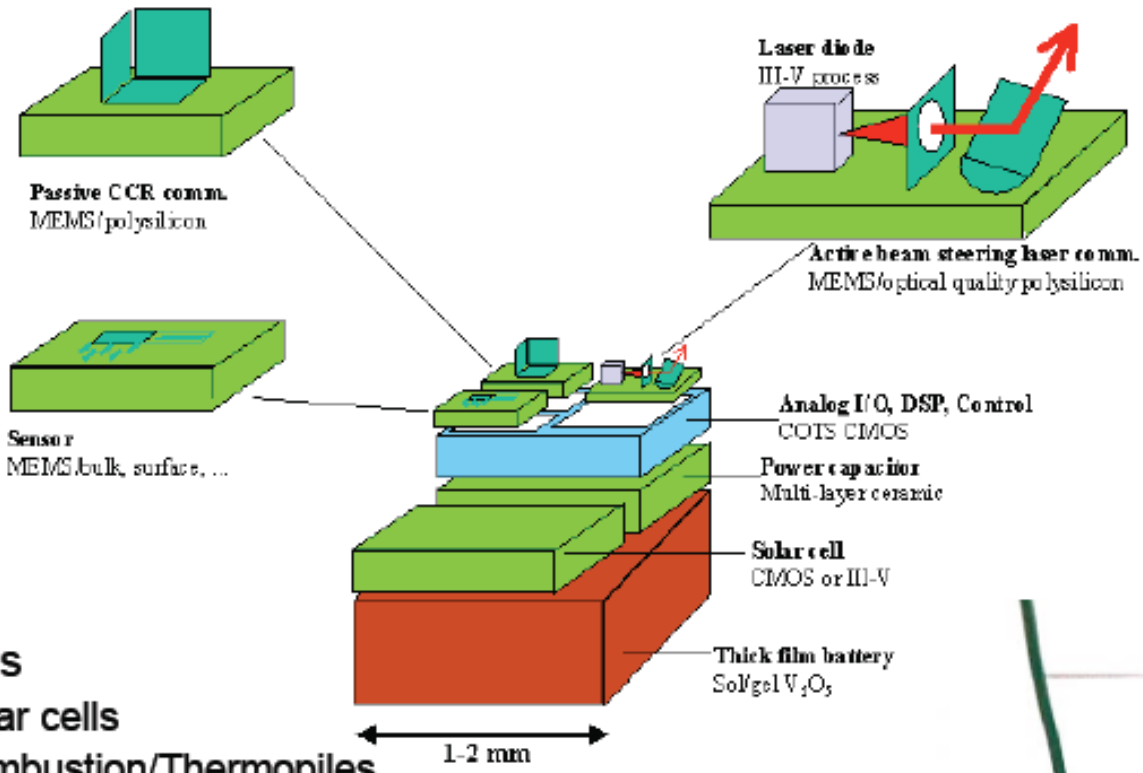




10 nm


IBM Advanced Storage Roadmap
10000
1000
100
10
1
0.1
0.01
Areal Density, Gbits/in2
X 300
Superparamagnetic Effect
Advanced Storage Technology/Holography
Enhanced Magnetic Disk Drive
>60 Gbits/in2
35.3 Gbits/in2
20.3 Gbits/in2
12.1 Gbits/in2
5 Gbits/in2 Demo
3 Gbits/in2 Demo
1 Gbit/in2 Demo
Travelstar 30GH
Deskstar 40GV
Ultrastar 73LZX
AFC media
15K RPM
Microdrive
10K RPM
Integrated Head/Suspension
Giant MR Head/Pico Slider
Ramp Load/Unload, Glass Substrates
No-ID
MR Head/Nano-slider
PRML Data Channel
Thin Film/High Coercivity Disks
Small Form Factor
Lab Demos
3.5 Inch FF
2.5 Inch FF
>10 Inch FF
85
90
95
2000
05
10
15
Availability Year

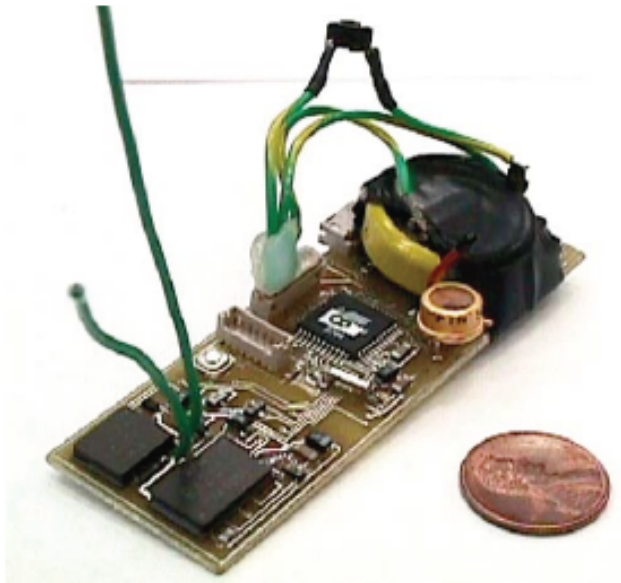
Smart dust components / smart sensors



Smart nanosensors

- Autonomous in energy
- Sensing
- Processing
- Communicating

- Sources
  - Solar cells
  - Combustion/Thermopiles
- Storage
  - Batteries ~1 J/mm^3
  - Capacitors ~1 mJ/mm^3
- Usage
  - Digital control: nJ/instruction
  - Analog circuitry: nJ/sample
  - Communication: nJ/bit



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Smart sensors

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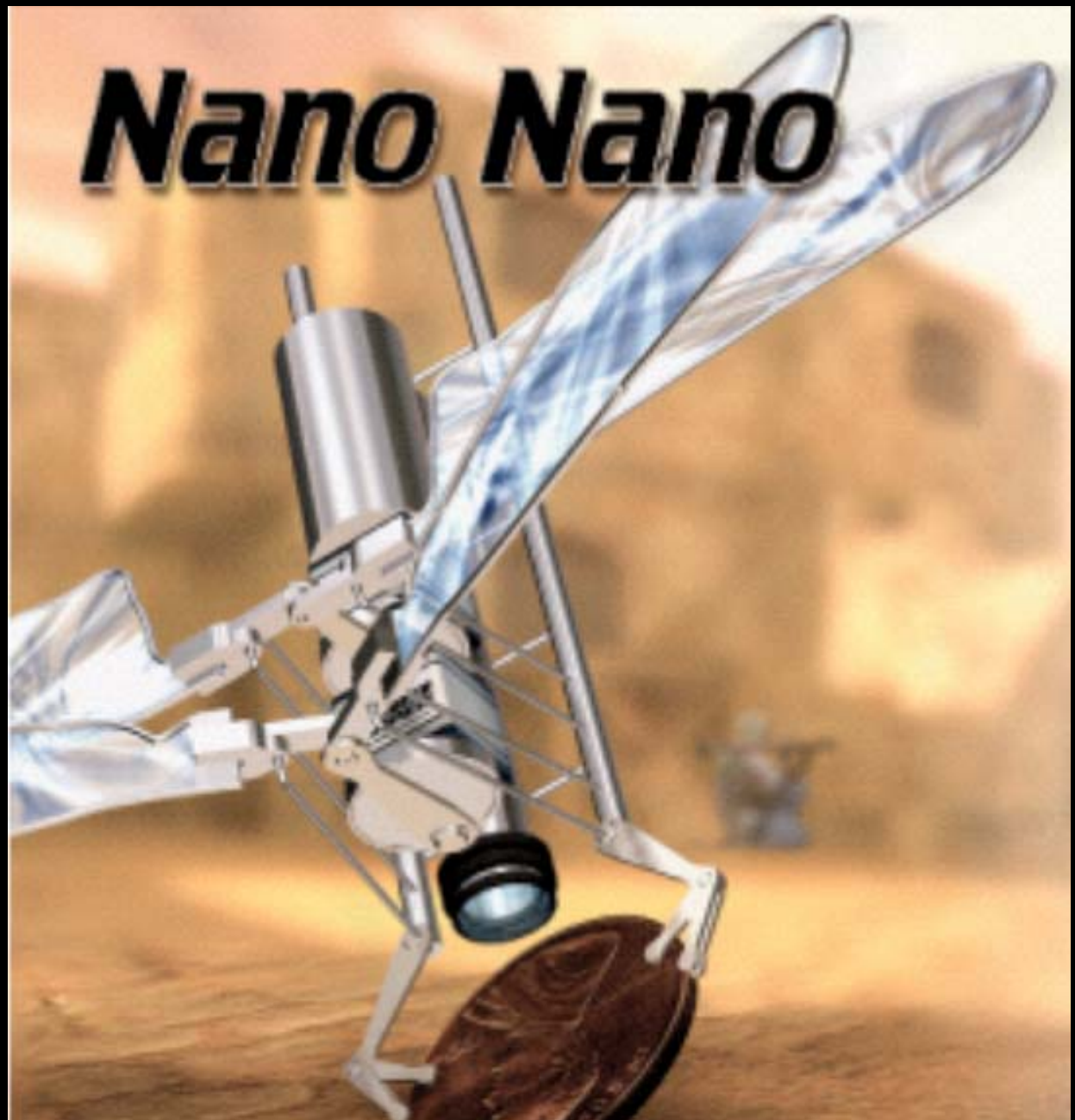
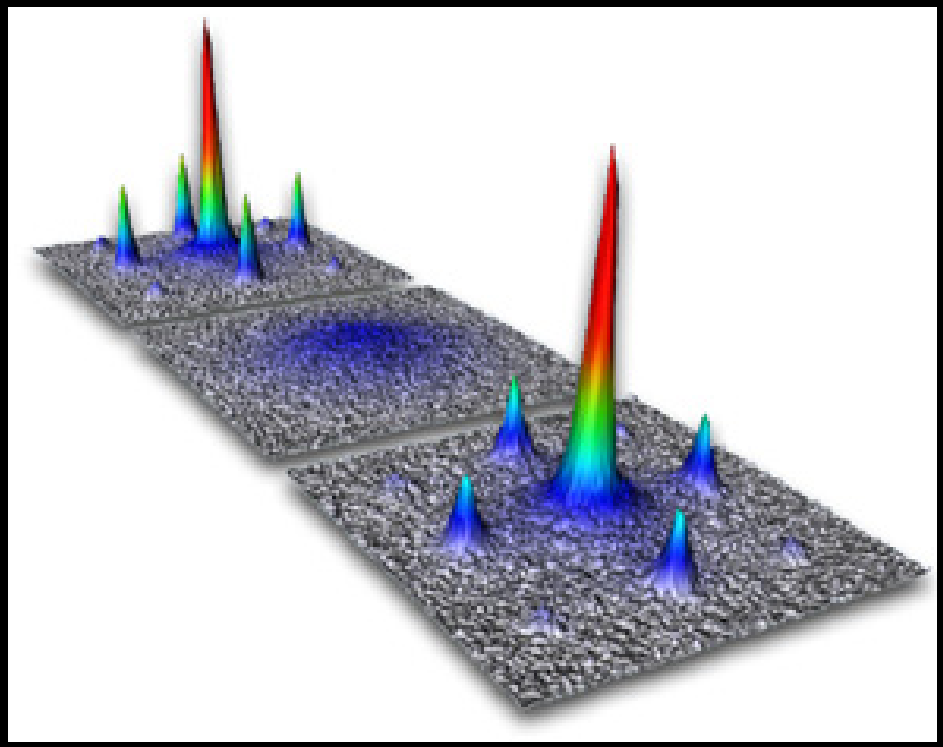
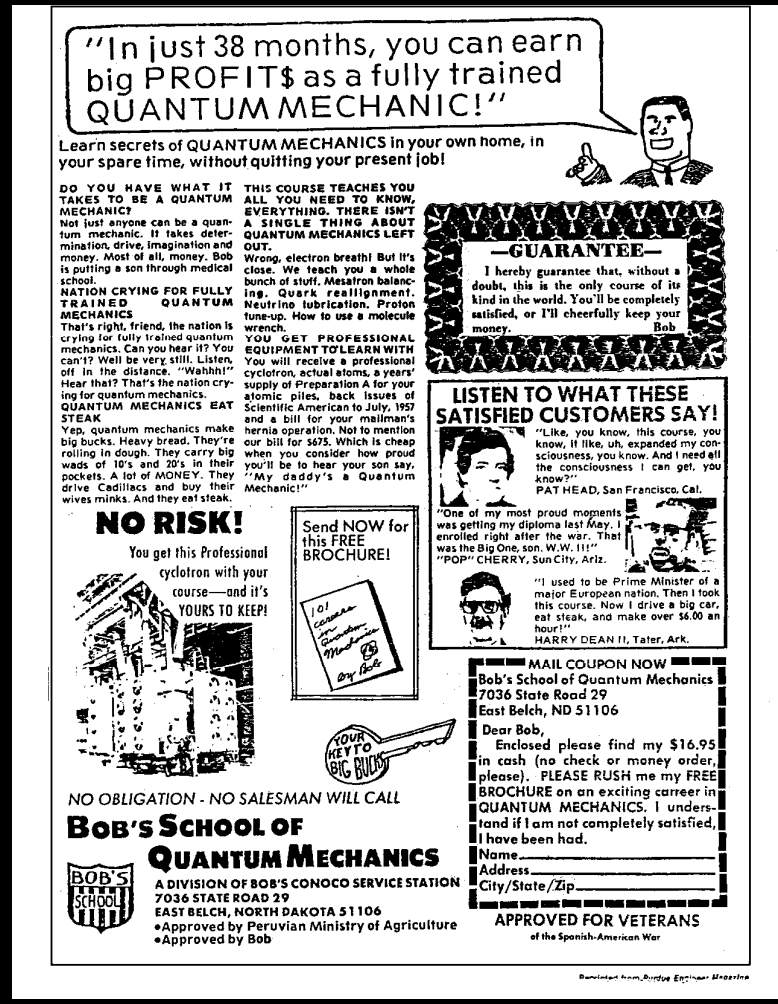
Smart sensors on micro flyers



UAV
insect size

Quantum computing





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DO YOU HAVE WHAT IT TAKES TO BE A QUANTUM MECHANIC?
Not just anyone can be a quantum mechanic. It takes determination, drive, imagination and money. Most of all, money. Bob is putting a son through medical school.

NATION CRYING FOR FULLY TRAINED QUANTUM MECHANICS
That's right, friend, the nation is crying for fully trained quantum mechanics. Can you hear it? You can't? Well be very still. Listen, off in the distance. "Wahhh!" Hear that? That's the nation crying for quantum mechanics.

QUANTUM MECHANICS EAT STEAK
Yep, quantum mechanics make big bucks. Heavy bread. They're rolling in dough. They carry big wads of 10's and 20's in their pockets. A lot of MONEY. They drive Cadillacs and buy their wives minks. And they eat steak.

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Wrong, electron breath! But it's close. We teach you a whole bunch of stuff. Mesatron balancing. Quark realignment. Neutrino lubrication. Proton tune-up. How to use a molecule wrench.

YOU GET PROFESSIONAL EQUIPMENT TO LEARN WITH
You will receive a professional cyclotron, actual atoms, a years' supply of Preparation A for your atomic piles, back issues of Scientific American to July, 1957 and a bill for your mailman's hernia operation. Not to mention our bill for $675. Which is cheap when you consider how proud you'll be to hear your son say, "My daddy's a Quantum Mechanic!"

—GUARANTEE—
I hereby guarantee that, without a doubt, this is the only course of its kind in the world. You'll be completely satisfied, or I'll cheerfully keep your money.
Bob

LISTEN TO WHAT THESE SATISFIED CUSTOMERS SAY!

"Like, you know, this course, you know, it like, uh, expanded my consciousness, you know. And I need all the consciousness I can get, you know?"
PAT HEAD, San Francisco, Cal.

"One of my most proud moments was getting my diploma last May. I enrolled right after the war. That was the Big One, son. W.W. II!"
"POP" CHERRY, Sun City, Ariz.

"I used to be Prime Minister of a major European nation. Then I took this course. Now I drive a big car, eat steak, and make over $6.00 an hour!"
HARRY DEAN II, Tater, Ark.

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A DIVISION OF BOB'S CONOCO SERVICE STATION
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EAST BELCH, NORTH DAKOTA 51106
•Approved by Peruvian Ministry of Agriculture
•Approved by Bob

MAIL COUPON NOW
Bob's School of Quantum Mechanics
7036 State Road 29
East Belch, ND 51106

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Name_____
Address_____
City/State/Zip_____

APPROVED FOR VETERANS
of the Spanish-American War

Reprinted from Purdue Engineer Magazine

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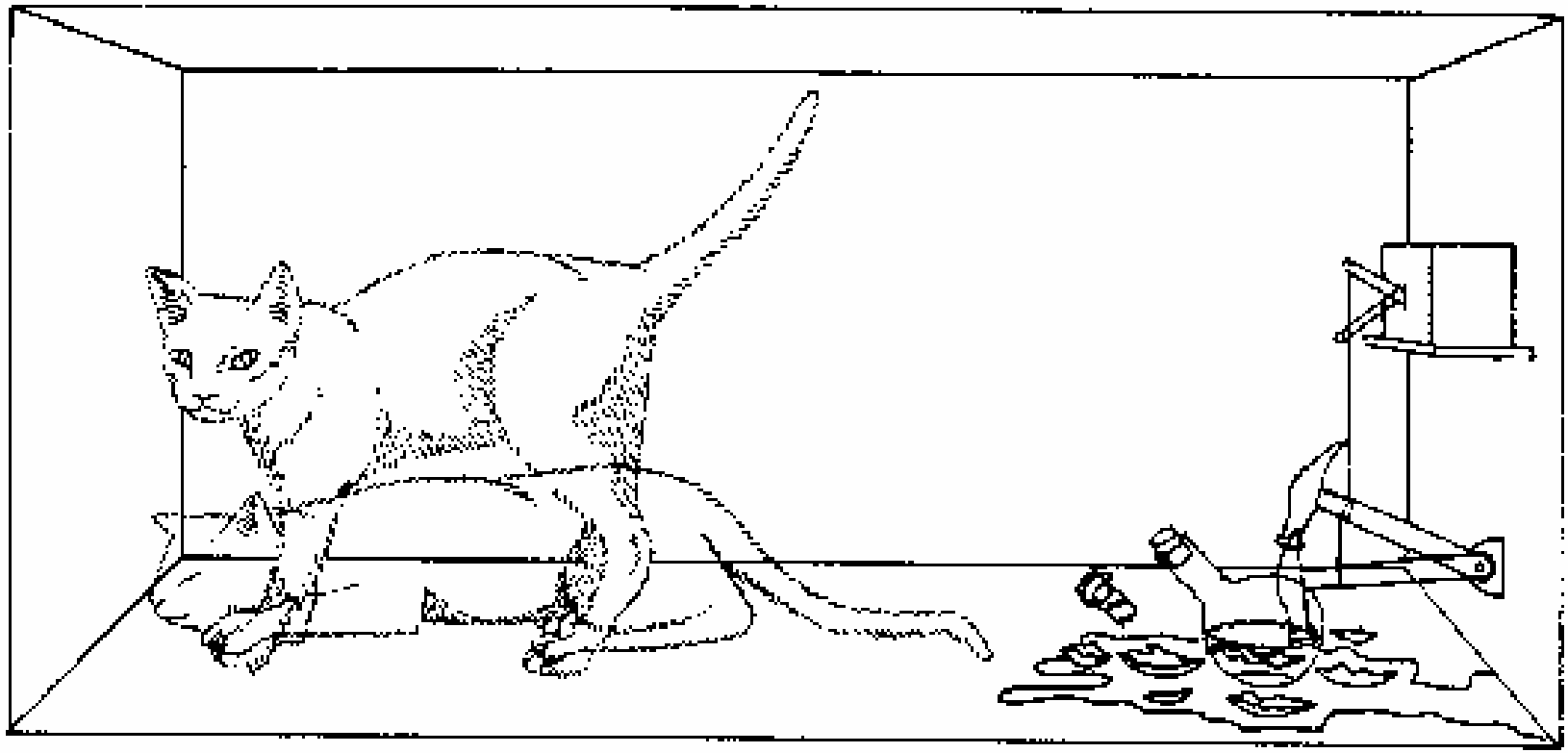
Schrödinger's cat

Take a cat, cyanide, a radioactive particle, put the whole in a box and let wait one hour!

Letter from Schrödinger to Einstein, 1935



$|\psi> = 1/\sqrt{2}\ |\text{Dead cat}> + 1/\sqrt{2}\ |\text{Alive cat}>$

Quantum computing

A traditional bit is **1** or **0**

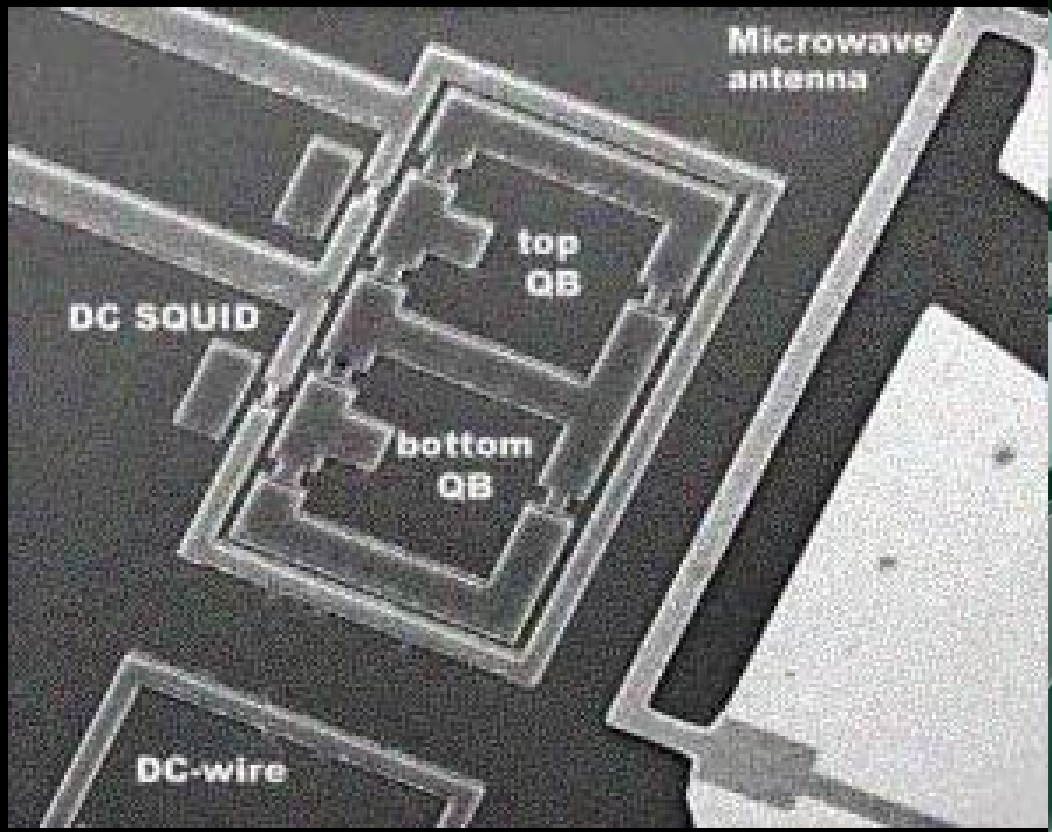
A Quantum bit (Qubit) is a superposition of state **1** and **0**

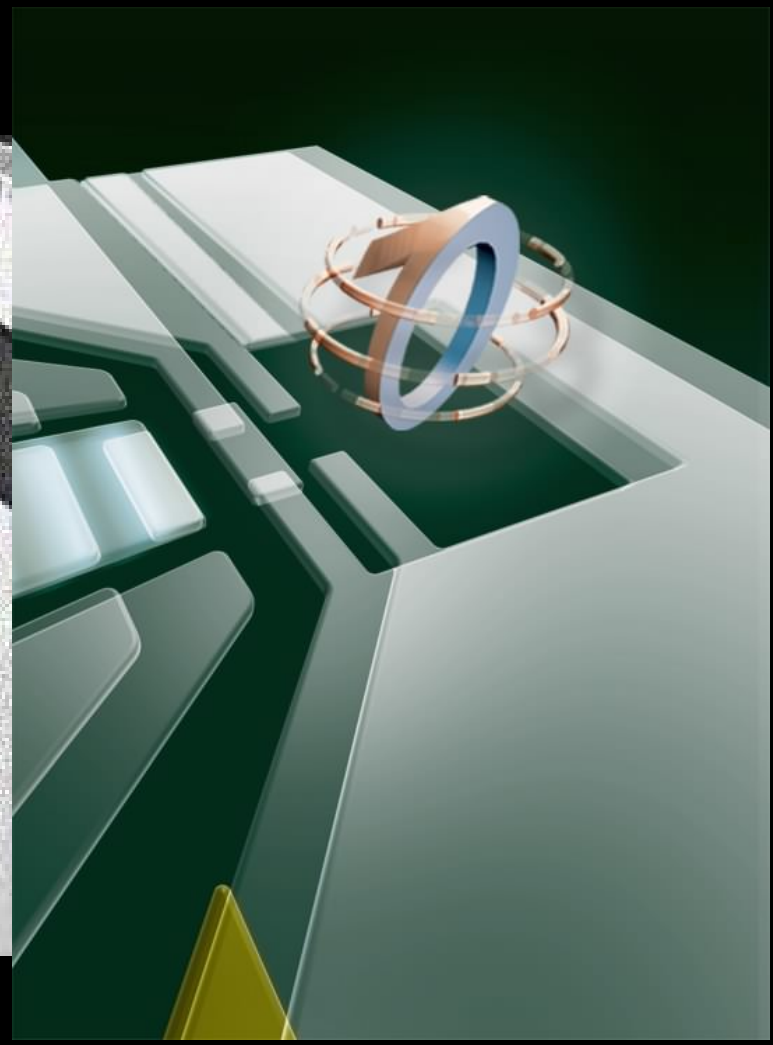
$$|\psi> = \alpha|0> + \beta\ |1>$$

$(0 \leq \alpha \leq 1$ and $0 \leq \beta \leq 1)$

Quantum computing

Is it SF ?





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Quantum computing
Shor's algorithm (1995)

Principle of RSA cryptography: factorization of a number

The solution is easy to verify (multiplication) but difficult to find (factorization in prime number)

Example:

Classical computing: three months to factorize a number of 130 digits and 10^{10} years (the age of the Universe) for a number of 400 digits

Quantum computing: still three months to factorize a number of 130 digits but only 3 years for a number of 400 digits!

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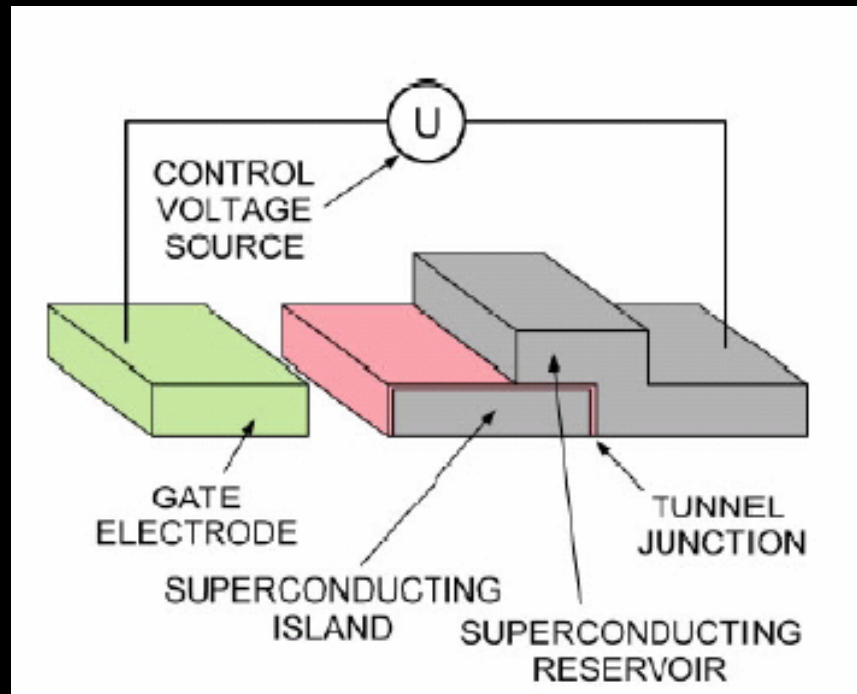
Quantum computing

First tentative

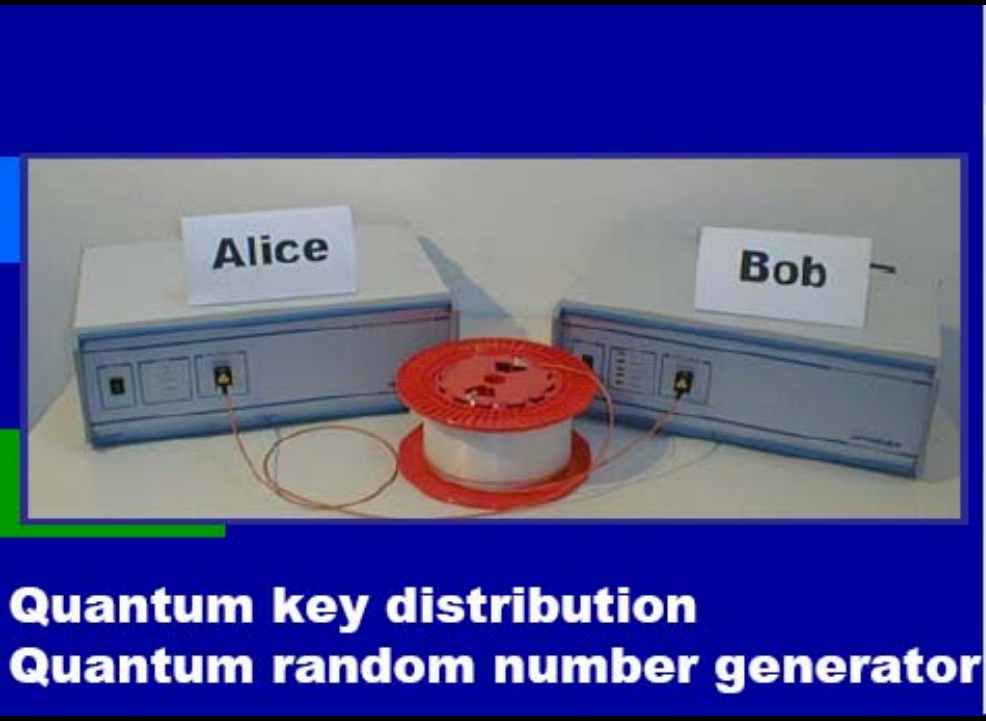
Qubit Ion trap
(NIST)

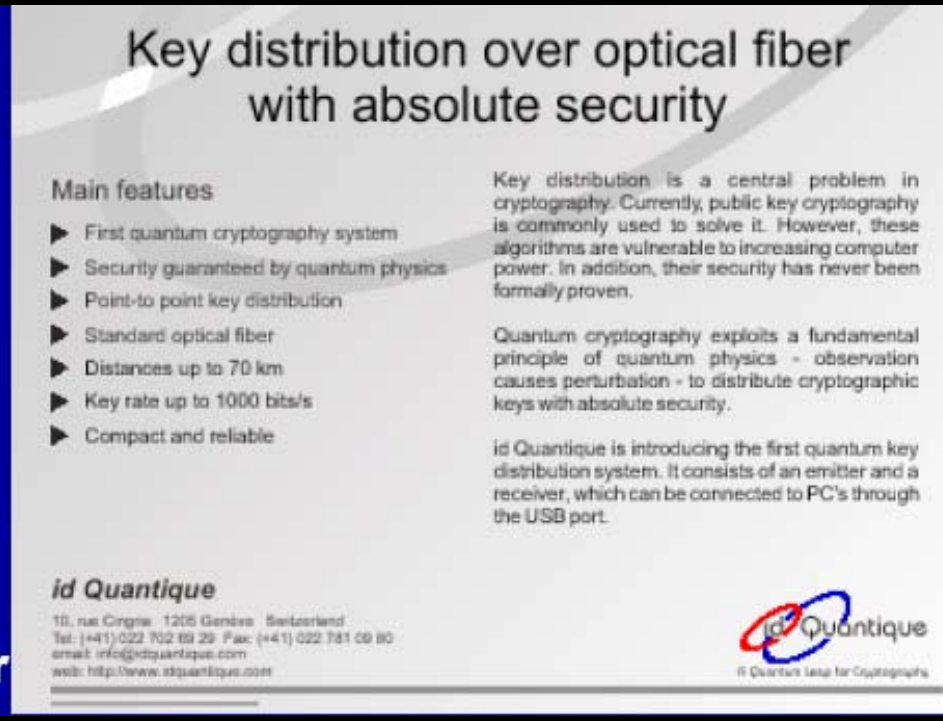
Quantronium super conducting qubit
(CEA)



Quantum computing is not for tomorrow !

Quantum cryptography





Example: Idquantique (start up) : www.idquantique.com

Quantum cryptography already exists :
60 km with OF ; 150 km with free space transmission

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OUTLINE

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- Carbon nanotubes, the way to transport electricity

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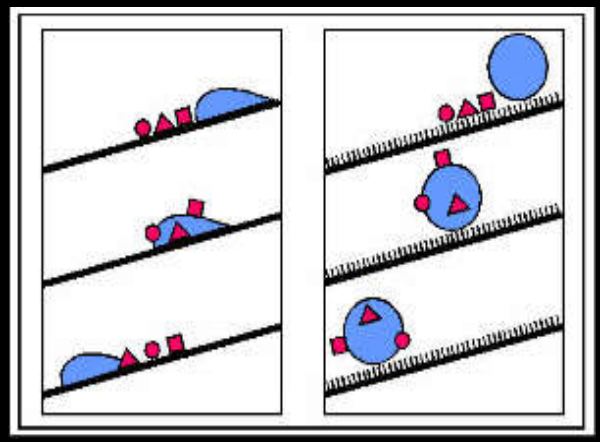
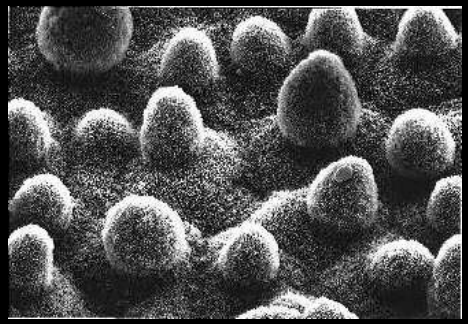
Materials and manufacturing

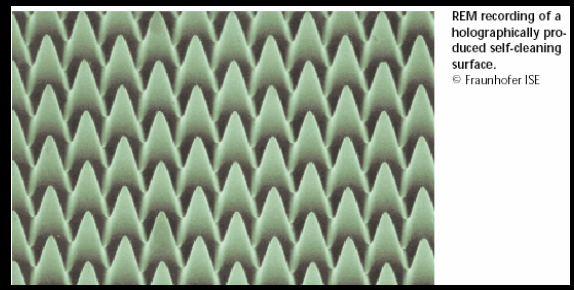


Self-cleaning surface (lotus effect)

W. Barthlott, Univ. of Hamburg

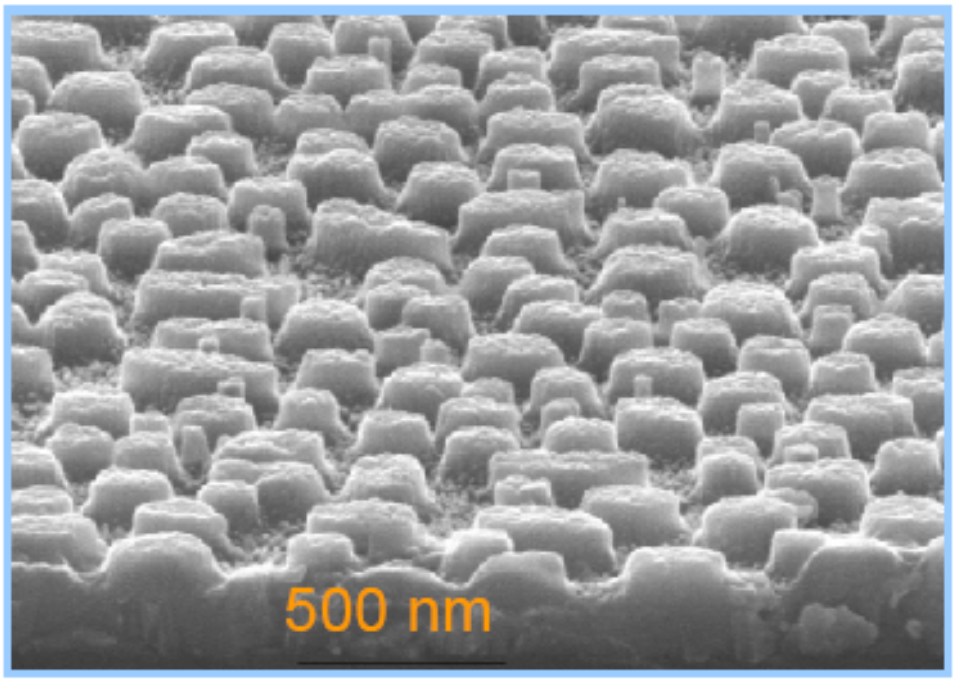


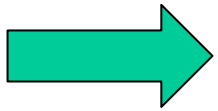
Epicuticular wax

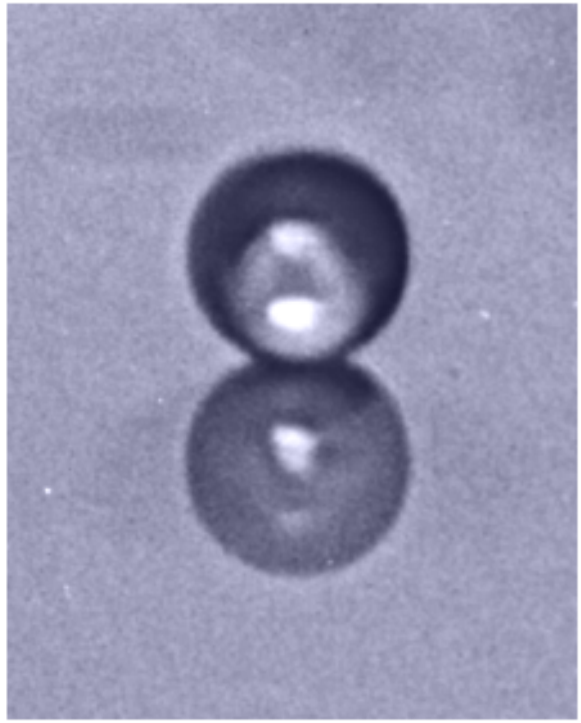


(Source: Metin Sitti, CMU)

Self-cleaning surface

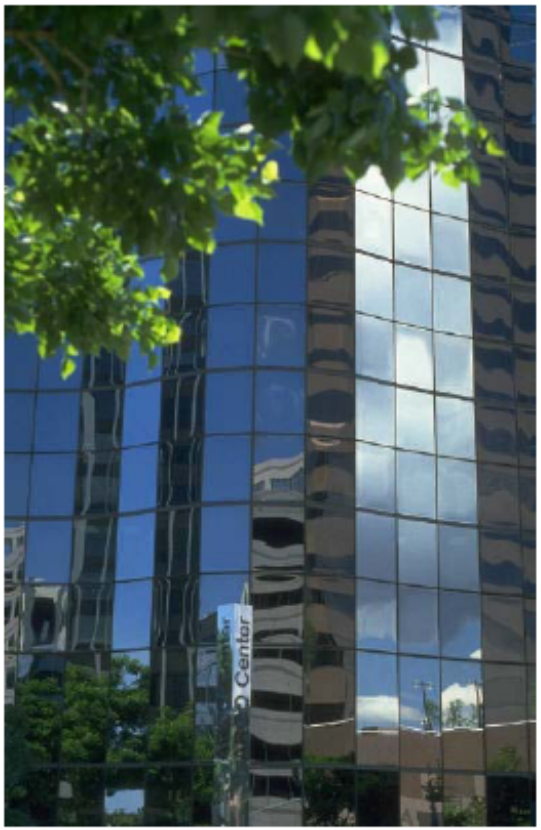




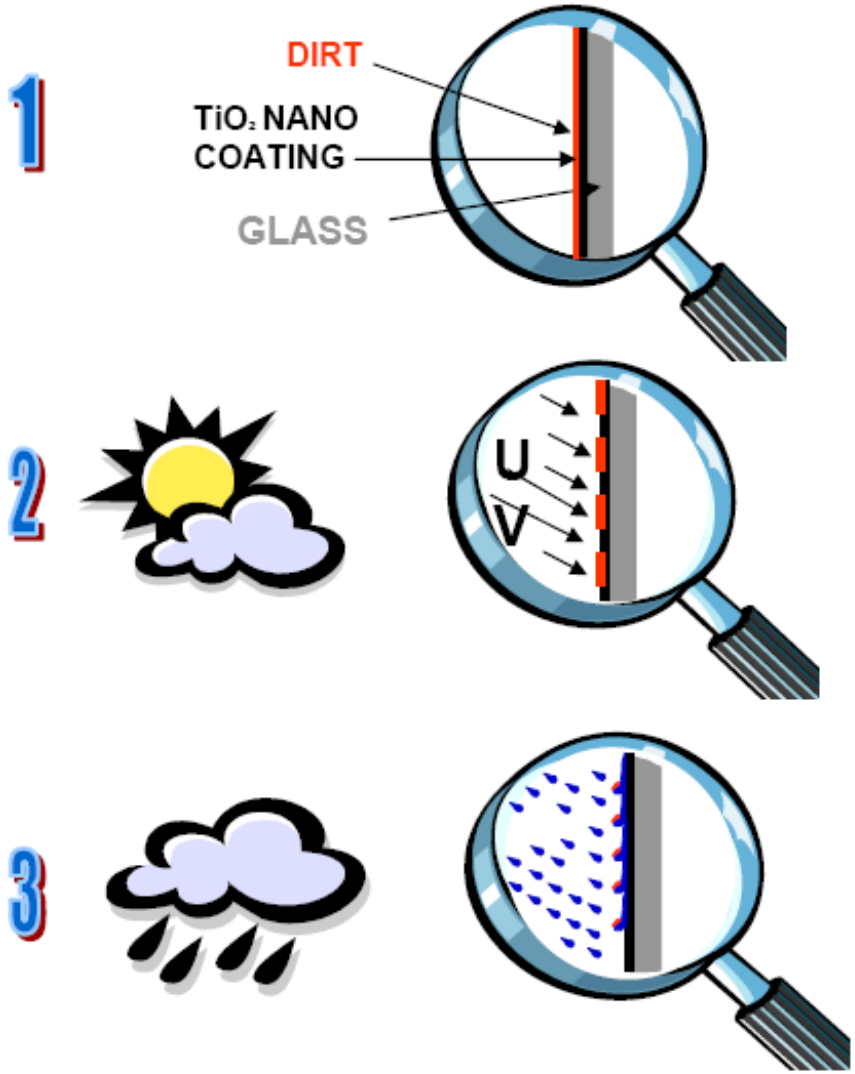


Nano relief => the water does not wet

Self-cleaning glass



Pilkington's self-cleaning glass



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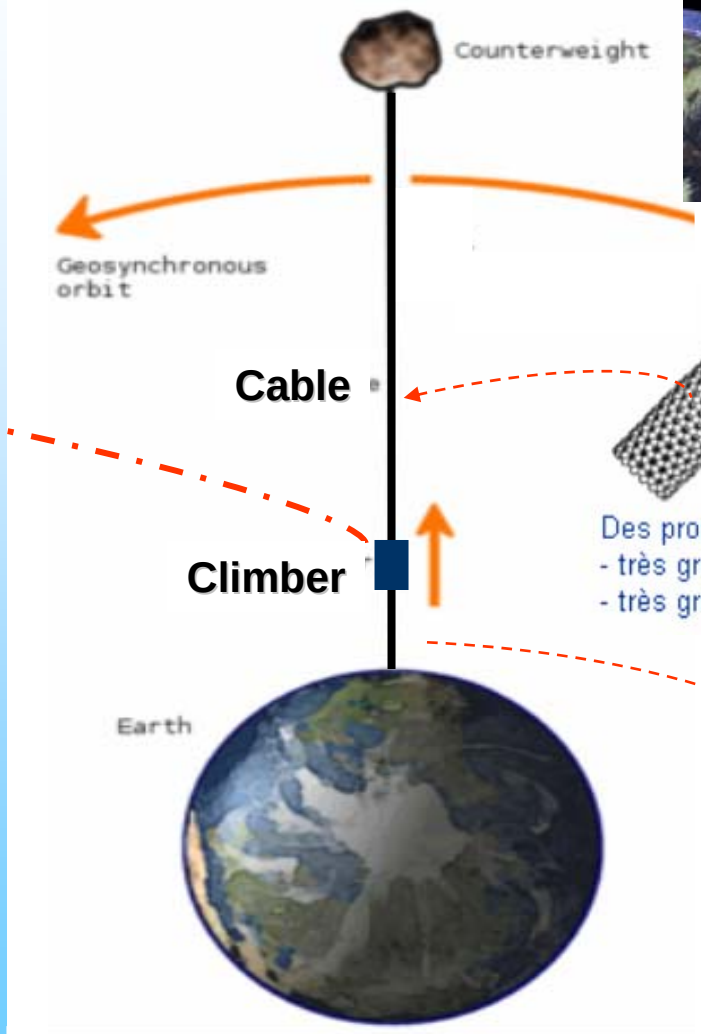
SPACEDAILY

YOUR PORTAL TO SPACE



A space elevator would consist of a cable attached to the surface and reaching

Carbon nanotubes

Des propriétés mécaniques hors du commun :
- très grande élasticité (module d'élasticité > 1000 GPa),
- très grande flexibilité (crack stress : 45 GPa)

ne concept for the space elevator has it tethered to a obile seagoing platform.

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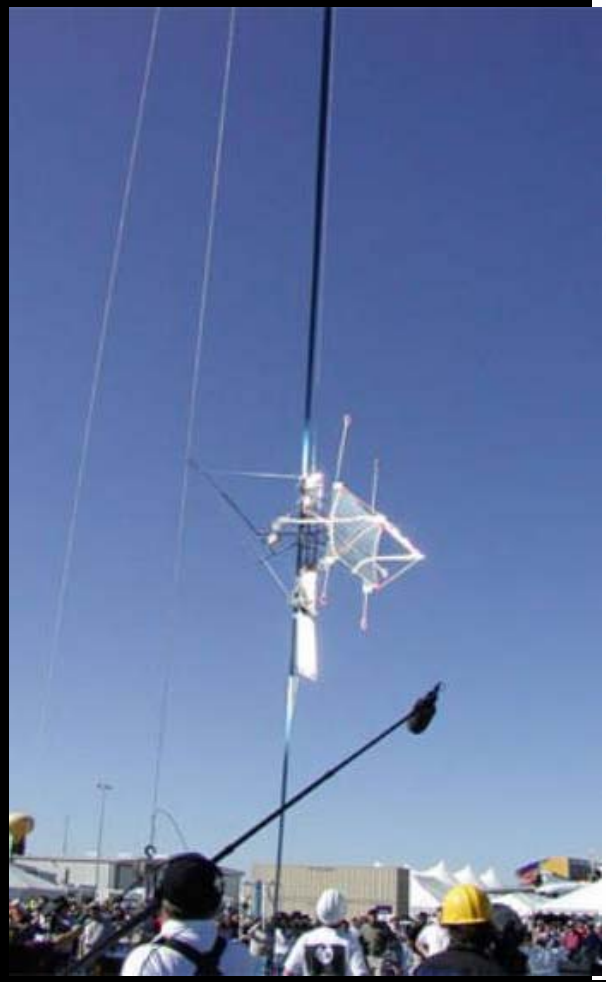
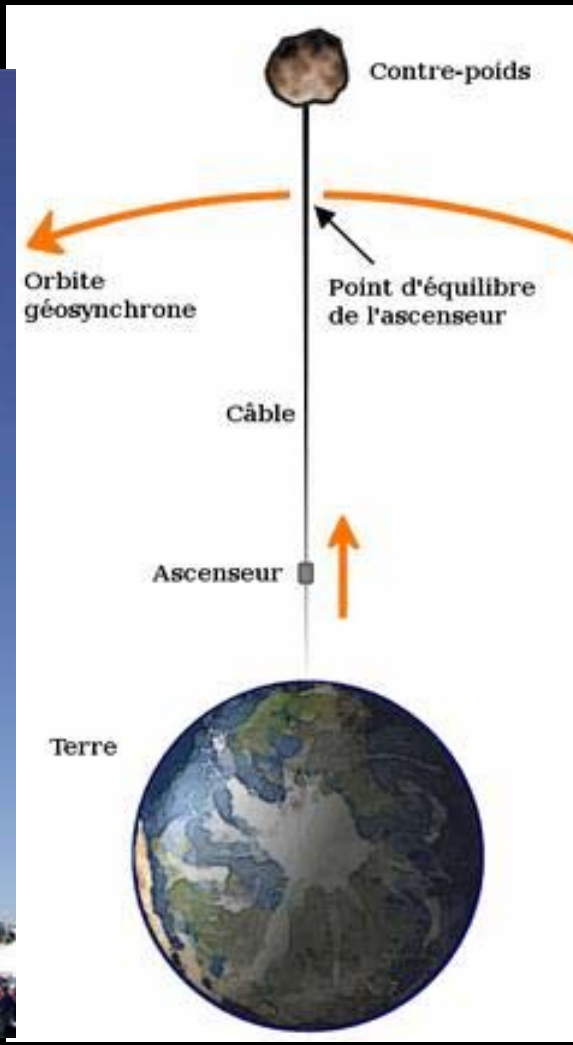
Space elevator

Edwards Bradley's project : The satellite is placed in orbit thanks to the CNT cable

The satellite is pushed thanks to the ground laser which strike the solar panels installed under the platform

Estimated cost ~ 6 billion $ for the first project





Nano ceramic

Capacitors

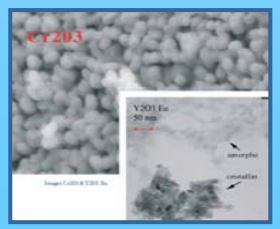
Mirrors

Medical

Optics

Nano Ceramic laser

Aero utic



Nano ceramic

When the wavelength is about the size of the grain in the ceramic, the light is diffused in material

light

Nano Ceramic

YAG

$Y_3Al_5O_{12}$: Nd

Nano ceramic

Capacitor

Mirrors

Medical

Optics

Nano Ceramic laser

Aeronautic

European project

Mirrors for space application

Glass :
60 kg / m²

Yesterday

CeSiC :
25 kg / m²

ALCATEL ALENIA SPACE

12 kg / m²

Today

Future

Nano ceramic

Capacitor

Mirrors

Medical

Optics

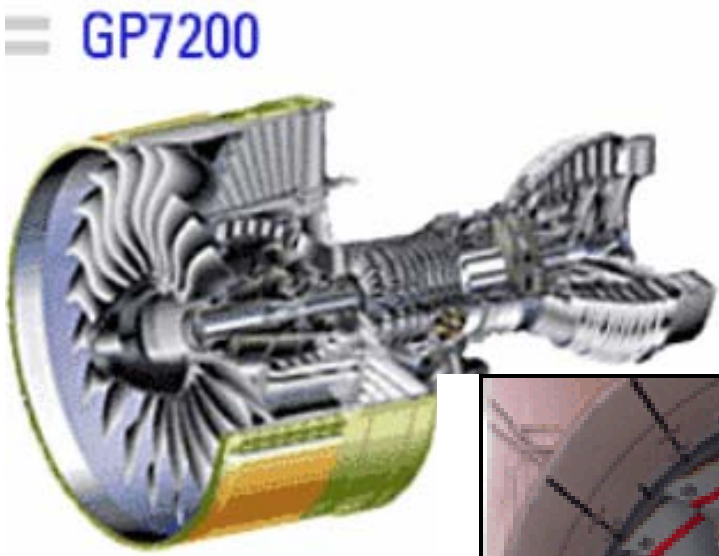
Nano Ceramic laser

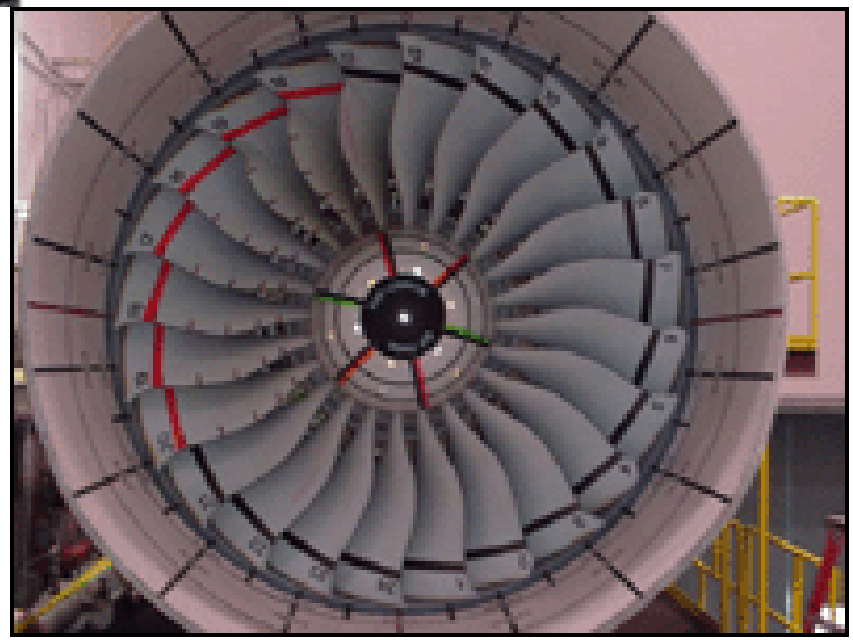
Aeronautic

Jet

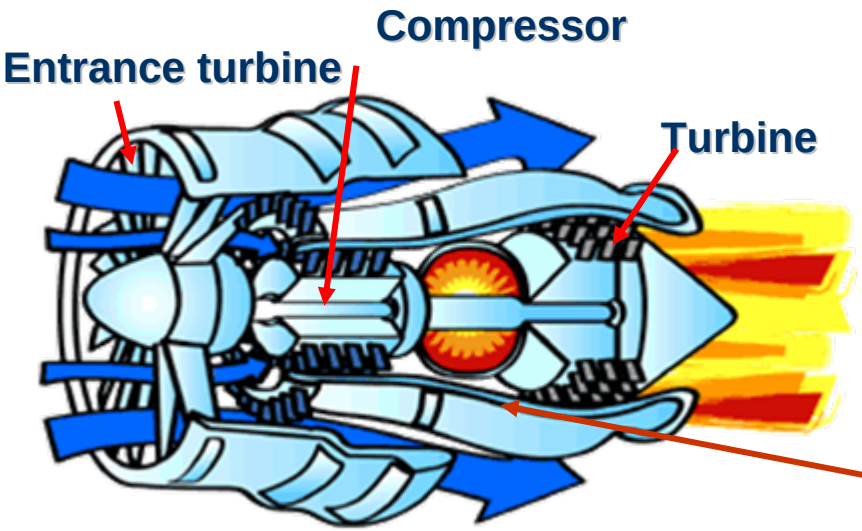
Various heat-resistant materials and alloys

- ~ Titanium
- ~ Ti6A4V
- ~ Ti6A4V with SiC





GP 7200 jet for A380



Composite combustion chamber containing **nanoparticules ceramics**

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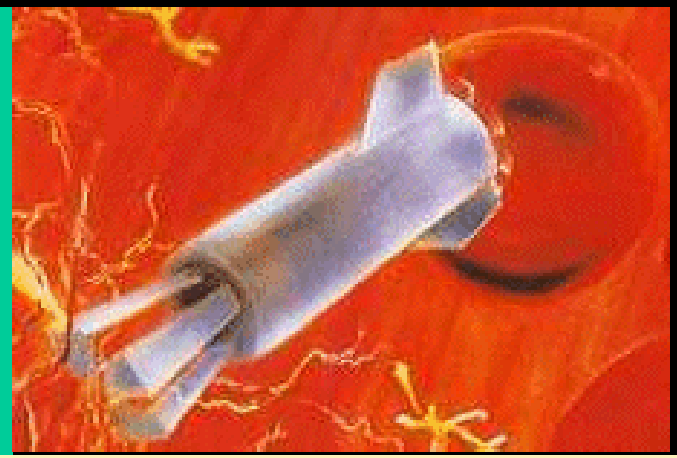
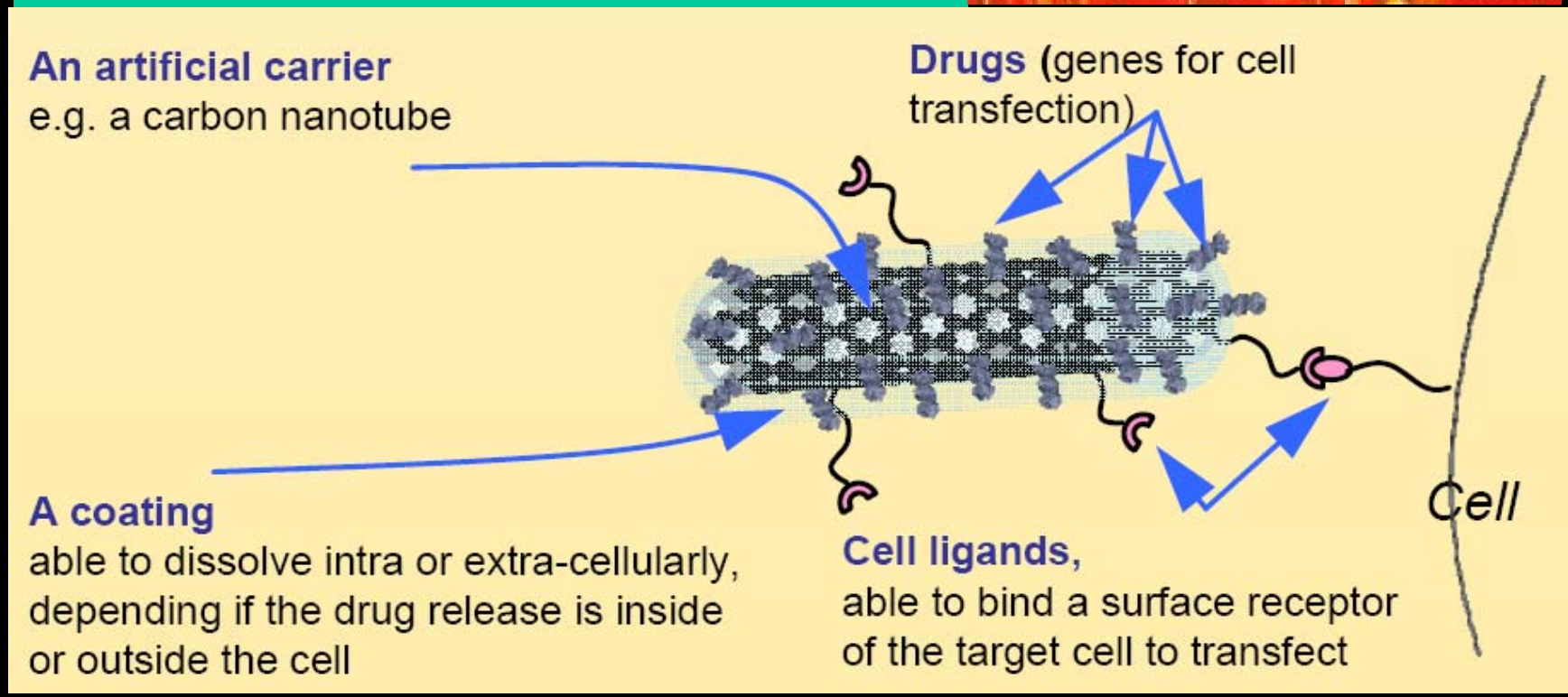
Health and Medicine

This nanoscopic “submarine” could, in the near future, penetrate in the blood vessels to destroy microbes, to correct genetic errors, to remove cancerous cells and to repair tissue





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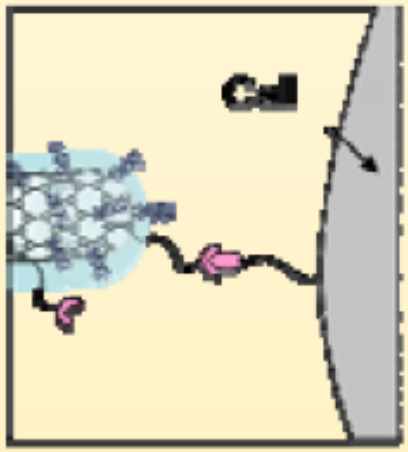
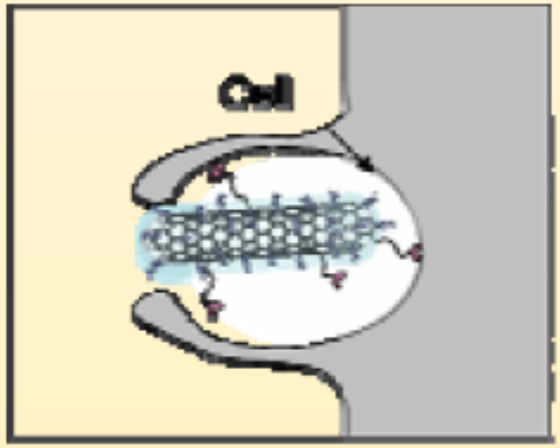
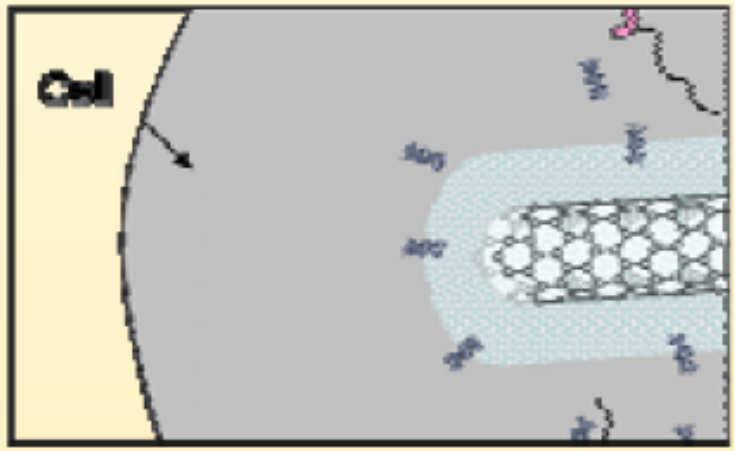
Health and Medicine



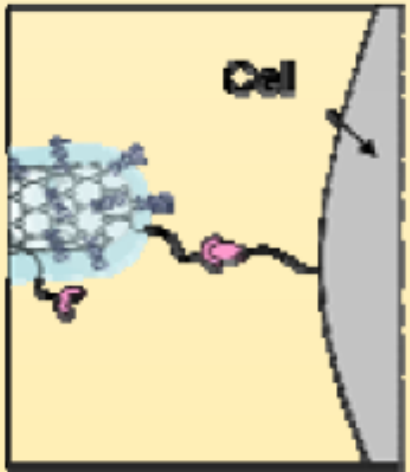
The cellular vector binds the target cell



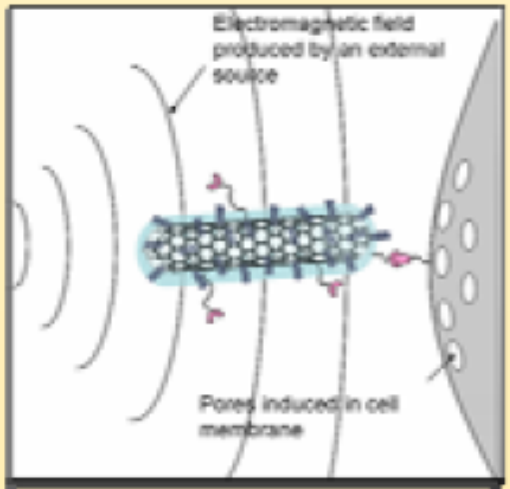
The cell phagocytes the vector



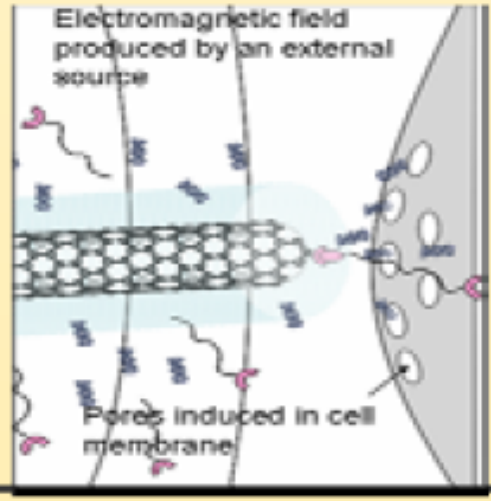
The vector has been up-taken by the cell: the coating dissolves and the genes are released



Cellular vector – cell binding



Cell electroporation via the cellular vector

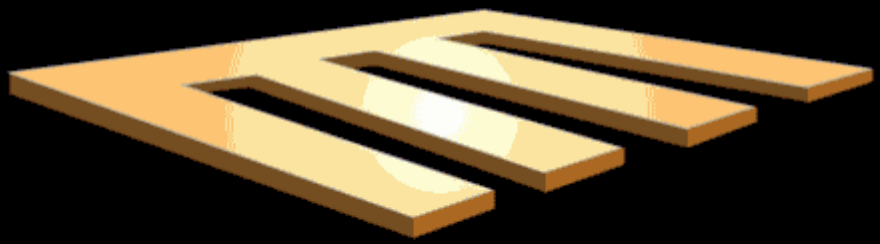


The coating dissolves, genes are released and diffuse across the pores

Return to Session

Health and Medicine

Detection of cancerous cells

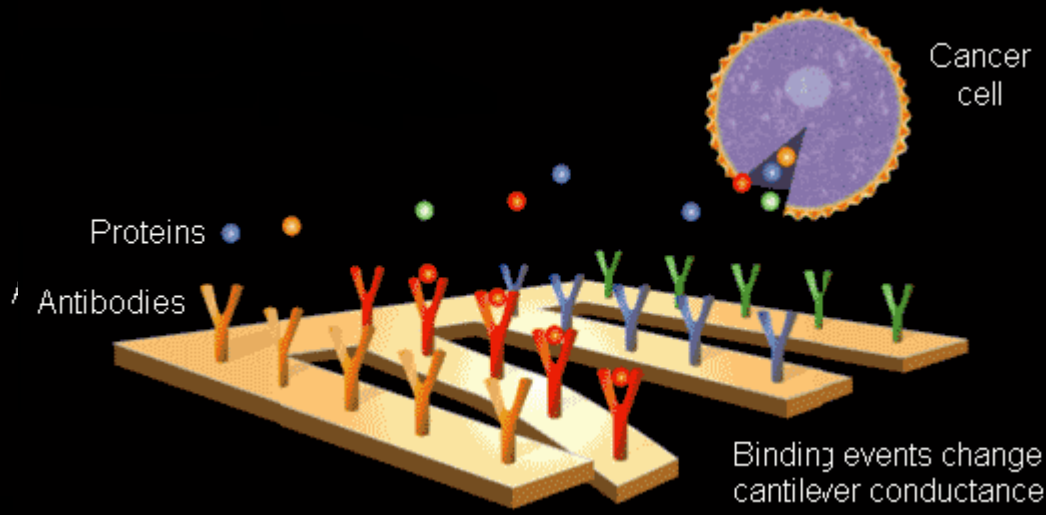


Diagnosis of mellitus diabetes

Detection of acetone in the breath of the patient

Diagnosis of cancer

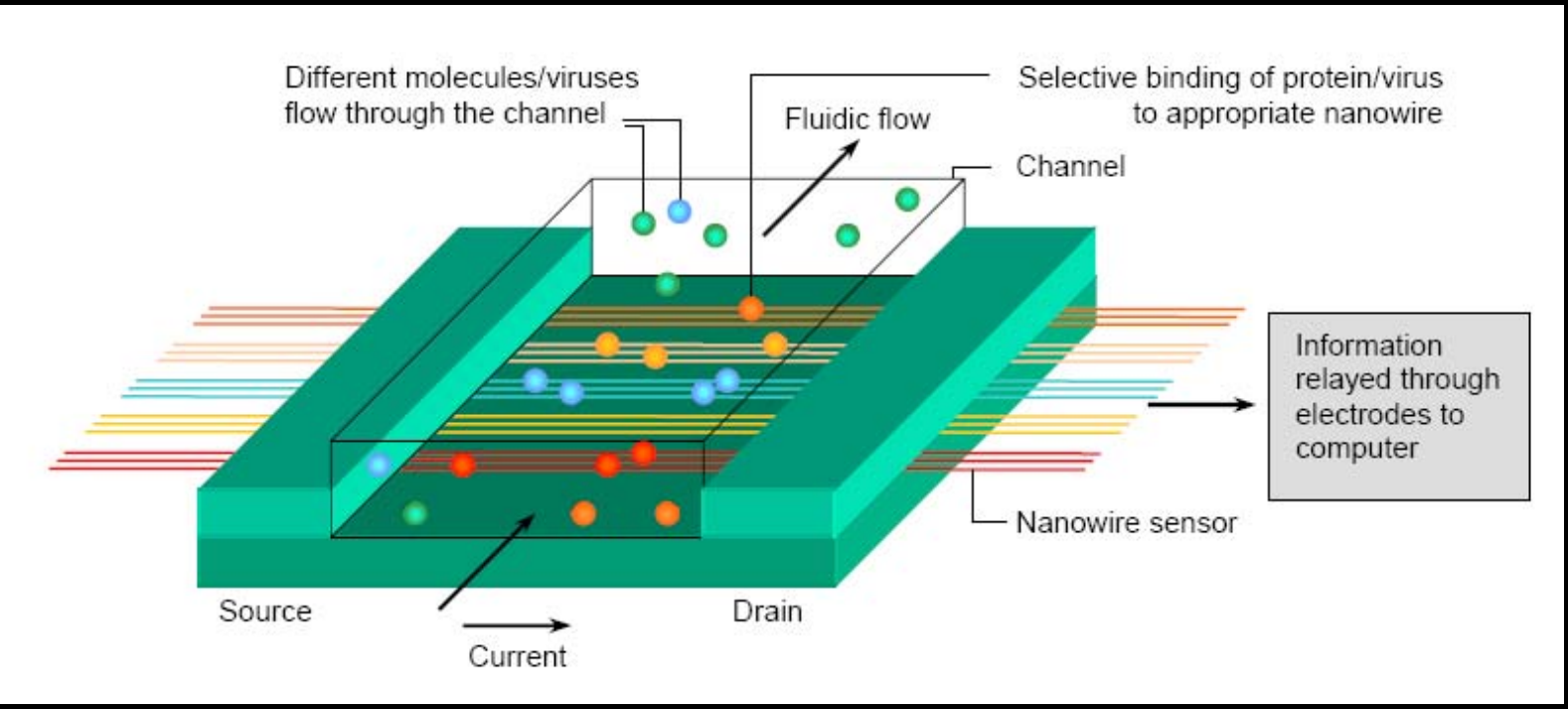
The cantilevers can facilitate the diagnosis of cancer when they bind to the cancerous molecules

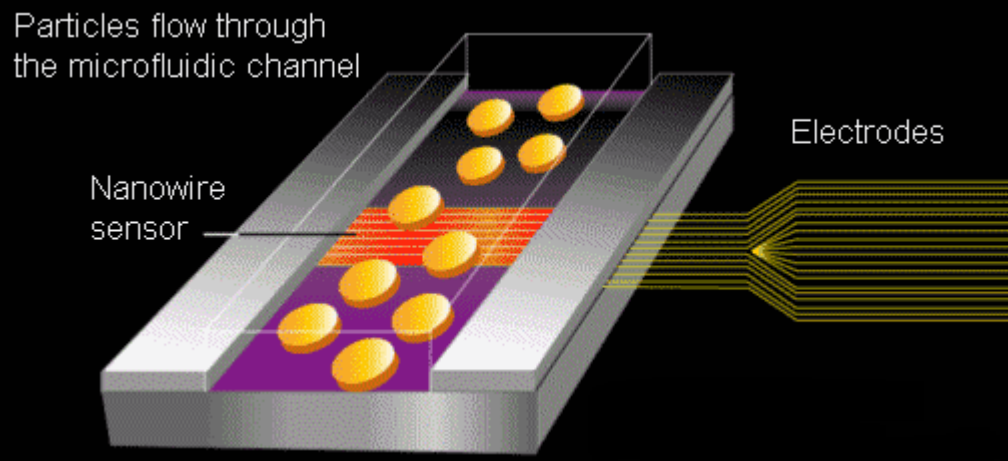


Return to Session

Health and Medicine

Electric detection of virus in solution by nanowire field-effect transistors





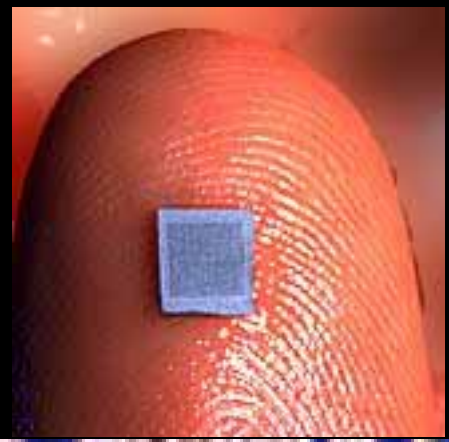
Return to Session

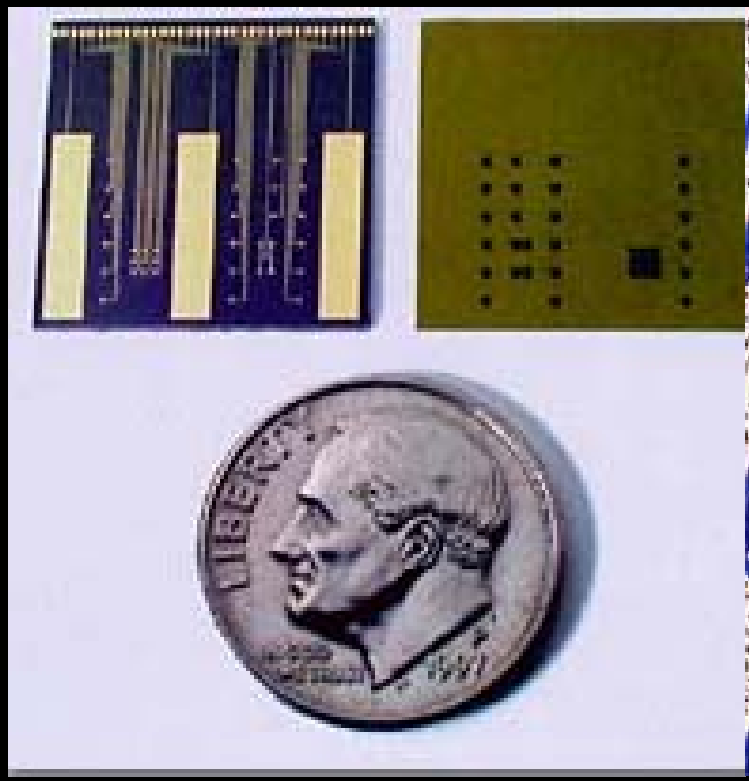
Health and Medicine

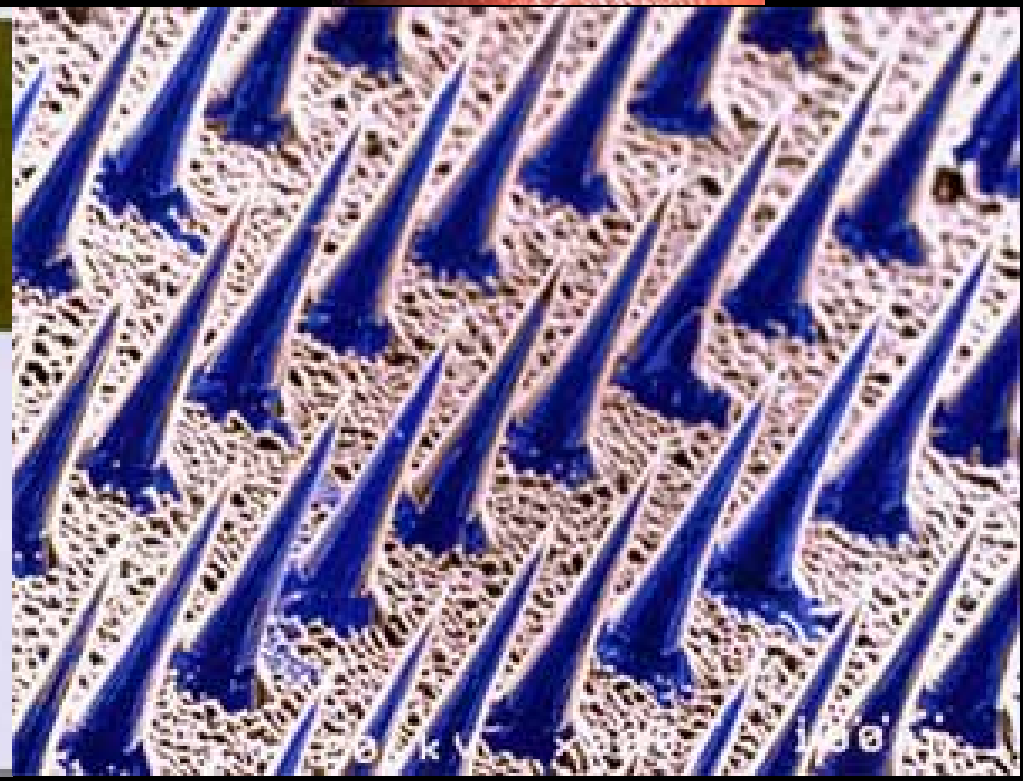
Administration of drug

by micro syringe

(e.g. insulin)



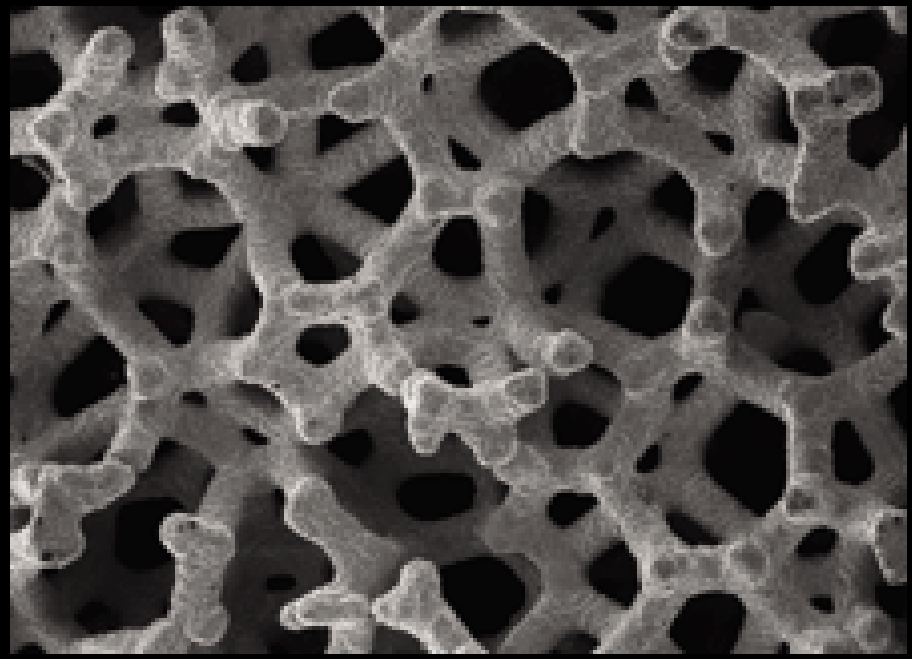




Return to Session

Health and Medicine

Implant materials, bones repair

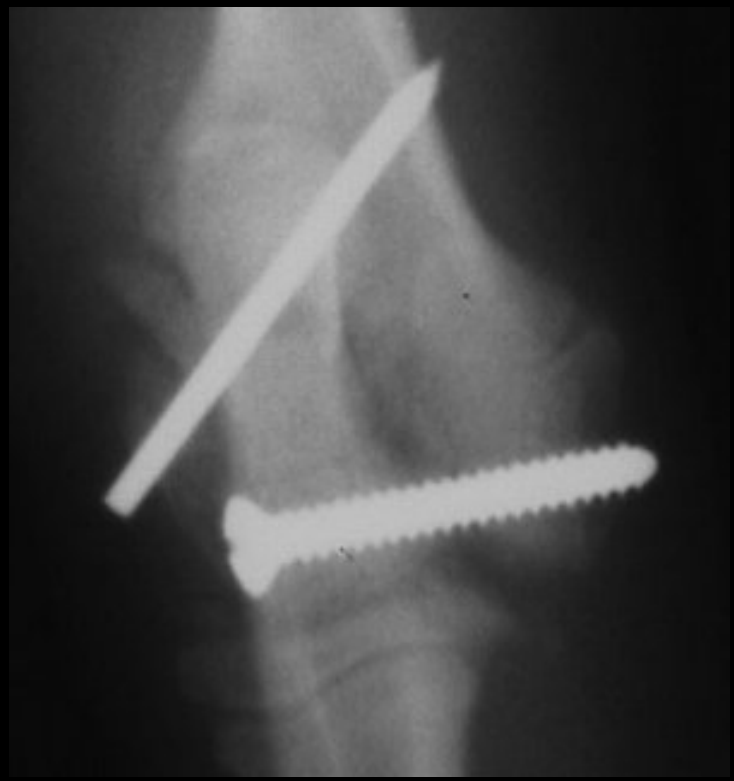


Implex®

Return to Session

Health and Medicine

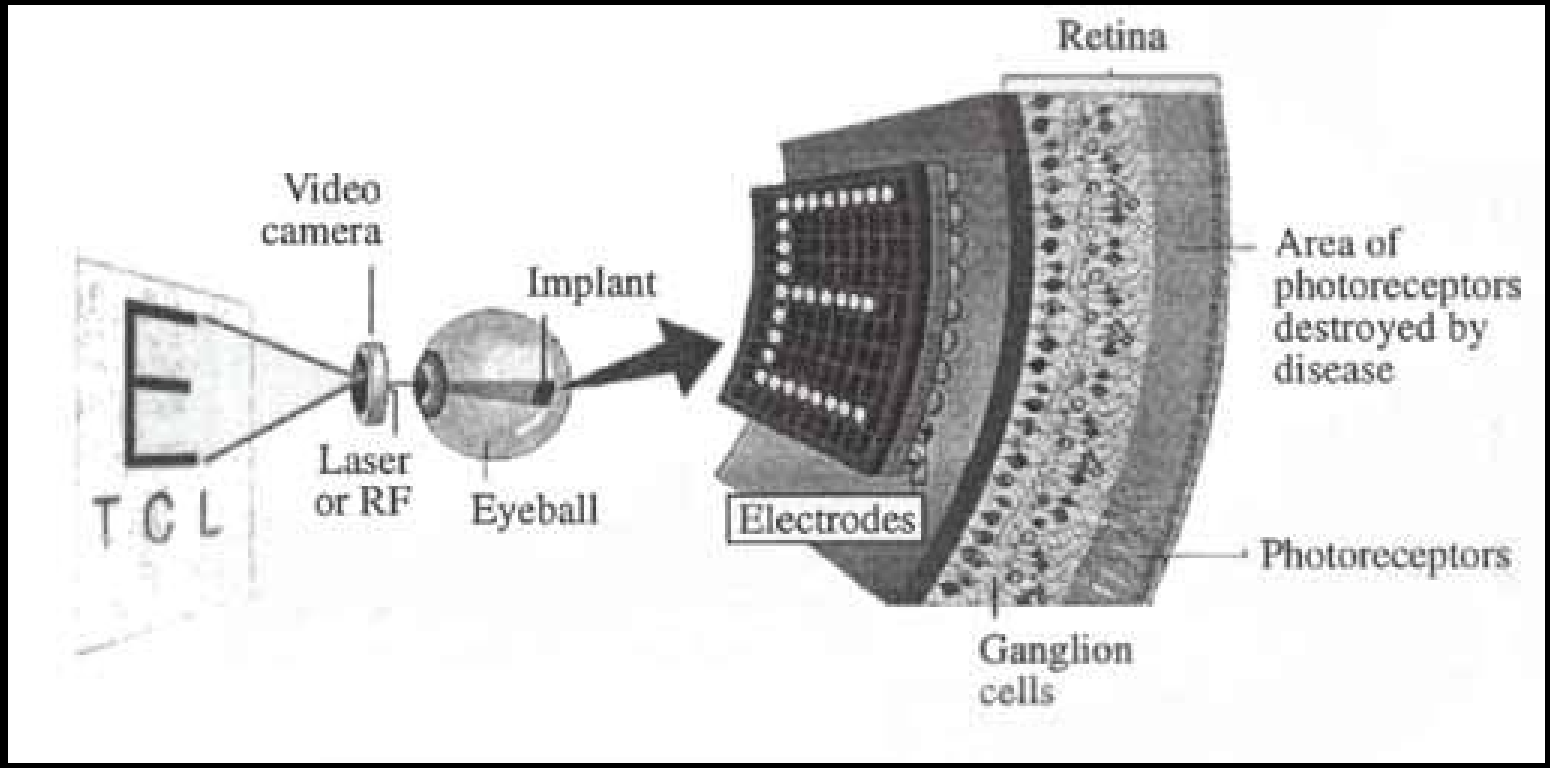
Bio resorb materials



Return to Session

Health and Medicine

Vision aid, retinal implant

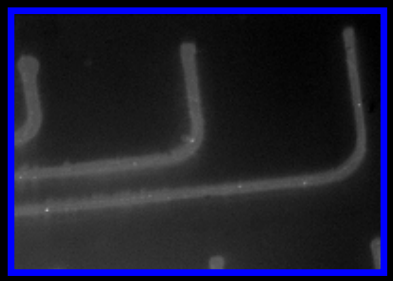


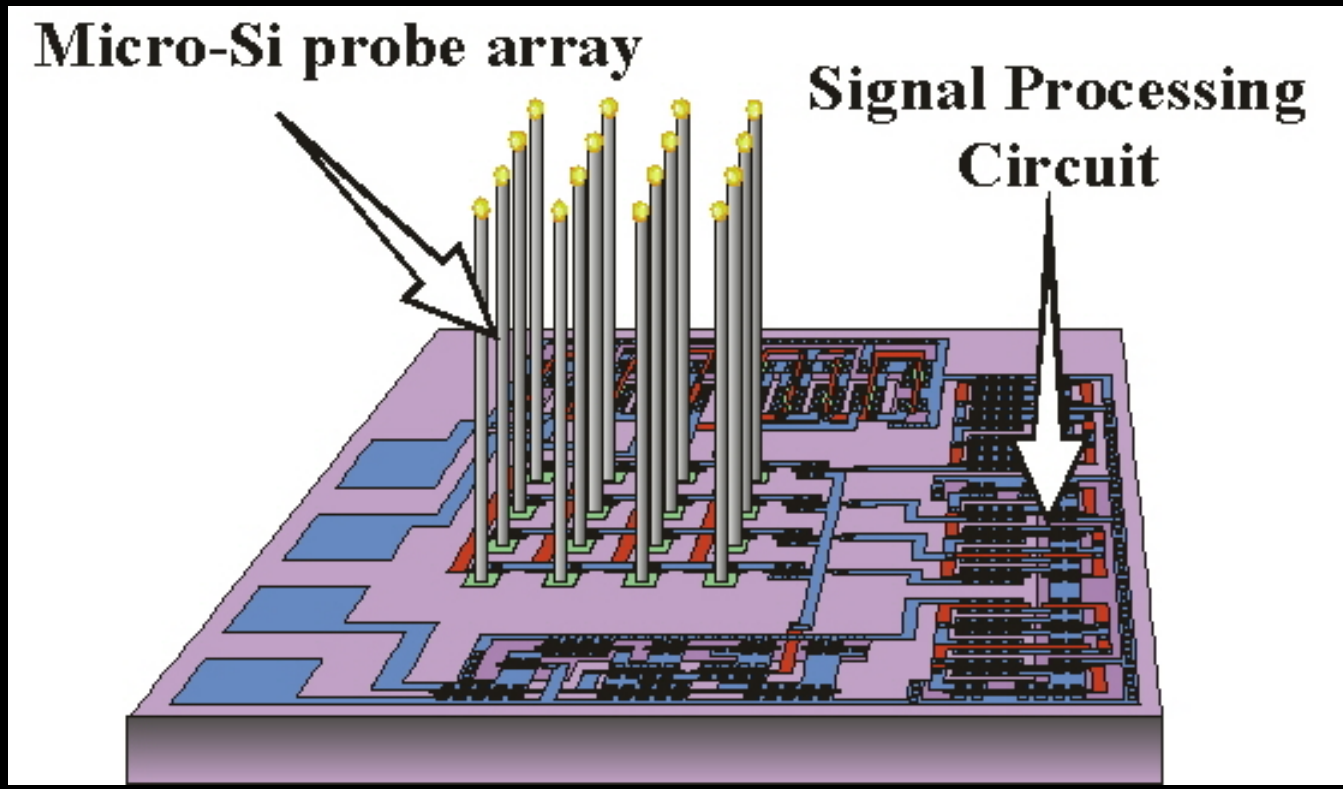
Return to Session

Health and Medicine

Vision aid, retinal implant

The interface with the neurons is made by microfluidic channels; stimulations are carried out by chemical ways

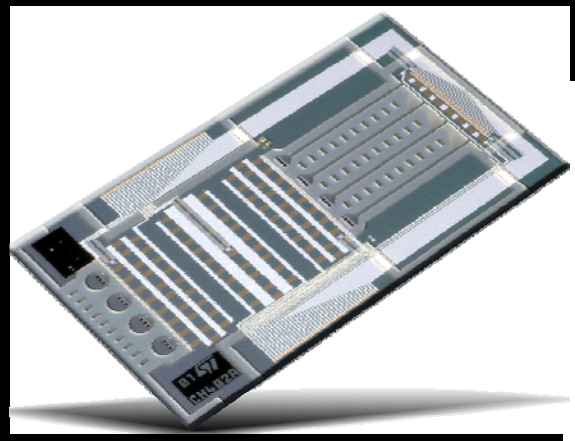


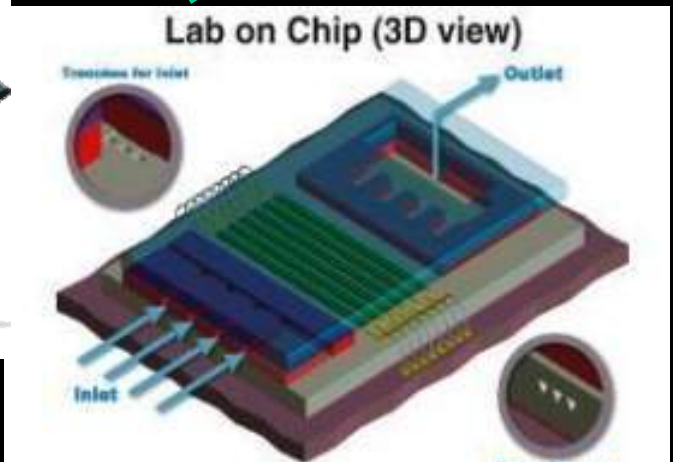


Makoto Ishida
Department of Electrical & Electronic Engineering, Toyohashi University of Technology

Return to Session

Health and Medicine





Pharmaceutical lab

Lab on chip

Return to Session

OUTLINE

- Computing and Data Storage
- Materials and Manufacturing
- Health and Medicine
- **Energy and Environment**
- Transportation
- Security
- Carbon nanotubes, the way to transport electricity

Return to Session

Energy and Environment

Two aspects: production and utilization

- Energy Production
  - Clean and low cost

- Energy Utilization
  - High efficiency lighting
  - Solid state lighting can reduce total electricity consumption by 10% and cut carbon emission by the equivalent of 28 million tons/year*

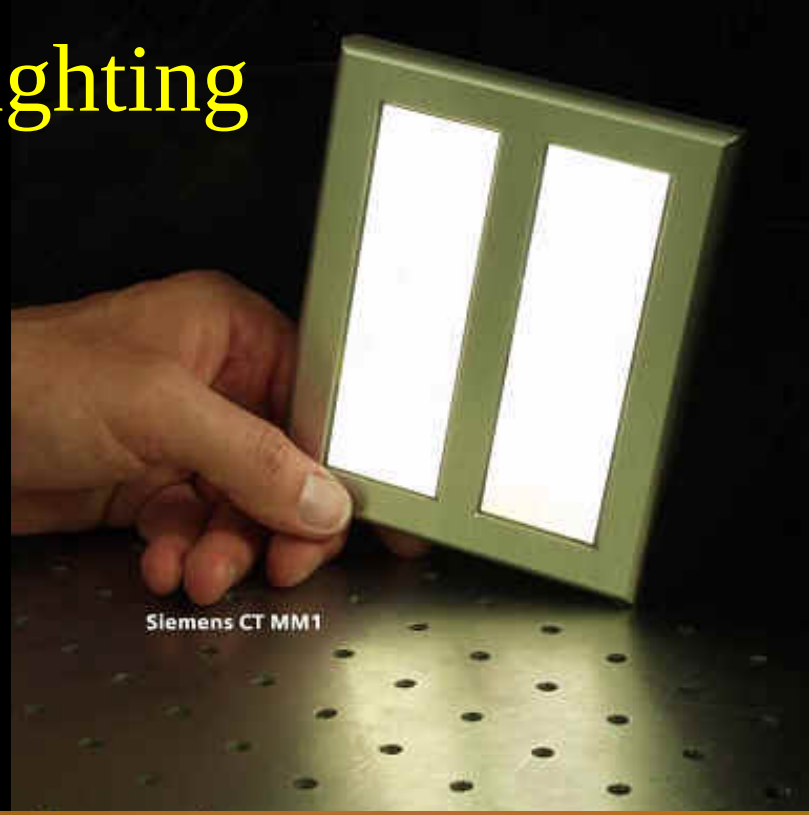
* Equivalent to 3 times the total power consumption of France

Lighting

Ambient intelligence – Philips HomeLab

Return to Session

Lighting

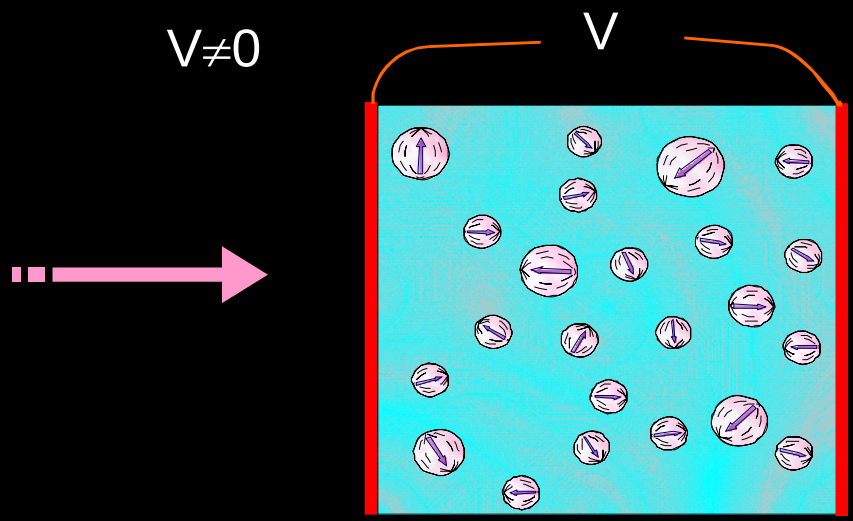


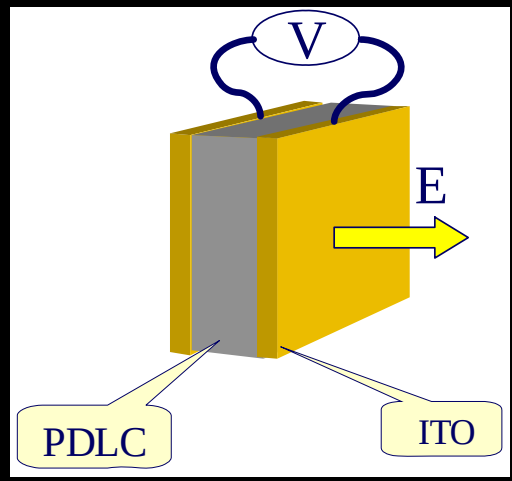
Lighting

From transparency to opacity

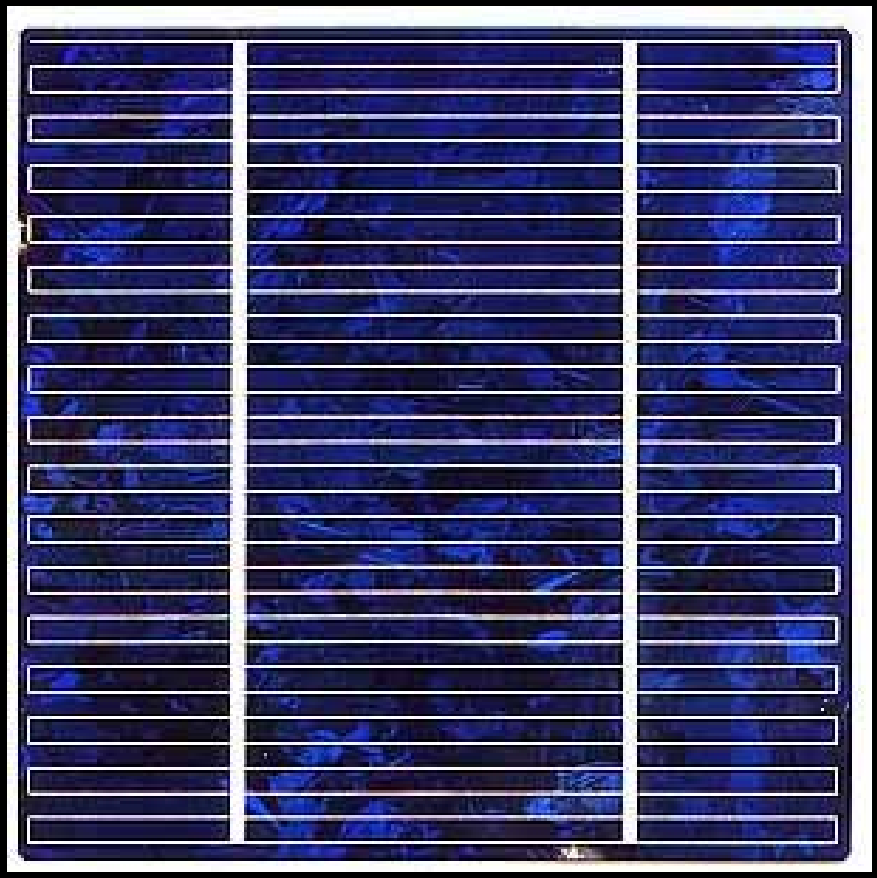
St Gobain

V≠0





Energy and Environment

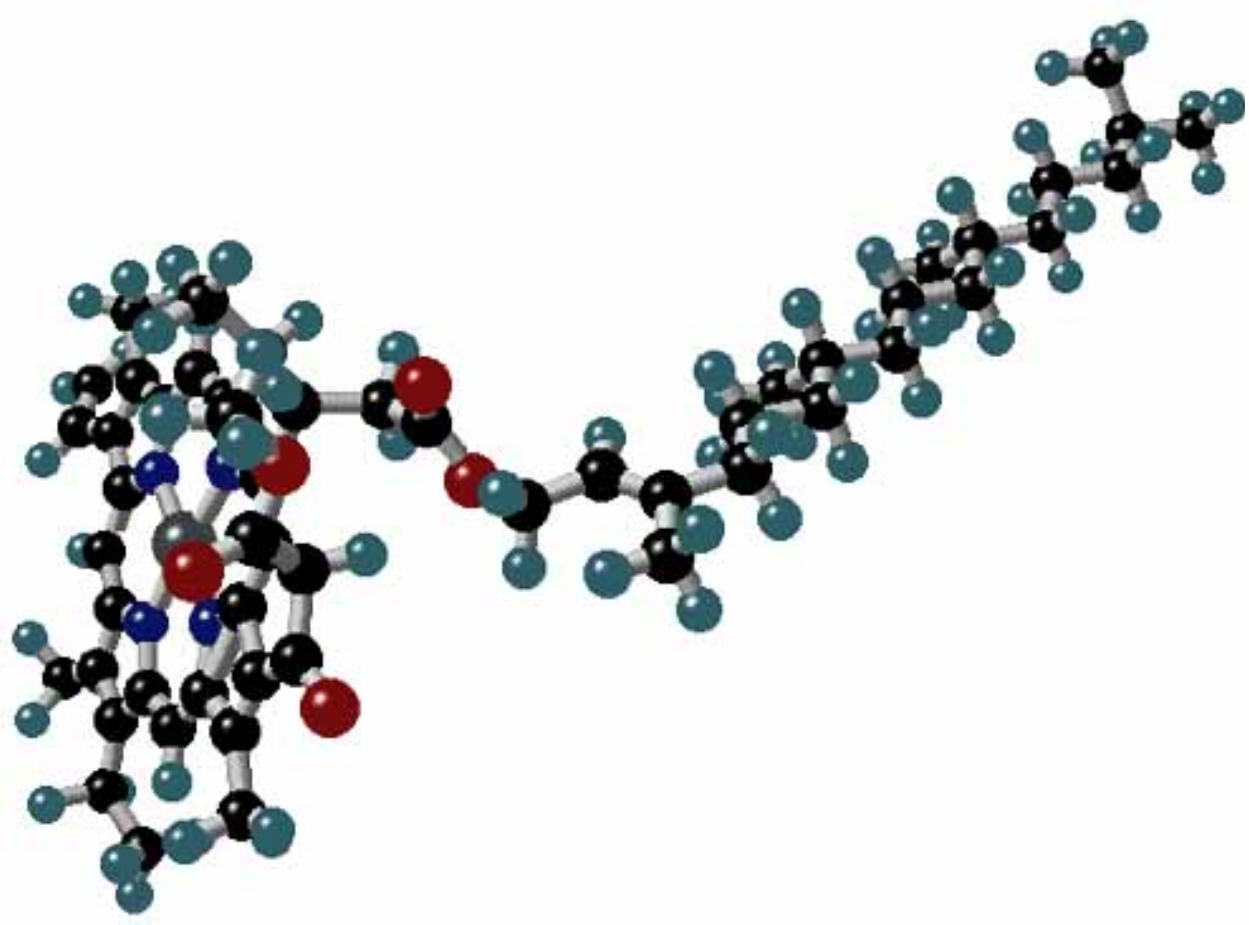


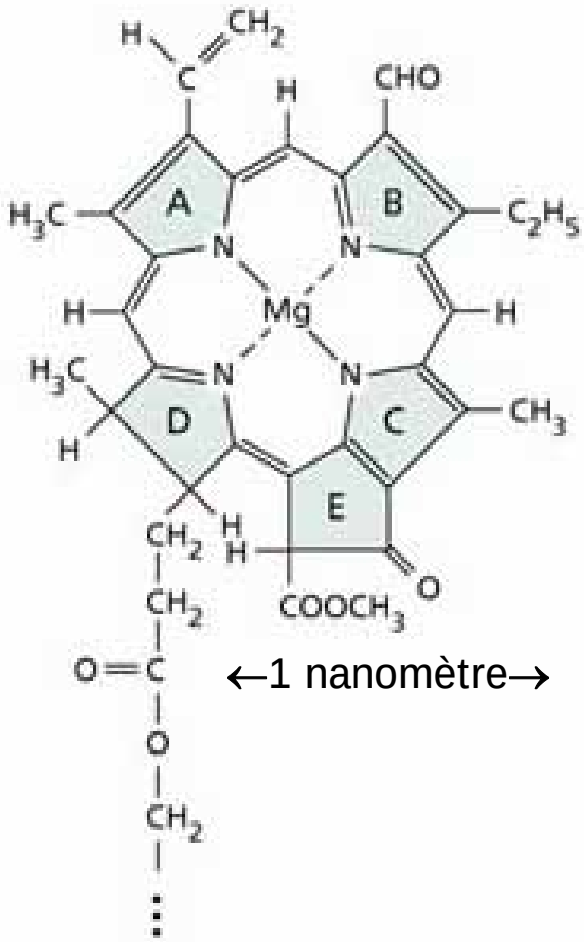
5 à 28 % Efficiency

80 % Efficiency

Energy and Environment

Reproducing the chlorophyllian synthesis

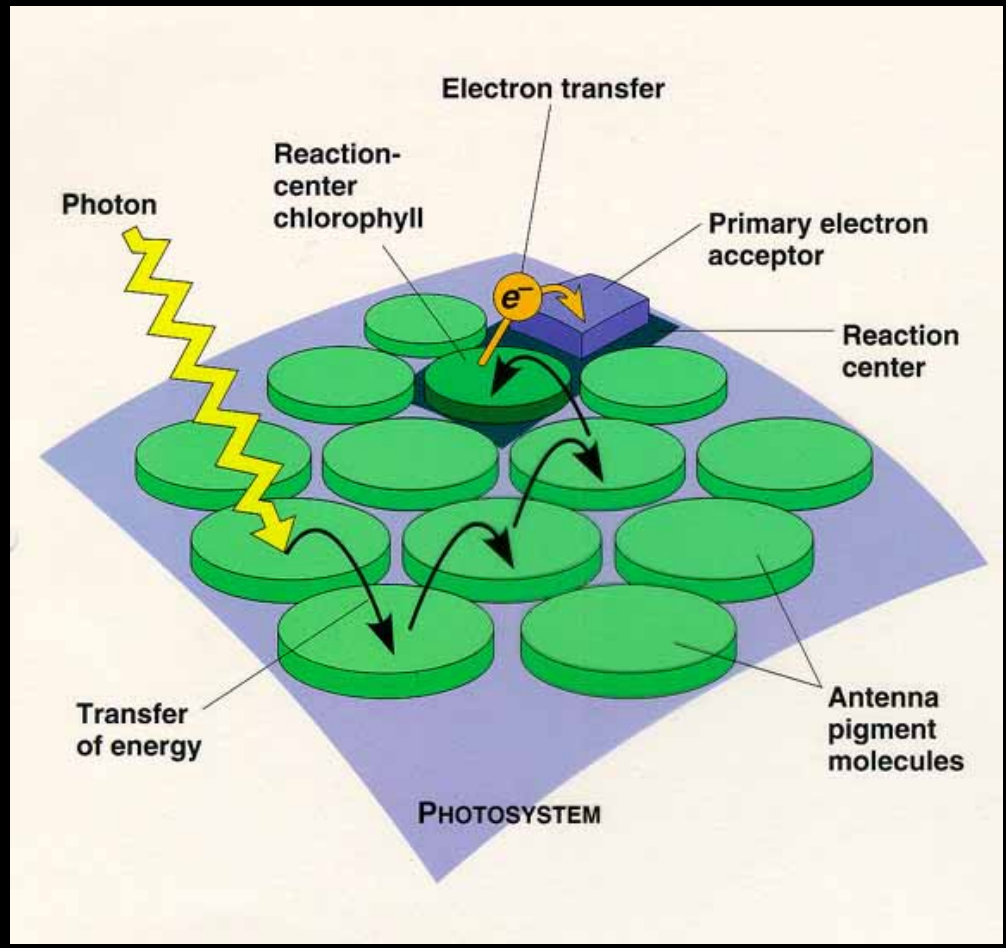




Return to Session

Energy and Environment

Reproducing the chlorophyllian synthesis

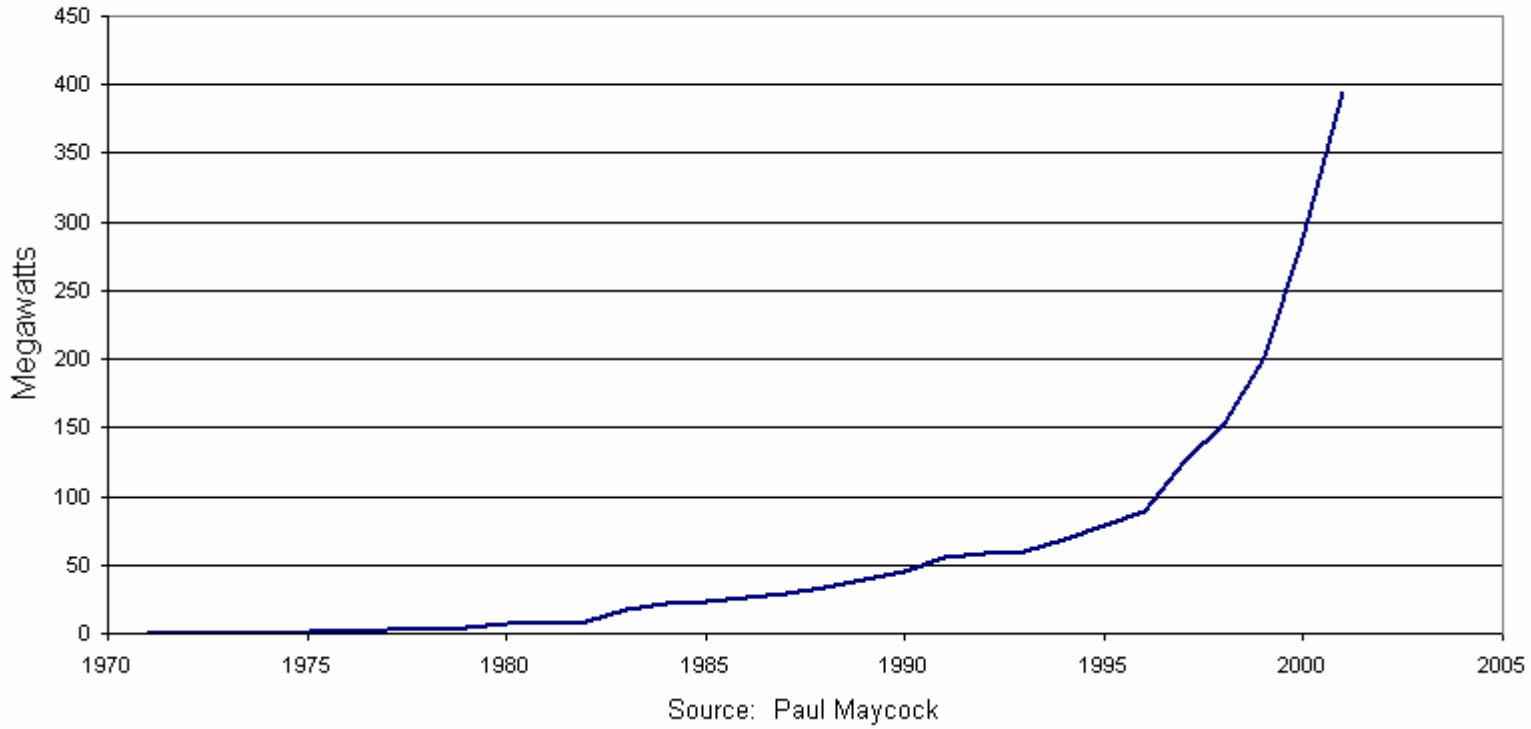


Brudvig Lab, Yale

Return to Session

Energy and Environment

Solar cells



2000 : 400 MW

2003 : 800 MW

2006 : 1800 MW

2001 : 3 G$

2006 : 10 G$

2011 : 20-30 G$

Return to Session

OUTLINE

- Computing and Data Storage
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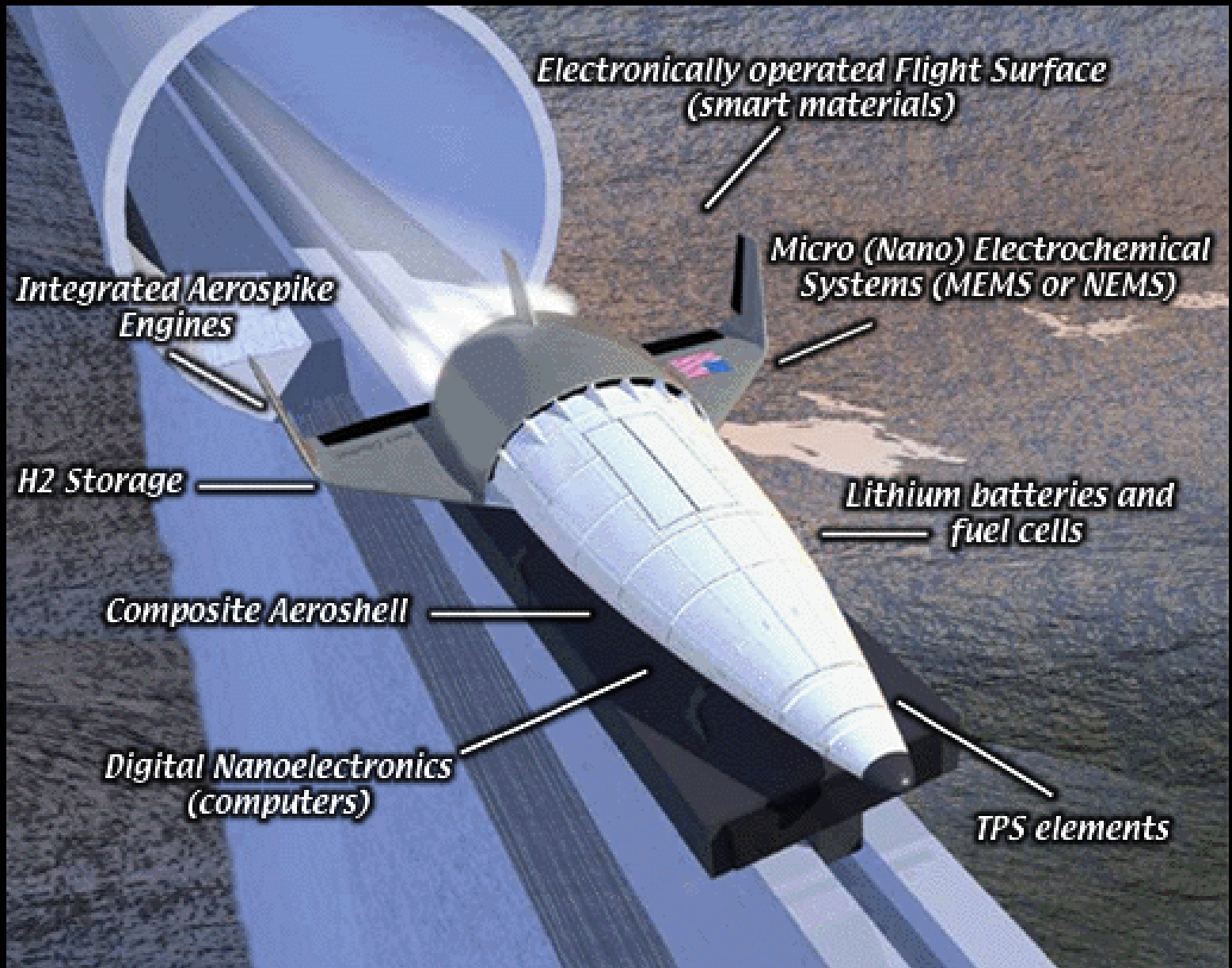
- Health and Medicine
- Energy and Environment
- **Transportation**
- Security
- Carbon nanotubes, the way to transport electricity

Return to Session

Transportation



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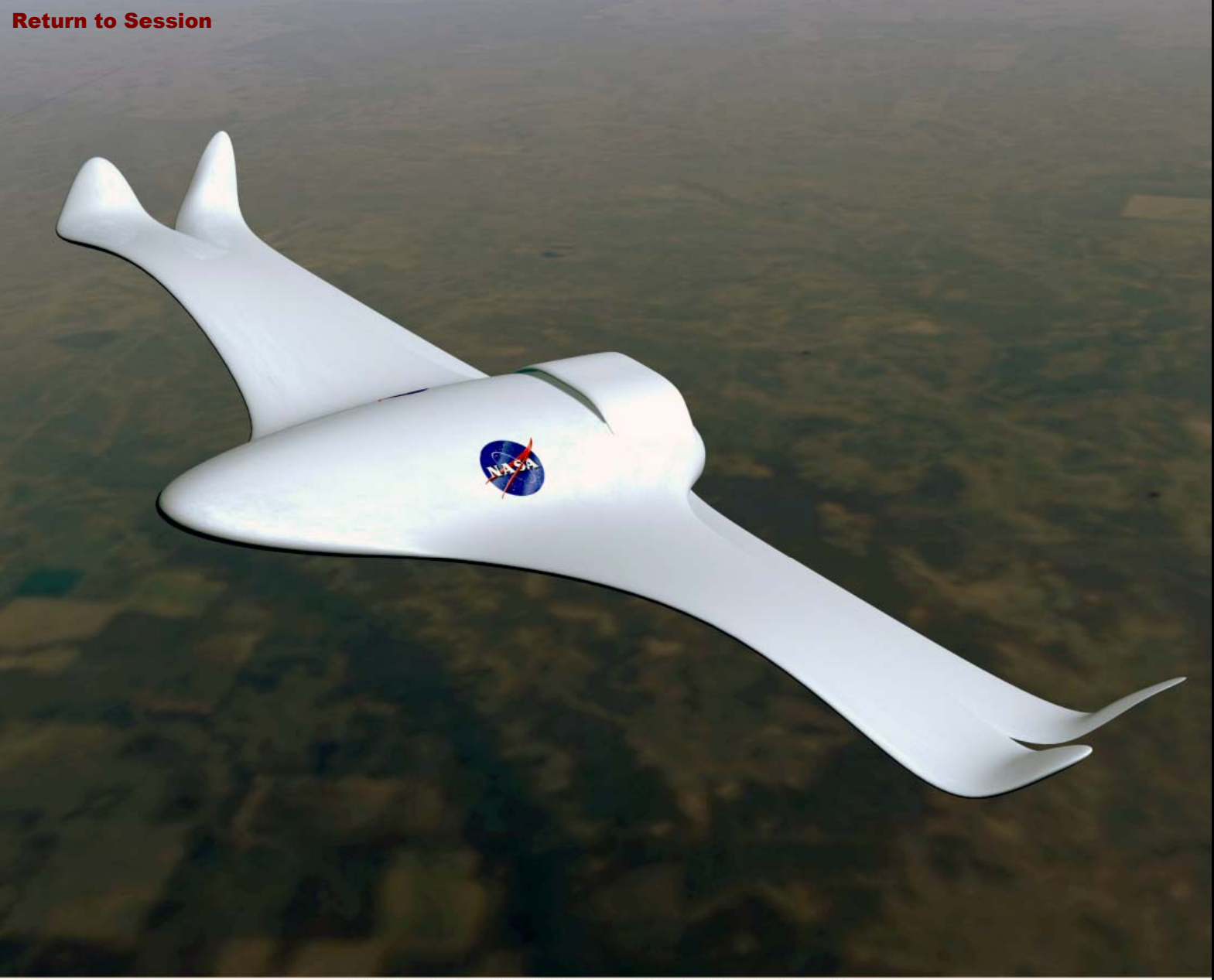
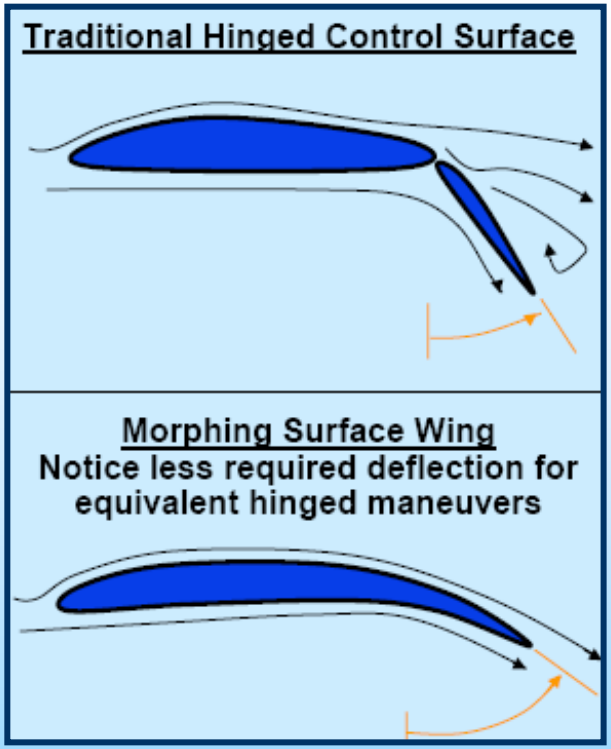
Morphing wing



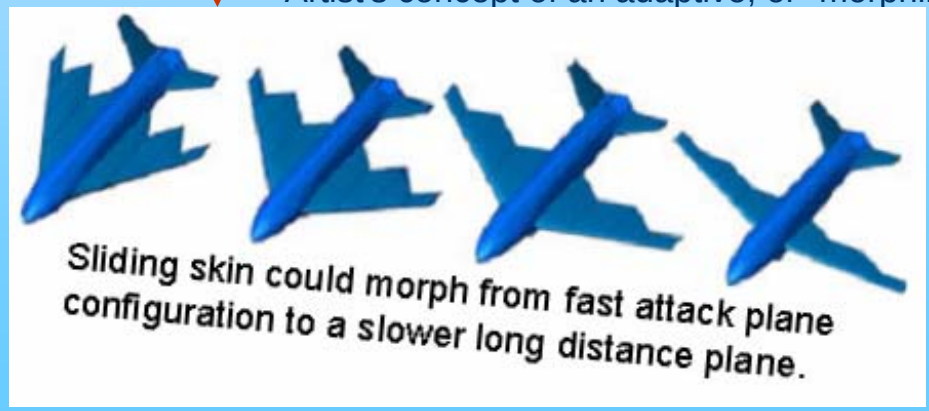
NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ED01-0348-1 Date: 2001 Photo by: NASA
An artist's rendering of the 21st Century Aerospace Vehicle, sometimes nicknamed the Morphing Airplane, shows advanced concepts NASA envisions for an aircraft of the future.

Morphing wing



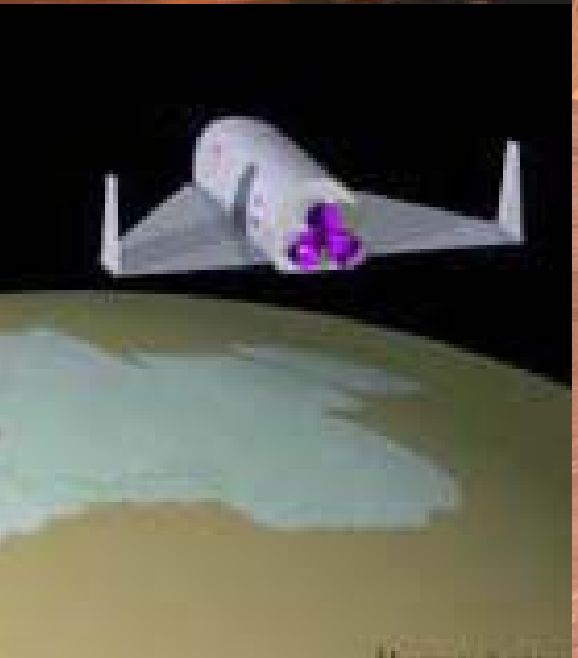
Designing the 21st Century Aerospace Vehicle

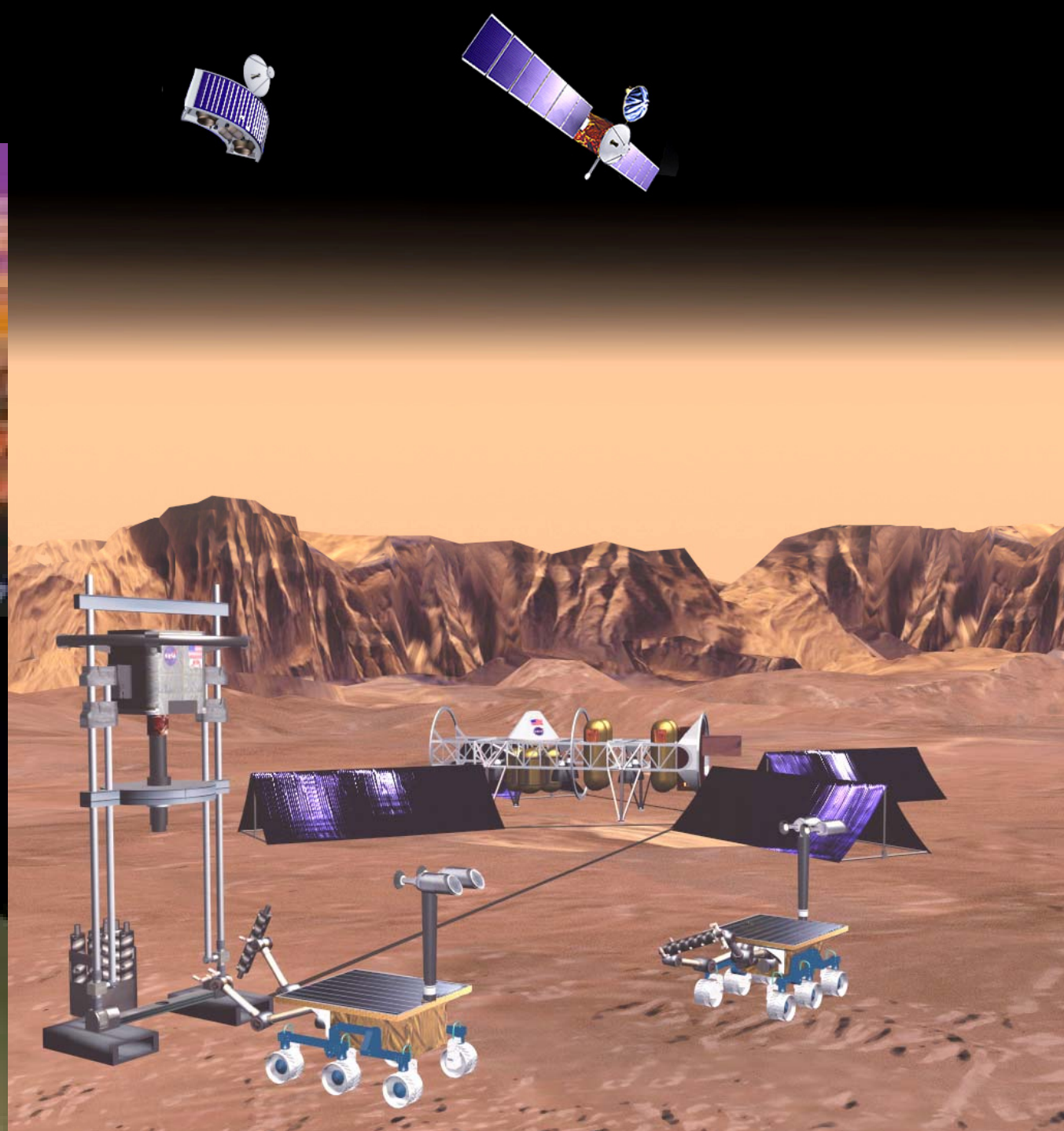
Artist's concept of an adaptive, or "morphing," aerospace vehicle



Return to Session

Space exploration

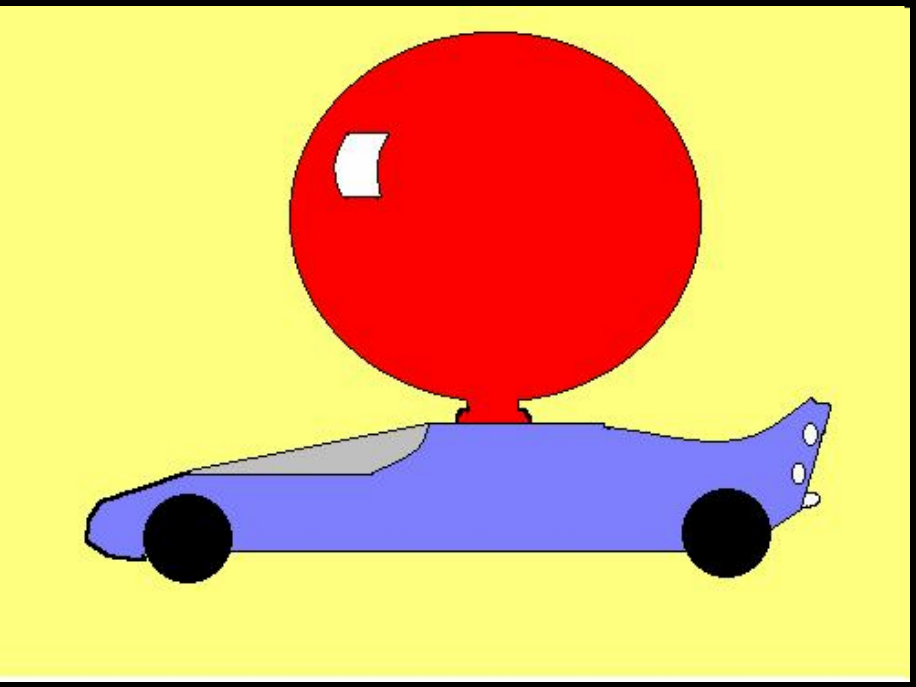




Return to Session

Transportation / energy

Hydrogen storage



A hydrogen tank having an energy storage equivalent to a gasoline tank should be 3000 times larger!

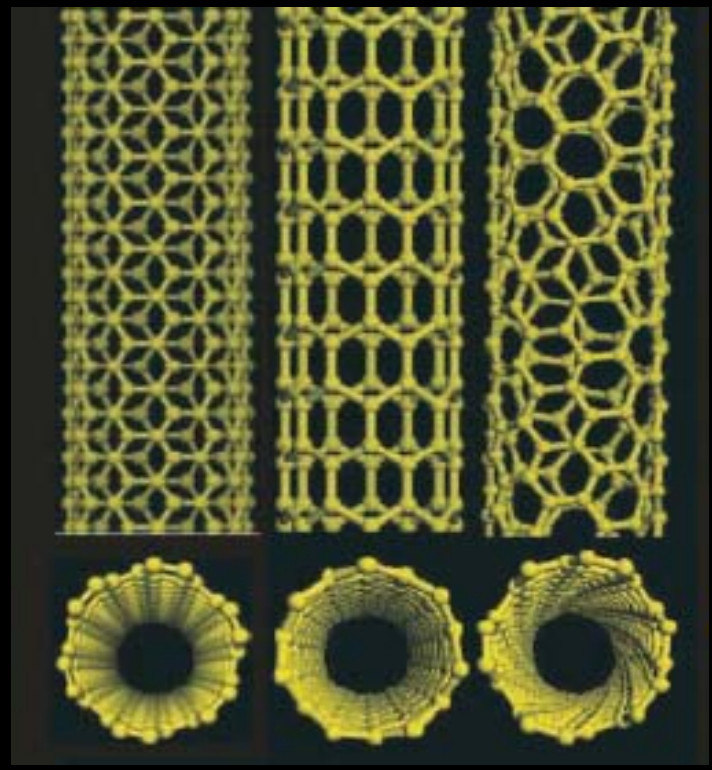
Return to Session

Transportation

Hydrogen storage

The carbon nanotubes are able to store from 4,2% to 65% of their weight of hydrogen

The density of stored hydrogen can be close to that of liquid hydrogen



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OUTLINE

- Computing and Data Storage
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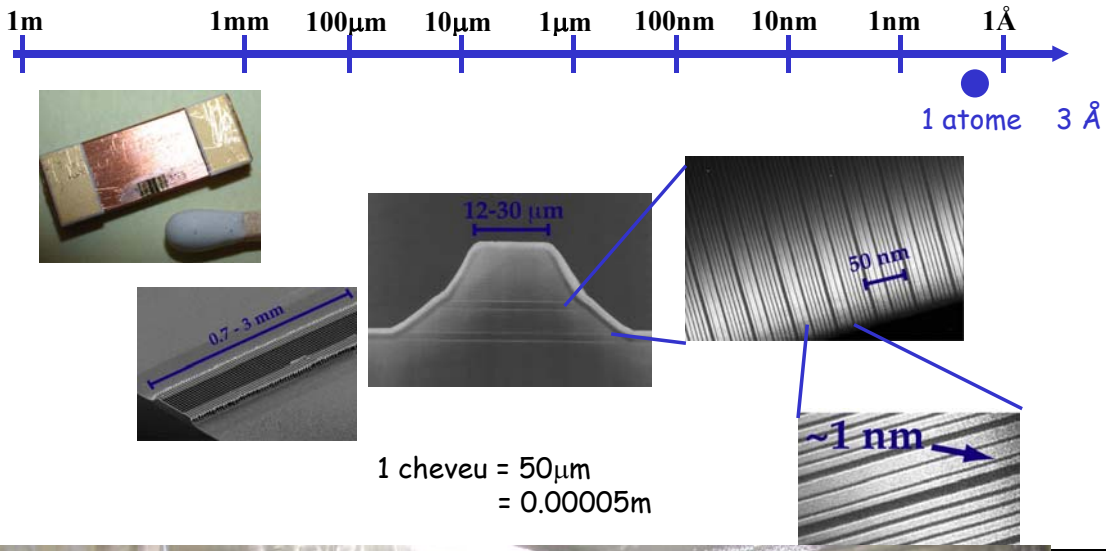
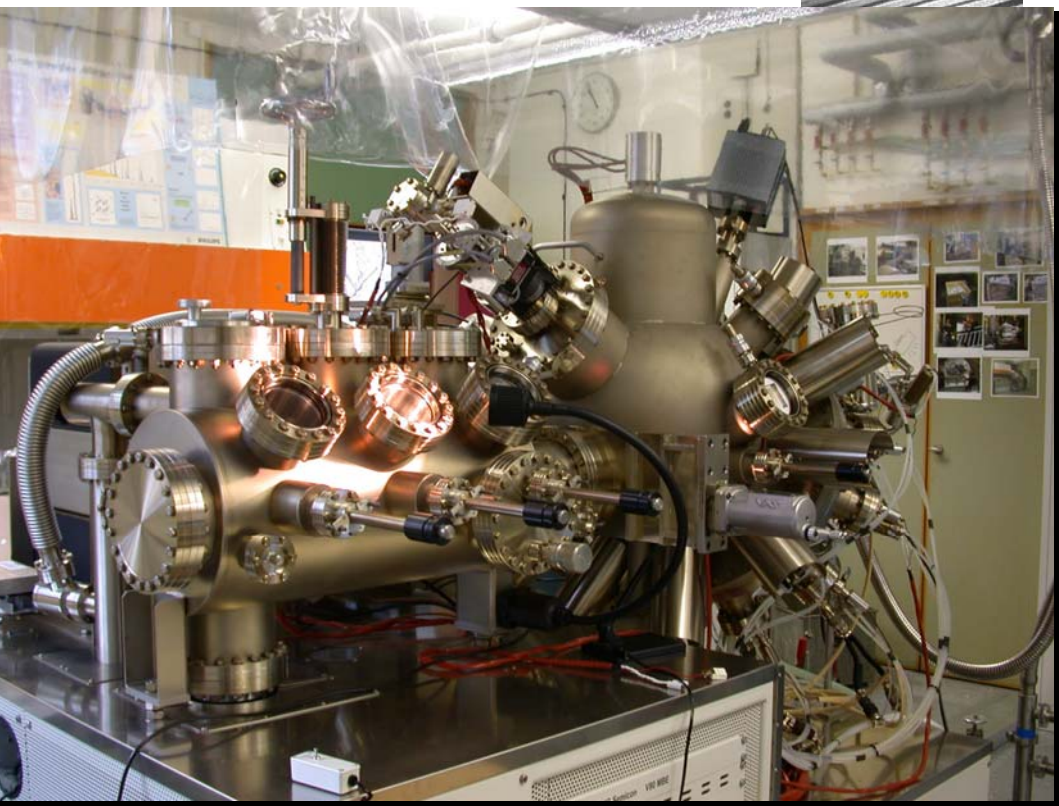
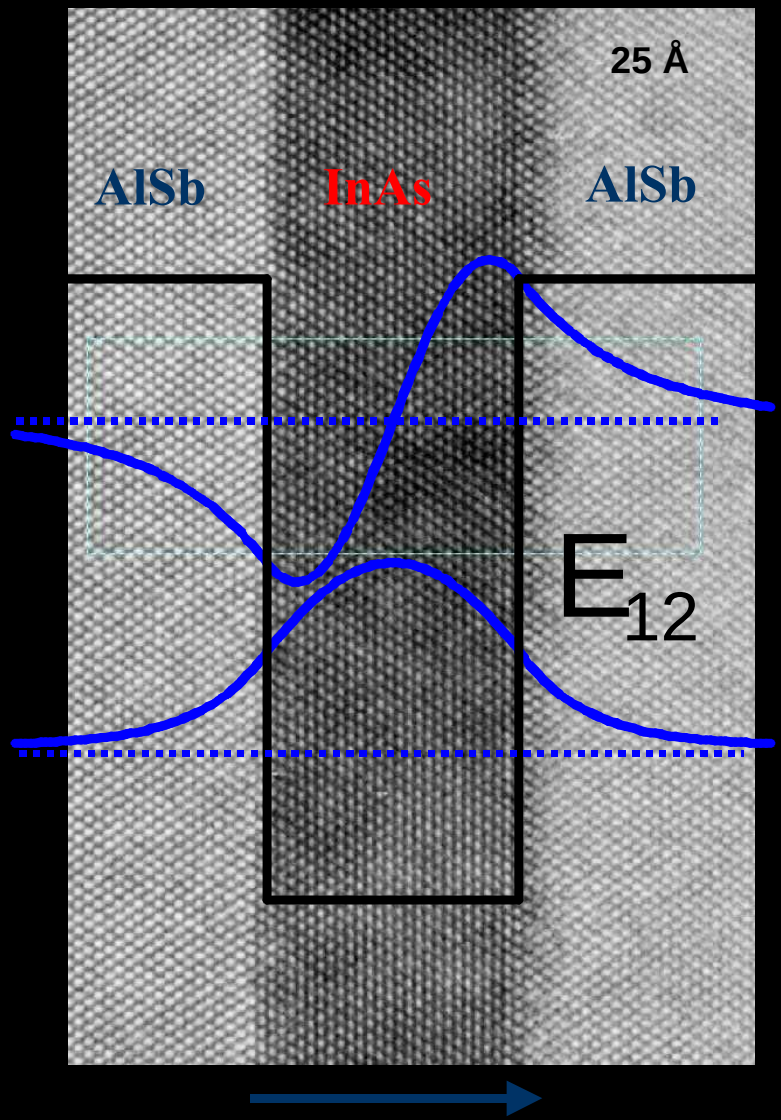
- Energy and Environment
- Transportation
- **Security**
- Carbon nanotubes, the way to transport electricity

Return to Session



Quantum Cascade Laser





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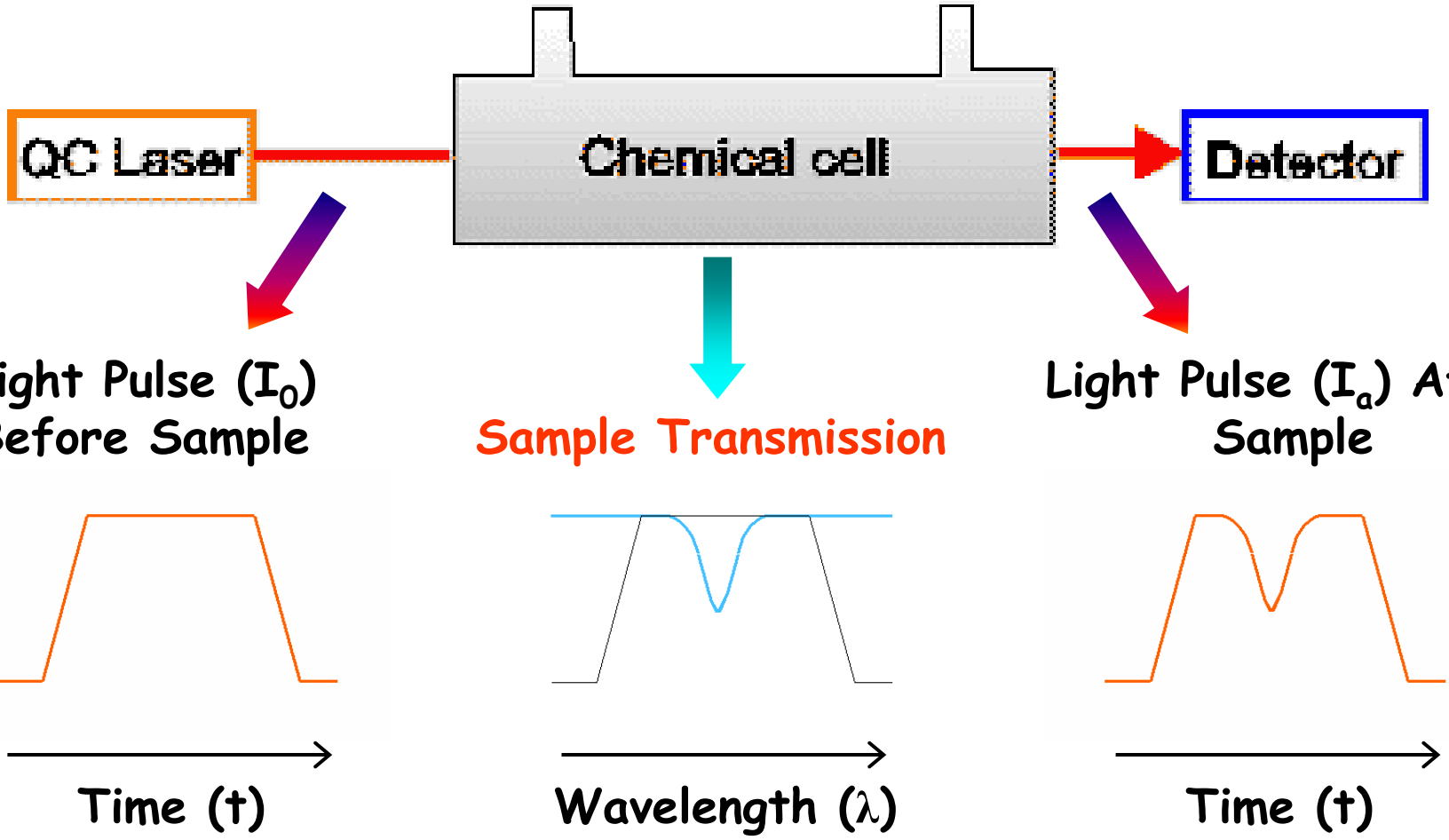
QC Laser spectrometer operating principle



Current pulse applied to diode contact

Wavelength tuning for pulse current duration by Instantaneous heating effect

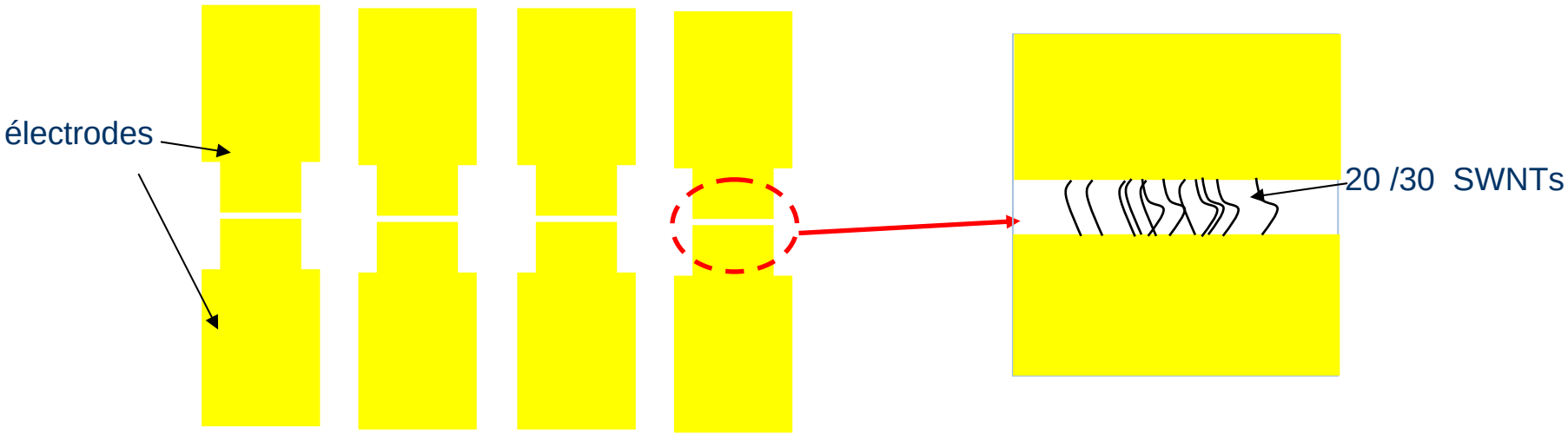
Linear tuning to ± 1% for 200ns

Security : CNT Transistor for gas detection

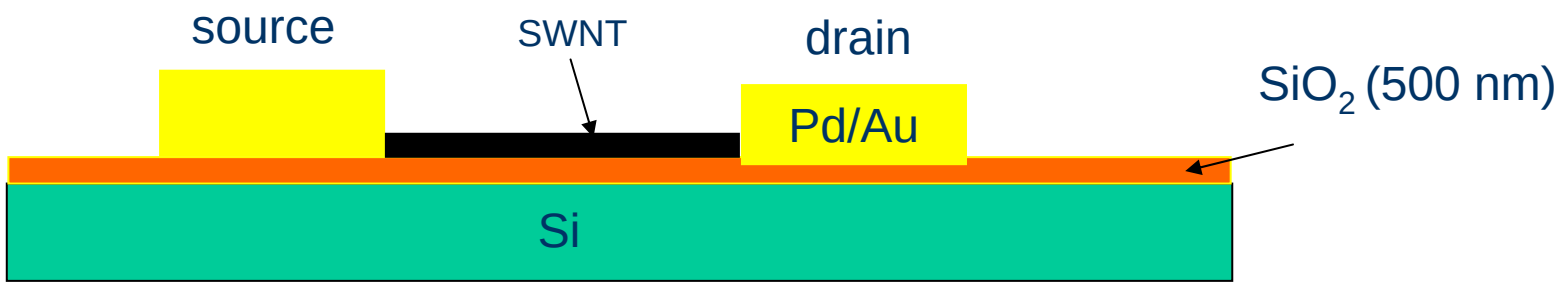
Dai et al.

Department of chemistry, Stanford University

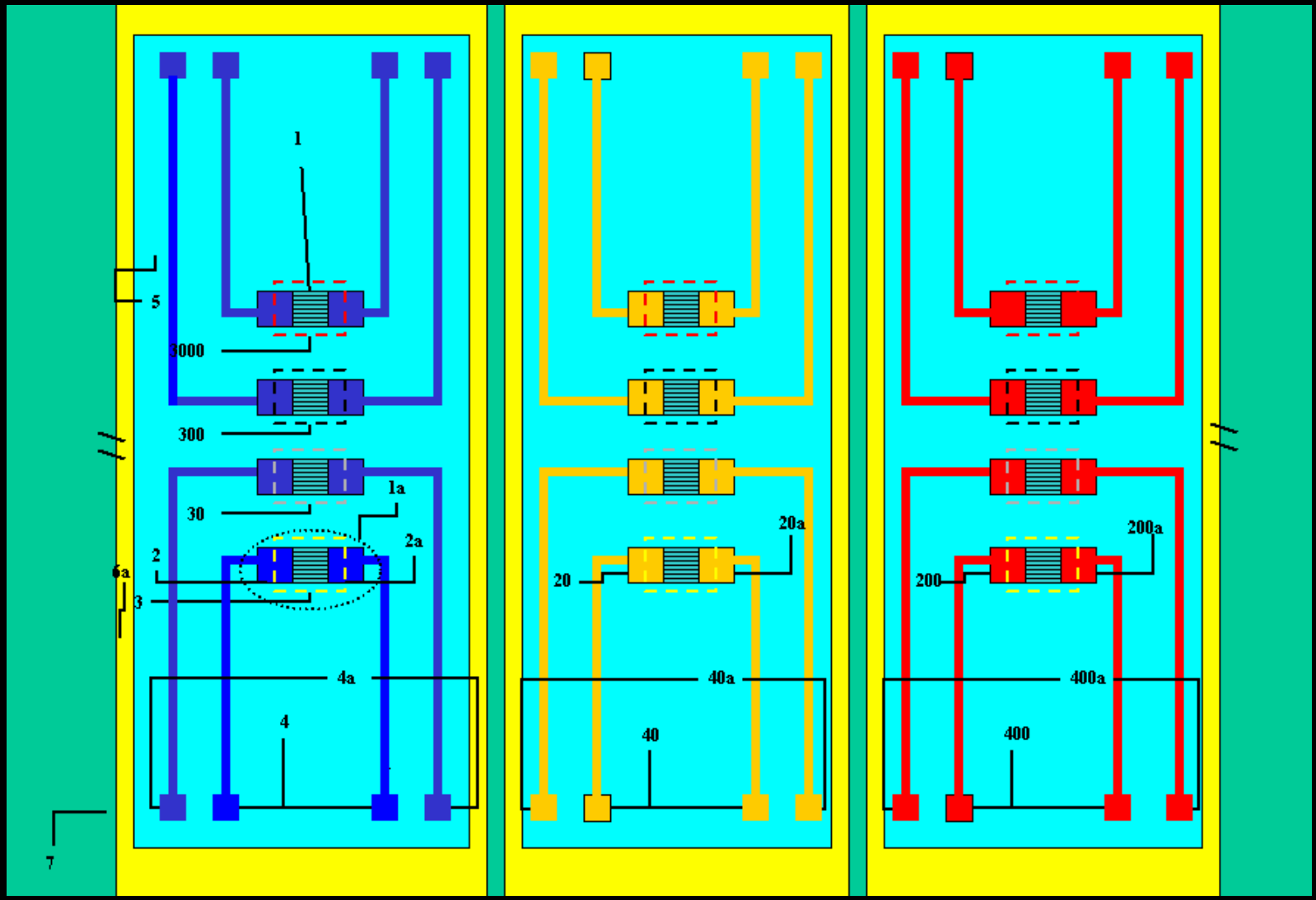
Top view



Bottom view



Security : CNT Transistor for gas detection



Return to Session

OUTLINE

- Computing and Data Storage
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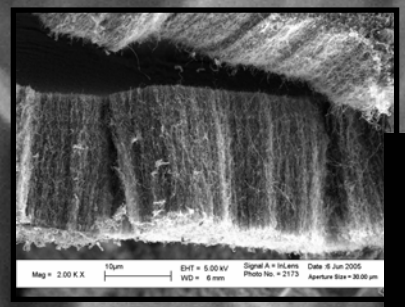
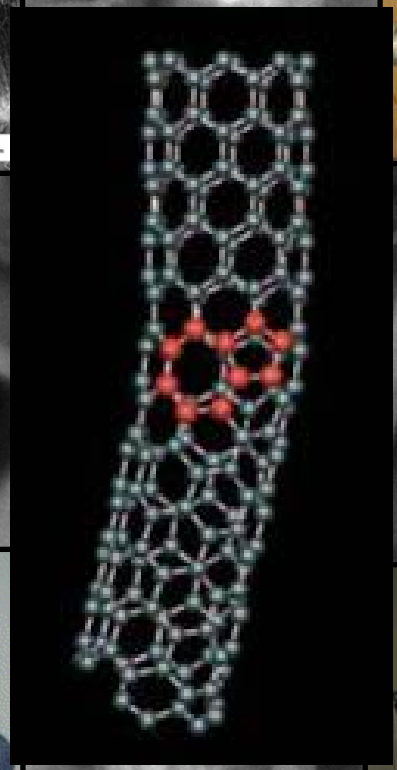
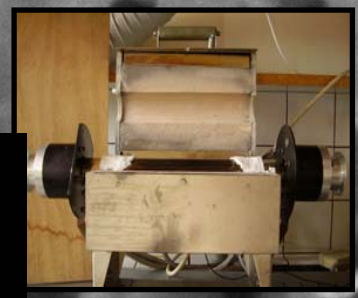
- Energy and Environment
- Transportation
- Security
- **Carbon nanotubes, the way to transport electricity**

Return to Session

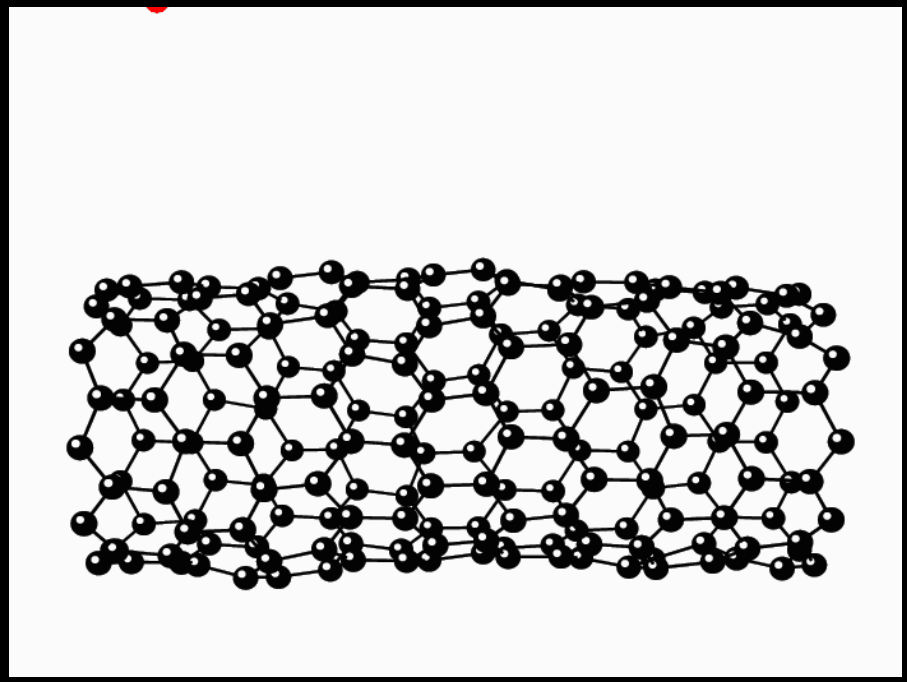
Carbon nanotube





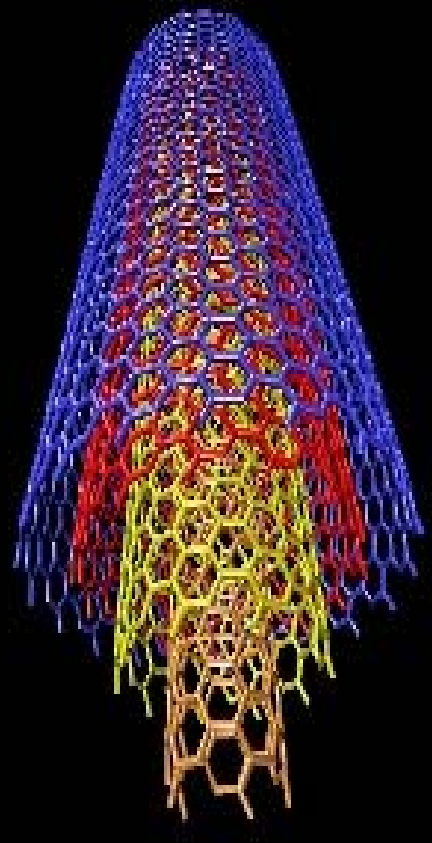


Single & Multi wall nanotubes



Single wall
carbon nanotube :
2/3 SC + 1/3 metallic

∅ ~ 1 nm



Multiwall
carbon nanotube :
metallic

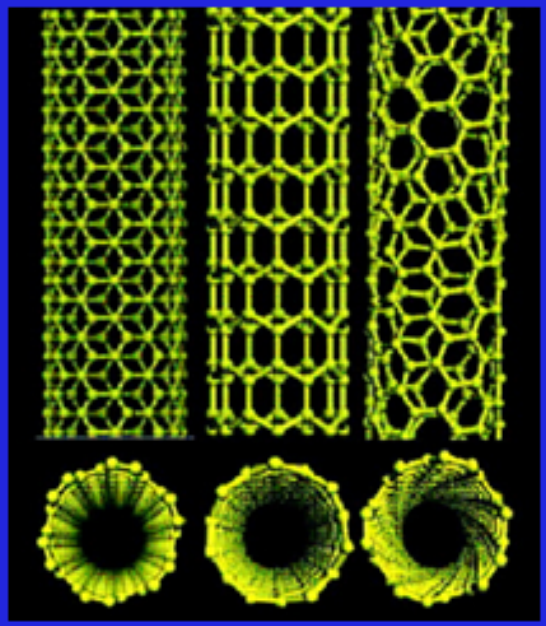
∅ ~ 20 nm

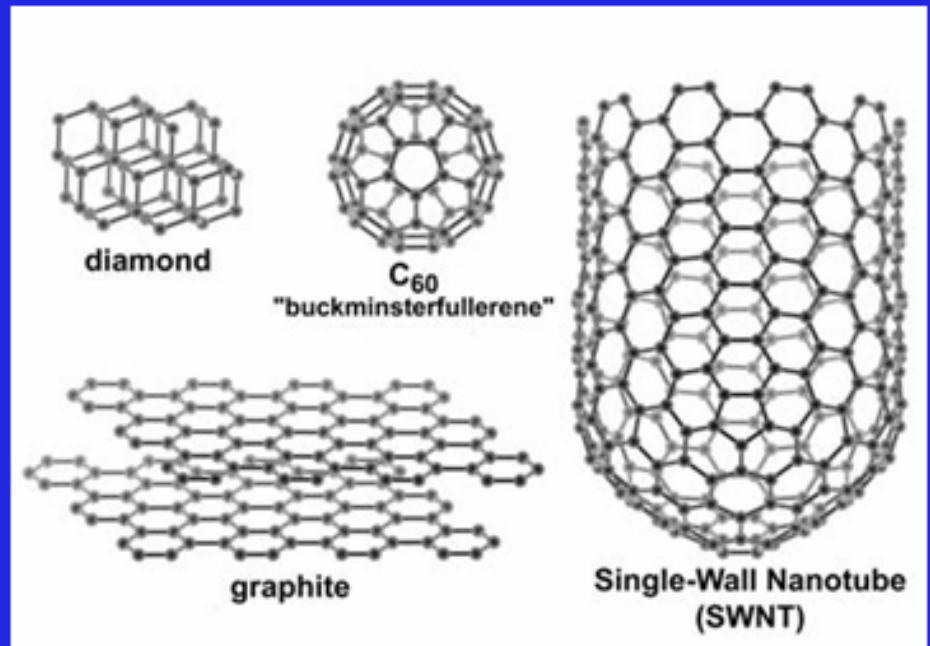
Return to Session

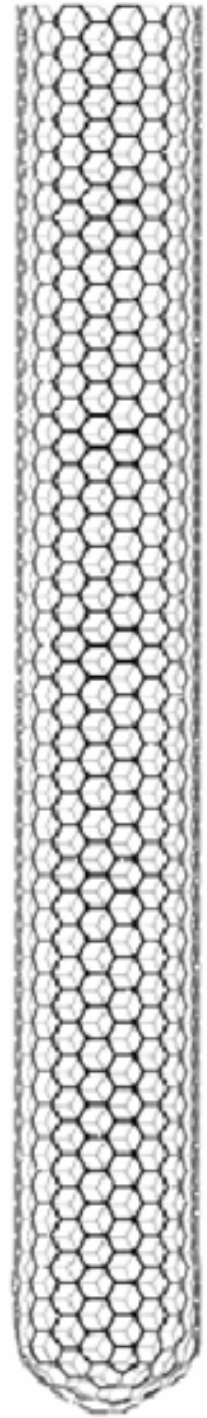
Why Single Wall Carbon Nanotubes?

MOLECULAR PERFECTION & EXTREME PERFORMANCE

- The Strongest Fiber Possible.
- Selectable Electrical Properties
  - Metallic Tubes Better Than Copper
  - Semiconductors Better Than InSb or GaAs
- Thermal Conductivity of Diamond.
- The Unique Chemistry of Carbon.
- The Scale and Perfection of DNA.
- The Ultimately Versatile Engineering Material.

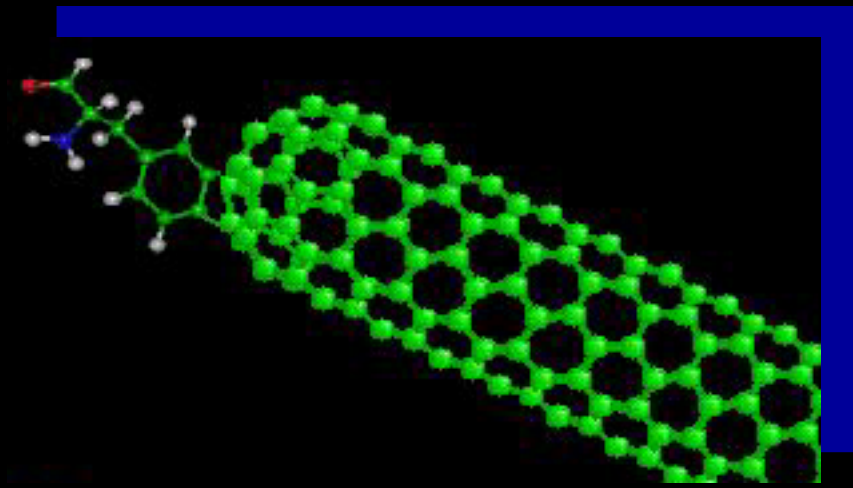






Electronic properties

- Electric conductivity = twice that of copper
- Able to support great density of current (10^9 A/cm^2)
- Excellent electronic emissivity (point effect)
- Can be functionalized (chemistry of carbon)
- SWNT can be metallic or semiconductor (depending on the chirality)

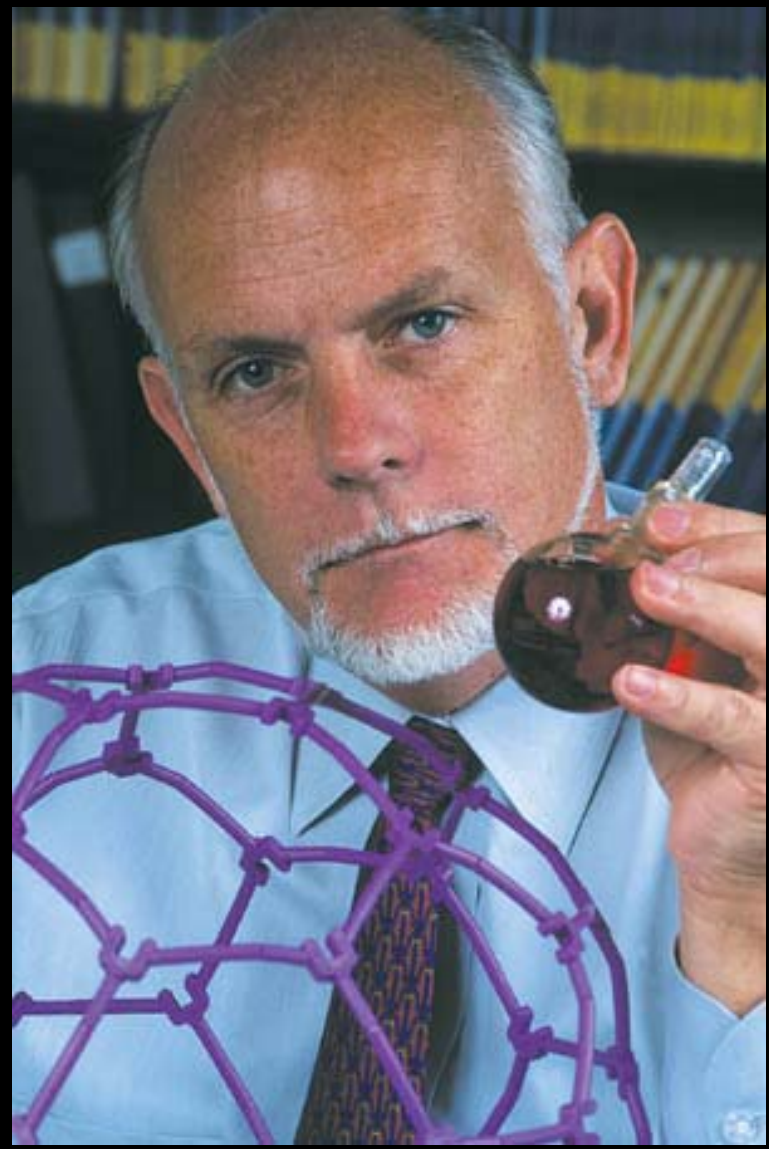


CNT : the way to transport electricity ?

Adapted from Richard Smalley

I think electric transmission is the destiny of this material and I want to make it happen

Richard Smalley,
co-discoverer of fullerene, Nobel Prize for Chemistry, 1996



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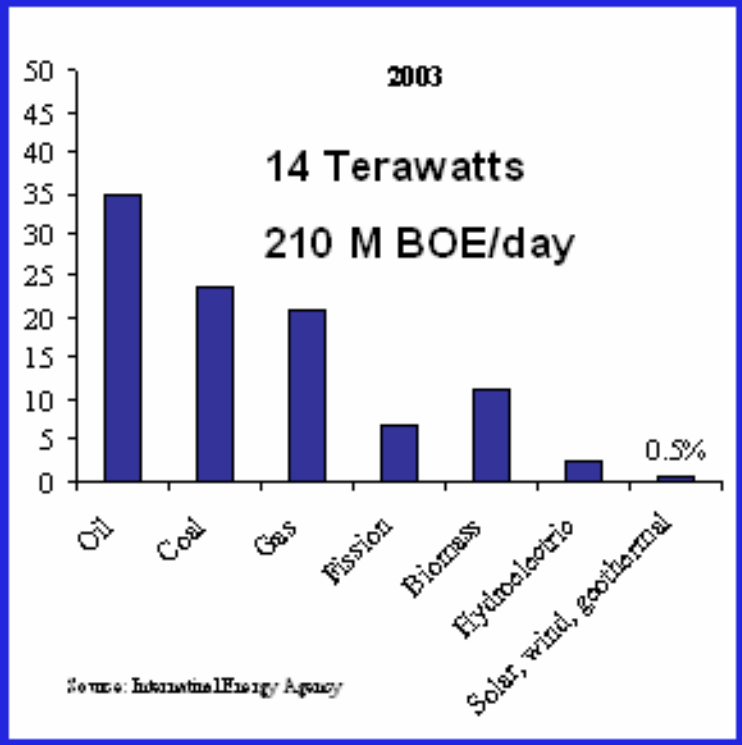
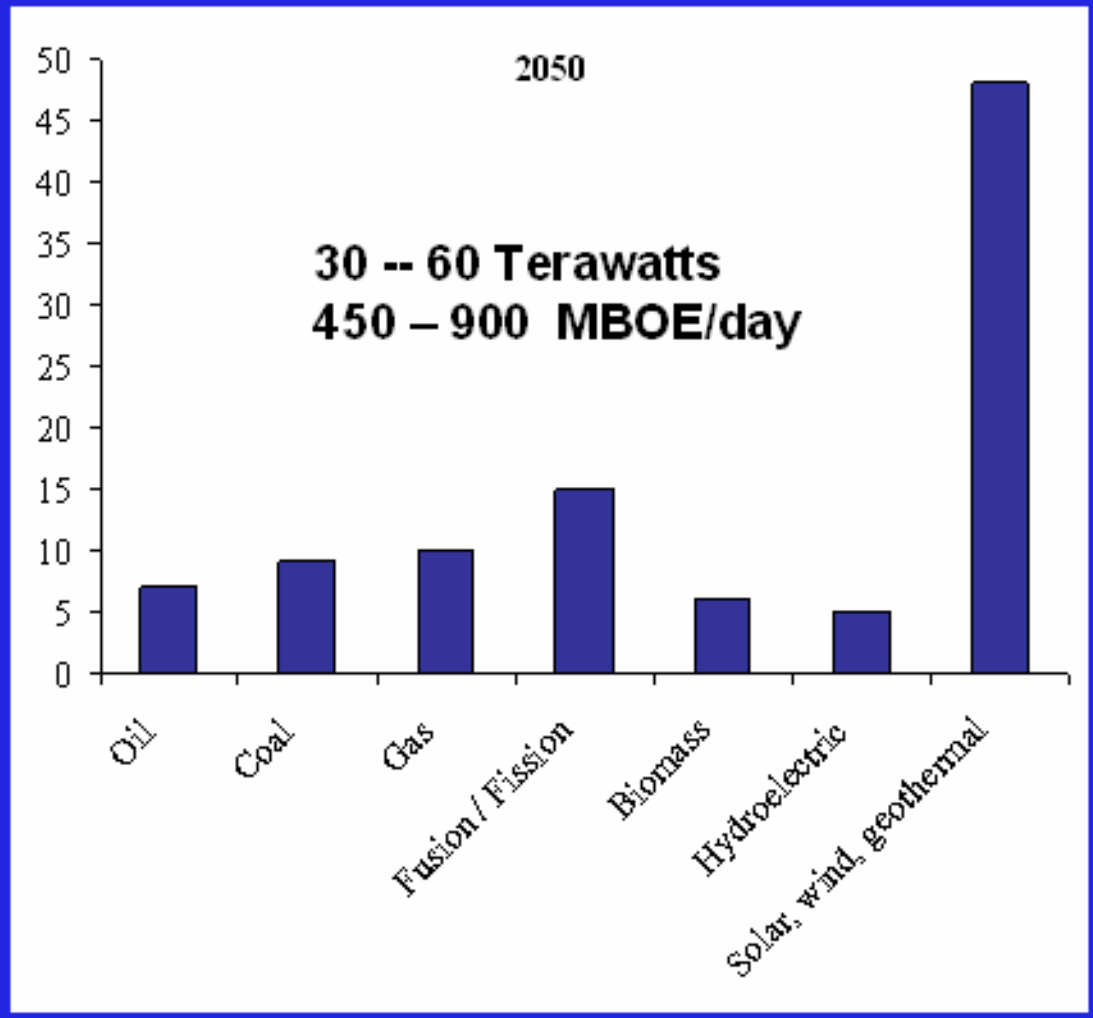
The ENERGY REVOLUTION (The Terawatt Challenge)





Energy:

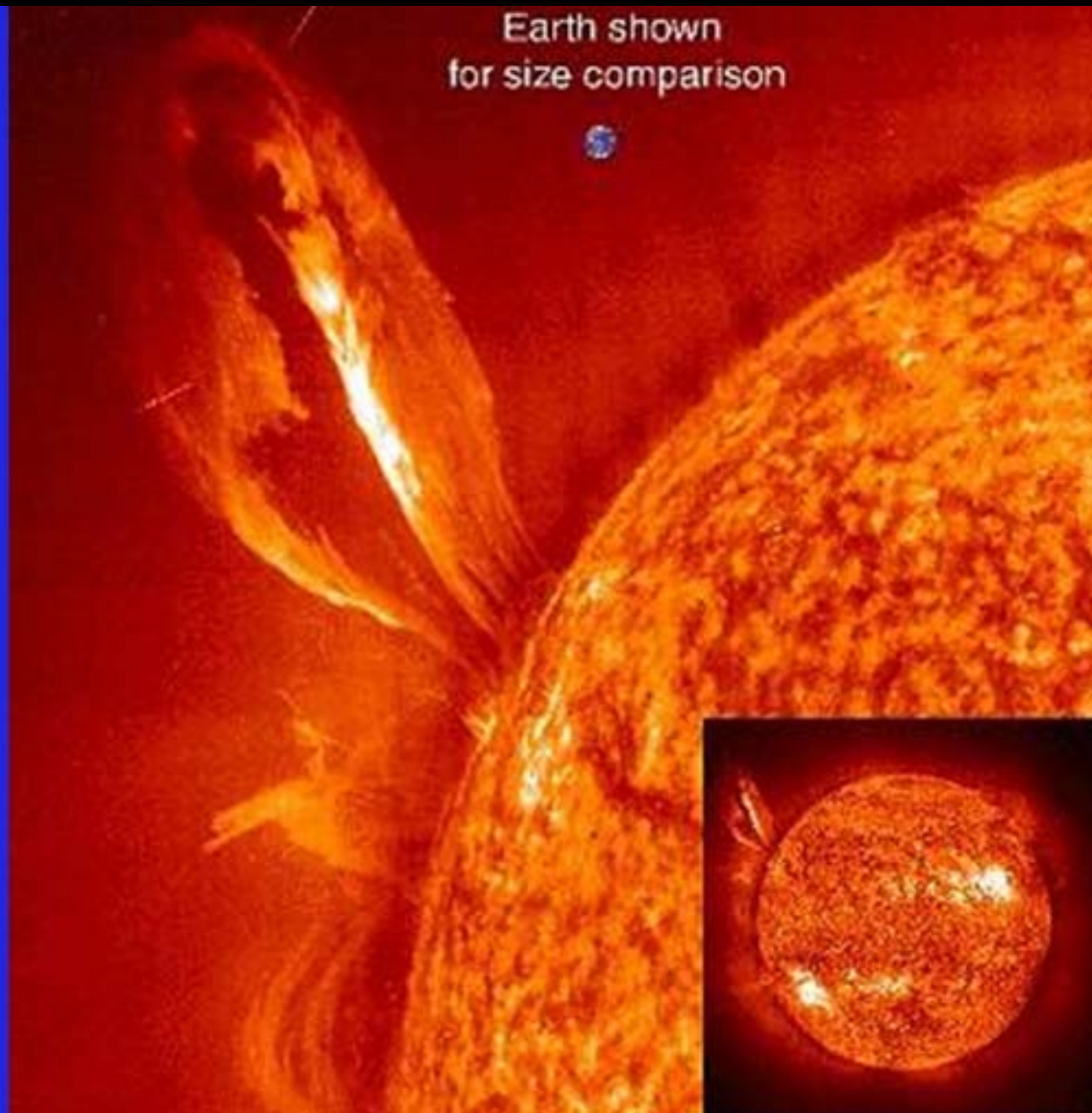
The Basis of Prosperity

20st Century = OIL

21st Century = ??

10 Terawatt minimum for 10^{10} people

165,000 TW
of sunlight
hit the earth



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One World Energy Scheme for 30-60TW in 2050: The Distributed Store-Gen Grid

- Energy transported as **electrical energy** over wire, rather than by transport of mass (coal, oil, gas)
- Vast electrical power grid on continental scale interconnecting ~ 100 million asynchronous "local" storage and generation sites, entire system continually innovated by free enterprise
- "Local" = house, block, community, business, town, …
- **Local storage** = batteries, flywheels, hydrogen, etc.
- **Local generation** = reverse of local storage + local solar and geo
- Local "buy low, sell high" to electrical power grid
- Local optimization of days of storage capacity, quality of local power
- **Electrical grid does not need to be very reliable, but it will be robust**
- Mass Primary Power input to grid via HV DC transmission lines from existing plants plus remote (up to 2000 mile) sources on TW scale, including vast solar farms in deserts, wind, NIMBY nuclear, clean coal, stranded gas, wave, hydro, space-based solar…"**EVERYBODY PLAYS**"
- **Hydrogen, methanol, ethanol are transportation fuels**
- Transition technology – Plug-in Hybrids

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Energy Nanotech Grand Challenges

from Meeting at Rice University May 2003
Report available!

1. Photovoltaics -- drop cost by 100 fold.
2. Photocatalytic reduction of CO_2 to methanol.
3. Direct photoconversion of light + water to produce H_2.
4. Fuel cells -- drop the cost by 10-100x + low temp start.
5. Batteries and supercapacitors -- improve by 10-100x for automotive and distributed generation applications.
6. H_2 storage -- light weight materials for pressure tanks and LH2 vessels, and/or a new light weight, easily reversible hydrogen chemisorption system
7. Power cables (superconductors, or quantum conductors) with which to rewire the electrical transmission grid, and enable continental, and even worldwide electrical energy transport; and also to replace aluminum and copper wires essentially everywhere -- particularly in the windings of electric motors and generators (especially good if we can eliminate eddy current losses).

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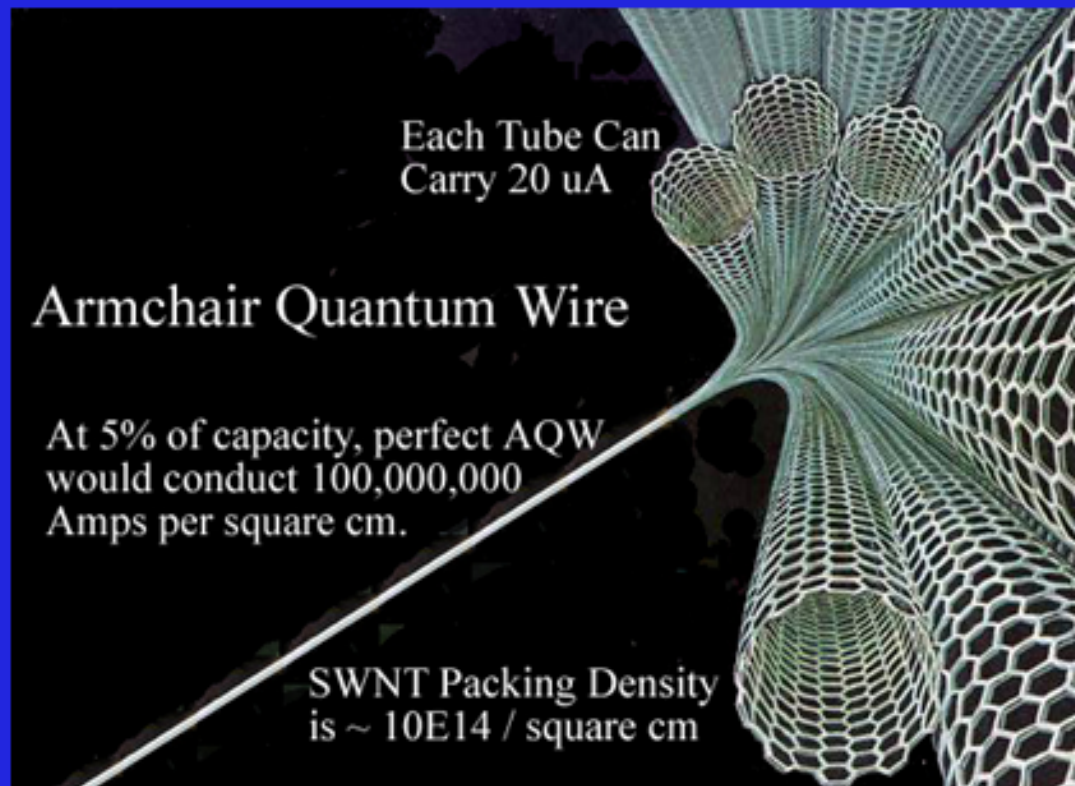
SWNT Quantum Wire

Expected Features
- 1-10x Copper Conductivity
- 6x Less Mass
- Stronger Than Steel
- Zero Thermal Expansion

Key Grid Benefits
- Reduced Power Loss
- Low-to-No Sag
- Reduced Mass
- Higher Power Density

SWNT Technology Benefits
- Type & Class Specific
- Higher Purity
- Lower Cost
- Polymer Dispersible



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Production Scale-Up Path

- Rice made 1 mg / day in 1997
- Lab-scale reactor at 1 gm / hour (2002)
- CNI Pilot plant producing 20 lb /day
- CNI now testing 100 lb / day reactor

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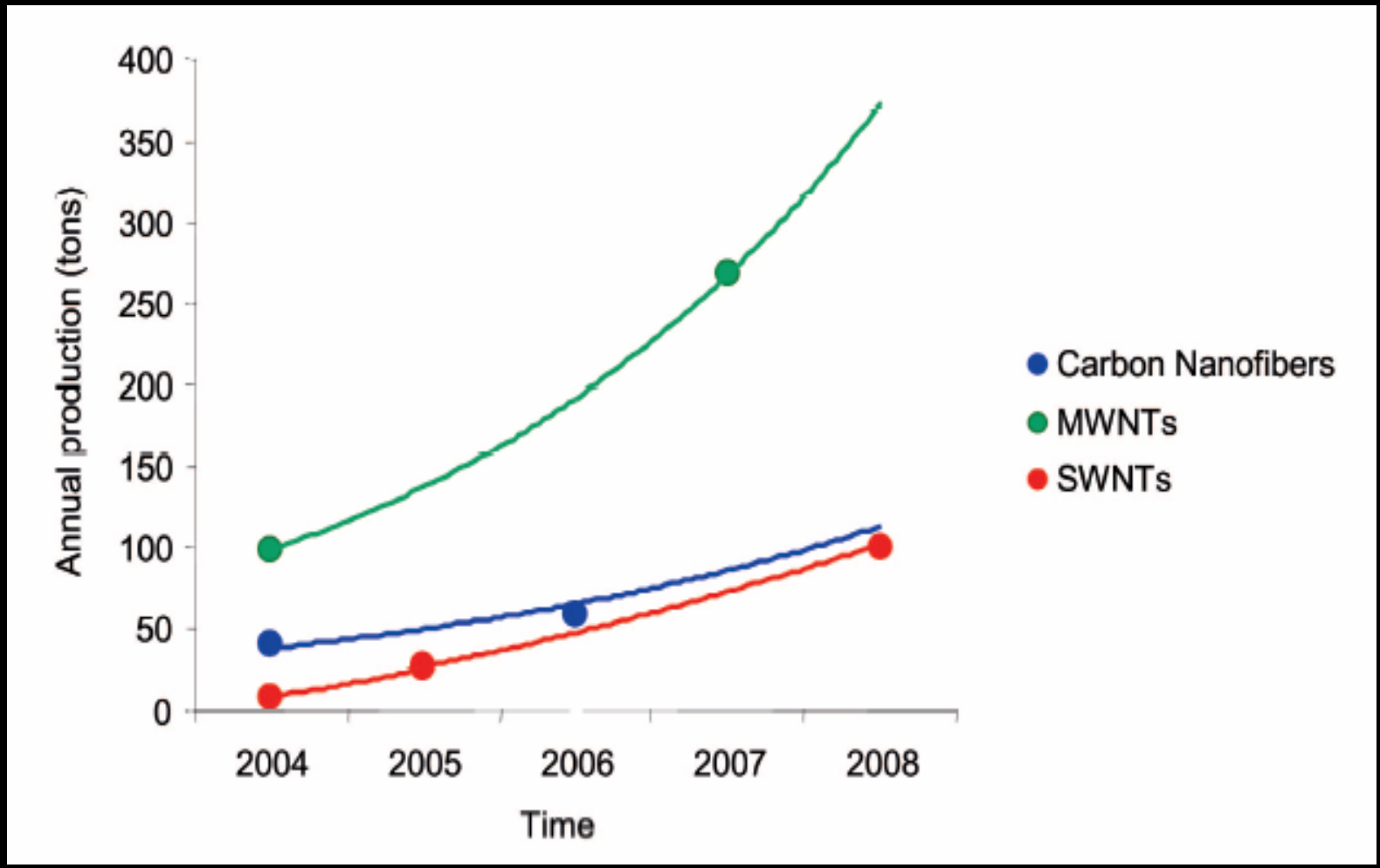
Estimated future global production of nanotubes



Reference: Cientifica 2004

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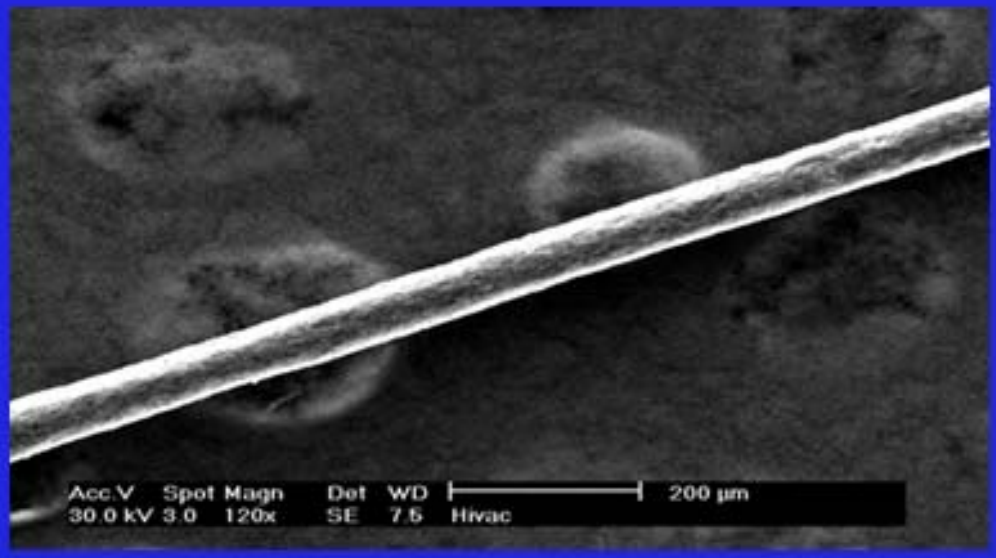
Prototype Wire - SWNT Fibers

- Producing Neat SWNT Fibers
- Dry-Spun from Oleum
- 6 to 14 Wt. % SWNT Dope
- Extruded as 50 μm Dia. Fibers
- 10^9 Tubes in Cross Section
- 100 Meters Long



***Science* 305, 1447-1450, 3 September 2004!!!**

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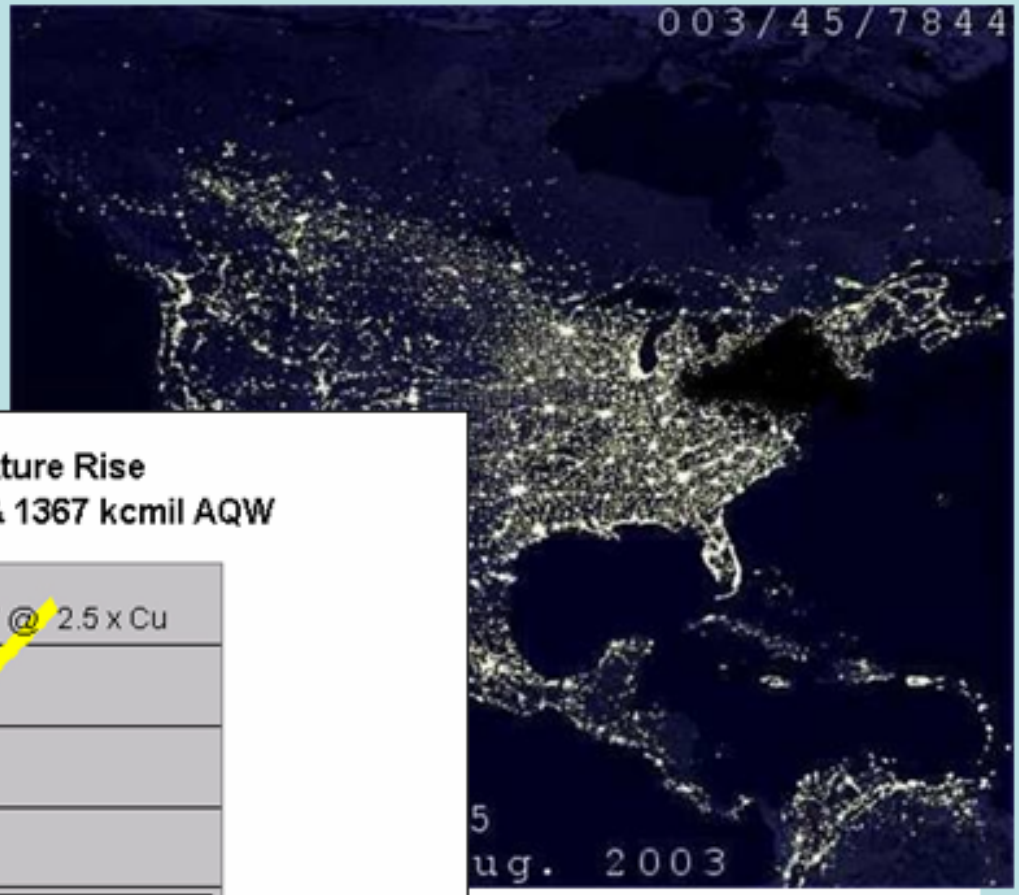
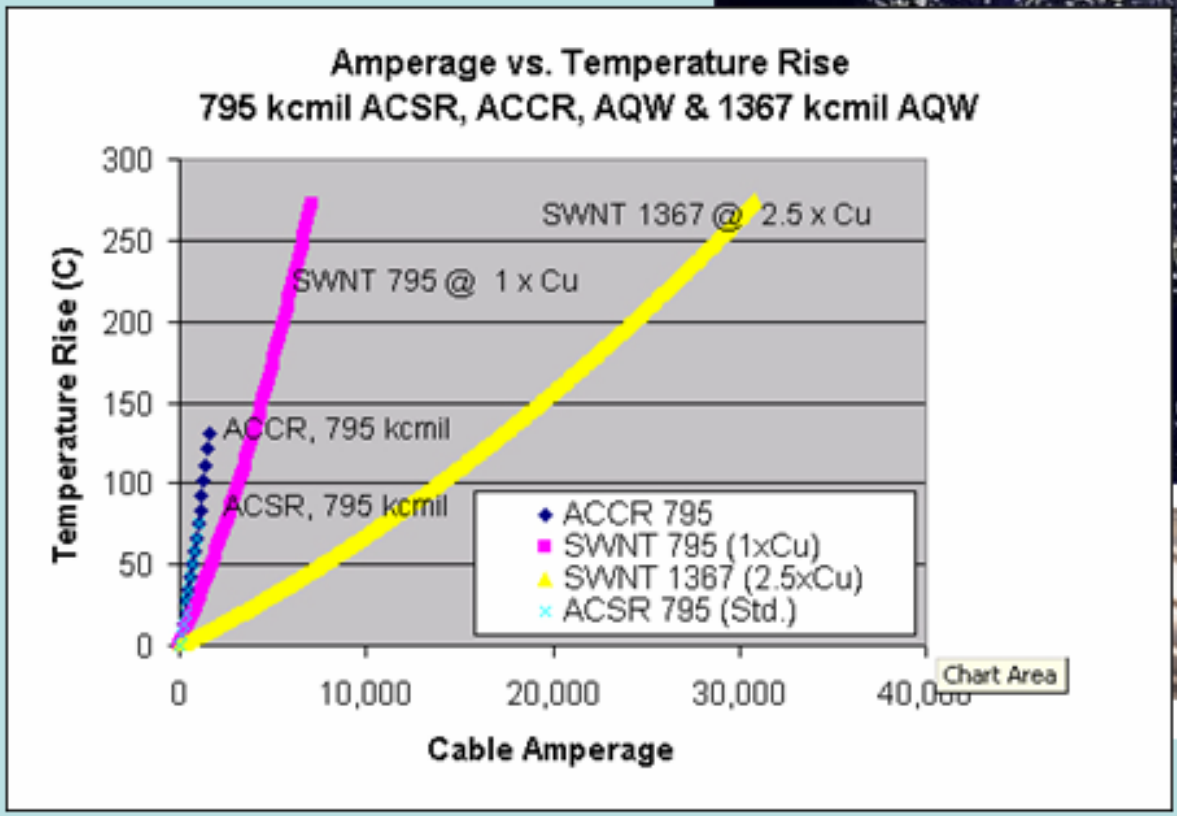
Quantum Wire on The Grid

Key Grid Benefits

- Eliminate Thermal Failures
- Reduce Wasted Power
- Reduce Urban R.O.W. Costs
- Enable Remote Generation





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Grid Applications & Benefits

- Eliminate Thermal-Sag Failure: Now a $100B+ a year problem.
- Short-Distance AC: AQW* could increase throughput up to ten-fold without increasing losses while using only existing towers and rights-of-way. Avoid new construction in congested urban areas – estimated over $100M per mile.
- Medium-Distance AC: AQW* could decrease resistive losses and voltage drop ten-fold if amperage were not increased. This would improve grid dynamics significantly in the range between 100 and 300 miles, where voltage stability limits deliverable power.
- Long-Distance HVDC: AQW* could permit amperage throughput ten fold or reduce losses ten-fold. New conventional lines cost $1M to $2M per mile, plus about $250M per AC/DC converter station.
- Remote Power: Could enable utilization of large-scale renewables and remote nuclear.

* AQW = Armchair Quantum Wire

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Conclusions

- The control of the matter produced, at the end of the 18th century, a first technological and industrial revolution
- In the middle of the 20th century, the control of the matter on a micrometer scale was at the origin of a second technological revolution, which was concretized by the development of micro electronics
- It is probable that the nanosciences and the nanotechnologies, will constitute, during the 21st century, the third technological and industrial revolution

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The End

Thank you for your attention