Sustainable & Renewable Energy: the Next Grand Challenge

Catalyzed by Applied Nanotechnology

NanoScience Exchange™

Energy Technologies to Reduce Dependence on Foreign Oil - Oct 2004

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SILICON VALLEY NANO VENTURES

Nano Electronics & Photonics Forum

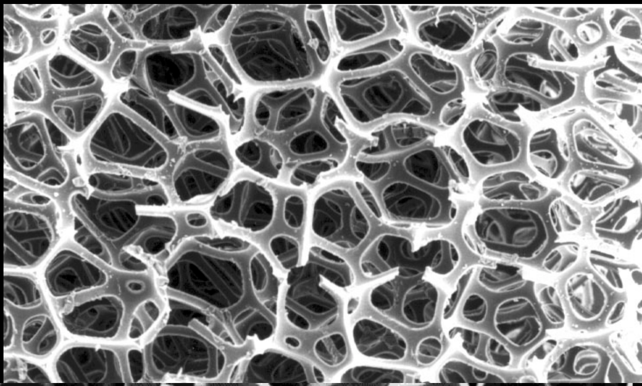
INSTITUTE FOR GLOBAL FUTURES

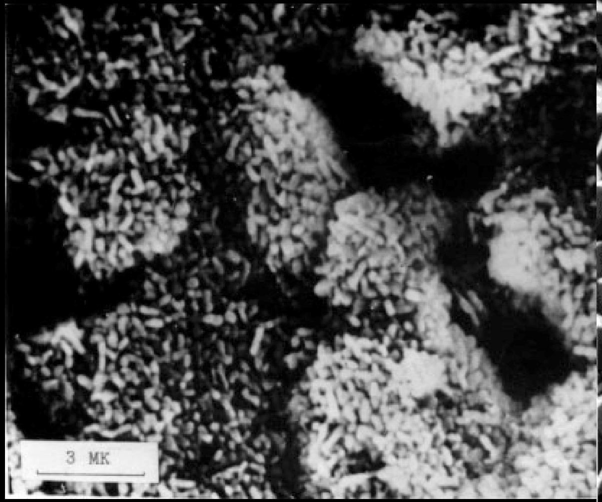
Sustainable and Renewable Energy – the Next Grand Challenge

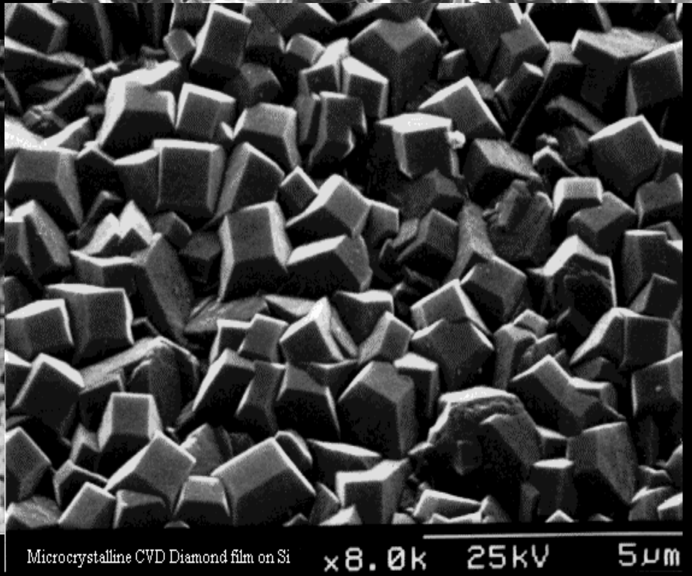
"Nanotechnology needs a ***grand challenge*** . . . "

James Von Ehr, Zyvex

- Production
- Conversion
- Application
- Storage



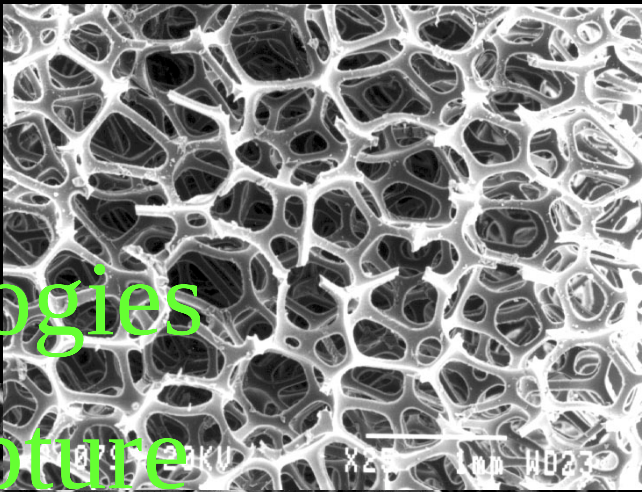


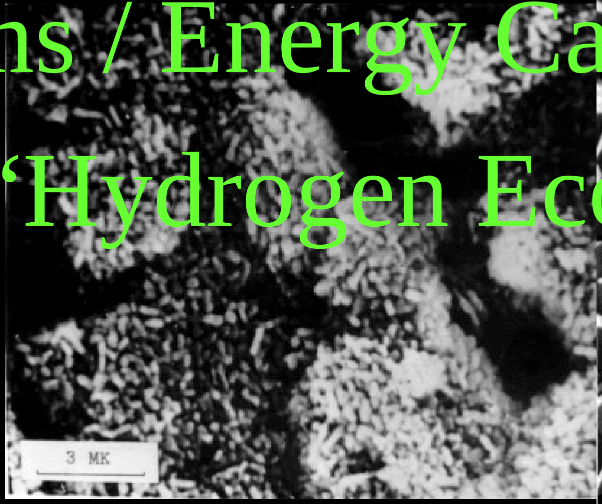


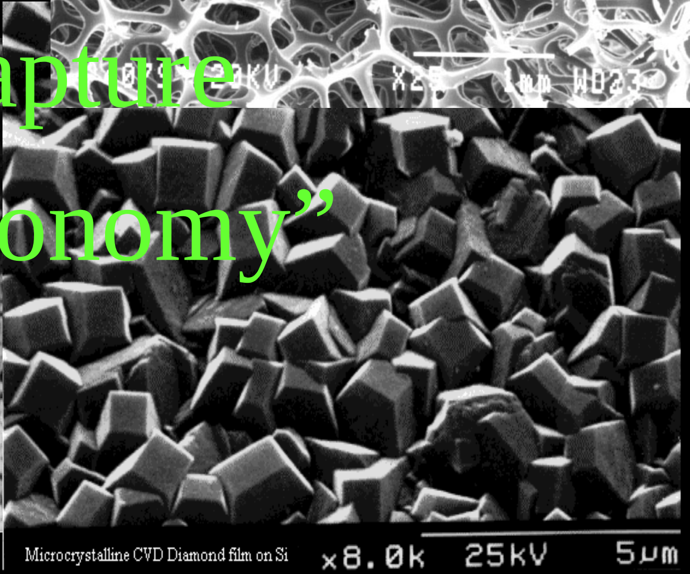
Sustainable and Renewable Energy – the Next Grand Challenge

Nanotechnology in nearterm applications towards

- Solar / Thermal Voltaics
- Batteries / Storage Technologies
- Wind Systems / Energy Capture
- Fuel Cells / "Hydrogen Economy"







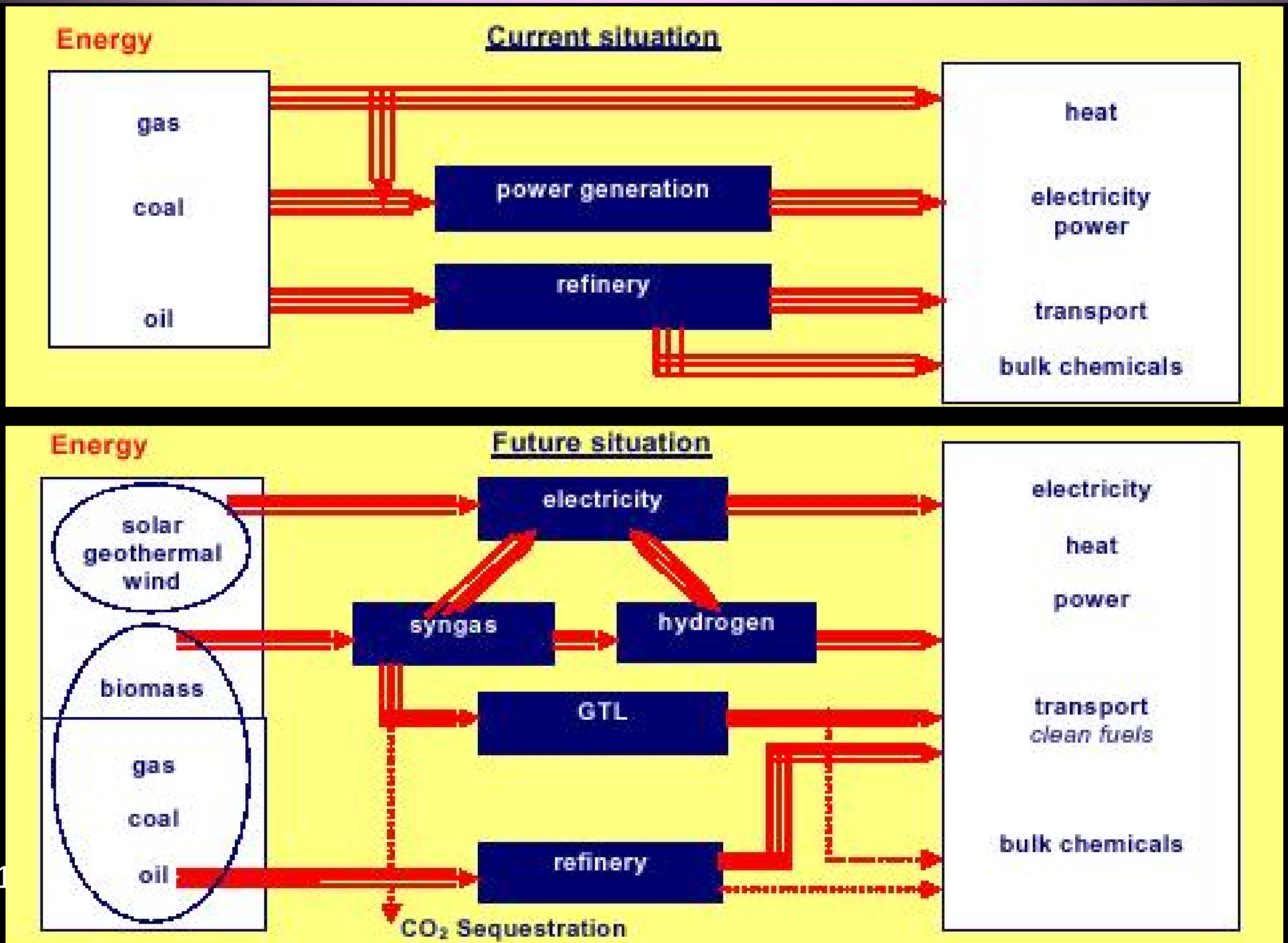
Major Nanotechnology Enabled Energy Applications Related Domains of Interest

- Nanostructured materials in reversible hydrogen fuel storage, high density electrical storage
- Mesoporous 3D structural manifolds in catalysis, storage, and conversion
- hybrid materials consisting of inorganic semiconductors and organic polymers, other variations of organic semiconductors in solar conversion
- Nanocatalysts, membranes, nanostructured materials in fuel cells
- Superconductive and "ultraconductive" nano-materials

Major Nanotechnology Enabled Energy Applications Related Domains of Interest

- carbon nanotubes and nanofibers
- catalysis materials
- nano-scale powders and particulates
- membranes and thin films
- organic semiconductors
- nanostructured materials and macro-molecules
- hybrid nano-material systems
- roll to roll “on demand” manufacturing
- self organizing and self assembling materials systems
- Utilizing Biology as a Foundry System

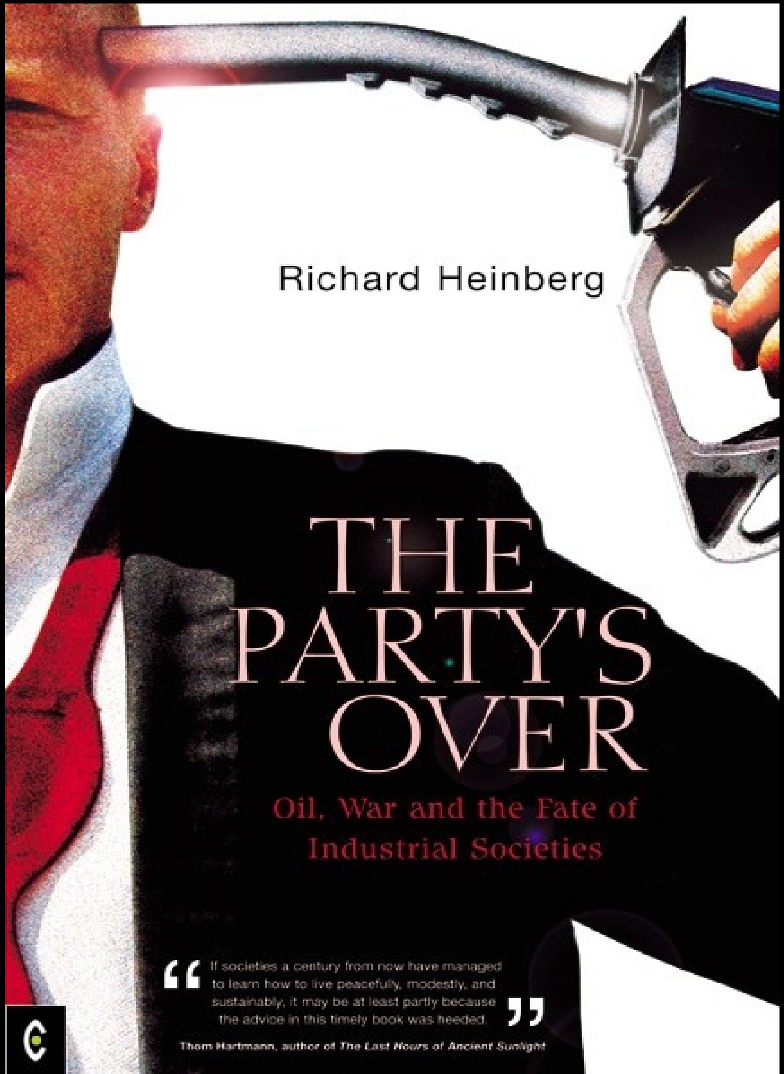
Current and Future Energy Situation - Catalysis Enabled Evolution



Peak Oil Threshold – at the Event Horizon

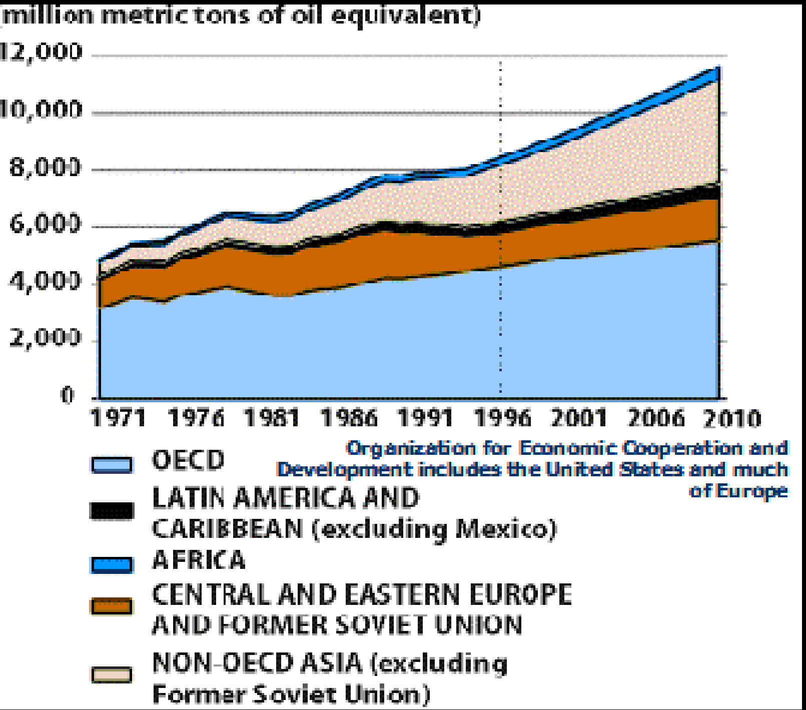
The Party’s Over

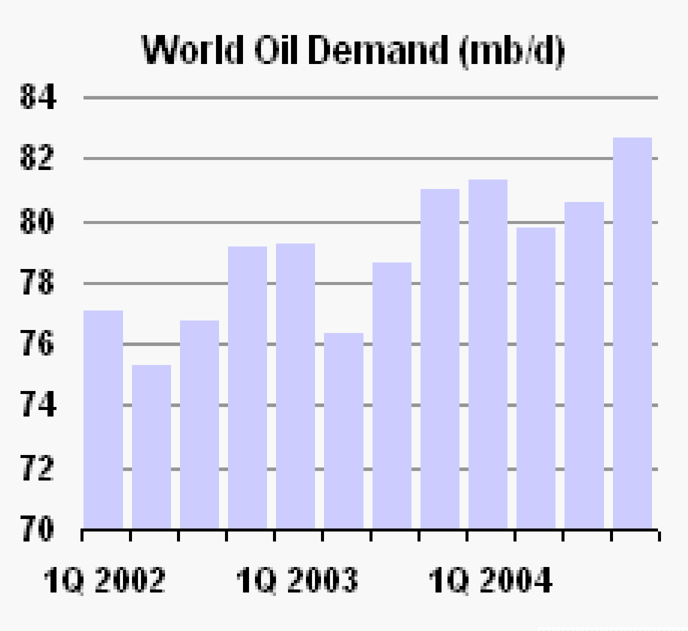
Richard Heinberg

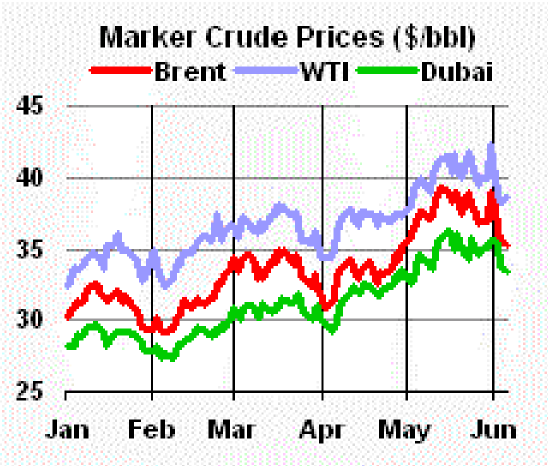


MAP OF MIDDLE EAST OIL RESERVE DISTRIBUTION

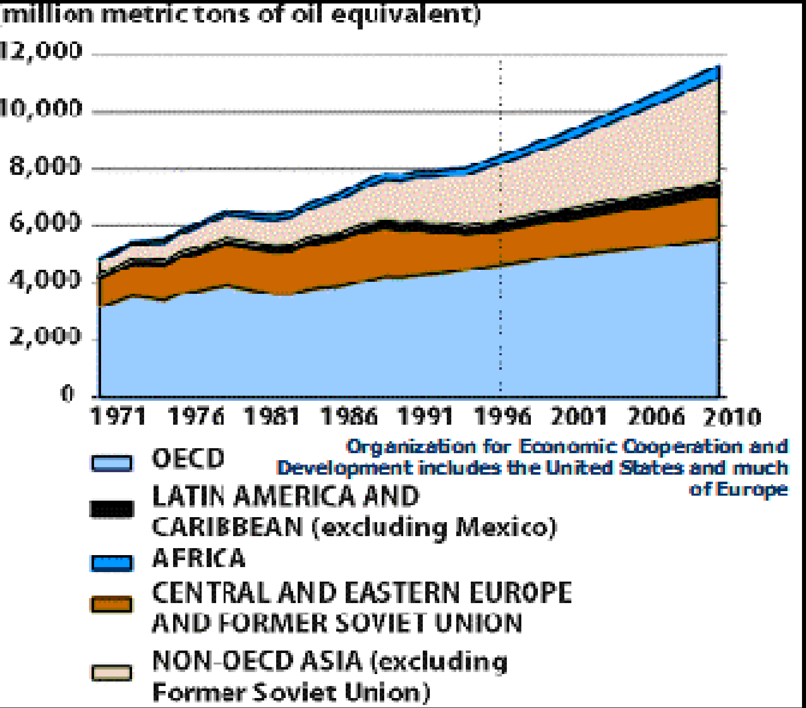
World Oil Demographics – Upward Consumption Vectors







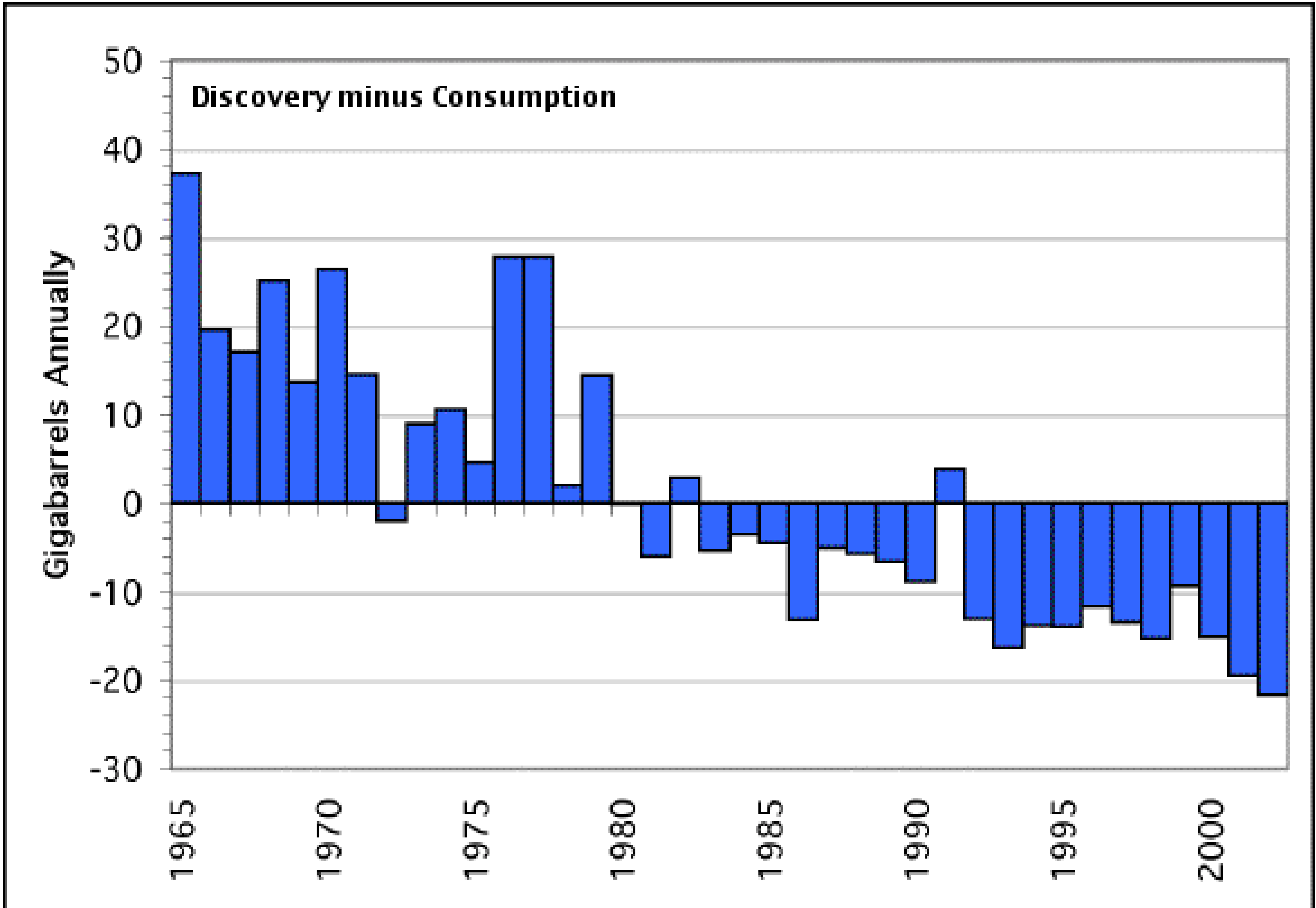
World Oil Demographics –
Upward Consumption Vectors
Downward Resource Drivers



- Geo-Political Complexities
- Sporadic Supply Logistics
- Exotic Extraction Technologies and Processes

Exotic Solutions – Next Generation Oil Rig . . .


The new drilling rig

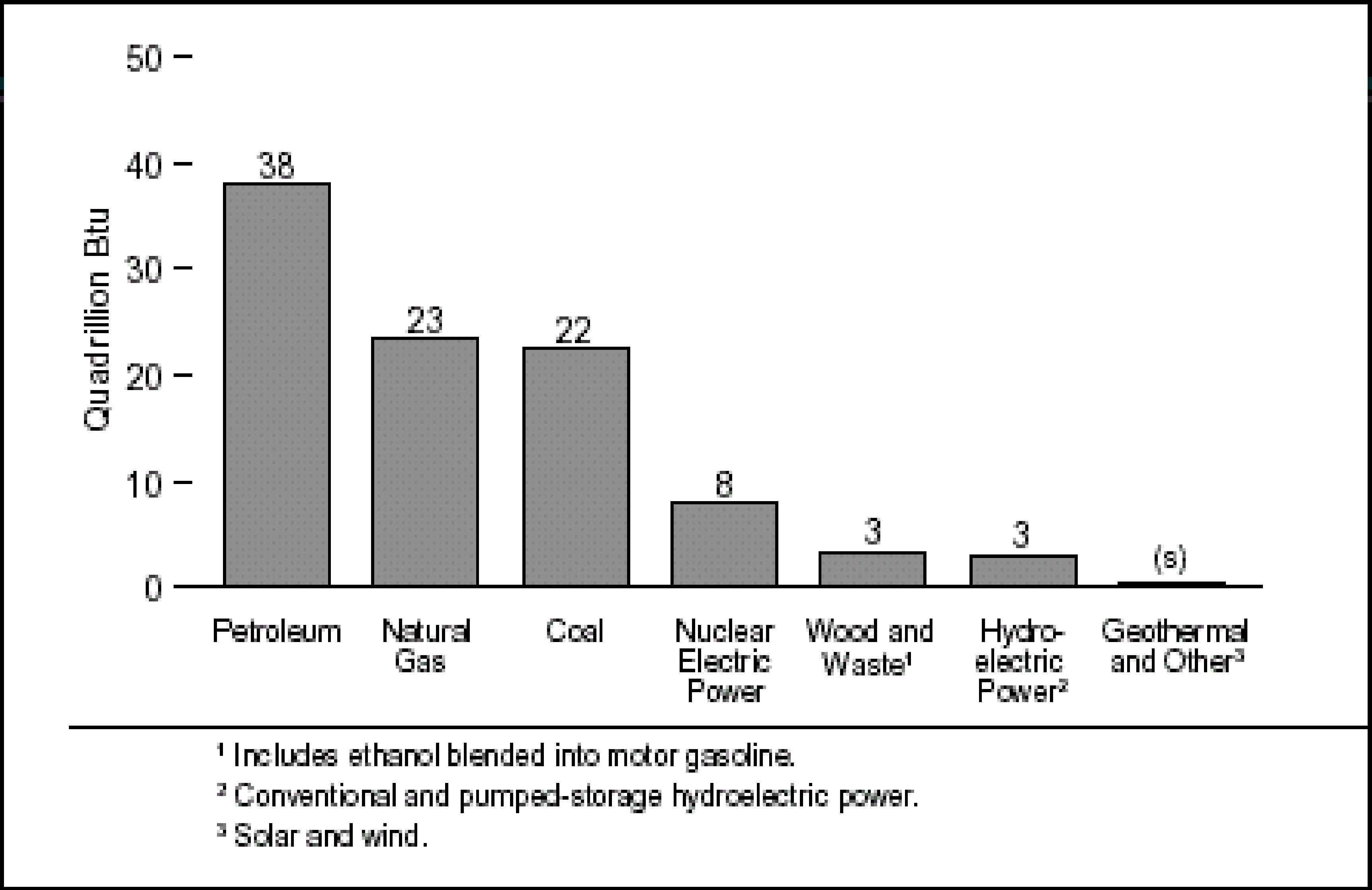

Discovery minus Consumption
Gigabarrels Annually
50
40
30
20
10
0
-10
-20
-30
1965
1970
1975
1980
1985
1990
1995
2000

Peak Oil Threshold – at the Event Horizon

Are low cost **solar voltaics, fuel cells, wind power systems,** and other alternative energy options far off in the future? Is the **"hydrogen economy"** just a distant dream of a future 20 years away? Think our only energy policy option is perpetual addiction to current foreign oil resources? Think again . . .

Though many of these alternative and sustainable energy concepts are not new, recent breakthroughs in technology, in particular, **nanotechnology**, which enables a broad new spectrum of **materials systems** and **manufacturing processes**, dramatically changes the potential cost of development and deployment of **alternative energy options**

US energy consumption by source



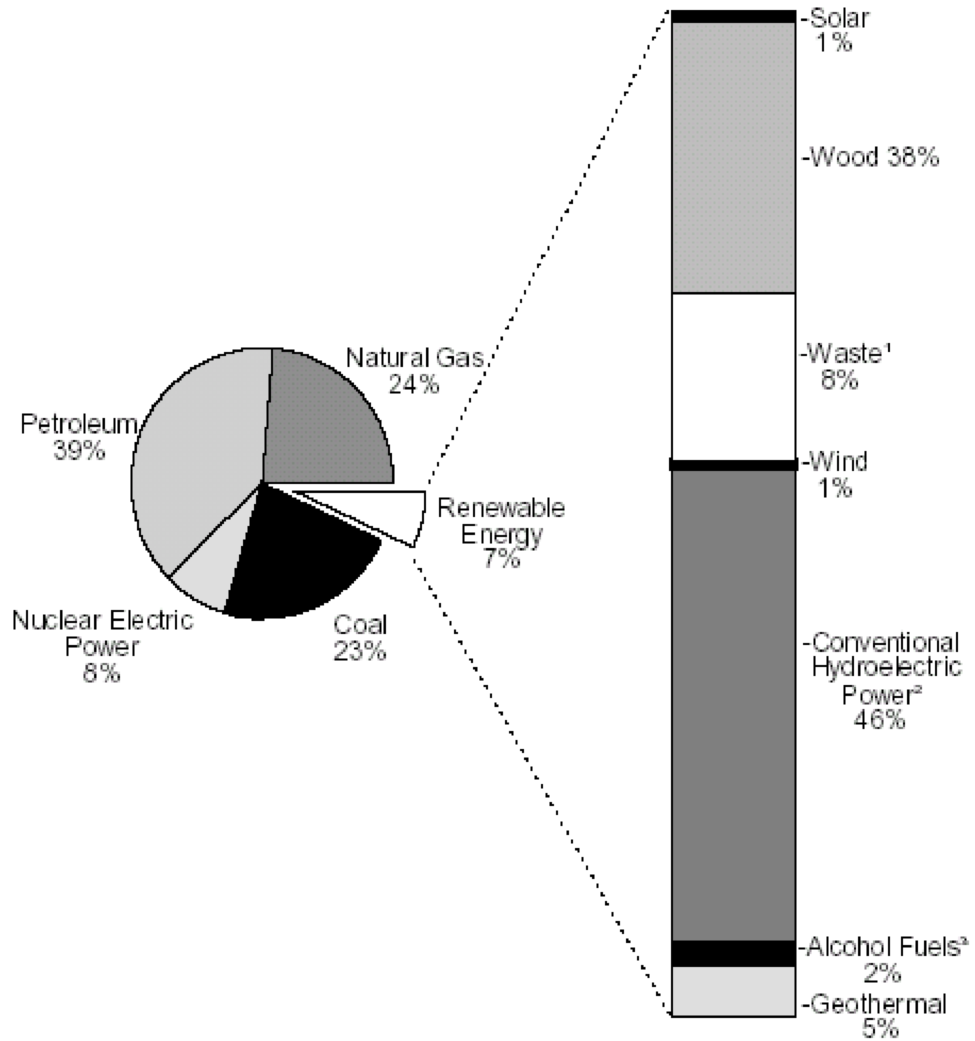
Source: US Energy Information Agency

Renewable energy as share of total US energy consumption

Hydro-Electric	46%
Wood	38%
Waste	8%
Geothermal	5%
Alcohol Fuels	2%
Solar	1%
Wind	1%

Source: US Energy Information Agency

10/12/2004



[1] Municipal solid waste, landfill gas, methane, digester gas, liquid acetonitrile waste, tall oil, waste alcohol, medical waste, paper pellets, sludge waste, solid byproducts, tires, agricultural byproducts, closed loop biomass, fish oil, and straw.

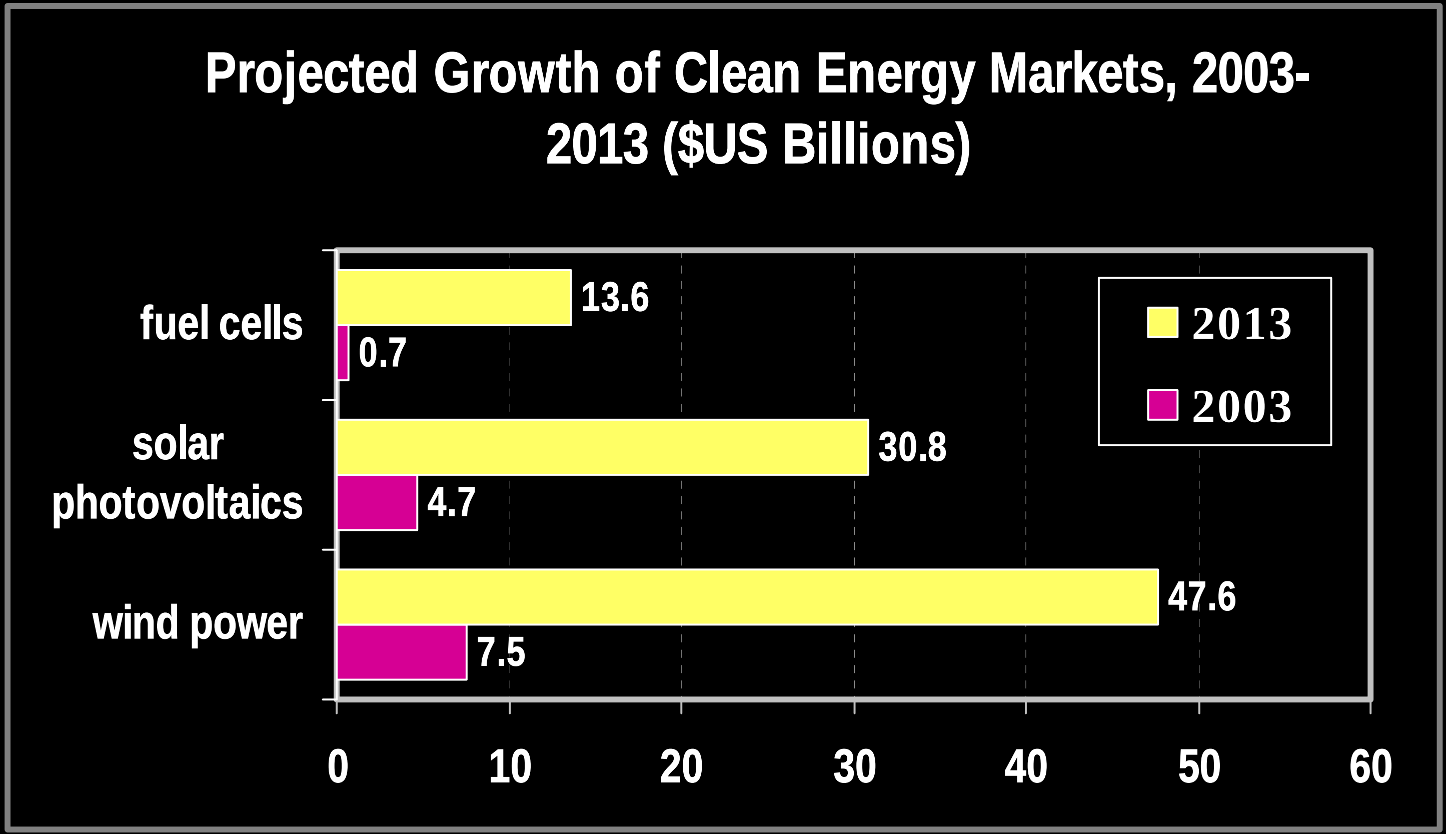
[2] Includes electricity net imports derived from hydroelectric power. Before 1989, includes net imports derived from all resources.

Distributed / Decentralized Power

Specific Solution Sets for Specific Situations

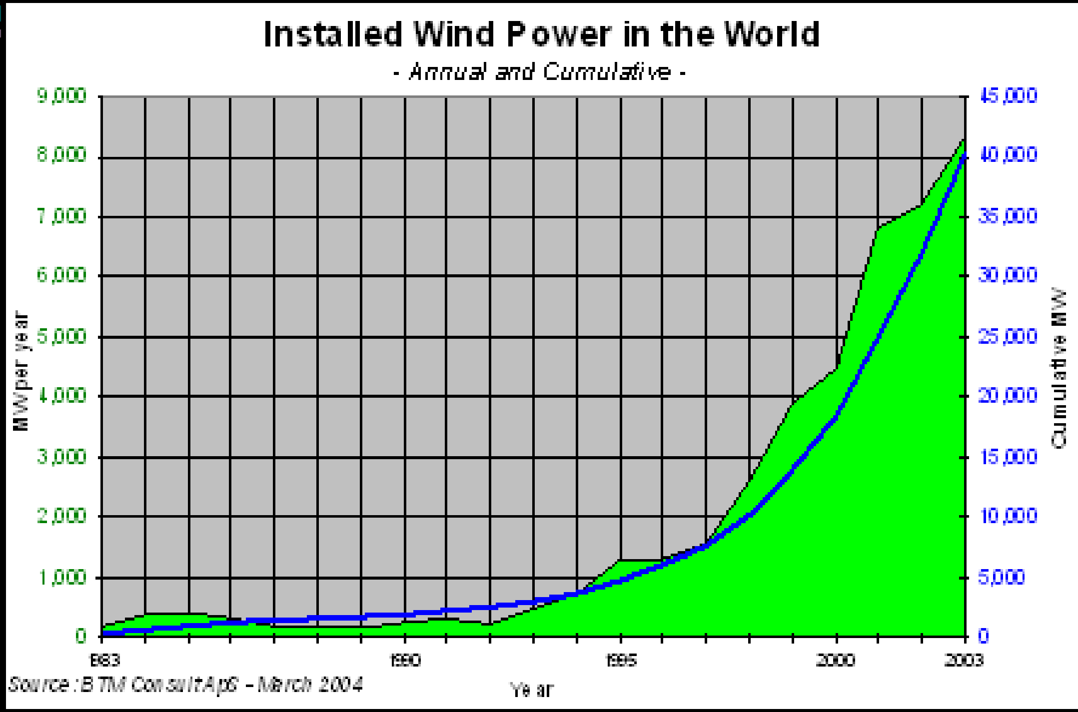
- relatively low insertion cost to bring energy capture and conversion into many diverse and remote situations
- encourages localized ownership of energy technology
- allows for independent deployment of solutions for immediate energy needs without the requirement of compliance to large complex energy systems, and highly centralized socio-economic regulatory authorities

Renewable Energy: A Small But Rapidly Growing Market Segment



Source: Clean Edge 2004

Installed Wind Capacity is Rapidly Growing, Especially in EU and US

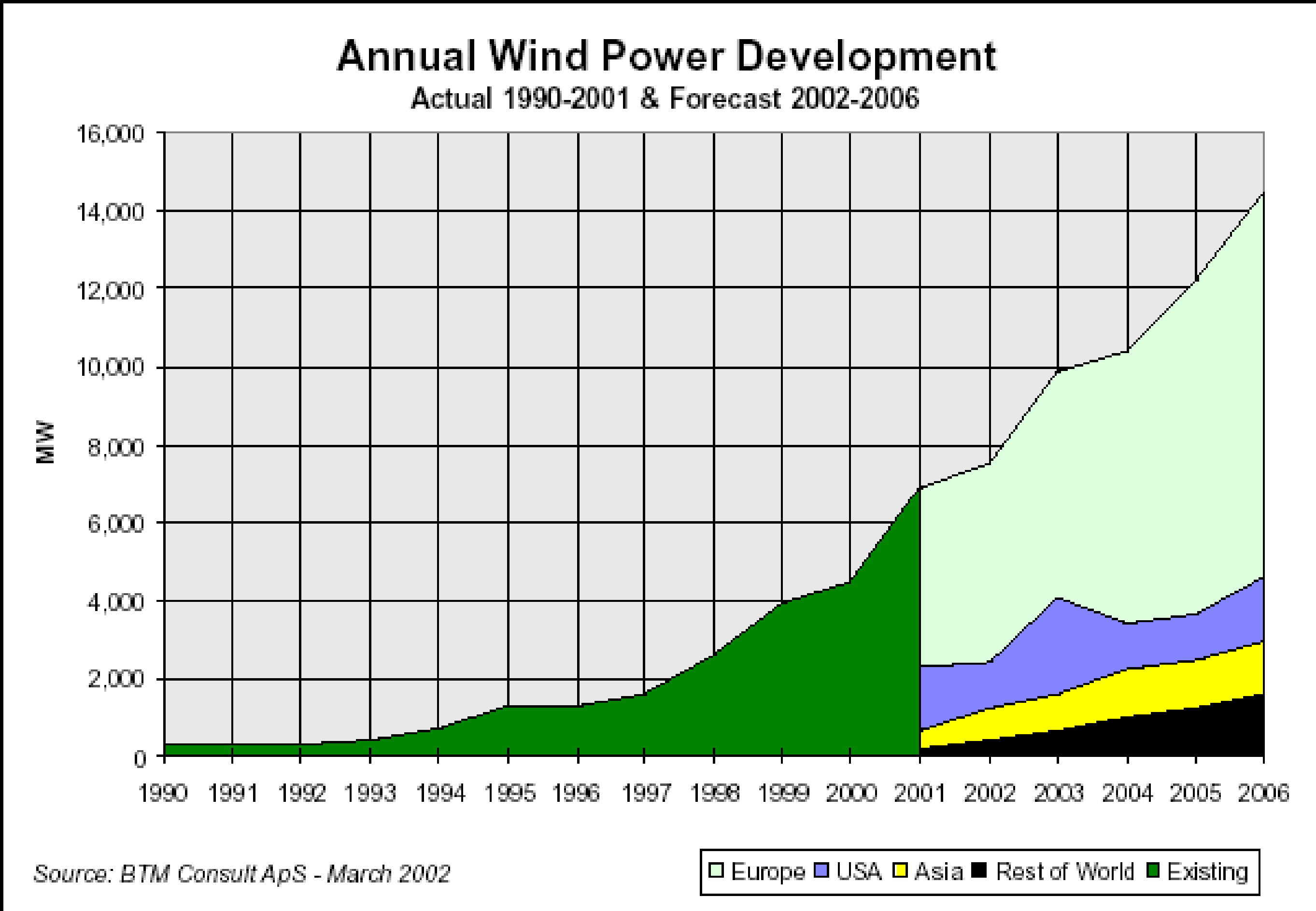


6,361 MW of wind currently installed in U.S.

Year:	Installed MW	Increase %	Cumulative MW	Increase %
1998	2,597		10,153	
1999	3,922	51%	13,932	37%
2000	4,495	15%	18,449	32%
2001	6,824	52%	24,927	35%
2002	7,227	6%	32,037	29%
2003	8,344	15%	40,301	26%
Average growth - 5 years		26.3%		31.7%

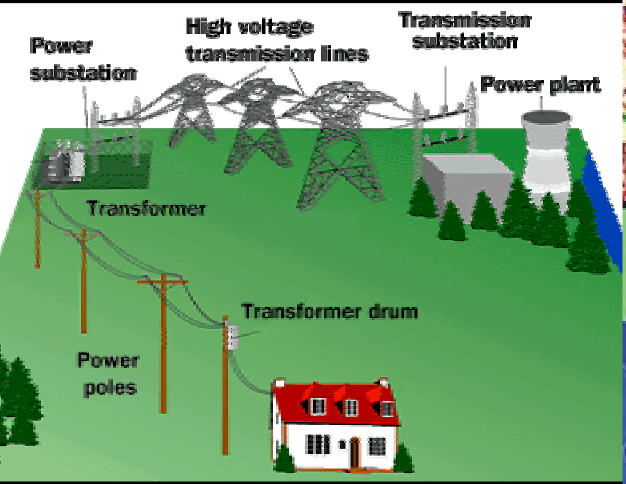
Aggressive Growth in Wind Installations is Expected to Continue

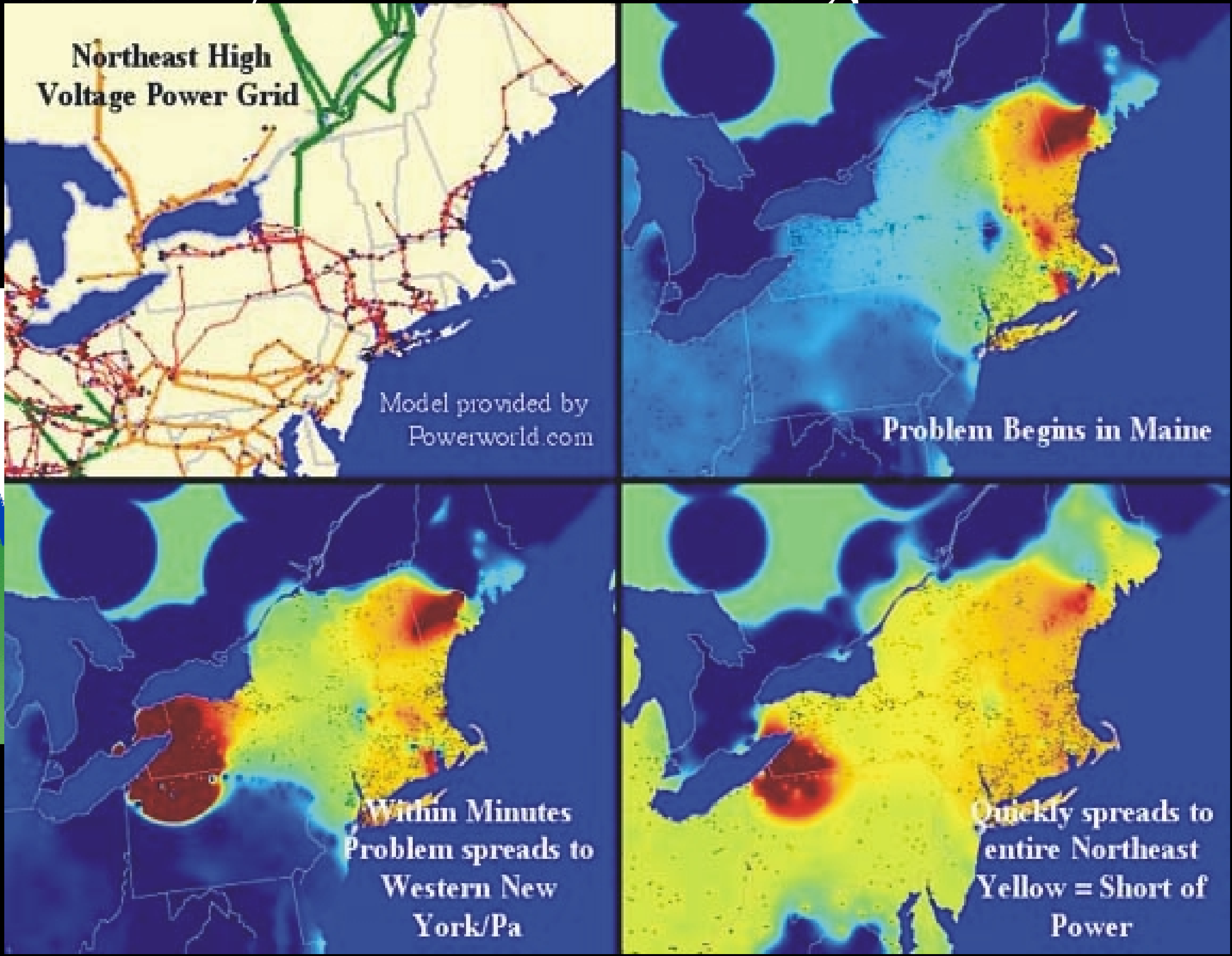
- **8,344 MW of new wind installations in 2003 represents >$8 billion in sales**
- **14,000 MW of expected 2006 installations represents ~ $14 billion of sales**



Fundamental Questions

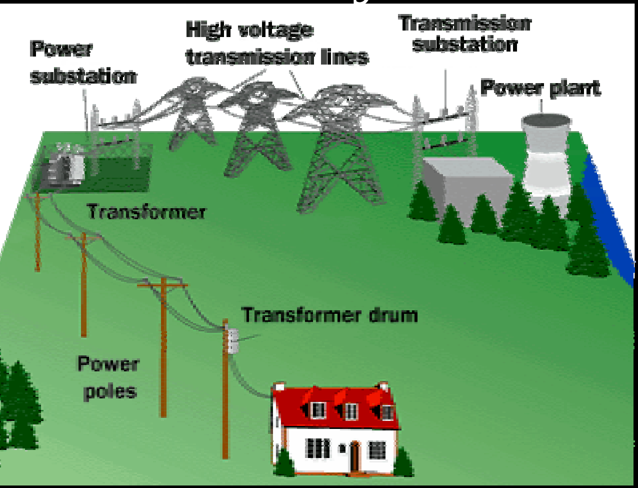
- Does electricity necessarily need to be "on the grid" for all uses?





Fundamental Questions

- Does electricity necessarily need to be "on the grid" for all uses?
- Does fuel for transportation necessarily have to come from refined hydrocarbons / biomass?



Define “Alternative” Fuel . . .

- Production of ethanol as an alternative fuel source, derived from corn as an example, requires more energy to grow and refine, than the actual fuel energy yield

Hydrogen – A Second Look – What if . . .

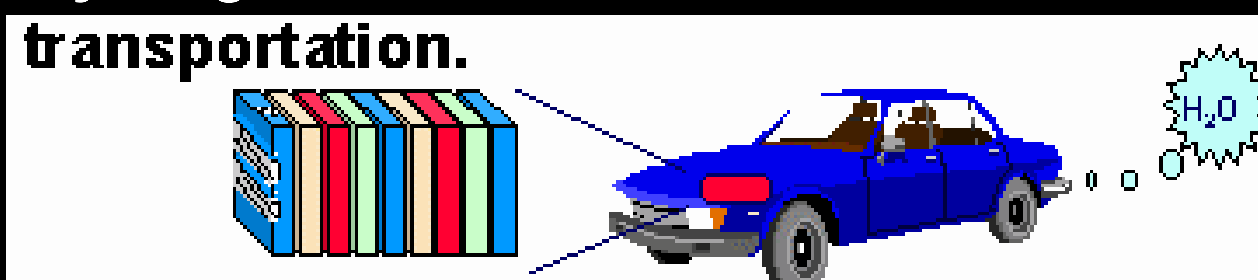
- Nanostructured materials, such as carbon nanotubes, and other mesoporous materials being developed for reversible storage
- Hydrogen production can become a new industrial infrastructure
- Modification to existing transportation vehicles relatively minor
- ***Wind generated electrical energy to create the hydrogen –*** nanostructured materials, as in lubricants and composite materials, can be applied to improved wind turbine performance, MTBF

Hydrogen fueling dispenser at the Las Vegas Energy Station - Air Products and Chemicals, Inc.

Hydrogen – Purported Arguments Against

- Requires enormous investments in electrical energy, such as from nuclear power plants, to create the hydrogen
- Dangerous, difficult to store and retrieve
- Disruptive to an already existing petroleum / ethanol fuel production infrastructure

Hydrogen Fuel Cells in



Hydrogen Infrastructure – Current, Future

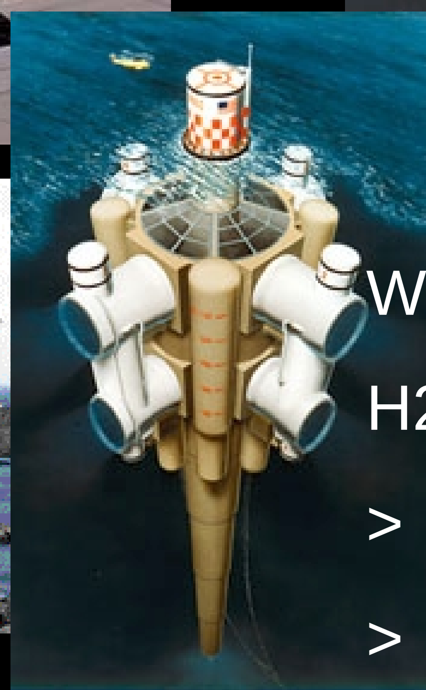
Congressman George Miller, (D-CA) testing the new hydrogen fuel pump at AC Transit's bus operating Division in Richmond, CA

Hydrogen Infrastructure – Current, Future

Figure 1. Xcellsis (Ballard) ZEbus

Figure 2. Mercedes-Benz NeBus

Hydrogen Infrastructure – Current, Future



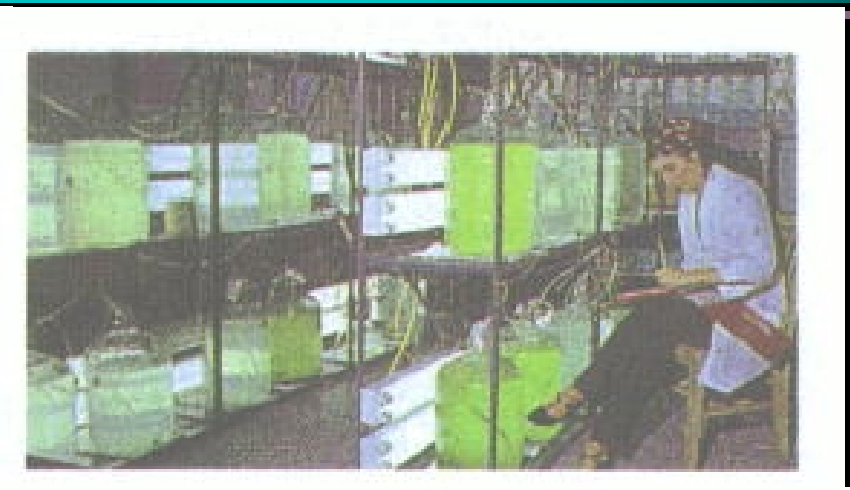
Wind + Ocean Currents

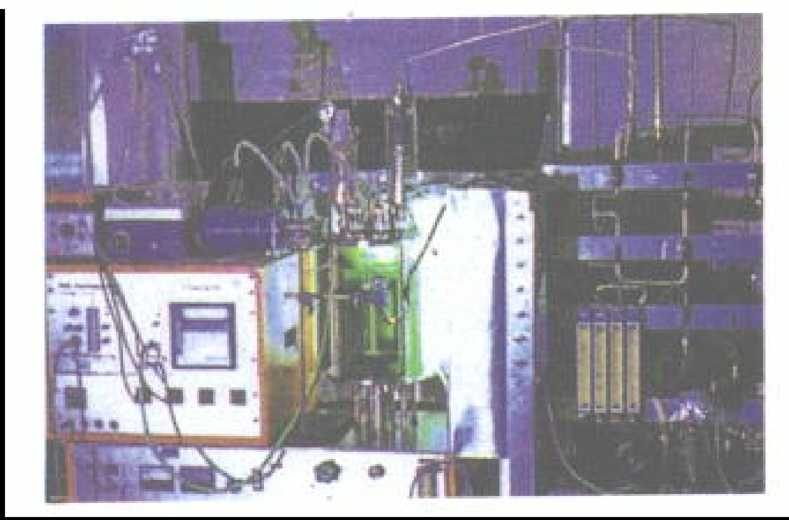
H2O + Electrolysis > Hydrogen

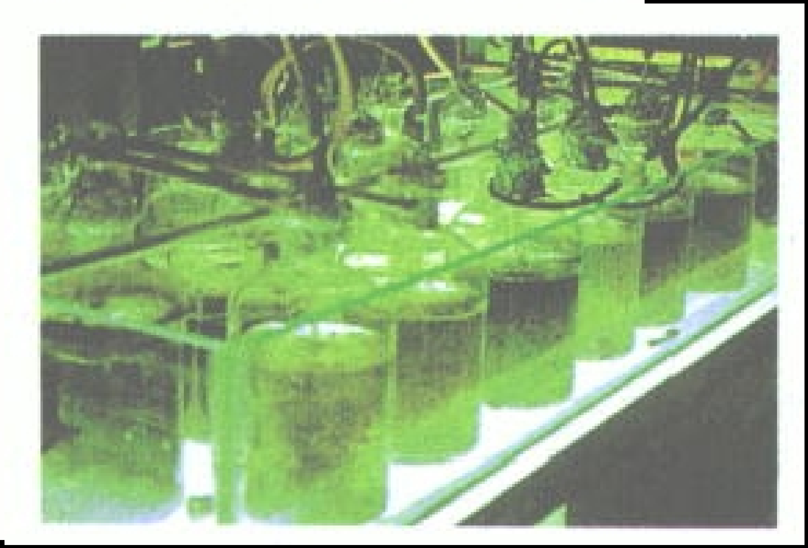
> Liquified Bulk Transport

> Distribution – auto, air, gen

Bio Hydrogen
- can we Grow Energy Efficiently?







Genomes for Energy: Harnessing Genome Power to Serve DOE Missions

scientific foundations → payoffs

Human Genome Project

In 1987 the DOE Office of Science launched the international Human Genome Project through its Biological and Environmental Research program. In 1994 BER began the Microbial Genome Program to apply the new technologies to further serve DOE missions.

Genomics technologies now produce a great diversity of data on genes. Genes control the synthesis of proteins responsible for the vast array of physical capabilities of life on earth—seen and unseen.

GENOMES to LIFE

BIOLOGICAL SOLUTIONS FOR ENERGY CHALLENGES

INNOVATIVE APPROACHES ALONG UNCONVENTIONAL PATHS

To achieve the full potential of the revolutionary advances in genomics and other biotechnologies, BER teams with the Advanced Scientific Computing Research program to take on an even greater challenge:

- To understand how genes, proteins, and, ultimately, cells work and how to put them to use.

GTL will use "nature's catalog" of microbial gene capabilities to develop an innovative, cost-effective tool kit for carrying out DOE missions.

Develop abundant clean energy sources and reduce dependence on foreign energy sources

Reduce global warming

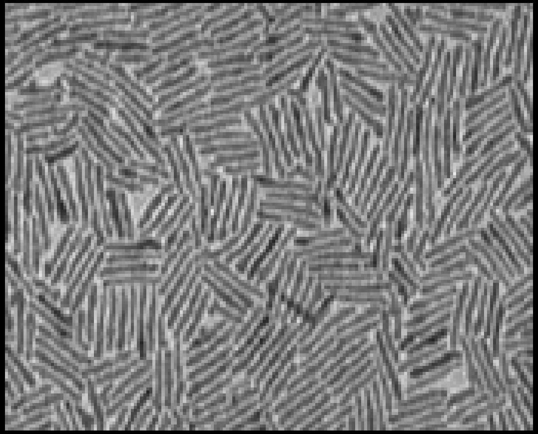
Clean up toxic waste from nuclear materials production

1987 1994 2001 the next step → future

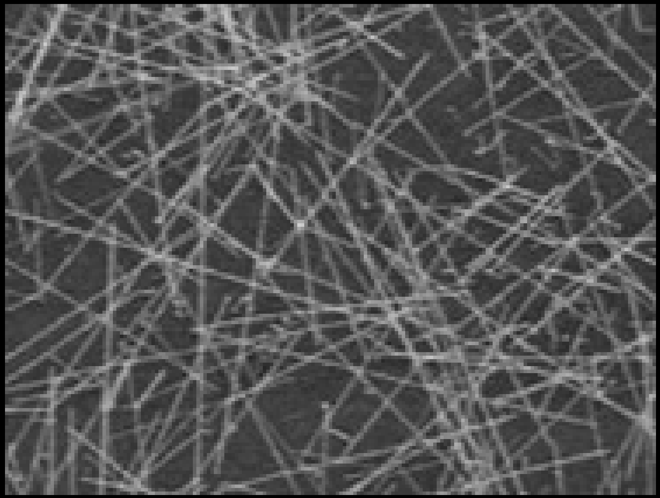
YGG-01-0396a

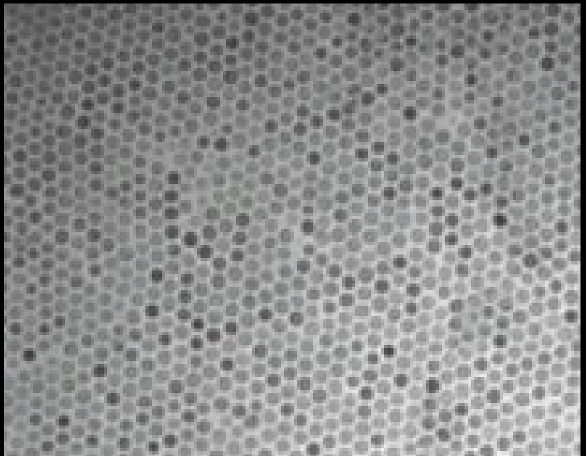
Nanofoundry – Nanostructured Materials

- Foundry processes / fabrication techniques enabling mass production of nanoparticles
- Broad range of functionality



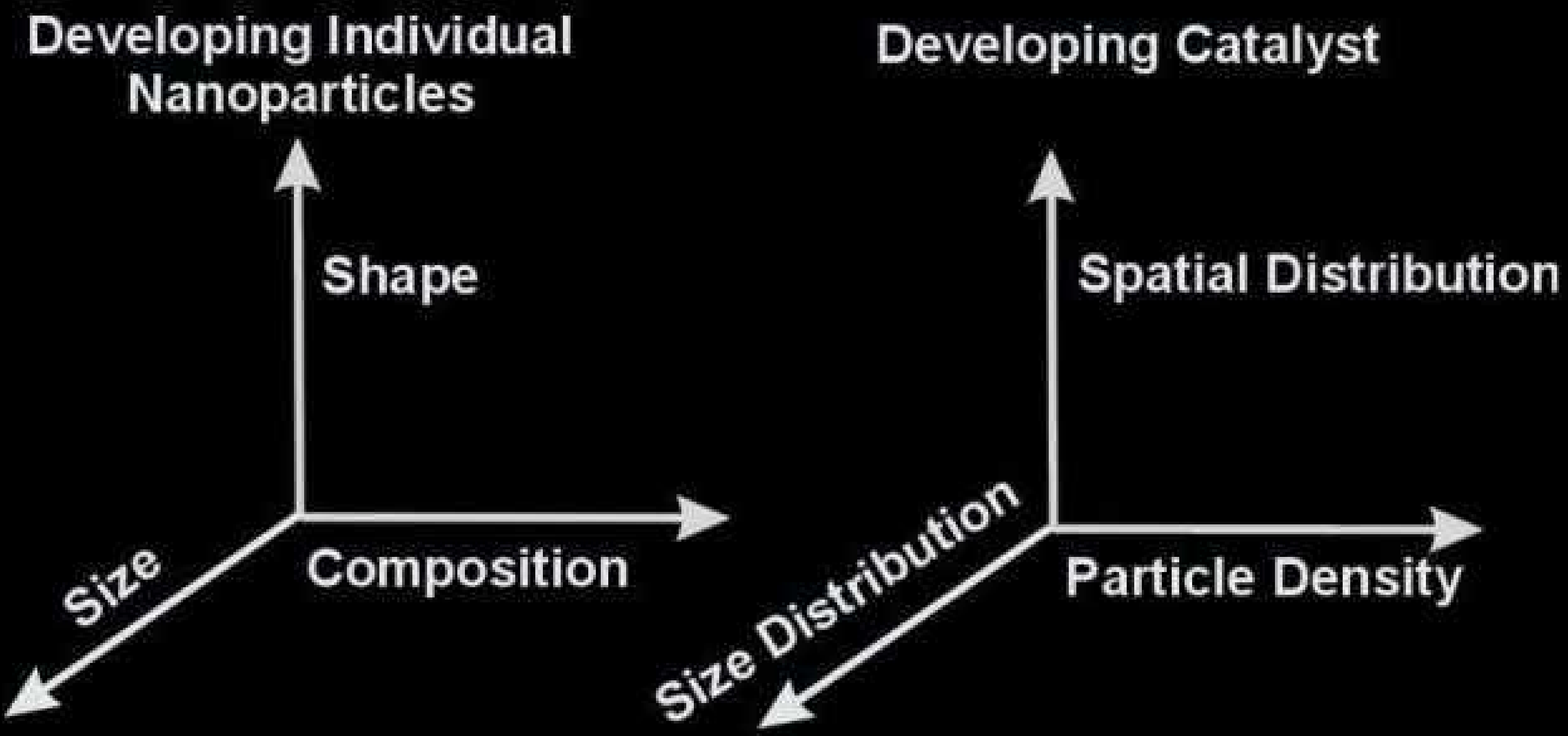
Courtesy NanoSys





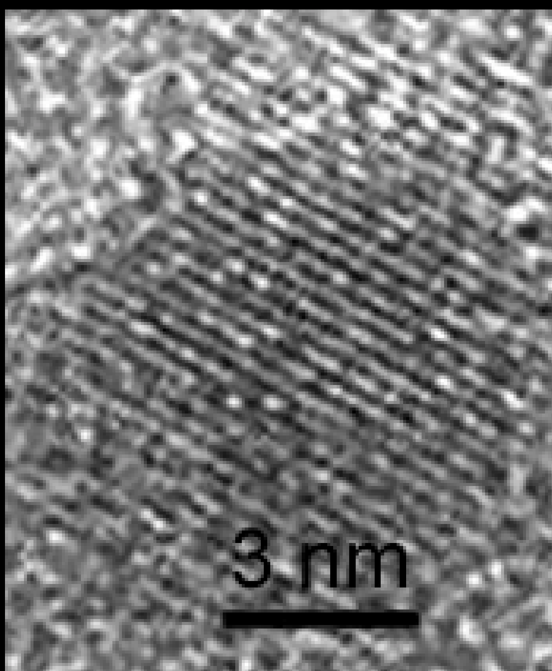
Nanostructured Catalysts

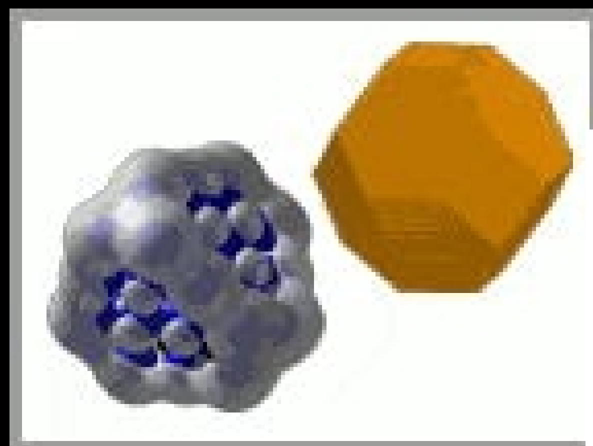
- Precise control of size, shape, spatial distribution, surface composition, and surface interface of atomic structure of the individual nanocomponents.

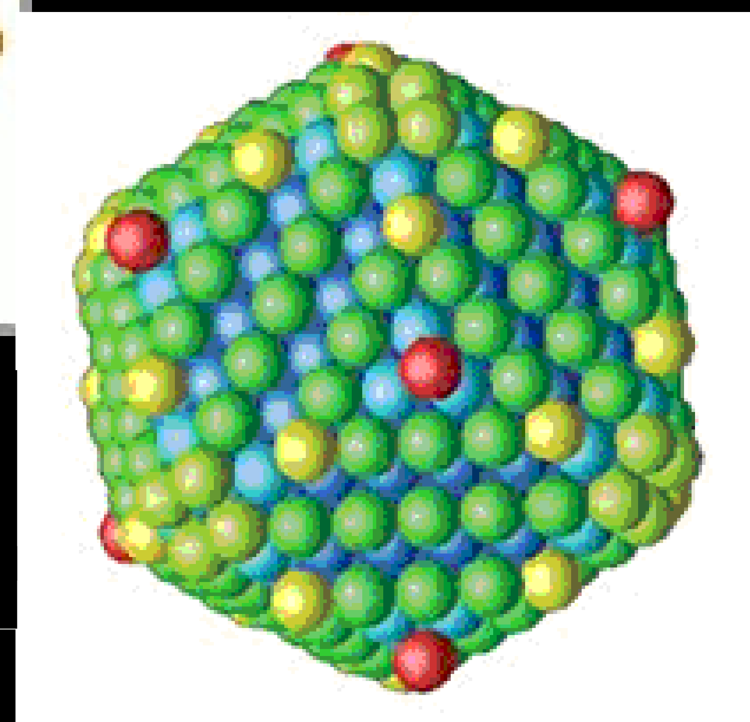


Quantum Modeling of Nanostructured Materials

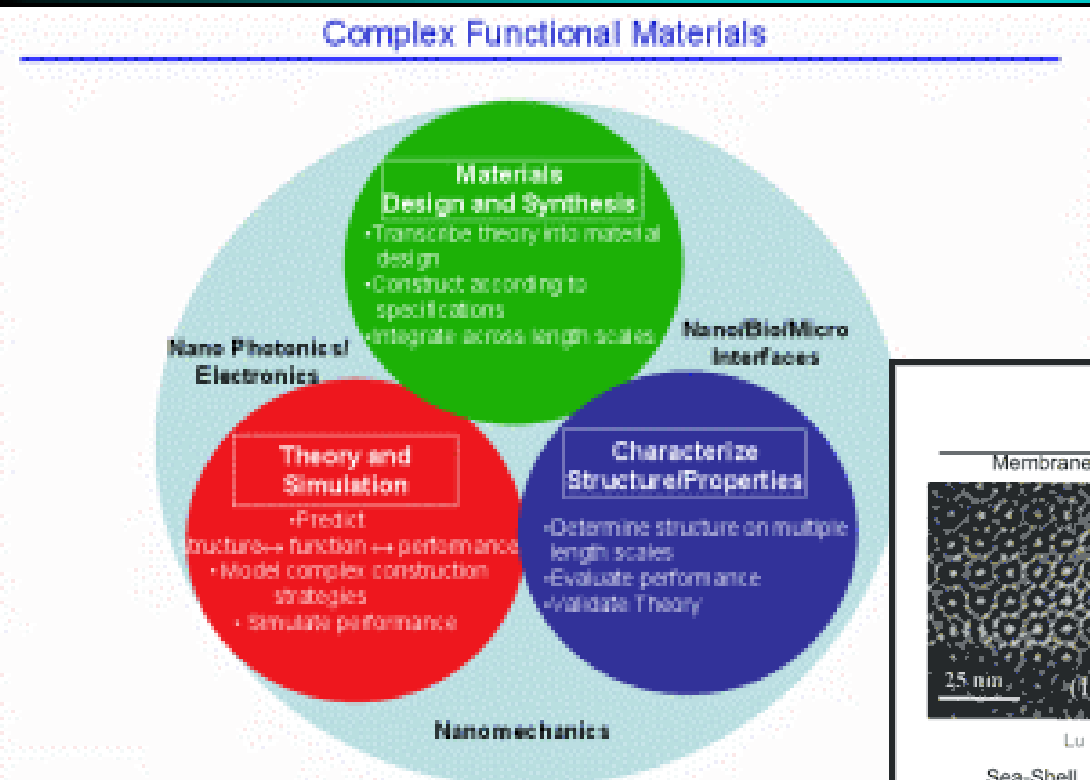
- Quantum Modeling of meta-scale nanostructured catalysts, nano-crystals, and membranes enables investigation into unique molecular forms with substantial cost savings over “conventional” material / chemical solutions

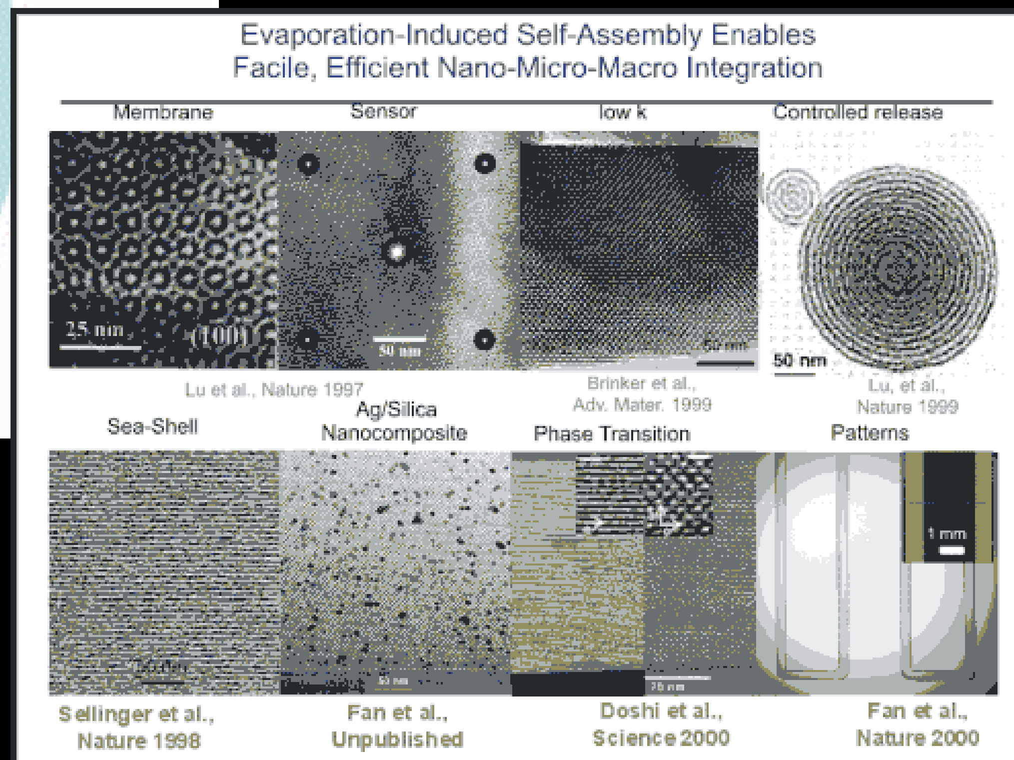






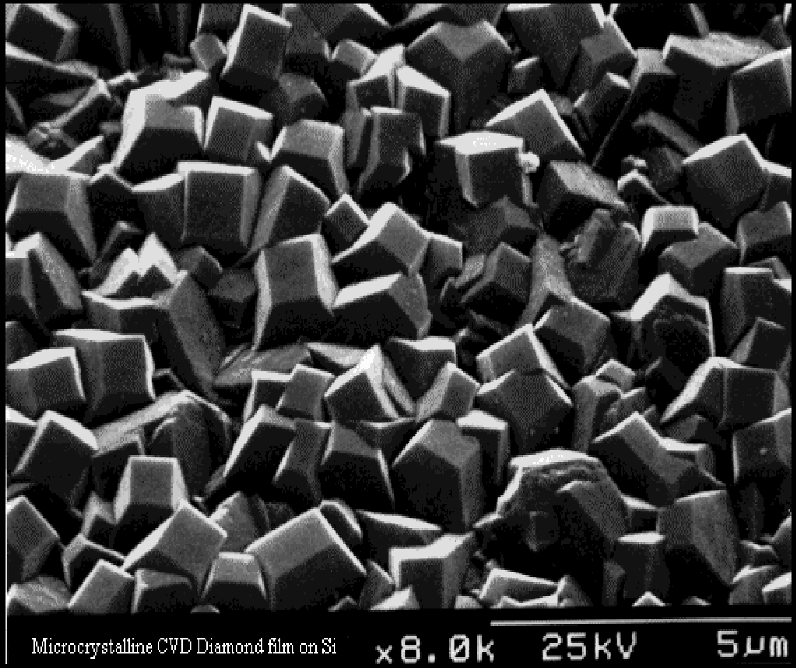
Integration of Nano Micro Macro Materials Regimes

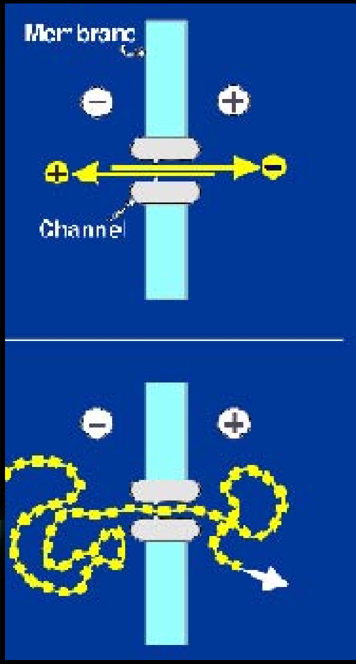




Nanotechnology Enabled Defense Development Domains Potentially Re-purposed Toward Energy Applications

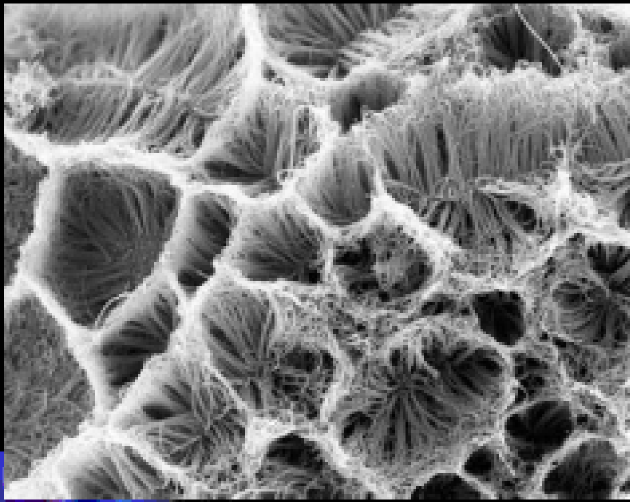
- Extreme high density energy storage and discharge systems
- “Smart” membranes, molecularly selective filters
- Aerogels, nanocrystals, composite nanostrcutured materials

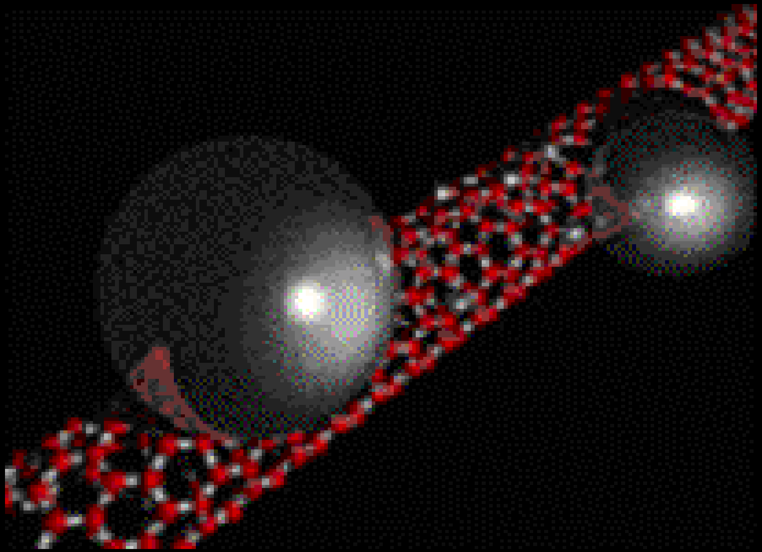


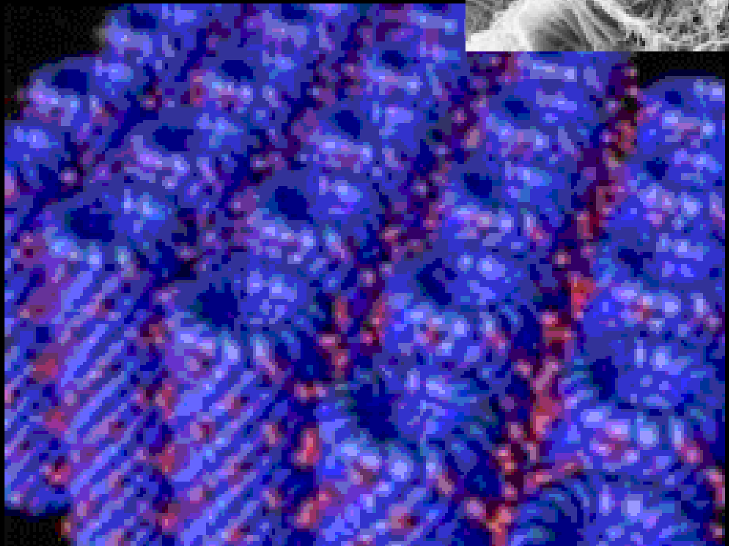


Carbon Nanotubes and Nanostructures

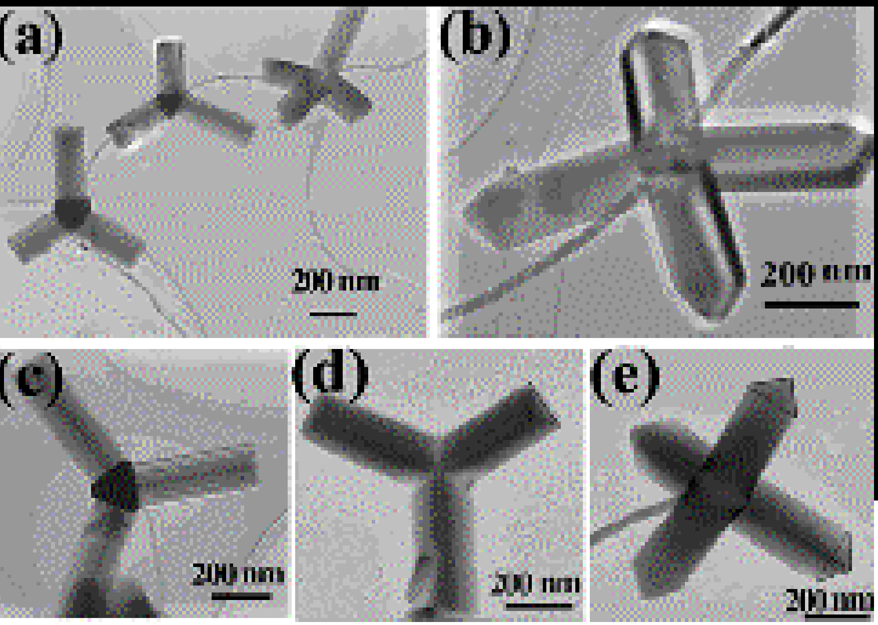
- PEM (Polymer Electrolyte Membrane / Proton Exchange Membrane) Fuel Cells
- Reversible Hydrogen Storage
- Ultra-Capacitors, Batteries



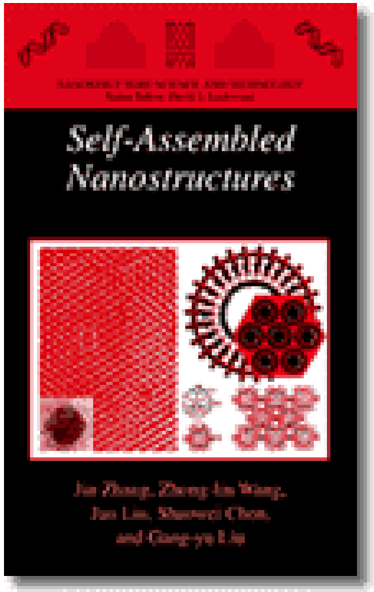




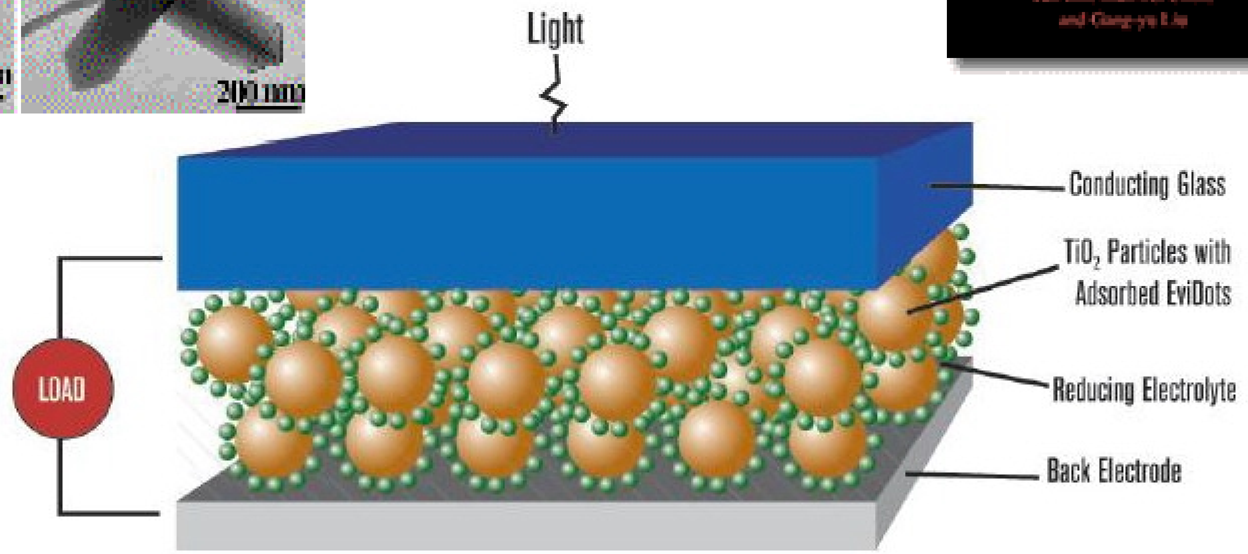
Self Assembly –
An Industrial Paradigm



- Tetrapods
- Periodic nanostructures
- Quantum dots
- Nanocrystals



Courtesy Nanosys



Courtesy

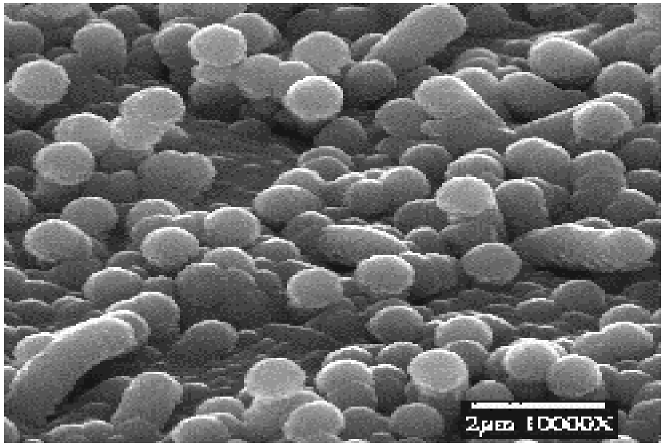
Evident Technologies

Self Assembly as a Foundry Process

Self-assembly is the most practical and realizable approach to fabricate arrays of nanodevices with the sub-100nm size features in short-term (the conventional lithographic methods of microsystem processing offer very limited control over the fabrication on the sub-100 nm scale)

Spontaneous self-assembly

This approach relies on structural disorder at the interface between the two materials with different physical properties (heteroepitaxy, fluctuations of the dopant concentration, etc.)

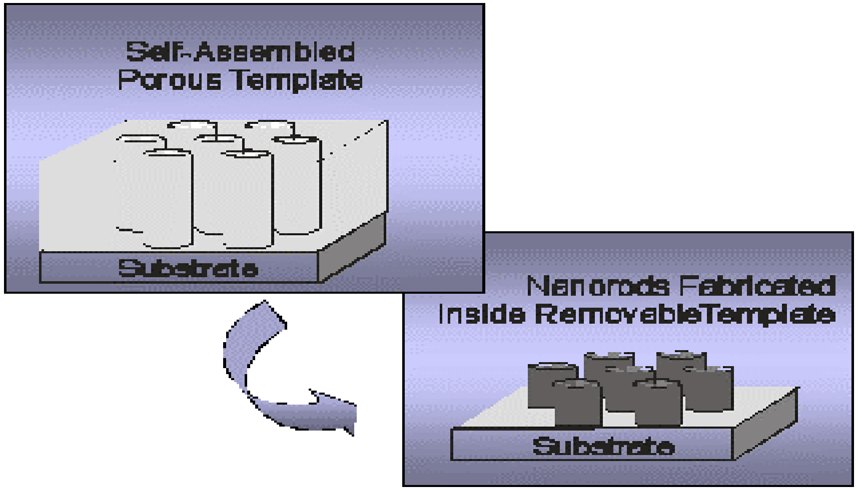


Self-assembled Si nanowires grown by magnetron sputtering

(E.A. Guliants and W.A. Anderson, "A Novel Method of Structure Control in Si Thin Film Technology", *197th Meeting of The Electrochemical Society*, Toronto, ON, May 2000)

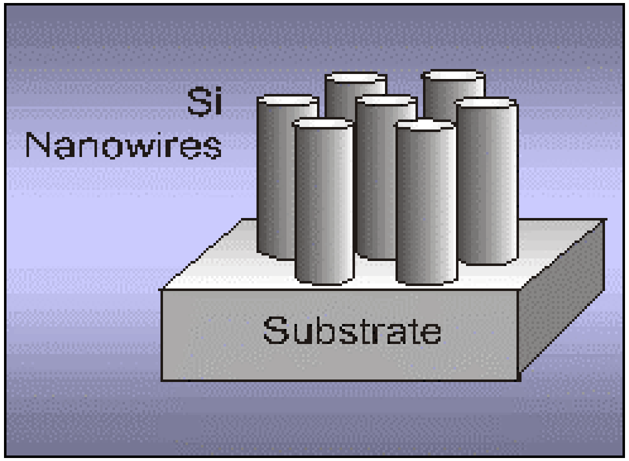
Controllable self-assembly

Involves self-assembly of the tools for fabrication of nanostructures and nanodevices, such as masks or templates.

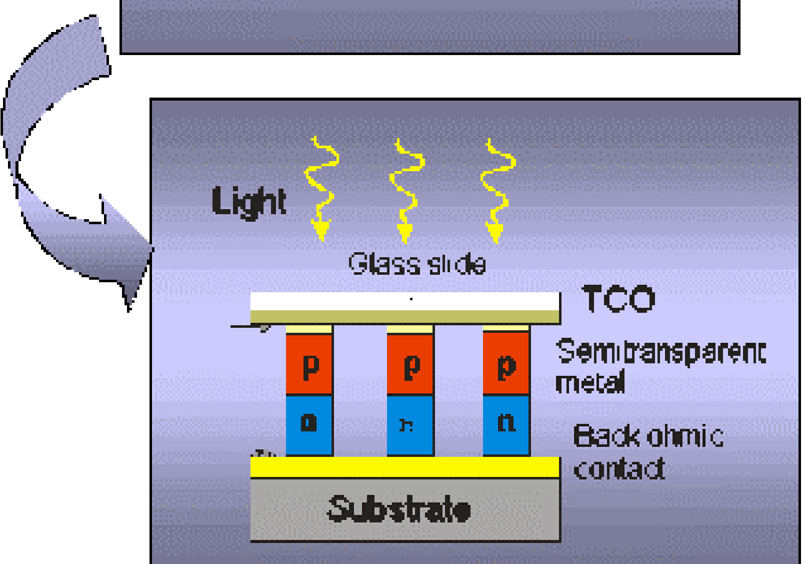


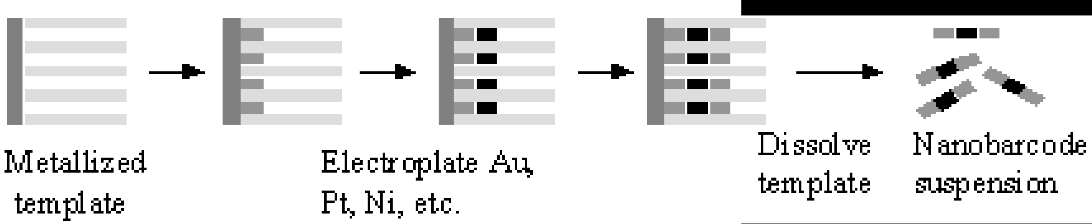
Periodic Nanostructures

Some of the potential applications of periodic nanostructures are:



- Quantum effect dots
- Resonant tunneling diodes
- Single-domain/bit magnetic storage media
- Single electron transistors (SETs)
- Light-emitting diodes (LEDs)
- Photodetectors
- Quantum well optoelectronic devices
- Quantum cellular automata
- High-density memory





Schematic of aSi photodetectorarray fabricated on periodicSi nanowires

Biology as a mechanism for material production, patterning, and fabrication

Key Properties:

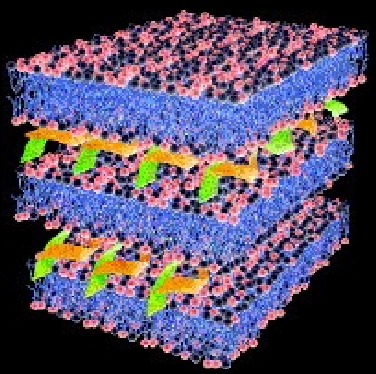
Photonic

Electronic

Mechnical

Chemical

Living Systems as Biofoundry



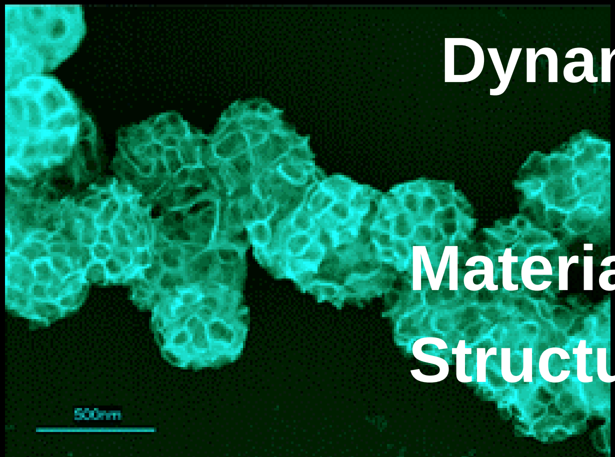
Genetic Magnification

Dynamic Agent

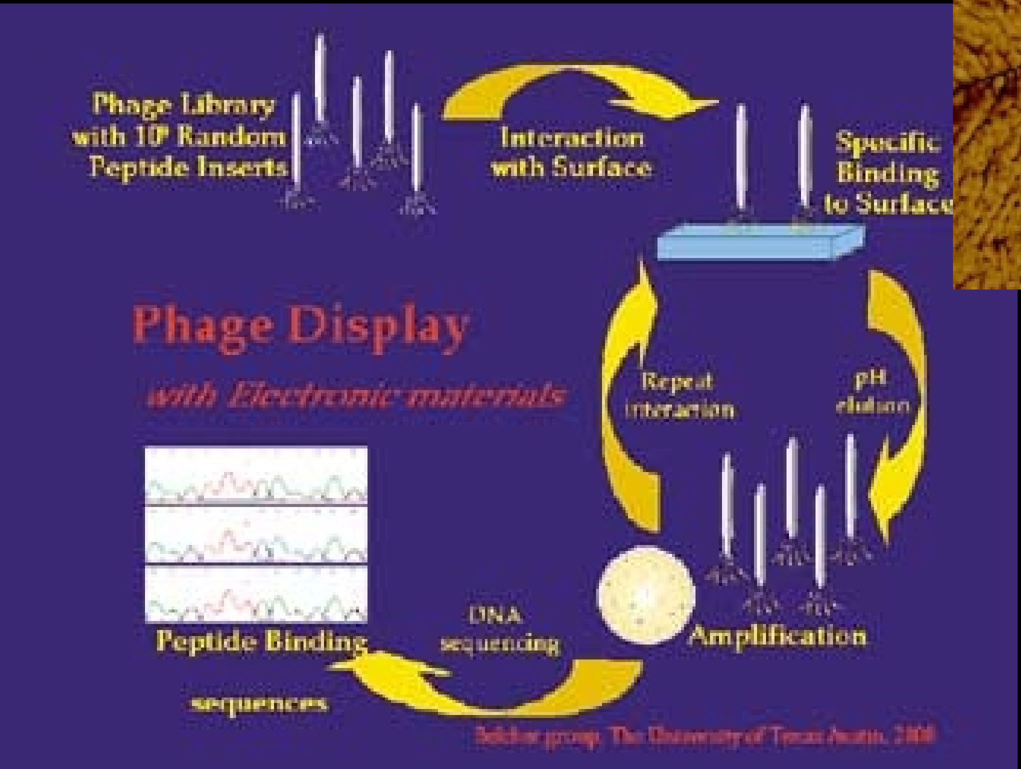
Controlled Replication

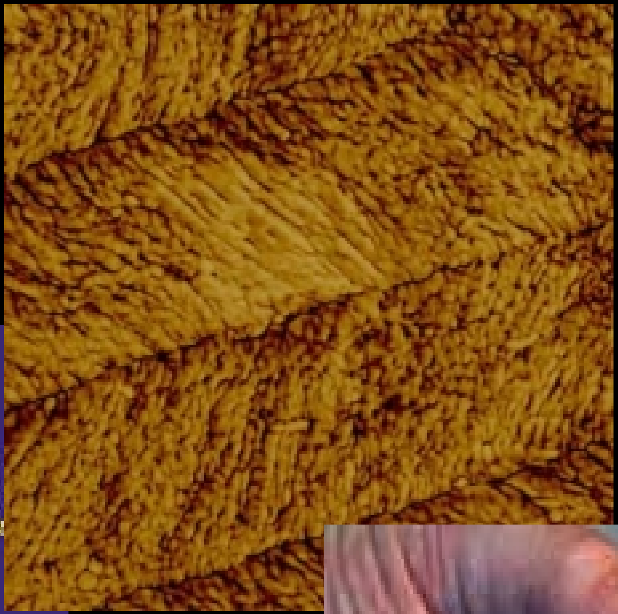
Material Patterning / Structural Systems

Materials Harvest / "Biocomponents"



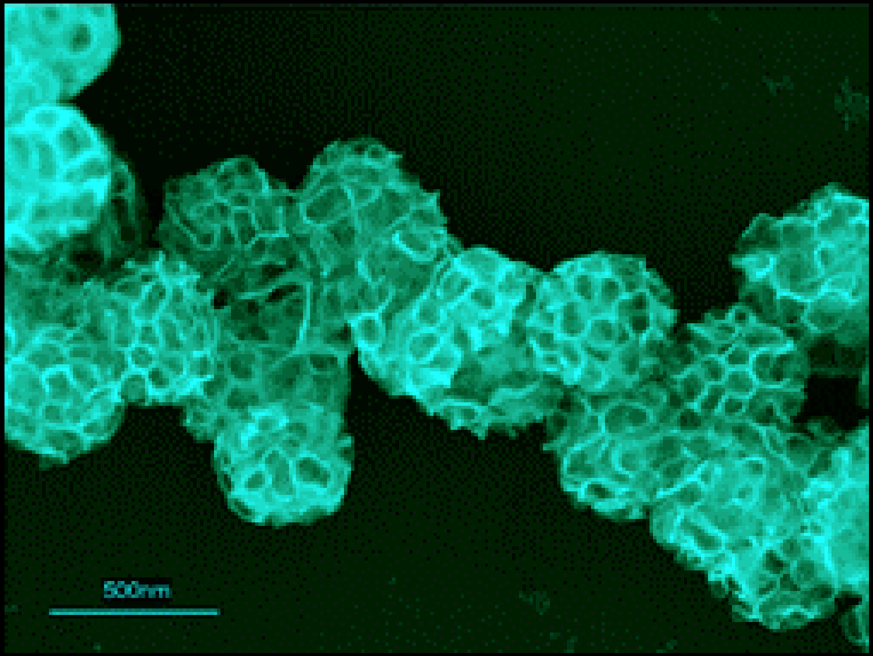
Define Foundry - ***BioFoundry***

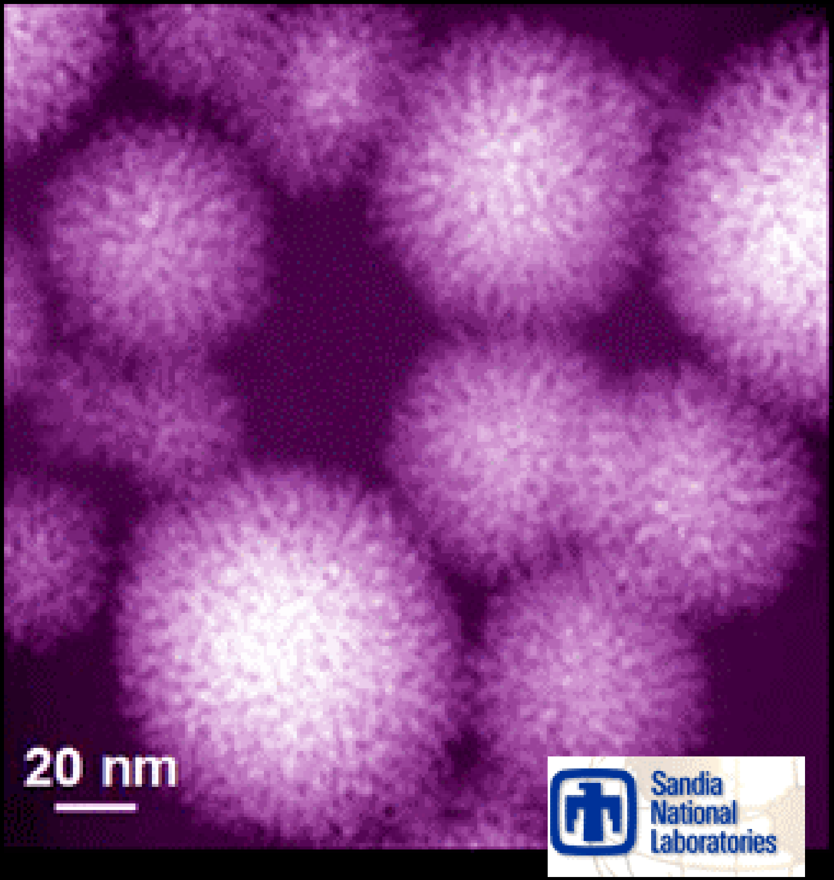




Biofoundry approach to cost effective catalysis and related functionalities

- Mimicking Photosynthetic Proteins to Manipulate Platinum



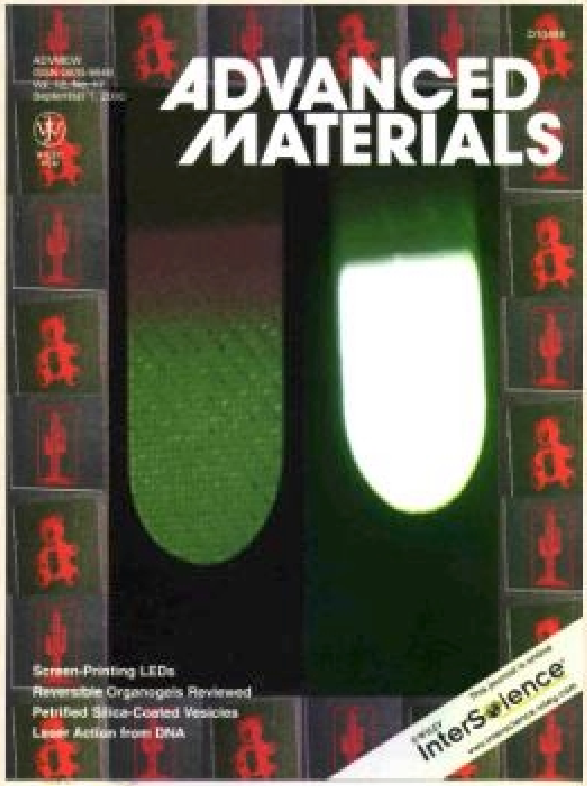


10/12/2004

NanoElectronic Photovoltaic Circuitry Printed on Paper, Cloth, Plastics

THE UNIVERSITY OF ARIZONA. TUCSON ARIZONA

Screen Printing for OLEDs and Flexible Solar Cells



Sep 2000

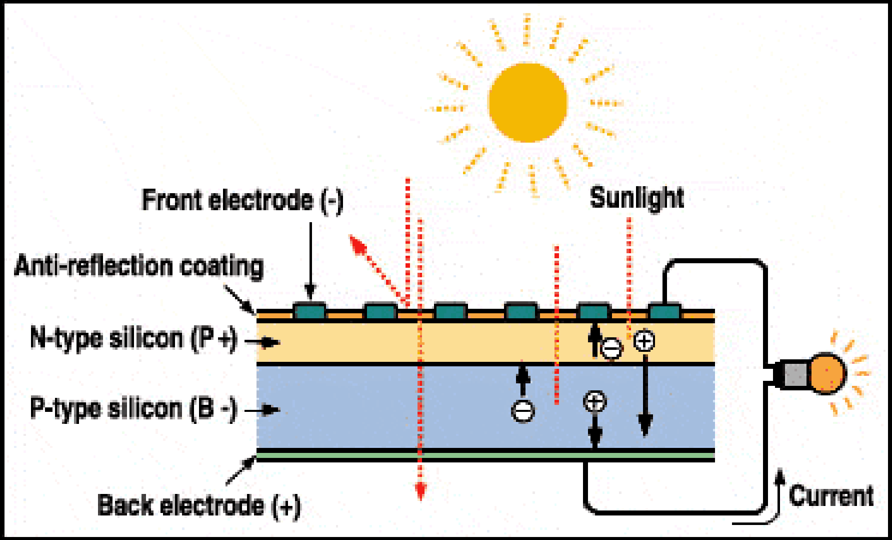
Wall-to-wall power
Solar cells printed like wallpaper.
Nature, 6 November 2001

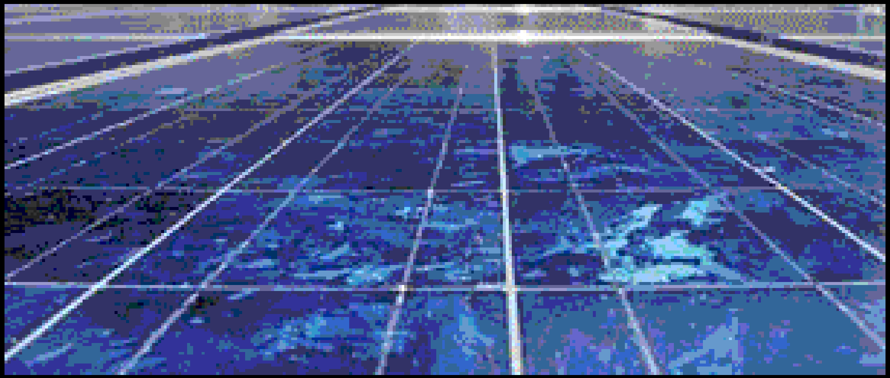
On a roll: solar panels could soon be as cheap and easy to print as wallpaper.

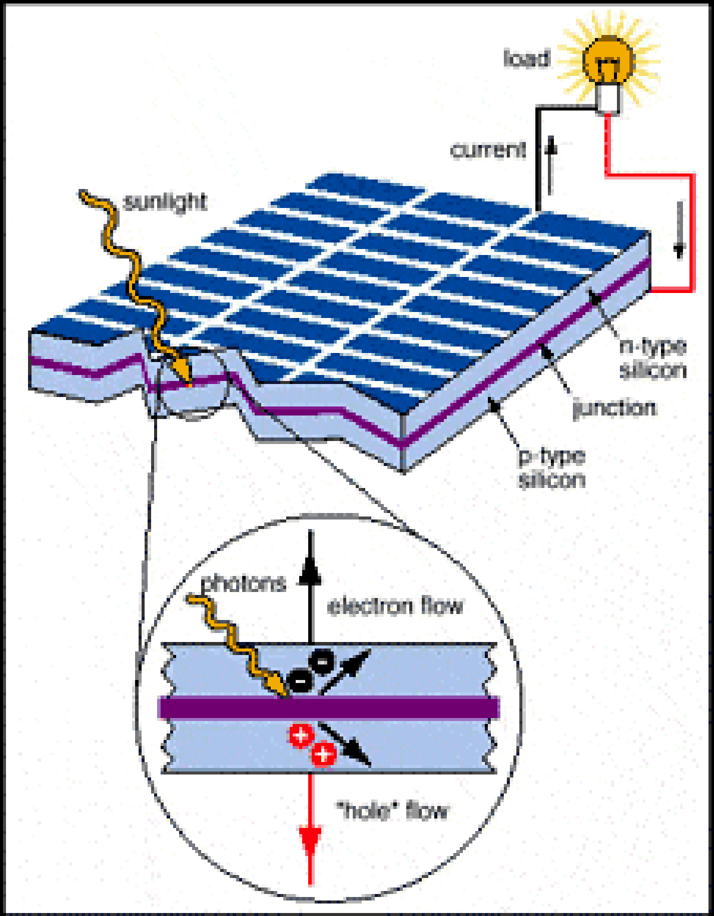
G. E. Jabbour Group
gej@optics.arizona.edu

S. E. Shaheen, R. Radspinner, N. Peyghambarian, and G. E. Jabbour, "Fabrication of bulk heterojunction plastic solar cells by screen printing," *Appl. Phys. Lett.*,79, 2996 (2001).

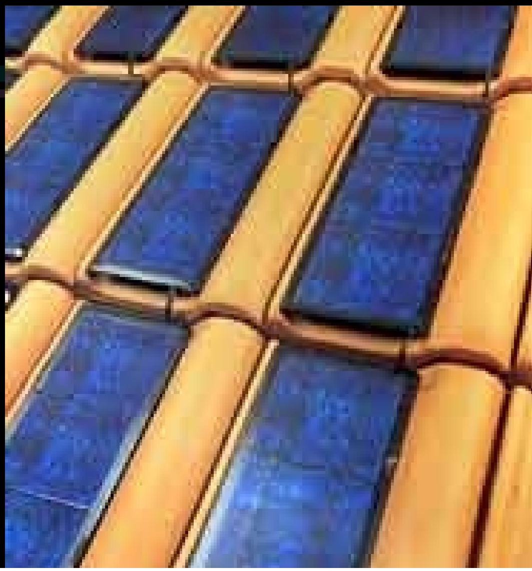
“Traditional” Crystalline Silicon Solar Voltaics

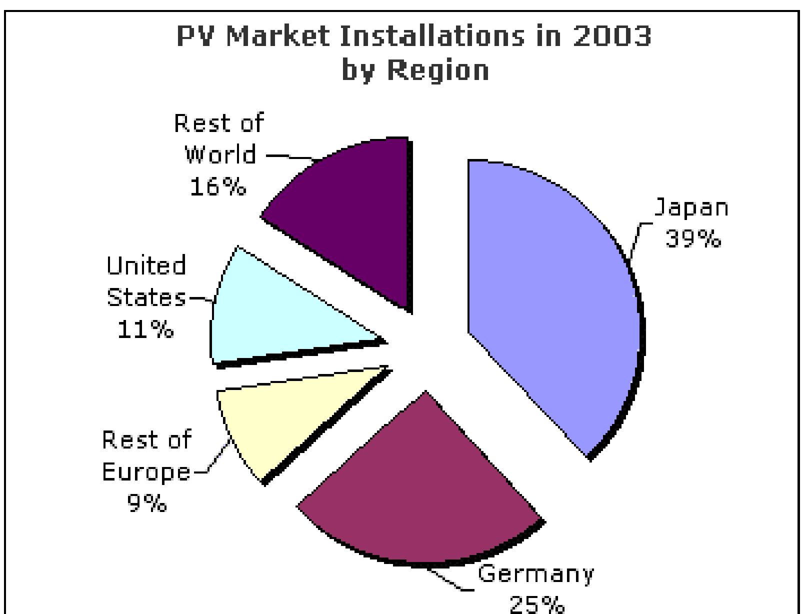


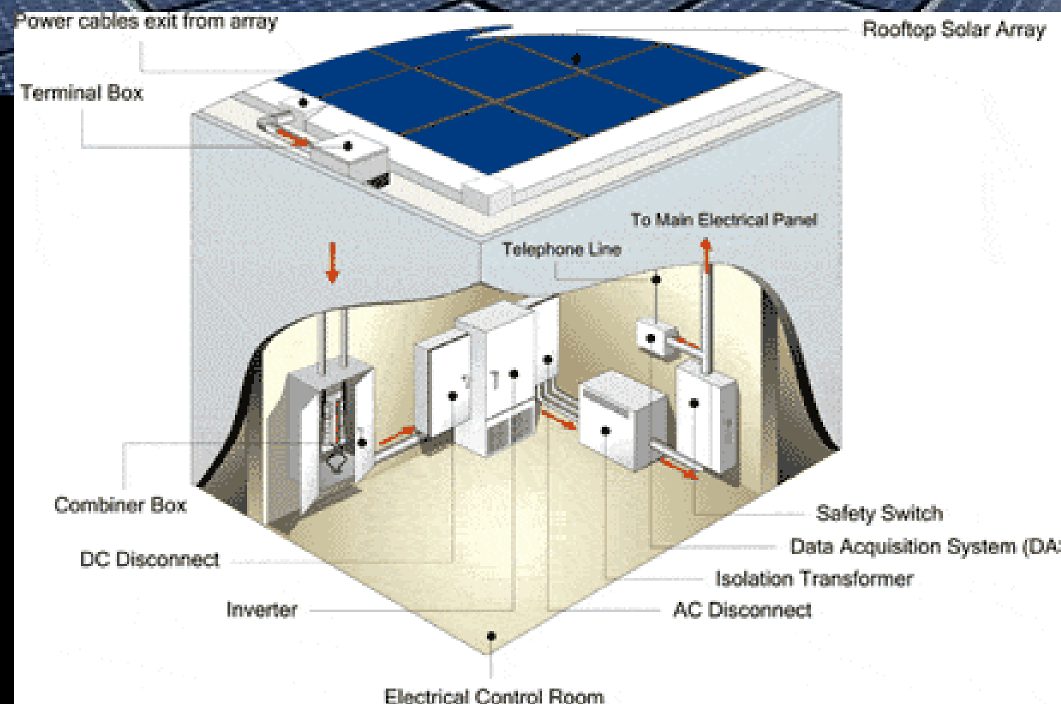




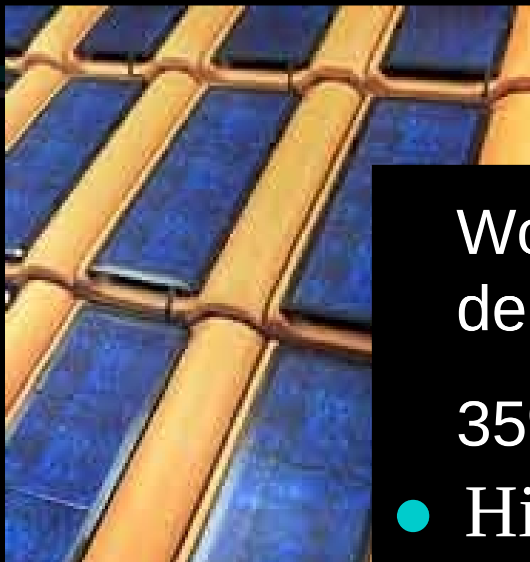
“Traditional” Crystalline Silicon Solar Voltaics

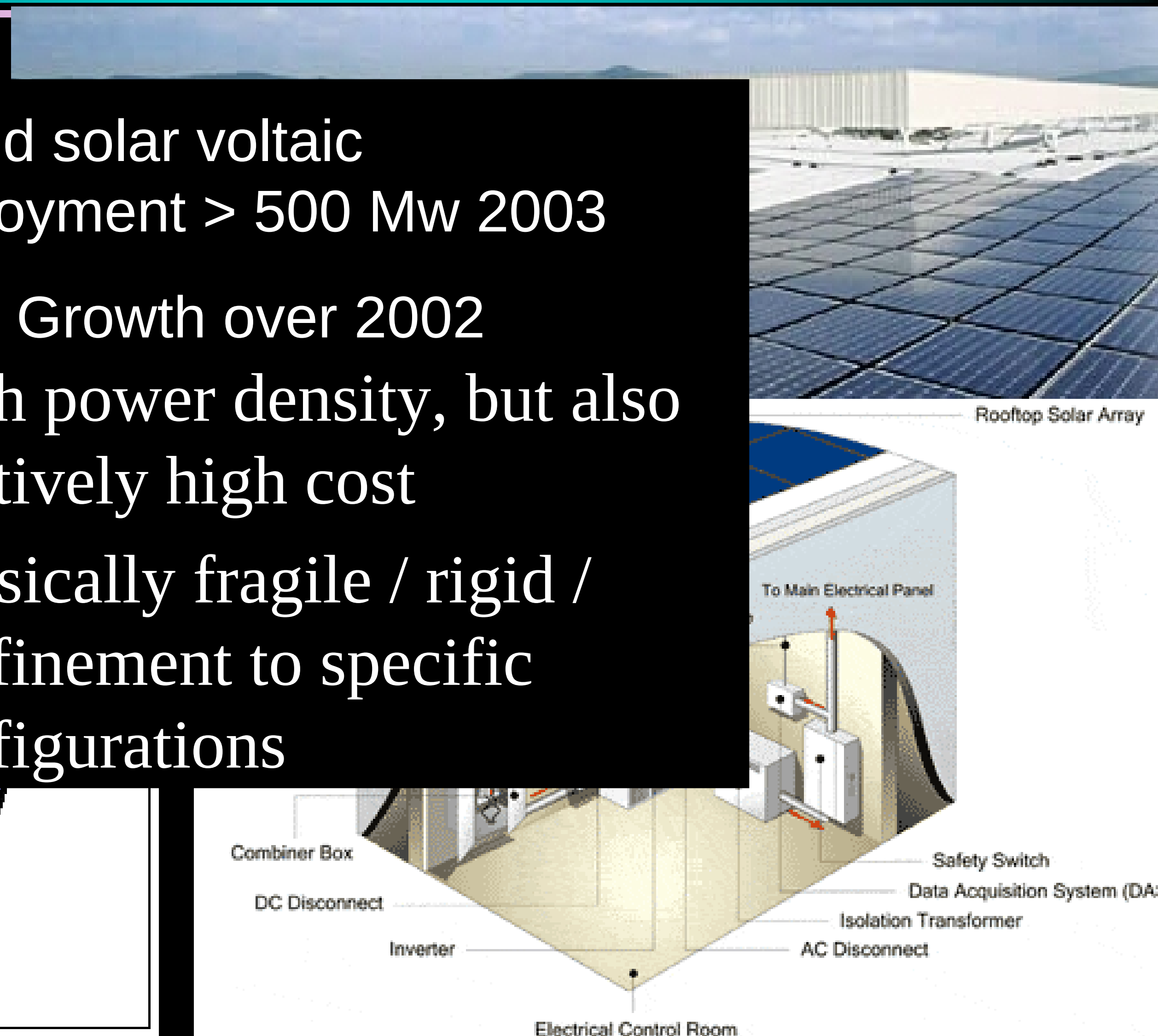






“Traditional” Crystalline Silicon Solar Voltaics

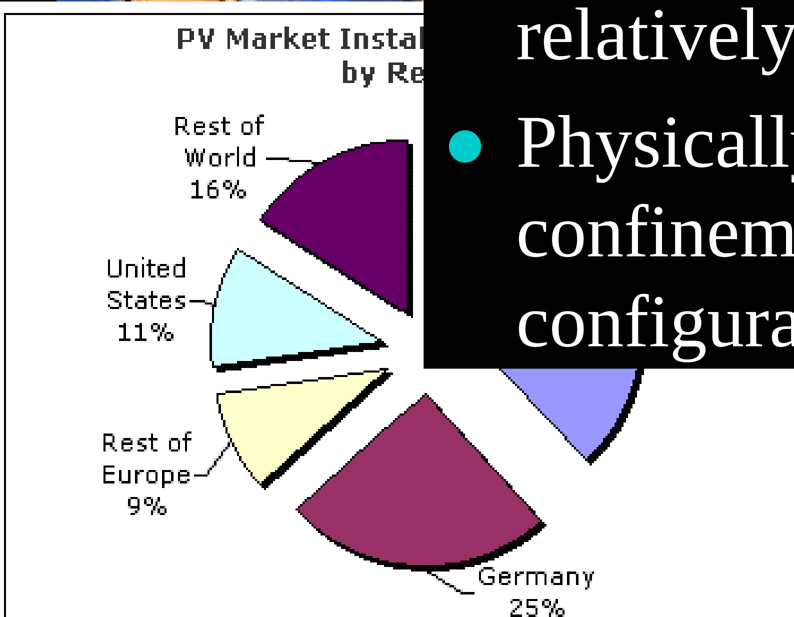




World solar voltaic deployment > 500 Mw 2003

35% Growth over 2002

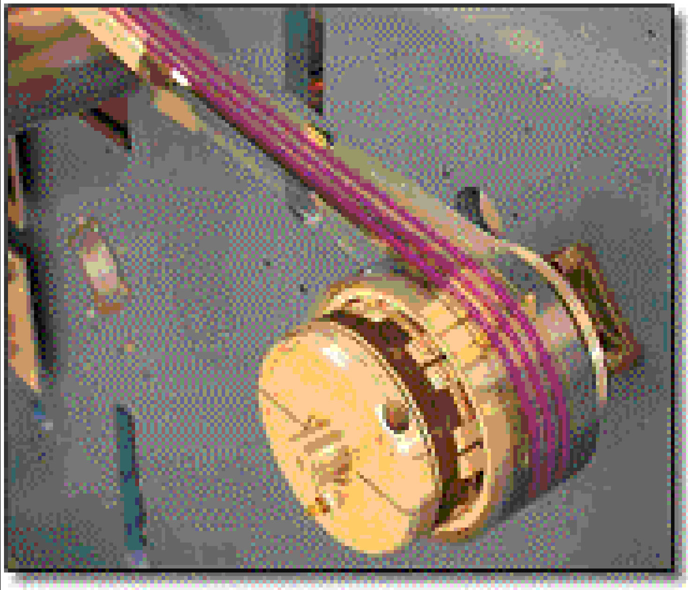
- High power density, but also relatively high cost
- Physically fragile / rigid / confinement to specific configurations



Organic Semiconductors in Solar Voltaics

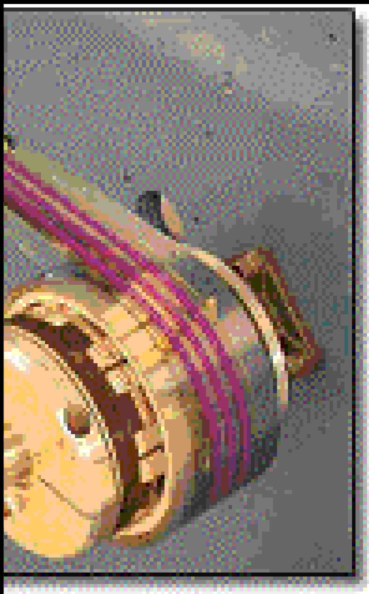
Concept image of Organic/Nanosolar manufactured product from Nanosolar.com

Organic Solar Cell

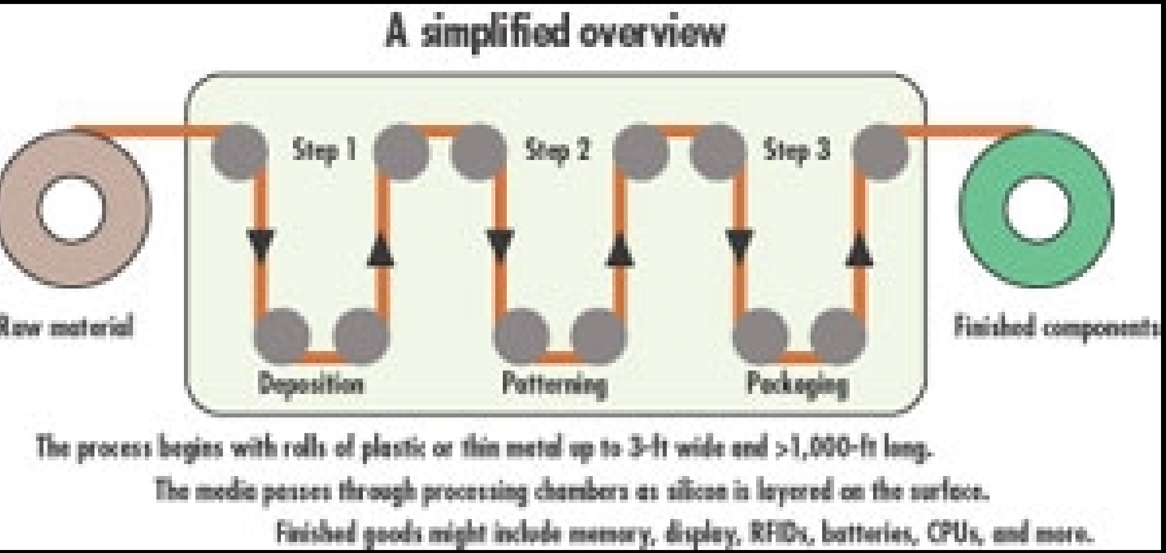


Organic Semiconductors in Solar Voltaics

- Lower power density, but also relatively much lower cost
- Physically flexible / can be applied to many configurations, surfaces
- Can suit applications not feasible with crystalline silicon



NanoElectronic Photovoltaic Circuitry "Printed" on Multifunctional Laminates



What is R2R manufacturing,
and what does it have to do with electronics?

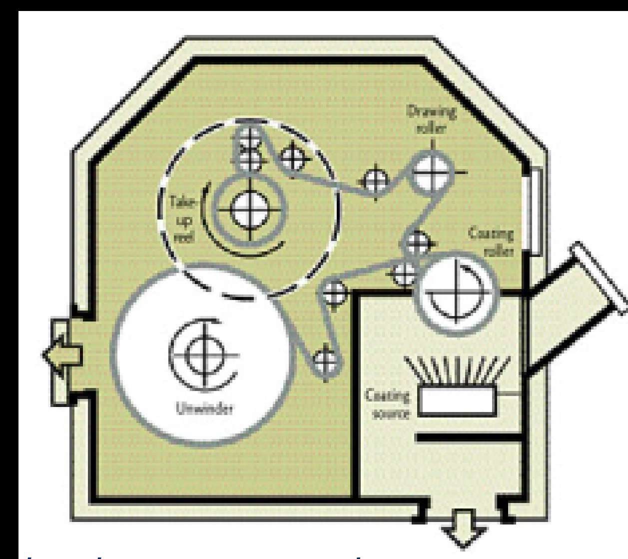
Thin film processing on a moving web of flexible substrate. A complete device may require several chambers.

Typical web properties:

Width: 0.3 – 3 m
Length: up to 50 km
Thickness: 0.6 to 300 microns
Speed: 0.1 – 1000 m/min.

Coating properties:

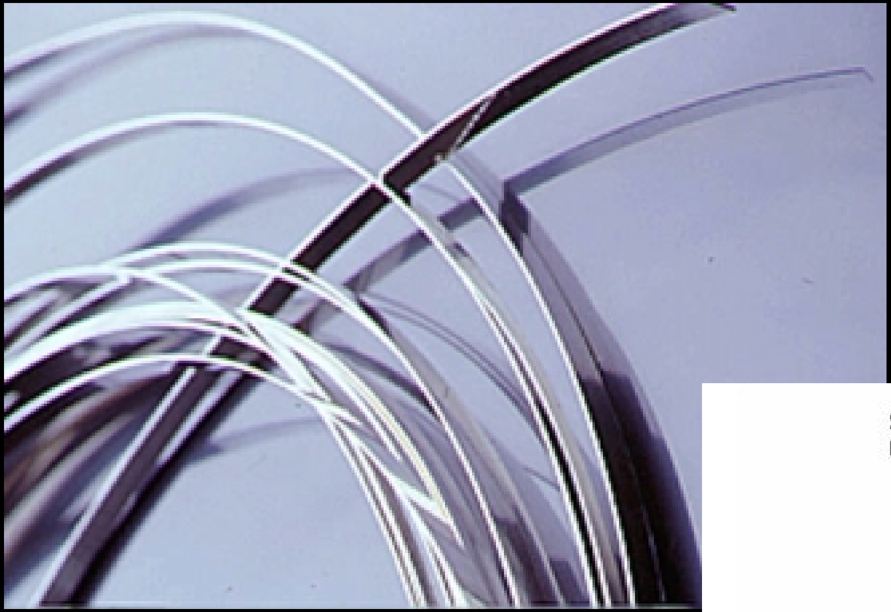
Thickness: <0.1 to 100 microns
Processes: evaporation, sputtering, PECVD (vacuum); gravure, slot die, etc. (liquid); inkjet



A simple vacuum web evaporator

For further technical details, see: J.R. Sheats, *SPIE Proceedings*, Vol. **4688** (2002), paper#27

HTS Wires / Conductors – New Approaches



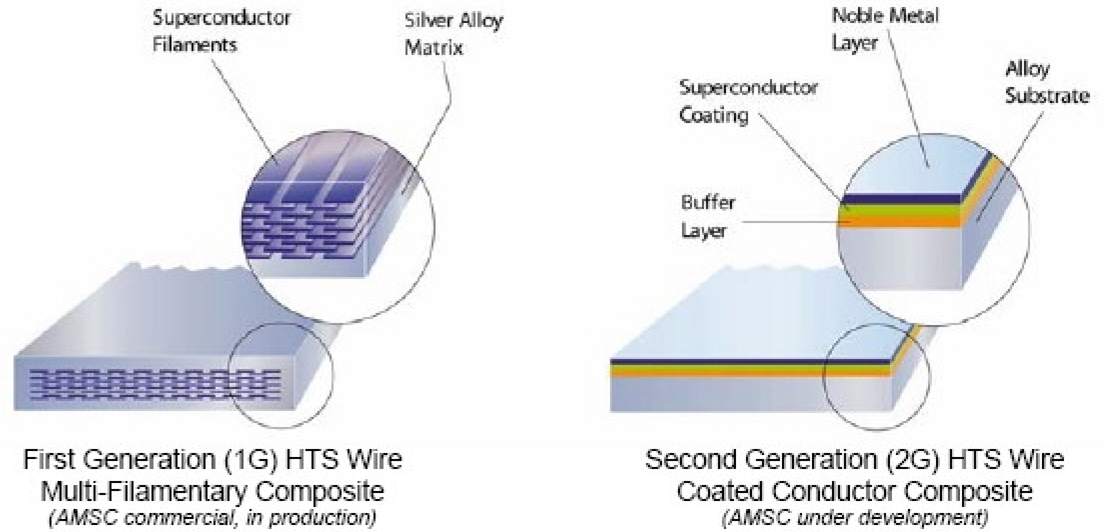


Fig. 1: High Temperature Superconductor (HTS) 1G and 2G wire architectures

HTS Wires / Conductors – New Approaches

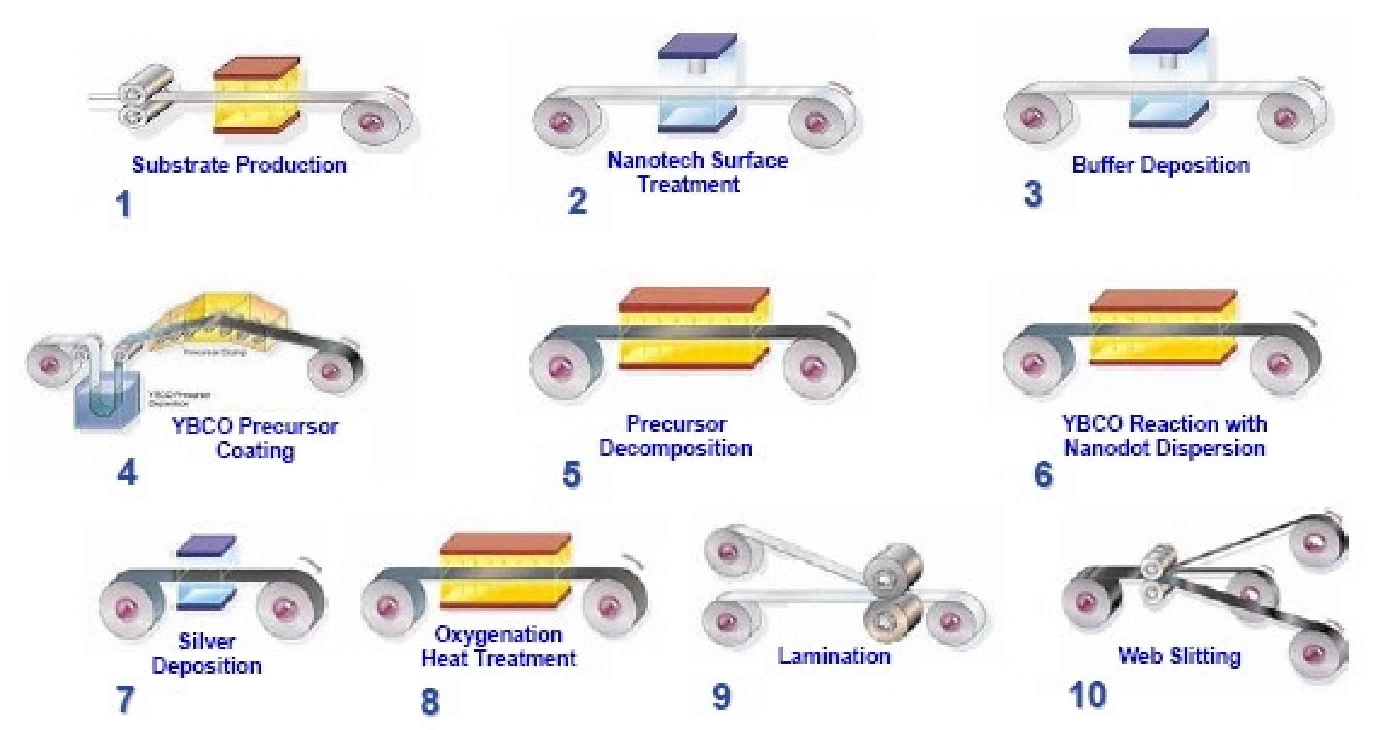
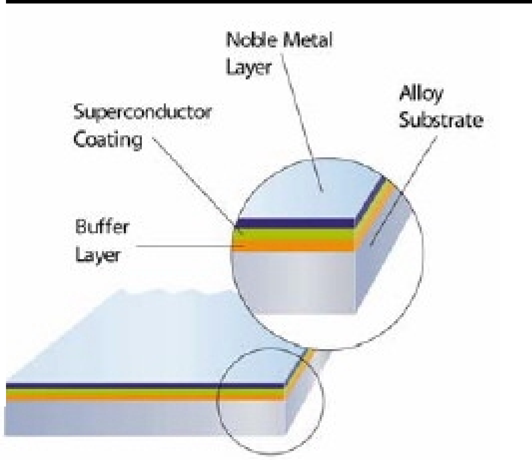


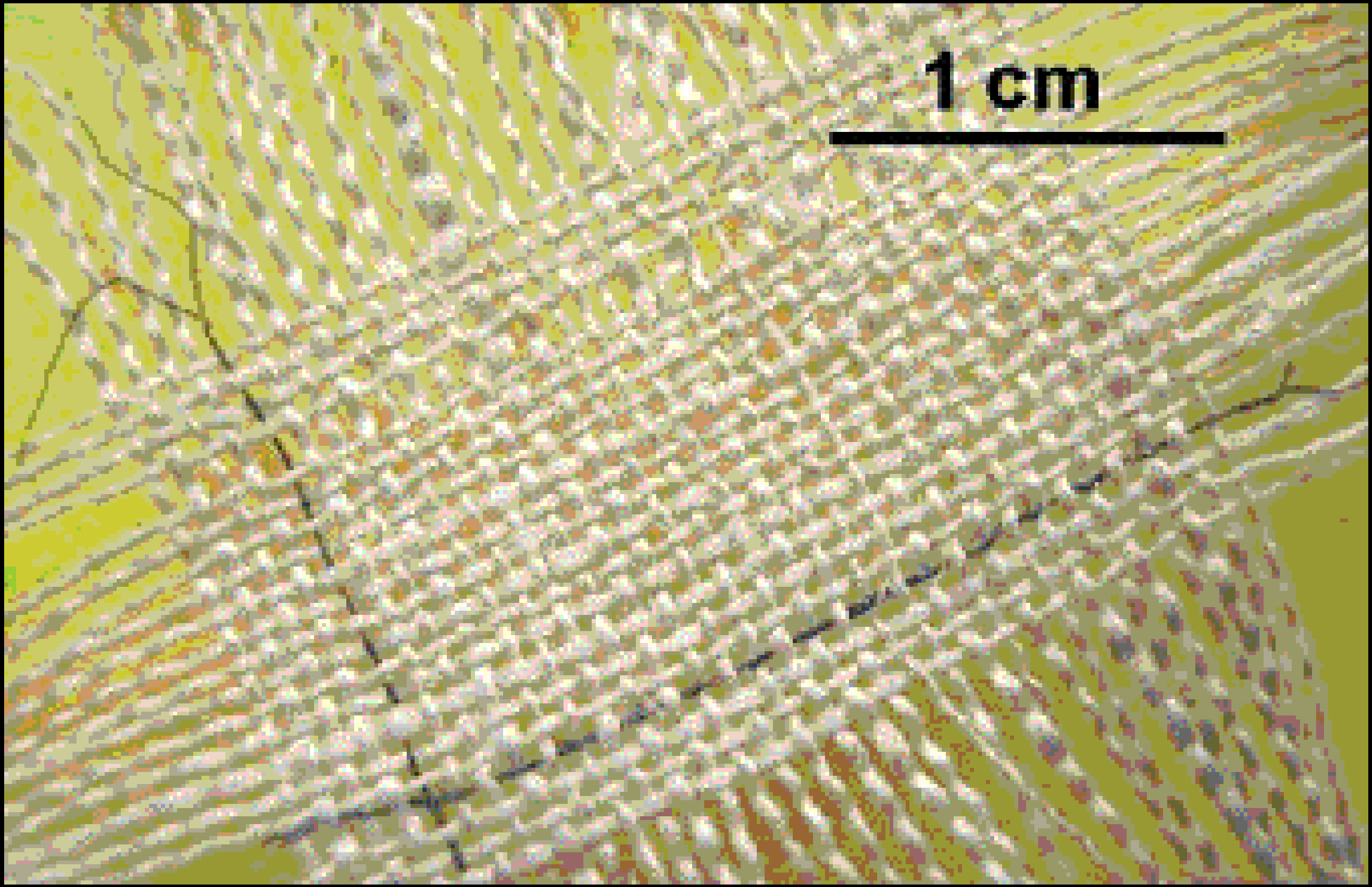
Fig. 5: 2G HTS wire manufacturing process



Second Generation (2G) HTS Wire
Coated Conductor Composite
(AMSC under development)

Fig. 1: High Temperature Superconductor (HTS) 1G and 2G wire architectures

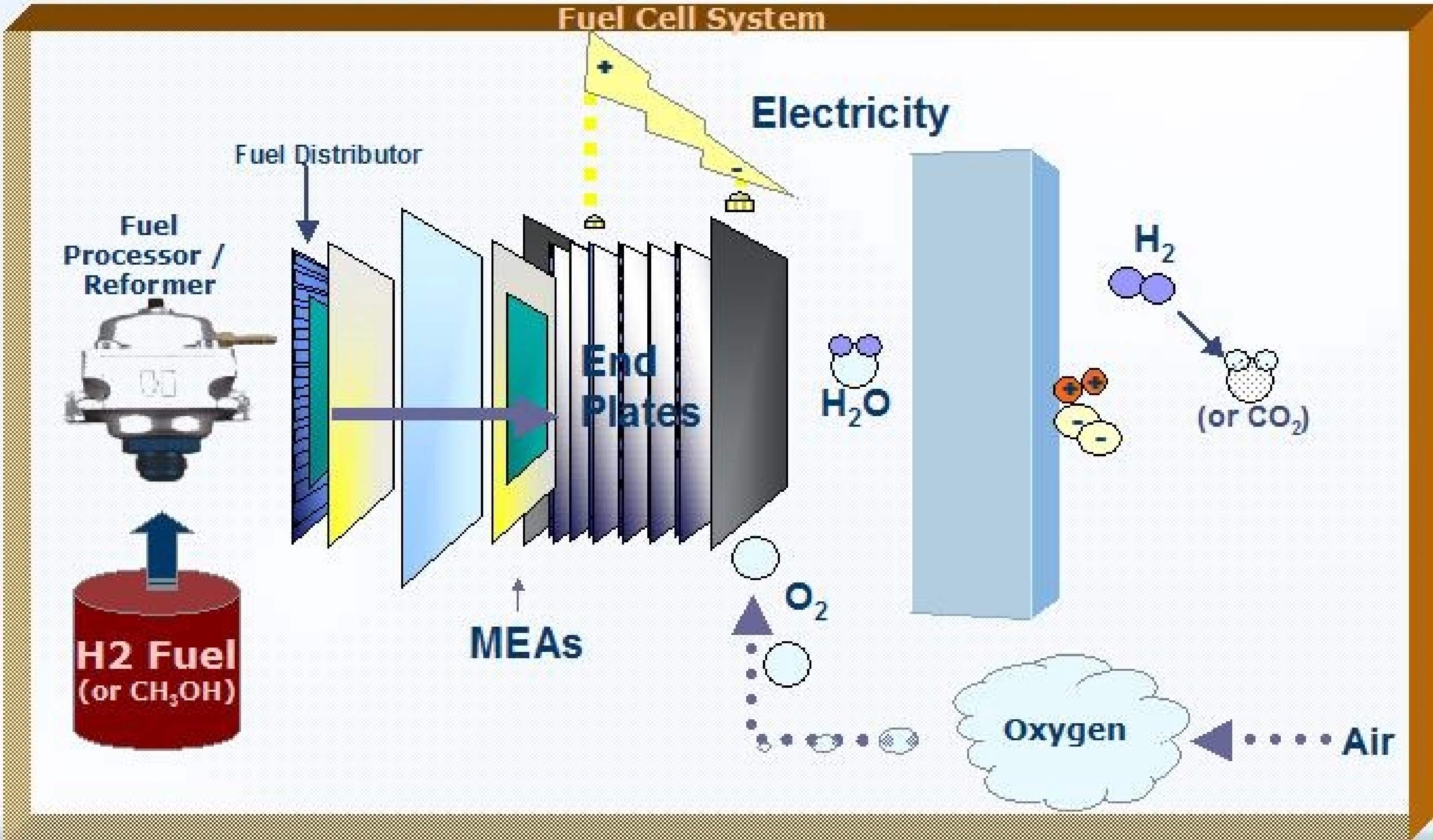
Ultra High Efficiency Conductors / Storage
New Approaches



What is a Fuel Cell?

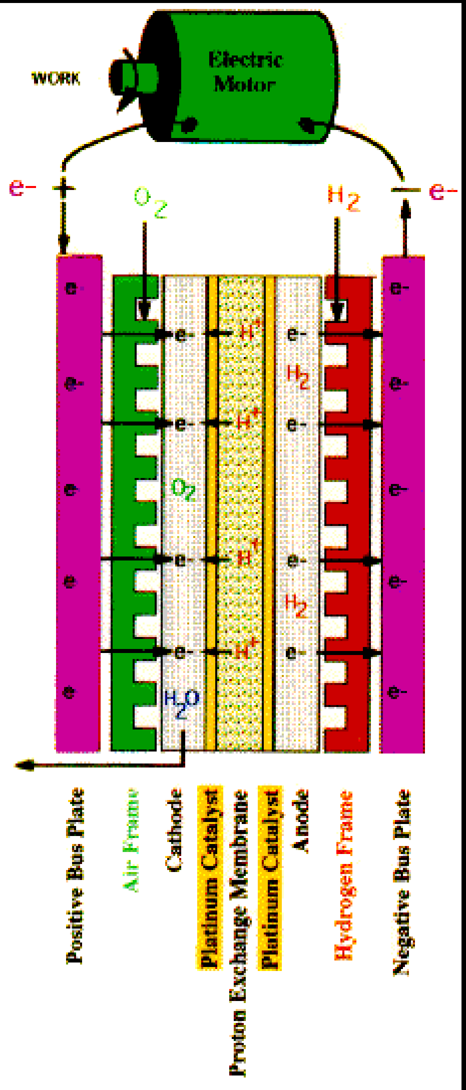
NEC

A Fuel cell uses chemical reaction, rather than combustion (burning a fuel), to produce electricity in a process that is the reverse of electrolysis.



Hydrogen Fuel Cells

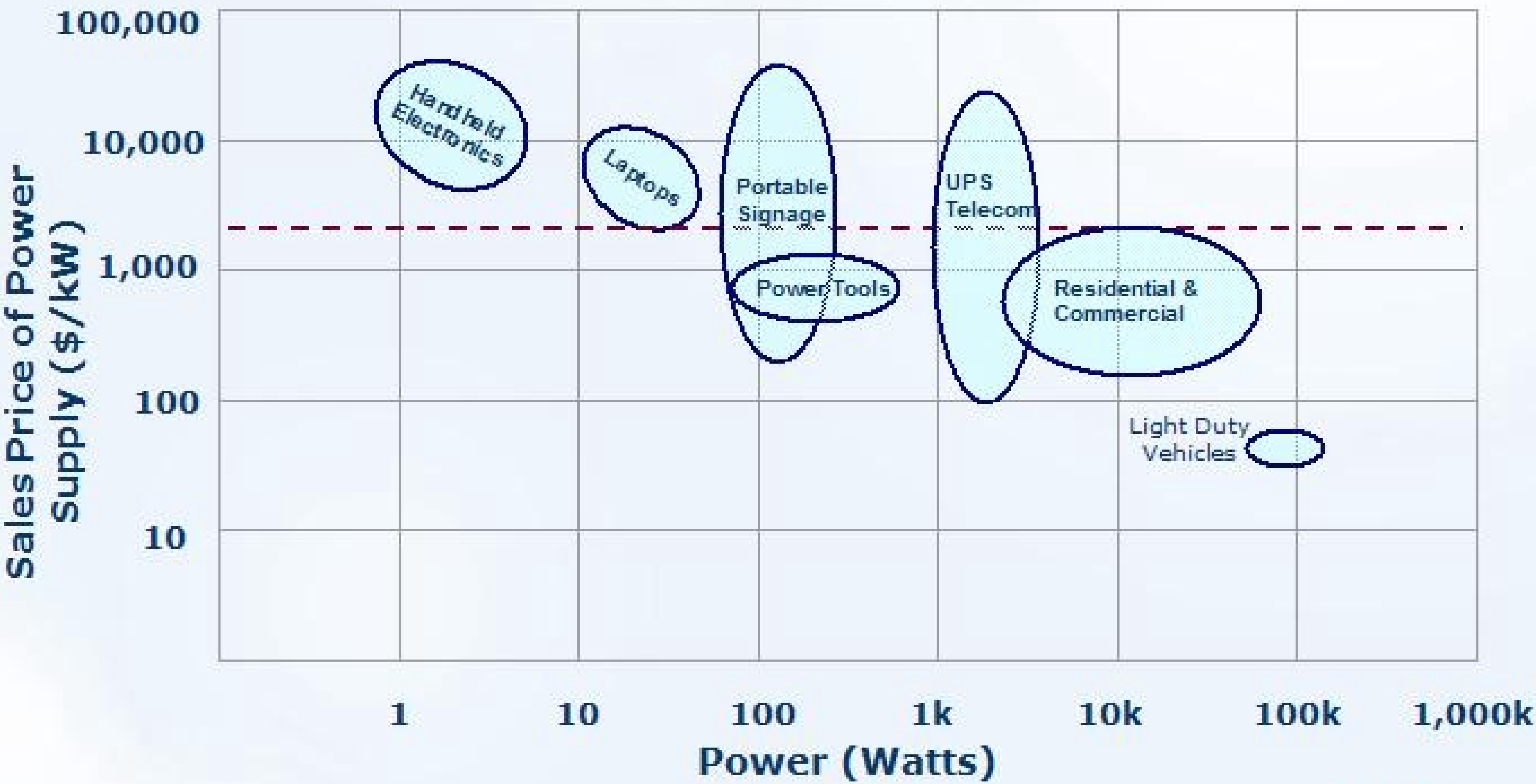
- A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. Hydrogen is fed to the anode, and oxygen is fed to the cathode. Activated by a catalyst, hydrogen atoms separate into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they reunite with oxygen and the electrons to produce water and heat



Price Points

NEC

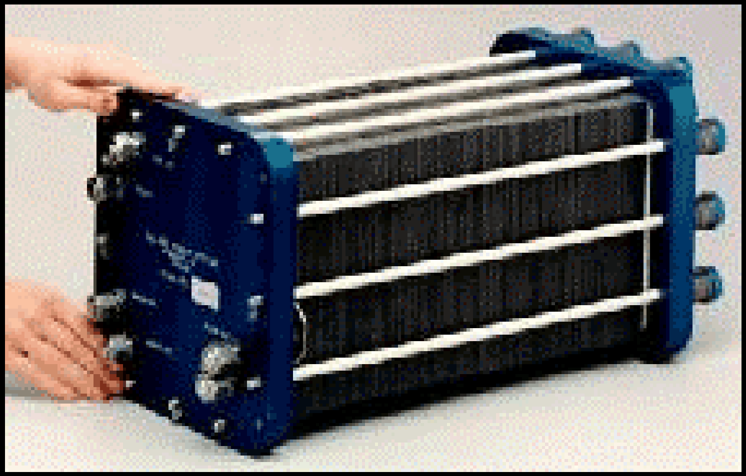
Applicability in the premium price markets

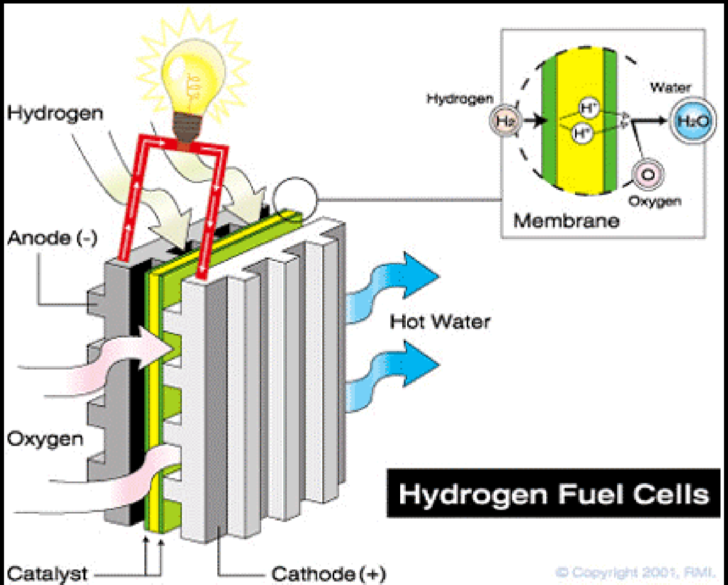


Source: USFCC

Examples of Hydrogen Fuel Cell Types

- Proton-Exchange Membrane Fuel Cells
- Phosphoric Acid Fuel Cells
- Solid Oxide Fuel Cells
- Molten Carbonate Fuel Cells
- Regenerative or Reversible Fuel Cells
- Alkaline Fuel Cells



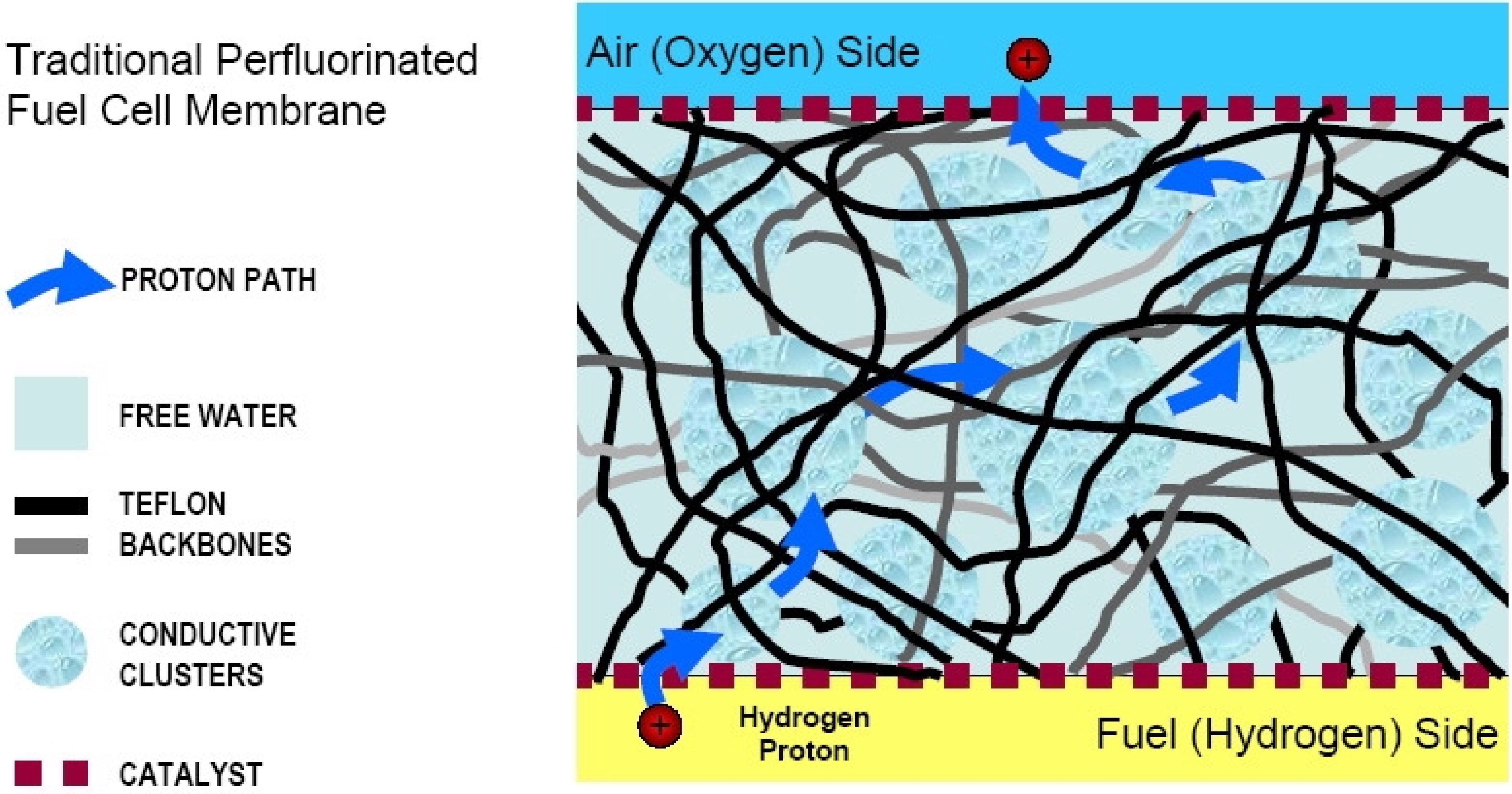


Fuel Cells -
From the laboratory, into markets

Anuvu Incorporated

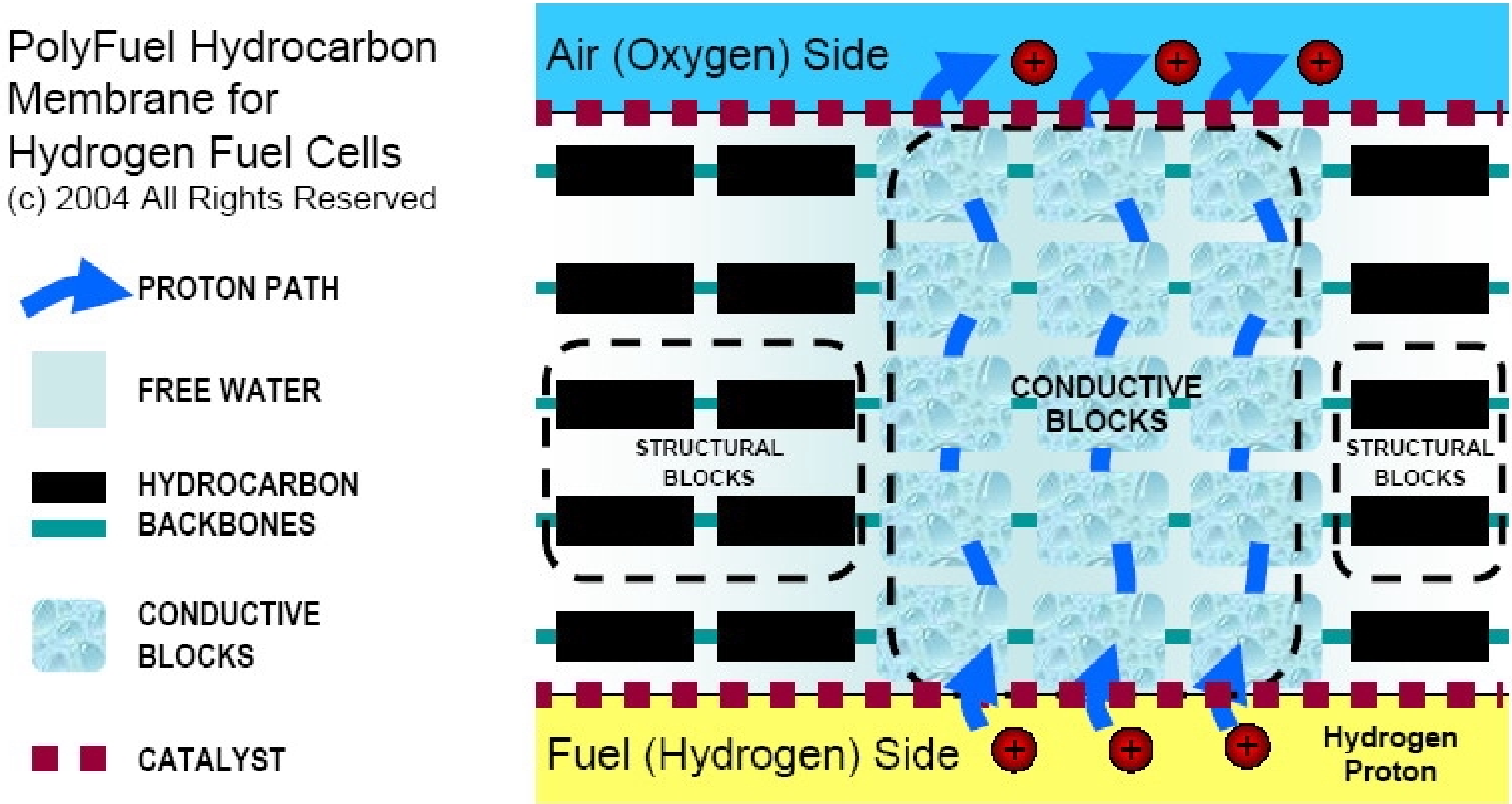
- 1.5 Kw module example
- Stackable Configurations
- Modular Architectures

Traditional Perfluorinated Fuel Cell Membrane



- The backbone of the membrane is formed from relatively weak Teflon®-like polymer fibers.
- Conductive clusters of water form at the ends of side chains (not shown) sprouting from the Teflon backbones.
- A proton follows a long and winding road from cluster to cluster while crossing the membrane. Between clusters, it is forced to use less conductive free water molecules as a pathway.
- Since the conductive clusters are relatively far apart, large amounts of free water (i.e, a higher level of humidification) is required to keep conduction going.
- At elevated temperatures the Teflon-like backbone expands, pulling the conductive groups farther apart. Some of the free water also evaporates. Together these two effects act to reduce membrane conductivity.

Courtesy PolyFuel



- The PolyFuel membrane consists of alternating nano-sized conductive blocks and structural blocks.
- The structural blocks bind together causing the conductive blocks to automatically line up.
- Water is attracted to the conductive blocks because of their molecular structure, and forms a continuous column from the fuel side of the membrane to the air side. This column acts like a superhighway for the protons.
- The nature of the hydrocarbon backbone structure makes the PolyFuel membrane 16 times stronger than perfluorinated membranes, even at elevated temperatures.
- Because the conductive blocks are closely aligned, less water is required to achieve good conductivity, i.e., the membrane performs well even at low humidification as well as at higher temperatures.

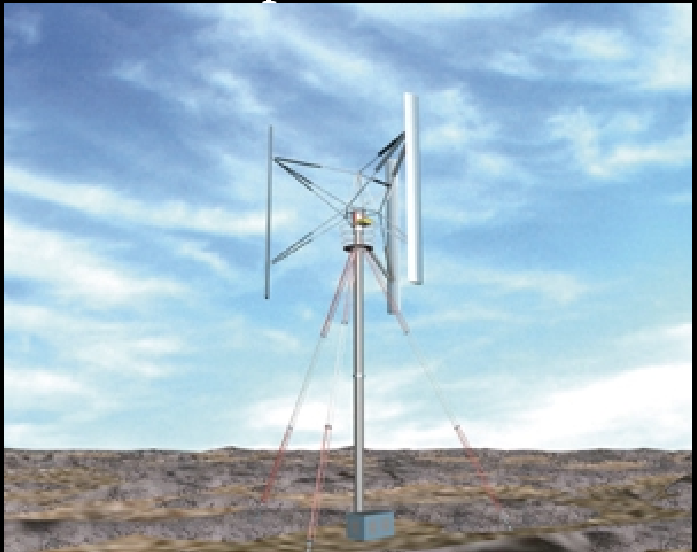
Courtesy PolyFuel

Option 1:
"Big" / Grid Compliant Wind Characteristics

1) Geographically tied to peak usage density logistics
2) Complex control and regulatory mechanisms and electronics
3) Substantial MTBF impact

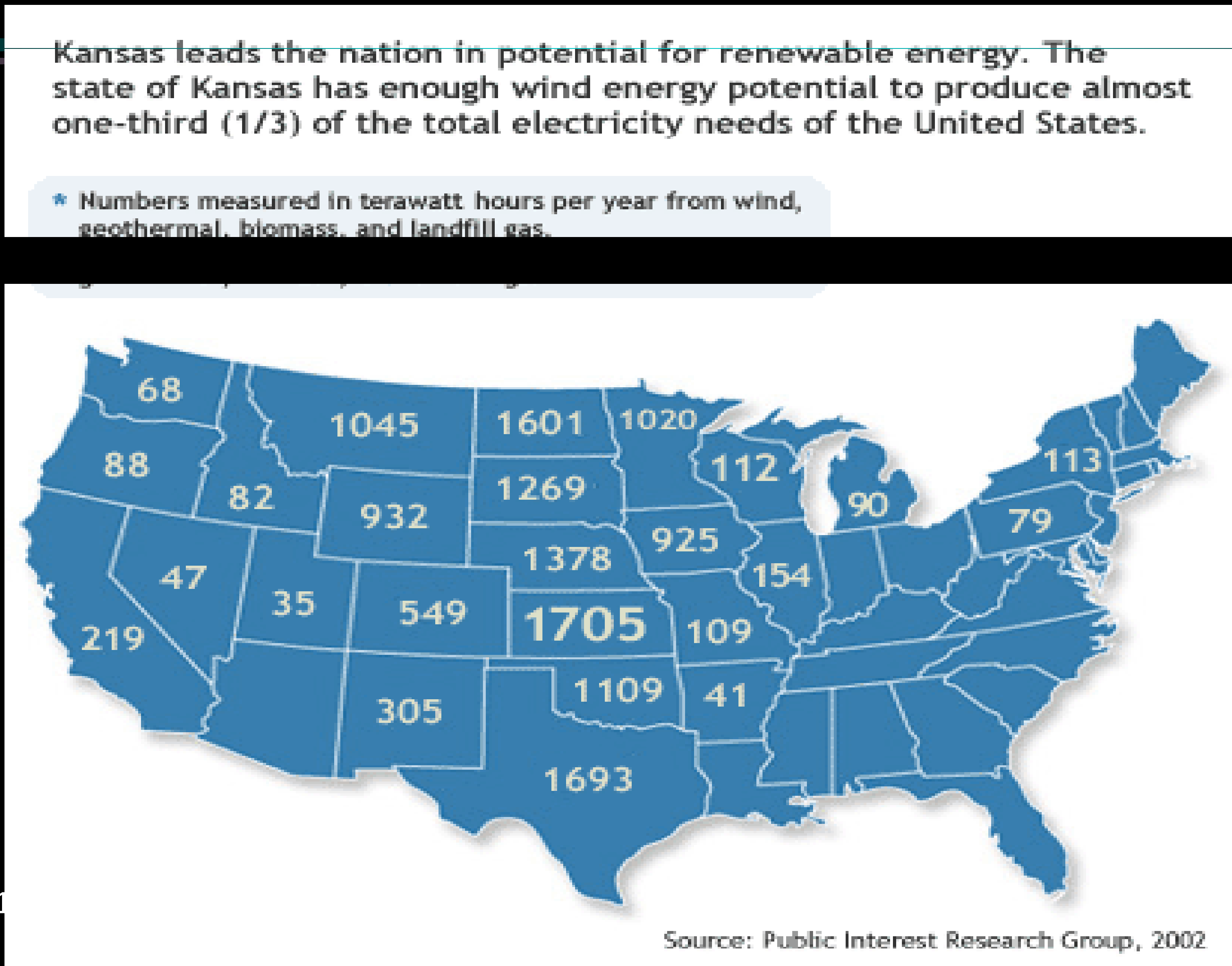
Option 2:
"Small" / Distributed Wind Characteristics

1) small wind systems can be deployed in many situations where big wind systems would not be viable
2) small wind systems can also be installed in parallel with big wind installations to re-capture low altitude surplus wind and turbulence activity not recognized by the big systems
3) small wind systems are highly mobile, can be constructed "on the fly" to suit localized phenomena and momentary energy requirements



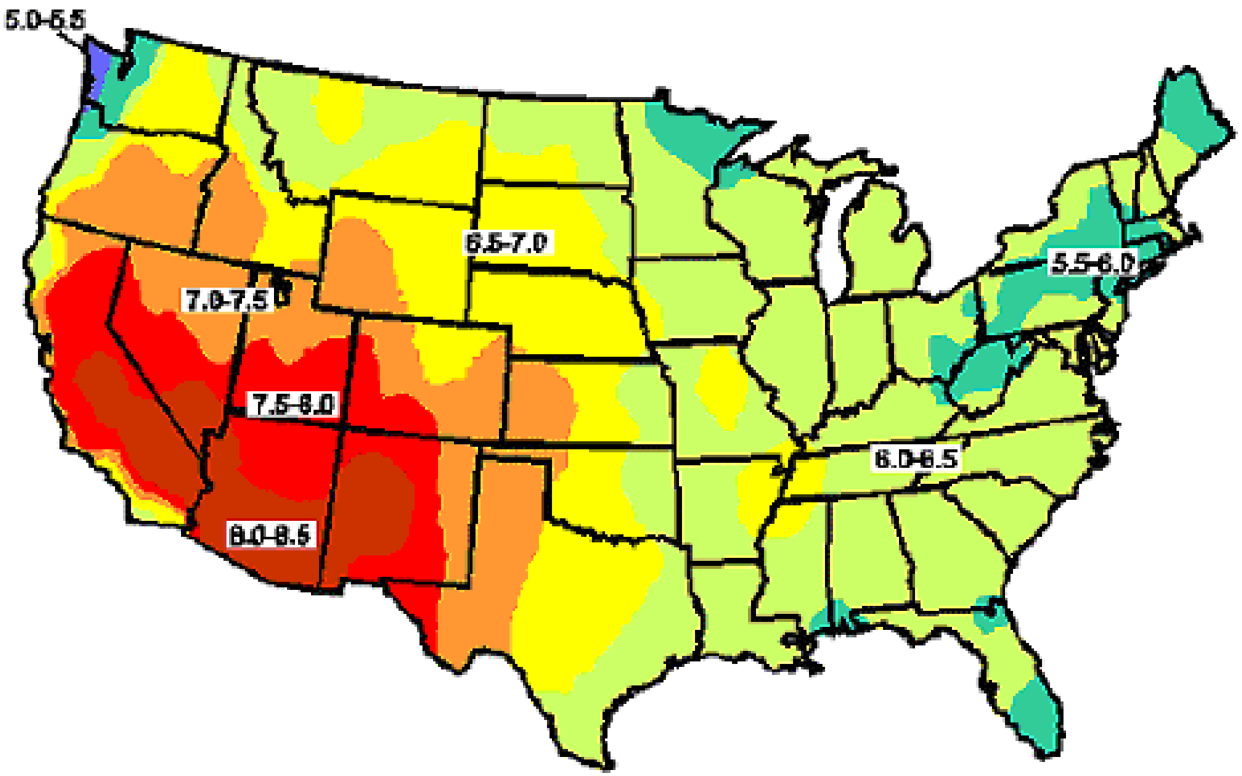
Option 3:
“Big” and “Small” Wind Combined
with Energy Storage

Wind Energy Resources Throughout the United States of America



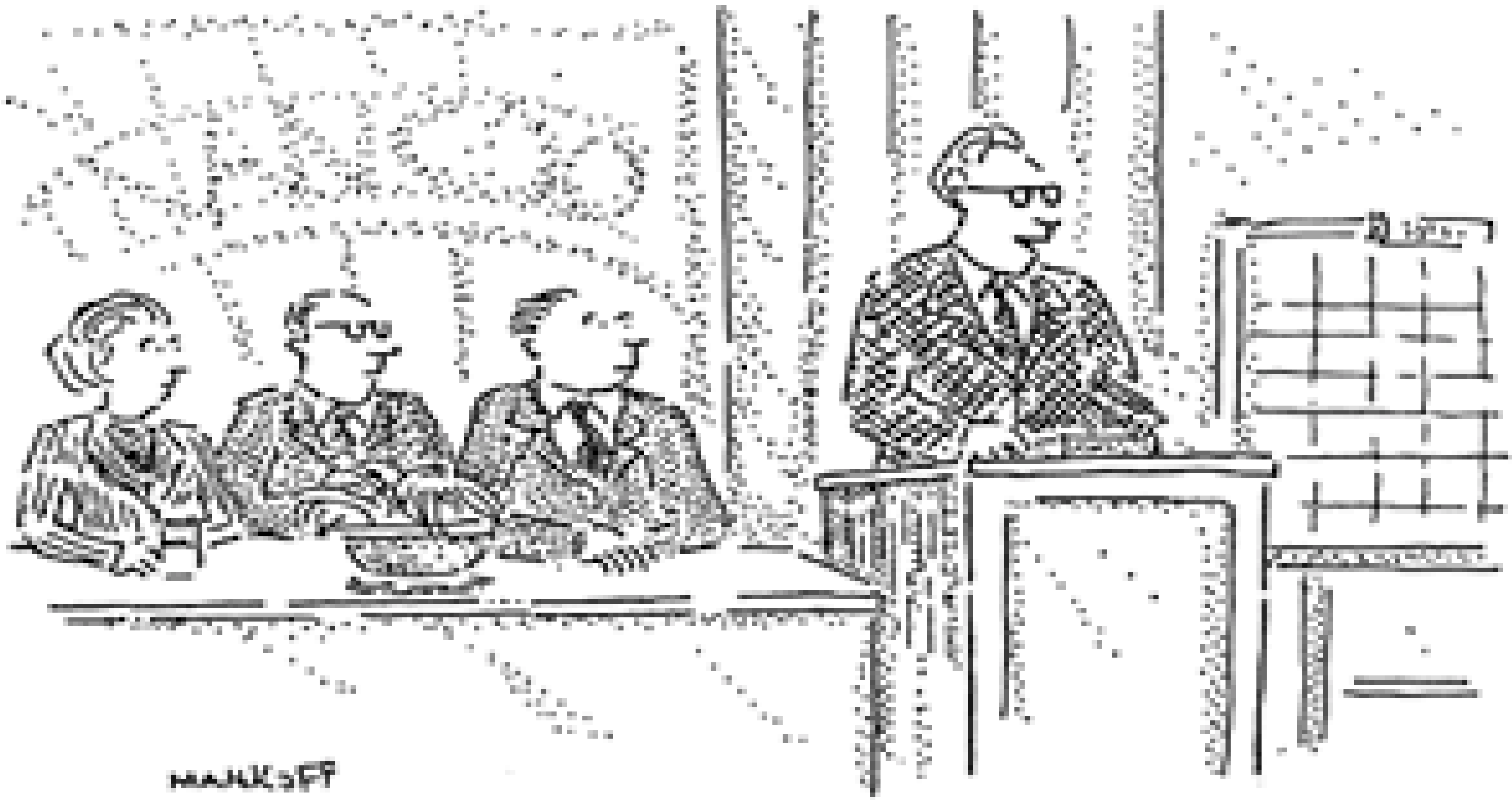
Solar Energy
Throughout the United States of America

Figure 2. U.S. Solar Resources



Note: Measurements indicate the average radiation received on a horizontal surface across the continental United States in the month of June as measured in kilowatthours per square meter.

Source: National Renewable Energy Laboratory.



"And so, while the end-of-the-world scenario will be rife with unimaginable horrors, we believe that the pre-end period will be filled with unprecedented opportunities for profit."

The New “Mission Critical” Imperative

- When JFK declared we would have men on the moon in a decade, many thought this was impossible.   Today the mission could be energy independence in 10 years.
- Ten years of development time now is very different than ten years of development time four decades ago.

The New "Mission Critical" Imperative – Concluding Statement

- Cheap, clean, sustainable, universally available energy in abundance -- is the single most important technical problem facing the world in the 21st century.
- If we solve this energy problem we can help solve most of the other top problems we face in this century: water, food, pollution, greenhouse gases, poverty in the developing nations and the over-population and lack of education that make them such potent breeding grounds for religious fanaticism, terrorism, and war.
- Conversely, if we don't solve the energy problem, there may not be an acceptable answer to any of these other problems.

\- Richard Smalley

Nano Electronics & Photonics Forum

NanoElectronics & Photonics Forum Conference

Oct 26, 2004   Palo Alto CA

Nano Electronics
& Photonics Forum

TOWNSEND
and
TOWNSEND
and
CREW
LLP

www.technofutures.com/charles1.htm

www.NanoSIG.org/nanoelectronics.htm

Catalyzing the next industrial revolution spawned by the convergence of interrelated domains of applied nanotechnology in electronics and photonics.

NanoElectronics & Photonics Forum Conference
Oct 26, 2004 Palo Alto CA

www.NanoSIG.org/nanoelectronics.htm

Cambrios - Dr. Michael Knapp Bio-assembled electronics / integrated devices

Integrated Nano-Technologies – Dr. Mark Nance DNA enabled electronic bio-sensors

U of Illinois, Urbana-Champaign - Prof Ralph Nuzzo Self assembling nano-electronics

Knowmtech - Alex Nugent Nanotechnology-based neural networks / integrated devices

Nanomateria - Prof Samuel Stupp, Northwestern U Self assembling bio-material systems

Sandia Lab – Dr. John Shelnutt Photosynthesis as a biofoundry platform for nanostructured materials

University of Toronto / MIT - Prof. Edward (Ted) H. Sargent Quantum dots utilized in low cost infrared CCD array

OFI Devices - Phillip Langton Next generation nanotech enabled “smartdust” distributed sensors, “spray on” computers

Office of the President, University of California - Dillon Auyoung, Principal Analyst, Industry-University Cooperative Research Program

Institute for Global Futures, Silicon Valley Nano Ventures - Charles Ostman Understanding the value proposition of applied nanotechnology in electronics, photonics, integrated systems

Draper Fisher Jurvetson - Alexei Andreev

DotEdu Ventures - Asha Jadeja`

Catalyzing the next industrial revolution spawned by the convergence of interrelated domains of applied nanotechnology in electronics and photonics.