RICE

Nanotechnology and Energy Be a Scientist – Save the World!

Wade Adams, Amy Jaffe, and Rick Smalley*

*in memoriam

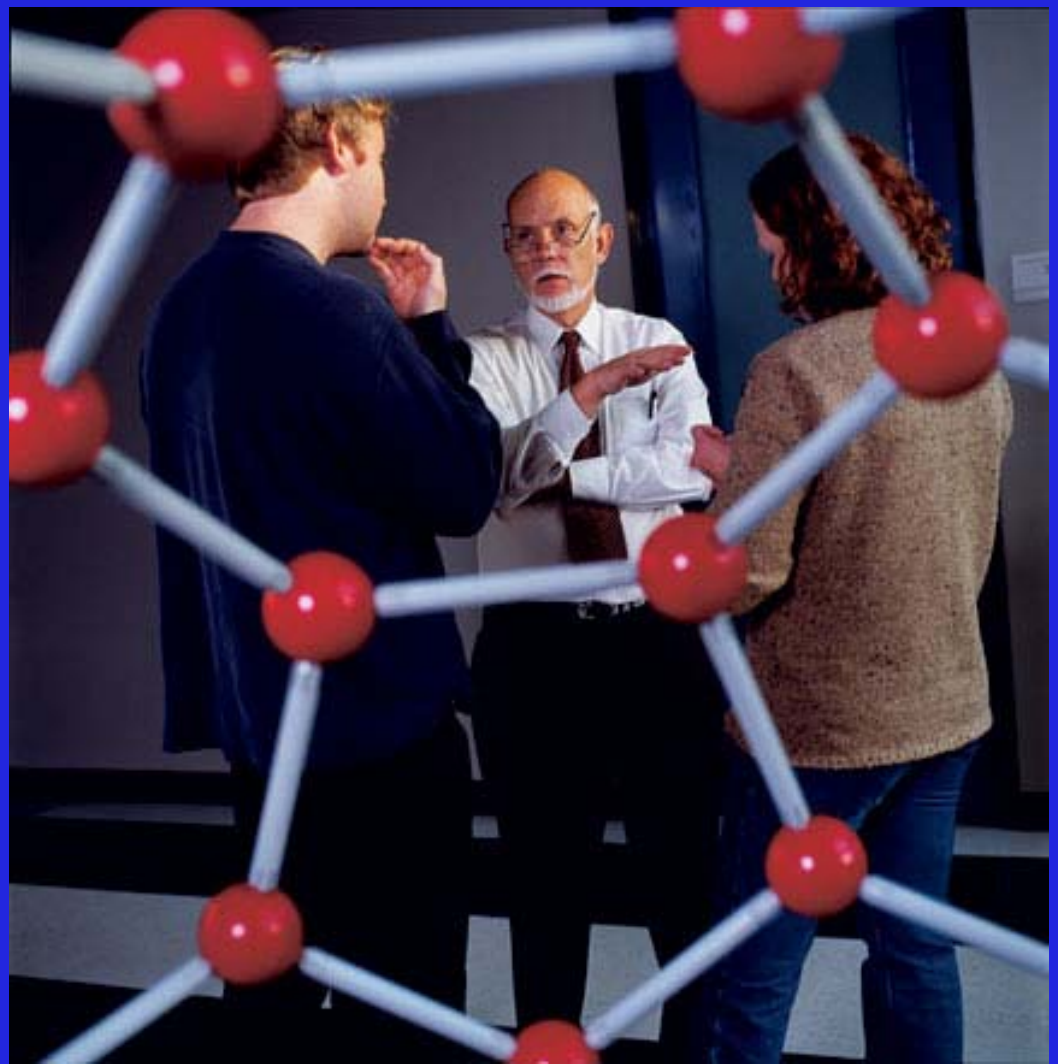
www.nano.rice.edu

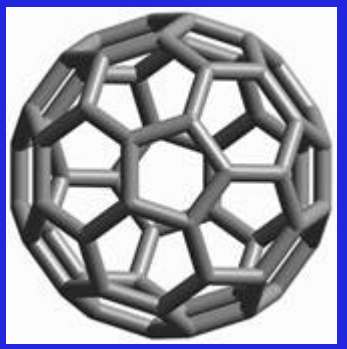
Professor Richard E. Smalley
1943 - 2005
Nobel Prize in Chemistry 1996

A 6 week summer project in 1985

2 – page paper in Nature

with Robert F. Curl and Harold Kroto





C60

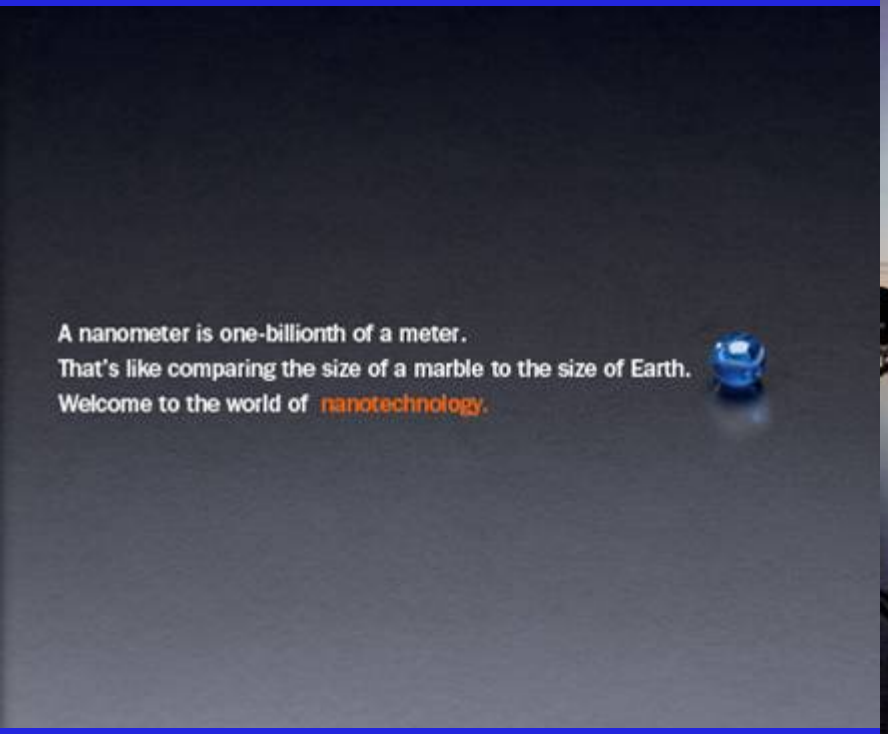
Buckminster-

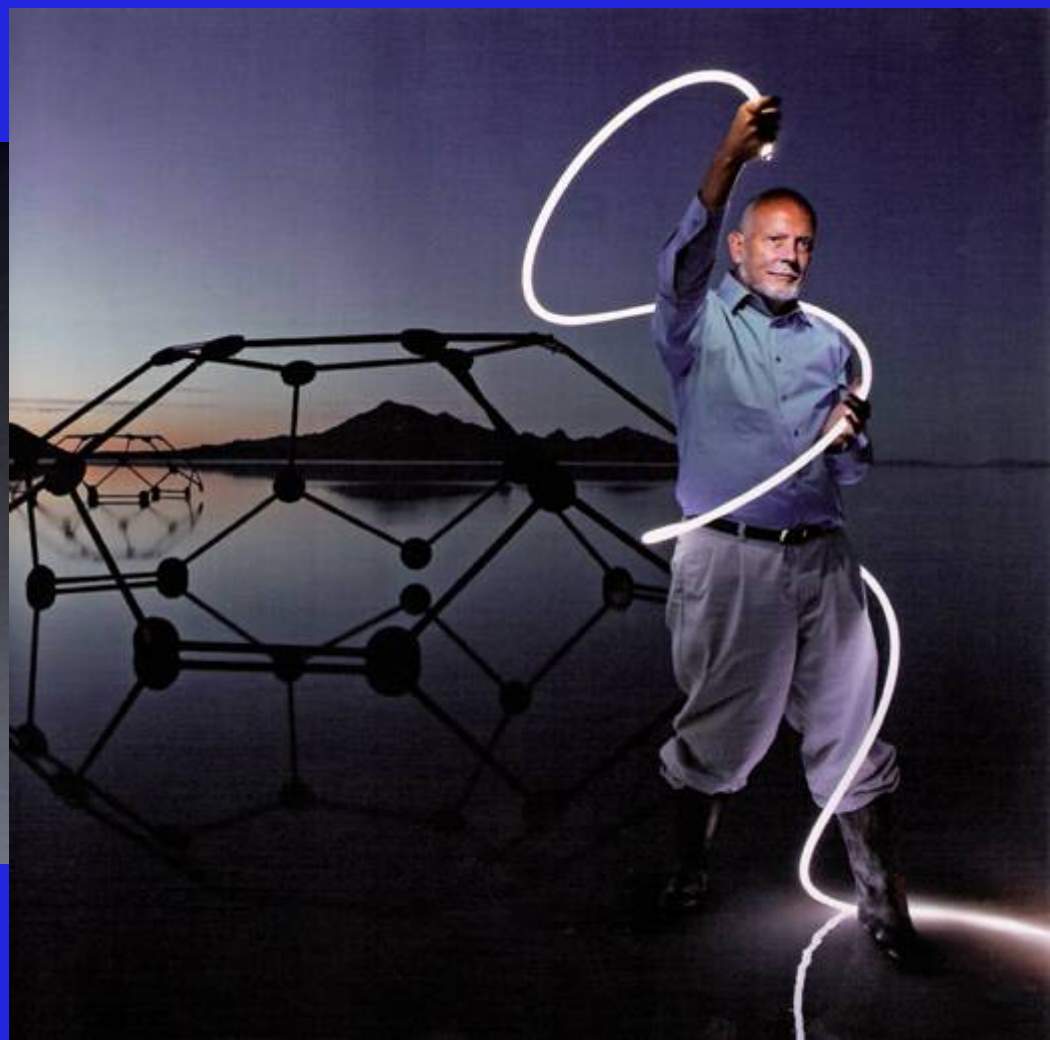
fullerene:

Buckyballs

National Nanotechnology Program
White House – November 2003

National Geographic Magazine June 2006 – “Nano’s Big Future”





Or In Italian…

I "nani" italiani

di Adriana Albini

Tanti i centri di ricerca che investono sulle nanotecnologie

Se potessimo diventare minuscoli ed entrare in una cellula tumorale, alloggiati in un comodo e veloce sommergibile immaginario, saremmo in grado di indagare da vicino cosa c'è che non va, quando essa inizia a "trasformarsi" per diventare cancerosa. Potremmo iniziare un viaggio fantastico alla ricerca, a distanza ravvicinata, dei difetti e delle alterazioni delle neoplasie. Non solo: impareremmo a sparare proiettili mirati per "far fuori" le modificazioni nocive. Mentre la cellula neoplastica misura tra i 20 e i 50 micron (milionesimi di metro), il diametro del DNA, guarda caso, è proprio della taglia giusta per le nanotecnologie: un paio di nanometri.

Prima di poter utilizzare le nanotecnologie per capire e curare i tumori, però, il passo fondamentale è di applicarle ai sistemi biologici. L'Italia è molto lanciata in questo settore: quasi tutte le città universitarie e i poli scientifici stanno investendo risorse nel campo, assieme all'Istituto nazionale di Fisica della Materia, oggi accorpato al CNR.

A Catanzaro, presso l'Università della Magna Grecia, è attivo il laboratorio BIONEM. «Particolare attenzione», spiega il professor Giovanni Cuda, «è dedicata al veicolaggio controllato dei farmaci per la cura dei tumori, utilizzando un sistema di microfluidica». Entrano in gioco nanocapsule, nanoparticelle e nanopolimeri, «basi per lo sviluppo di una "pillola intelligente"», precisa il nanotecnologo Enzo di Fabrizio. Aggiunge il rettore Salvatore Venuta: «La ricerca riguarda anche la diagnosi precoce del cancro; si punta a evidenziare particolari marcatori, proteine a basso peso molecolare e peptidi, mediante la messa a punto di dispositivi innovativi basati su silicio nanoporoso. Dall'università è nata anche un'azienda *spin-off* per l'industrializzazione di dispositivi nanotecnologici».

Modena è il campo di azione della "signora delle nanotecnologie", la scienziata Elisa Molinari, responsabile del Centro S3 (la sigla sta per "NanoStructure and BioSystems at Surfaces"). Presso il Nanobiolab del centro è stato messo a punto il primo modello di nanobio-transistor basato su una singola proteina: l'azurina, una molecola appartenente alla famiglia delle metallo-proteine a rame blu. Queste proteine hanno la capacità di trasferire elettroni, processo fondamentale per funzioni vitali quali la respirazione e la fotosintesi. Spiega Paolo Facci, ricercatore del centro: «Siamo riusciti a mettere a punto un transistor innovativo, operante in ambiente liquido. L'azurina è in posizione centrale, tra due elettrodi in oro; un terzo elettrodo, che agisce da *gate*, le permette di far fluire la corrente». Si prevedono applicazioni per nanosensori ad alta sensibilità.

Sempre a Modena, nell'ambito del progetto europeo PROETEX coordinato da Annalisa Bonfiglio, si stanno studiando i tessuti intelligenti per il personale che lavora in situazioni di emergenza o di calamità. Gli indumenti speciali così realizzati saranno in grado di aiutare gli operatori di soccorso durante le loro missioni: potranno monitorare il loro stato di salute e di affaticamento attraverso la registrazione di parametri come il battito cardiaco, il ritmo della respirazione, la postura, ma anche la composizione del sudore e del sangue per valutare il livello di stress e la disidratazione.. I vestiti del futuro ci diranno come stiamo?

I nanotubi, le resistentissime molecole tubolari cave a base di carbonio studiate negli USA da Matteo Pasquali (vedi l'articolo precedente) sono al centro delle ricerche di Maurizio Prato nel laboratorio TASC di Trieste, mentre a Genova Ugo Valbusa studia un'altra famiglia di nanomateriali dalla struttura geometrica: le nanopiramidi.

Alla Scuola Normale Superiore di Pisa la nanotecnologia sposa la biologia molecolare per indagare sul funzionamento delle proteine all'interno dell'organismo, sulle modalità con cui vengono trasportate e interagiscono con altre molecole all'interno delle cellule e tra

NUOVI MODELLI

Gli scienziati Matteo Pasquali (al centro della foto) e Wade Adams, che guidano la ricerca sulle nanotecnologie alla Rice University di Houston, con un modello di nanotubo, la molecola di carbonio super-resistente. Pasquali lavora negli USA, ma sono molti i centri di ricerca italiani impegnati nello stesso campo di studi.

una cellula e l'altra. Nel laboratorio NEST, diretto da Fabio Beltram, è stata frammentata la proteina TAT, che il virus HIV utilizza per invadere le cellule sane e moltiplicarsi. «Abbiamo sfruttato nanotecnologie utili per trasportare, attaccati a TAT, frammenti terapeutici nelle cellule», ha dichiarato tempo fa Beltram. In collaborazione con l'équipe del fisico Mauro Giacca dell'Università di Trieste, il laboratorio pisano ha sperimentato il FRET (*fluorescence resonance energy transfer*), un sistema che emette fluorescenza quando due proteine si trovano a stretto contatto fisico, a una distanza inferiore ai 10 nanometri. La tecnica ha consentito di identificare anche i partner con cui TAT interagisce per invadere le cellule sane. Infine Roberto Cingolani, che segue sia il Laboratorio nazionale di nanotecnologie (NNL) a Lecce sia l'IIT di Genova, si occupa di "eccitoni" (elettroni eccitati) e addirittura prefigura un'interfaccia nanotecnologica tra chip e neuroni nel cervello umano.

Alla ricerca sulle nanotecnologie in Italia è dedicato un sito Web: *www.nanotec.it* □

Adriana Albini è vicedirettore scientifico dell'Istituto nazionale per la Ricerca sul cancro di Genova.

FOTO: TOMMY LAVERGNE, RICE UNIVERSITY

What is Nanotechnology?

- "Nanotechnology now represents no less than the next Industrial Revolution." *Red Herring*, December 2001

  "Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications."

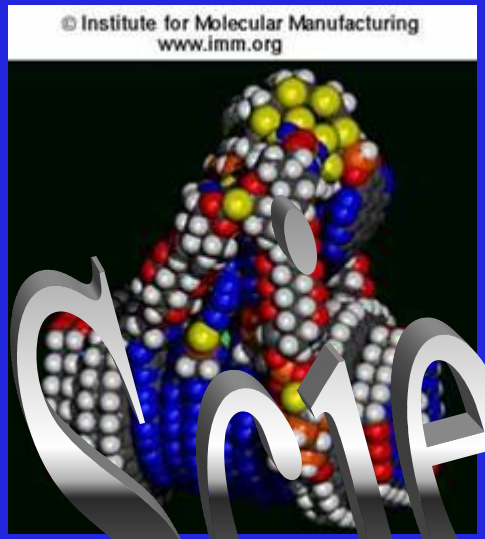
  "Nanoscale science, engineering and technology -- nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."

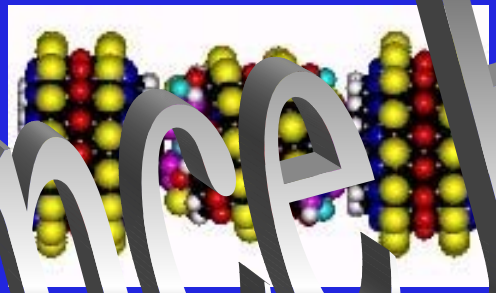
  "Anything is nanotechnology that, under the rubric of nanotechnology, makes money." *Rice Alliance Entrepreneurship Workshop*, October 2002

What is Nanotechnology?

Molecular Engineering?

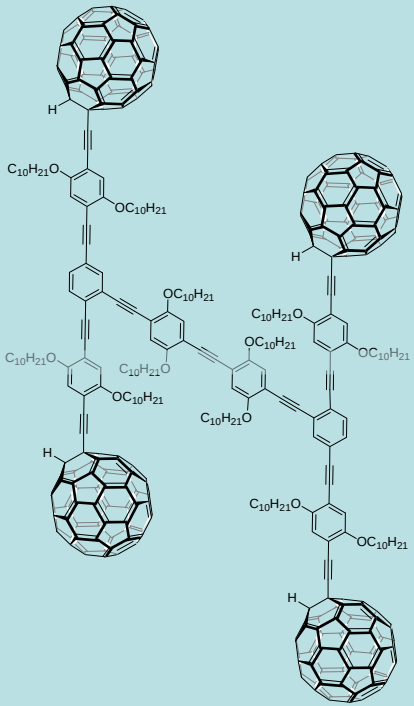
Nanobots?

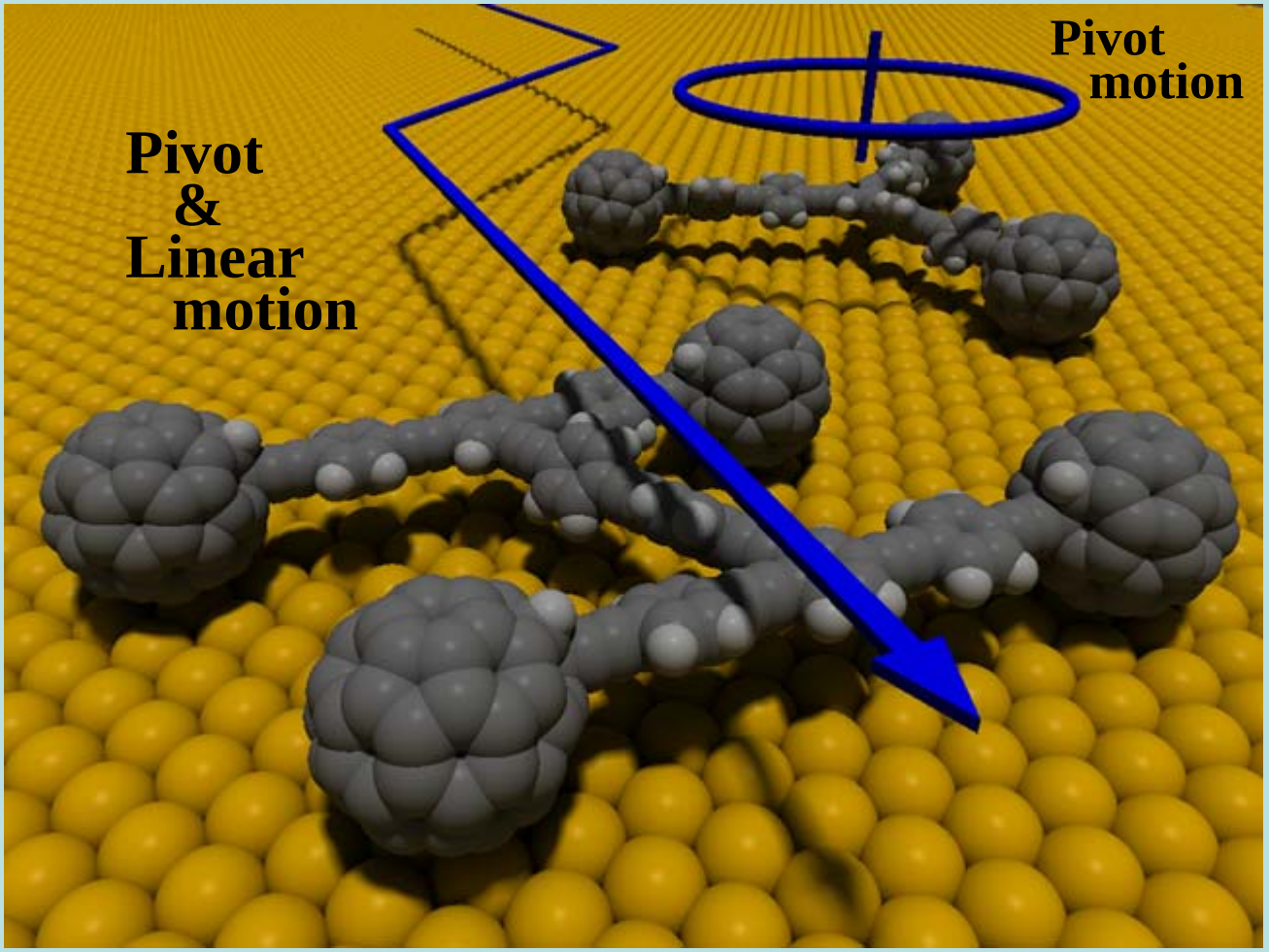




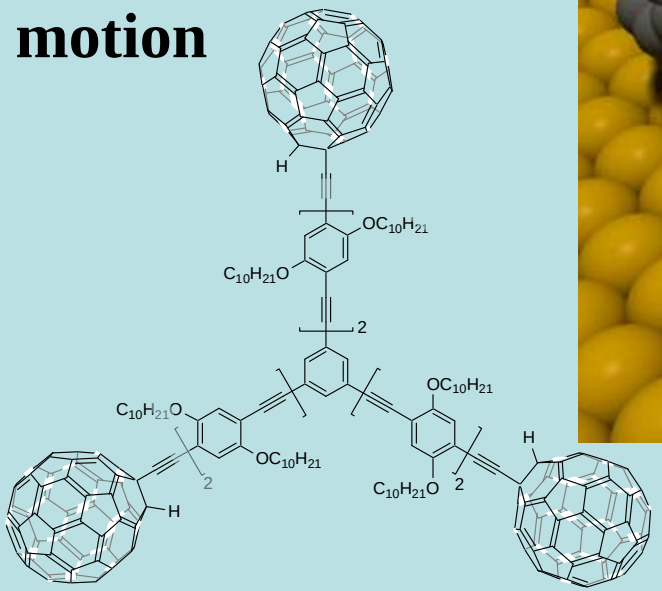
Science Fiction

C_{60}-wheel-assisted motions





No lateral motion



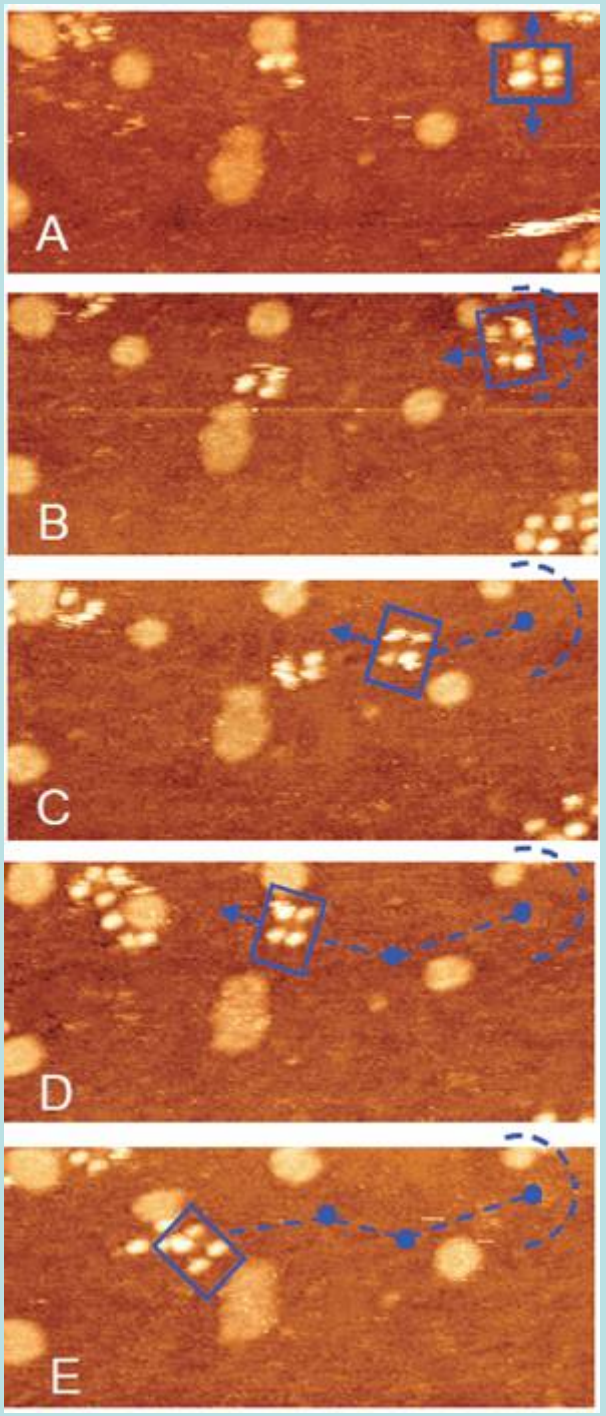
Pseudo-1D Brownian motion

Y. Shirai, K. Kelly

Random Thermal Motion (Brownian Motion)

NanoCars are mobile at high temperature (~194ºC), and show random thermal motion.

Lateral motion is parallel to NanoCar chassis.
(Pseudo-1D Brownian motion)
Supports the idea that NanoCar is rolling, not sliding via a stick slip mechanism



Pivot & rolling

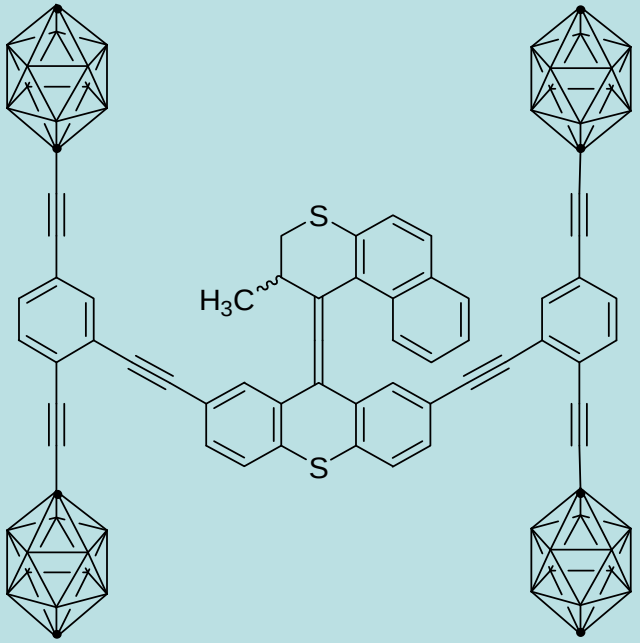
Pivot & rolling

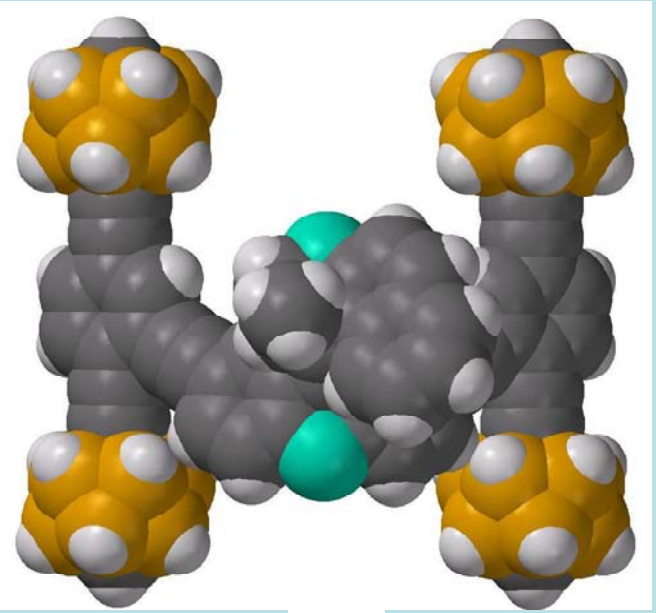
Pivot & rolling

NanoCollision!

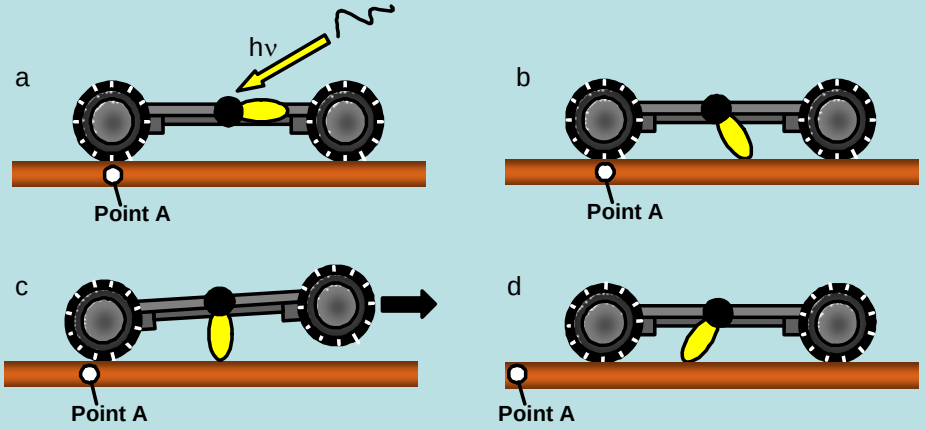
Y. Shirai
K. Kelly

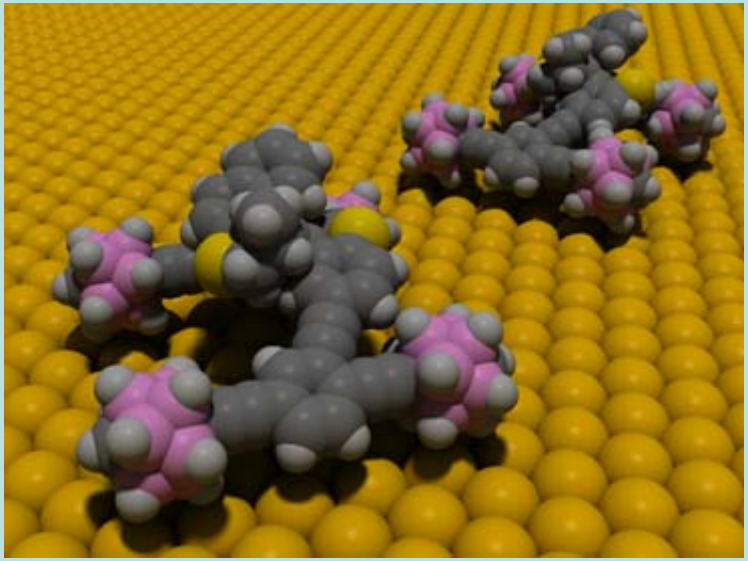
Motorized NanoCar – Light Power!





Carborane wheel

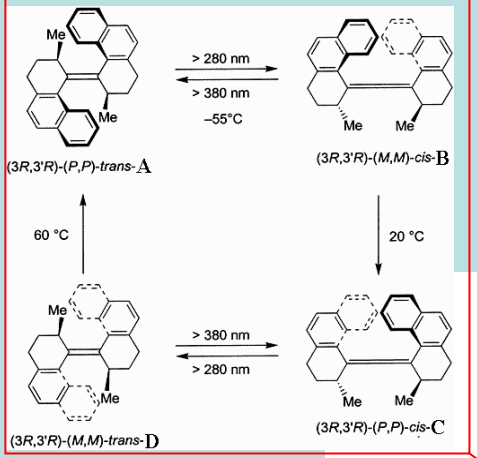




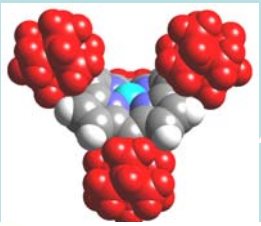
Nanotransporters

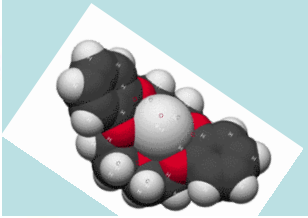
Understanding Nanoscale Componentry

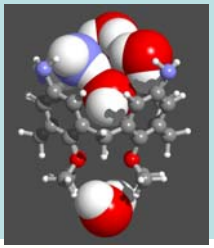
Motor

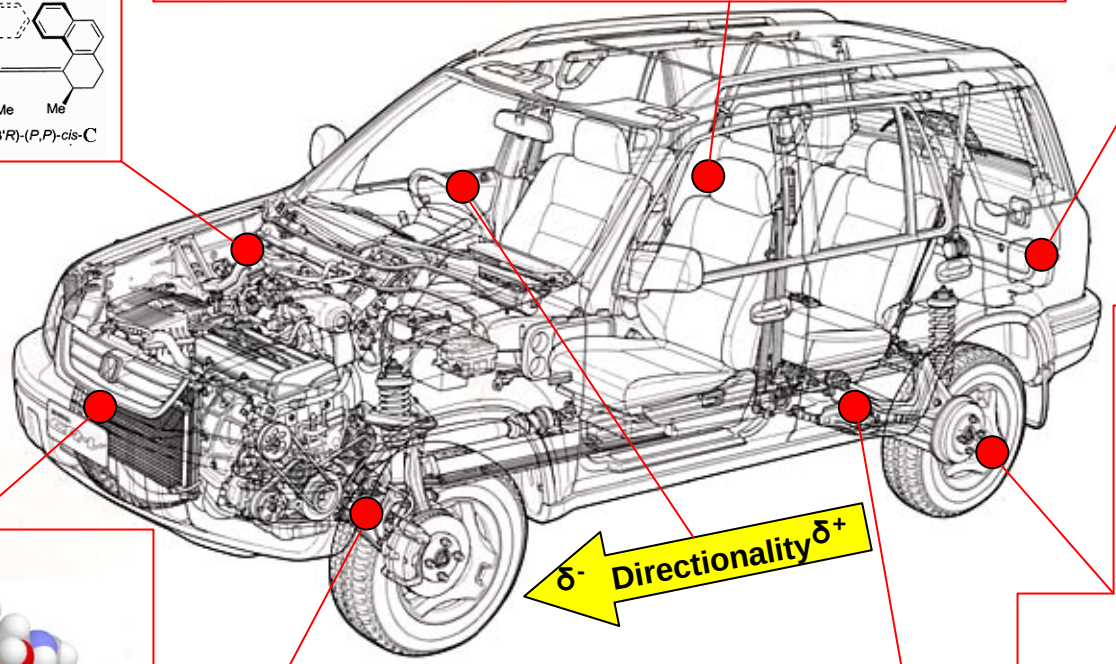


Cargo Transport

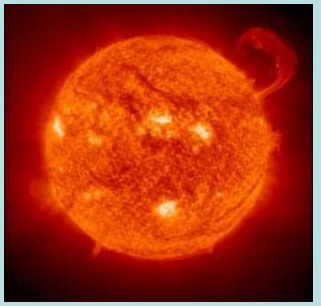




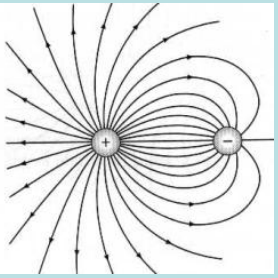




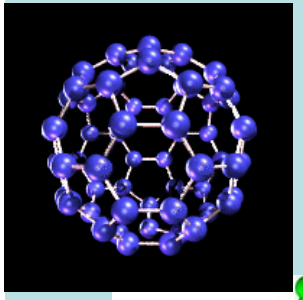
Fuel

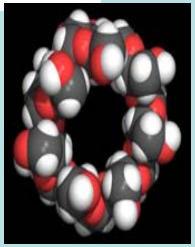


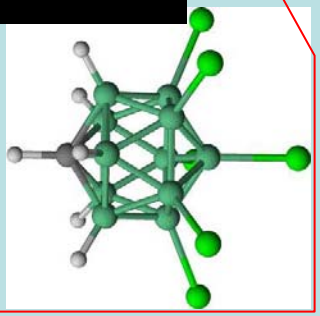
Sensors/Actuators



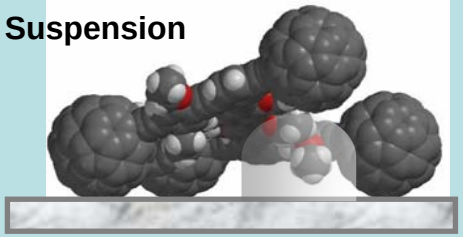
Wheels



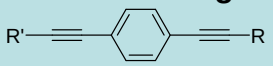




Suspension



Axle/Bearings



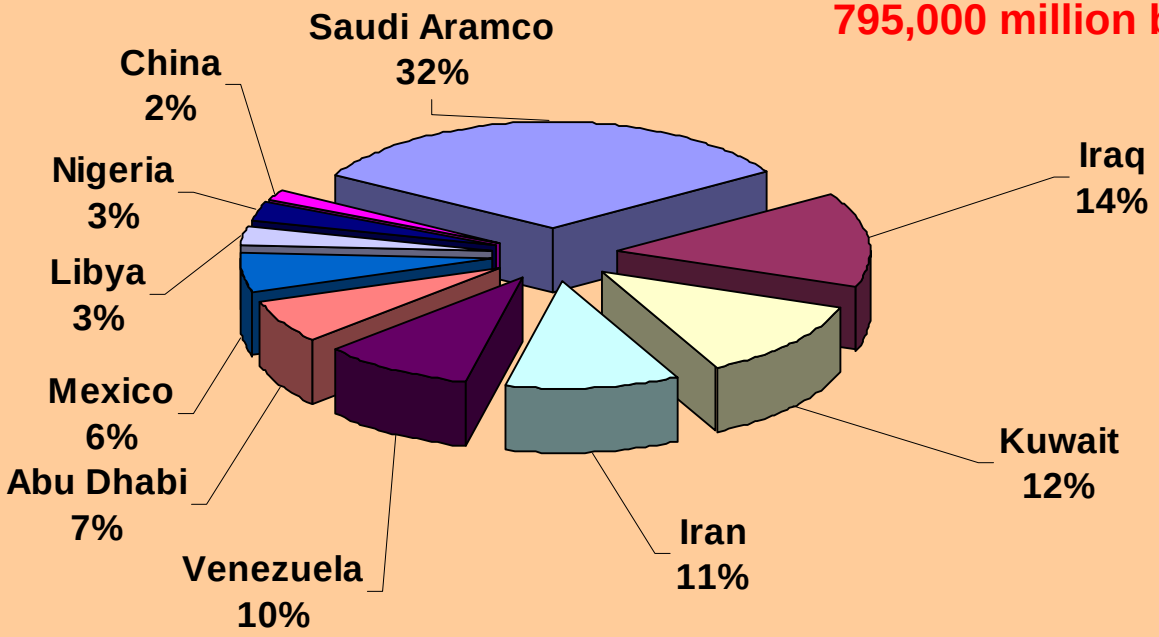
Energy-efficient Commuting

Lewis Norman from Halliburton at the May 2002 NNI Regional Meeting, Session on Energy and Petrochemicals – Rice University

Oil will become scarce, and then gas, and it will happen sooner than people think. Only technology will solve our problems.

World Oil Reserves

World Oil Reserves
Top Ten Owner
Companies



795,000 million bbls (80 %)

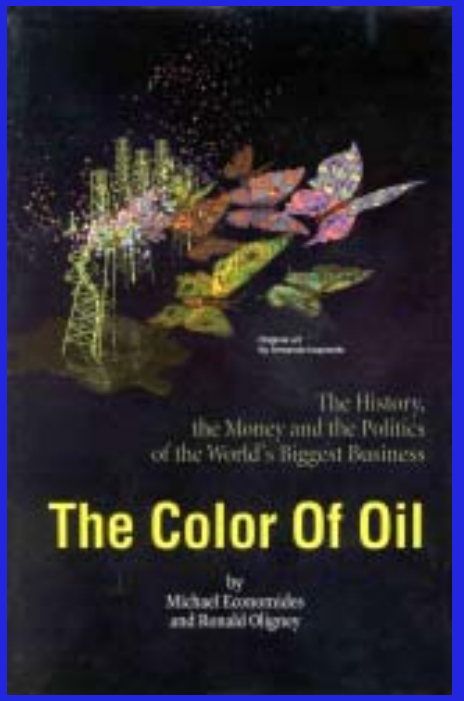
Total World Oil Reserves: Approximately 1,000,000 million bbls

Source: The Oil Daily, 12/23/1999

Lewis Norman
Halliburton Energy Services

Energy Industry

"Our Energy will be primarily from fossil fuels for the next 50 years"



Lewis Norman
Halliburton Energy Services

Economides, M. and Oligney, R.: The Color of Oil, Round Oak Publishing Company, Inc., Katy, TX, 2000

Shocked into Action

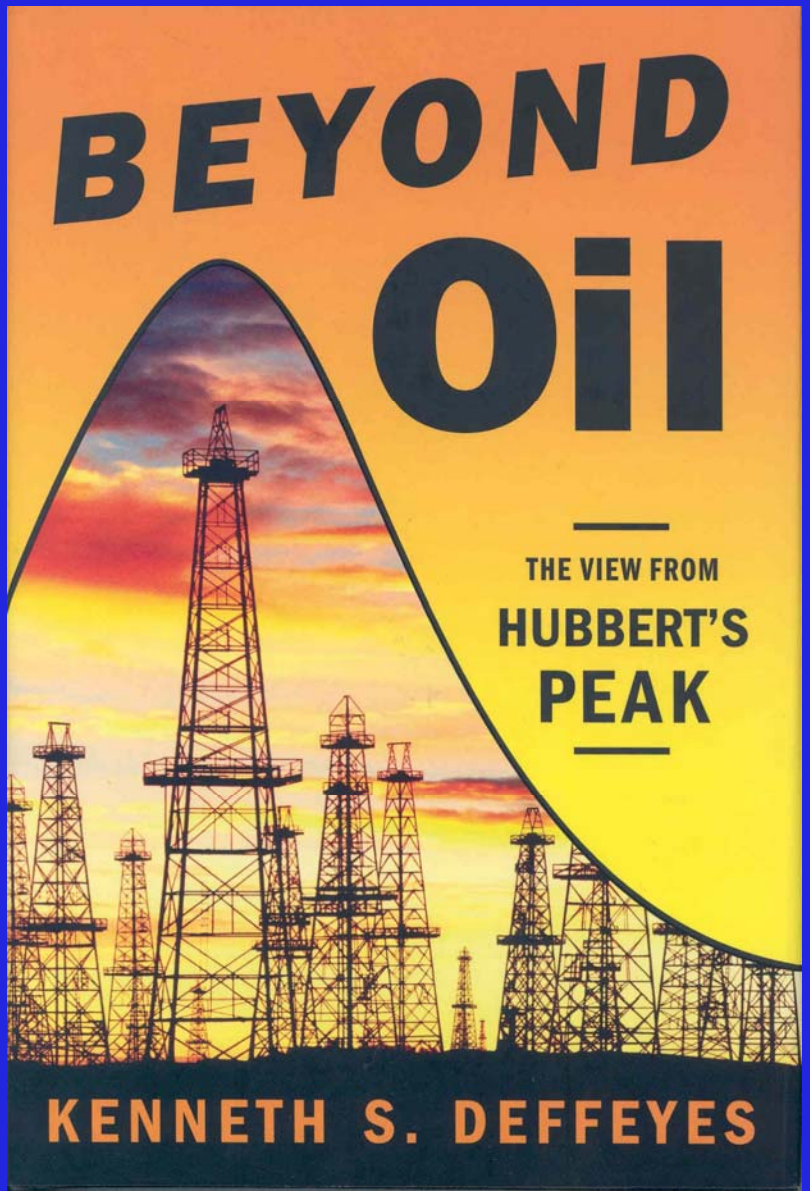
- Mike Roco, Rick and I discussed at lunch – felt like we were hit in the head with a 2x4!
- Meeting with Amy Jaffe (Baker Institute for Public Policy) and Neal Lane (fresh from Washington “vacation”)
  - Nano in Energy emerged
  - “Be a Scientist – Save the World” also emerged
- Decided to launch workshops to develop the scientific and policy basis for action
  - 2003 – Energy and Nanotechnology
  - 2004 – Solar
  - 2005 – The Grid and Storage

Humanity's Top Ten Problems for next 50 years

1. **ENERGY**
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

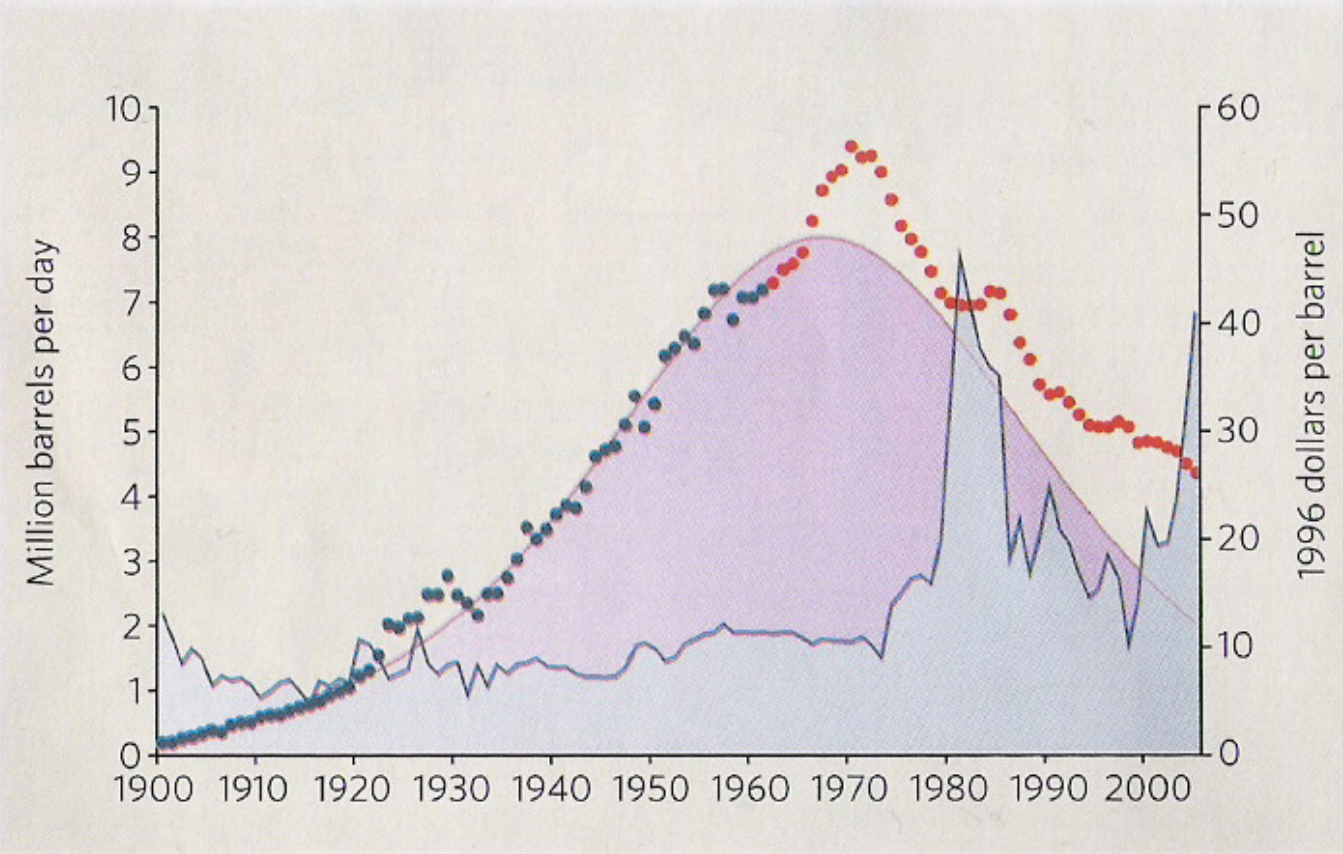
2003 6.5 Billion People
2050 8-10 Billion People

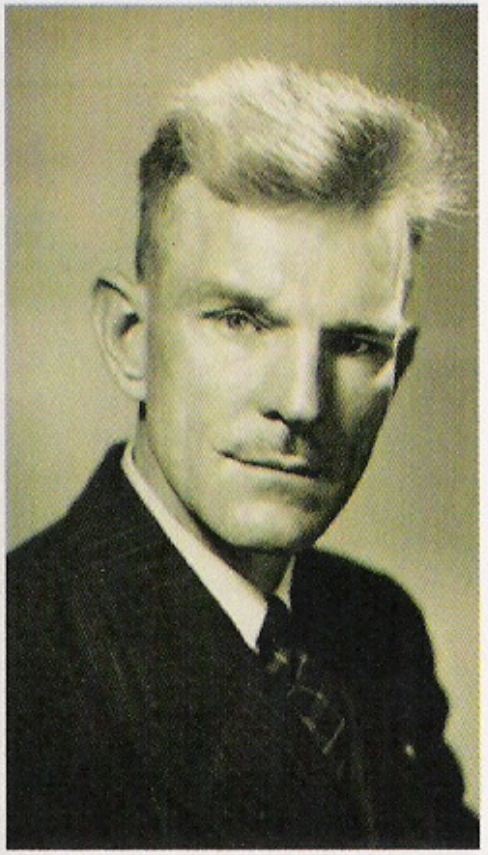
Hubbert's Peak



U.S. Oil Production

SOURCE: R. KAUFMANN

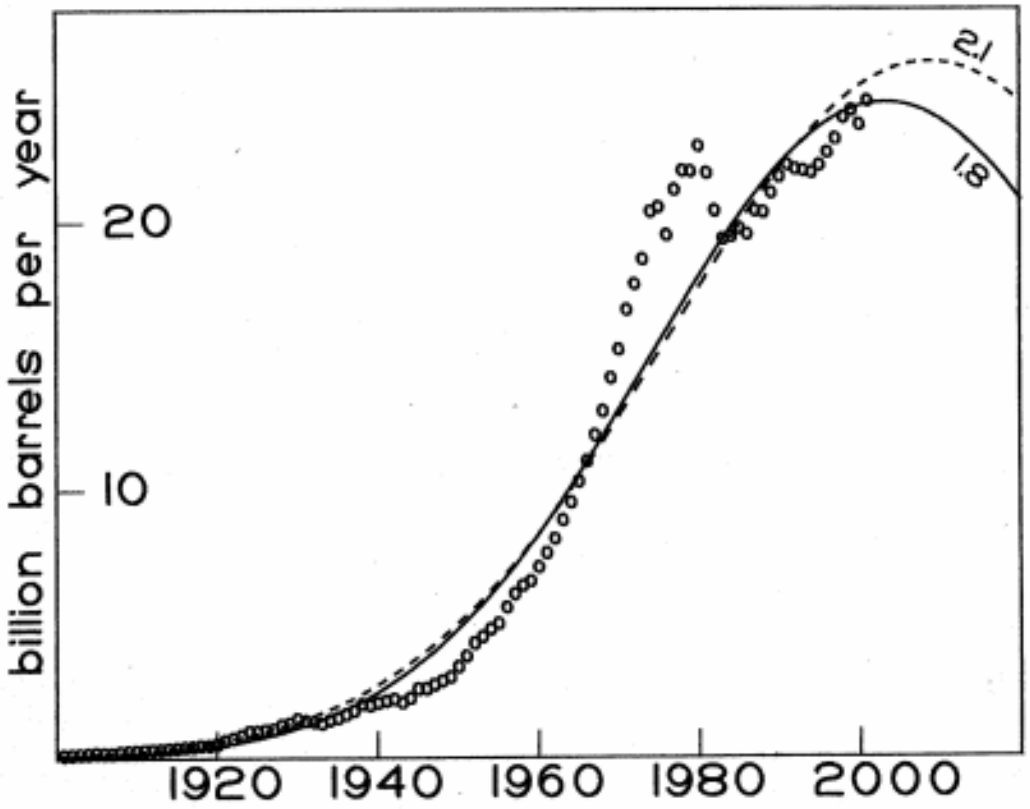




Fan club: M. King Hubbert (right) gained instant notoriety for his 1956 prediction that oil production in the 48 contiguous US states (purple shaded area) would peak around 1970. It did, but production was much higher that year and in later years (red dots) than Hubbert foresaw.

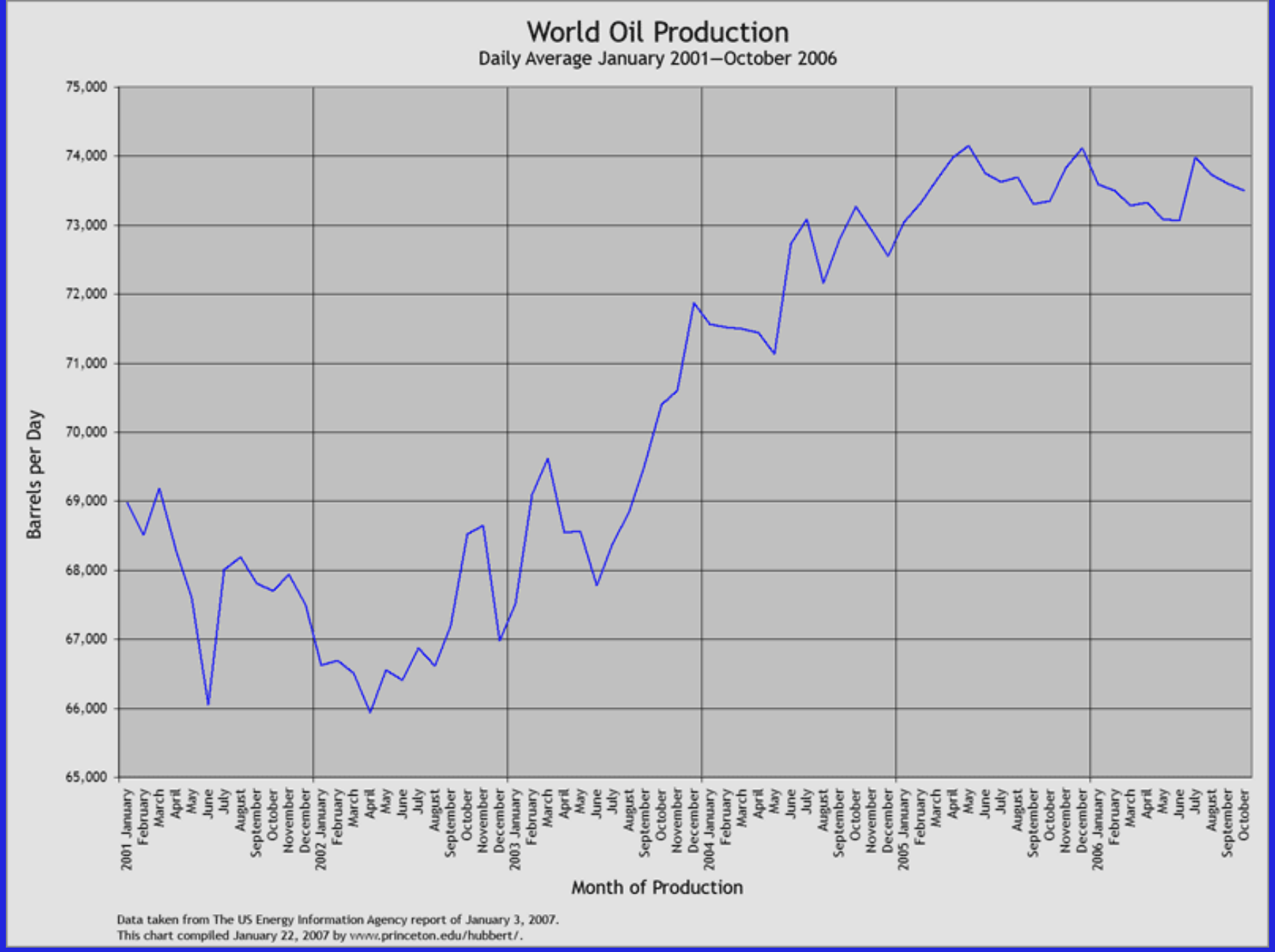
Nature 4 Jan 07 pp14-17

WORLD OIL PRODUCTION

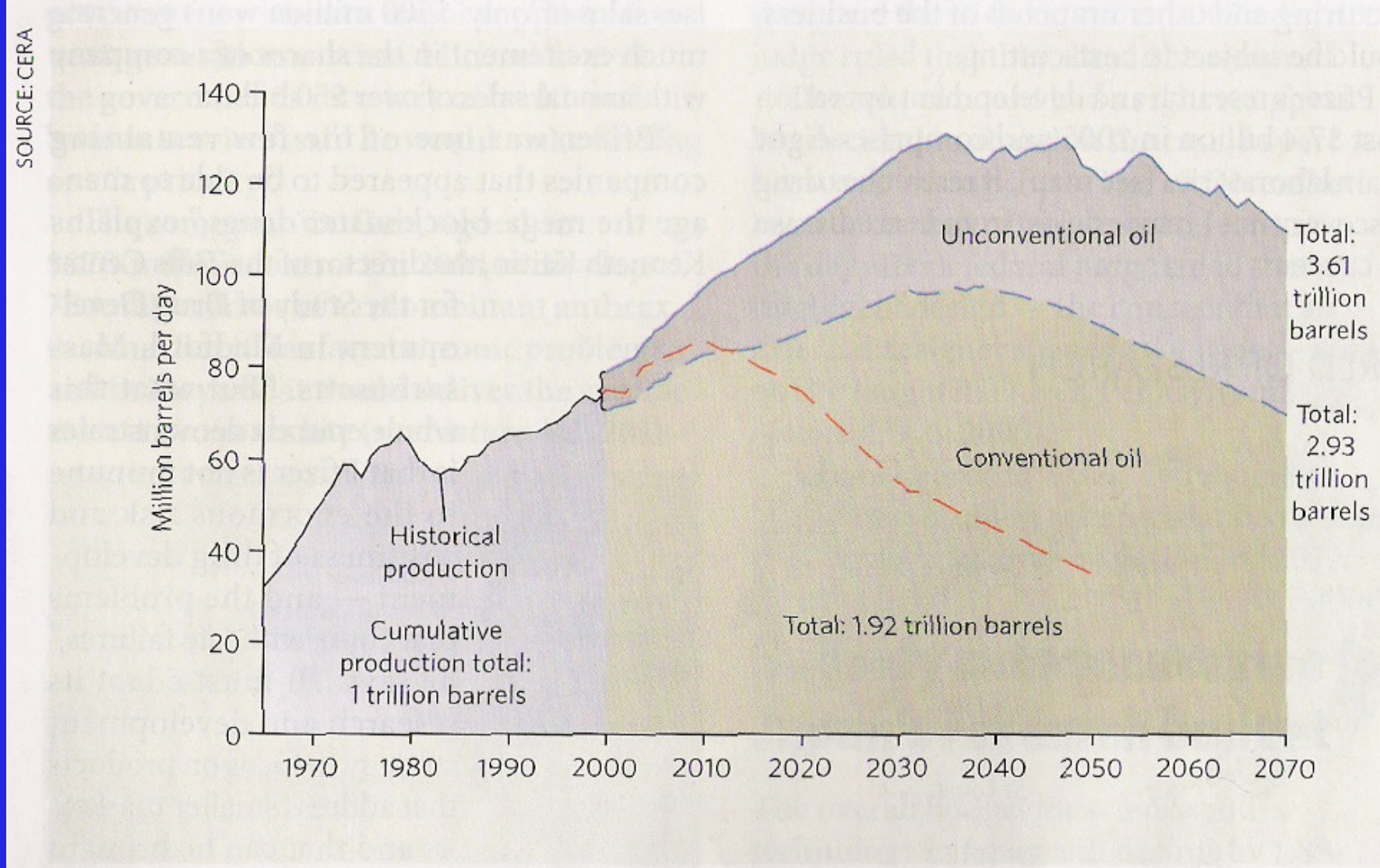


Annual production of world oil (circles), with Gaussian curves corresponding to total eventual oil recovery of 1.8 and 2.1 trillion barrels. A steeper rising curve with its top chopped off by market limitations would make a better fit.

Hubbert's Peak (2001)



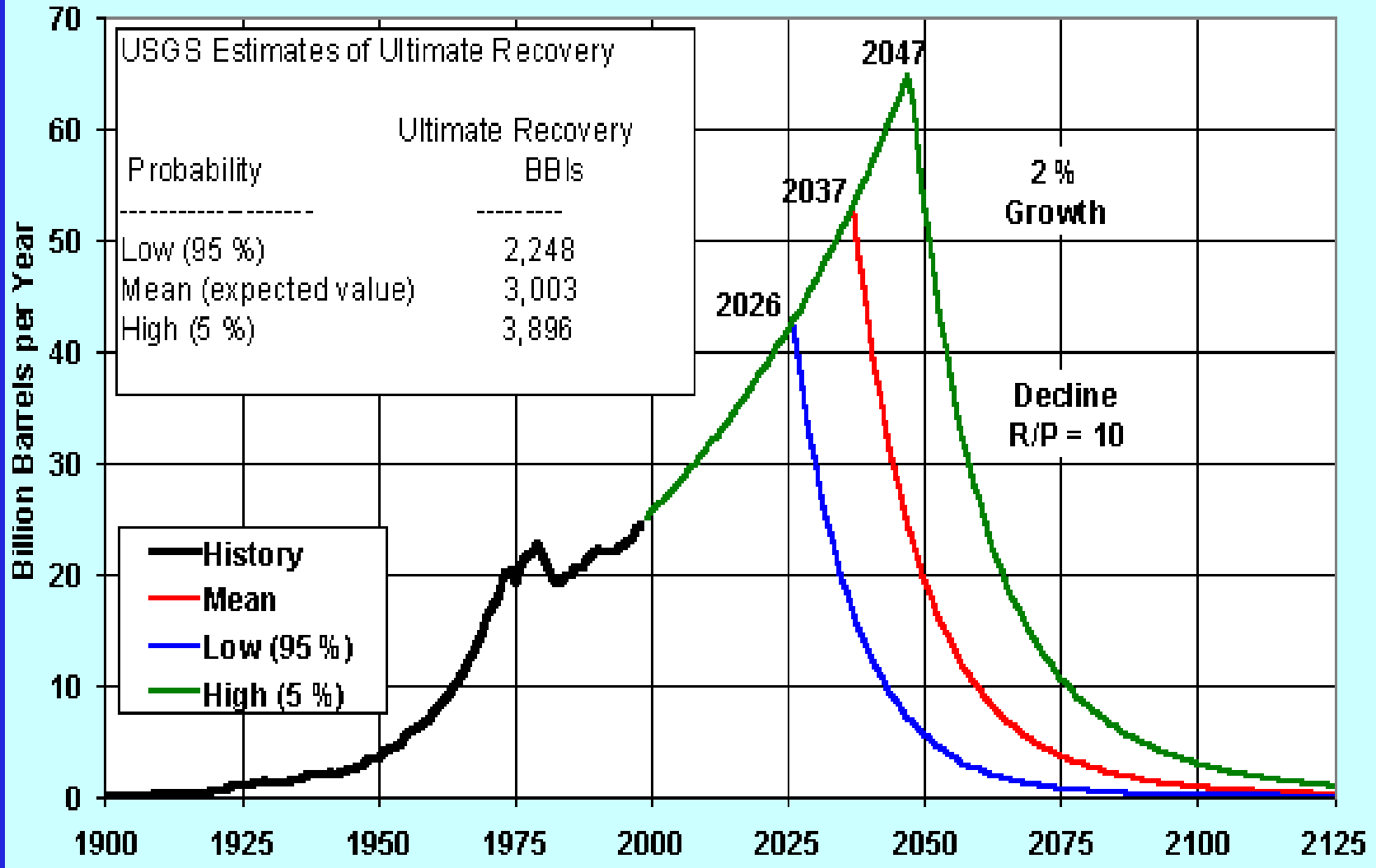
Ken Deffeyes website – Feb 07 http://www.princeton.edu/hubbert/



Twin peaks: peak-oil supporters think we have already reached or will soon reach a historical maximum of oil production (red line); others argue that oil production will not peak until at least 2030 (blue lines).

Nature 4 Jan 07 pp14-17

Annual Production Scenarios with 2 Percent Growth Rates and Different Resource Levels (Decline R/P = 10)



Note: U.S. volumes were added to the USGS foreign volumes to obtain world totals.

Peak oil?

Contrary to the theory, oil production shows no sign of a peak.

Will we soon reach a point when the world's oil supply begins to decline? Yes, according to so-called "peak oil" proponents. They theorize that, since new discoveries have not kept up with the pace of production in recent years, we will soon reach a point when oil production starts going downhill. So goes the theory.

The theory does not match reality, however. Oil is a finite resource, but because it is so incredibly large, a peak will not occur this year, next year or for decades to come.

According to the U.S. Geological Survey, the Earth was endowed with over 3.3 trillion barrels of conventional recoverable oil. Conservative estimates of heavy oil and shale oil push the total resource well over four trillion barrels. To put these amounts in perspective, consider this: Since the dawn of human history, we have used a total of about one trillion barrels of oil.

Moreover, new technologies — such as multidimensional mapping tools and advanced drilling techniques — have improved our ability to recover oil from previously discovered fields. Because of such technology gains, estimates of how much recoverable oil remains have consistently *increased* over time. Oil production and production capacity have increased, too.

So there is a lot of oil yet to be tapped. And we are getting better — technically and environmentally — at tapping it every day.

As a large scale, broad-based transportation fuel, oil currently has no equal. Demand for it is increasing to support economic growth worldwide. Thankfully, there is enough potential supply to meet this demand.

Realizing this potential, however, means we all must do our part. Energy companies help through investment and technology. Governments help by providing an attractive business environment. And we all can help by using energy more efficiently.

With abundant oil resources still available — and industry, governments and consumers doing their share — peak production is nowhere in sight.

ExxonMobil

Taking on the world's toughest energy challenges.™

Recent Newspaper Ad

BUSINESS AS USUAL

Matthew Simmon's Presentations on Saudi Arabian Oil (www.simmons-intl.com) and his new book "Twilight in the Desert" John Wiley & Sons publishers, May 2005

Does Greatest Vulnerability Reside In Middle East?

- For decades, all supply/demand models have assumed Middle East oil is "inexhaustible" and cheap.
- Saudi Arabia (with 90 years proven reserves and little exploration) is the inexhaustible Energy King.
- Middle East oil has been the world's most reliable supply (other than geopolitical jitters).

- Everyone has assumed this cornucopia of oil lasts "forever"!
- There is no data to support this belief!

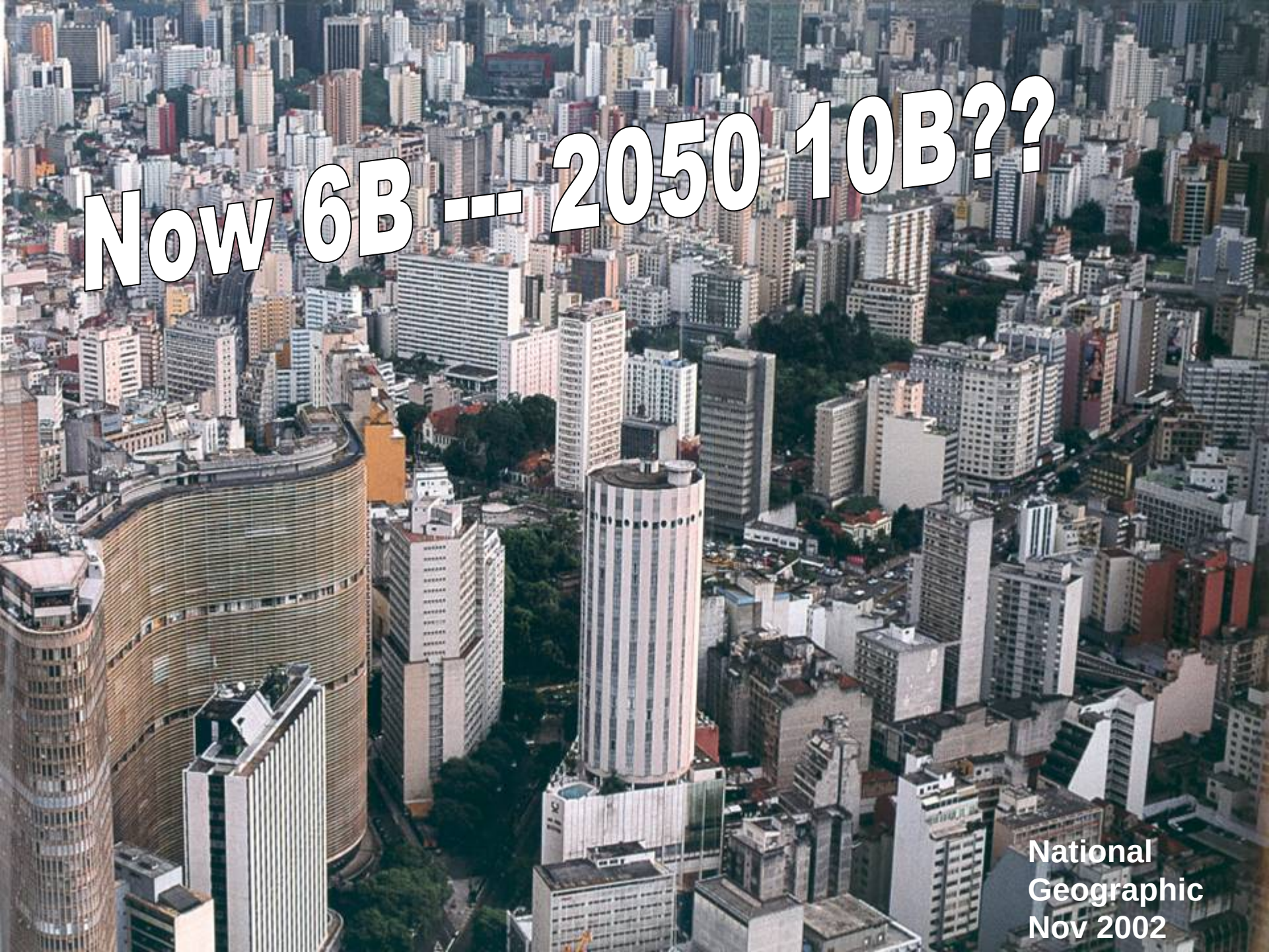
SIMMONS & COMPANY INTERNATIONAL

When Saudi Arabia Peaks
So does the World.

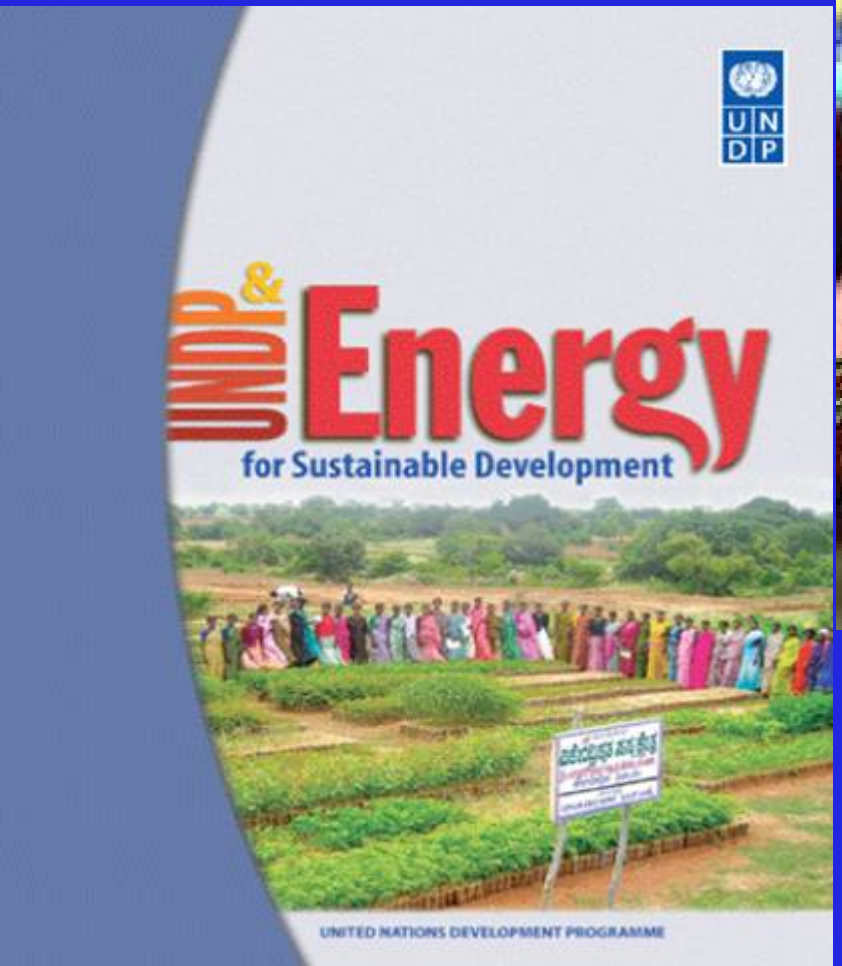
GHAWAR, by far the world's Largest and most prolific oil field may have already peaked.

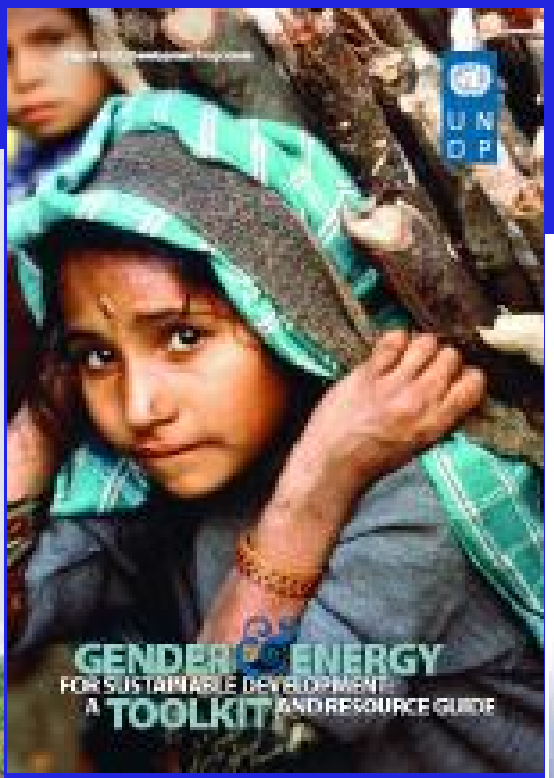
The days of cheap oil are over.

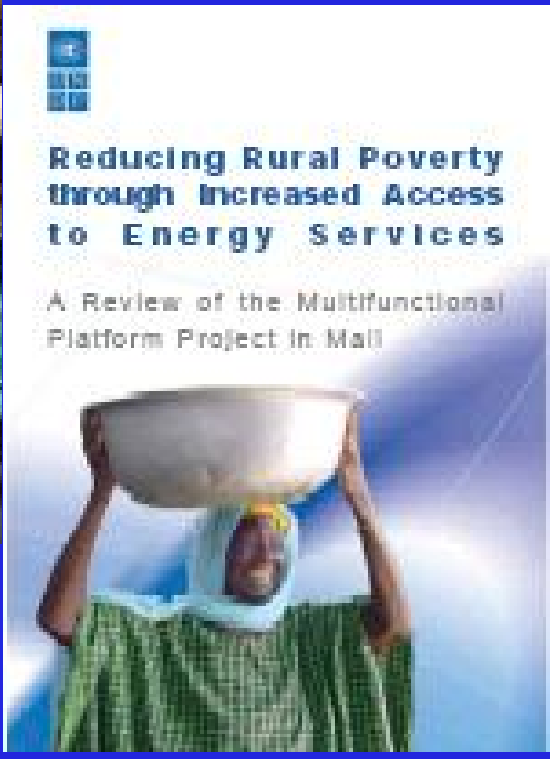
Also Google "peak oil" and look at sites such as "peakoil.com"


Now 6B --- 2050 10B??
National
Geographic
Nov 2002

2 Billion Poor – No Electricity
2 Billion Poor – Biomass Heating

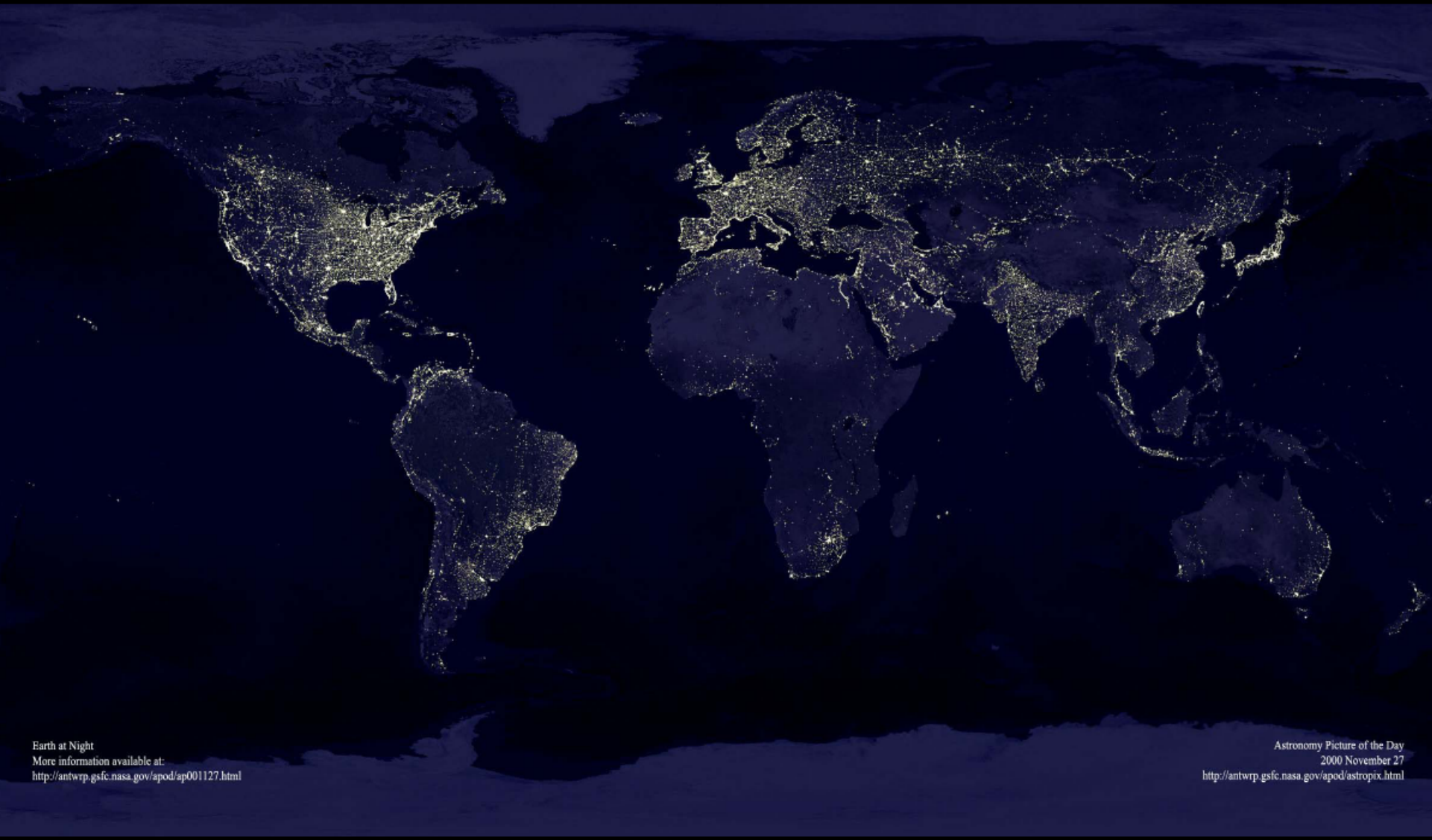






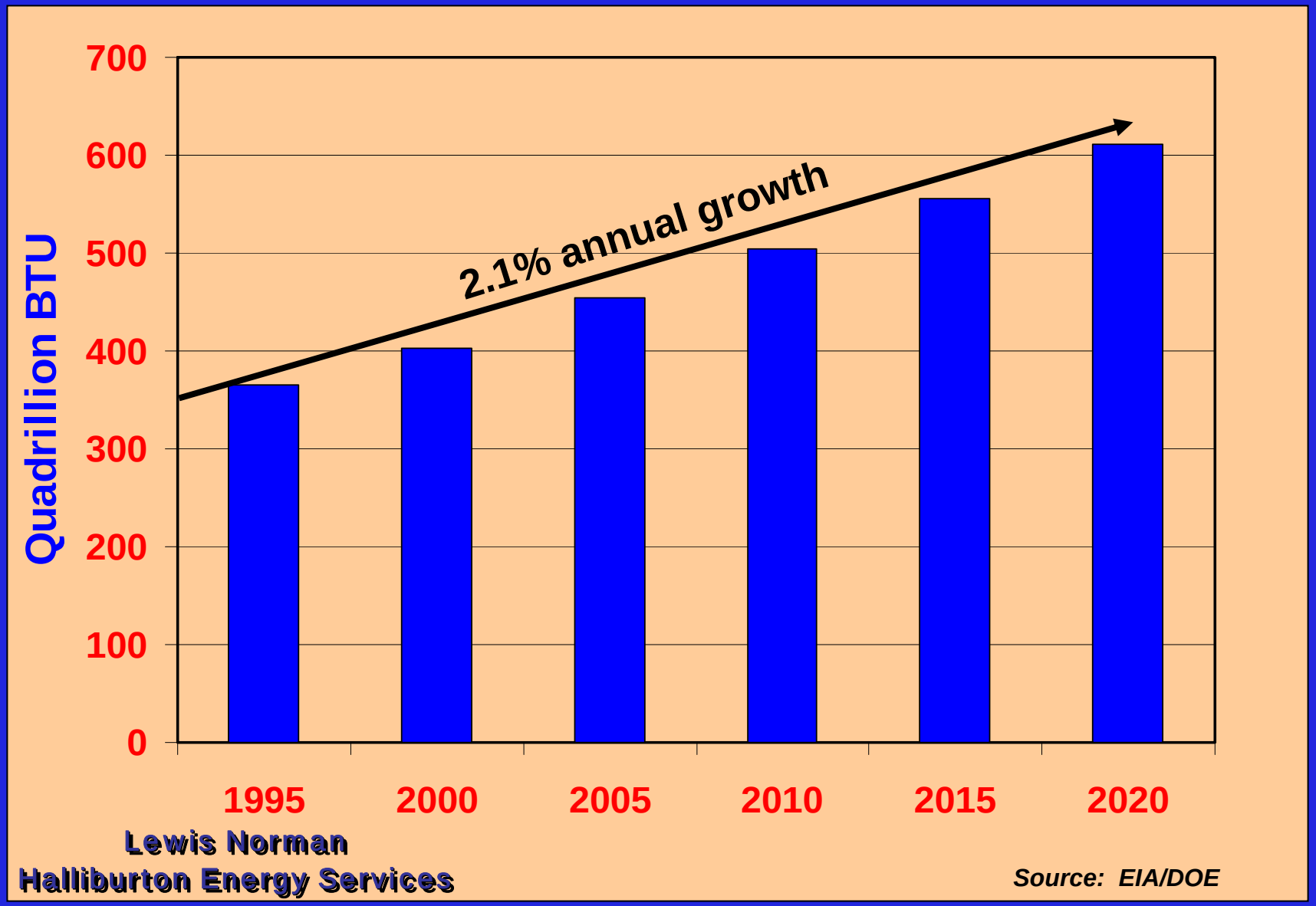
http://www.undp.org/energy

Earth at Night as viewed from Space



…yet 1/3 of Earth's human population lacks access to electricity…

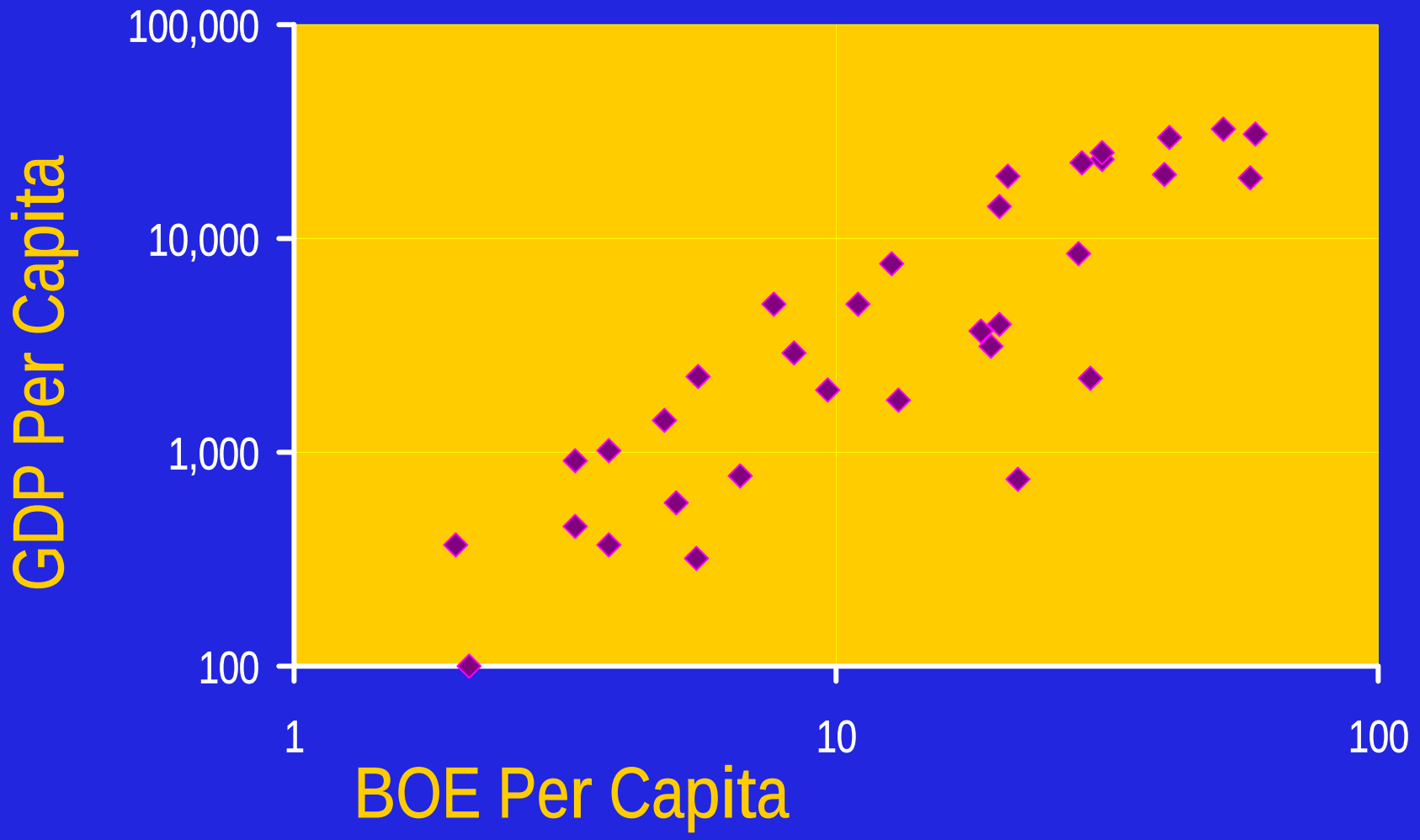
Global Energy Demand Will Continue to Grow



Lewis Norman
Halliburton Energy Services

Source: EIA/DOE

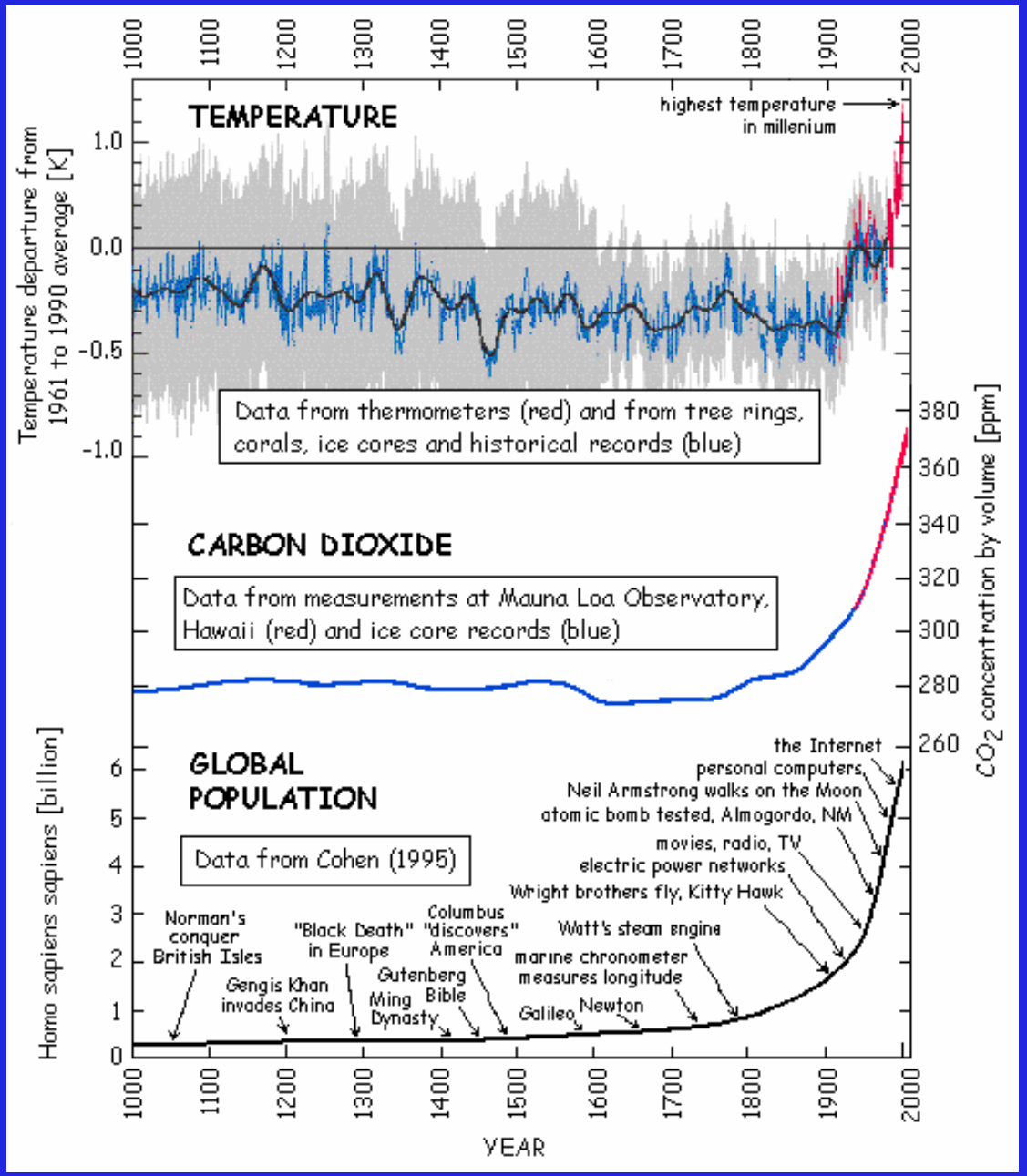
Energy Use and National Wealth



Global warming over the past millennium

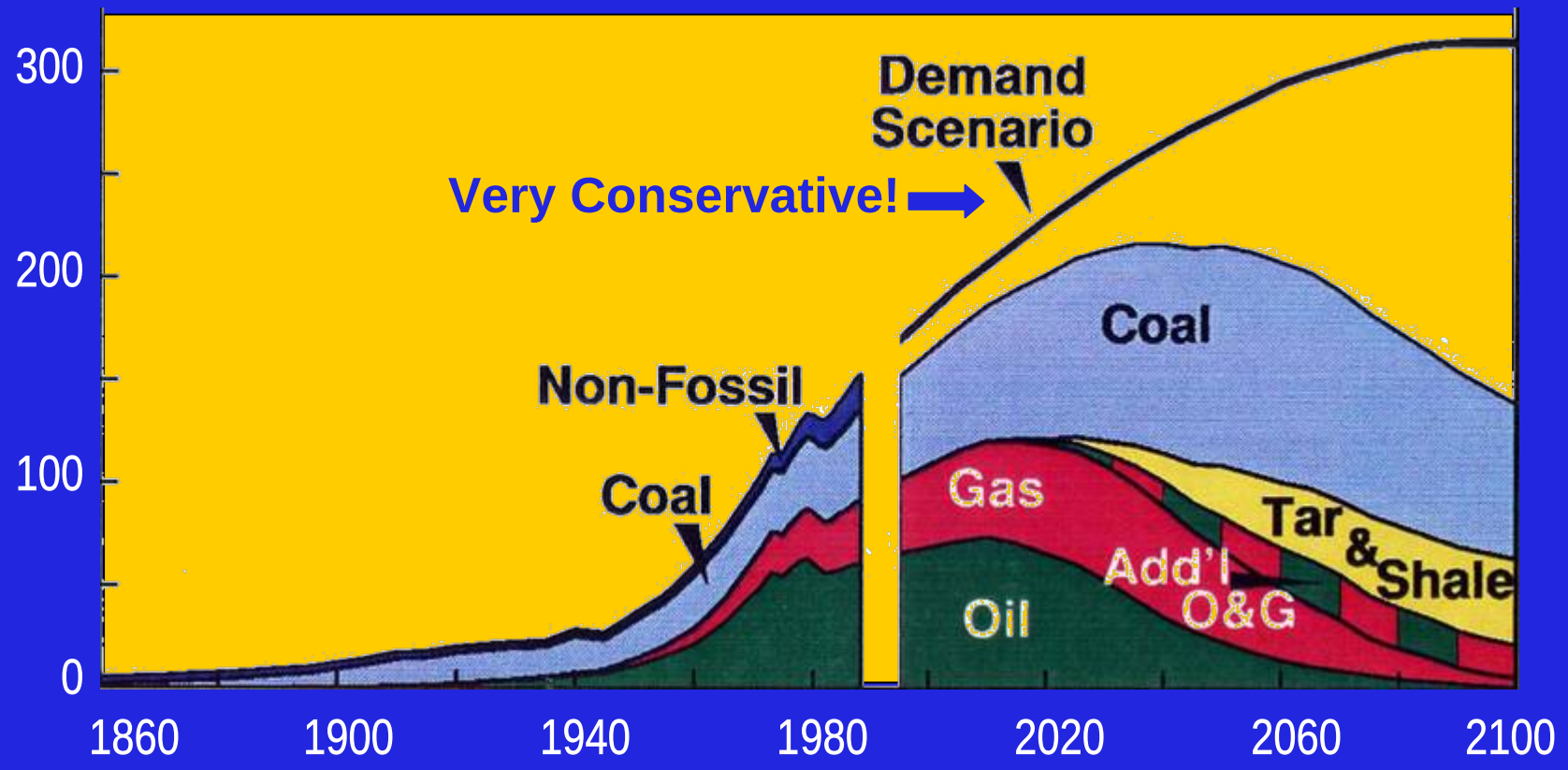
Very rapidly we have entered uncharted territory -– what some call the *anthropocene* climate regime. Over the 20th century, human population quadrupled and energy consumption increased sixteenfold. Near the end of the last century, we crossed a critical threshold, and global warming from the fossil fuel greenhouse became a major, and increasingly dominant, factor in climate change. Global mean surface temperature is higher today than it's been for at least a millennium.

Slide from Marty Hoffert NYU



World Energy

Millions of Barrels per Day (Oil Equivalent)



Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).

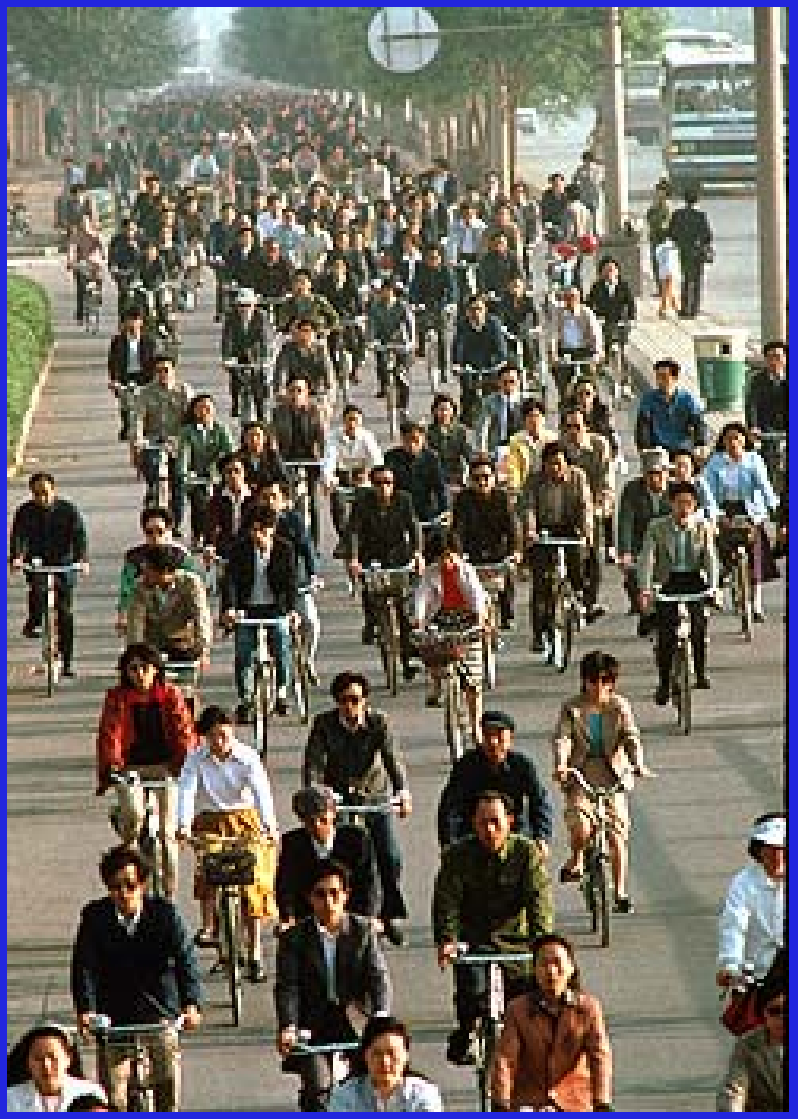
Uh Oh – China!!

1 Billion + people!

BUYING INTO CAPITALISM, newly prosperous professionals are clogging Chinese cities with cars. In 1984 the first private vehicle appeared in Beijing amid a flood of bicycles. Today a stream of vehicles surrounds the Forbidden City (above), five concentric beltways ring the growing metropolitan area, and a 15-mile commute to work can take the better part of an hour. Last September the city's first drive-through fast-food outlet opened (below). Located in a suburb popular with young executives, the business serves about 200 mobile customers

Energy Growth Rate ~10%!!

National Geographic June 2004

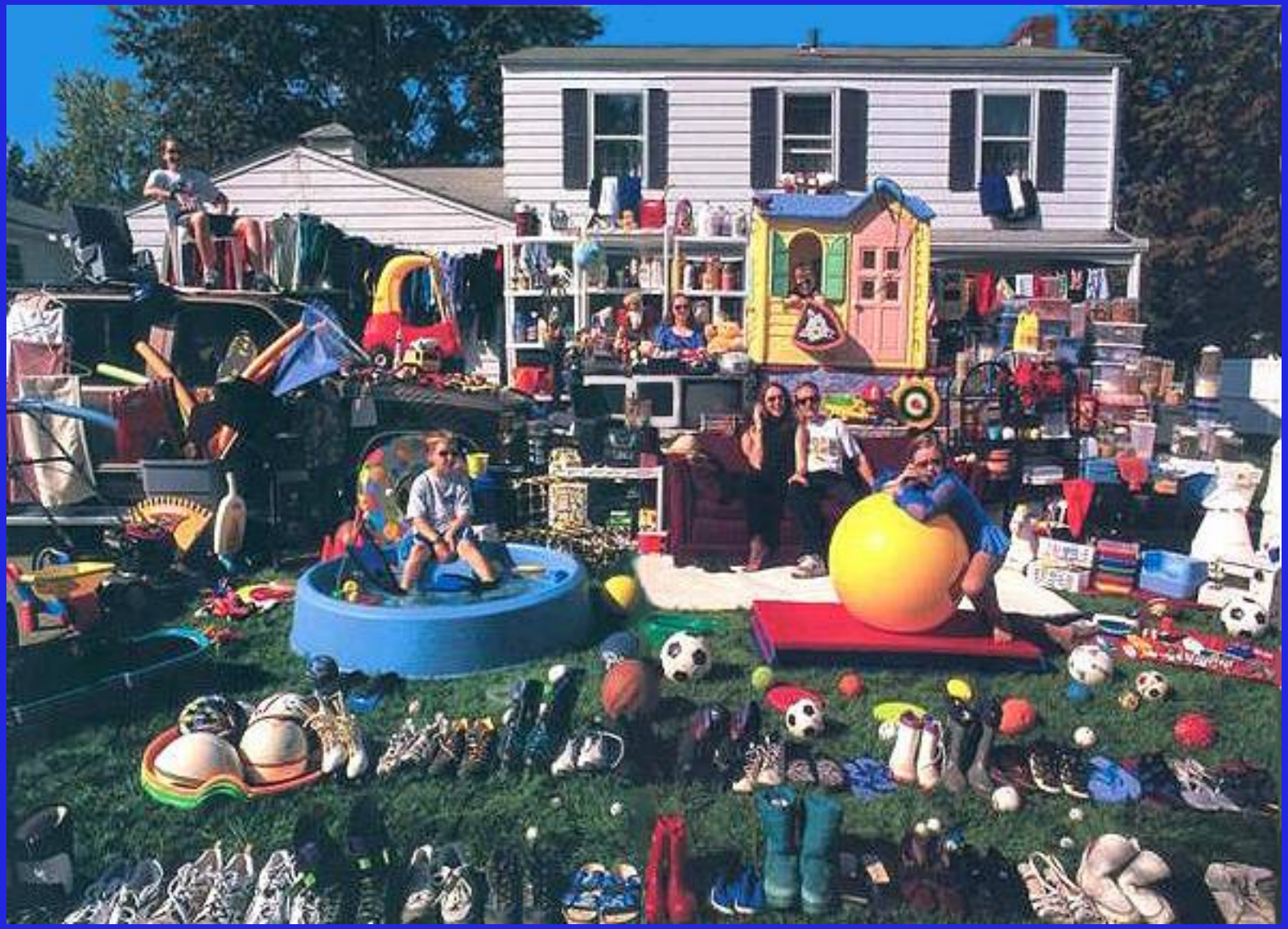


Gee, this isn't my mother-in-law's Buick!!

From bicycles…….

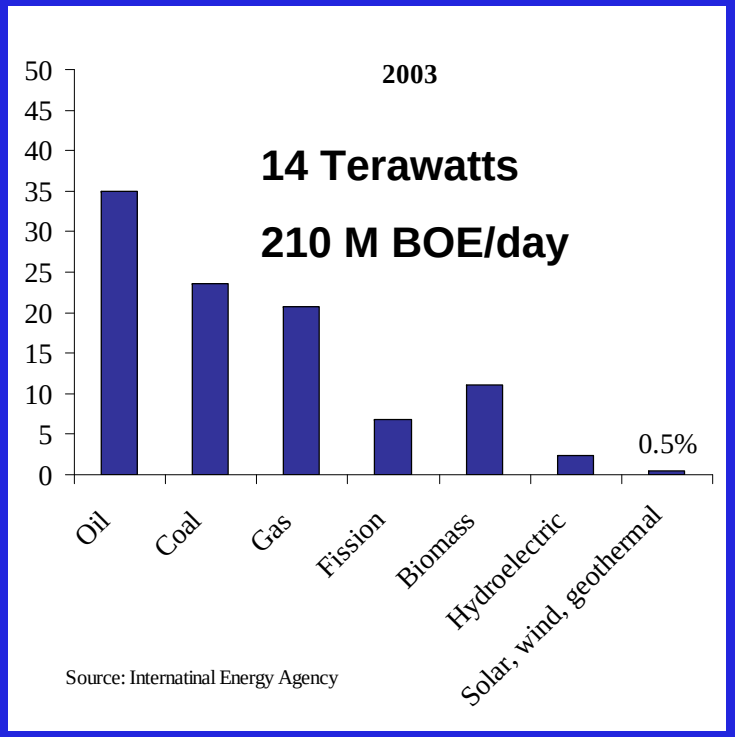
to Buicks!!

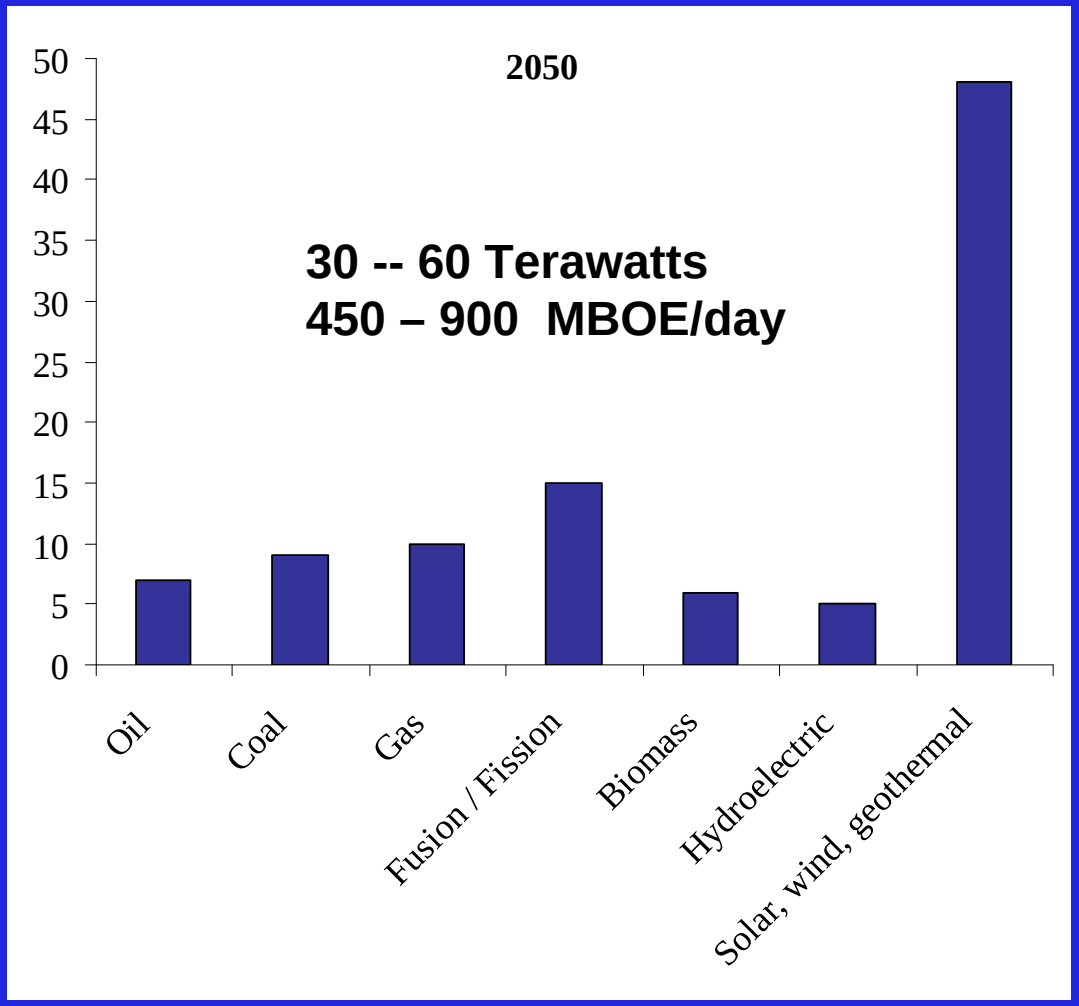
A Much Better Use for Oil than Gasoline!



Professor Mark Foster and Family (Univ. of Akron Polymer Science Department) with all their oil-based polymer belongings! -- Nat. Geog. June 2004

The ENERGY REVOLUTION (The Terawatt Challenge)





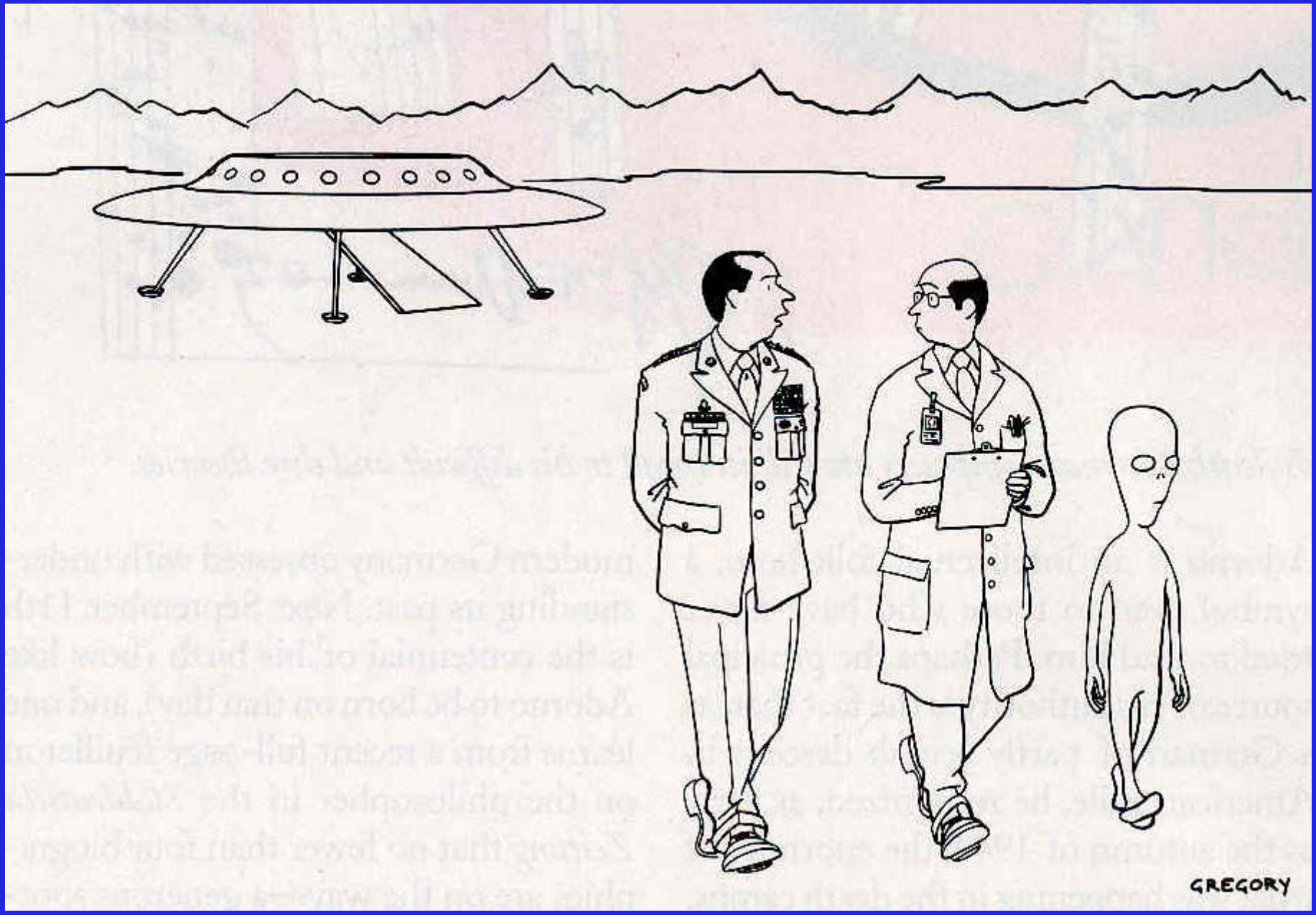
Energy:

The Basis of Prosperity

20st Century = OIL

21st Century = ??

All I’m saying is **now** is the time to develop the technology to deflect an asteroid.



"This galaxy he's from---ask him if it's got oil."

WEEKLY WORLD
NEWS
April 15, 2003

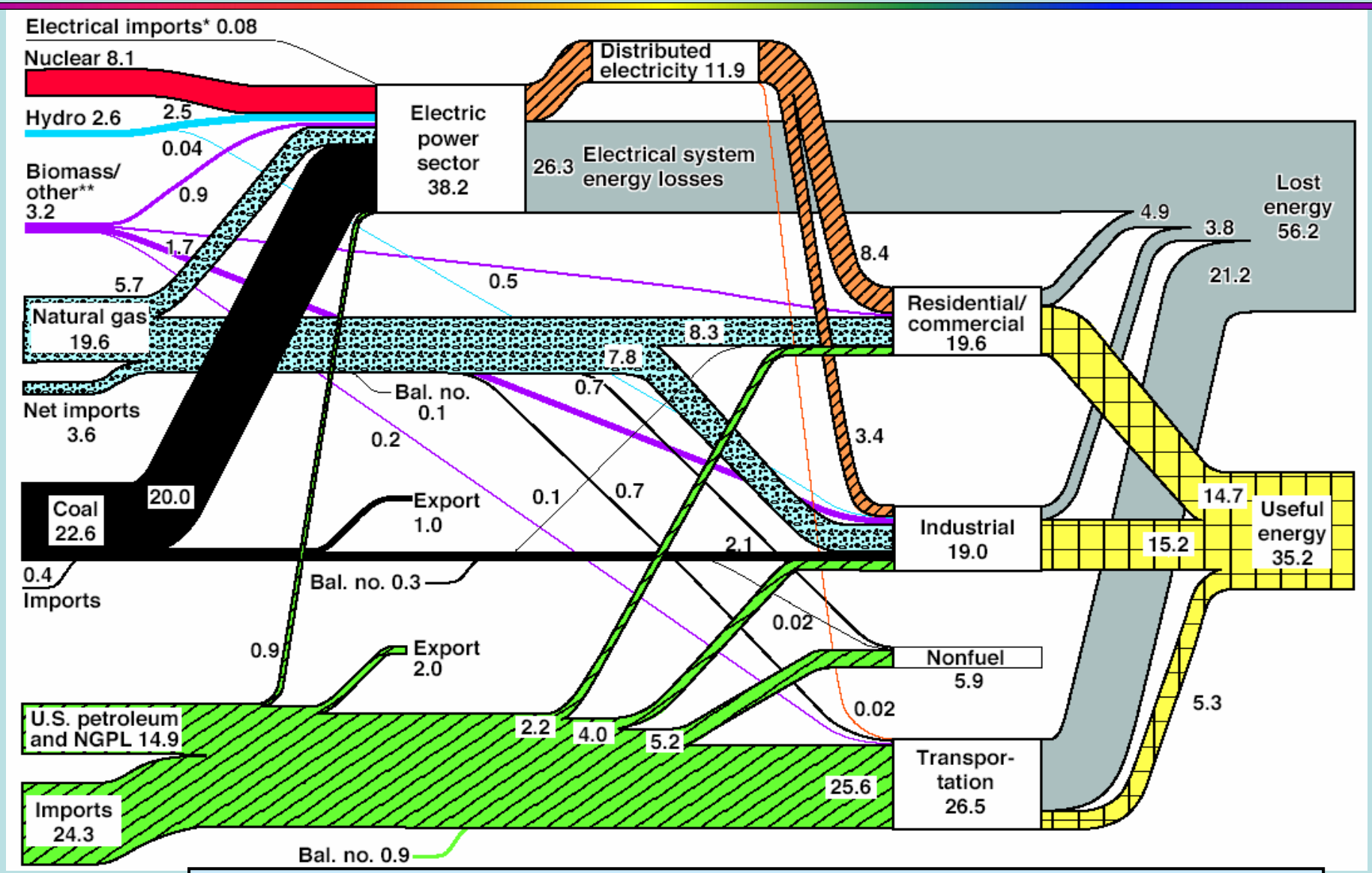
DOUBLE ISSUE!

Teen buys nuke off the Internet!

OIL FOUND ON MOON!

Gas prices will fall to 10¢ a gallon as Arab oil becomes obsolete!

U.S. Energy Flow, 2002 (Quads)



- 39% of primary energy goes toward electricity generation; 69% of that is lost energy.
- 80% of energy used in the transportation sector is lost energy.
- Overall, 58% of primary energy is lost energy.

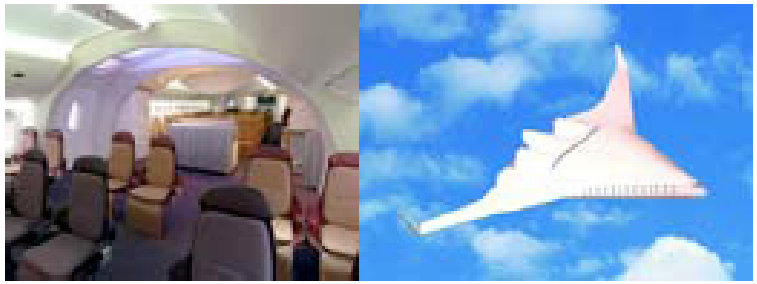
June 2004
Lawrence Livermore National Laboratory
http://eed.llnl.gov/flow

www.rmi.org

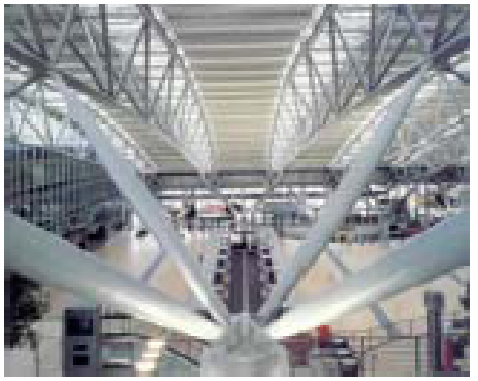
The future is already here: today's concept vehicle approaches will be tomorrow's mainstream …

CARS: save 69% at 57¢/gal

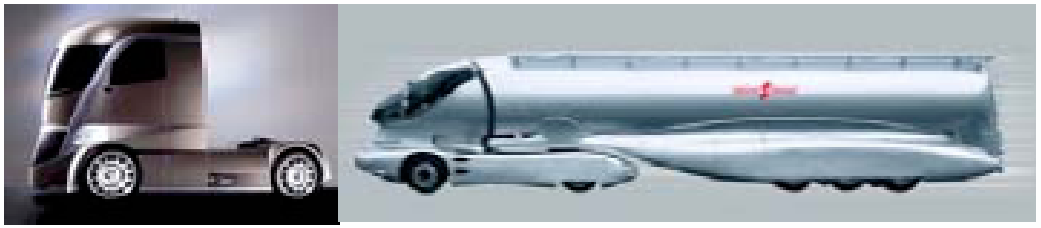
PLANES: save 20% free (*7E7*), 45% @ 46¢/gal



BLDGS/IND: big, cheap savings; often *lower* capex

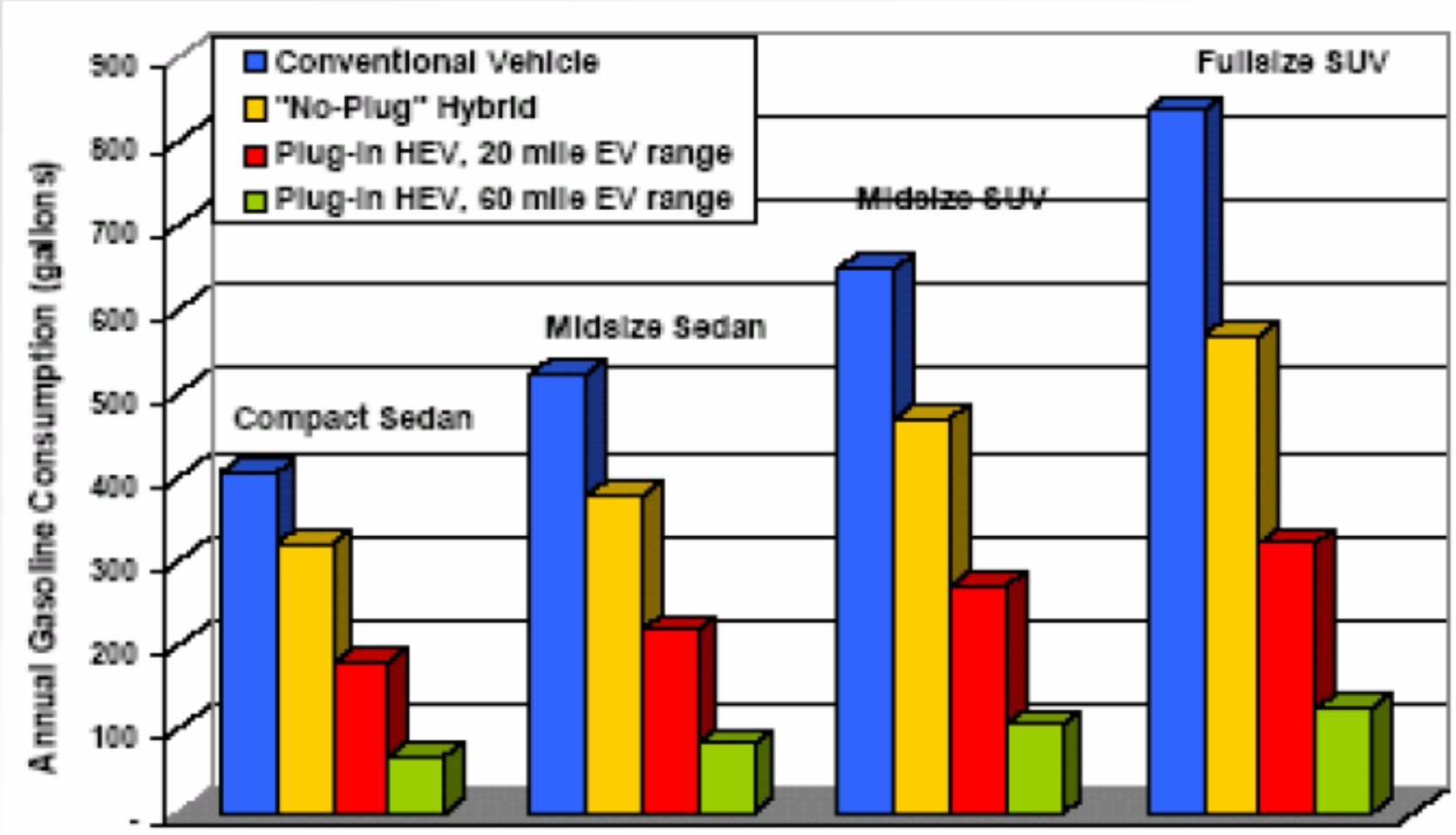


TRUCKS: save 65% @ 25¢/gal

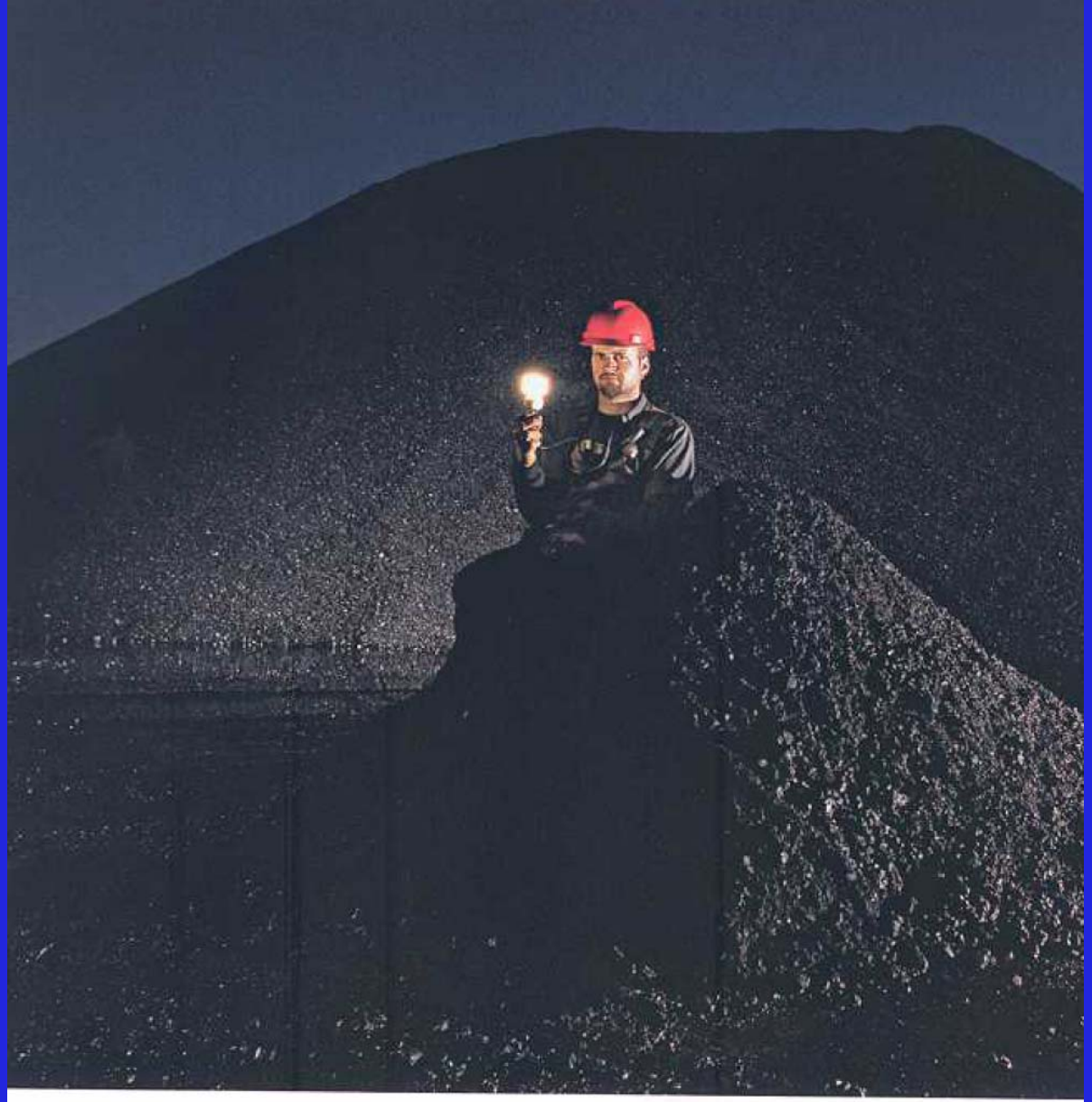


Technology is improving faster for efficient end-use than for energy supply

Greatly reduced annual gasoline consumption



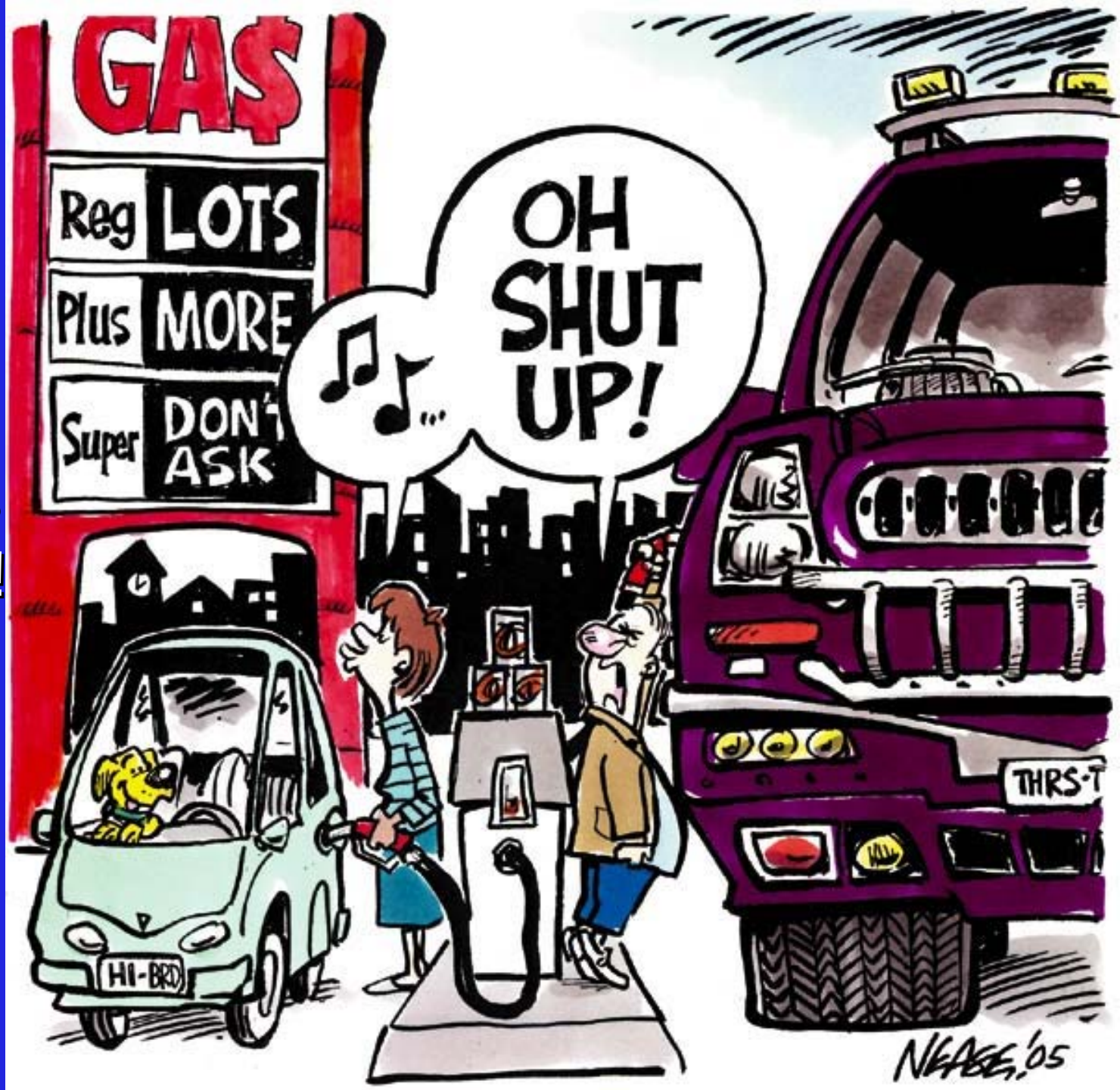
Compare the fuel consumption of a PHEV full size SUV to that of a conventional compact sedan!



Small efficiencies matter!

National Geographic August 2005

Big efficiencies matter, too!



Boeing 787

Going in the right direction –

Efficiency and economy

By MARGOT ROOSEVELT

Over the Columbia

River on a high desert ridge, the world's largest wind farm sprawls across 50 sq. mi. of Oregon and Washington. When the last of its 460 turbines are installed this post modern power plant will offer clean electricity to 70,000 homes and businesses. Every month hundreds of tourists come to gawk at its fiber-glass blades, twirling with balletic grace atop 160-ft. poles. "People are

The Winds of Change

Since fossil fuels are heating up the earth, the race is on to develop coo

in awe of wind power," says Anne Walsh, community relations manager of the State line Energy Center.

And guess what? Wind is becoming more than a quixotic sideshow. It's now the world's fastest growing power source: a high-tech challenge to the coal mines, oil rigs, nuclear reactors and hydroelectric dams that seem, well, so 20th century. Experts say wind could provide up to 12% of the earth's electricity within two decades.

RESPONSIBLE CARE: FOCUS ON SUSTAINABLE DEVELOPMENT

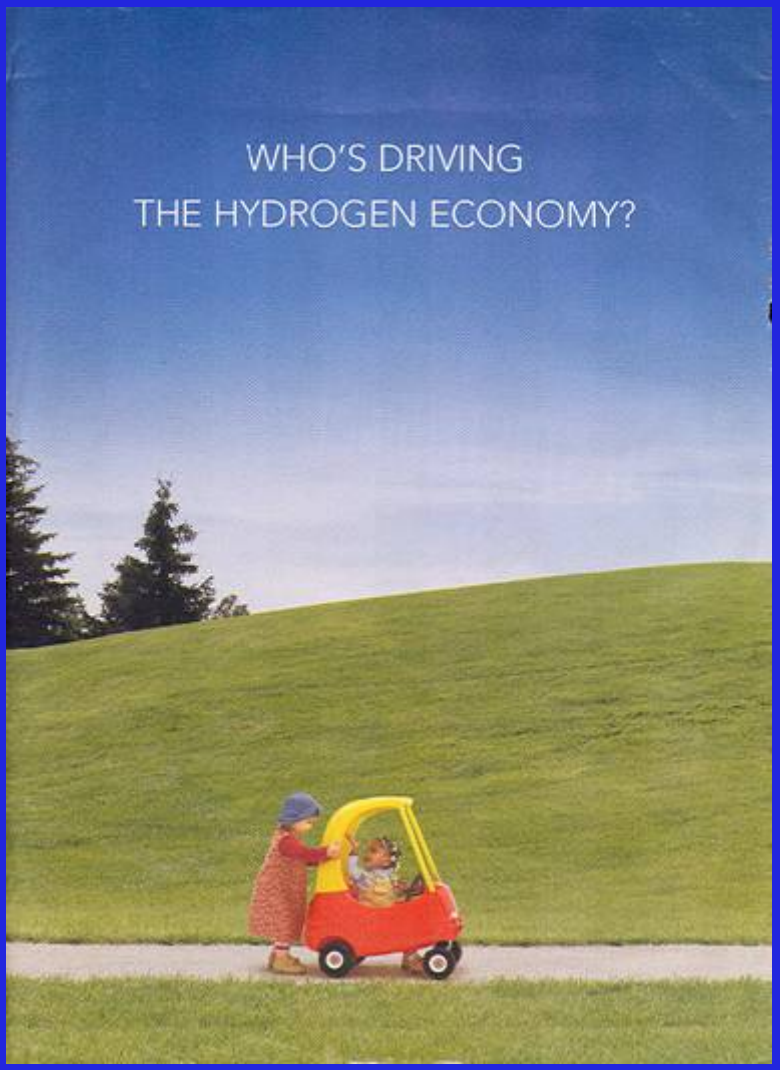
CHEMICAL & Engineering News

SEPTEMBER 3, 2001

NUCLEAR POWER

Energy angst may resurrect controversial industry

Hydrogen – Not a Primary Fuel



PRIMARY ENERGY SOURCES
Alternatives to Oil

TOO LITTLE

- **Conservation / Efficiency -- not enough**
- **Hydroelectric -- not enough**
- **Biomass -- not enough**
- **Wind -- not enough**
- **Wave & Tide -- not enough**

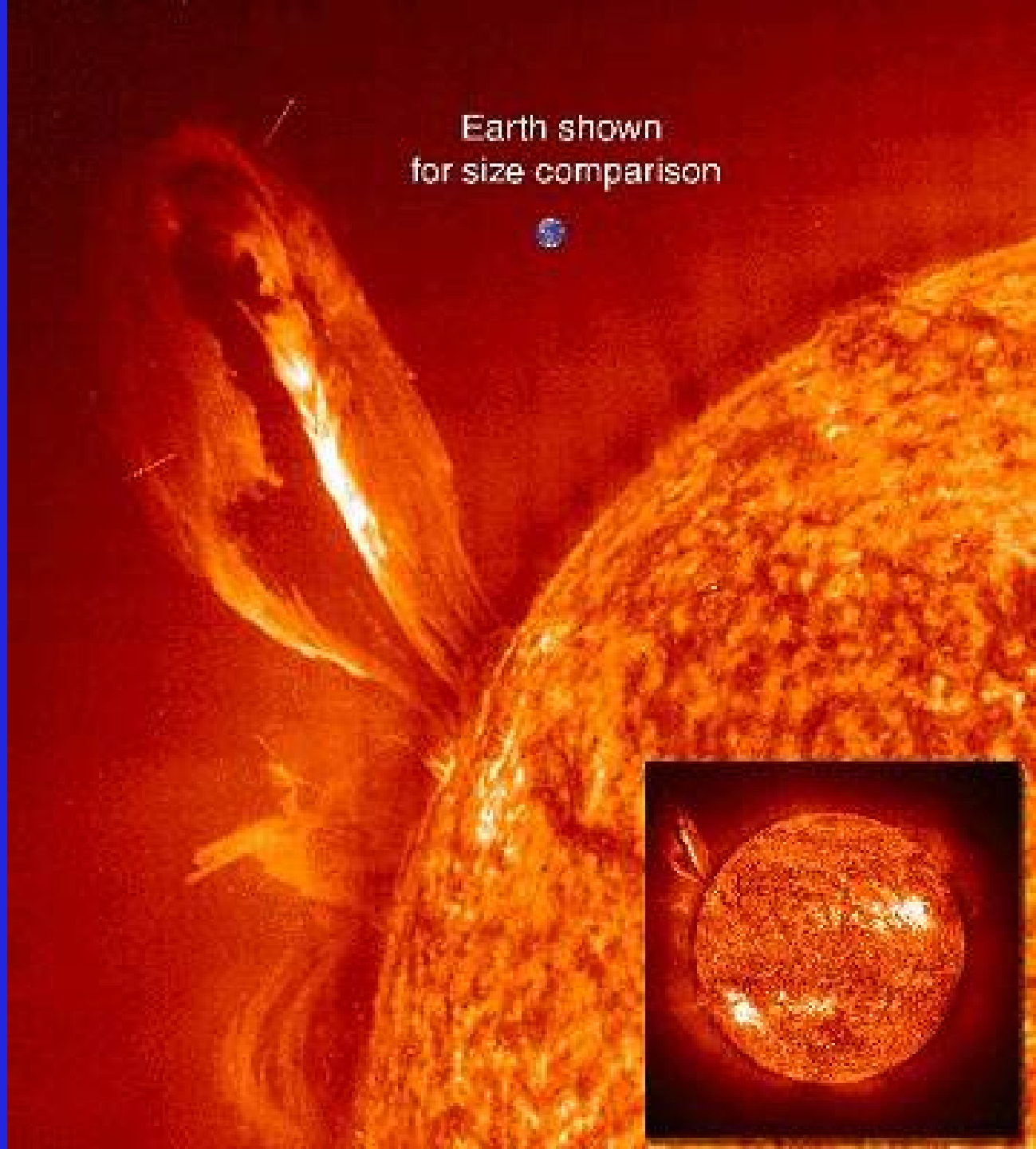
CHEMICAL

- **Natural Gas -- sequestration?, cost?**
- **Gas Hydrates -- sequestration?, cost?**
- **Clean Coal -- sequestration?, cost?**

NUCLEAR

- **Nuclear Fission -- radioactive waste?, terrorism?, cost?**
- **Nuclear Fusion -- too difficult?, cost?**
- **Geothermal HDR -- cost ? , enough?**
- **Solar terrestrial -- cost ?**
- **Solar power satellites -- cost ?**
- **Lunar Solar Power -- cost ?**

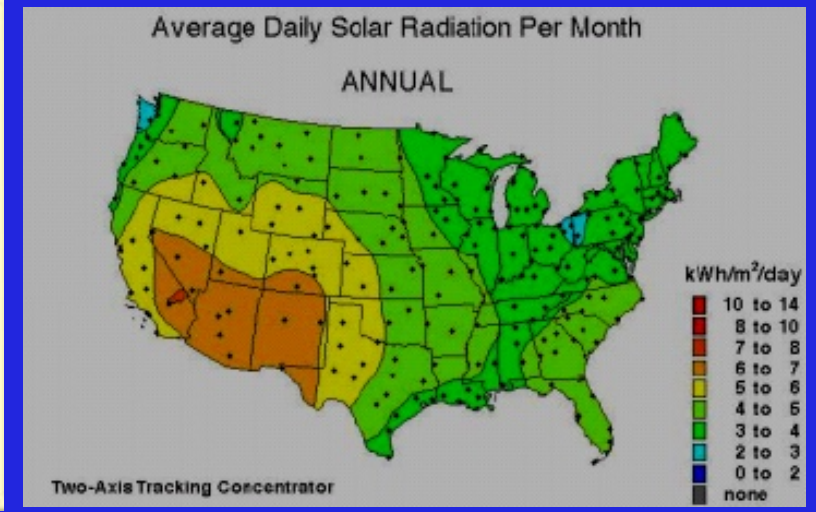
165,000 TW of sunlight hit the earth every day

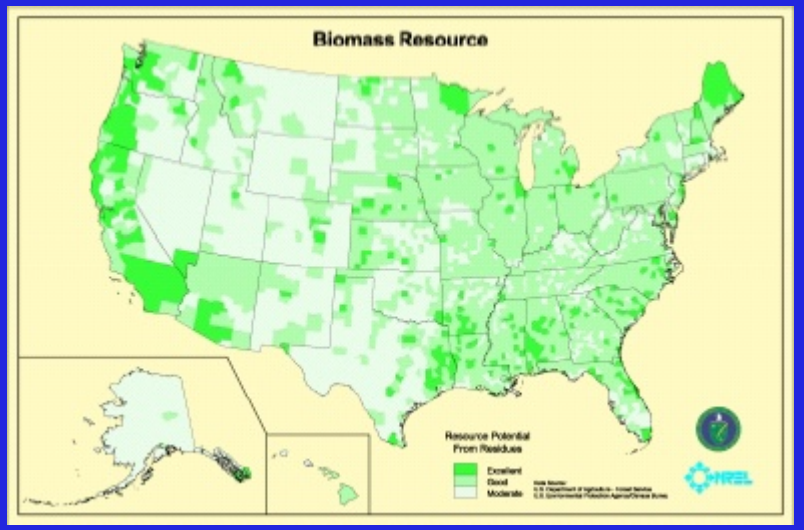


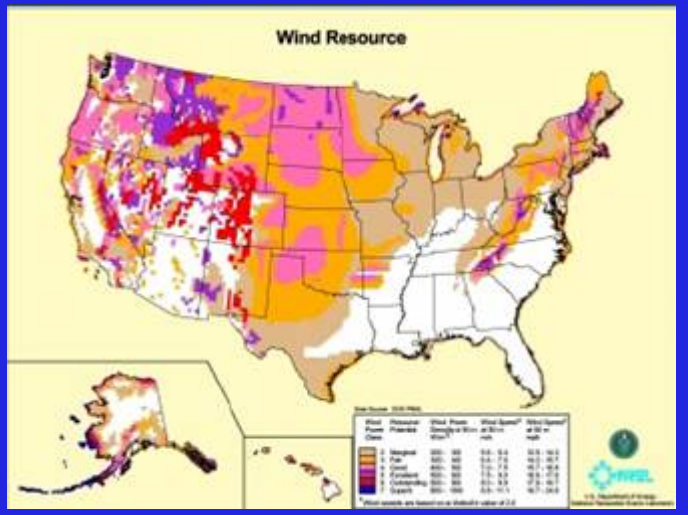
PV Land Area Requirements

Renewable Resource Maps

Renewable sources generally remote from major population centers



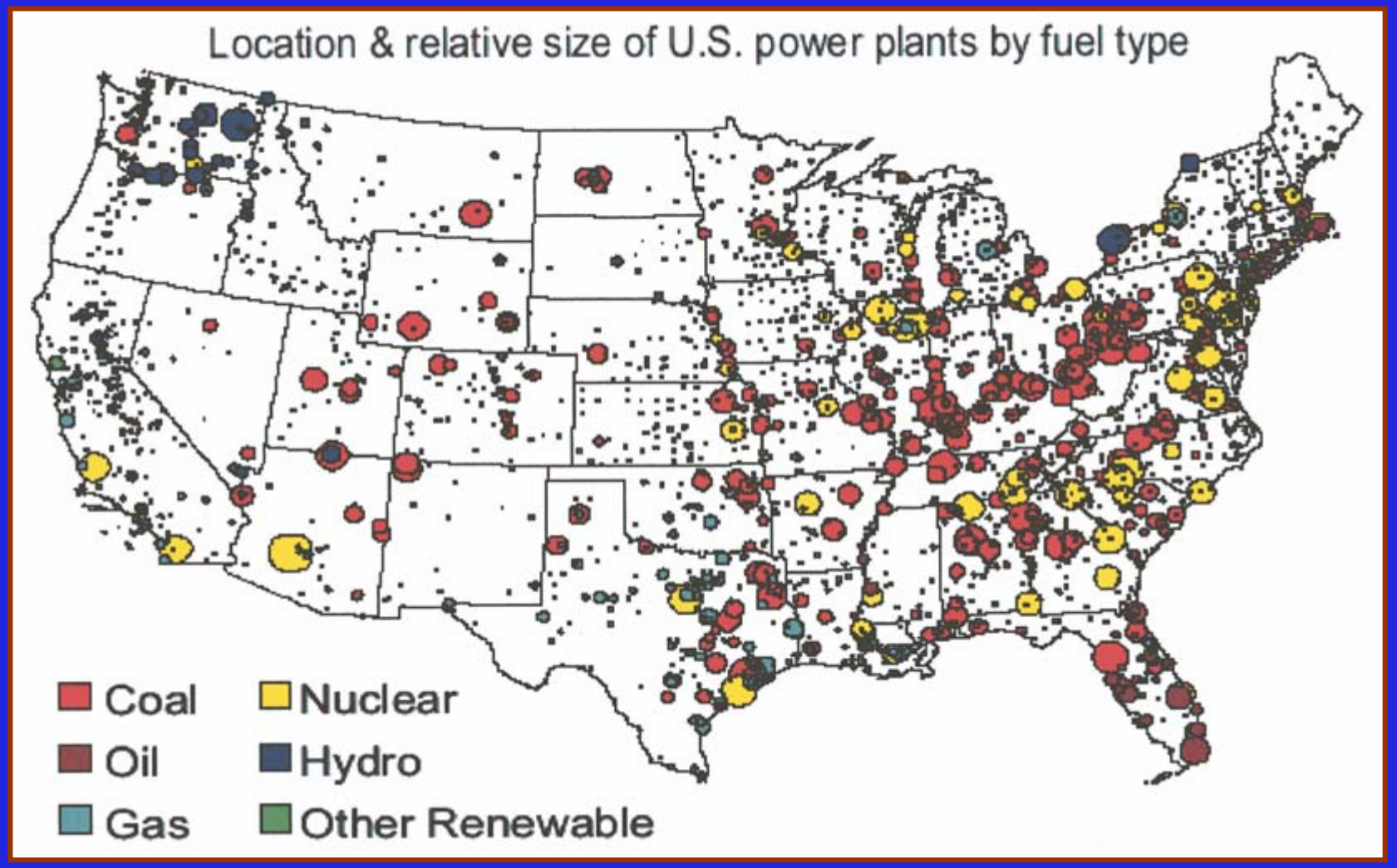




Source: NREL

US Power Production Map

Currently, power is generated close to population centers



Source: DOE & Nate Lewis, Caltech

The Blackout from Space

Hoax Photo!!

But it does nicely outline the black-out area!

Energy Nanotech Grand Challenges

from Meeting at Rice University May 2003
Report available!

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

Energy Nanotech Grand Challenges

8. Nanoelectronics to revolutionize computers, sensors and devices.

9. Nanoelectronics based Robotics with AI to enable construction maintenance of solar structures in space and on the moon; and to enable nuclear reactor maintenance and fuel reprocessing.

10. Super-strong, light weight materials to drop cost to LEO, GEO, and later the moon by > 100 x, to enable huge but low cost light harvesting structures in space; and to improve efficiency of cars, planes, etc.

11. Thermochemical processes with catalysts to generate H_2 from water that work efficiently at temperatures lower than 900 C.

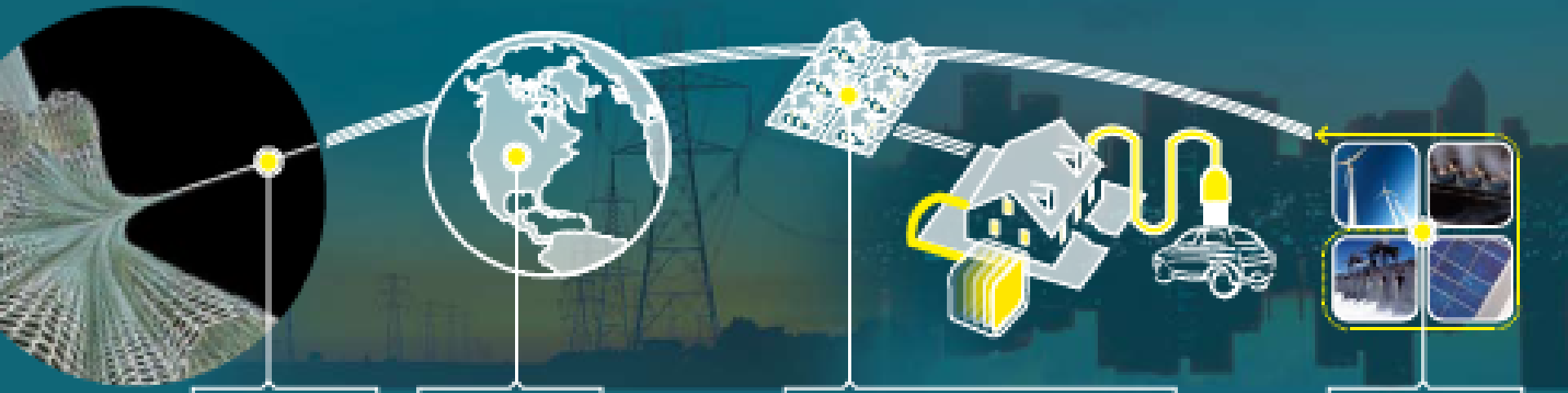
12. Nanotech lighting to replace incandescent and fluorescent lights

13. NanoMaterials/ coatings that will enable vastly lower cost of deep drilling, to enable HDR (hot dry rock) geothermal heat mining.

14. CO_2 mineralization schemes that can work on a vast scale, hopefully starting from basalt and having no waste streams.

The Distributed Storage-Generation Grid:
One World Energy Scheme for 2050

Energy will be transported as electricity over wire, rather than by transport of mass (coal, oil, gas)



Single Walled Carbon Nanotube (SWNT) fibres are spun into **quantum wires**, to re-wire the grid.

Vast electrical power grid
- Continental scale
- Interconnect asynchronous "local" storage and generation sites
- System continually innovated by free enterprise

"Local"
- House, block, community, business, town, ...
- Local storage: batteries, flywheels, hydrogen fuel cells, supercapacitors, etc.
- Local optimization: days of storage capacity, quality of local power

Local generation
- Solar, geothermal, wind, etc.
- "Buy low, sell high" to electrical power grid

THE BENEFITS OF THE QUANTUM WIRE:

Expected Features
- 10x Copper Conductivity
- 6x Lighter
- Stronger Than Steel
- Zero Thermal Expansion

Key Grid Benefits
- Reduced Power Loss
- Low-to-No Sag
- Lightweight
- Higher Current-Carrying Capacity

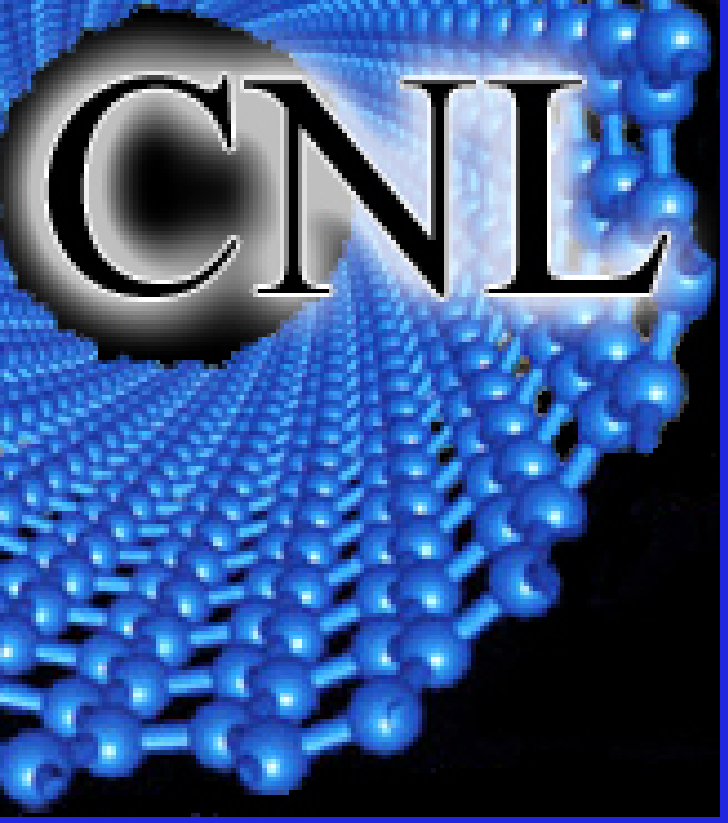
SWNT Technology Benefits
- Type Specific
- High Purity
- Low Cost
- Scalable Processing

THE WORLD OF THE GRID:

Global grid
- Robust
- Massive primary power input to grid via HV DC lines.
- New input from vast solar farms in deserts, wind, NIMBY nuclear, clean coal, stranded gas, wave, hydro, biomass, space-based solar... "Everybody Plays"
- Ethanol / Methanol / Hydrogen are transportation fuels
- Transition technology – Plug-In Hybrids

Rick Smalley's vision of a global energy network.

RICE UNIVERSITY



Carbon Nanotechnology Laboratory

Making Buckytubes
"Be All They Can Be"

Founded by Rick Smalley in 2003 as a division of CNST
Coordinates SWNT Research with 10 Faculty in 6 Departments

Prof. James M. Tour – Director
Prof. Matteo Pasquali – Co-Director
Dr. Howard K. Schmidt - Executive Director
Dr. Robert H. Hauge - Technology Director

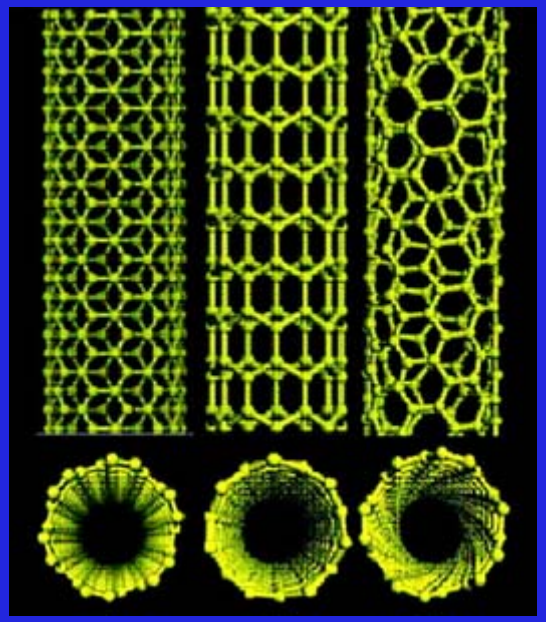
RICE

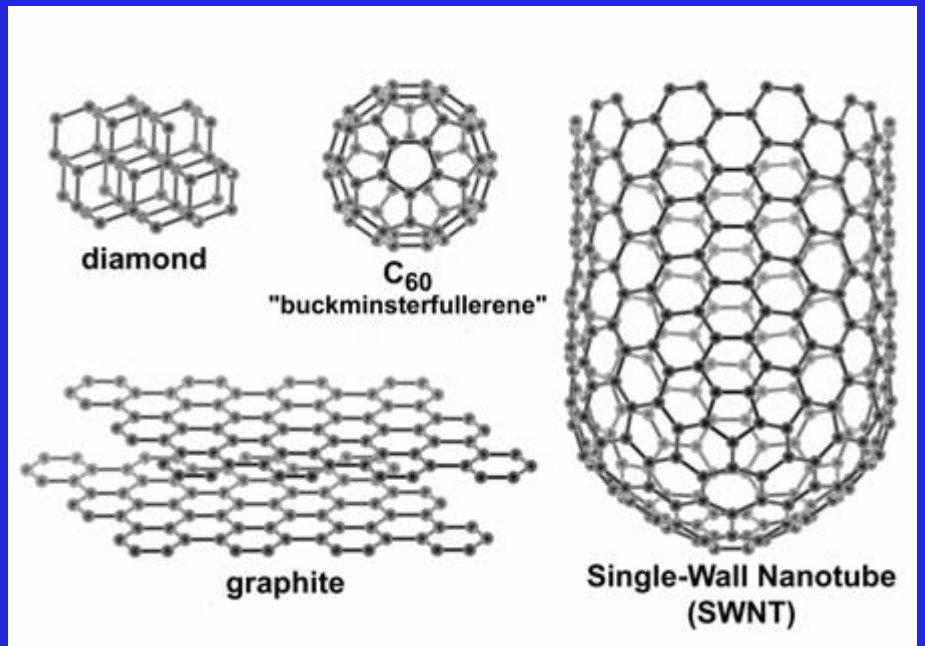
Smalley Institute

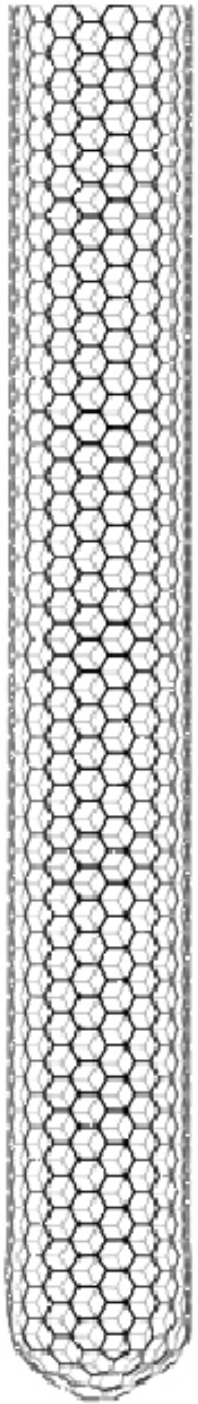
Why Single Wall Carbon Nanotubes?

MOLECULAR PERFECTION & EXTREME PERFORMANCE

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

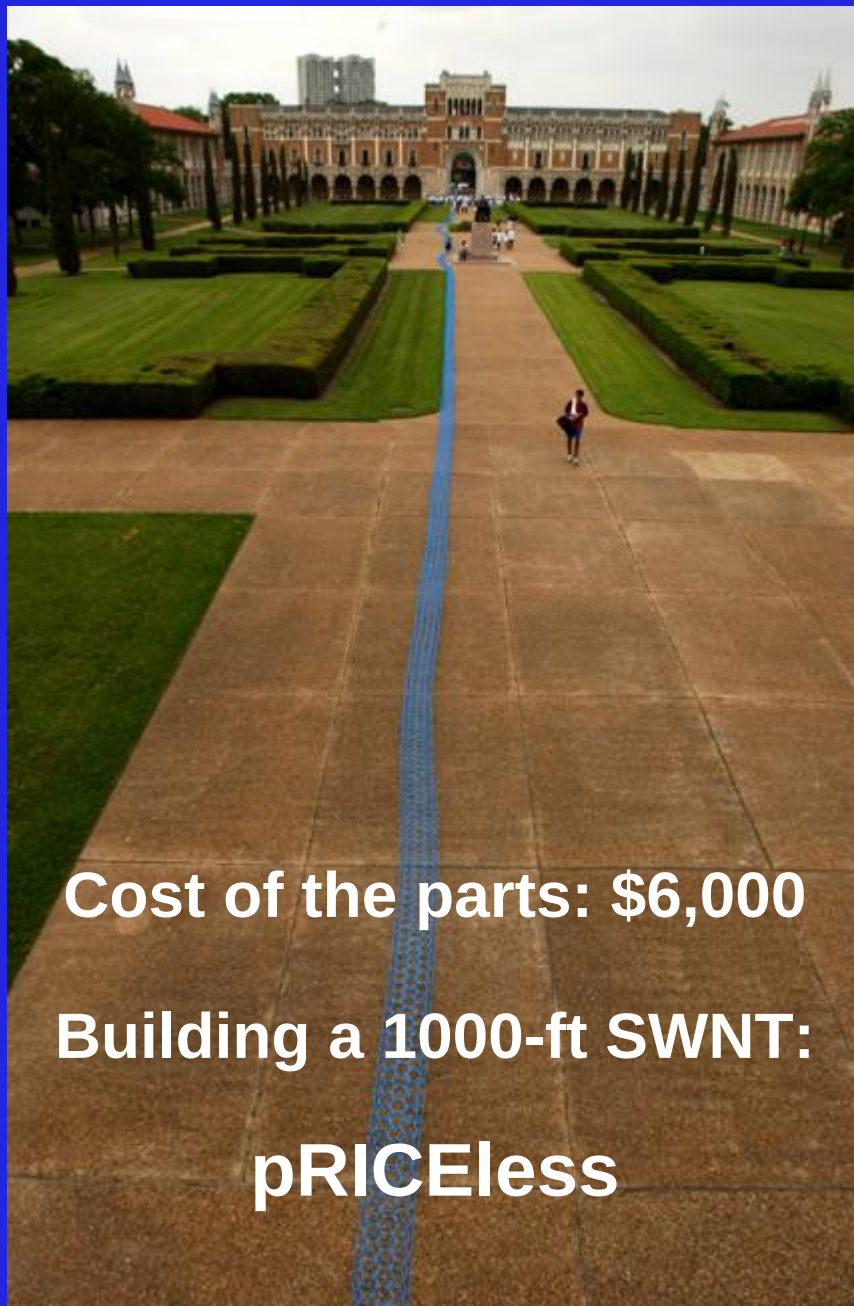






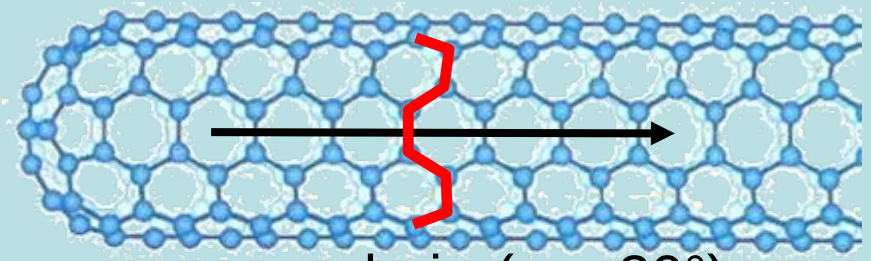
OUTREACH: BUILDING A GIANT NANOTUBE!

- World's largest SWNT model
  (22 April 2005, Guinness world record)
- Model of a 5-5 SWNT
- ~65,000 pieces
- 360 m long, 0.36 m wide
- about 80 builders
- over 1000 in attendance
- "Supremely Silly" (from Rick Smalley)

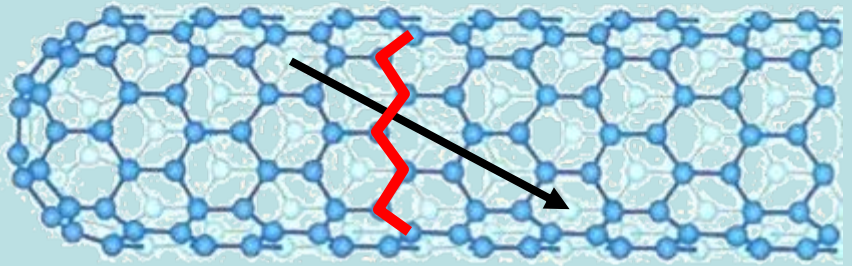


Types of SWNT

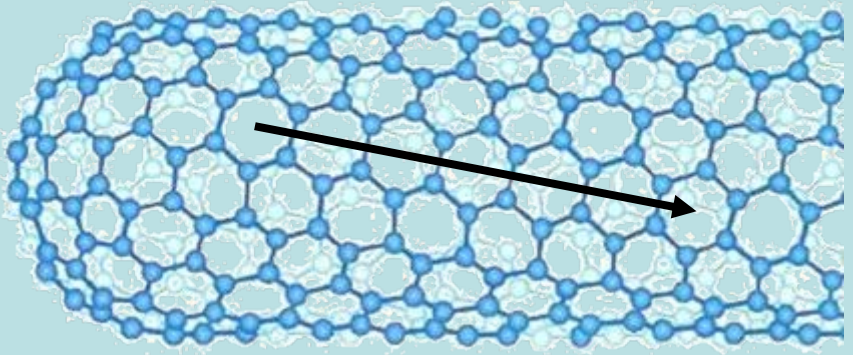
- Cylindrical graphene sheet
- Diameters of 0.7 – 3.0 nm
  - Observed tubes typically < 2 nm
- Both metallic and semi-conductor species possible
- Length to diameter ratio as large as 10^4 – 10^5
  - can be considered 1-D nanostructures



armchair ($\alpha = 30°$)



zigzag ($\alpha = 0°$)



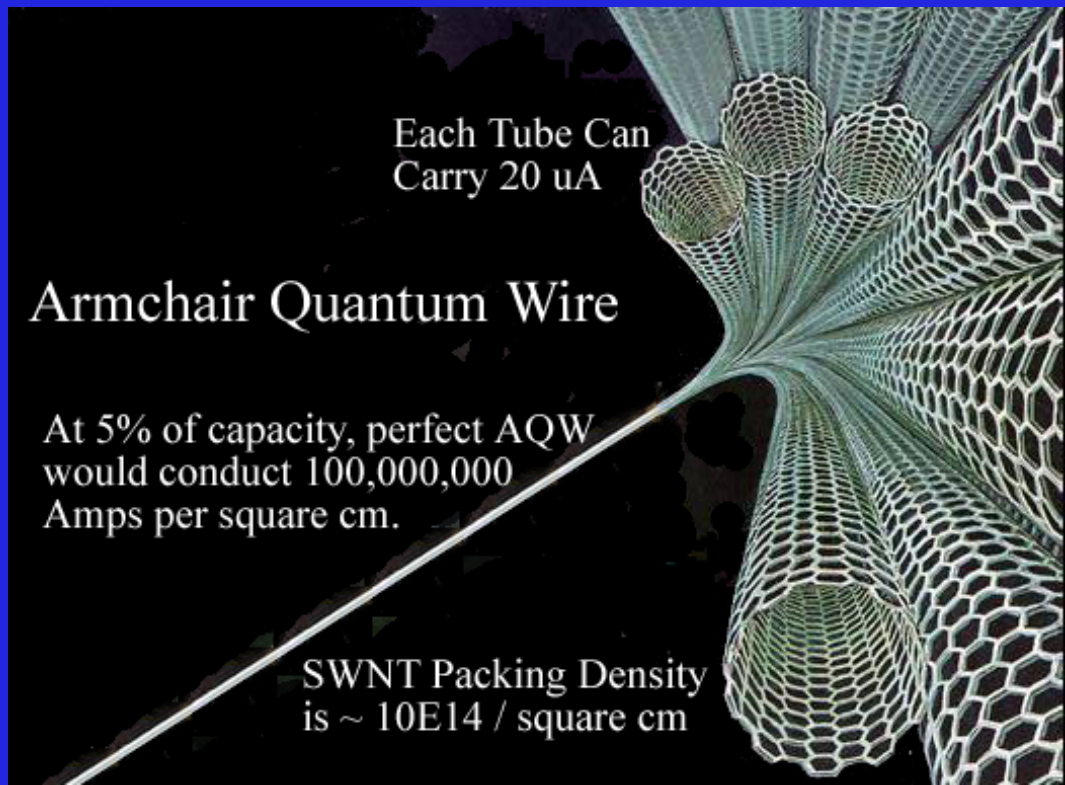
intermediate ($0 < \alpha < 30°$)

SWNT Quantum Wire

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

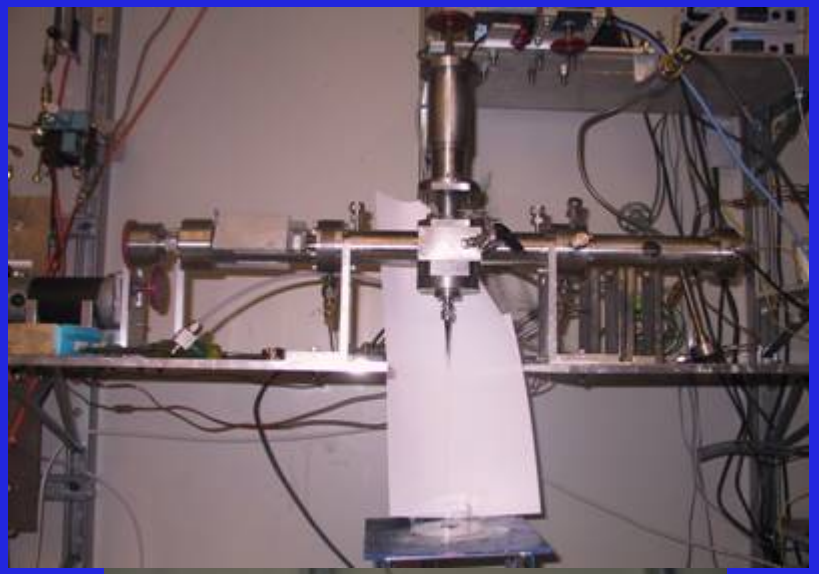
Key Grid Benefits
- Reduced Power Loss
- Low-to-No Sag
- Reduced Mass
- Higher Power Density

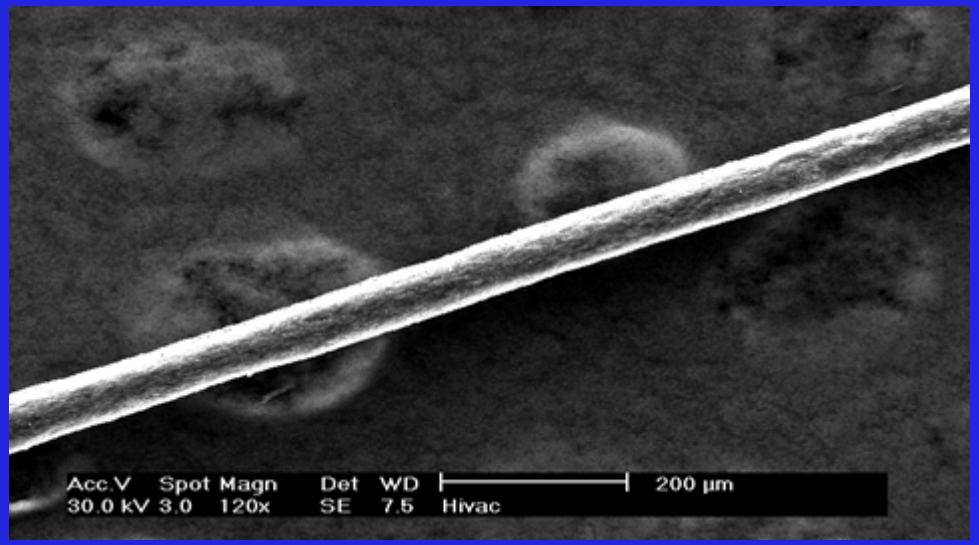
SWNT Technology Benefits
- Type & Class Specific
- Higher Purity
- Lower Cost
- Polymer Dispersible



Prototype Wire - SWNT Fibers

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





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

NASA Success Stories

High Pressure CO (HiPCO) Process

CNL, April 26th, 2005 – NASA Announces new $16M Graduate and University Research Centers – Quantum Wire

Tuesday, Actively building new collaborations to fund this Critical research program!!!

Roadblocks

- Vision without funding is hallucination.
  - Da Hsuan Feng – UT Dallas
- Vision without hardware is delusion.
  - Lockheed engineer

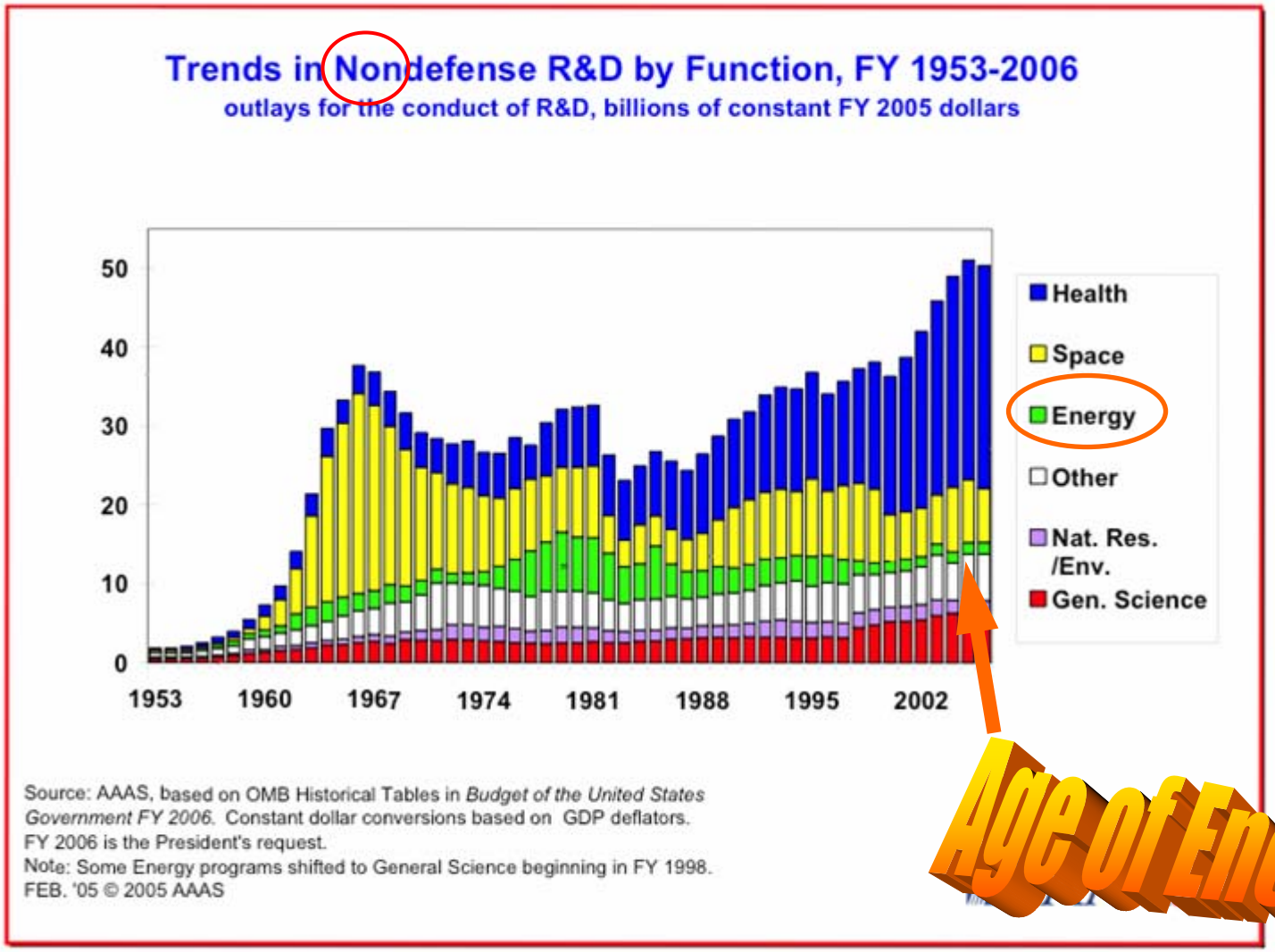
The biggest single challenge for the next few decades:

ENERGY

for 10^{10} people

- **At MINIMUM we need 10 Terawatts (150 M BOE/day) from some new clean energy source by 2050**
- **For worldwide energy prosperity and peace we need it to be cheap.**
- **We simply can not do this with current technology.**
- **We need Boys and Girls to enter Physical Science and Engineering as they did after Sputnik.**
- **Inspire in them a sense of MISSION (BE A SCIENTIST --- SAVE THE WORLD)**
- **We need a bold new APOLLO PROGRAM to find the NEW ENERGY TECHNOLOGY**

From the age of Space to the age of Medicine



New Energy Research Program
(Smalley's Nickel & Dime Solution)

- **For FY06-FY10 collect 5 cents from every gallon of oil product**
  Invest the resultant > $10 Billion per year as additional funding in frontier energy research distributed among DOE, NSF, NIST, NASA, and DoD.

- **For the next 10 years collect 10 cents from every gallon;**
  invest the >$20 Billion per year in frontier energy research.

- **Devote a third of this money to New Energy Research Centers**
  located adjacent to major US Research Universities, especially Zip Code 77005.

- **At worst this endeavor will create a cornucopia of new technologies and new industries.**

- **At best, we will solve the energy problem before 2020,**
  and thereby lay the basis for energy prosperity & peace worldwide.

We Know We Have to do this: Revolutionize Energy

WHAT ARE WE WAITING FOR?

- An Energy Crisis ?
- A Global Warming Disaster?
- A New Administration?
- An Asian Technology Boom?

(or)

consensus in the S&T establishment, DoD, IC, State Dept.

and

POLITICAL LEADERSHIP

Leadership

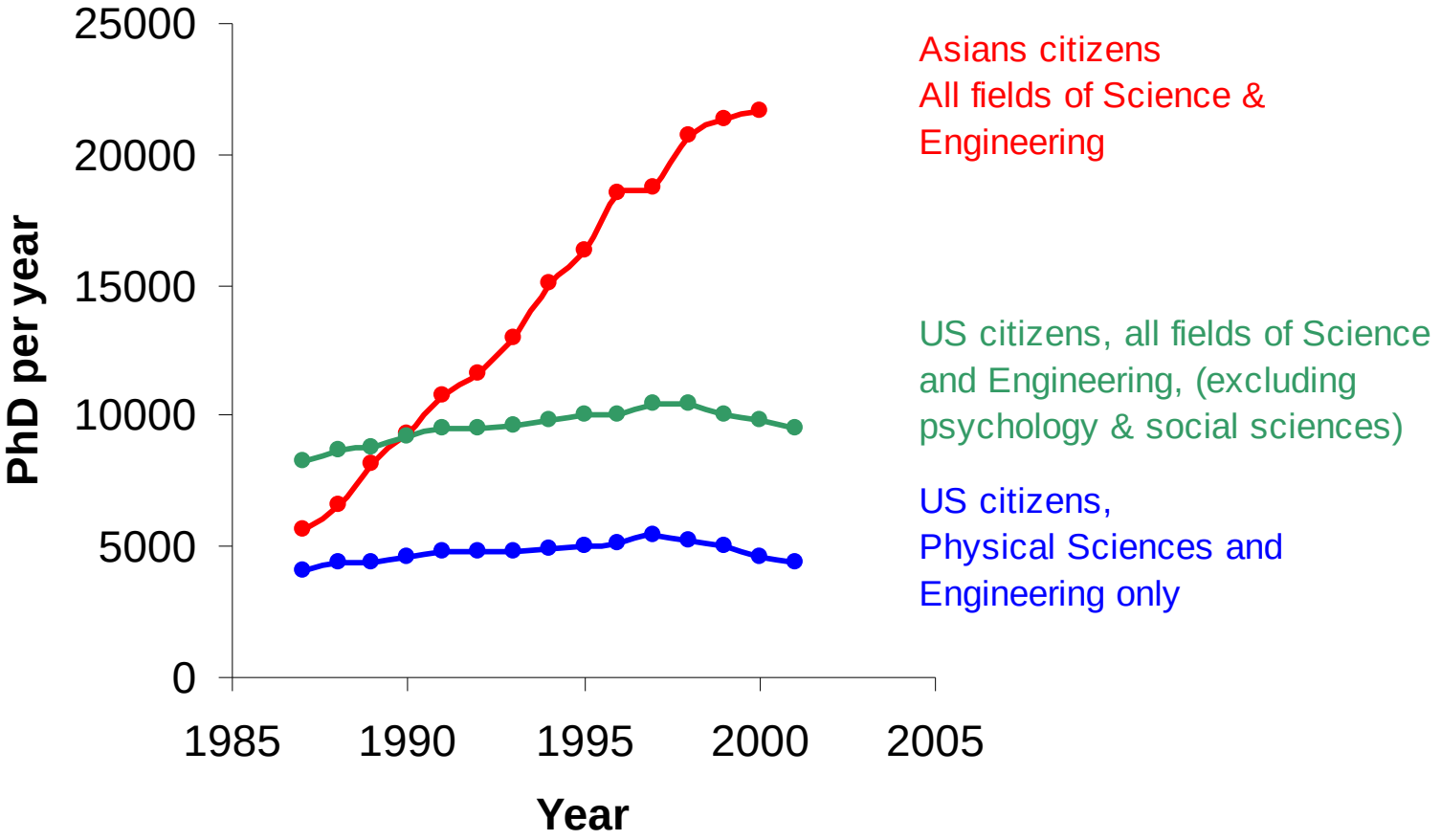
- President Bush – State of the Union Address – Jan 31, 2006
  - "America is addicted to oil"
  - Replace oil imports from Middle East by 75% by 2025
- DOE Advanced Energy Initiative 22% increase in clean energy research
  - Zero emission coal
  - Solar and wind
  - Clean, safe nuclear
  - Batteries, Hydrogen, ethanol

- A BIG change from the 2001 Cheney Energy Report – drill our way to independence!

But…

- Are these ideas tough or aggressive enough?
- NO!
  - Biofuels budget actually smaller than in FY06
  - No market signal for more efficient vehicles
    - Fuel economy standards – regulatory
      - 40 mpg in 10 years saves 2.5M BOE/day
    - Substantial gas tax – market mechanism
- Up to Congress to execute programs
  - Incentives for alternate fuel production/vehicles
  - Funding for research initiatives

PhD Degrees in Science and Engineering



Source: Science and Engineering Indicators, National Science Board, 2002

By 2012, if current trends continue,
over 90% of all physical scientists and engineers in the world will be Asians working in Asia.

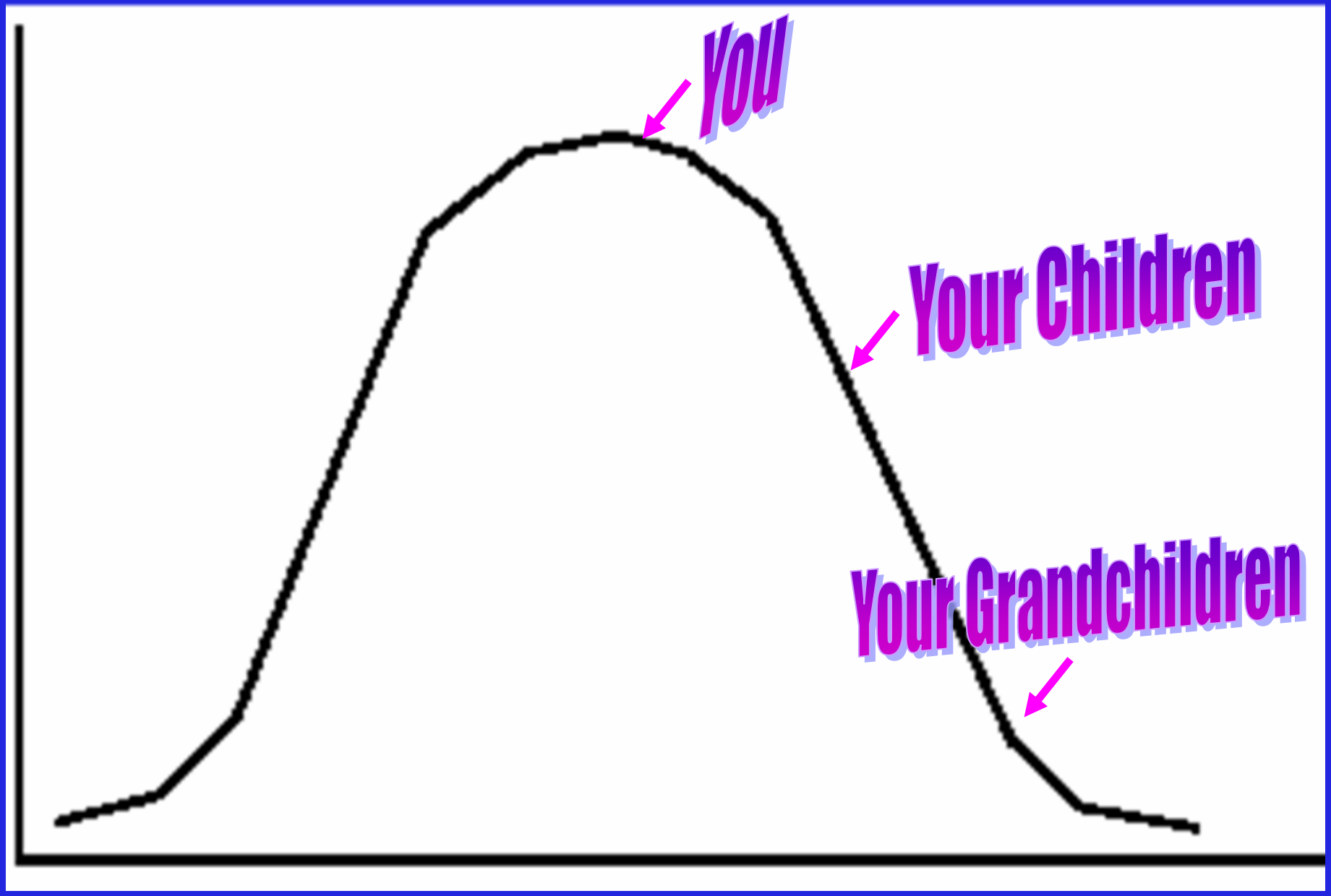
Education

- American Competitiveness Initiative
  - Double physical sciences research funding in ten years (including nanotech, supercomputing, alternative energy sources)
  - Permanent R&D Tax Credit
  - HS Math/Science teacher training (70,000) and add 30,000 M&S professional teachers
- YEA!
  - But will Congress fund the initiatives?
  - And will they sustain the funding??

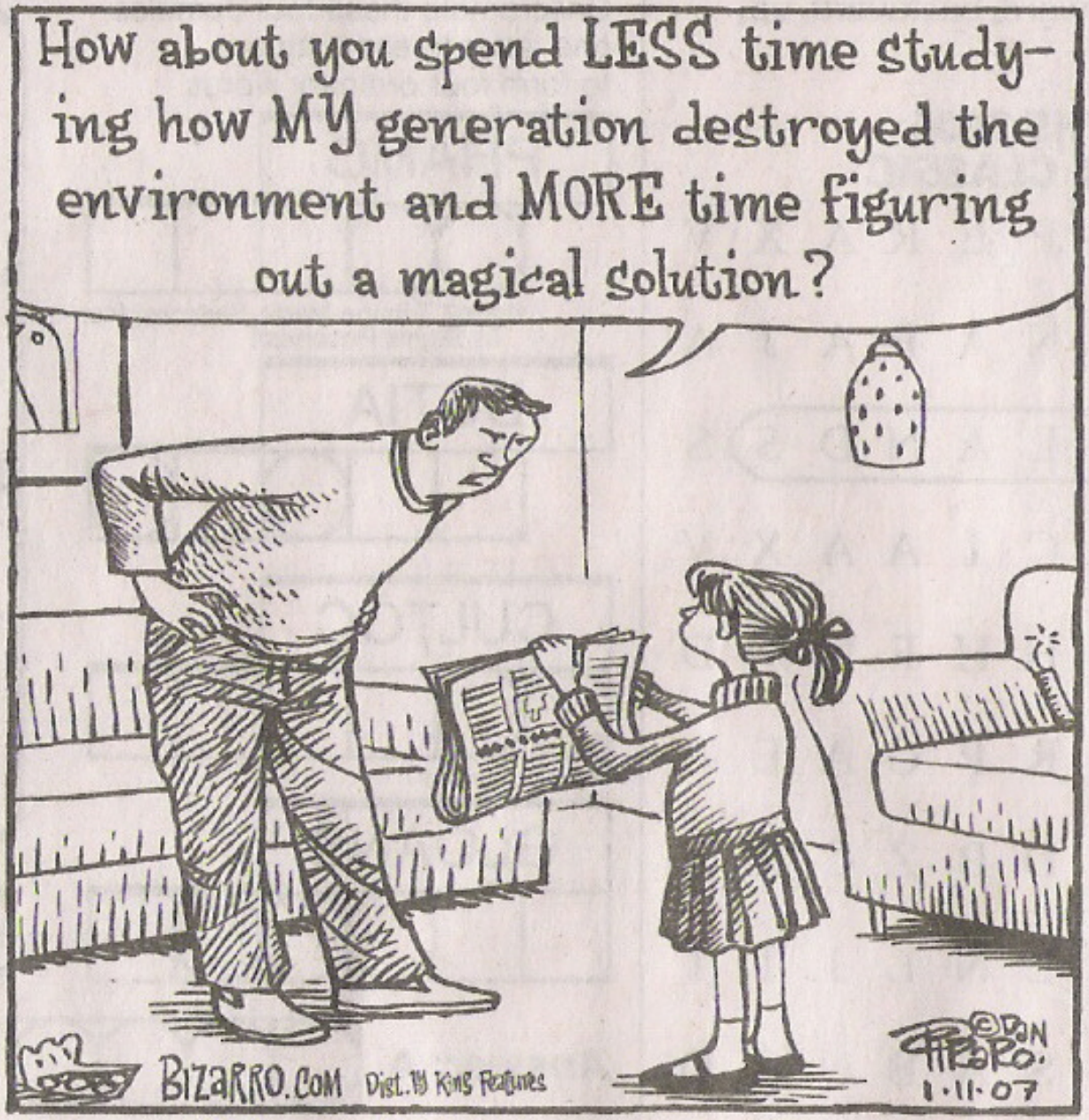
Rick Smalley with his favorite students: anyone, any age!!

www.rmi.org

Why should you care enough to act?


You
Your Children
Your Grandchildren

Bizarro


How about you spend LESS time studying how MY generation destroyed the environment and MORE time figuring out a magical solution?
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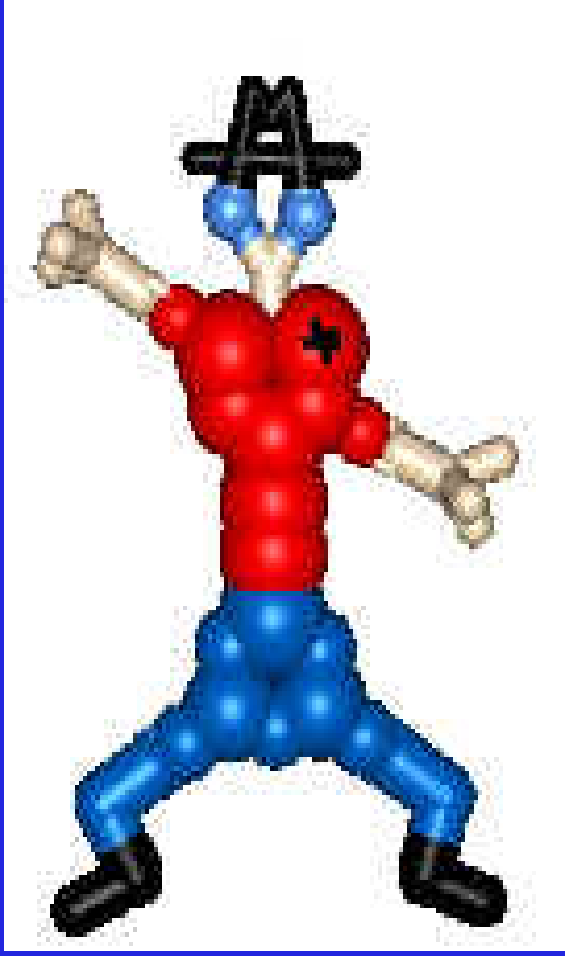
What Can **YOU** Do Now?



- **Learn as much as possible about energy**
- **Learn as much as possible about nanotechnology**

- **Encourage kids to study science and engineering!!**

Reading Assignments

- Twilight in the Desert, Matthew R. Simmons
- Winning the Oil Endgame, Amory Lovins
- Beyond Oil: The View from Hubbert's Peak, Kenneth S. Deffeyes
- Out of Gas, Daniel Goodstein
- The End of Oil, Paul Roberts
- The Prize, Daniel Yergin
- Hubbert's Peak, Kenneth S. Deffeyes
- The Hydrogen Economy, Jeremy Rifkin
- Twenty Hydrogen Myths, Amory Lovins (www.rmi.org)
- Matt Simmons, web site: (www.simmons-intl.com)
- M.I. Hoffert et. al., *Science*, **2002**, 298, 981,
- DOE BES Workshop Report on Hydrogen (www.sc.doe.org/bes/hydrogen.pdf)
- State of the Future, (www.stateofthefuture.org)
- Nanotechnology and Energy, 2003 Report, (www.nano.rice.edu)
- National Nanotechnology Program, (www.nano.gov)


BE A SCIENTIST -- SAVE THE WORLD


BE AN ENGINEER -- SAVE THE WORLD