CHALLENGES IN MICRO AND NANO SCIENCE AND TECHNOLOGY: HOW CAN WE MAKE AN IMPACT

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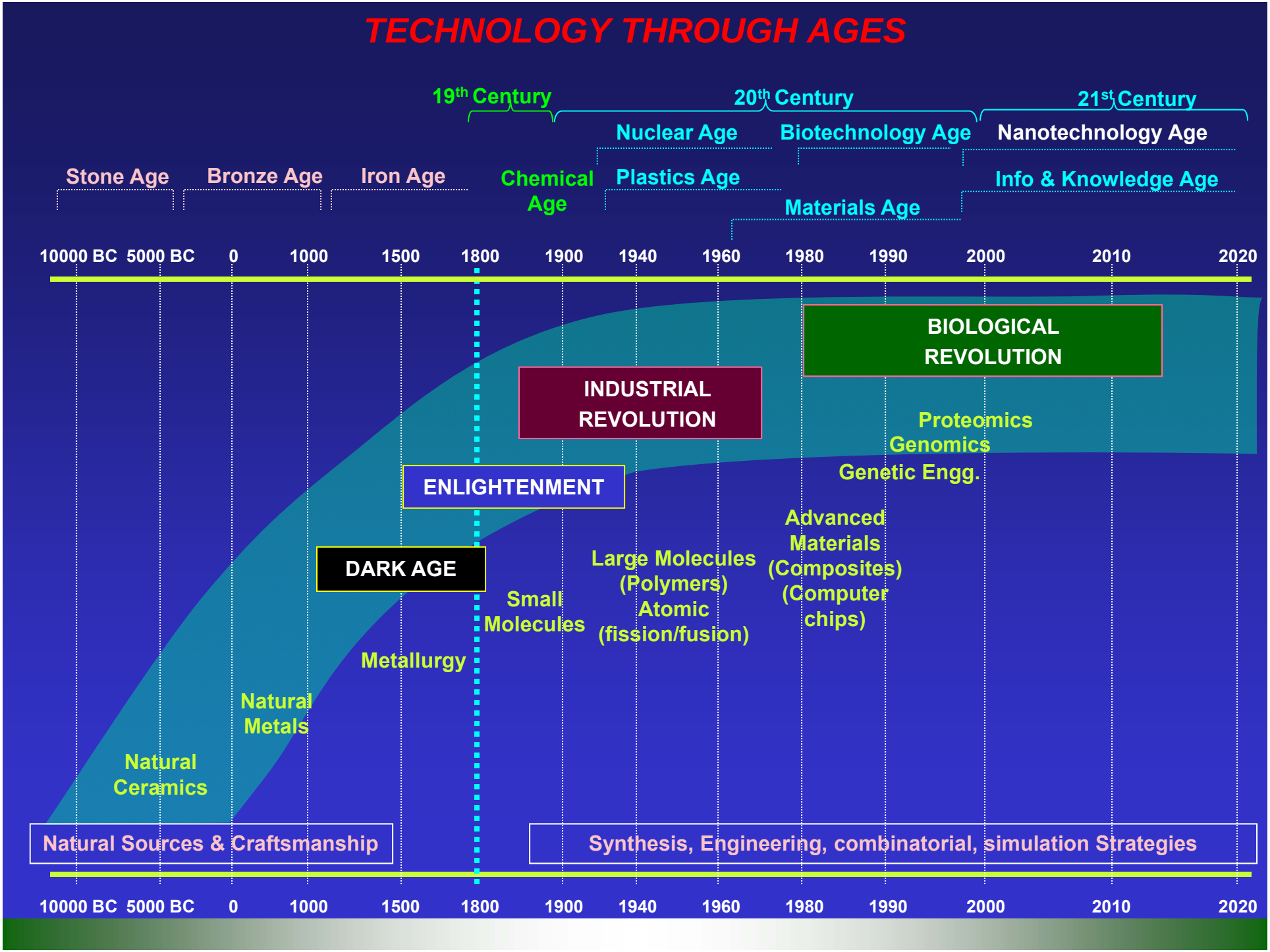
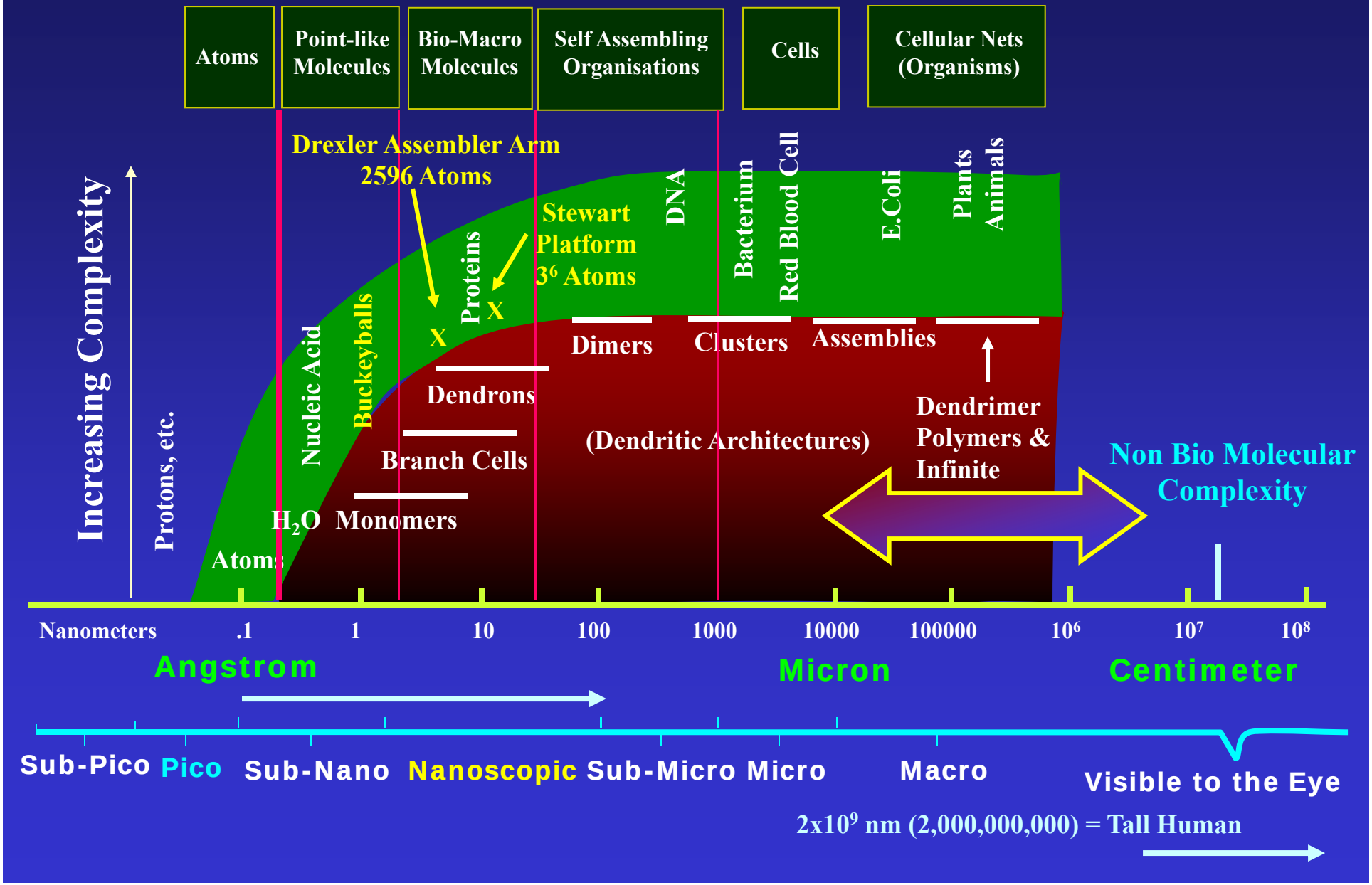
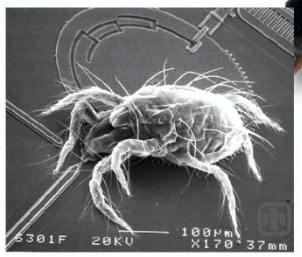

TECHNOLOGY THROUGH AGES
19th Century
20th Century
21st Century
Nuclear Age
Biotechnology Age
Nanotechnology Age
Stone Age
Bronze Age
Iron Age
Chemical Age
Plastics Age
Info & Knowledge Age
Materials Age
10000 BC
5000 BC
0
1000
1500
1800
1900
1940
1960
1980
1990
2000
2010
2020
BIOLOGICAL REVOLUTION
INDUSTRIAL REVOLUTION
ENLIGHTENMENT
DARK AGE
Proteomics
Genomics
Genetic Engg.
Advanced Materials (Composites) (Computer chips)
Large Molecules (Polymers) Atomic (fission/fusion)
Small Molecules
Metallurgy
Natural Metals
Natural Ceramics
Natural Sources & Craftsmanship
Synthesis, Engineering, combinatorial, simulation Strategies

MOLECULAR COMPLEXITY



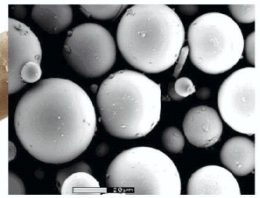
things Natural

Dust mite
200 µm



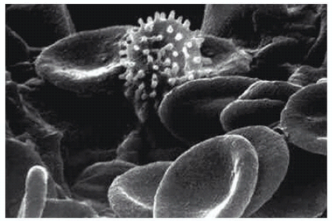
Ant
~5 mm

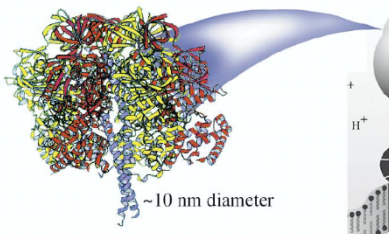
Fly ash
~10–20 µm



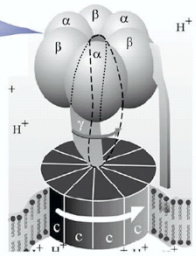
Human hair
~50–150 µm wide

Red blood cells
with white cell
~2–5 µm

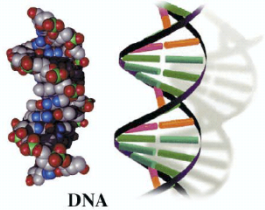




~10 nm diameter



ATP synthase



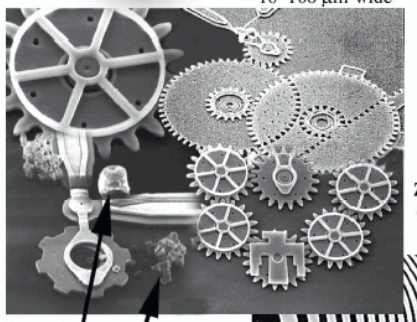
DNA
~2.5 nm diameter

Atoms of silicon
Spacing: a few tenths of a nanometer

things Manmade

Head of a pin
1–2 mm

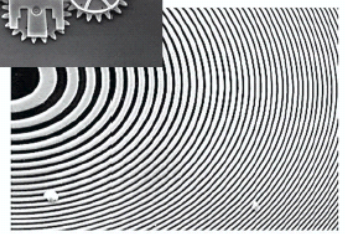
Microelectromechanical devices
~10–100 µm wide

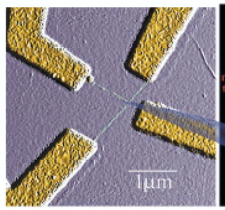


Pollen grain

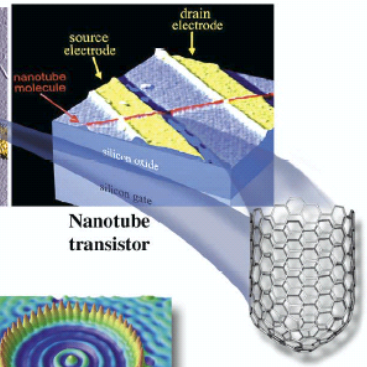
Red blood cells

Zone plate X-ray "lens"
Outermost ring spacing
~35 nm

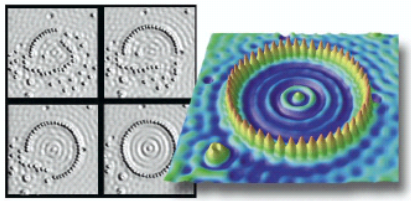




Nanotube electrode

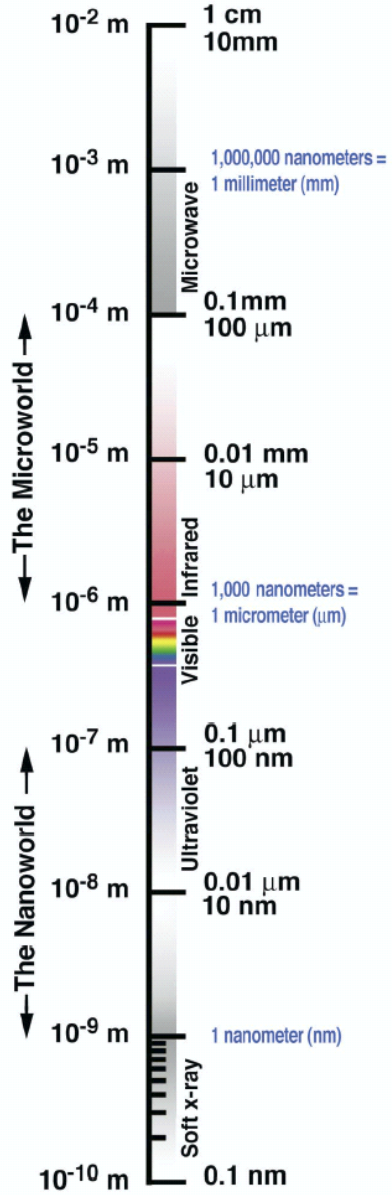


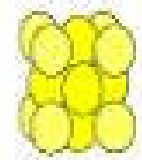
Nanotube transistor



Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm

Carbon nanotube
~2 nm in diameter



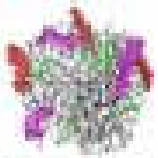


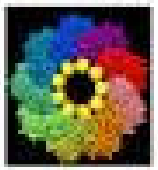
1st: Passive nanostructures **(1st generation products)**

a. *Dispersed and contact nanostructures.* Ex: aerosols, colloids

b. *Products incorporating nanostructures.* Ex: coatings; nanoparticle reinforced composites; nanostructured metals, polymers, ceramics

~ 2000





2nd: Active nanostructures

a. *Bio-active, health effects.* Ex: targeted drugs, biodevices

b. *Physico-chemical active.* Ex: 3D transistors, amplifiers, actuators, adaptive structures

~ 2005

3rd: Systems of nanosystems

Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary

~ 2010

4th: Molecular nanosystems

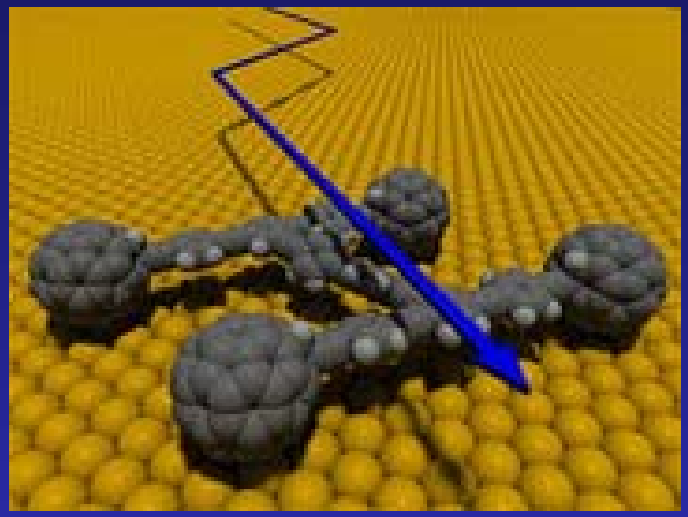
Ex: molecular devices 'by design', atomic design, emerging functions

~ 2015-2020

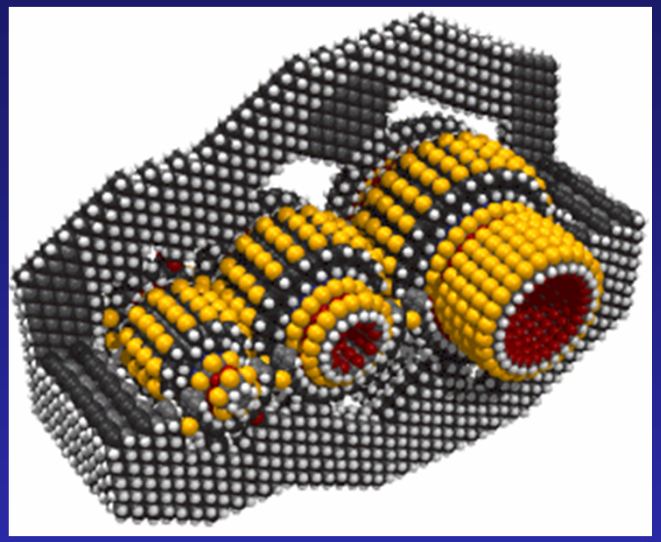
Risk Governance Frame 1

Frame 2

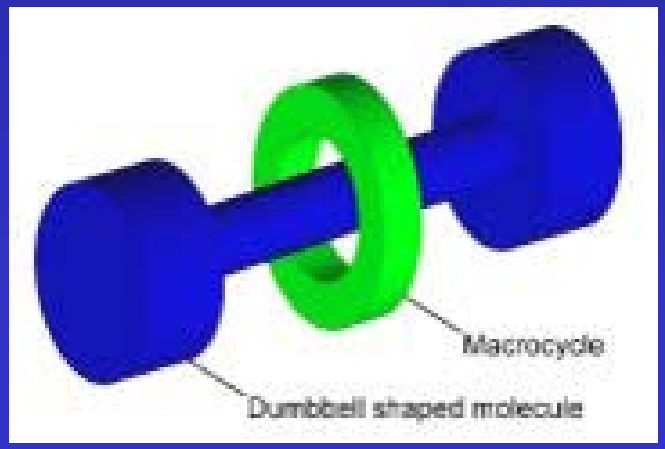
NANO OBJECTS



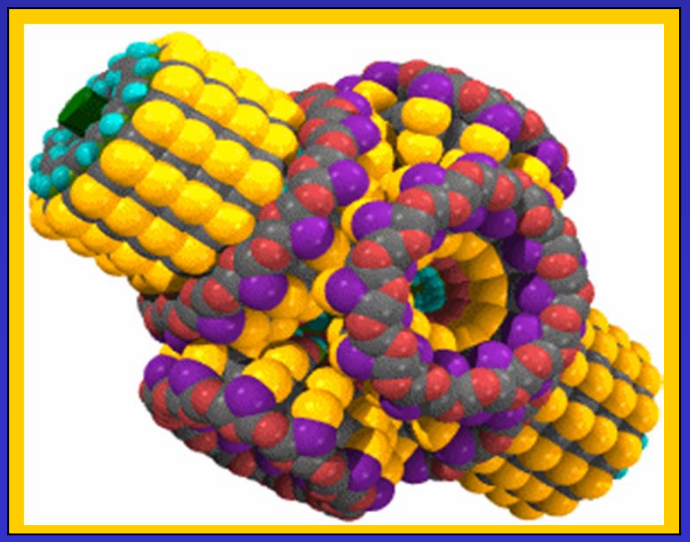
NANOCAR

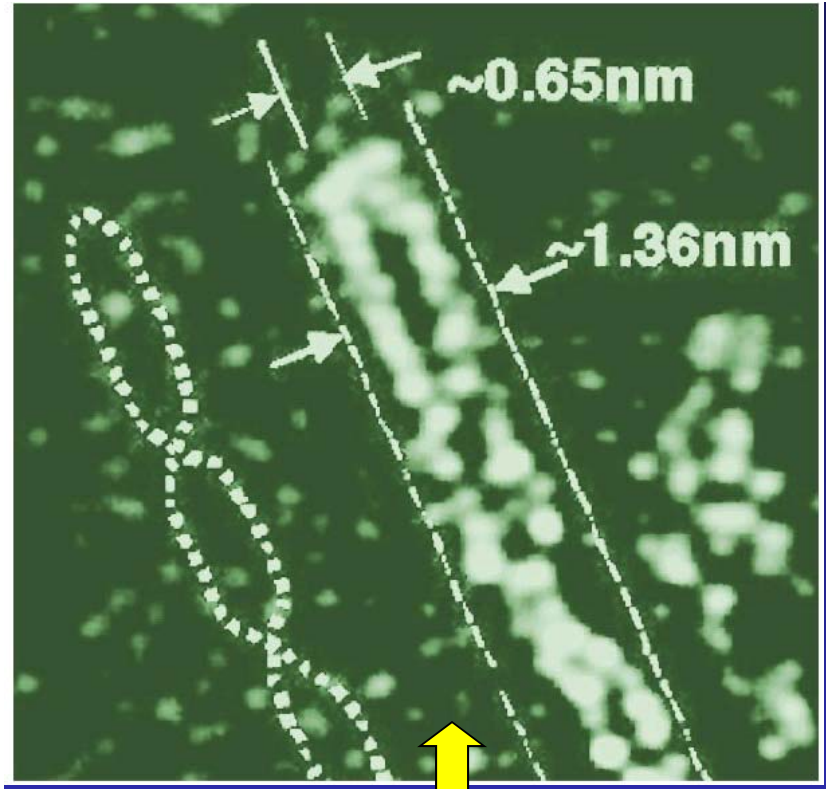


NANOMOTORS



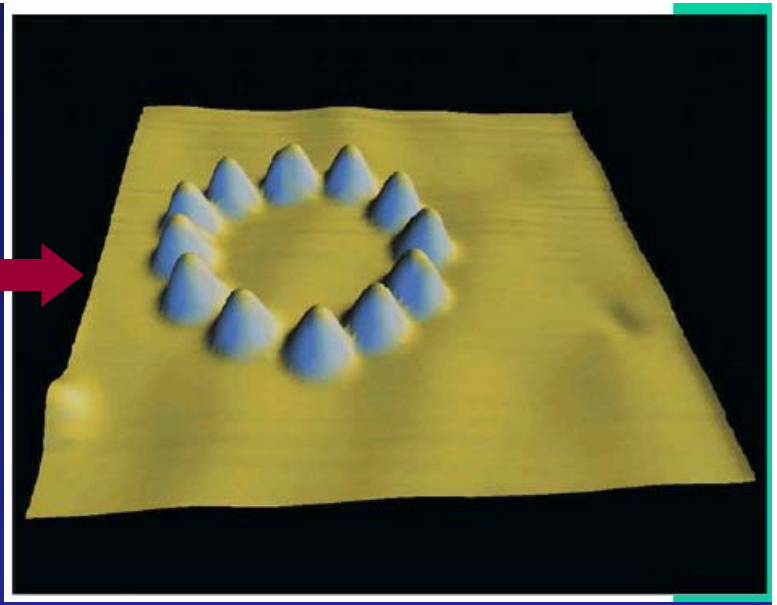
NANOSWITCH



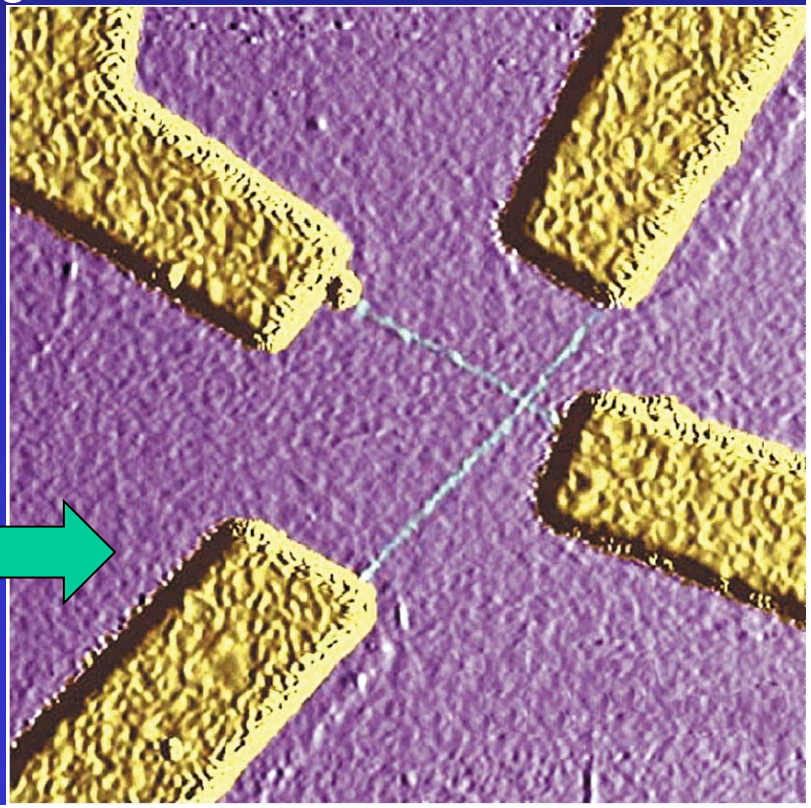


Electron microscopy reveals a double helix chain of iodine atoms inside a carbon nanotube.

Quantum corral of 12 sodium atoms, constructed using the tip of a scanning tunneling microscope .



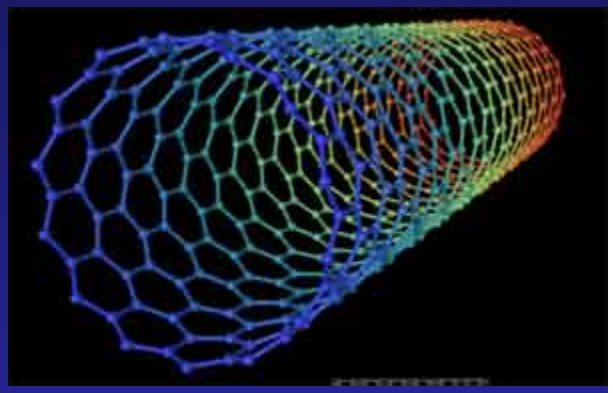
Atomic force microscope image showing two single walled nanotubes spanning gold contacts. These structures form the basis of the first nanoscale electronic devices.



THE LEGENDARY DAMASCUS SWORD

Sharp, tough and malleable; can cleave through a silk scarf floating to the ground

Composite of carbon Nanotube with nanowire of Fe3C (cementitie)



Carbon nanotube

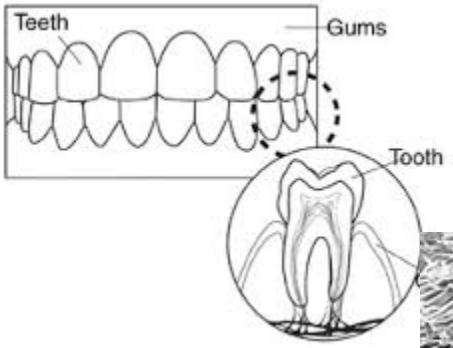
Key to its properties : Nanotechnology inadvertently used by blacksmiths in 17 th century, long before modern science

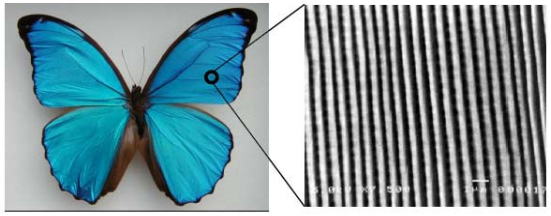
Reibold et al, Nature 44, 286 (2006)

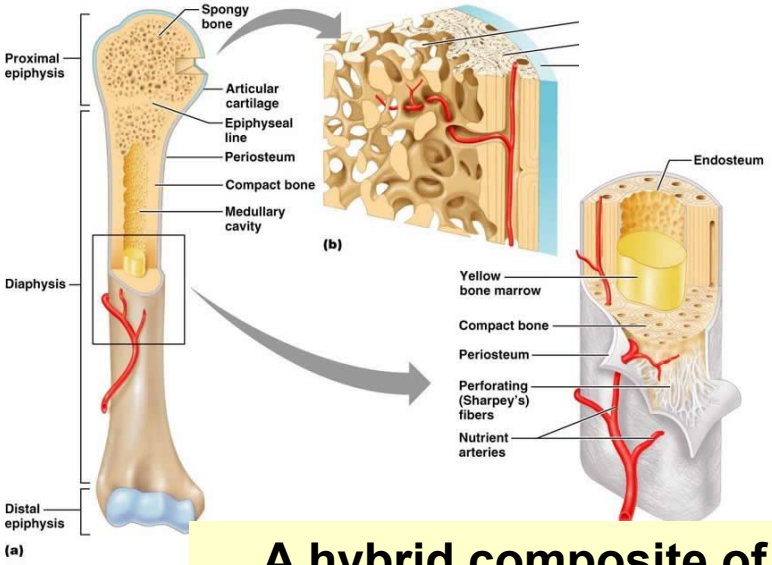
Superhydrophobic surface

Abalone shell

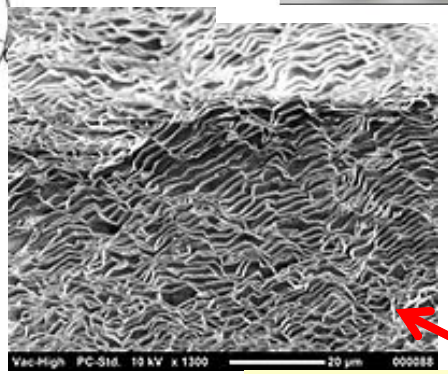
Surface Photonic Gratings



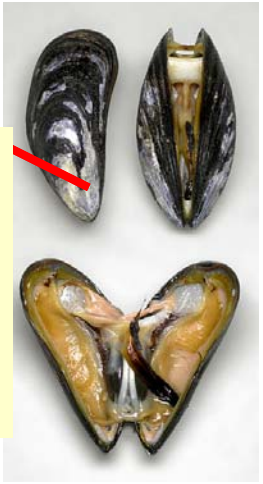




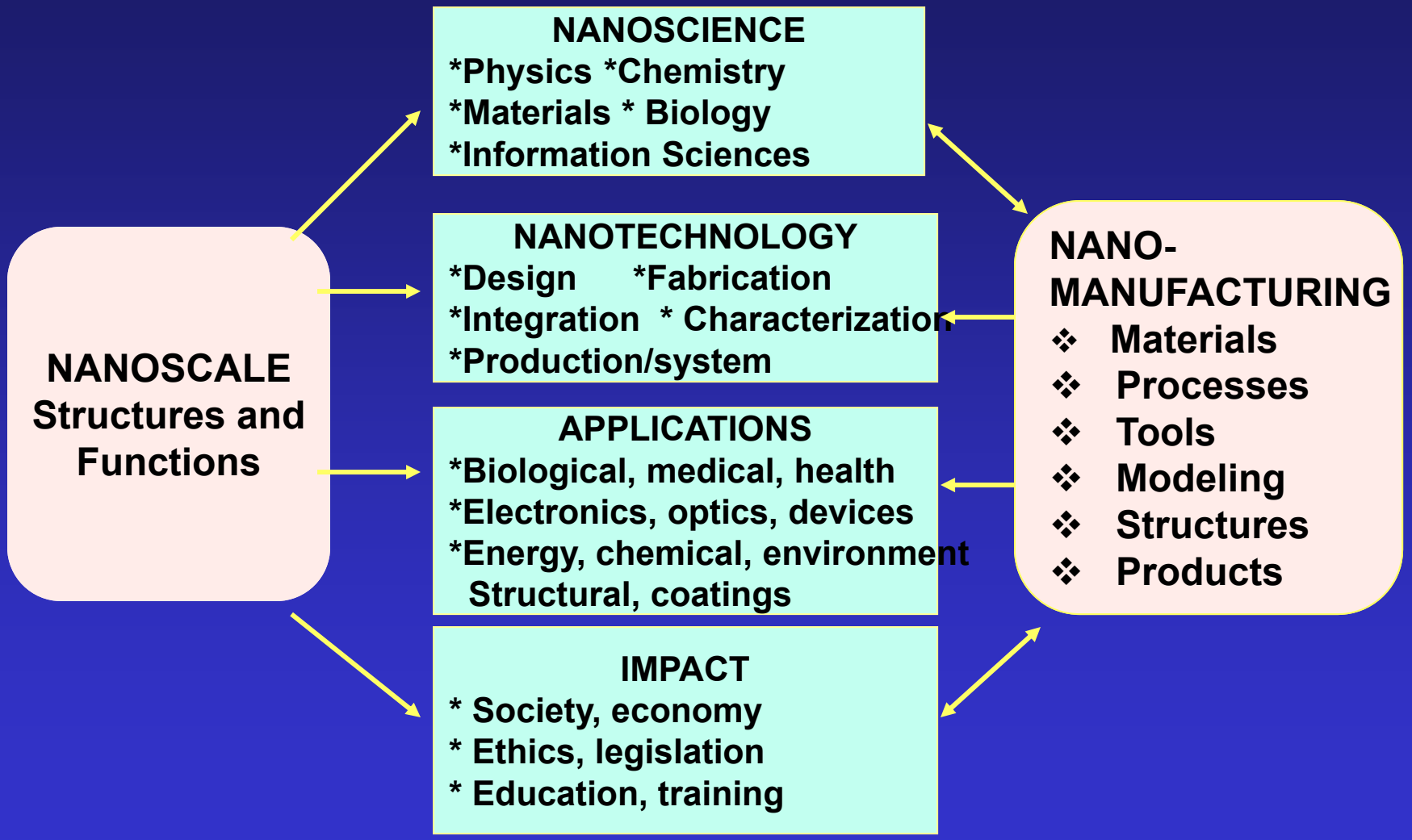
A hybrid composite of Hydroxyapatite and Collagen Type II



Aragonite layers in the nacre of a blue mussel



CONVERGENCE OF SCIENCE AND ENGINEERING



NEW CHALLENGES

- Disciplines of scientific knowledge and merging boundaries of science and engineering
- Learning and teaching science
- Practice and organization of science in institutions
- Processes for creating value out of science and bringing its benefits to society

We need fresh thinking, unburdened by our past, to bring transformation in all areas above, if we have to make a difference

INTEGRATIVE LEARNING

"Making connections within disciplines, between fields, between curriculum, co-curriculum, or between academic knowledge and practice"

Awbrey, S.M, Dana, D., Miller, V.W., Robinson, P., Ryan, M.M. and Scott, D.K. (Eds.), (2006). Integrative Learning and Action: A Call to Wholeness (Studies in Education and Spirituality),New York: Peter Lang Publications

CONTEXT LED APPROACH TO EDUCATION

)

- Instead of teaching science in the traditional way, context led approach relies on engaging students natural curiosity to understand the world around them
- It teaches them to solve real life problems by exploring the underlying science
- Its emphasis is on interpretation and analysis rather than the breadth of conceptual coverage
- The teaching does not subdivide science in terms of traditional disciplines ; instead it teaches science through illustrative examples from everyday experiences that a student can easily relate to

CHALLENGE TO TEACHING

- Convey the flavor of inter-disciplinarity in science (chemistry, physics, biology and mathematics)
- Erase the boundaries between engineering and science
- Illustrates the agony and ecstasy of science and technology led innovations
- Exemplify the molecules to devices journey

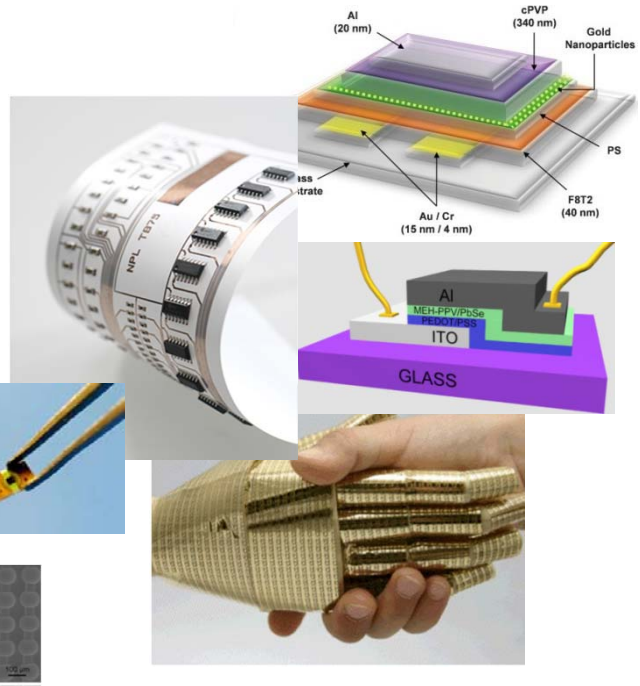
Is the way our academic departments are presently structured capable of meeting these challenges ?

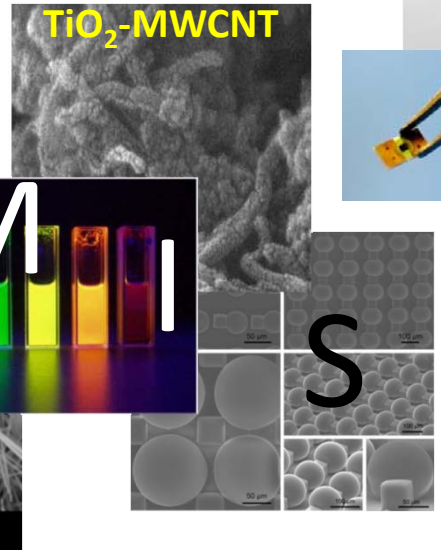
MOLECULES TO MATERIALS & DEVICES

CHEMISTRY
Molecular Design and Engineering
Architecture through Assembly
Economy through scalability

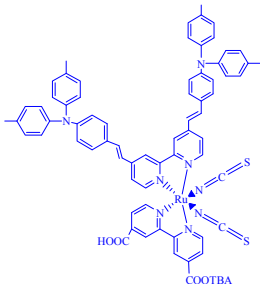
C H E M I S T R Y

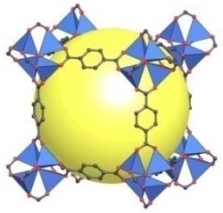
Functionality through Design





Magic of molecules

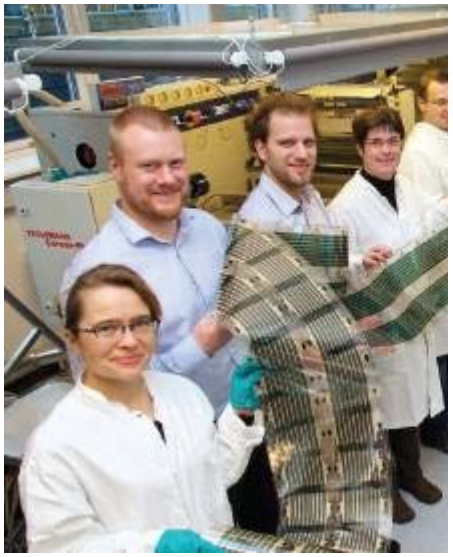


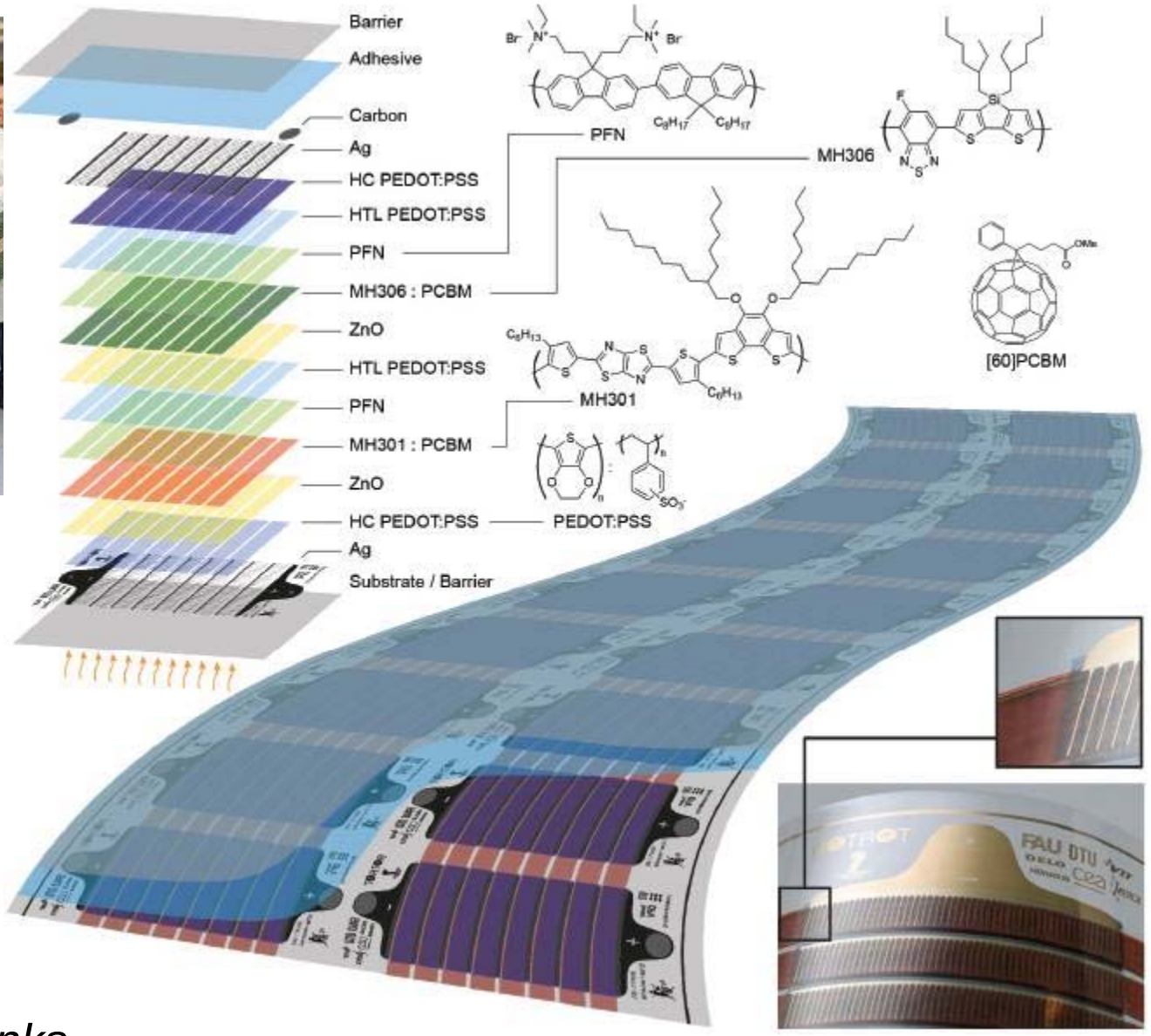


Novelty of Response

Energy : Solar Cells, Batteries, Fuel Cells, LEDs
Environment: Sensors, Adsorbants
Health: Biosensors, Controlled Drug Delivery
Water: Filters, Purifiers
Food: Smart Packaging
Electronics: Computers, Robotics (Flexible Electronics)

ORGANIC PHOTOVOLATAICS





Maximum certified efficiency : 11.5 %

Konarka, USA
Heliatec, Germany
Solarmer
819, UK
Infinity PV(Denmark)
Plextronics(Solvay) : inks

FROM THE LABORATORY TO MARKET : THE ARDOUS JOURNEY

- **Research : ideas, concepts, principles, techniques, theories (*Discover)***

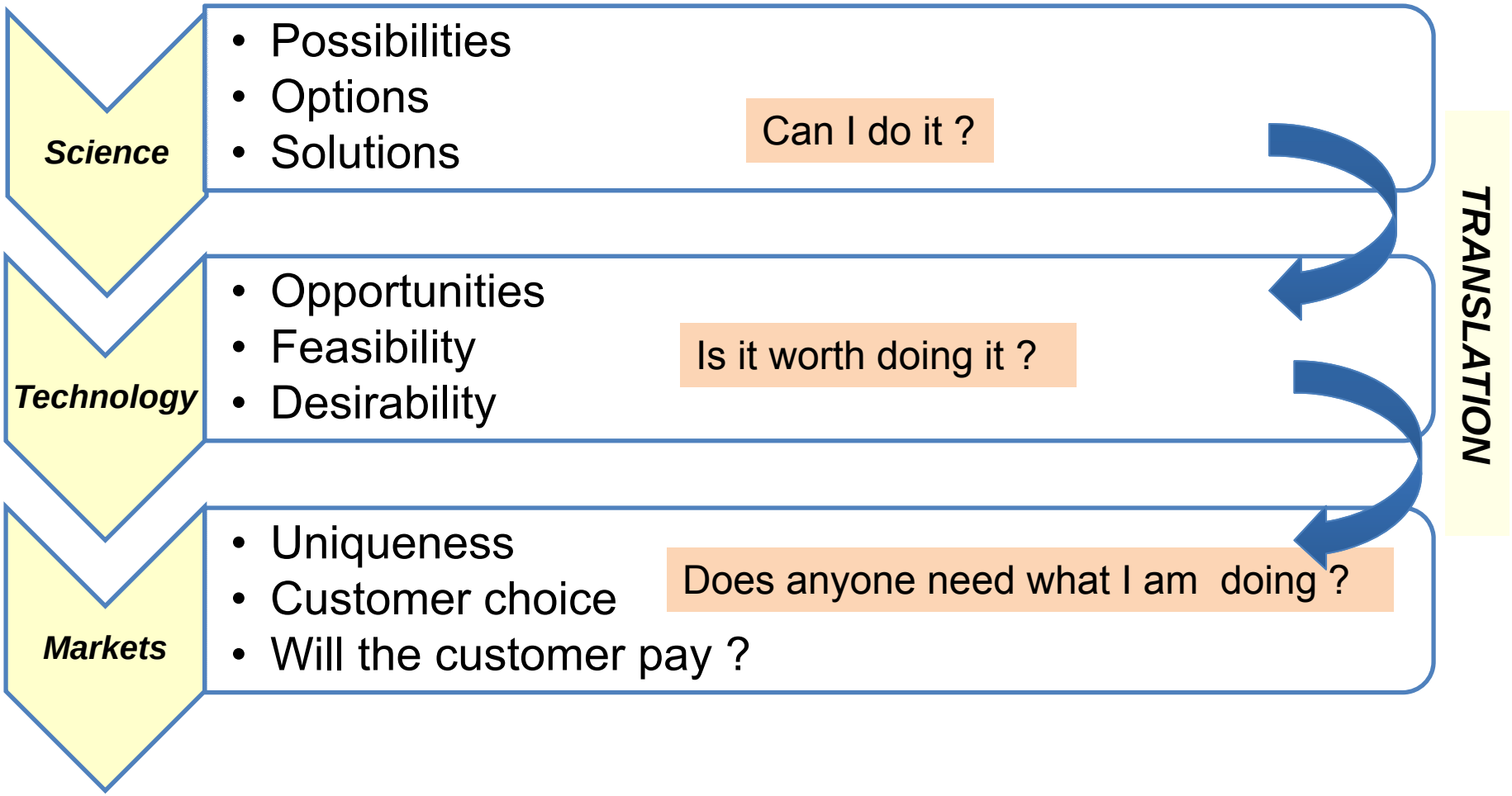
- **Translation : proof of concept, connecting solutions with needs, validation (*Develop*)**

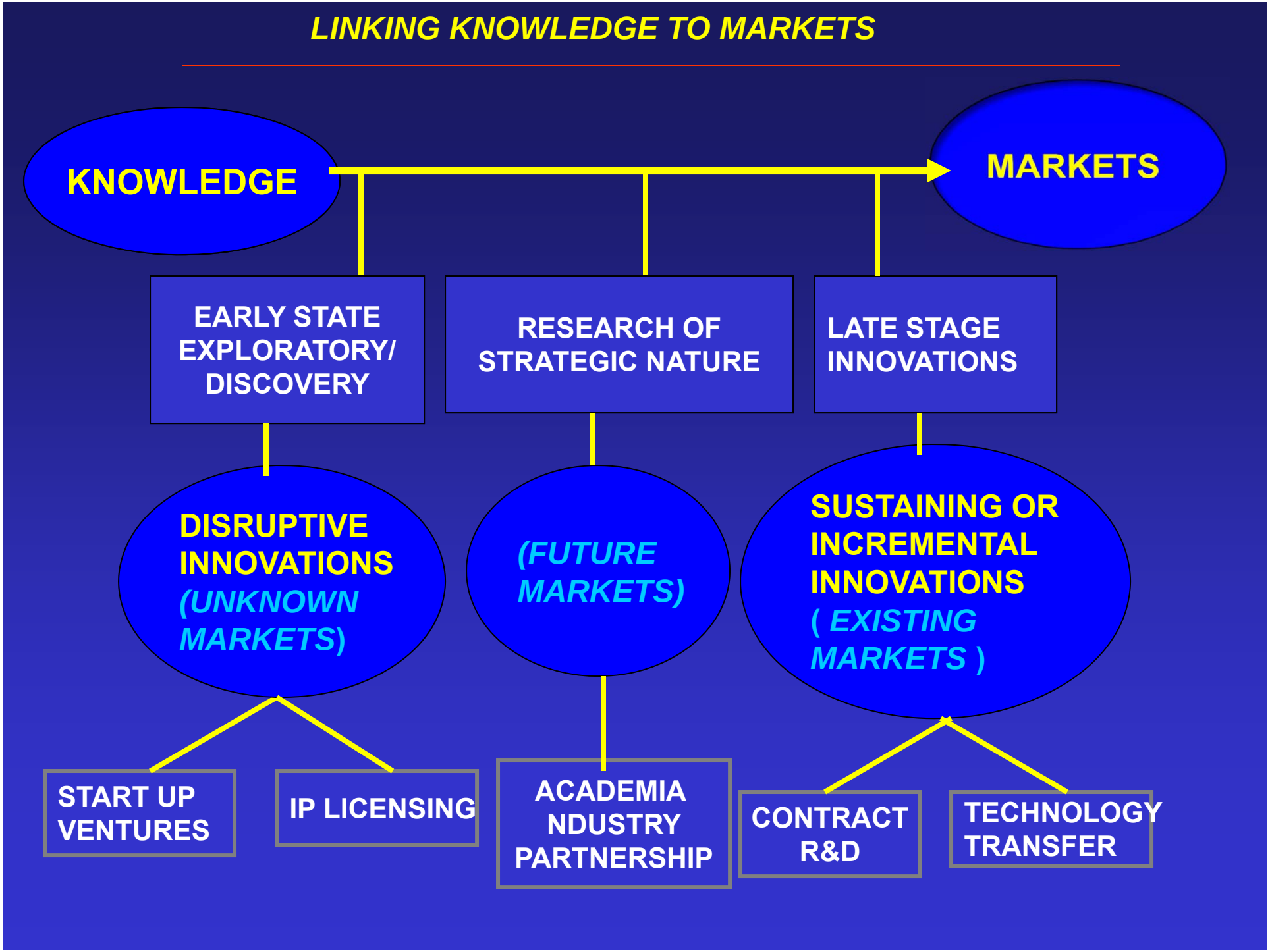
- **Defining the customer and his needs (met or unmet) and cost –performance targets, prototype or pilot plant development, customer acceptance, business plan, investment and economics *(Demonstrate)***

- **Marketable Product *(Deploy)***

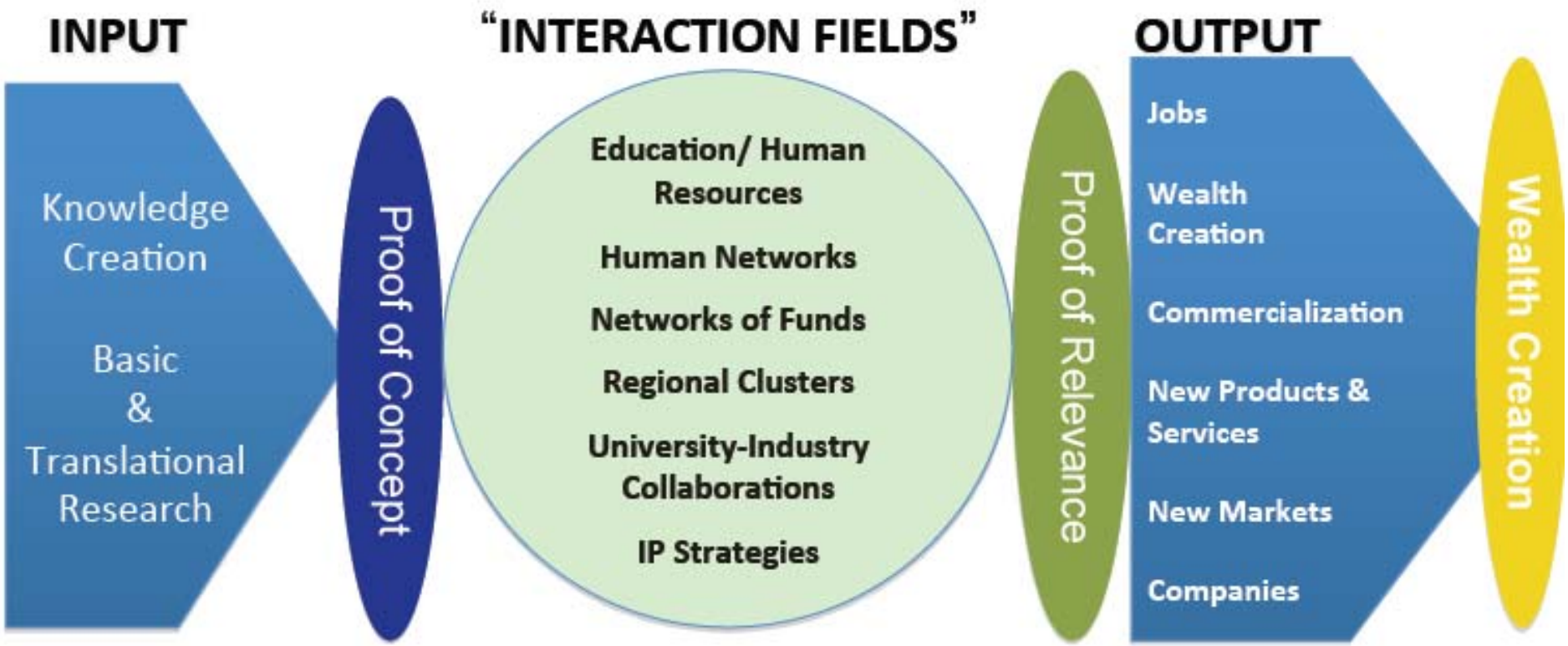
Success in the laboratory does not always translate into success in the market place

SCIENCE, TECHNOLOGY AND MARKETS



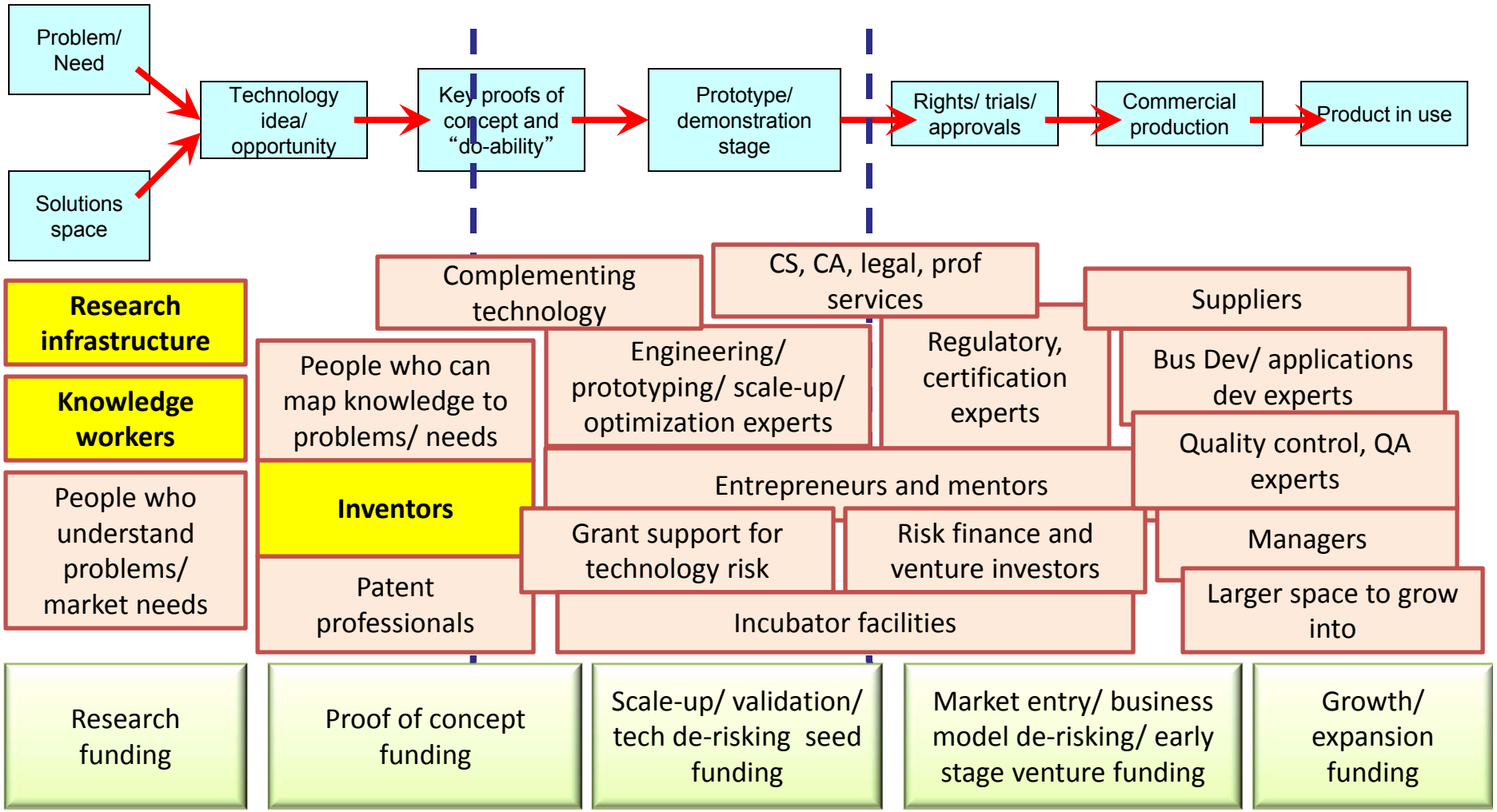

LINKING KNOWLEDGE TO MARKETS
KNOWLEDGE
MARKETS
EARLY STATE EXPLORATORY/ DISCOVERY
RESEARCH OF STRATEGIC NATURE
LATE STAGE INNOVATIONS
DISRUPTIVE INNOVATIONS (UNKNOWN MARKETS)
(FUTURE MARKETS)
SUSTAINING OR INCREMENTAL INNOVATIONS (EXISTING MARKETS)
START UP VENTURES
IP LICENSING
ACADEMIA NDUSTRY PARTNERSHIP
CONTRACT R&D
TECHNOLOGY TRANSFER

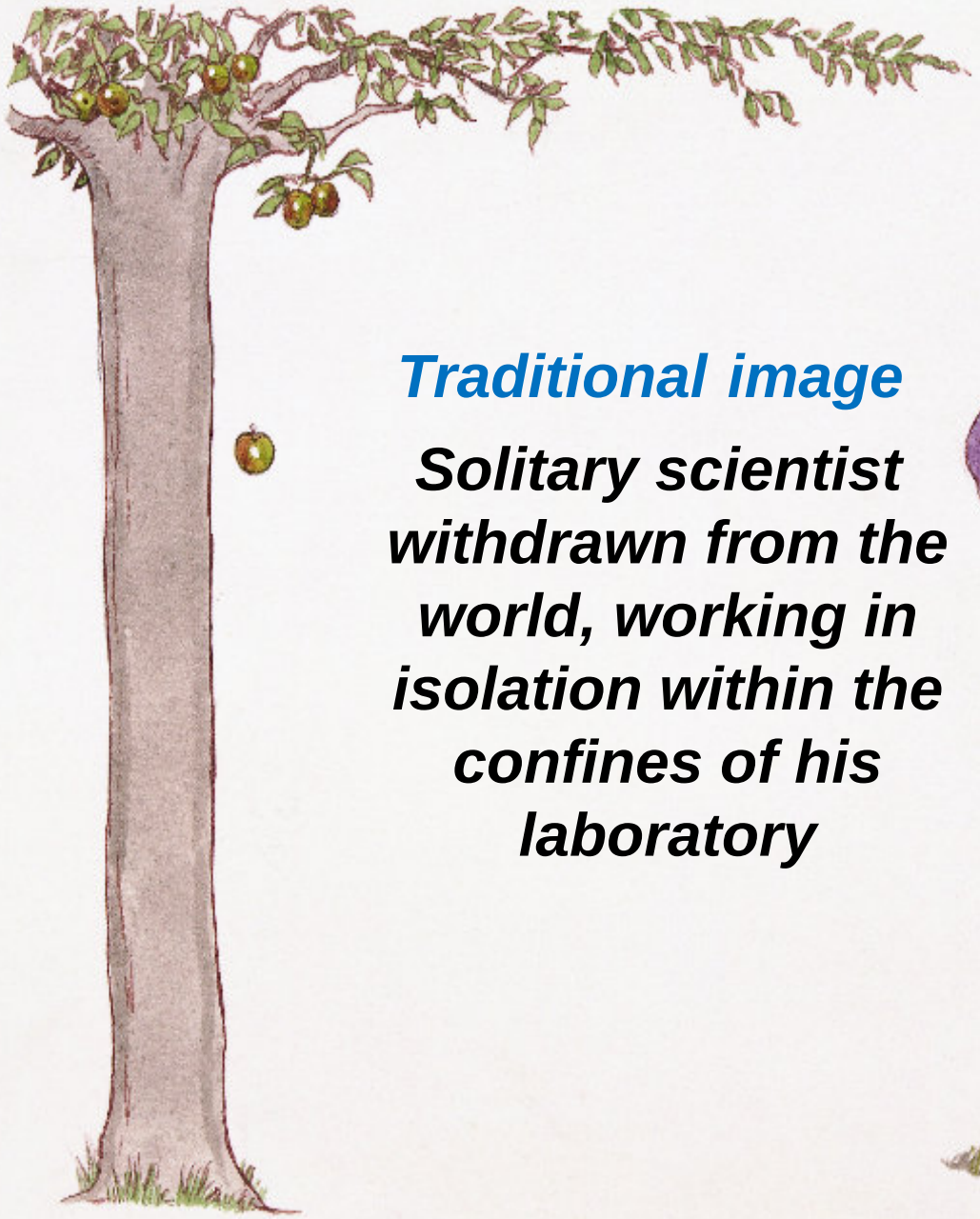
INNOVATION ECOSYSTEM



The concept of the **Innovation Ecosystem** stresses that the flow of technology and information among people, enterprises and institutions is key to a vibrant innovation process.

TRANSLATING SCIENCE – THE ECOSYSTEM





Traditional image

Solitary scientist withdrawn from the world, working in isolation within the confines of his laboratory

WHERE ARTS IS AHEAD…

Organizing scientific research on the scale of big operatic and theatrical production is still something new in science

LEARNING TO MANOUVERE THE "VALLEY OF DEATH"

Knowledge
Solutions
Ideas
Low Risk

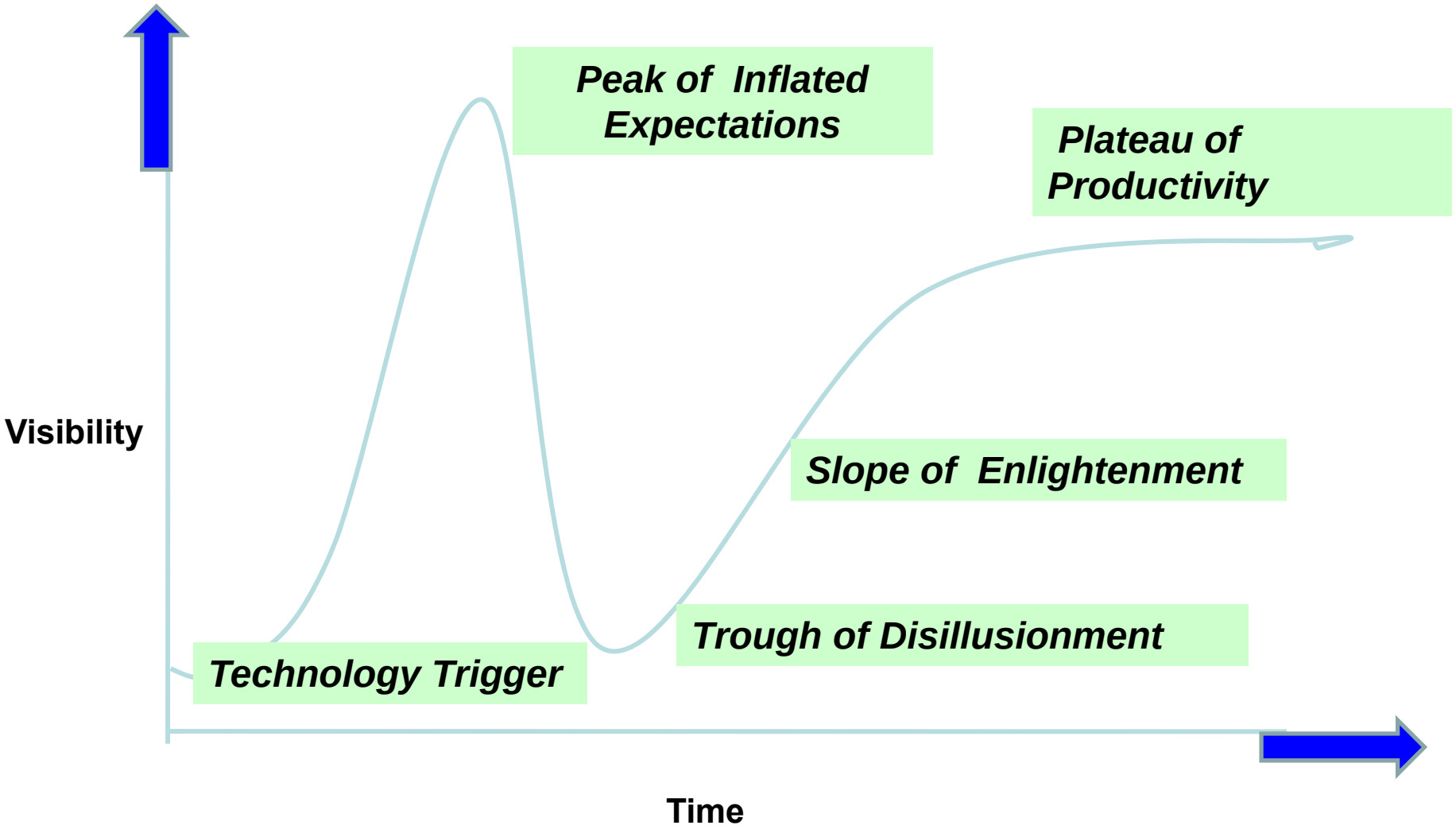
RISK MITIGATION

Applications
Validation
Markets
High Risk

Too often an obsession with inventing something "totally new" or unique versus extracting value from the creative understanding of what is already known;
Translation and innovation is more about prospecting, refining , mining and adding value; this requires an ecosystem

EVOLUTION OF TECHNOLOGIES : THE HYPE CYCLE

(http://en.wikipedia.org/wiki/Hype_cycle)



PROMISE OF AN EMERGING TECHNOLOGY

- Not just new products — a new *means of production*
- Manufacturing systems that make more manufacturing systems — *exponential proliferation*
- Accelerated product improvement — *cheap rapid prototyping*
- Affects all industries— *general-purpose technology*
- Inexpensive raw materials, potentially negligible capital cost — *economic discontinuity*
- Portable, desktop-size factories — *social disruption*
- Impacts will cross borders — *global transformation*

It is very hard to bring a new material to market. Unfortunately the rules of the game are not set by the rules of scientific knowledge, but by the rules of economics and development……. Where money goes is not always where the best technology is.

K. Novoselov, Nobel Laureate, 2010
University of Manchester

ACKNOWLEDGMENTS

IISER PUNE

THANK YOU

for your patient listening

CSIR-National Chemical Laboratory, Polymers and Advanced Materials Laboratory