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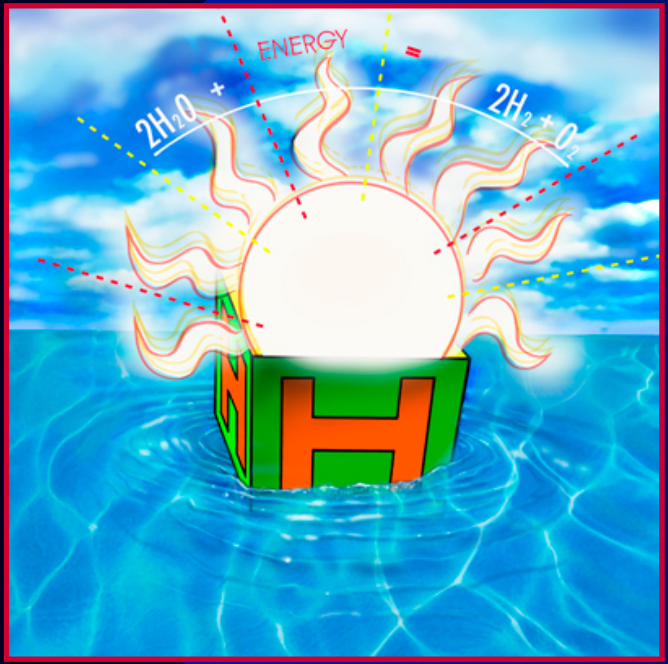

Cutting-edge Discoveries: Transforming Lives, Fueling the Economy

Fall 2006 Series

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The Innovators

Nanotechnology: The Power to Fuel an Energy Revolution

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- Context
- Example 1 - Hydrogen storage
- Example 2 - Catalysis
- Example 3 - Solar energy conversion
- Conclusions

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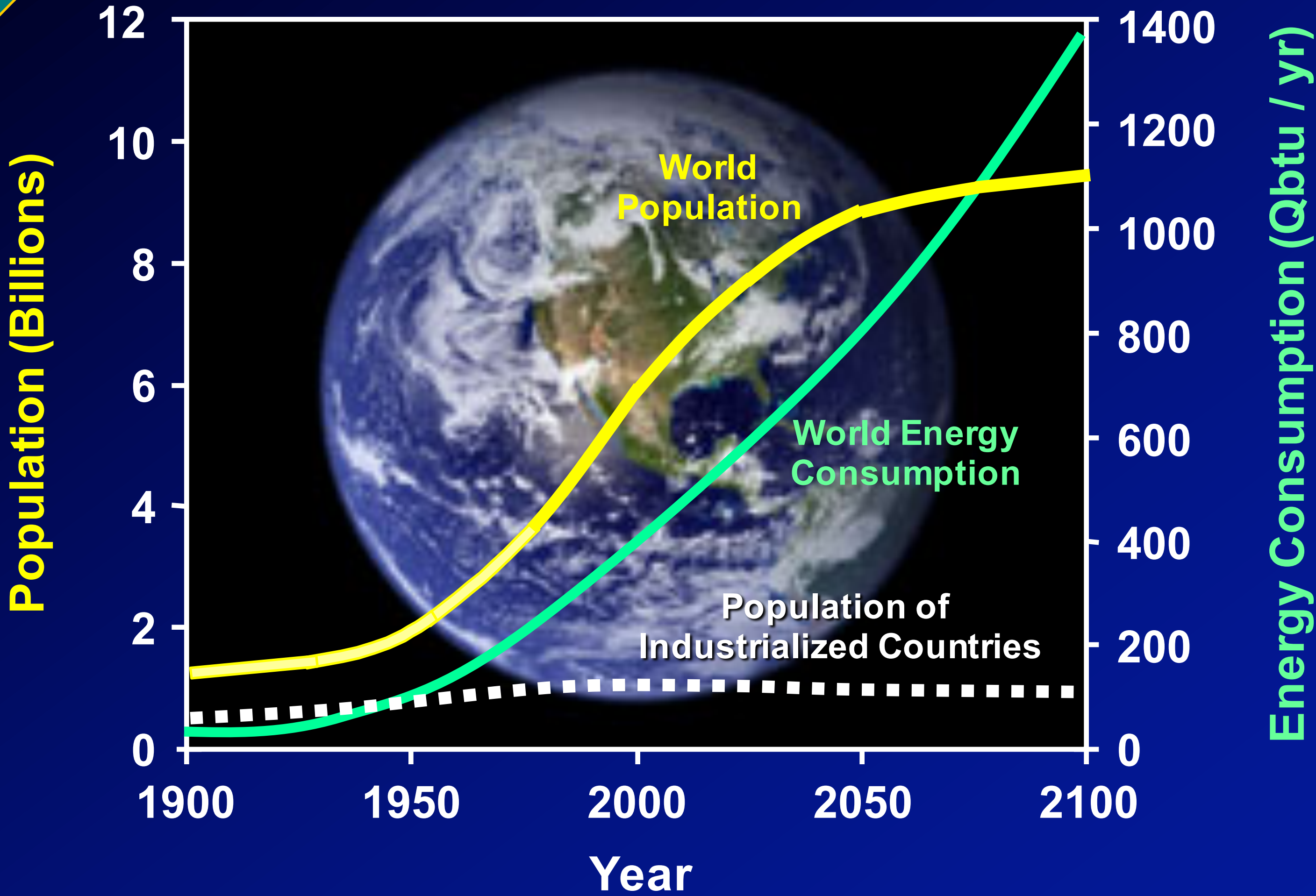
This is the challenge!



Energy Projections: "Global Energy Perspectives" ITASA / WEC
Population Projections: United Nations "Long-Range World Population Projections: Based on the 1998 Revision"

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Inevitable Transition to New Energy Technologies

19th Century 1800s

Direct, wood, wind, water, animals

Steam Engine – Coal 1830-1940

20th Century 1900s

Electric Dynamo – Coal 1900-1940

Internal Combustion Engine-Oil 1910-1970

Nuclear 1970-1990

Combined-Cycle Gas Turbine 1990

21st Century 2000 & beyond

Fuel Cell Hydrogen

Direct Electric Solar

Advanced Biobased Technologies

Zero Energy Homes

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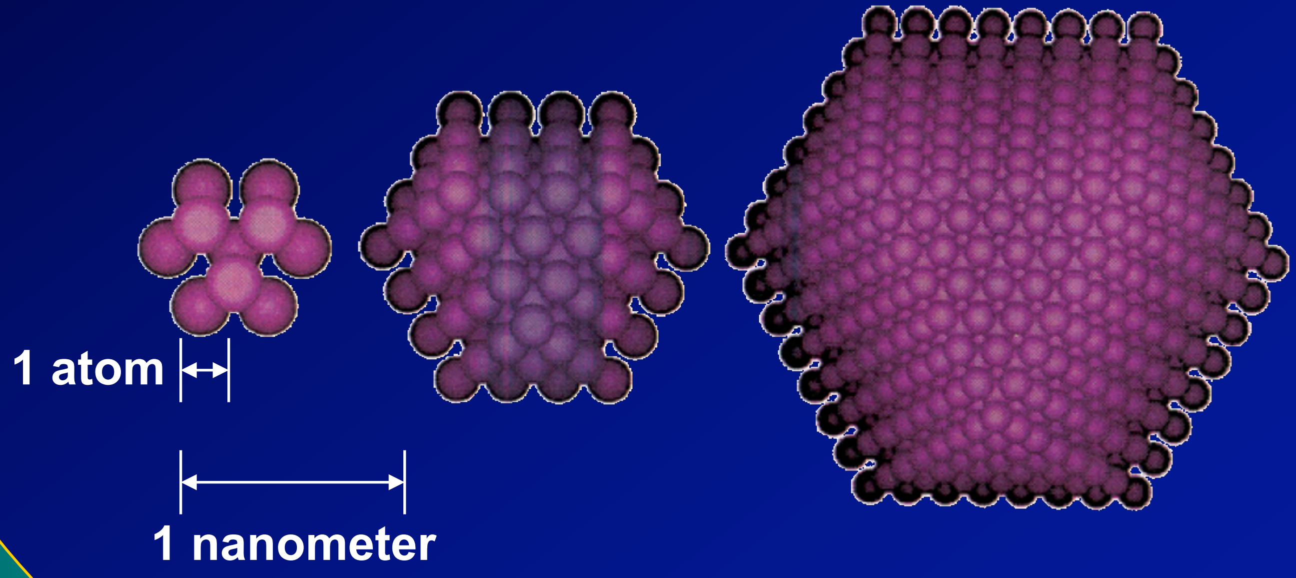
The Role of Nanotechnology

"Innovations in nanotechnology and other advances in materials science would make it possible to transform our vision of plentiful, low-cost energy into a reality" *Richard E. Smalley*, 1996 Nobel Laureate in Chemistry (June 2005)

"Technology helps and good ideas spread -- these are two laws of nature" Mr. Patel speaking to his wife in *The Life of Pi,* Yann Martel, Harcourt, Orlando (2001)



The Hydrogen Economy

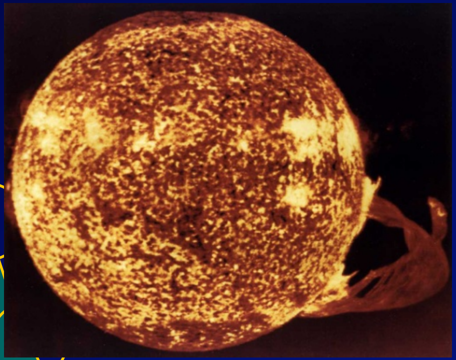
Hydrogen Production → **Hydrogen Storage** → **Hydrogen Conversion**

From:
- Fossil fuels
- Biomass
- Water

Either:
- Chemically
- Physically

To:
- Electricity
- Heat

Energy Stream



H_2 →

H_2O →

The research needs of the hydrogen economy are quintessentially "nano"

- **Catalysis**
- **Hydrogen storage**
- **Electrodes for fuel cells**

All depend on nanoscale processes and architectures

***US Department of Energy* (2003)**

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The Transportation Challenge

Effective Storage is Key

- Enough hydrogen for 300 miles (480 km) -- about 5-10 kg of useable hydrogen
- Charge/recharge near room temperature
- Quick uptake and release (refueling in 5 minutes)
- None of the current approaches is close to meeting targets

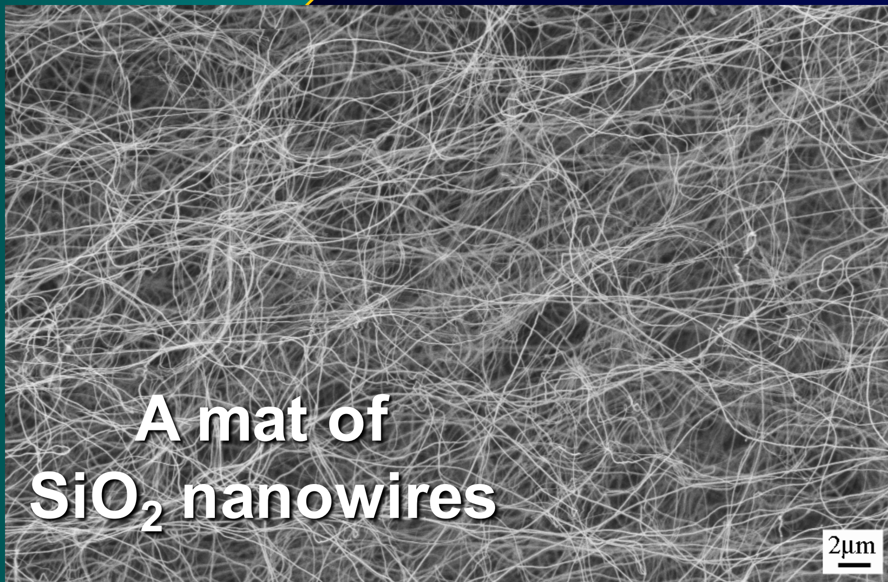
Our Approach

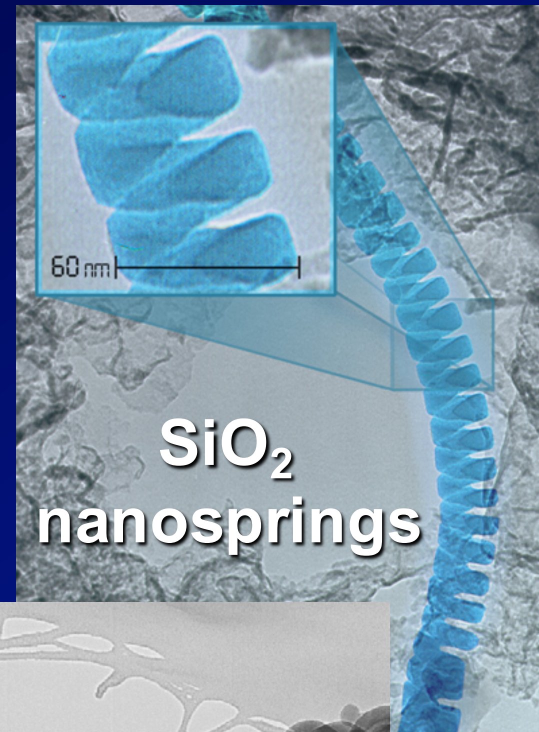
- Attach molecular hydrogen to the surface of nanomaterials through weak surface-molecular bonds

Our Material

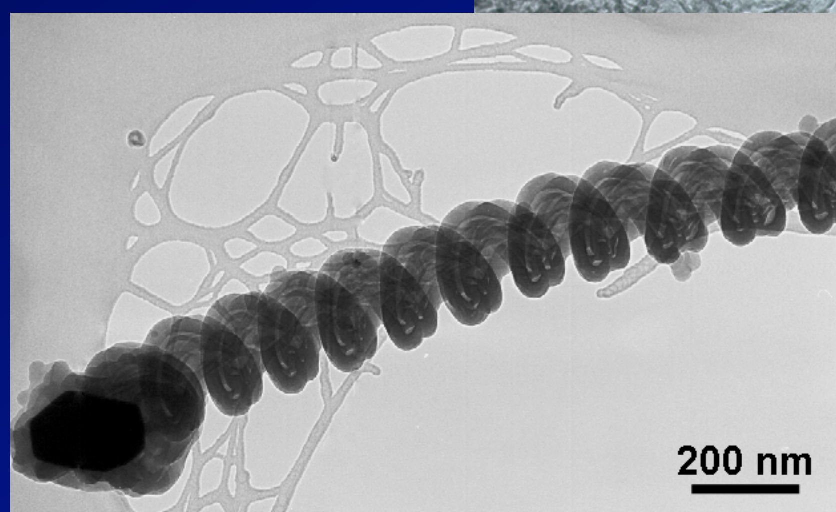
- One dimensional nanostructured glass “springs”

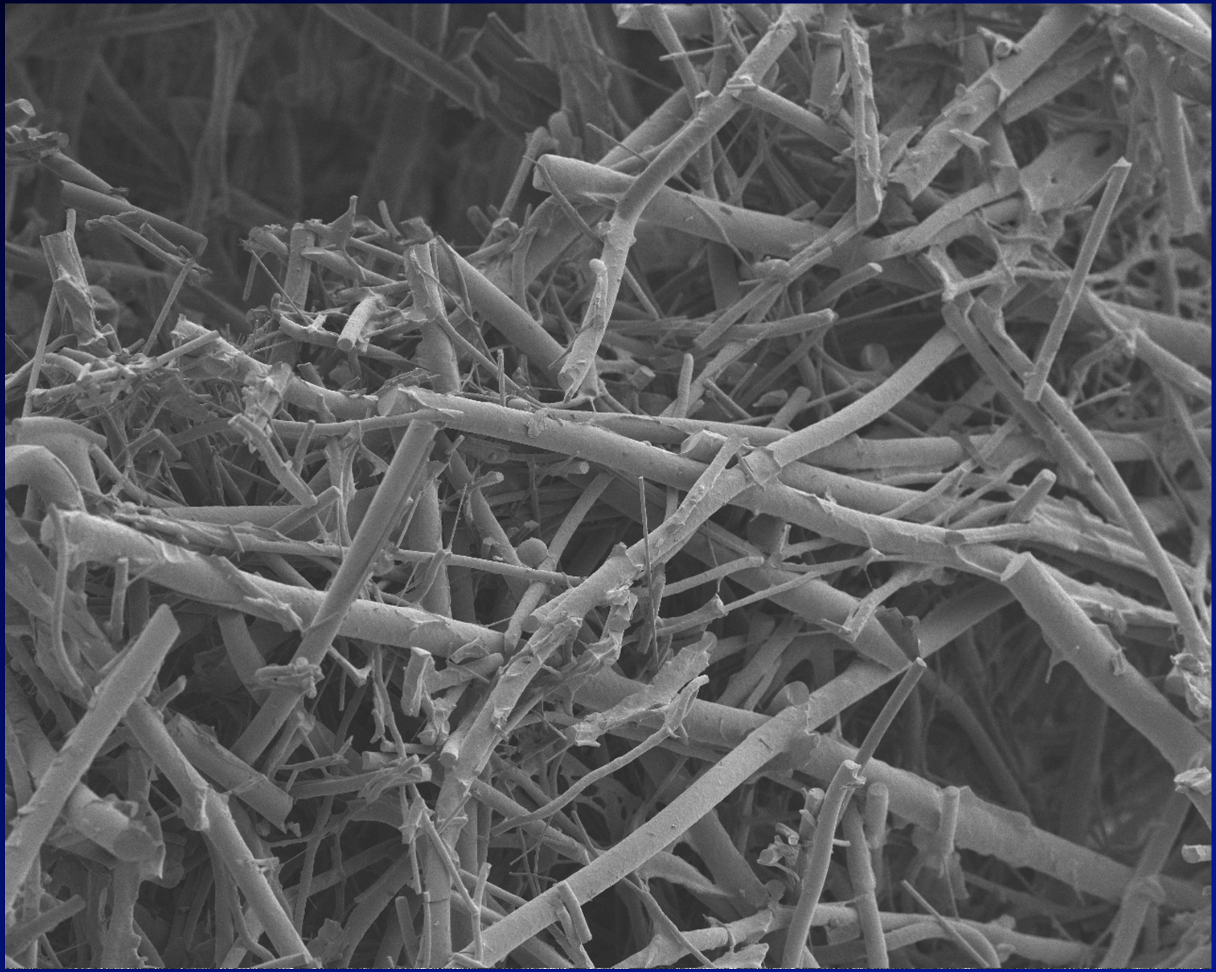
1D Silica Nanostructures





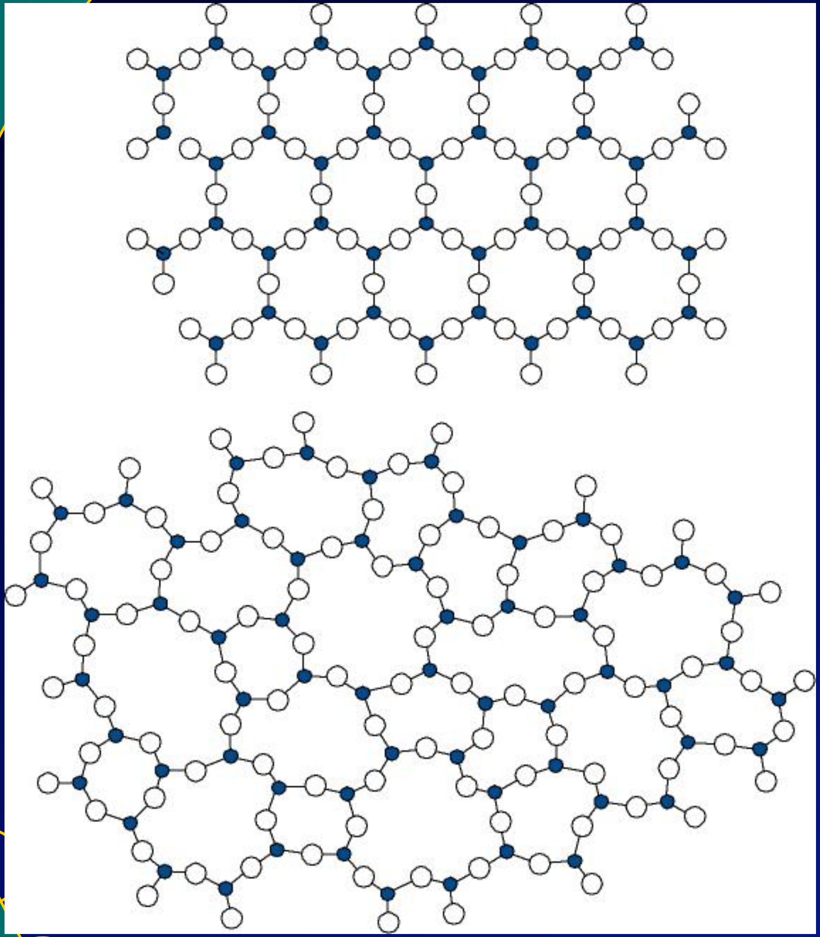
SiO_2
nanocoils





These are silica glass - this is the surface of the space shuttle tiles.
200 nanosprings could fit in each fiber.

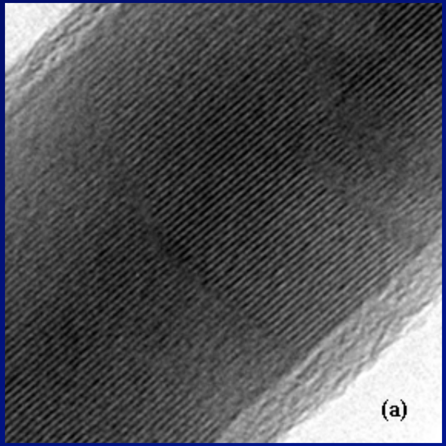
What is a Glass?



A crystal

↔

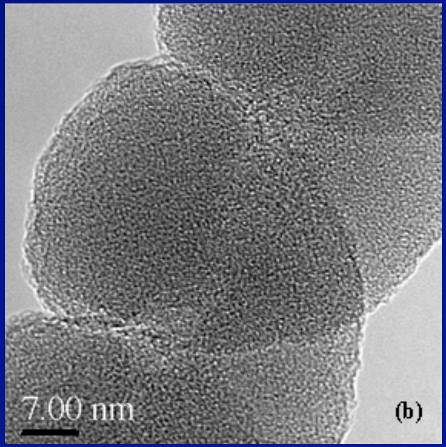
Order



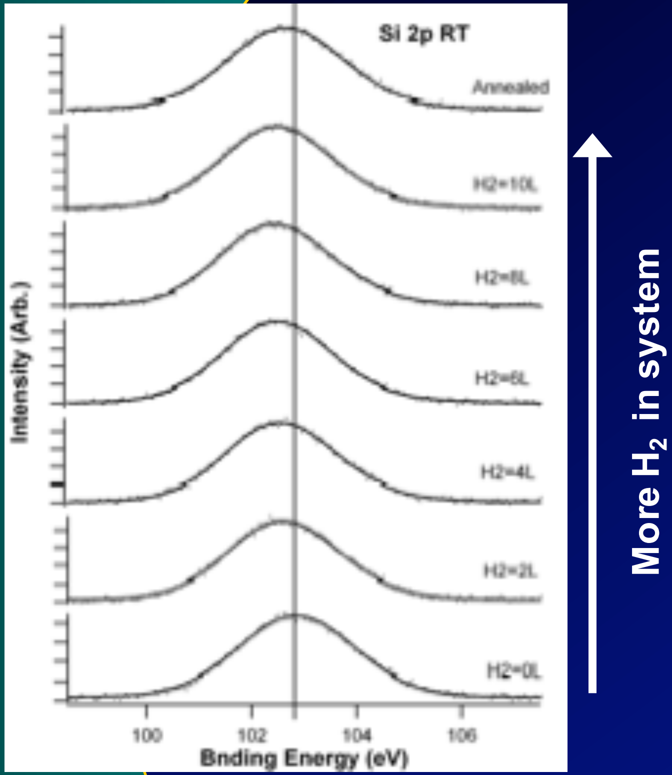
A glass

↔

Disorder



How Do We Know H_2 Attaches?



Si 2p XPS spectra

- We measure shifts in binding energy
- We form a monolayer (one molecule thick) of H_2 on surface
- Additional layers then form on top (coadsorption) This is unique to this system
- The H_2 bonds only to the silicon
- It goes on at 25°C
- It comes off at 100°C
- This is better than any current alternative
- How much goes on?
  More than 5% (gravimetric)
  More than 70% (volumetric)

Need to go from the nanoscale to the macroscale

This can be achieved by forming the nanosprings on polymers (plastics), which can be produced cheaply in complex 3D shapes, e.g., a honeycomb

Fill the channels with nanosprings

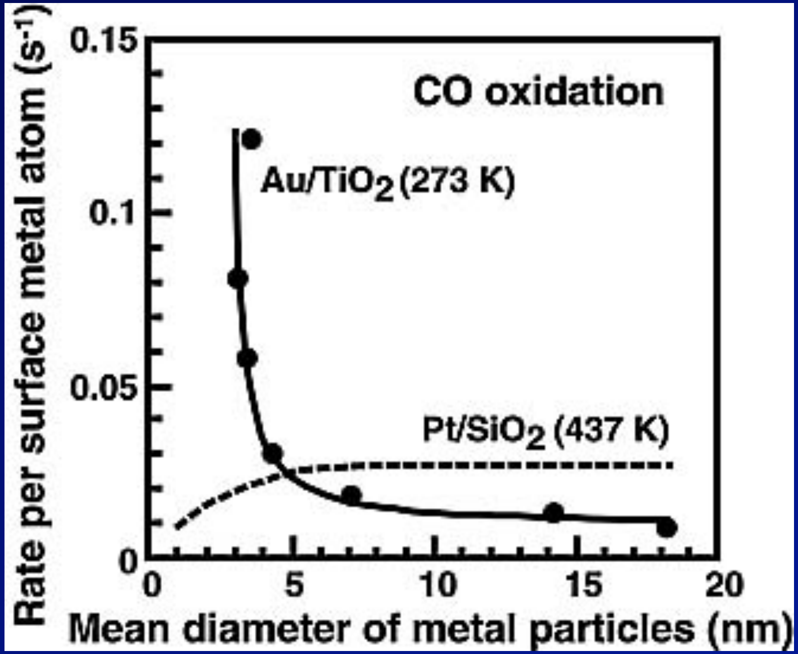
Nanoparticle Catalysts

Catalysts are central to energy conversion

An example is the water gas shift reaction for H_2 production

$$CO + H_2O \rightarrow CO_2 + H_2$$

"Water Splitting"



Reaction rate as a function of nanoparticle size

Gold is only catalytically active at sizes < 10 nm

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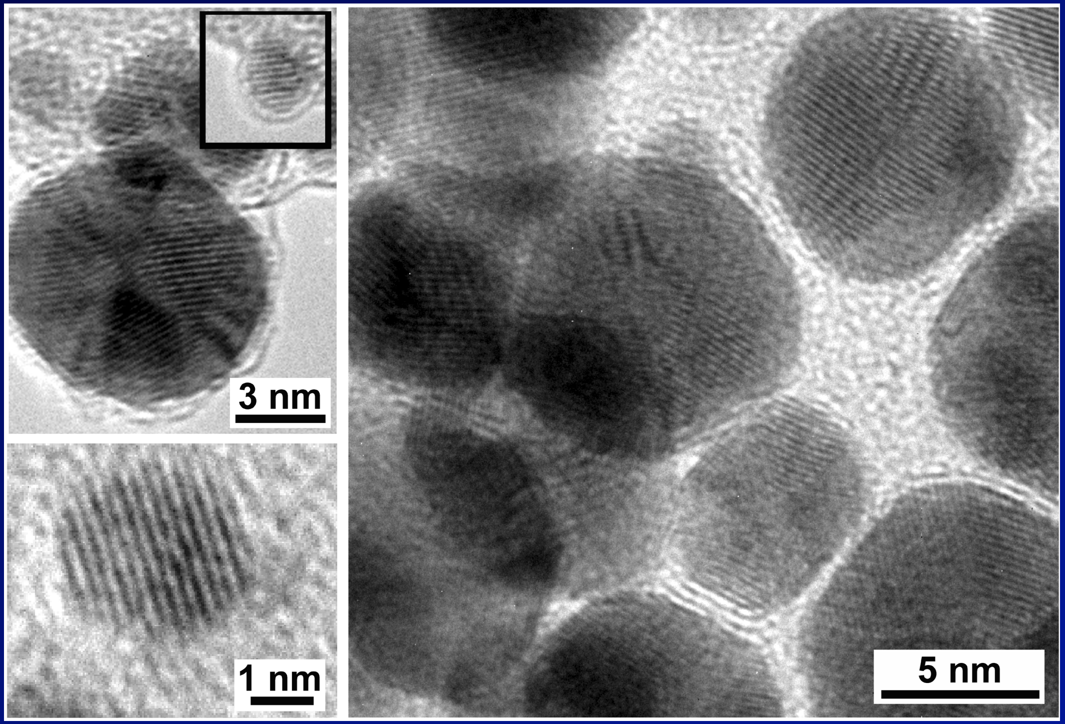
Nanoparticle Gold is Particularly Exciting

1350 BCE

Inert



2006

Potent catalyst

Nanoparticle Gold is Not New

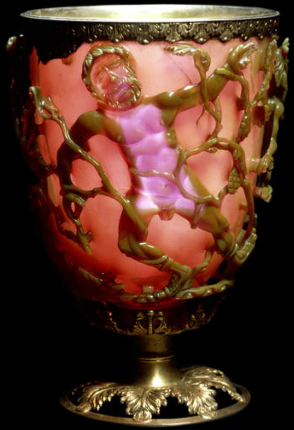
‘Purple of Cassius’
after Andreas Cassius

- 1685
- Color is due to small gold particles

Lycurgus Cup

- Rome 4th Century
- Dichroic — color due to colloidal gold and silver

Reflected light



Transmitted light

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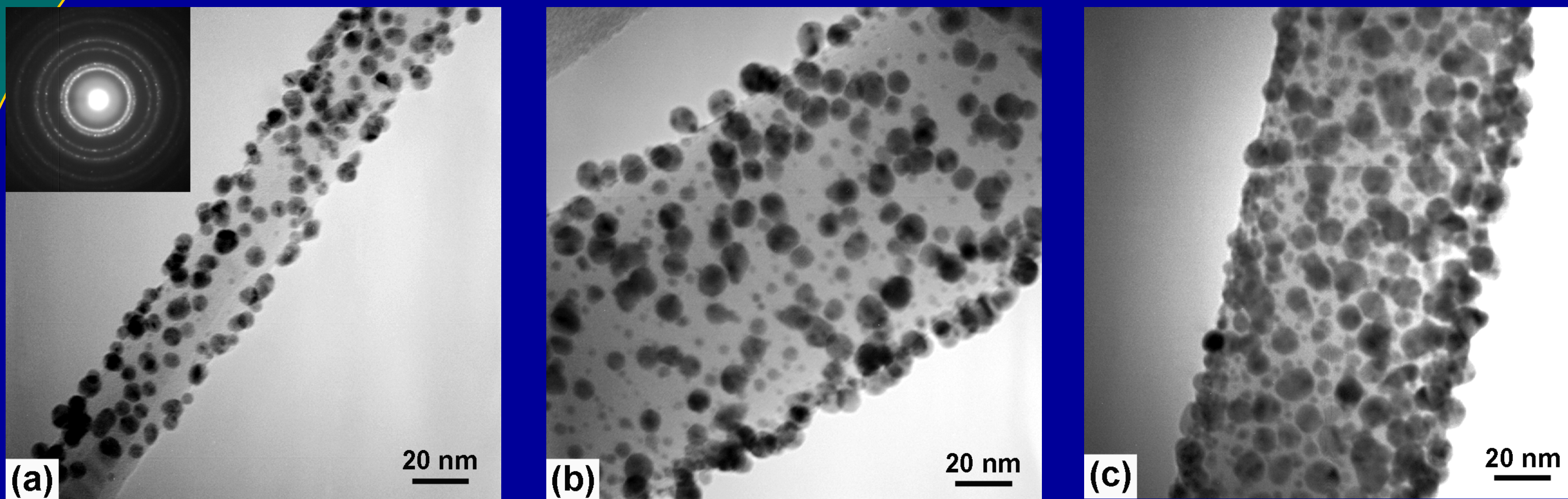
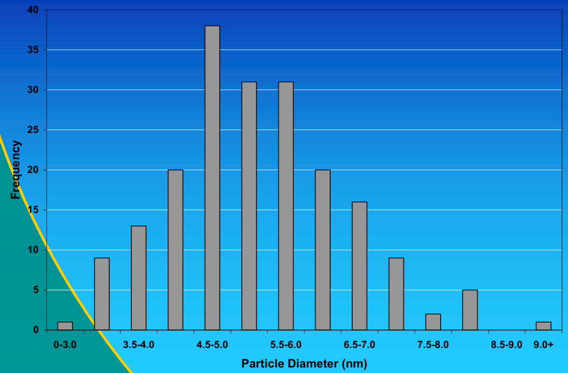
1D Nanostructures as Catalyst Supports

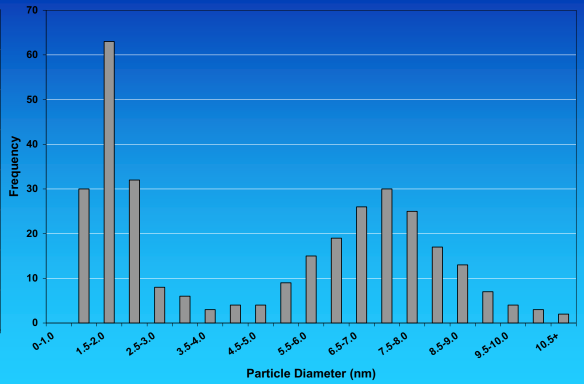


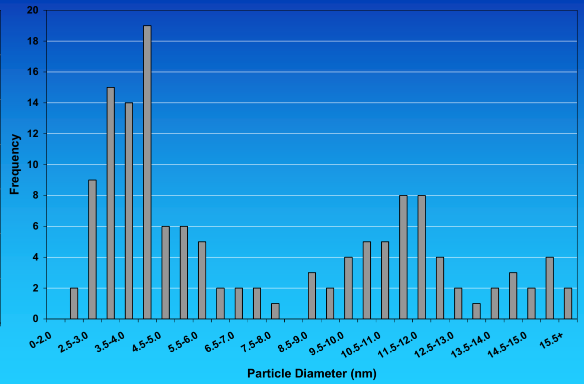
T = 573 K

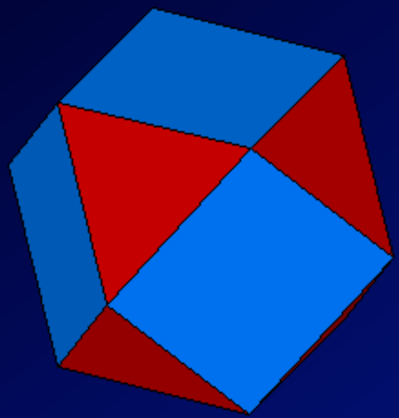
T = 723 K

T = 873 K









Small particles are cubeoctahedra

Significant fraction of atoms occupy surface sites
—not all surface sites are equal

Example:

C=O groups preferentially activated on {111} surfaces;
C=C activated at corner and edge sites

For 3 nm cubeoctahedron:

- Corner atoms 5% Edge atoms 25%
- {100} faces 10% {111} faces 60%

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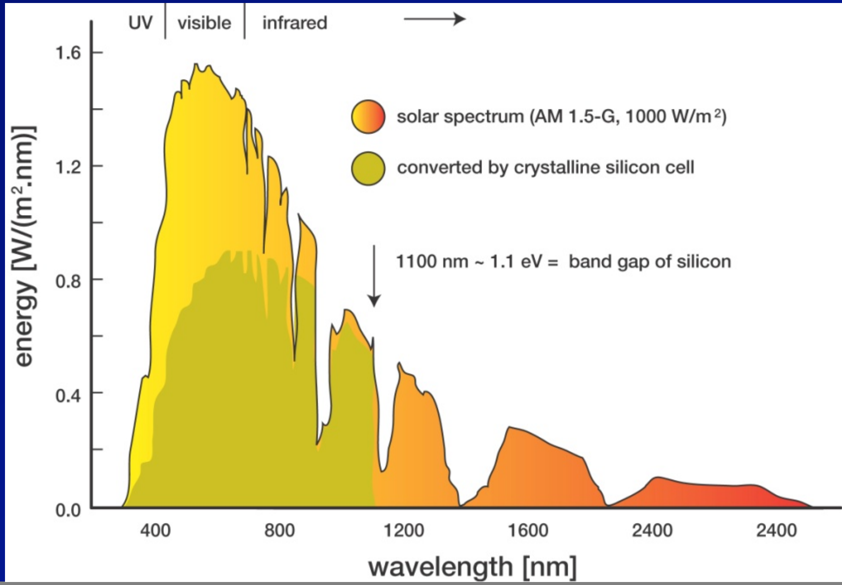
Solar Energy

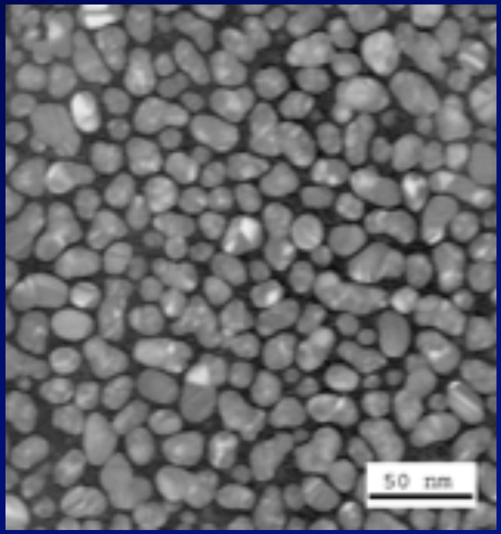
- Sunlight provides by far the largest of all carbon-neutral energy sources
- Solar energy striking the Earth in one hour 4.3×10^{20} J
- Energy consumed on planet in one year 4.1×10^{20} J
- Solar energy provides less than 0.1% of world's electricity



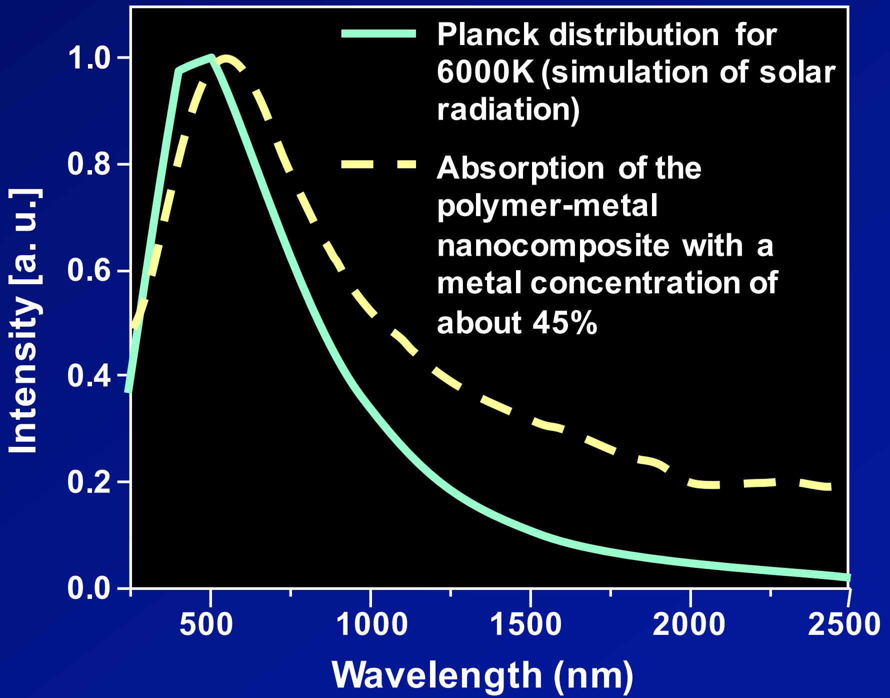
Solar Energy Systems

Nanomaterials may have vital role in improving energy efficiency of solar cells

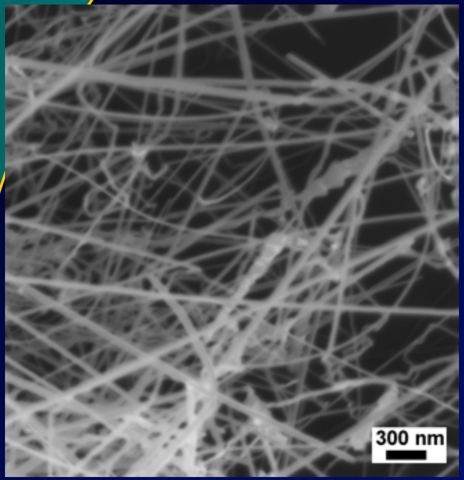
- Efficiency of conventional solar cells limited by absorption range
- Metal nanoparticles have the potential to harvest more of the sun's energy
- Ease of fabrication
- Scale-up



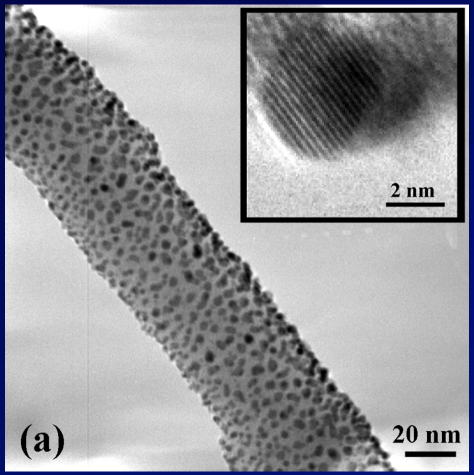
Ag nanoparticles in Teflon AF



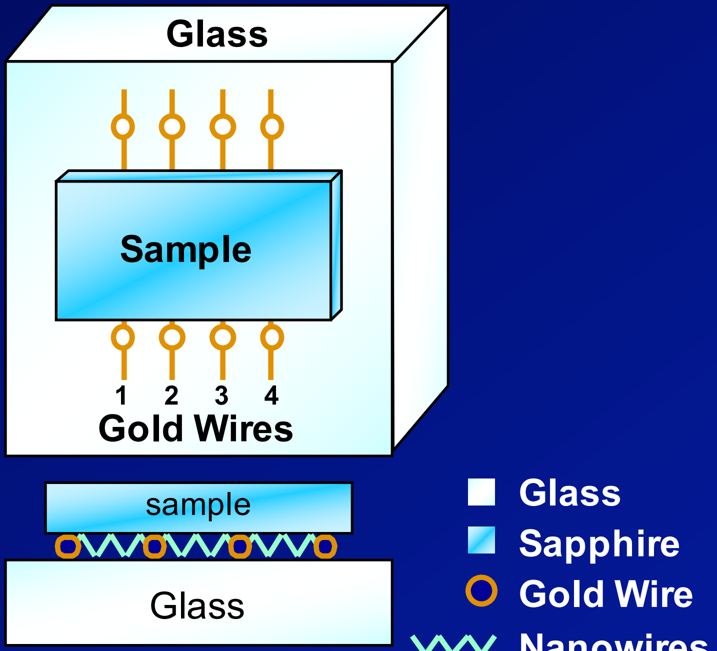
Active Nanosystems for Solar Energy Conversion



Take a mat of semiconducting nanowires (Gallium nitride)

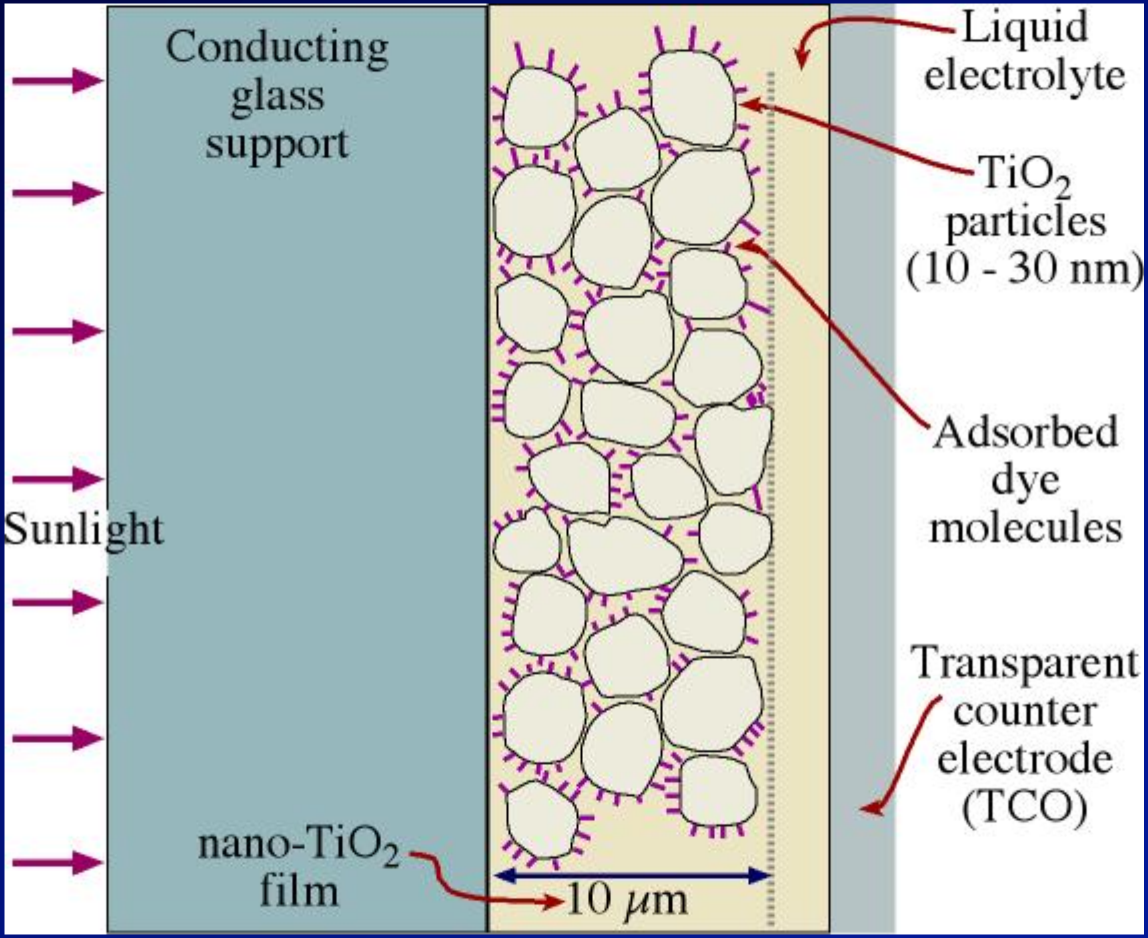


Deposit metal nanoparticles



Build a device

Other Approaches Using Nanomaterials Dye-sensitized Nanocrystalline Solar Cell



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Energy Research — Connecting the Pieces

- Nanomaterials
- “Green” architecture
- Bioenergy
- Solar cells
- Energy harvesting
- Energy efficiency
- Fuel cells

Washington State University has strengths in all these areas — our approach is to coordinate these activities with public policy and outreach to address this grandest of the “grand challenges.”

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