Mapping a Strategy for the Future – Energy Resources, New Technologies 10 – 15 Year Horizon

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11/13/2004

Oil Refinery

Where are we Now?
Where do we Want To Be?
Getting There . . .
Concluding Statements

Solar Power
from Space

Mapping a Strategy for the Future – A composite of integrated solutions

today > 5 – 10 years > 10 – 20 years

Wind

Solar

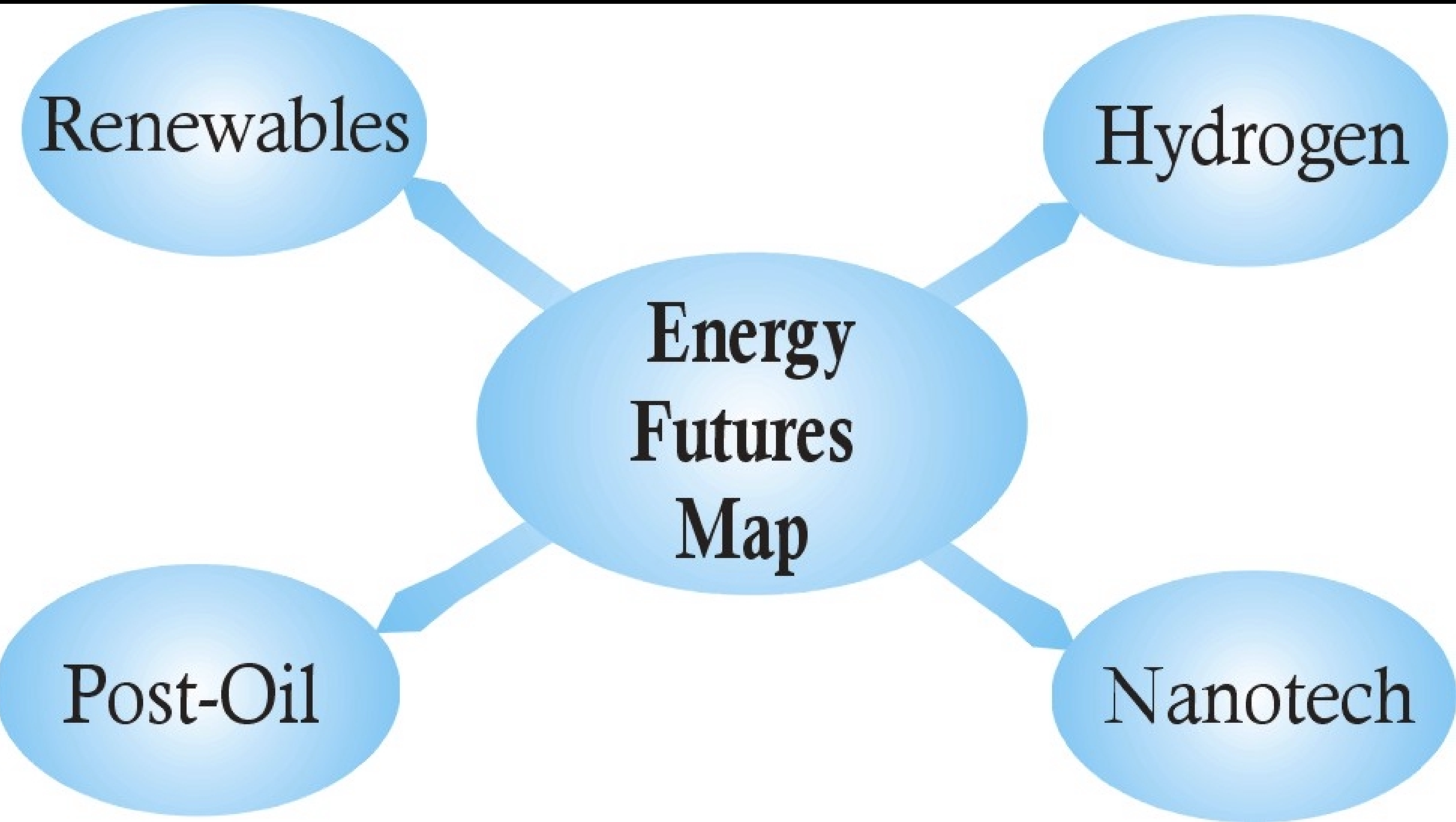
Hydrogen

Biomass

Gas/Coal

New Tech

Mapping a Strategy for the Future – A composite of integrated solutions



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Toward A Pan-American Energy Community?

L. Ronald Scheman | Tuesday, May 04, 2004

The American Energy community would encompass all forms of energy: fossil, hydroelectric, geothermal, solar and renewable.

Attitude Adjustment:

Before an energy community can be formed, the United States will have to confront the mythology of low-cost Middle East oil.

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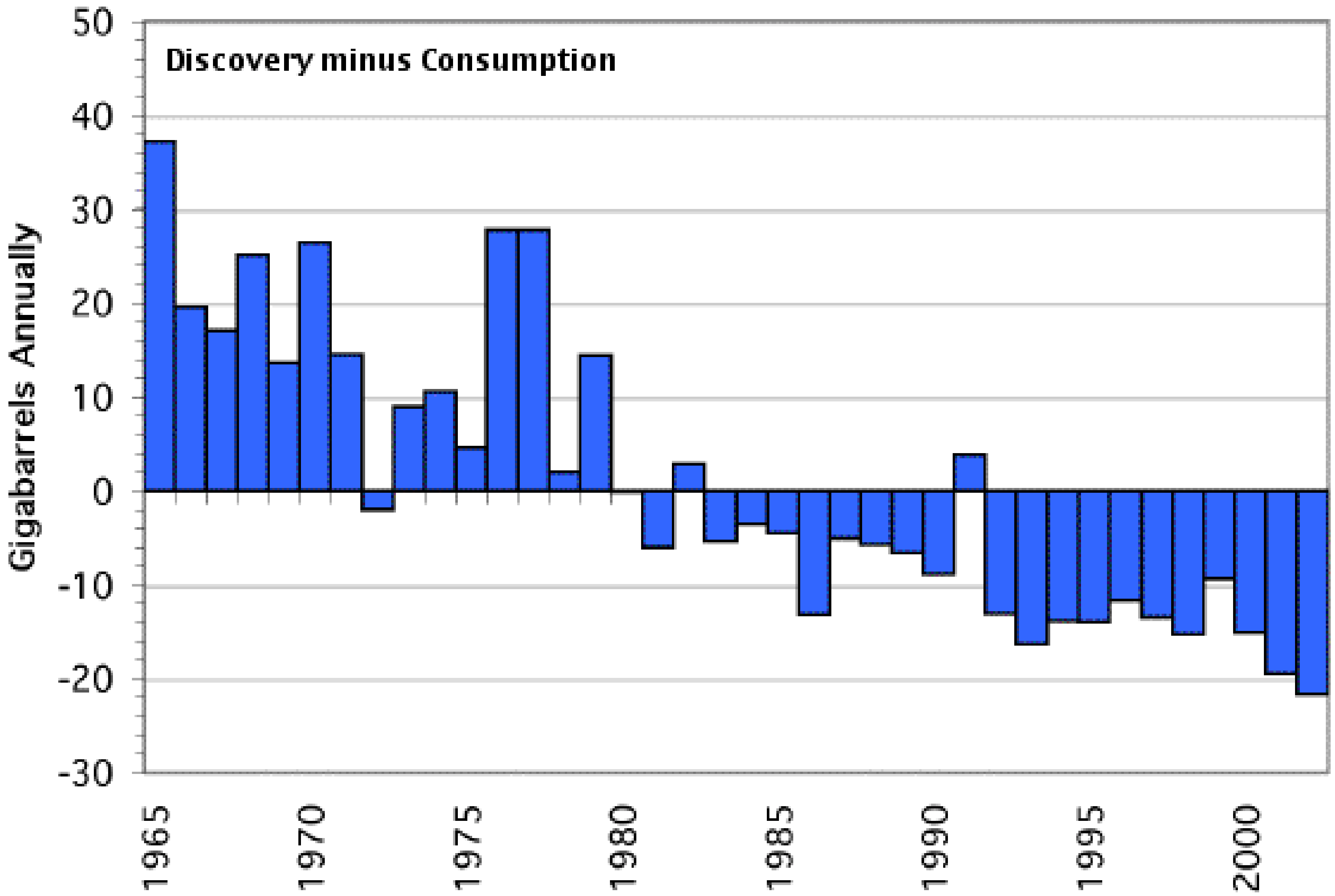
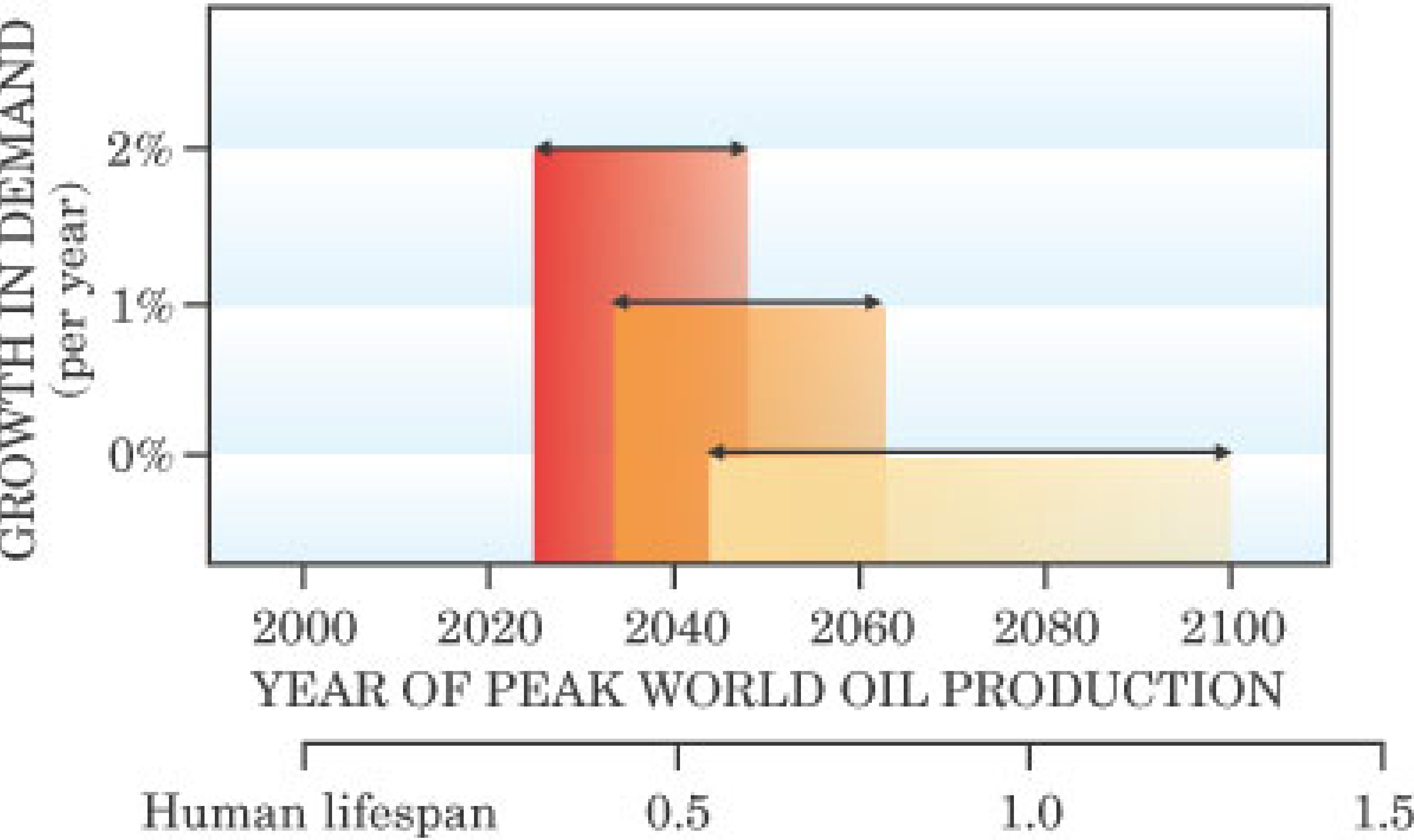
Attitude Adjustment:

Before an energy community can be formed, the United States will have to confront the mythology of low-cost Middle East oil.

Middle East oil is the most expensive fuel the world has ever known — considering its penchant for extremism and that the region has yet to feel the impact of the information revolution and the pressures for democracy.



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


GROWTH IN DEMAND (per year)
2%
1%
0%
2000
2020
2040
2060
2080
2100
YEAR OF PEAK WORLD OIL PRODUCTION
Human lifespan
0.5
1.0
1.5

Strategic Energy Domains – Mapping Demands to Arenas of Optimization

World energy demand is continuing to grow by 3% per annum, so by 2020 it will be up by over 40%. Most of this growth will be in China - The future lies in energy efficiency but consumption is rocketing

Building Technology

•Non-residential

•Residential

Industrial Technology

•Process/Manufacturing

•Operation & Management

Transportation Technology

•Alternative Transportation Fuels

•Energy Efficient Fleet Management

•Mass Transit/Carpooling Programs

Utility Technology

•Demand-Side Management

•Renewable Energy Systems

•Production/Supply/Network

•Efficiencies

Strategic Energy Domains – Mapping Demands to Arenas of Optimization

- Production
- Conversion
- Application
- Storage

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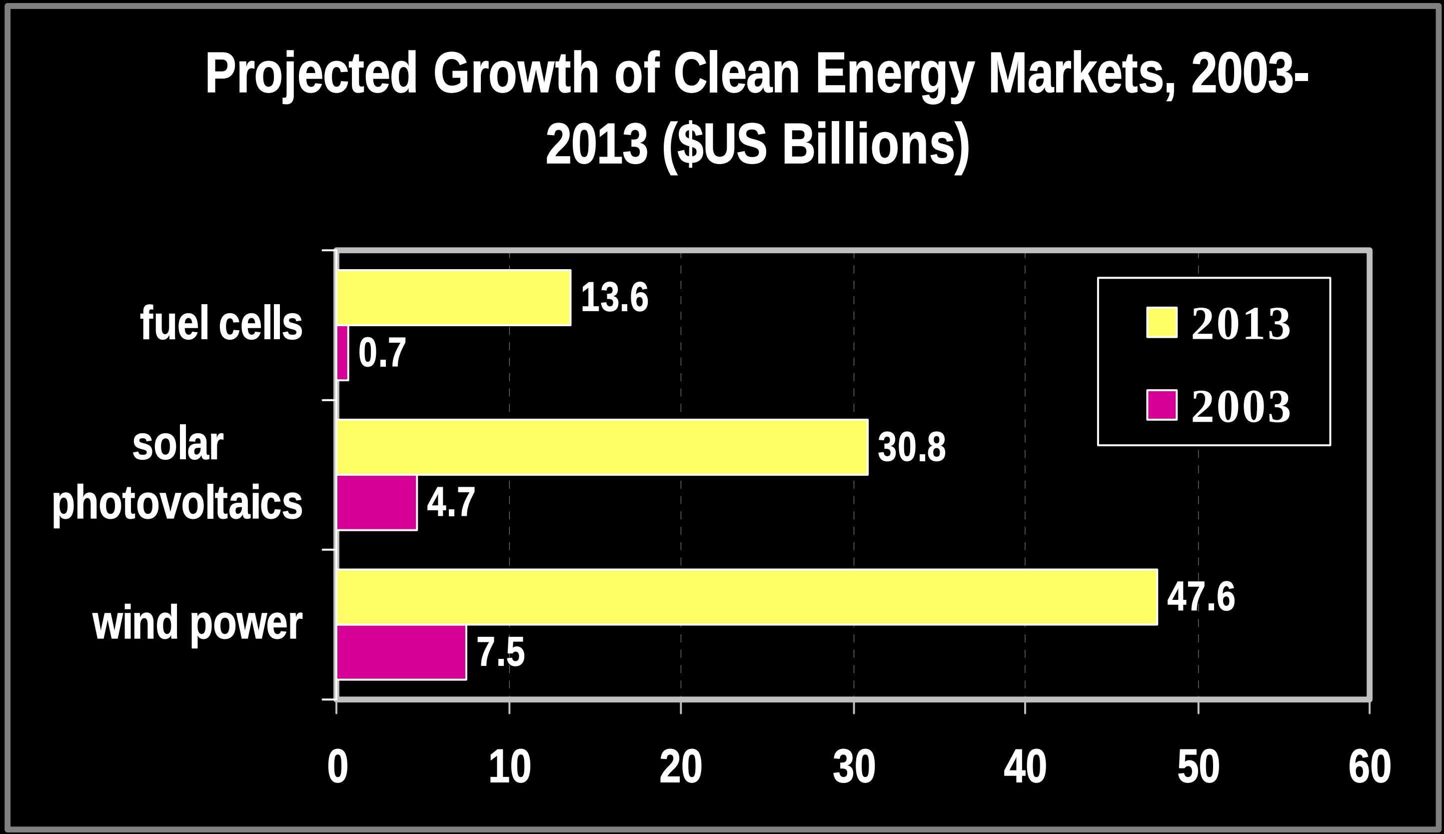
Distributed / Decentralized Power

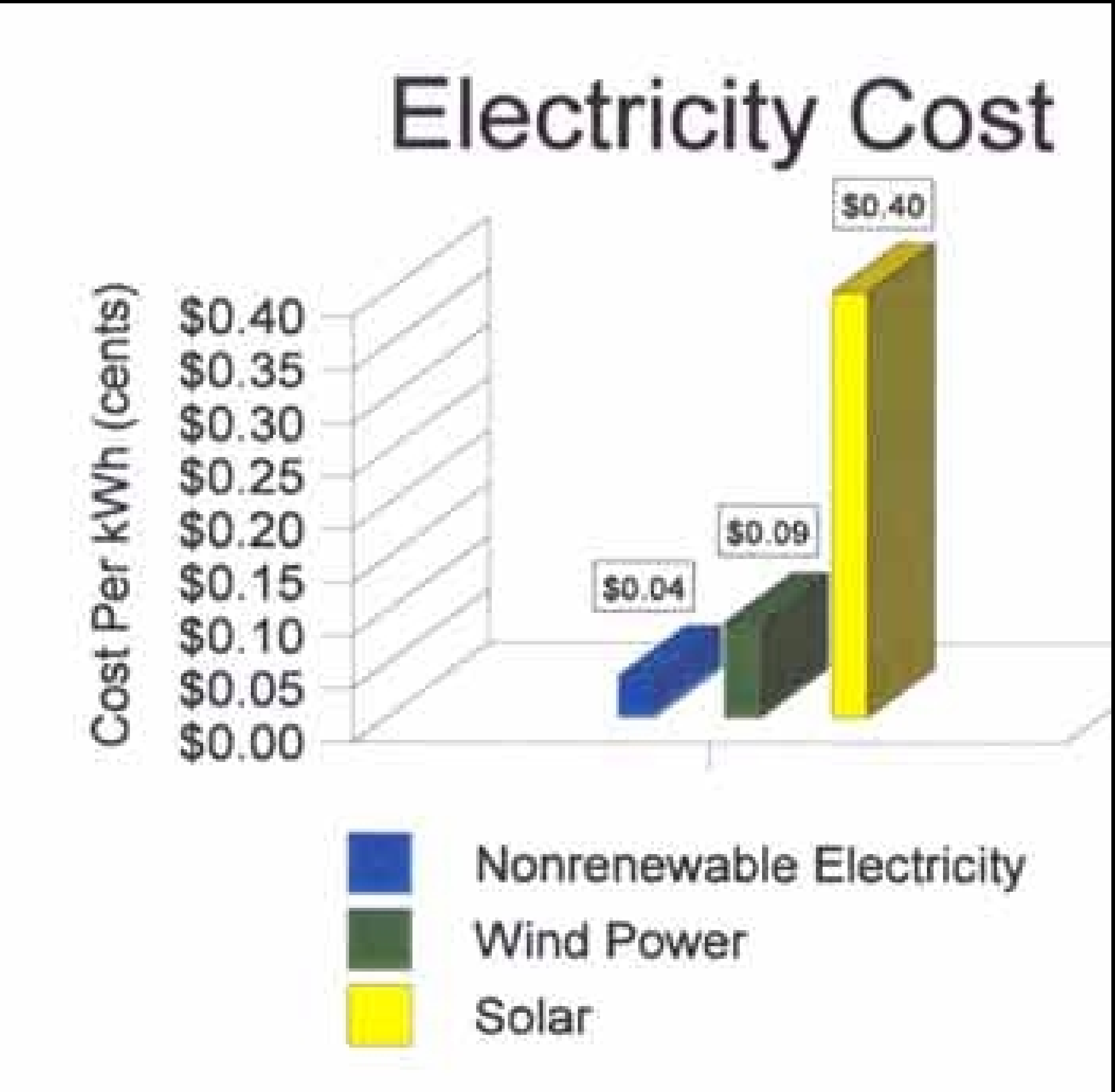
Specific Solution Sets for Specific Situations

- 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



Current Cost Index

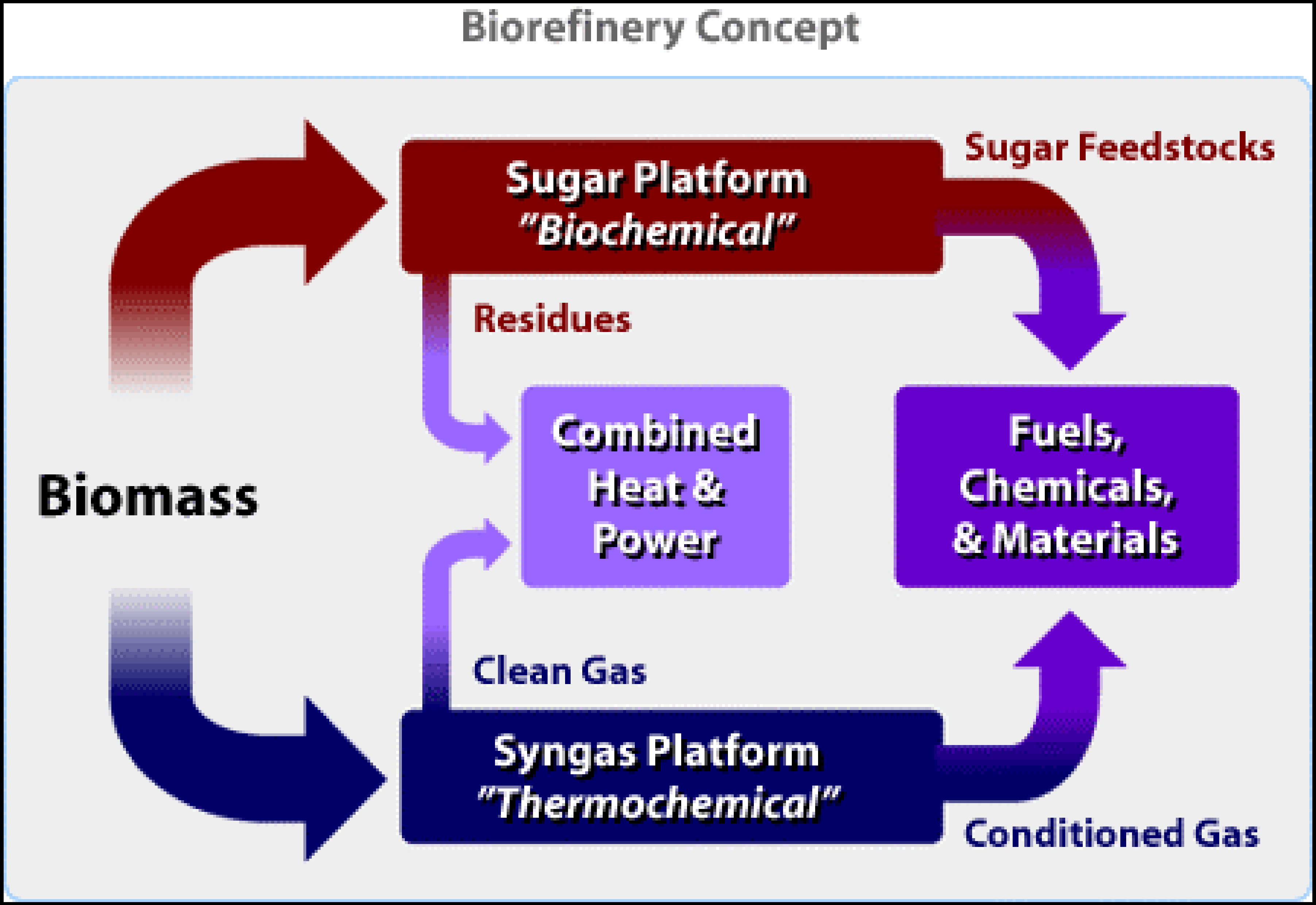
a “true” picture?

Future Cost Index

Depends on Many

Variables . . .

Aggregate of Distributed and “Grid” power, direct and secondary apps > interrelated value chains


Biorefinery Concept
Sugar Feedstocks
Sugar Platform
"Biochemical"
Residues
Combined Heat & Power
Fuels, Chemicals, & Materials
Biomass
Clean Gas
Syngas Platform
"Thermochemical"
Conditioned Gas

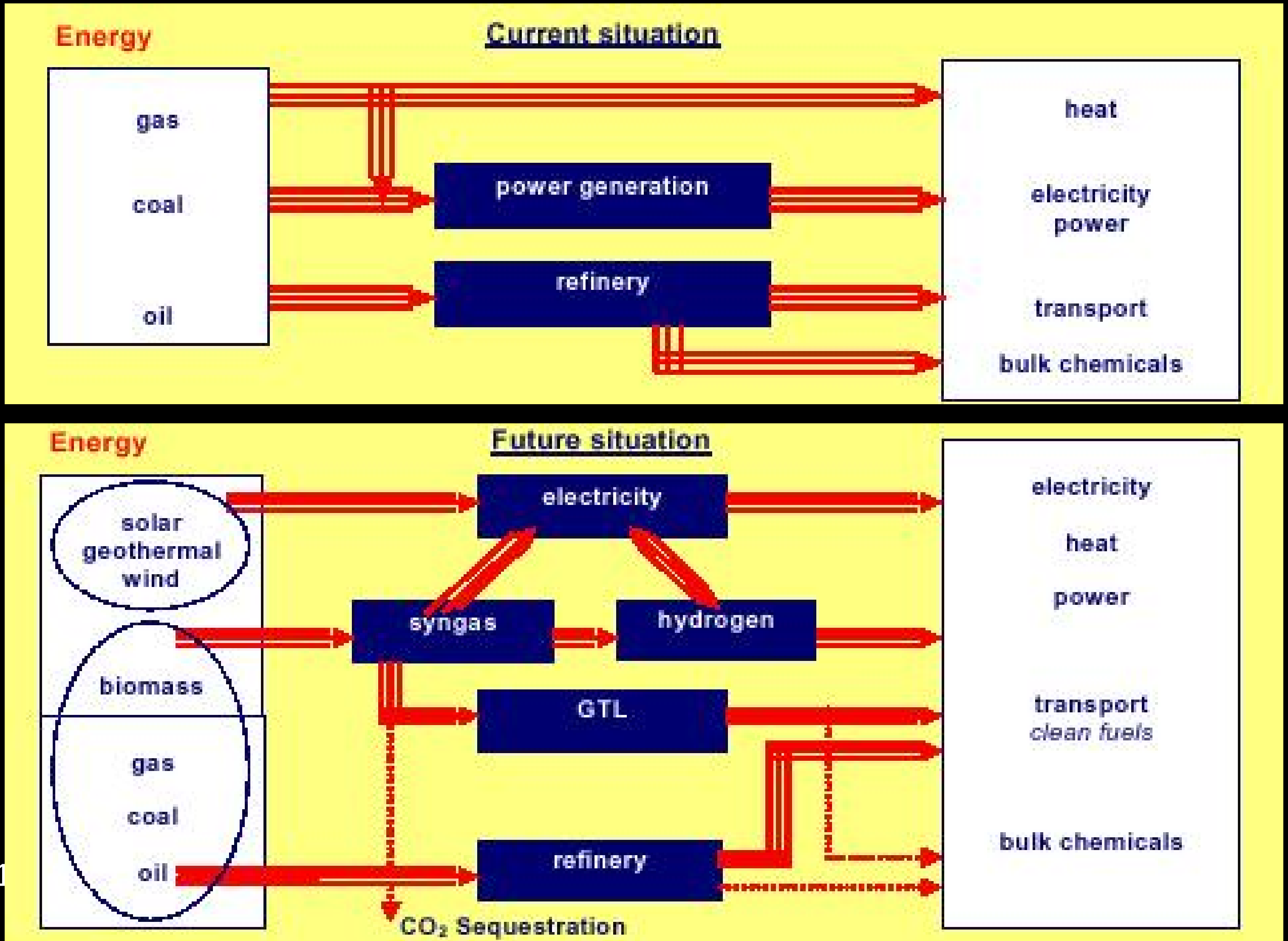
Biomass Infrastructure – Current, Future

Hydrogen Infrastructure – Current, Future

Figure 1. Xcellsis (Ballard) ZEbus

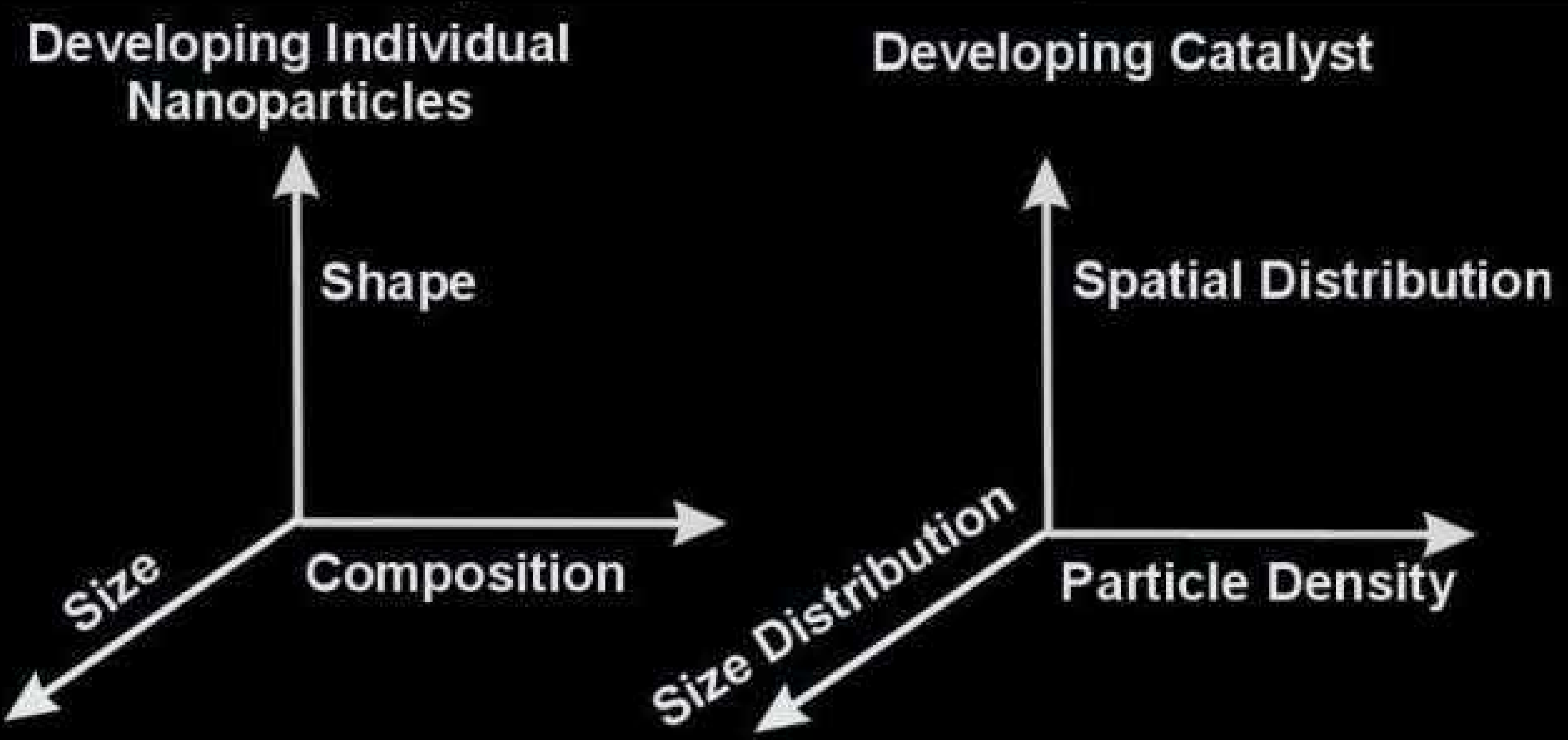
Figure 2. Mercedes-Benz NeBus

Current and Future Energy Situation - Catalysis Enabled Evolution



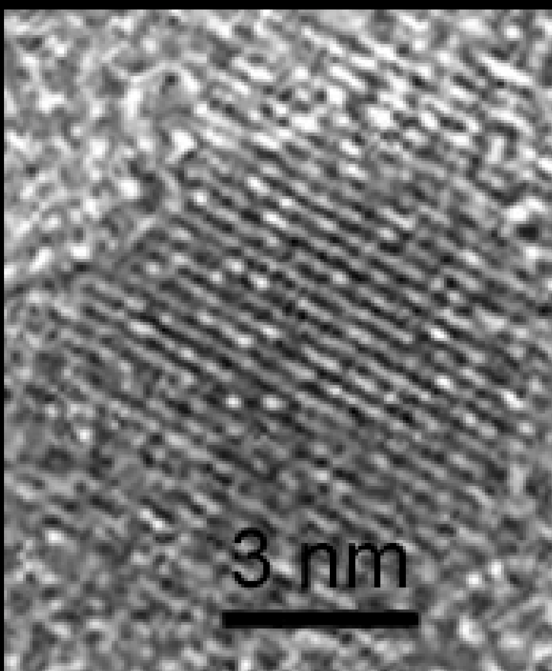
Nanostructured Catalysts

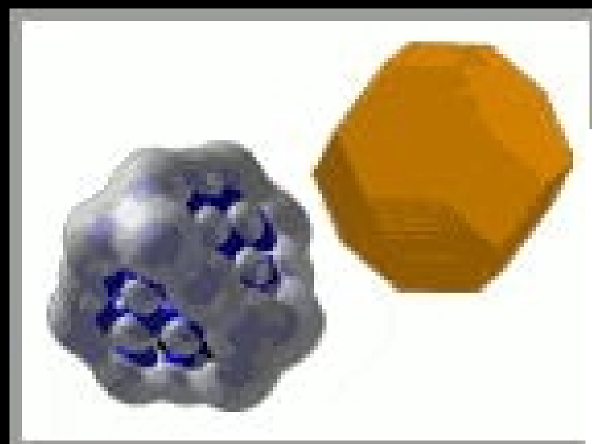
- Precise control of size, shape, spatial distribution, surface composition, and surface interface of atomic structure of the individual nanocomponents.

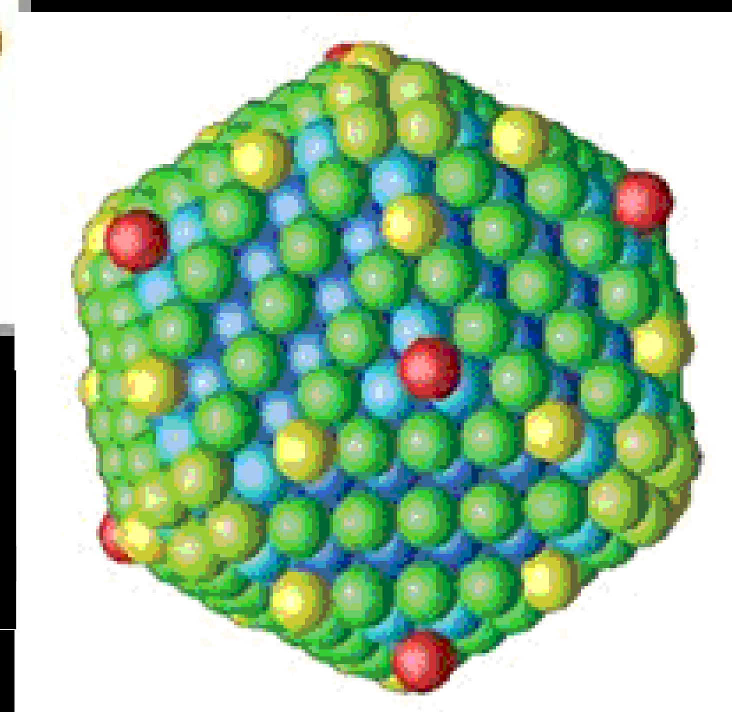


Quantum Modeling of Nanostructured Materials

- 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

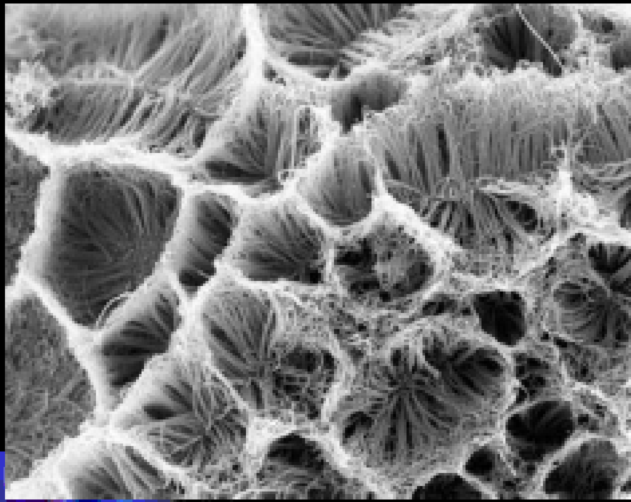


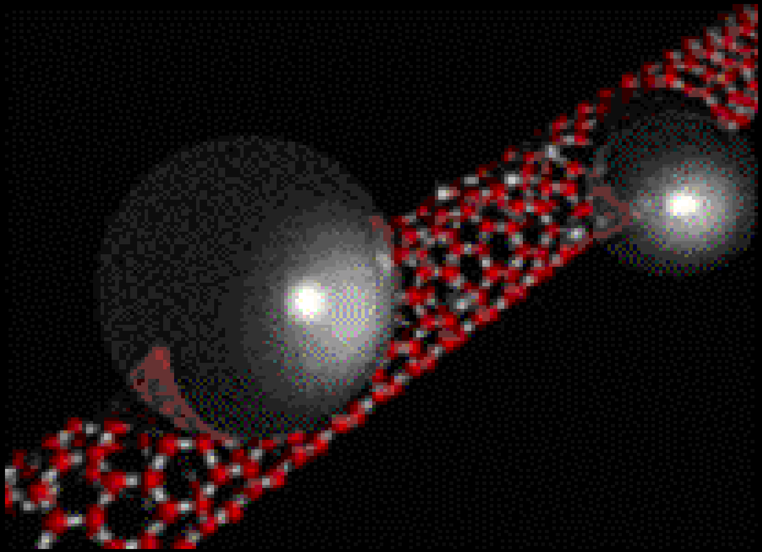


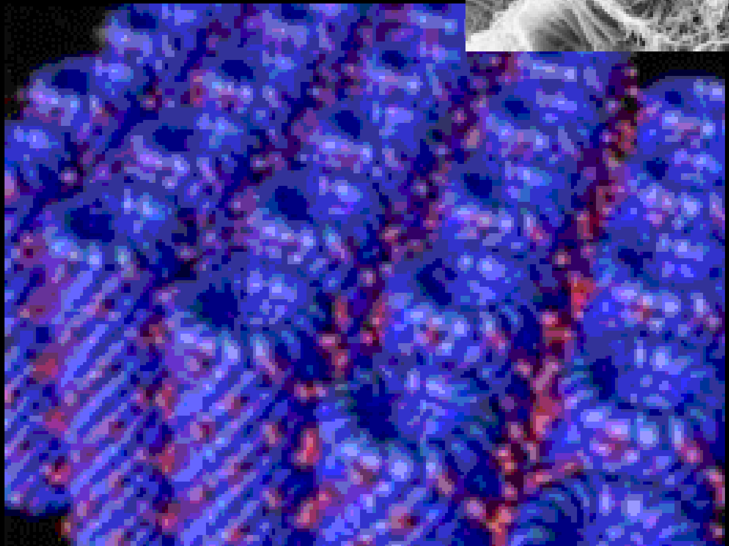


Carbon Nanotubes and Nanostructures

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

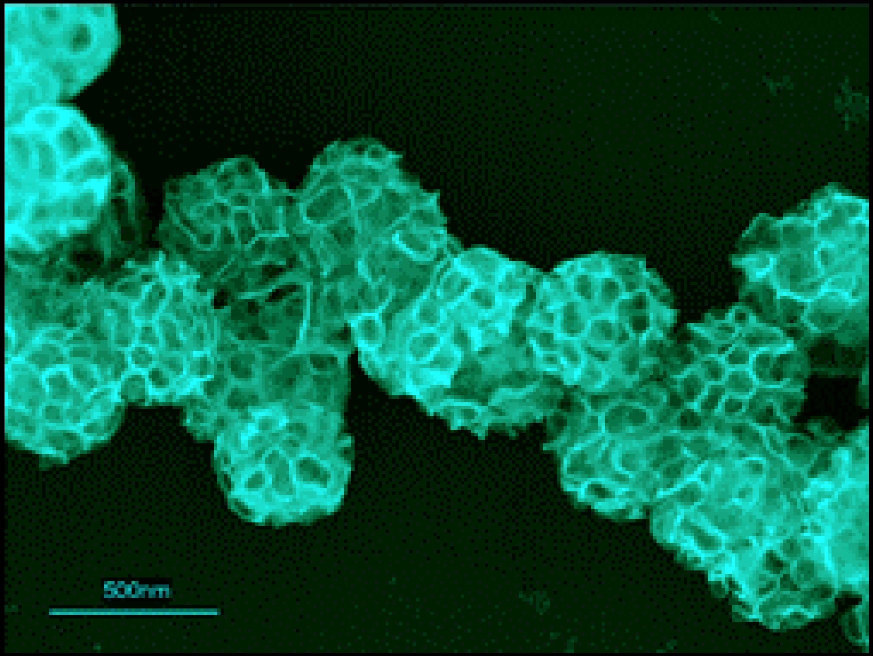


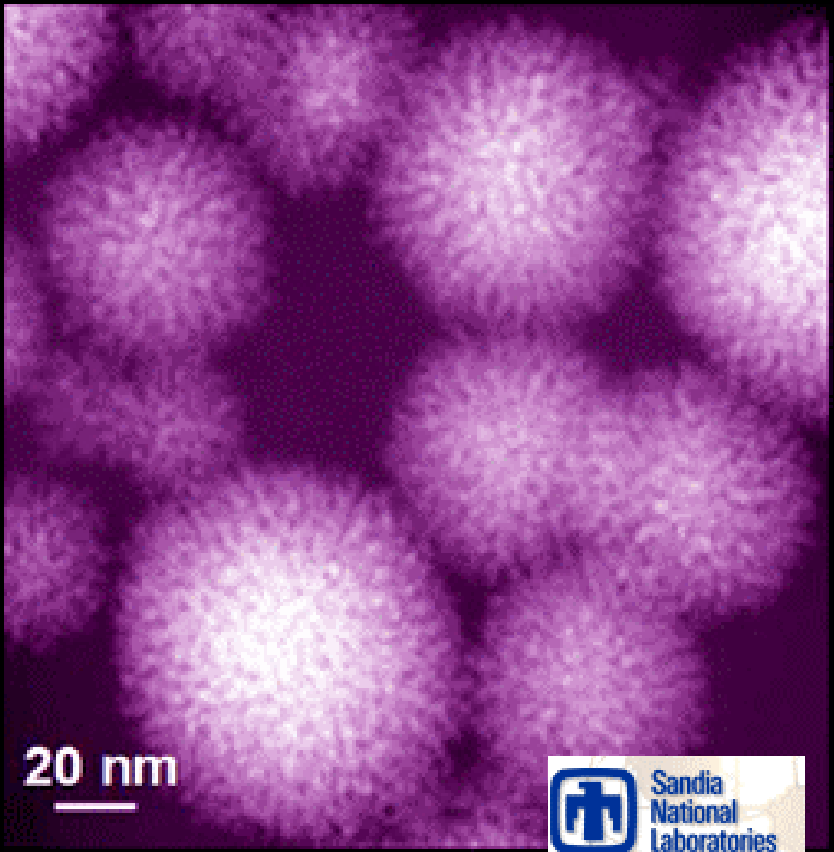




Biofoundry approach to cost effective catalysis and related functionalities

- Mimicking Photosynthetic Proteins to Manipulate Platinum





Sandia National Laboratories

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

Key Properties:

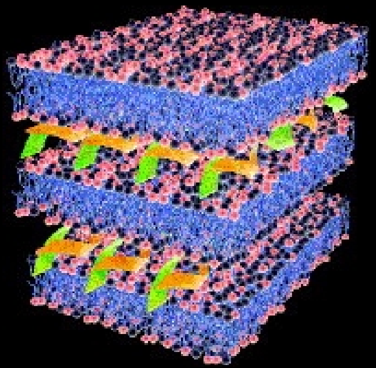
Photonic

Electronic

Mechnical

Chemical

Living Systems as Biofoundry



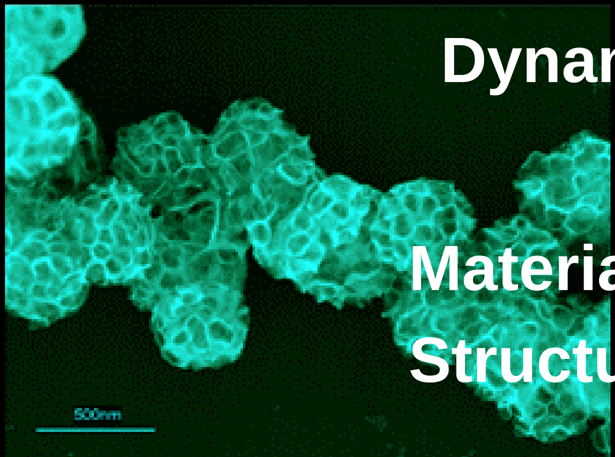
Genetic Magnification

Dynamic Agent

Controlled Replication

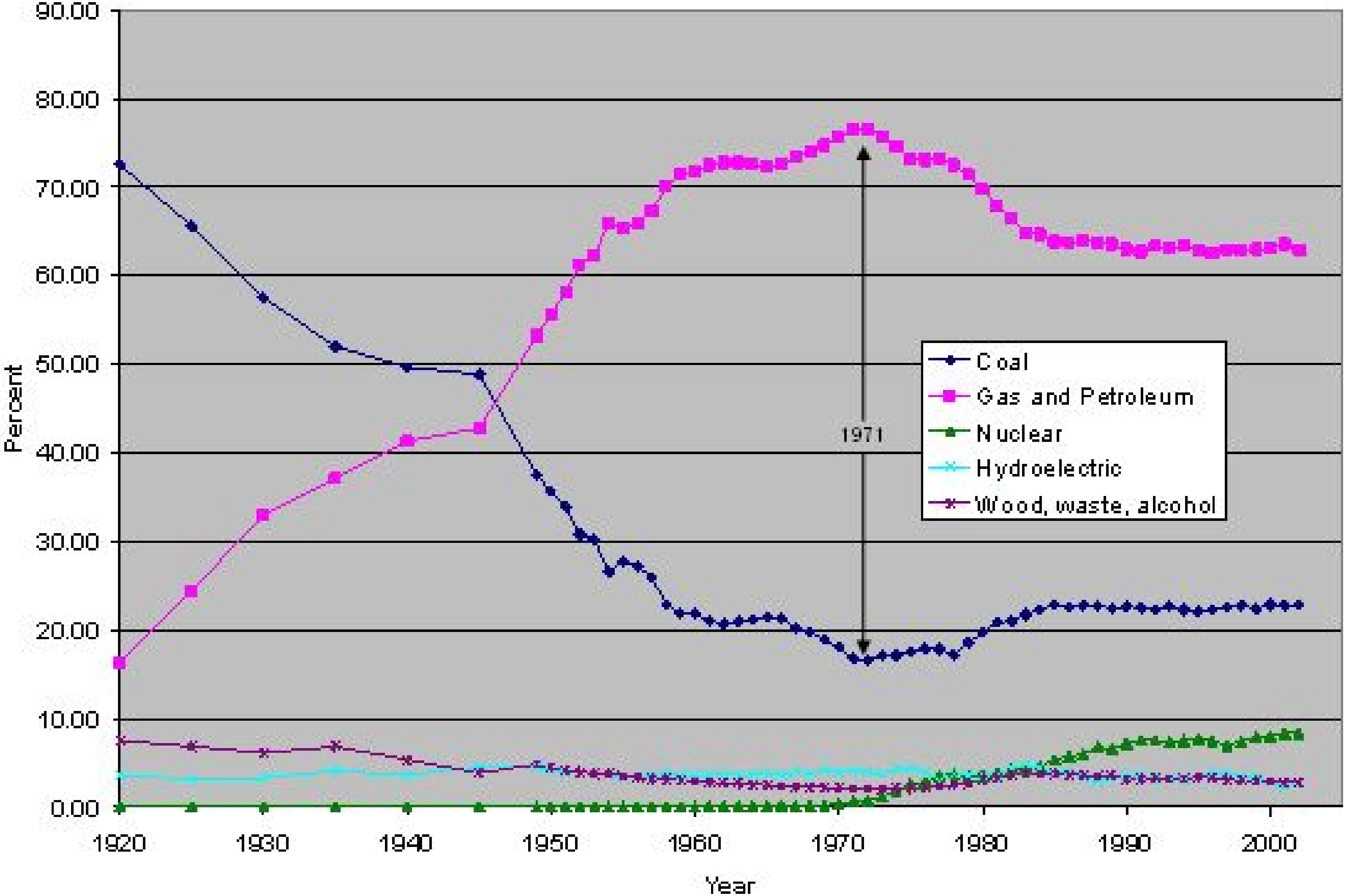
Material Patterning / Structural Systems

Materials Harvest / "Biocomponents"



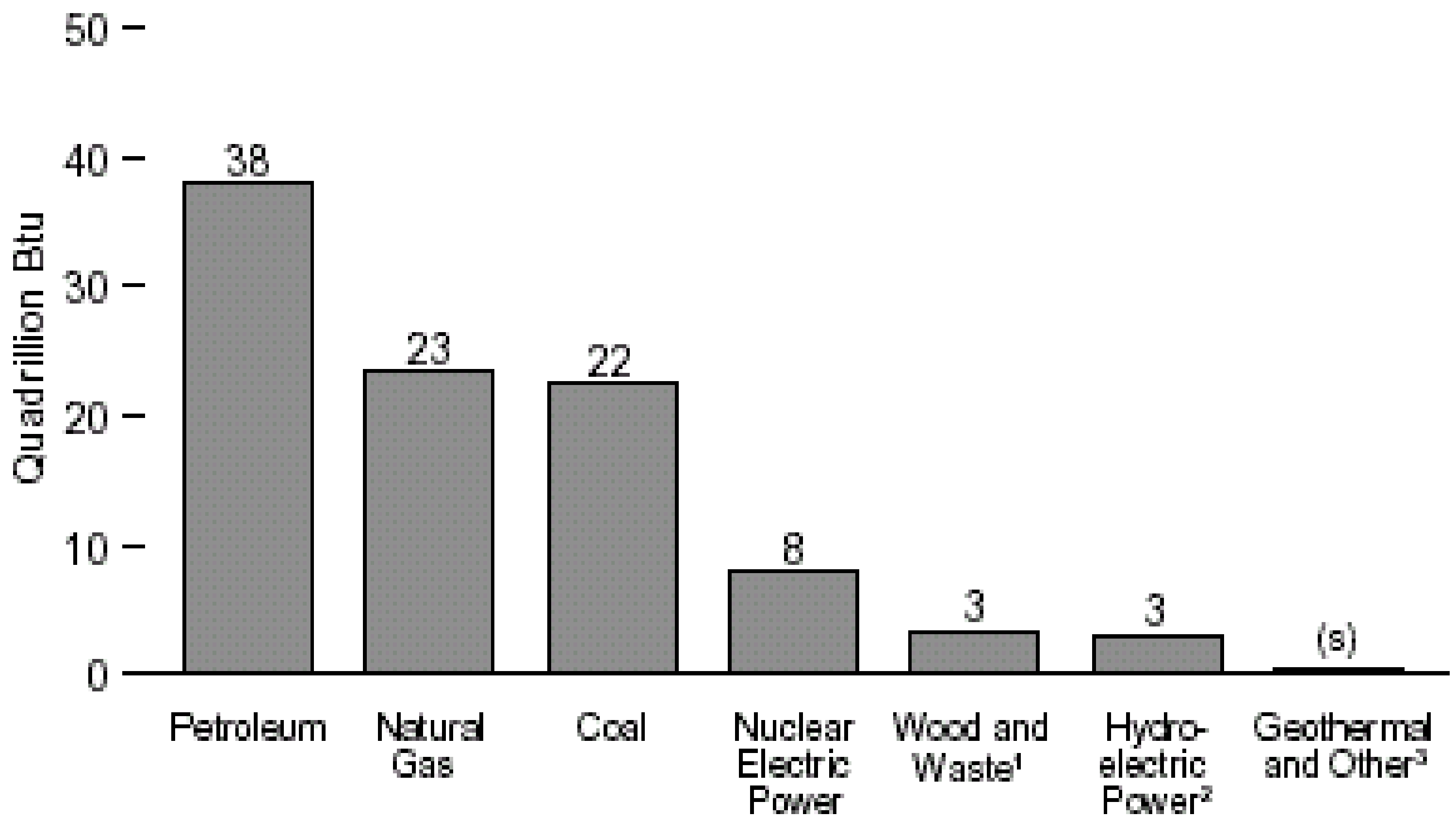
Technologies that could employ coal mine methane

1) coal fired utility and industrial boilers;
2) internal combustion engines;
3) fuel cells;
4) methanol production;
5) brine water treatment;
6) greenhouses;
7) blast furnaces;
8) microturbines;
9) heating mine facilities;
10) turbines;
11) cogeneration;
12) synfuel production;
13) ventilation air heating;
14) coal dryers;
15) ventilation air as combustion air in turbines and IC engines;
16) enrichment of coal mine gas;
17) upgrading coal mine gas via blending and spiking;
18) storage of coal mine methane in abandoned mines;
19) coal mine methane and liquified natural gas;
20) generating energy from coal mine ventilation air using oxidizers.



90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Percent
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year
1971
Coal
Gas and Petroleum
Nuclear
Hydroelectric
Wood, waste, alcohol

US energy consumption by source



[1] Includes ethanol blended into motor gasoline.

[2] Conventional and pumped-storage hydroelectric power.

[3] Solar and wind.

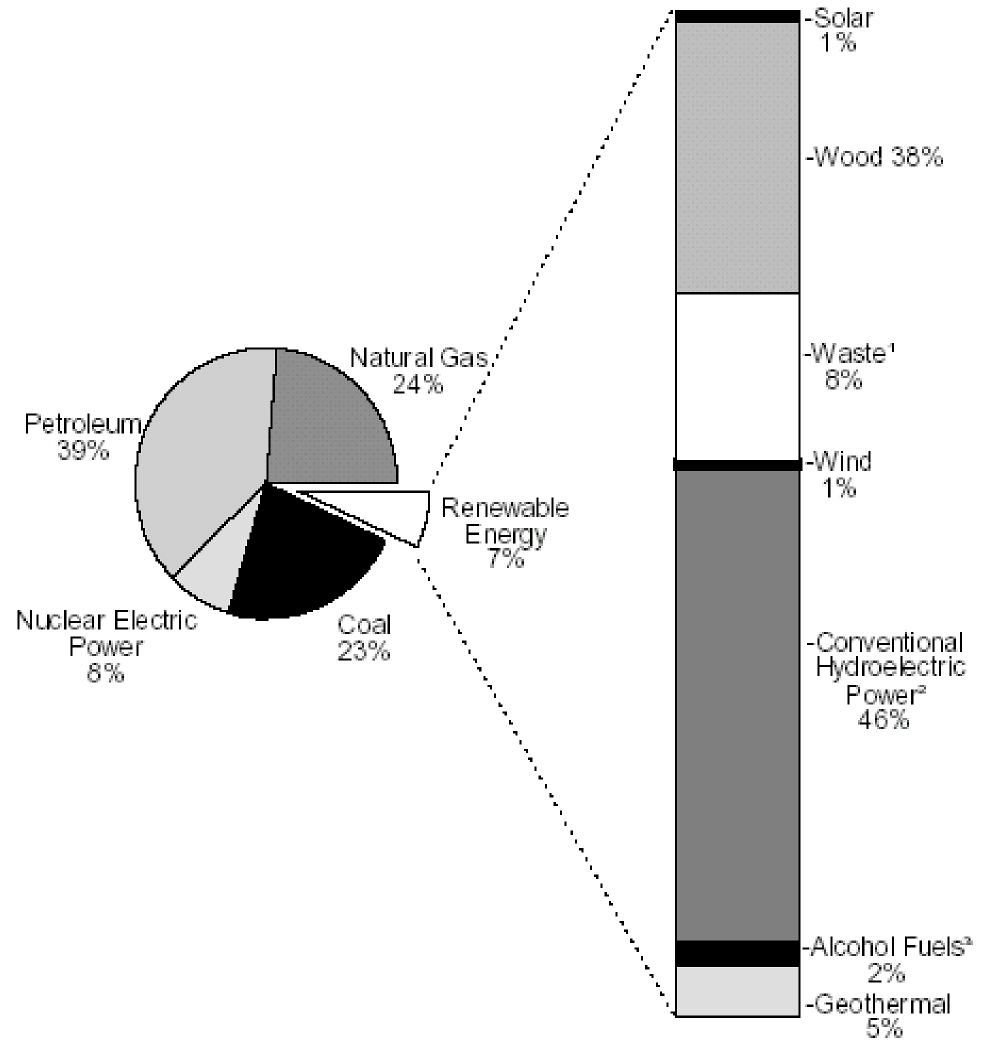
Source: US Energy Information Agency

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

11/13/2004



[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.

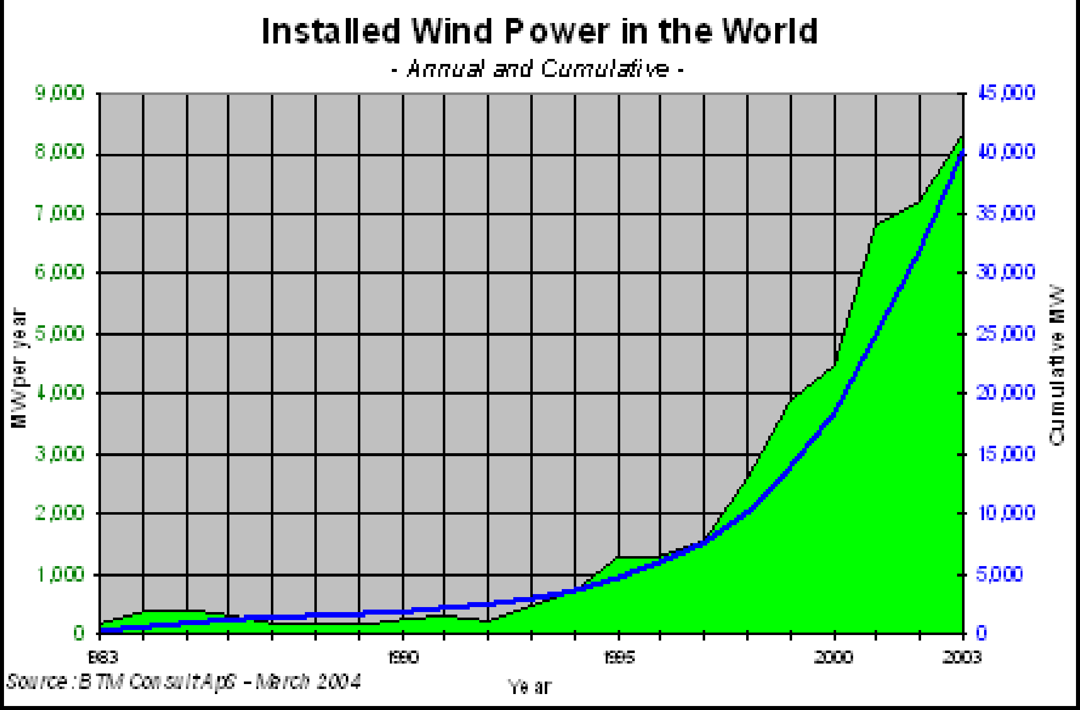
[2] Includes electricity net imports derived from hydroelectric power. Before 1989, includes net imports derived from all resources.

Solar Cell Area Requirements to Meet Energy Demand in Select Countries

	Energy consumed per year*		Land area	Approximate solar cell area needed	
	Quads per 10^6 people	Total quads	10^3 km^2	10^3 km^2	% of land
US	0.36	100	9 591	263	2.7
Belgium	0.27	2.7	30	7	24.0
Australia	0.19	4.8	7 580	13	0.2
Russia	0.17	26	16 981	69	0.4
Japan	0.17	21.8	372	58	15.4
Germany	0.17	14	356	37	10.3
UK	0.17	10	243	26	10.8
France	0.17	10	546	26	5.0
Brazil	0.05	8.6	8 466	23	0.3
China	0.03	32	9 377	84	0.9
Egypt	0.03	2.0	996	5	0.5

*Data from Department of Energy/Energy Information Administration *International Energy Annual 1999*.

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

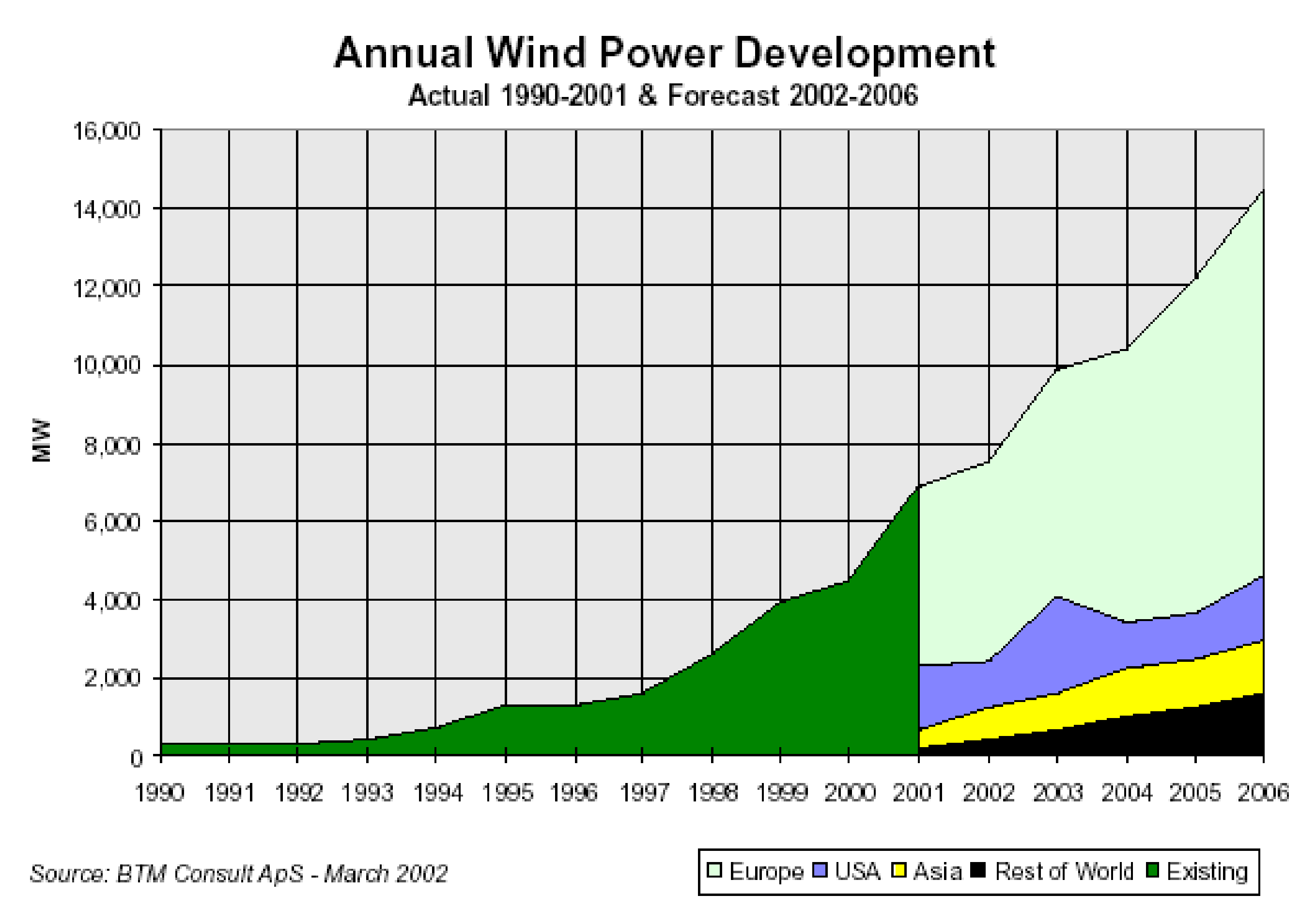


6,361 MW of wind currently installed in U.S.

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%

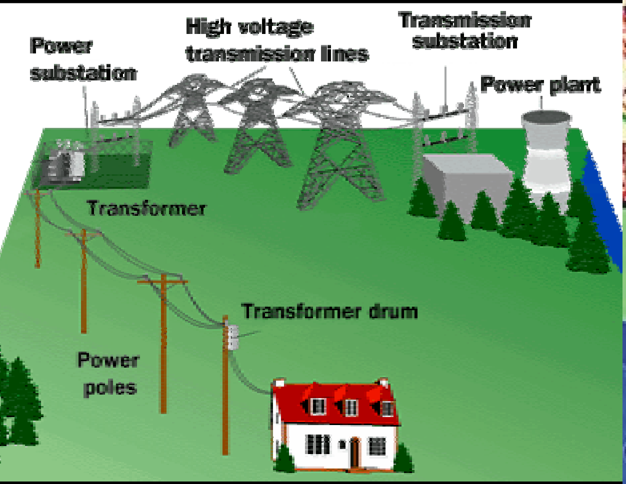
Aggressive Growth in Wind Installations is Expected to Continue

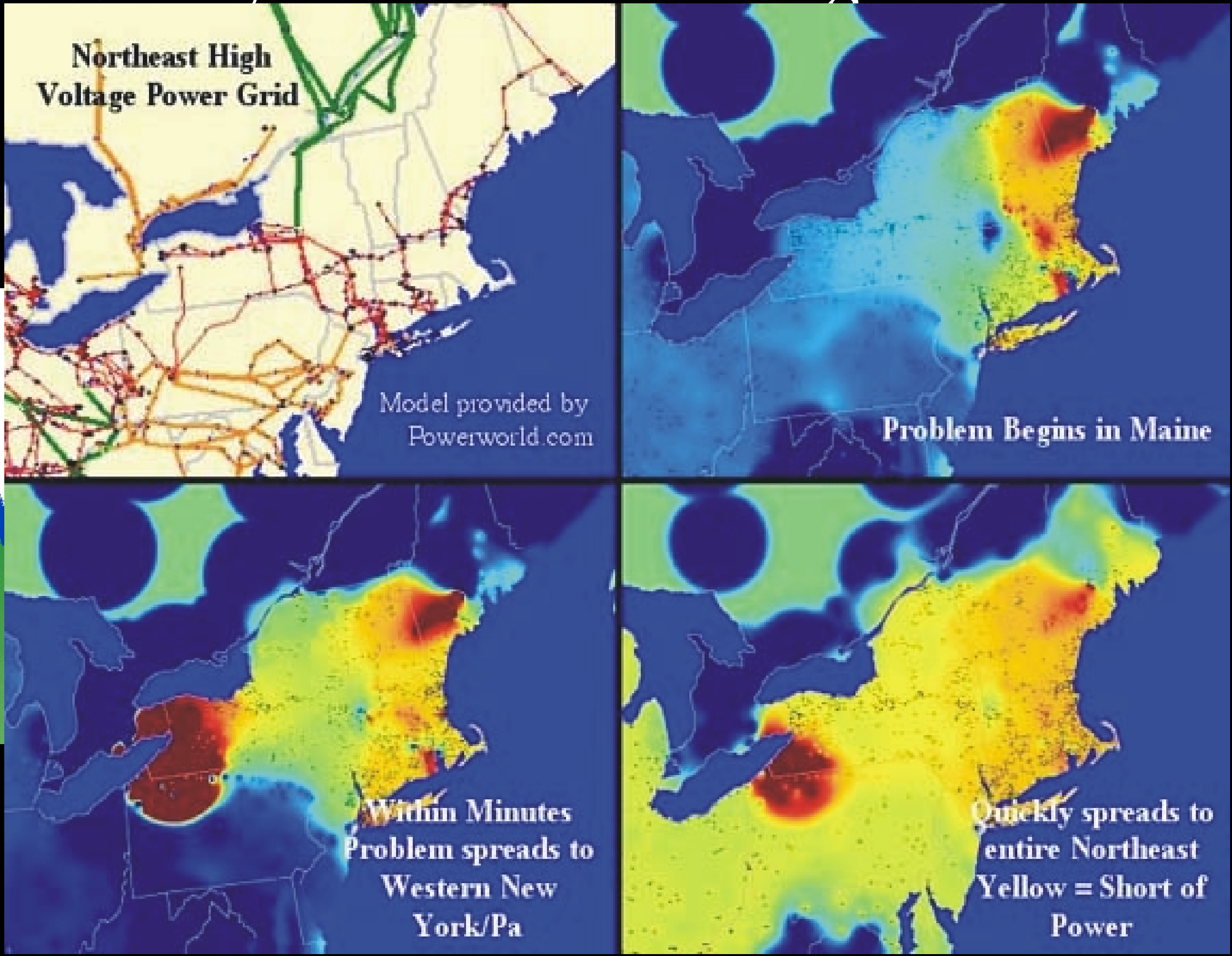
- **8,344 MW of new wind installations in 2003 represents >$8 billion in sales**
- **14,000 MW of expected 2006 installations represents ~ $14 billion of sales**



Fundamental Questions

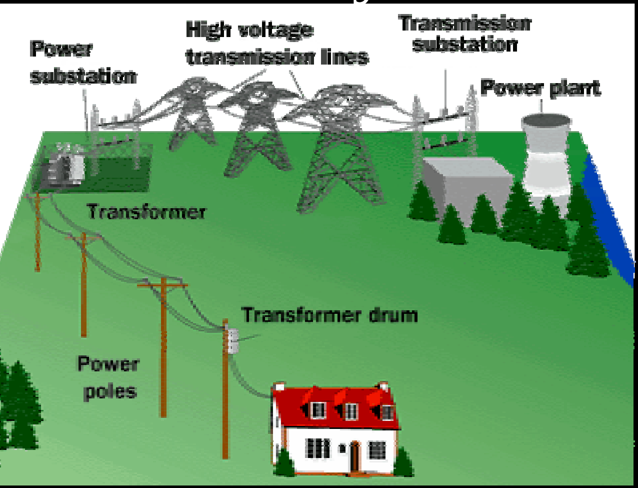
- Does electricity necessarily need to be “on the grid” for all uses?





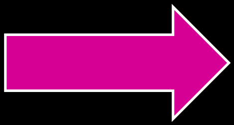
Fundamental Questions

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



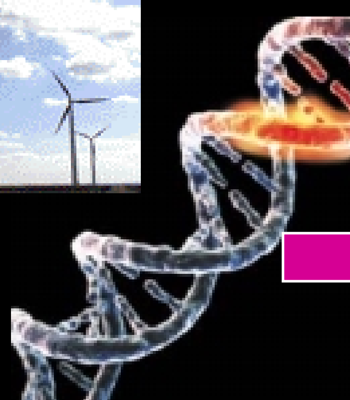
Define “Alternative” Fuel . . .

- 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 being developed for reversible storage
- Biofoundry techniques applied to hydrogen production
- Wind generated electrical energy applied to hydrogen production



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

Hydrogen – A Second Look – What if . . .

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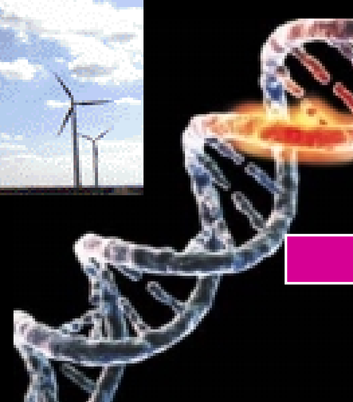
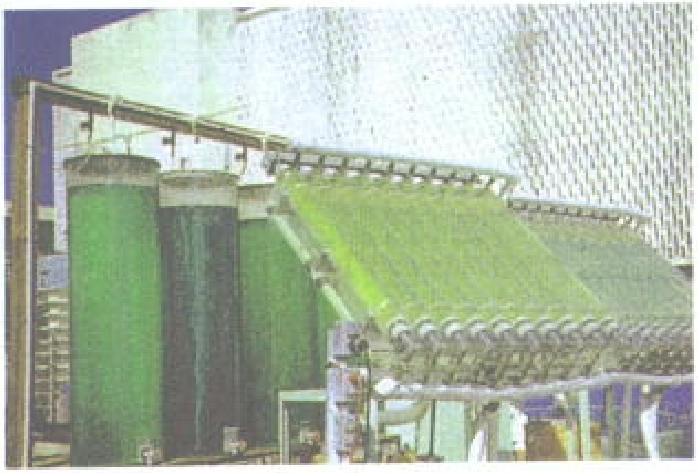
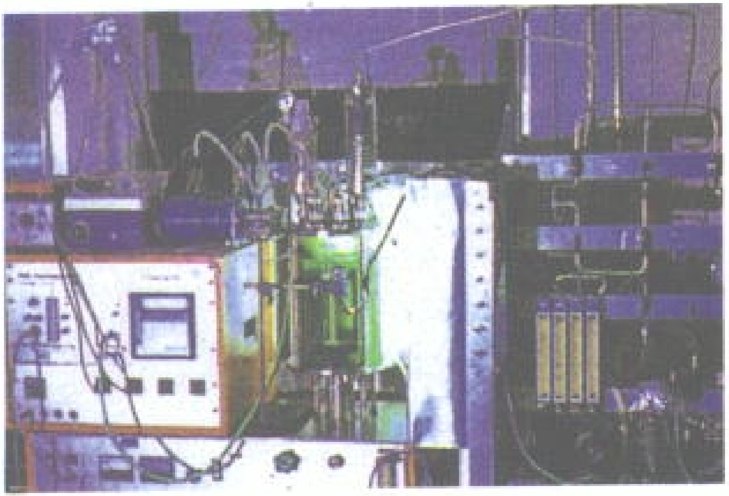
- Wind generated electrical energy applied to hydrogen production
- Hydrogen production becomes a new ***composite*** industrial infrastructure

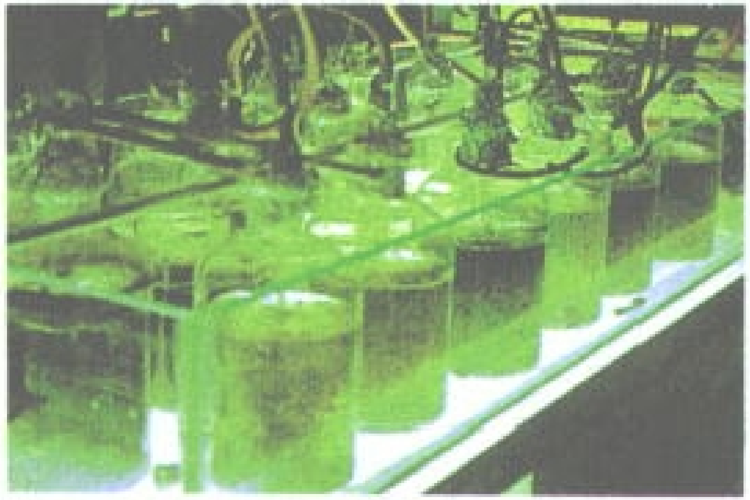


Hydrogen fueling dispenser at the Las Vegas Energy Station - Air Products and Chemicals, Inc.

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

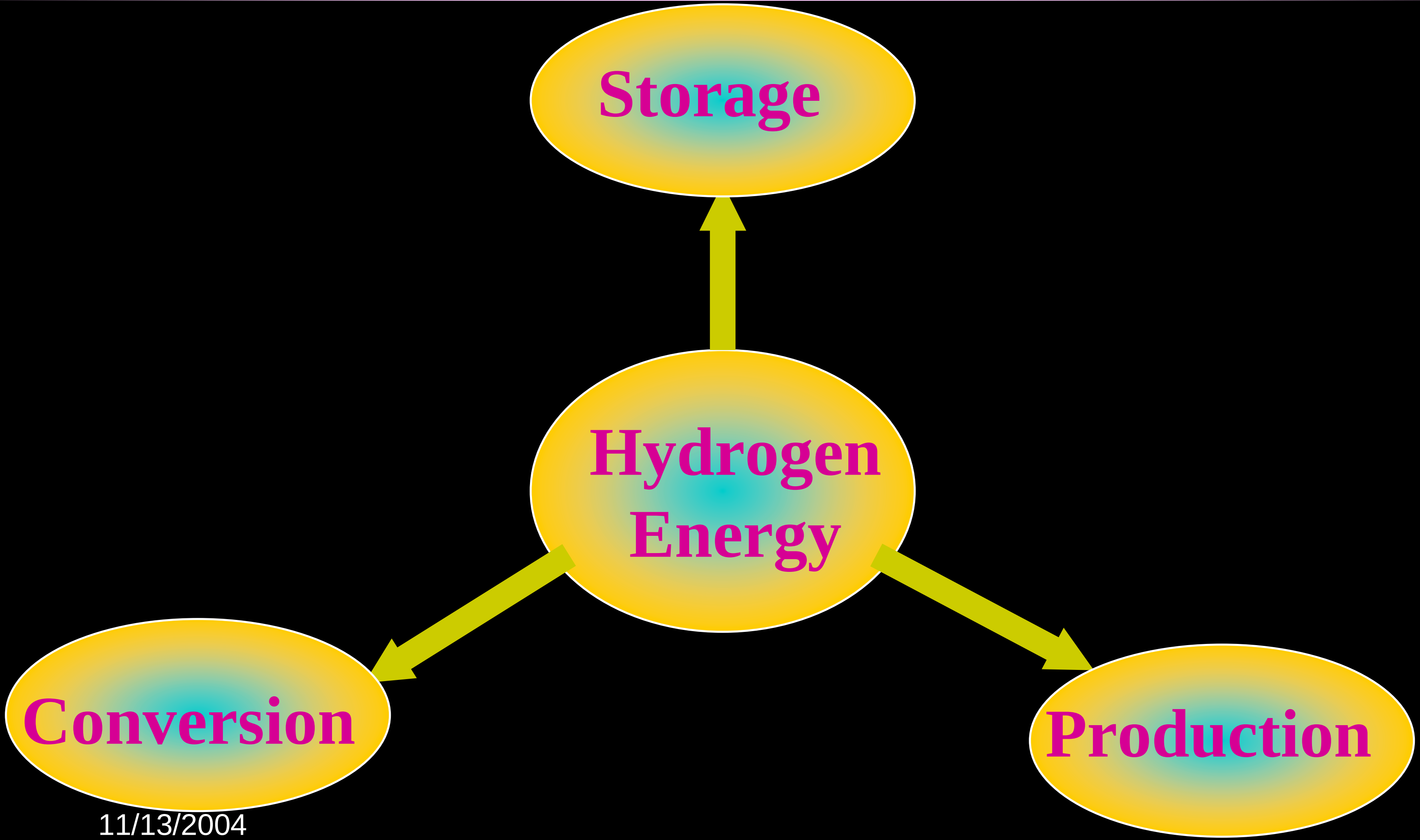
Reduce global warming

Clean up toxic waste from nuclear materials production

1987 1994 2001 the next step → future

YGG-01-0396a

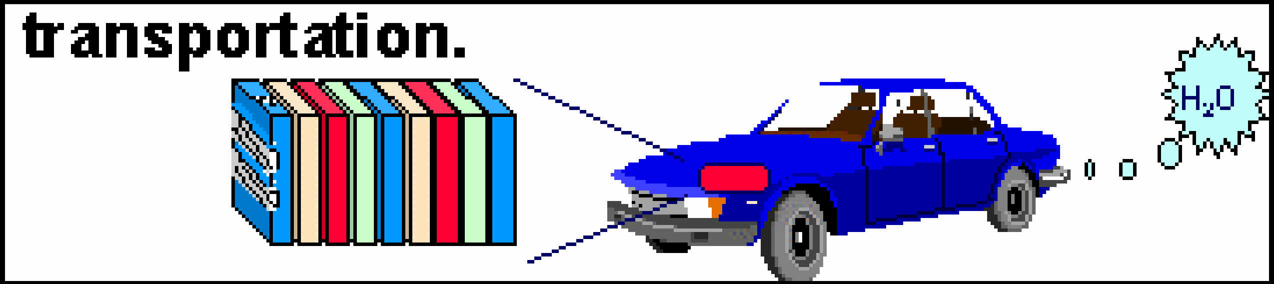
Nanotechnology in Hydrogen Energy Development



Hydrogen – Purported Arguments Against

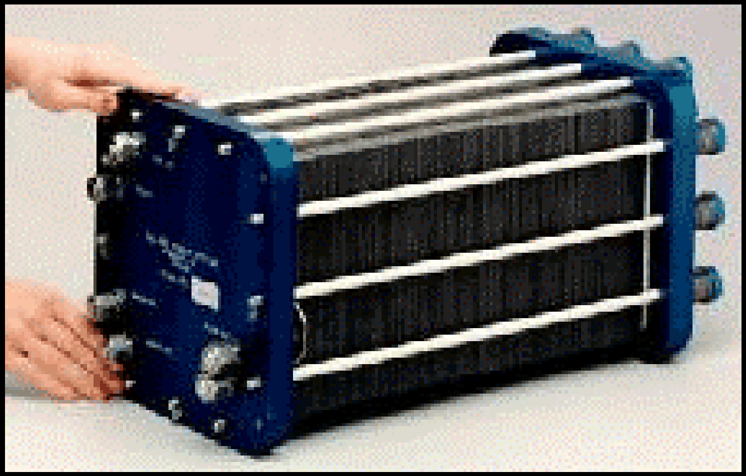
- Requires enormous investments in electrical energy, such as from nuclear power plants, to create the hydrogen
- Dangerous, difficult to store and retrieve
- Disruptive to an already existing petroleum / ethanol fuel production infrastructure

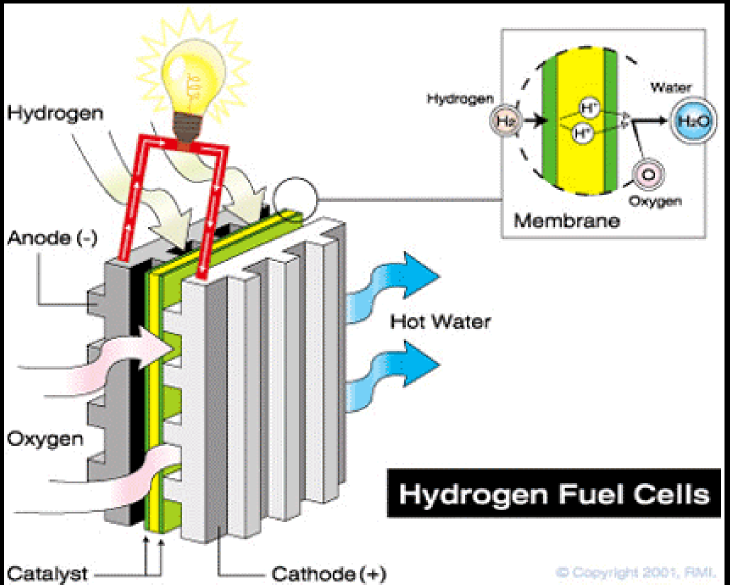
Hydrogen Fuel Cells in



Examples of Hydrogen Fuel Cell Types

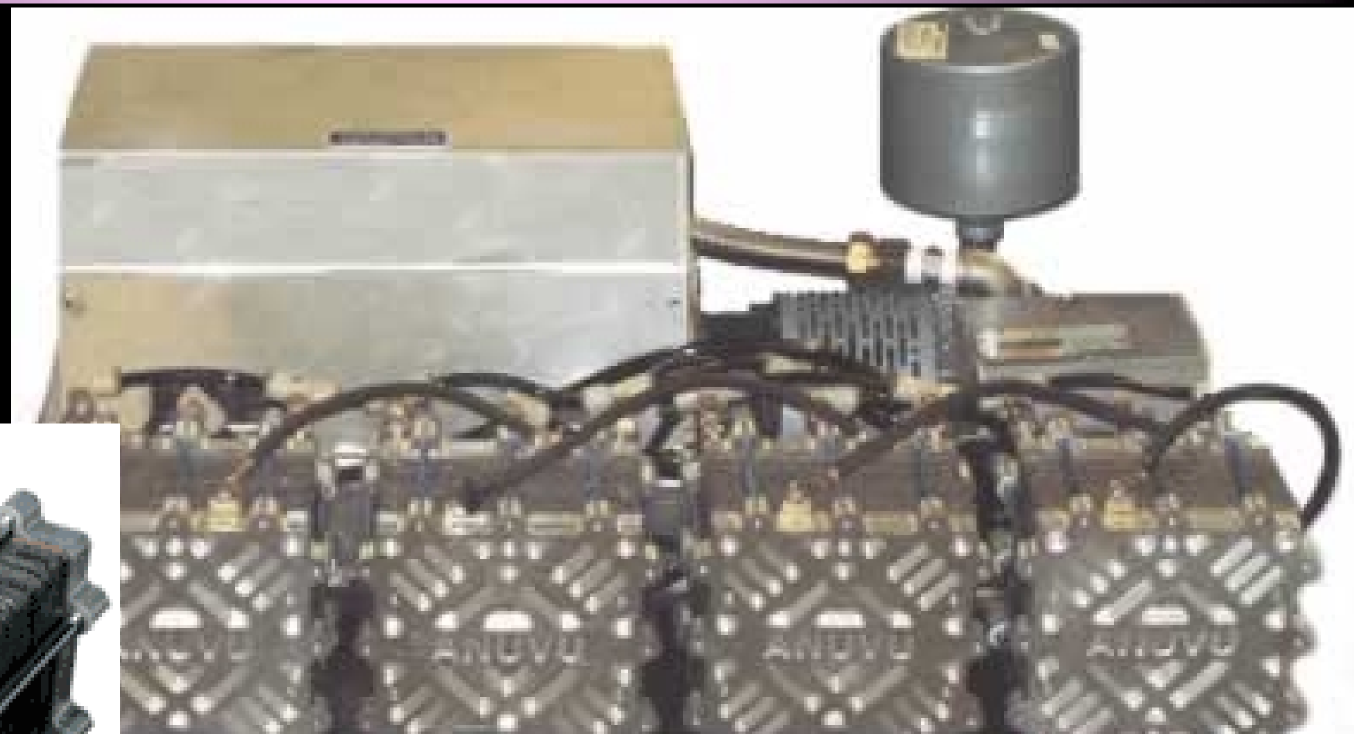
- Proton-Exchange Membrane Fuel Cells
- Phosphoric Acid Fuel Cells
- Solid Oxide Fuel Cells
- Molten Carbonate Fuel Cells
- Regenerative or Reversible Fuel Cells
- Alkaline Fuel Cells

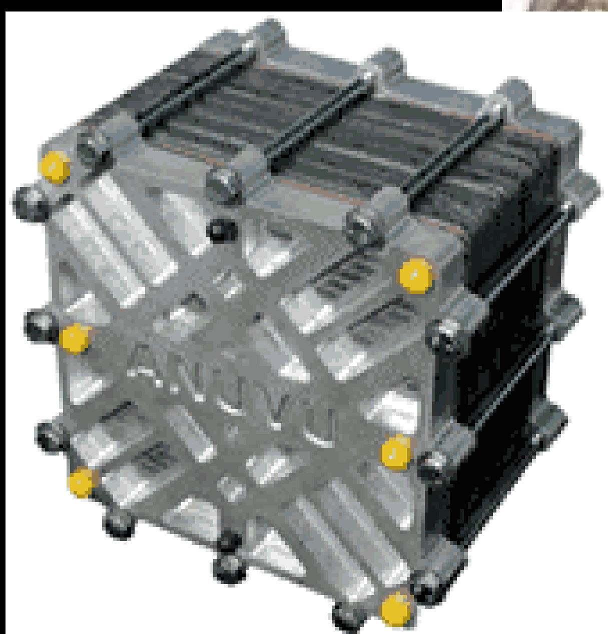




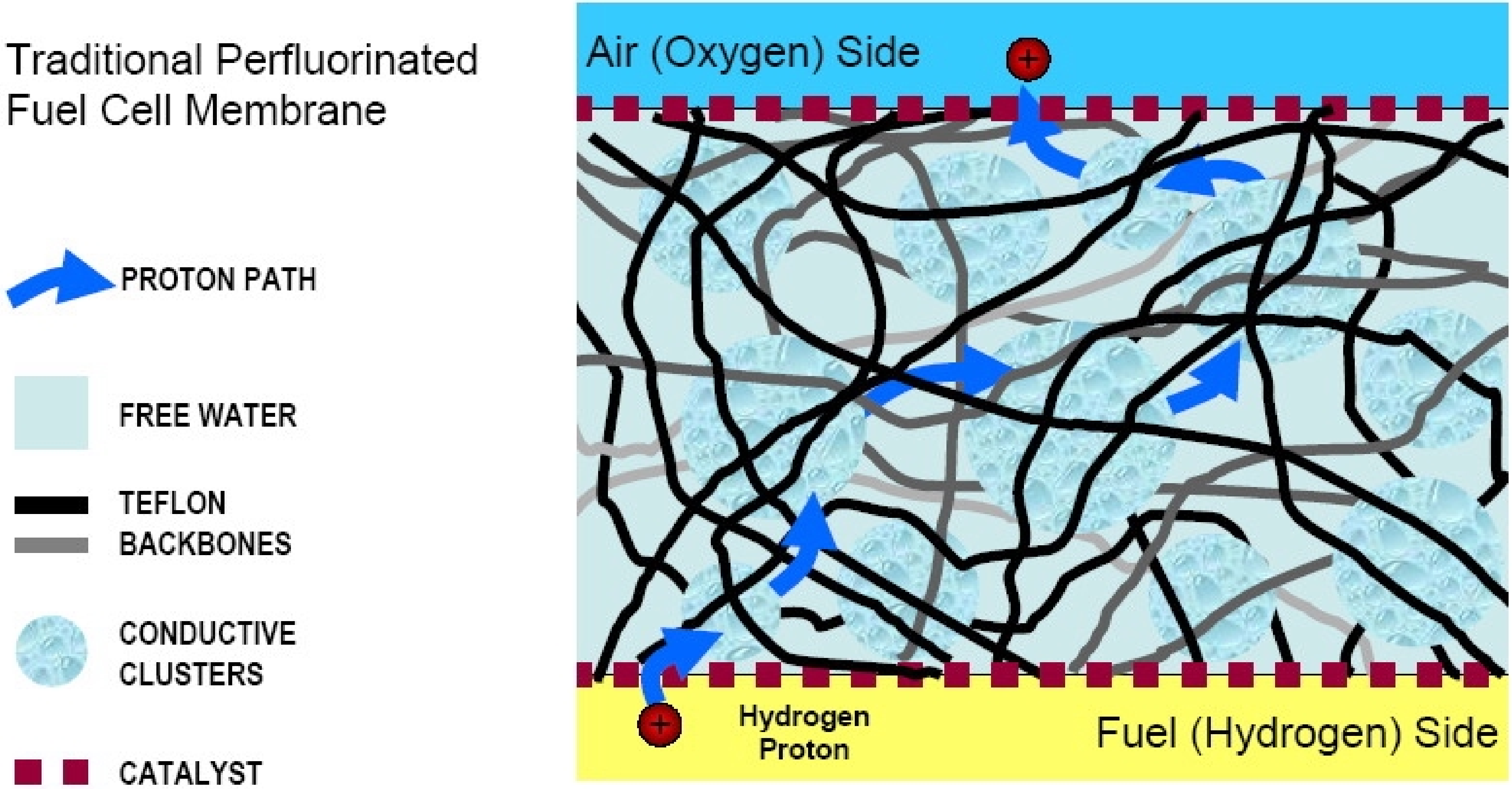
Fuel Cells -
From the laboratory, into markets

Anuvu Incorporated



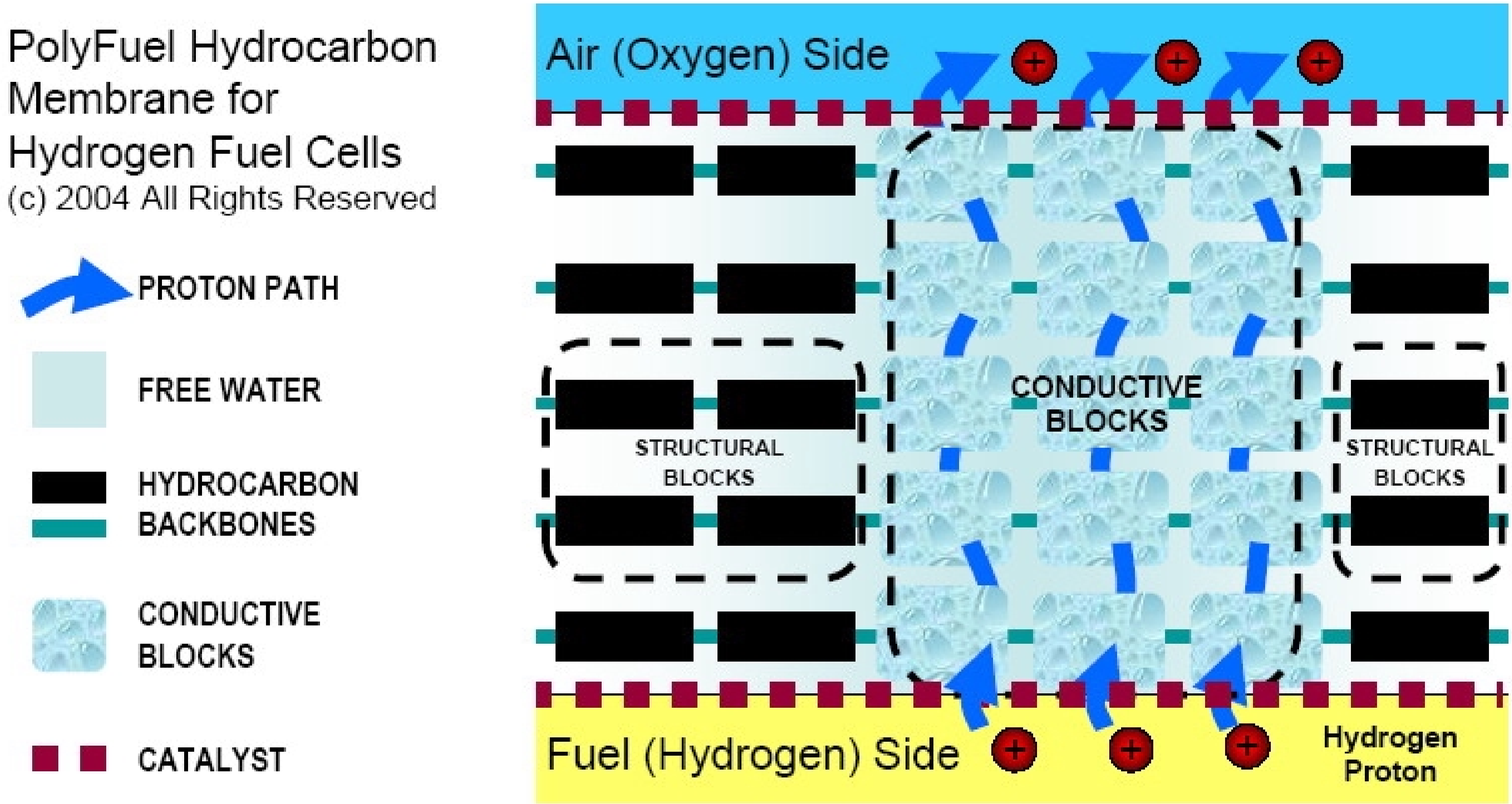


- 1.5 Kw module example
- Stackable Configurations
- Modular Architectures



- 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

Hydrogen Infrastructure – Current,

Hydrogen Infrastructure – Current, *Future*

Wind + Ocean Currents

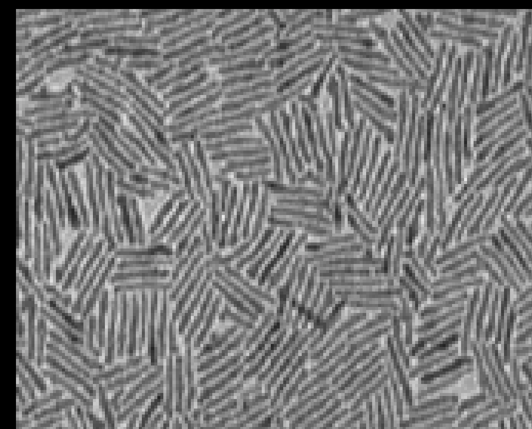
H2O + Electrolysis > Hydrogen

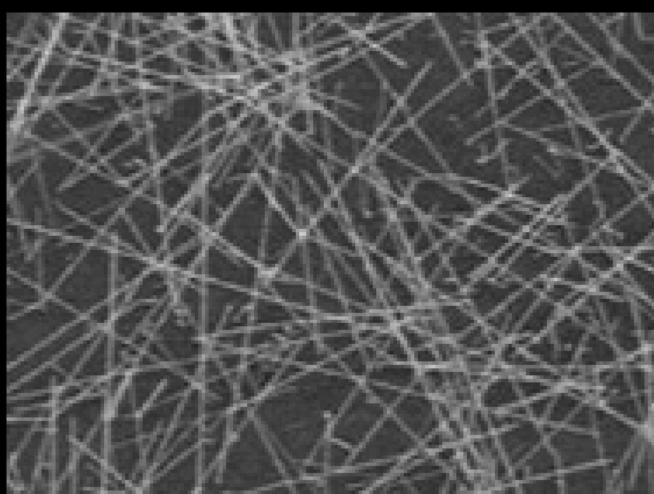
> Liquified Bulk Transport

> Distribution – auto, air, gen

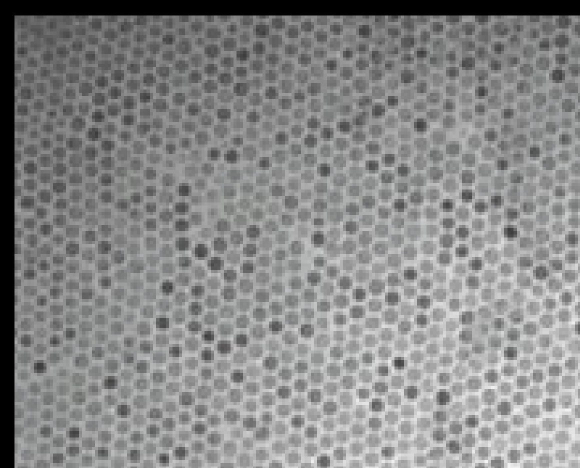
Nanofoundry – Nanostructured Materials

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

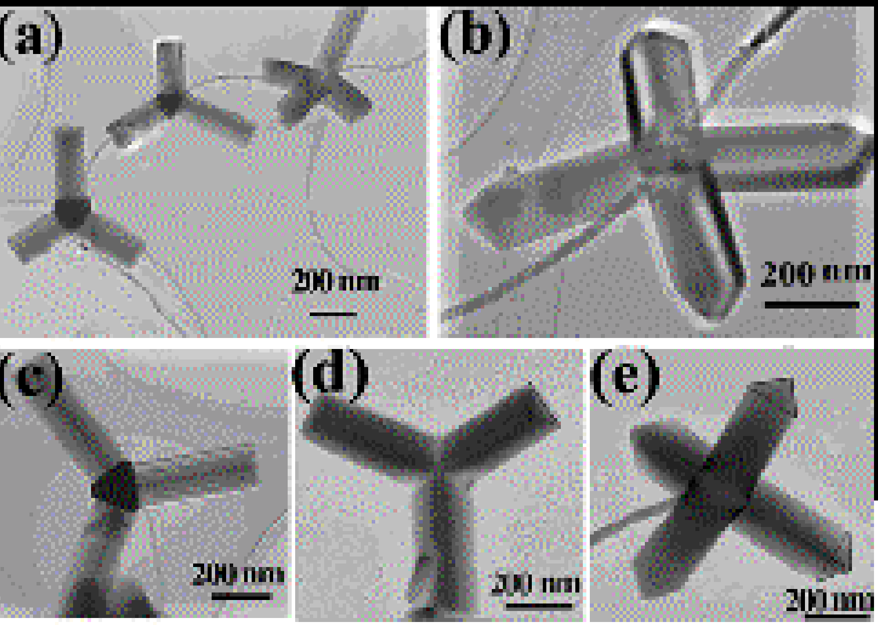




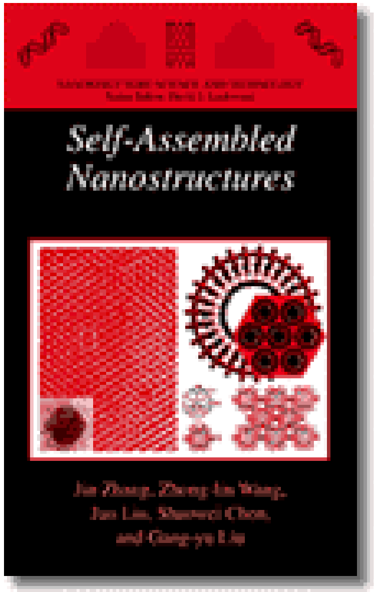
Courtesy NanoSys



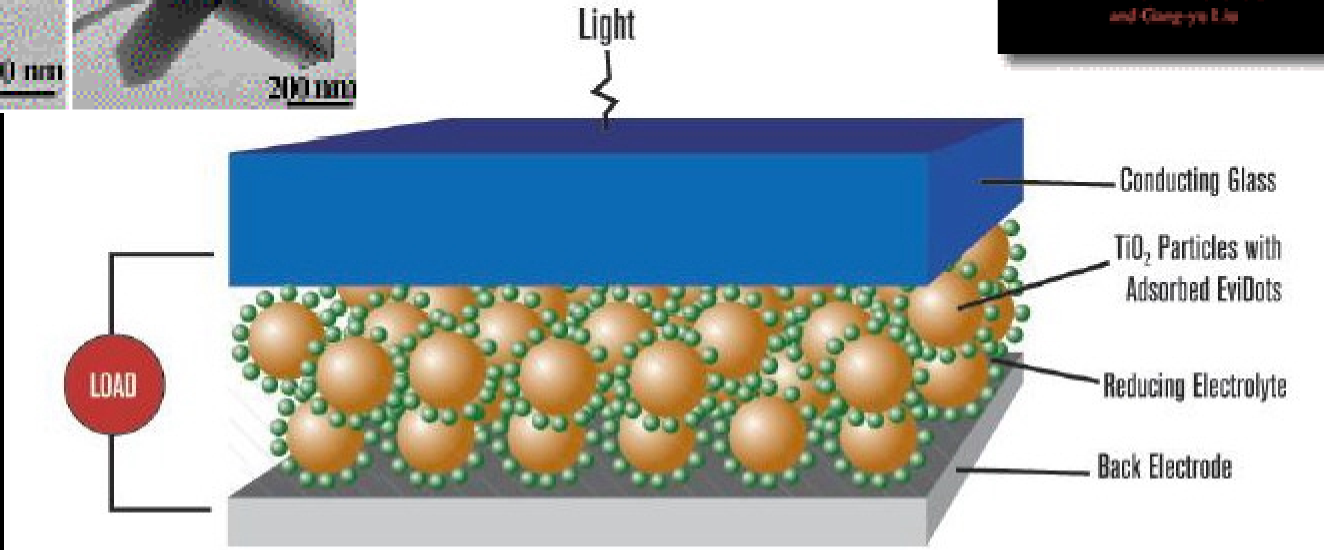
Self Assembly – An Industrial Paradigm



- Tetrapods
- Periodic nanostructures
- Quantum dots
- Nanocrystals



Courtesy Nanosys



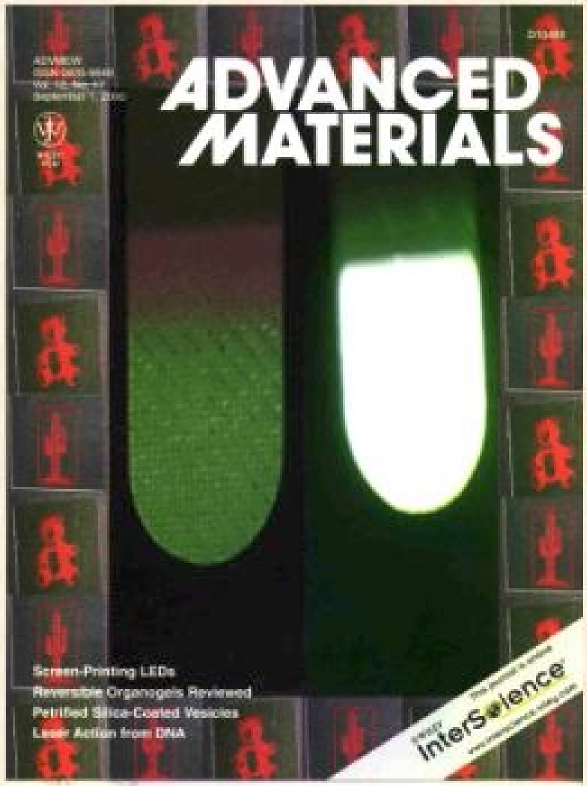
Courtesy

Evident Technologies

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

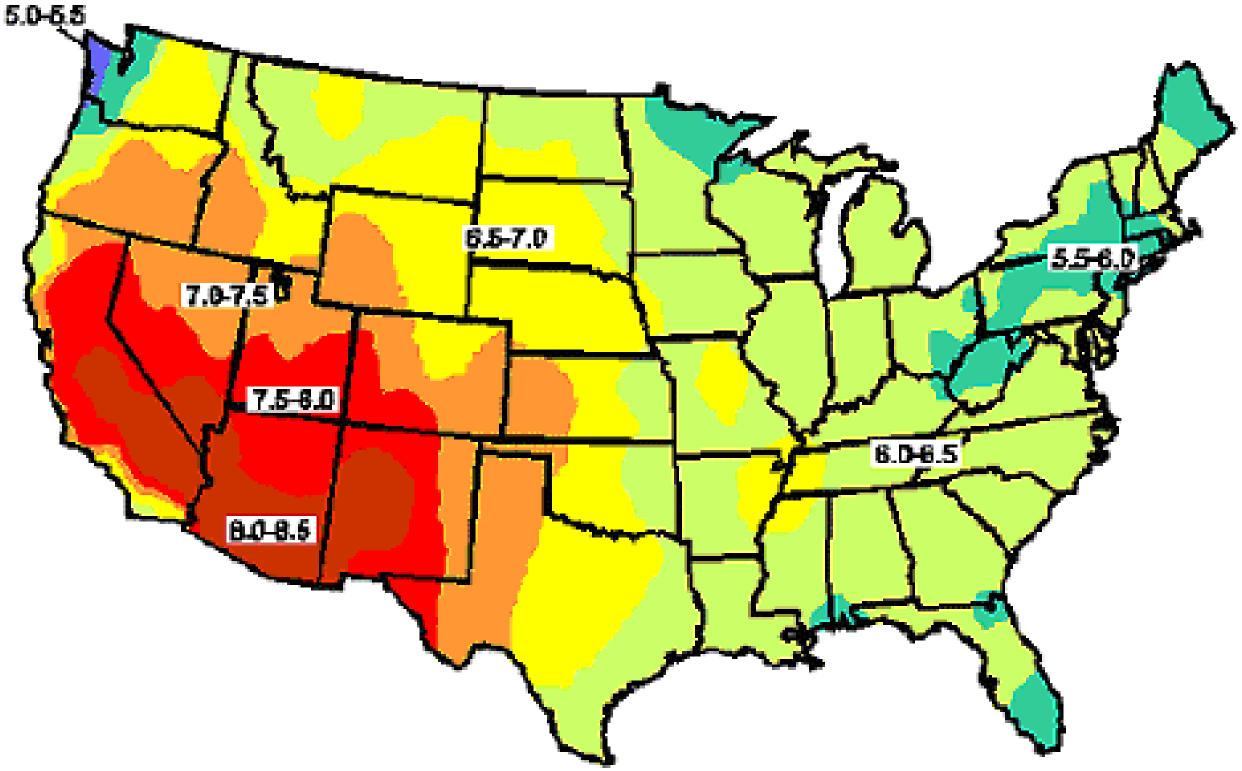
On a roll: solar panels could soon be as cheap and easy to print as wallpaper.

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).

Solar Energy
Throughout the United States of America

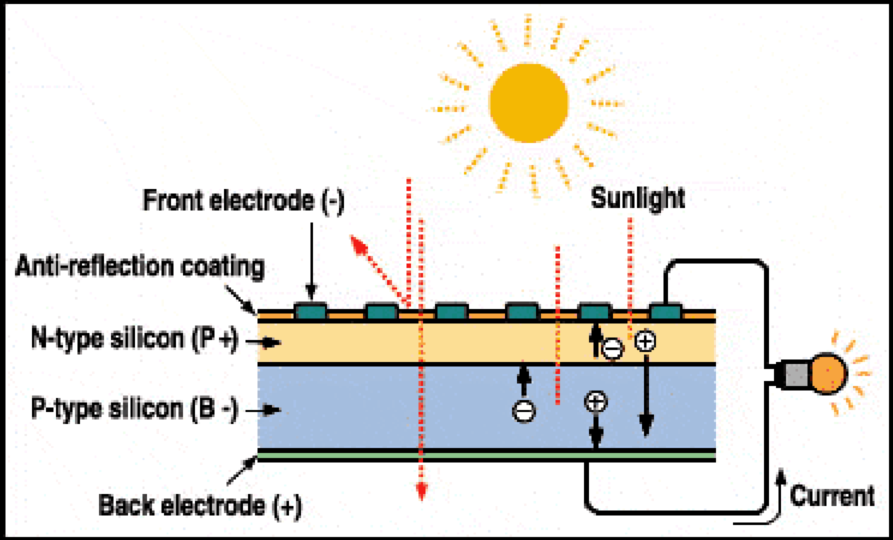
Figure 2. U.S. Solar Resources

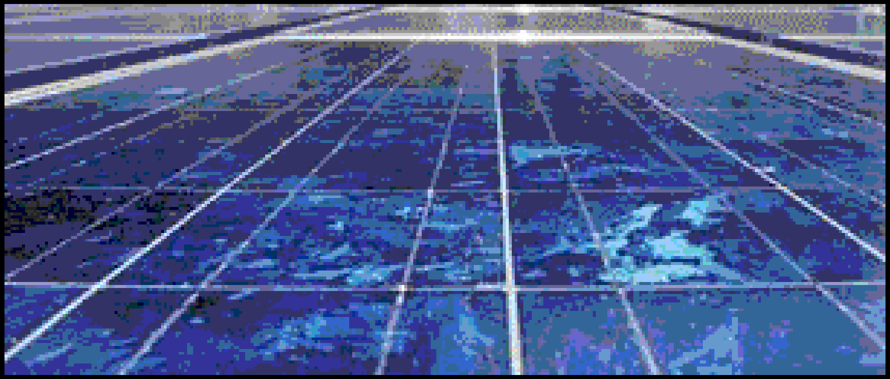


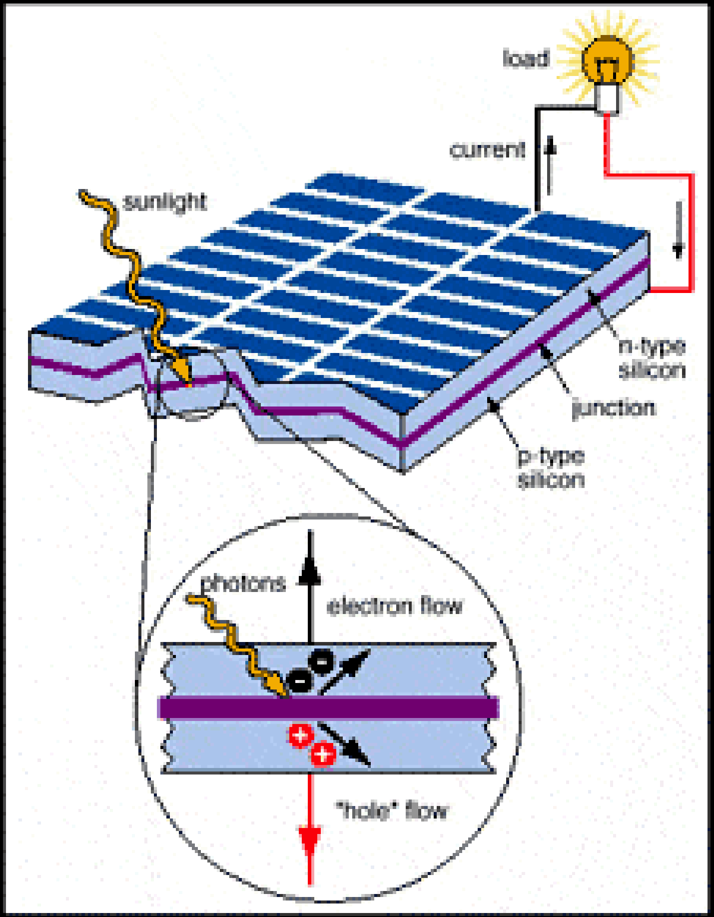
Note: Measurements indicate the average radiation received on a horizontal surface across the continental United States in the month of June as measured in kilowatthours per square meter.

Source: National Renewable Energy Laboratory.

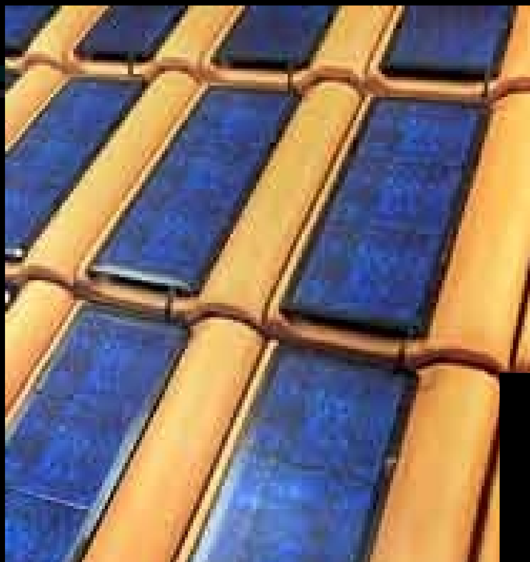
"Traditional" Crystalline Silicon Solar Voltaics

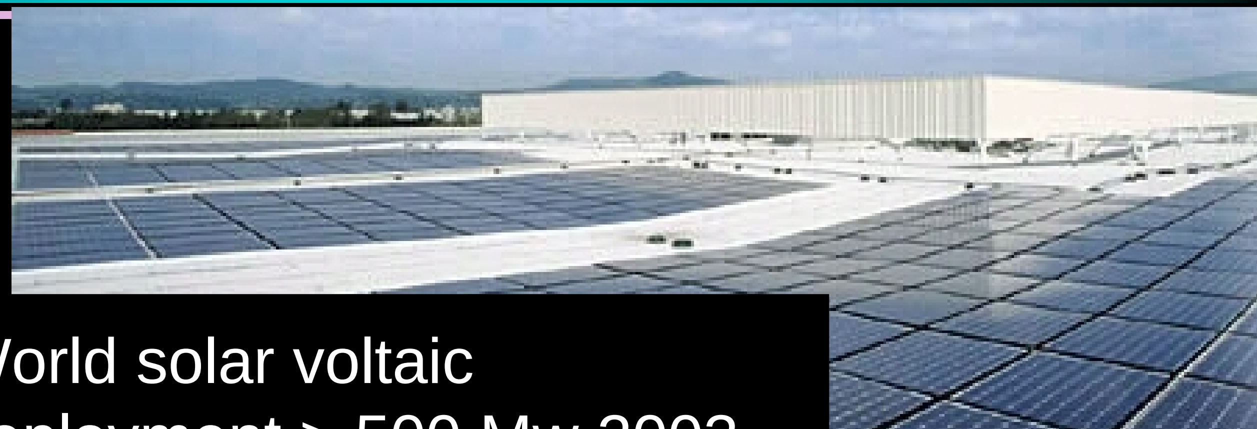






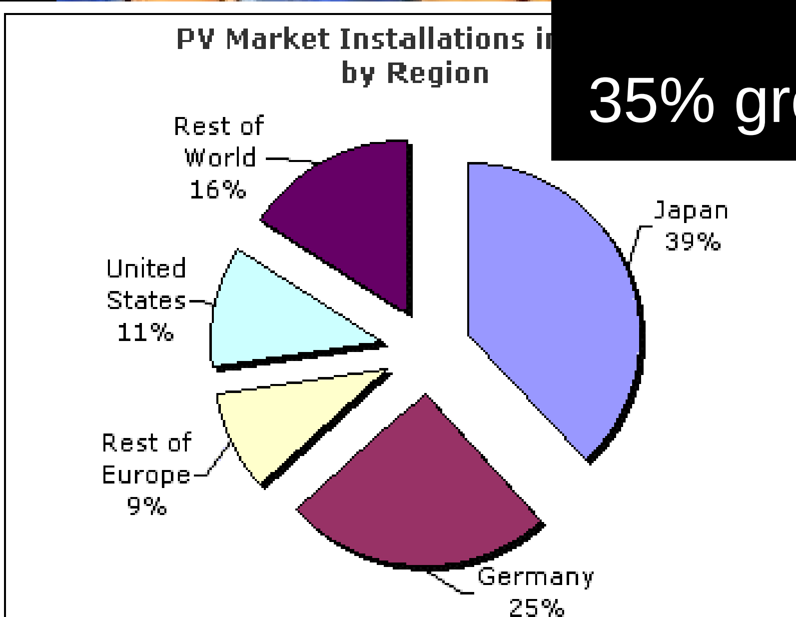
“Traditional” Crystalline Silicon Solar Voltaics

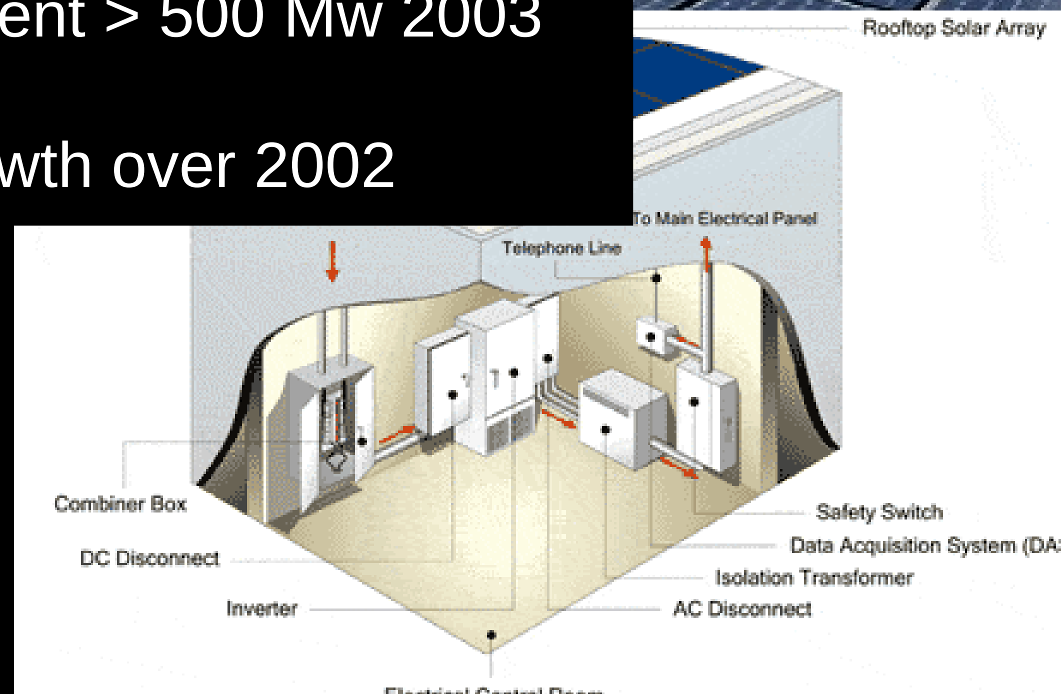




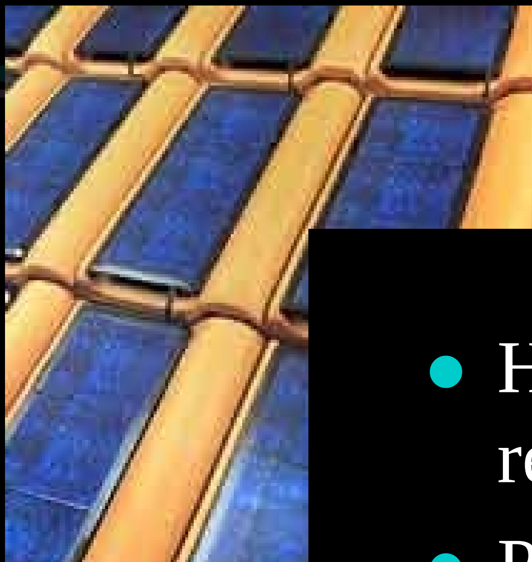
World solar voltaic deployment > 500 Mw 2003

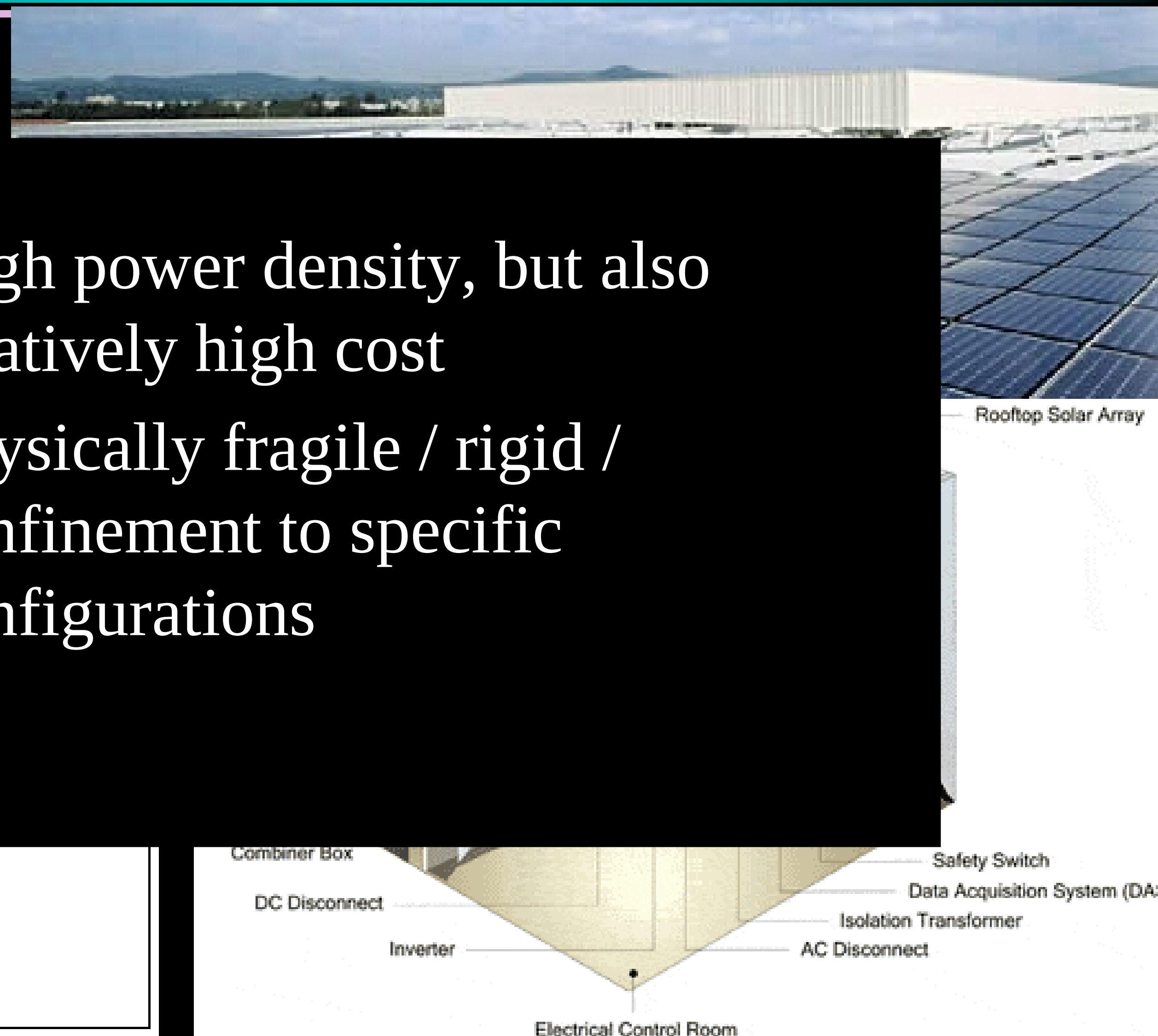
35% growth over 2002



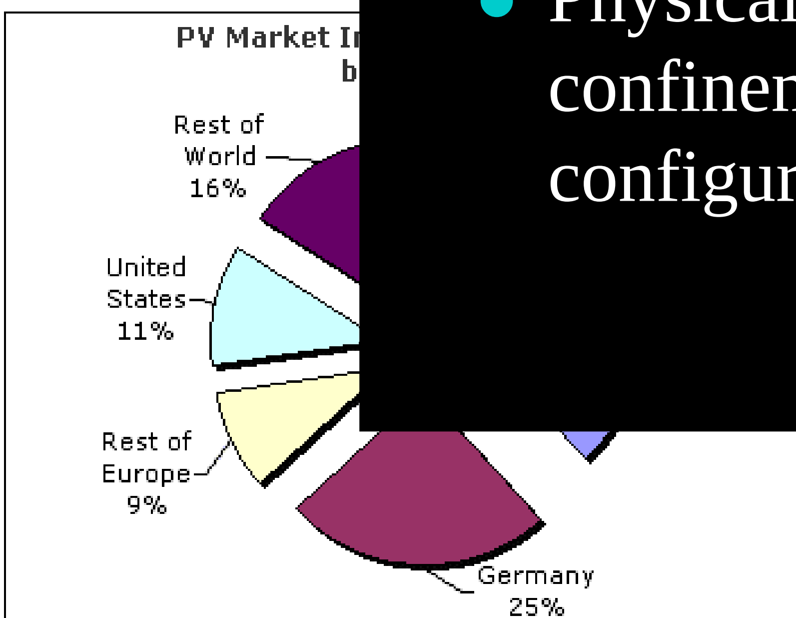


“Traditional” Crystalline Silicon Solar Voltaics





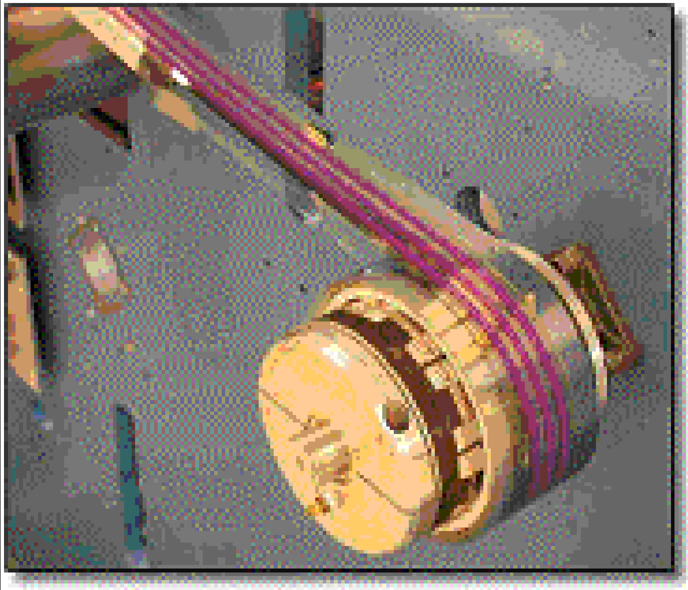
- High power density, but also relatively high cost
- Physically fragile / rigid / confinement to specific configurations



Organic Semiconductors in Solar Voltaics

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

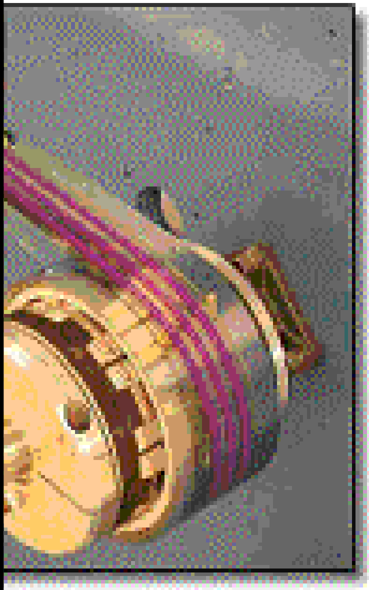
Organic Solar Cell



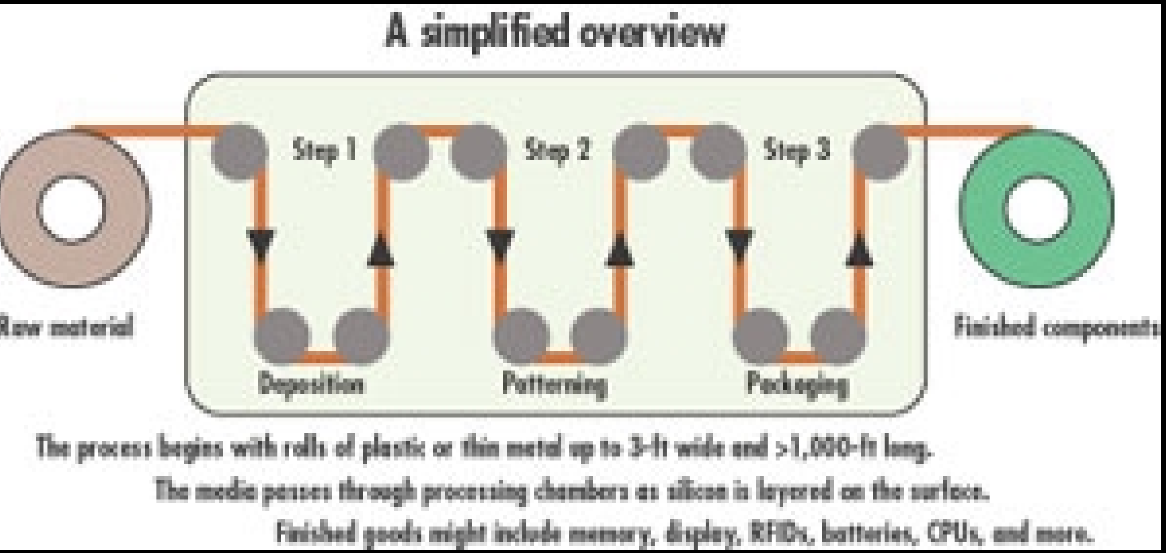
Organic Semiconductors in Solar Voltaics

Concept image of Organic
manufactured product fro

- 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

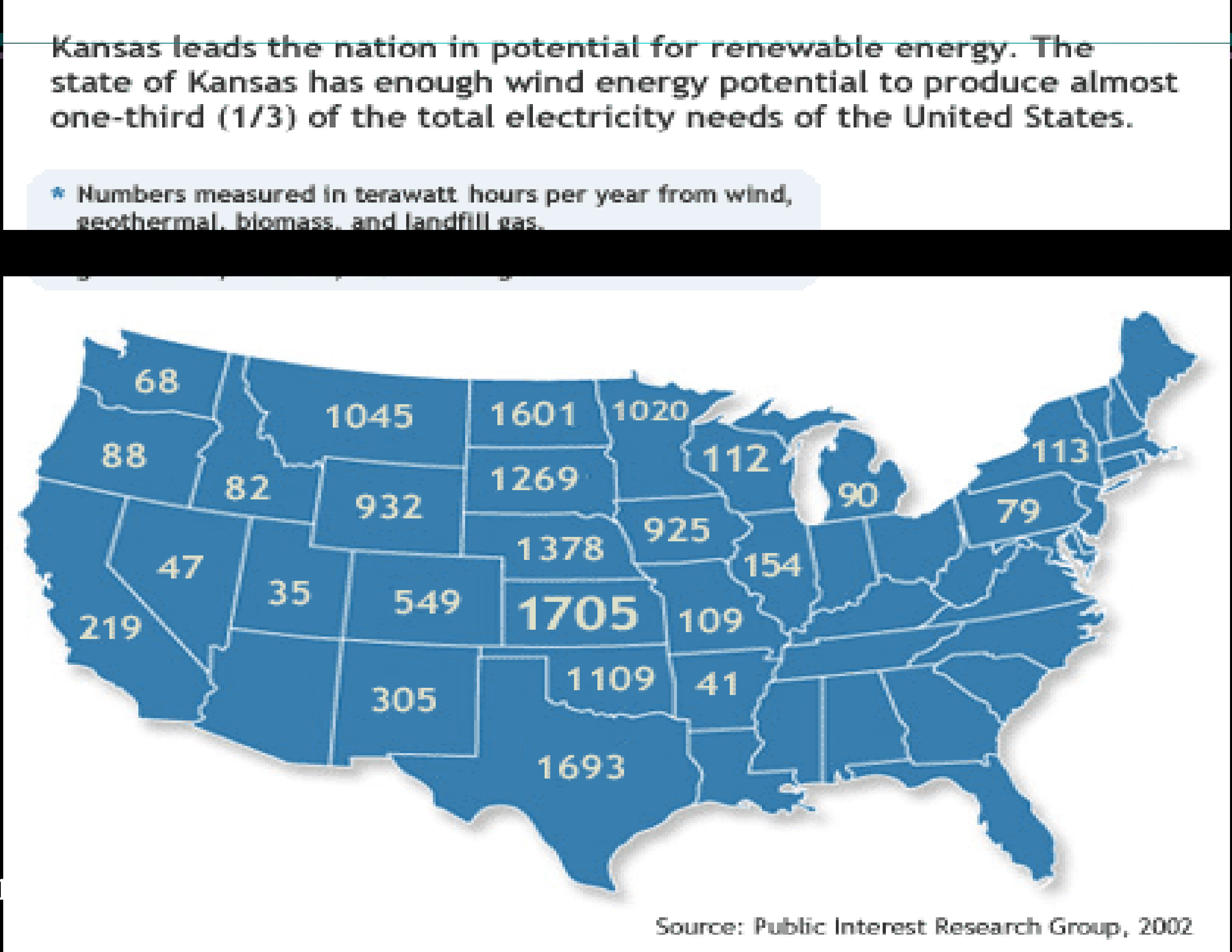


NanoElectronic Photovoltaic Circuitry "Printed" on Multifunctional Laminates

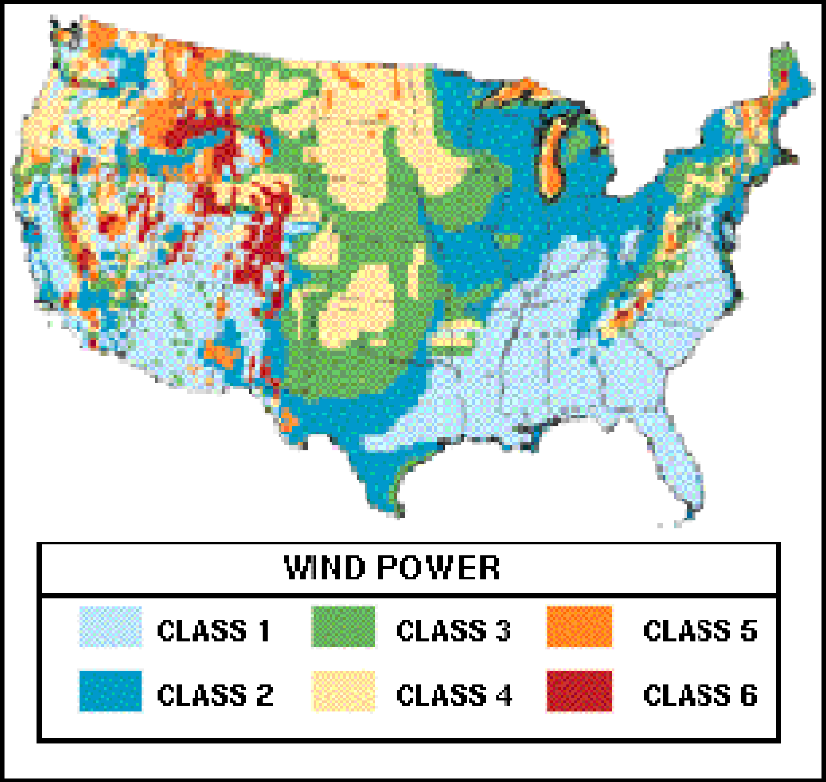


Solar on the ***Ground*** is Geographically Limited Solar from Space however . . .

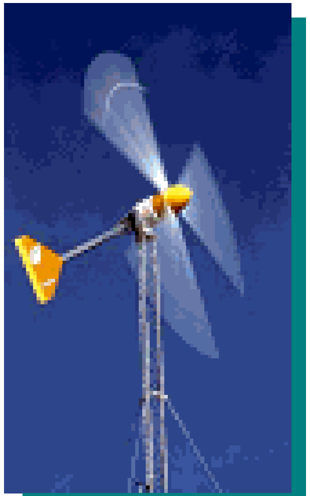
Wind Energy Resources Throughout the United States of America



Wind Energy Resources Throughout the United States of America



Wind Turbine Sizes and Applications

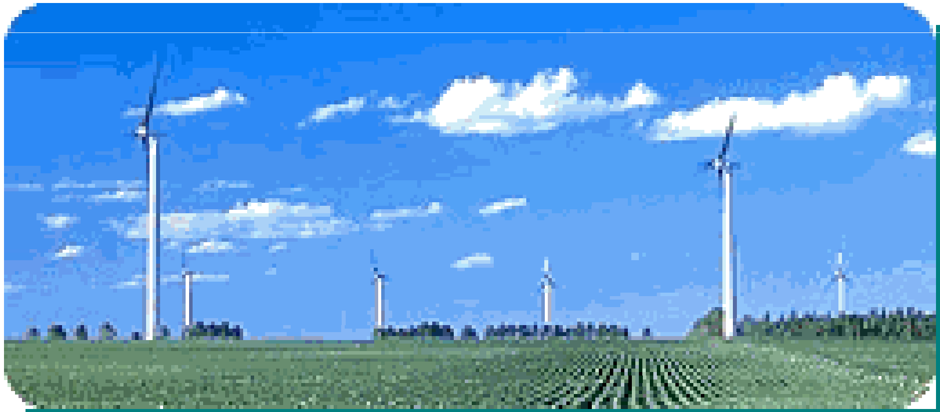


Small (≤10 kW)

- Homes
- Farms
- Remote Applications
  - (e.g. water pumping, telecom sites, icemaking)

Intermediate (10-250 kW)

- Village Power
- Hybrid Systems
- Distributed Power



Large (250 kW – 2+ MW)

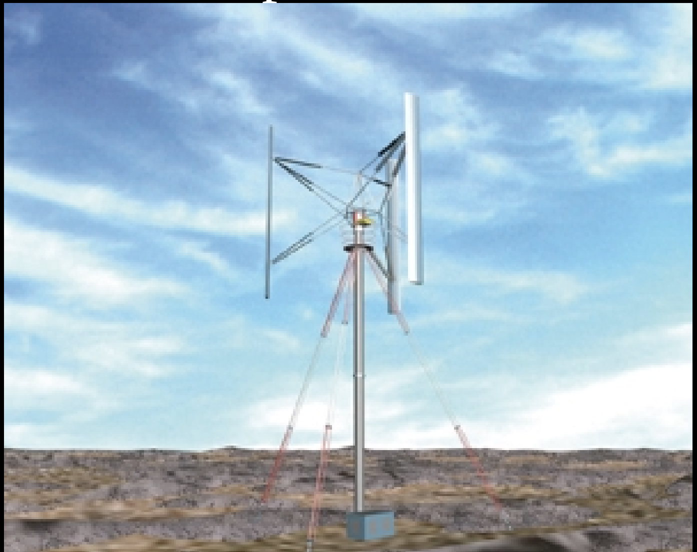
- Central Station Wind Farms
- Distributed Power

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

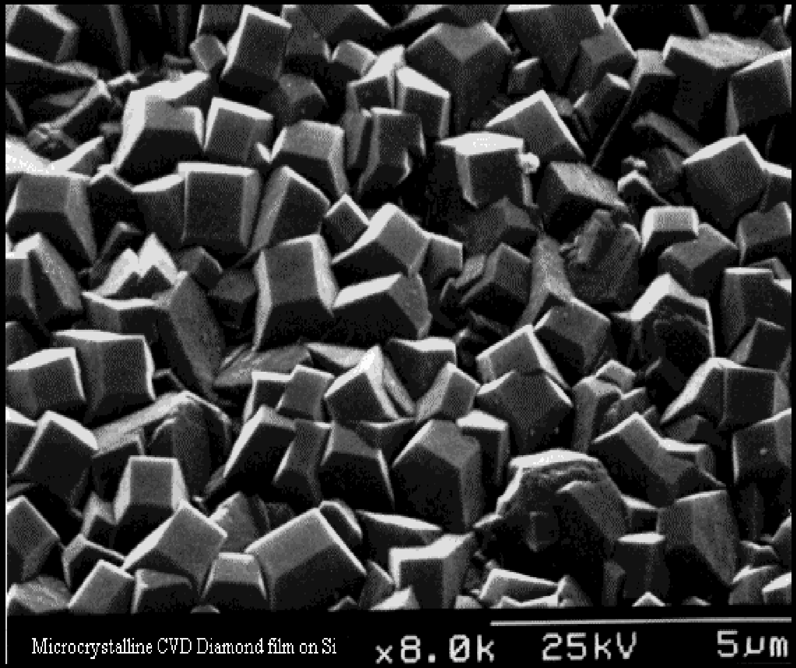
1) small wind systems can be deployed in many situations where big wind systems would not be viable
2) small wind systems can also be installed in parallel with big wind installations to re-capture low altitude surplus wind and turbulence activity not recognized by the big systems
3) small wind systems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

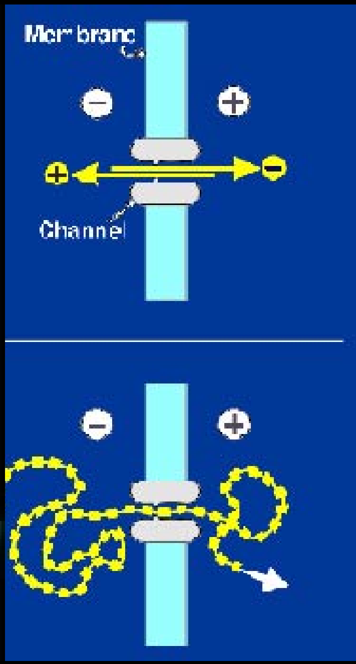


Option 3: “Big” and “Small” Wind Combined with Energy Storage

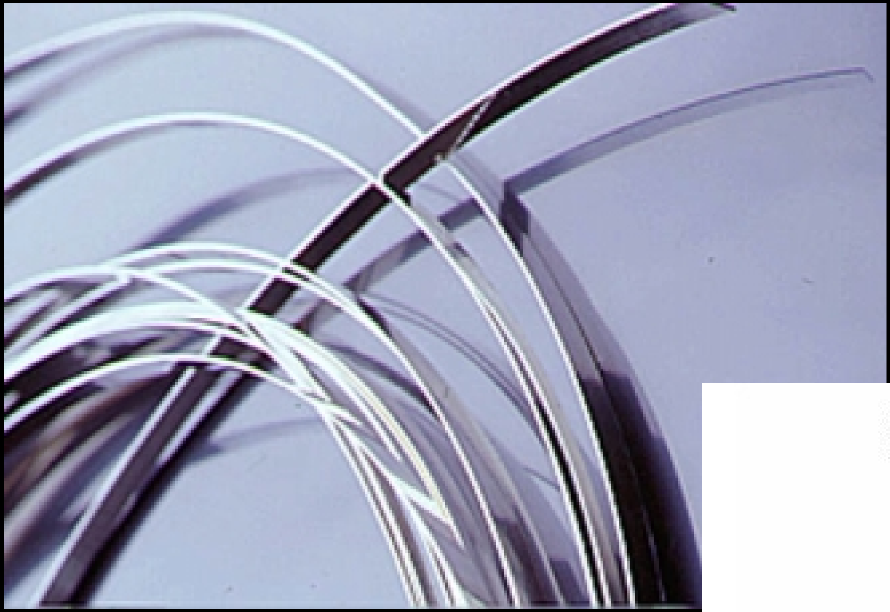
Nanotechnology Enabled Defense Development Domains Potentially Re-purposed Toward Energy Applications

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





HTS Wires / Conductors – New Approaches



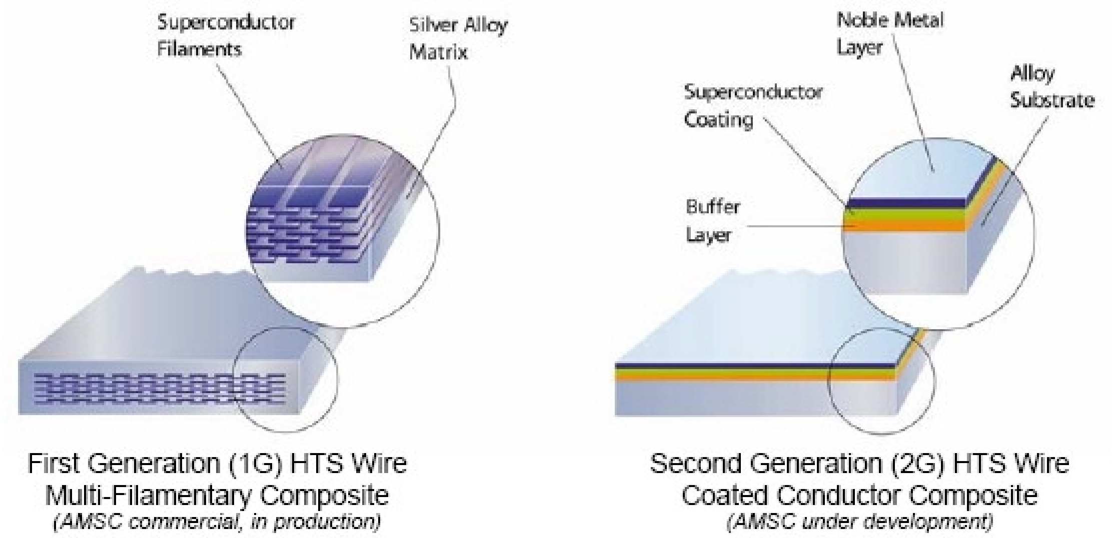


Fig. 1: High Temperature Superconductor (HTS) 1G and 2G wire architectures

HTS Wires / Conductors – New Approaches

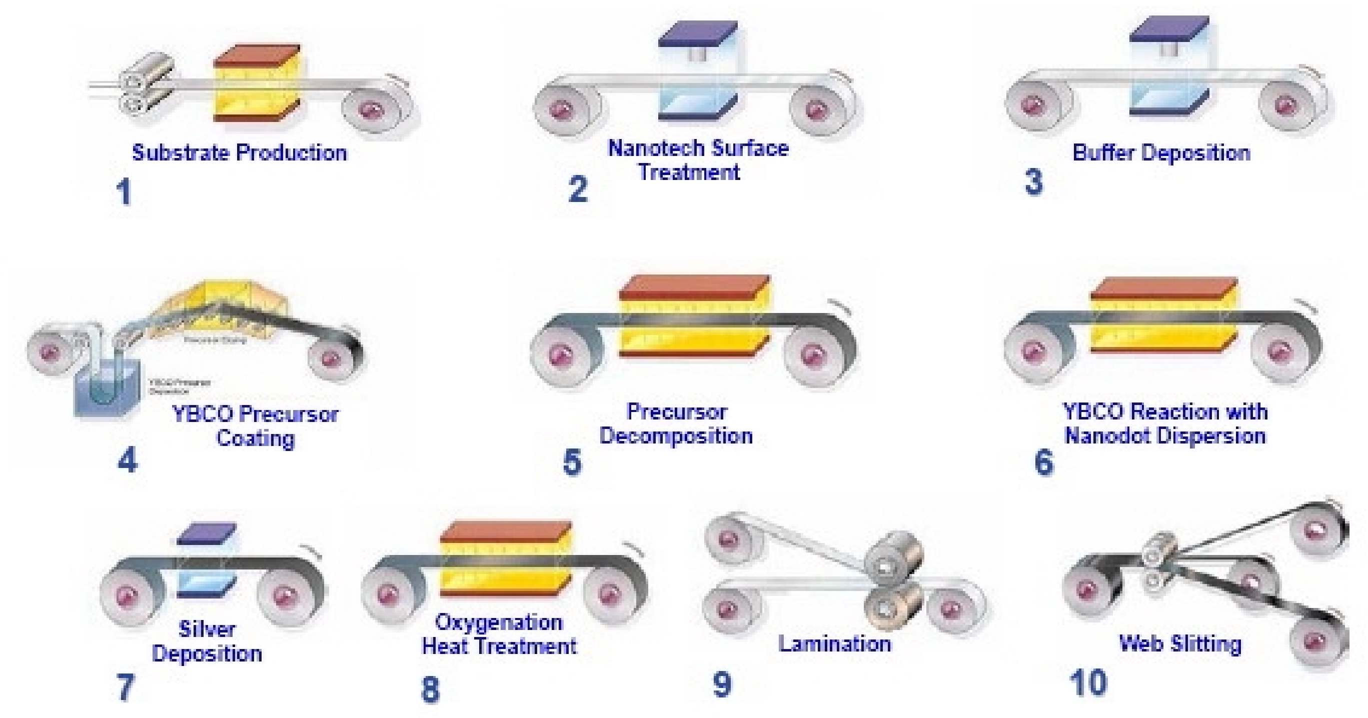


Fig. 5: 2G HTS wire manufacturing process

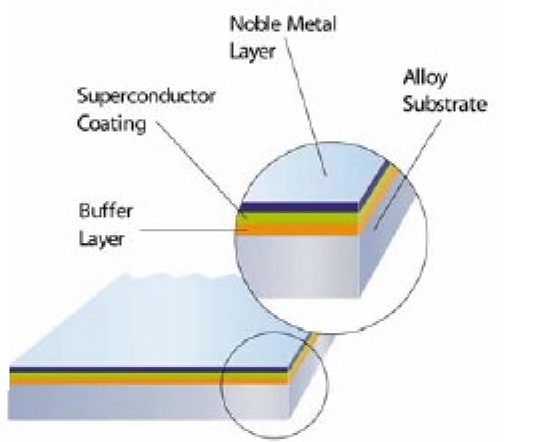
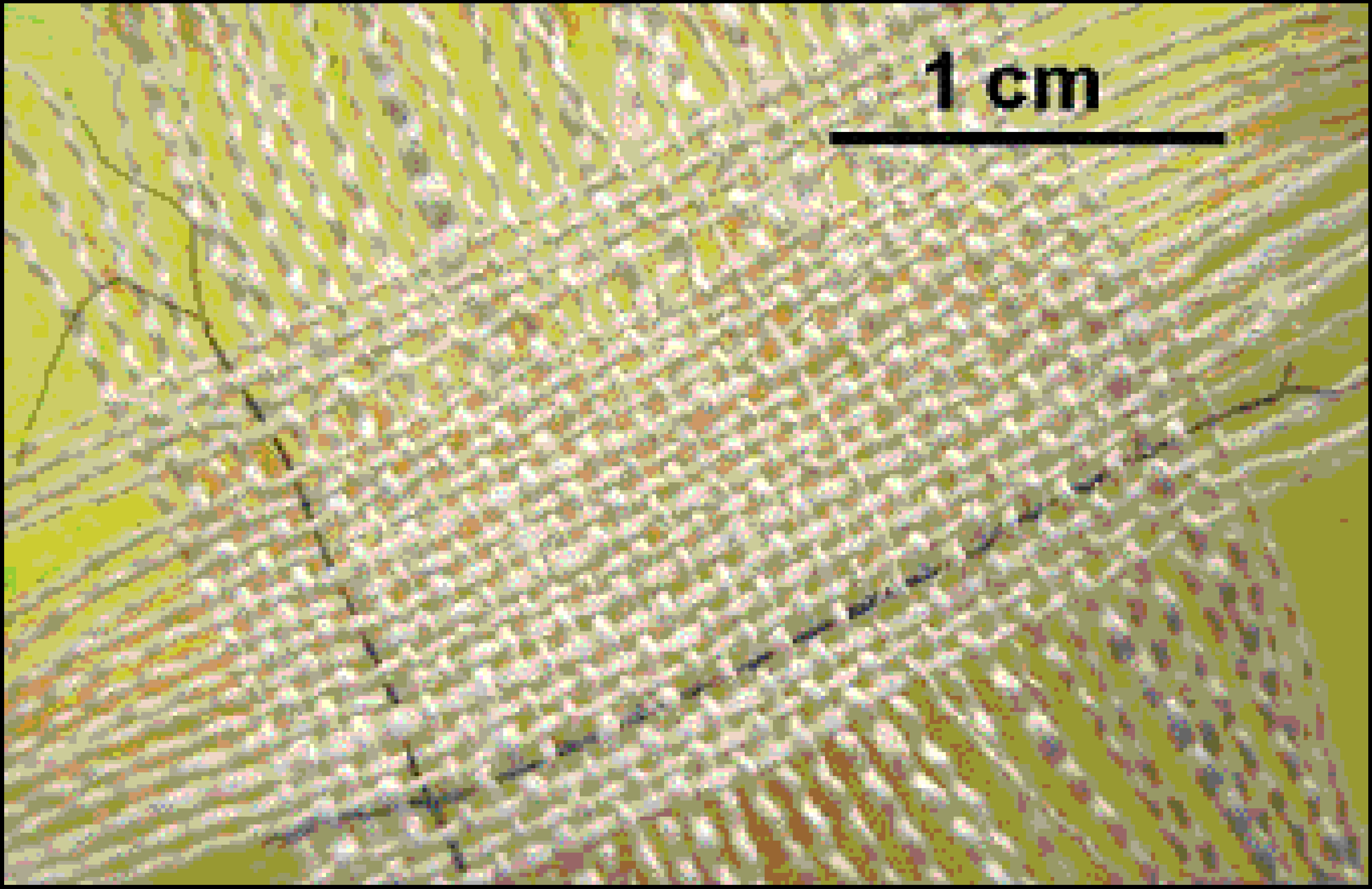
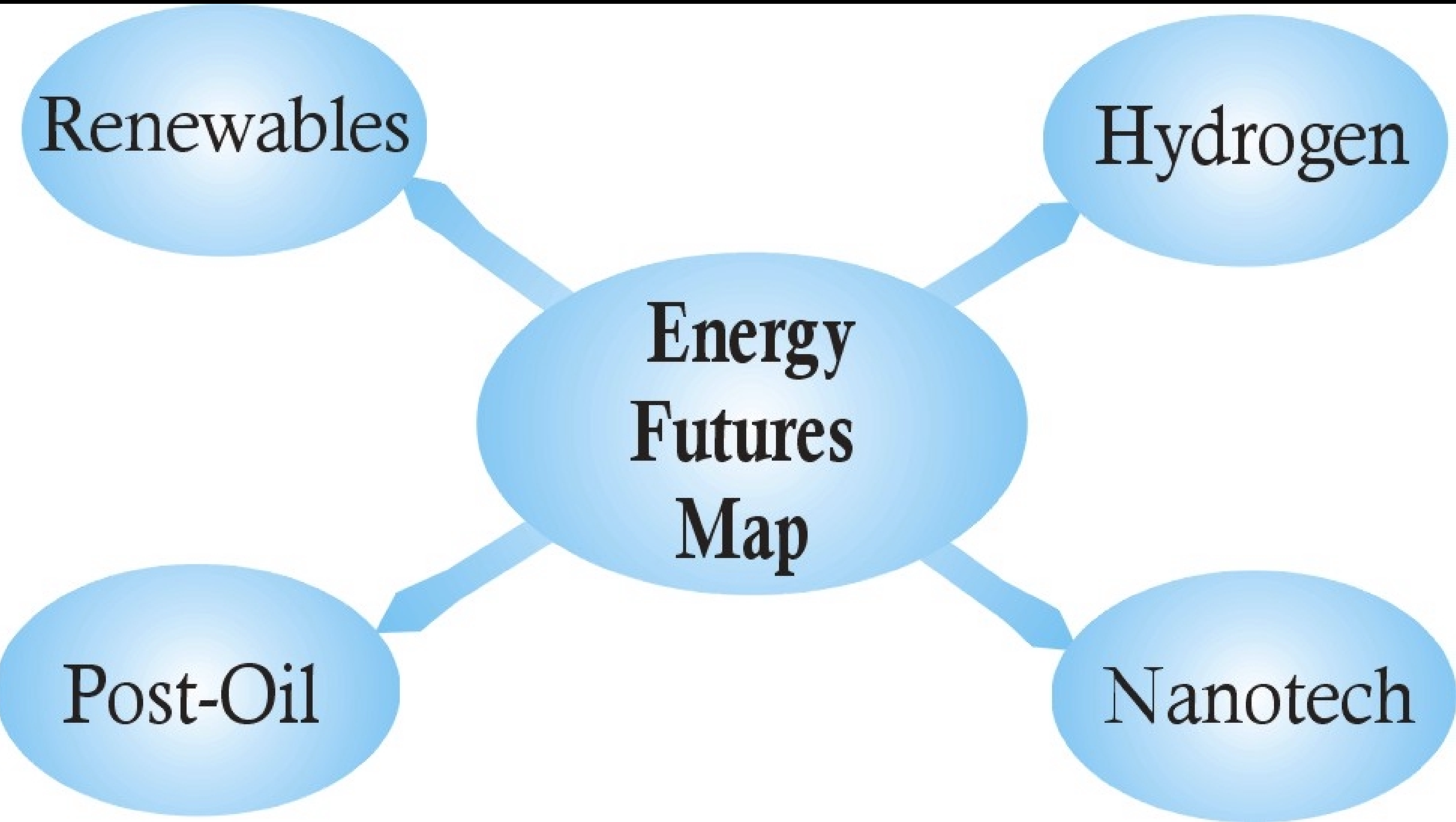


Fig. 1: High Temperature Superconductor (HTS) 1G and 2G wire architectures

Ultra High Efficiency Conductors / Storage
New Approaches



Mapping a Strategy for the Future – A composite of integrated solutions



Mapping a Strategy for the Future – Energy Resources, New Technologies 10 – 15 Year Horizon

Energy Sources: The Emerging Technologies - Nov 2004

Charles Ostman

Senior Fellow - Institute for Global Futures

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