Great Works For The 21st Century:
A Critical Role for the Modern Research University




BA257
David Levine
October 19th, 2004

Dean A. Richard Newton
Tom Kalil

Berkeley

The United Nations 2015 Millenium Development Goals

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability

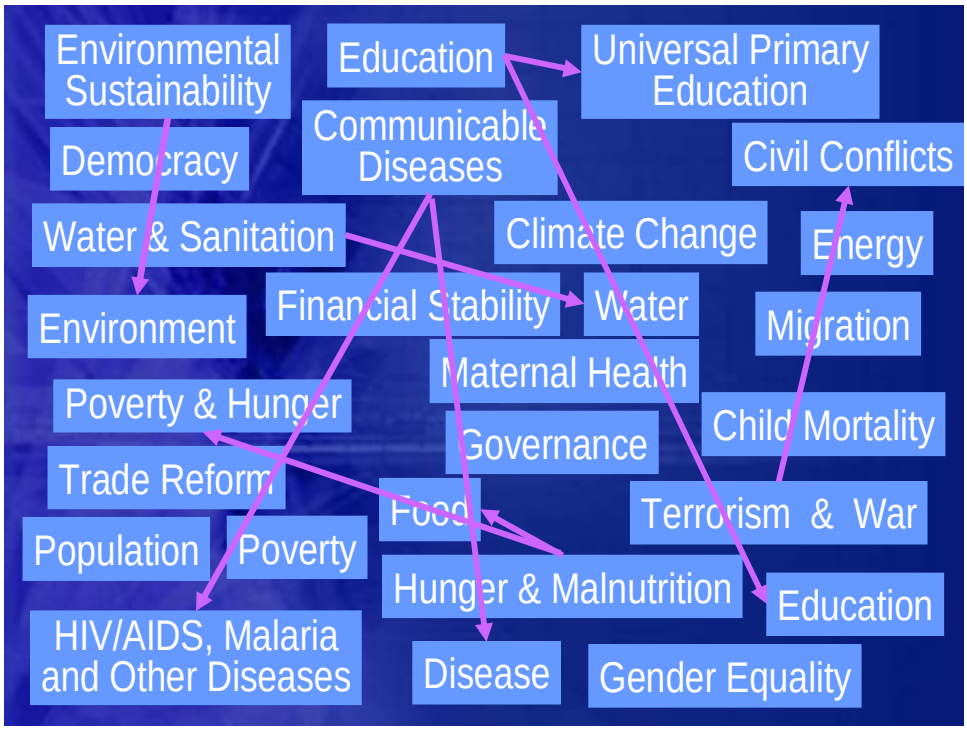
The Copenhagen Consesus
Ten Great Global Challenges

- Civil Conflicts
- Climate Change
- Communicable Diseases
- Education
- Financial Stability
- Governance
- Hunger & Malnutrition
- Migration
- Trade Reform
- Water & Sanitation

Professor Richard Smalley
Ten Great Global Challenges

- Energy
- Water
- Food
- Environment
- Poverty
- Terrorism & War
- Disease
- Education
- Democracy
- Population


Environmental Sustainability
Education
Universal Primary Education
Democracy
Communicable Diseases
Civil Conflicts
Water & Sanitation
Climate Change
Energy
Environment
Financial Stability
Water
Migration
Maternal Health
Poverty & Hunger
Child Mortality
Governance
Trade Reform
Food
Terrorism & War
Population
Poverty
Hunger & Malnutrition
Education
HIV/AIDS, Malaria and Other Diseases
Disease
Gender Equality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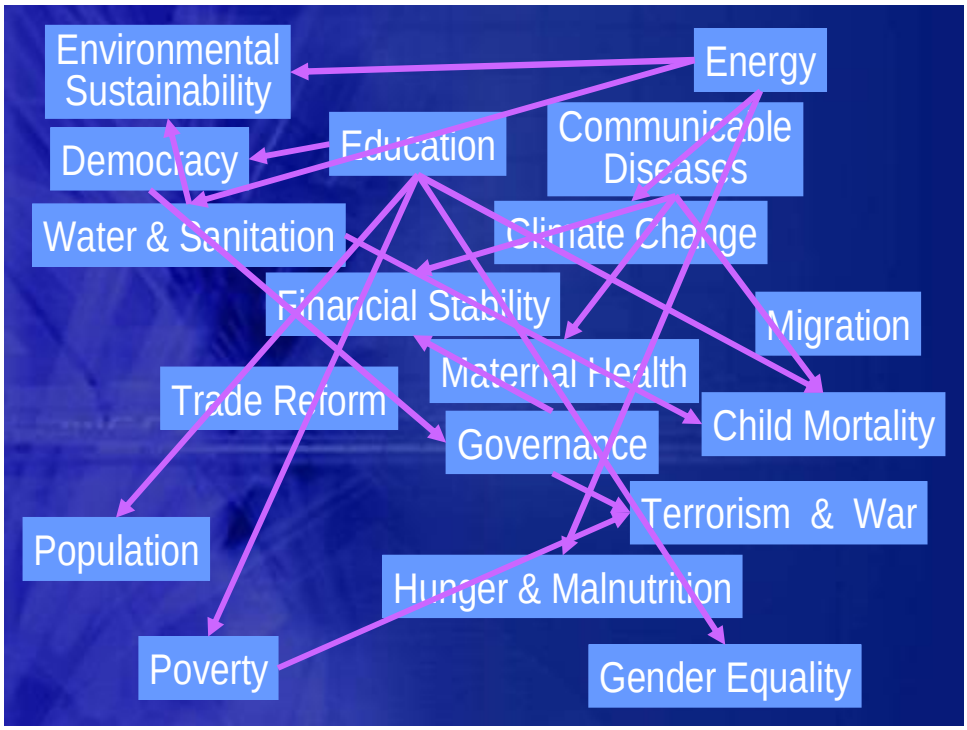
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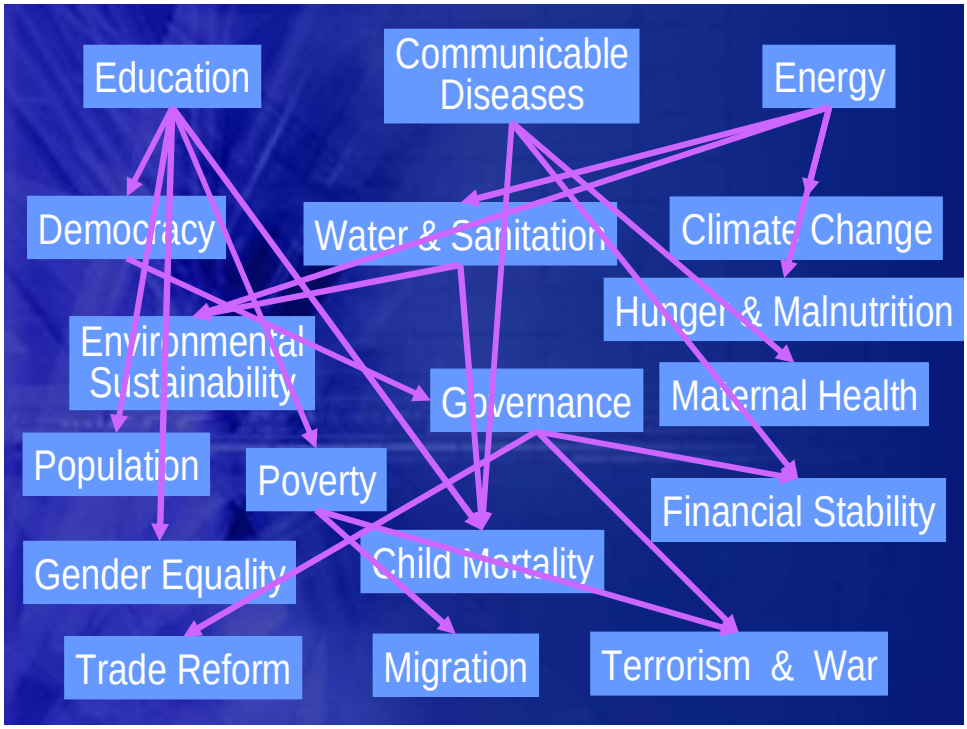
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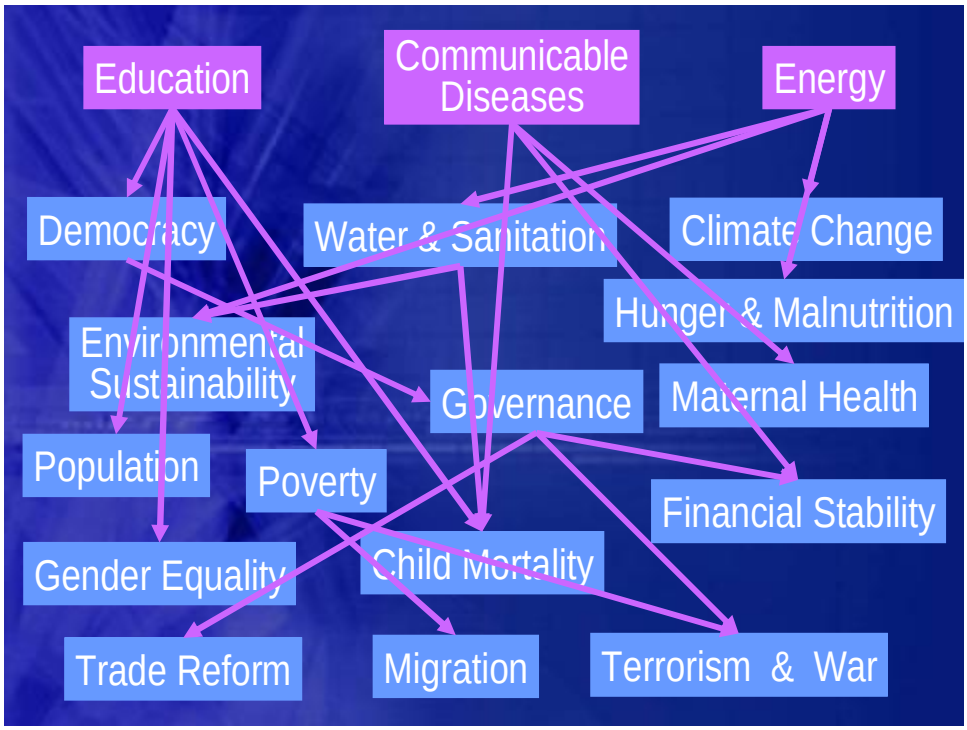
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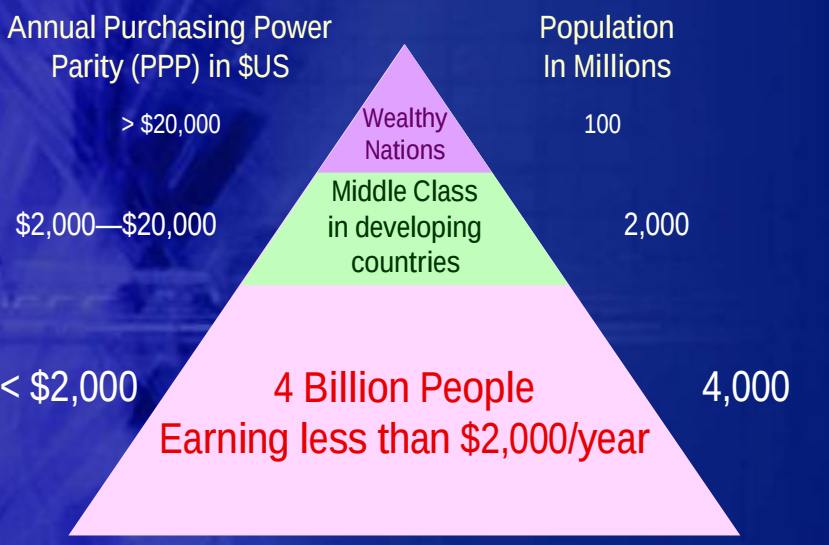
Great Works as an Organizing Principal

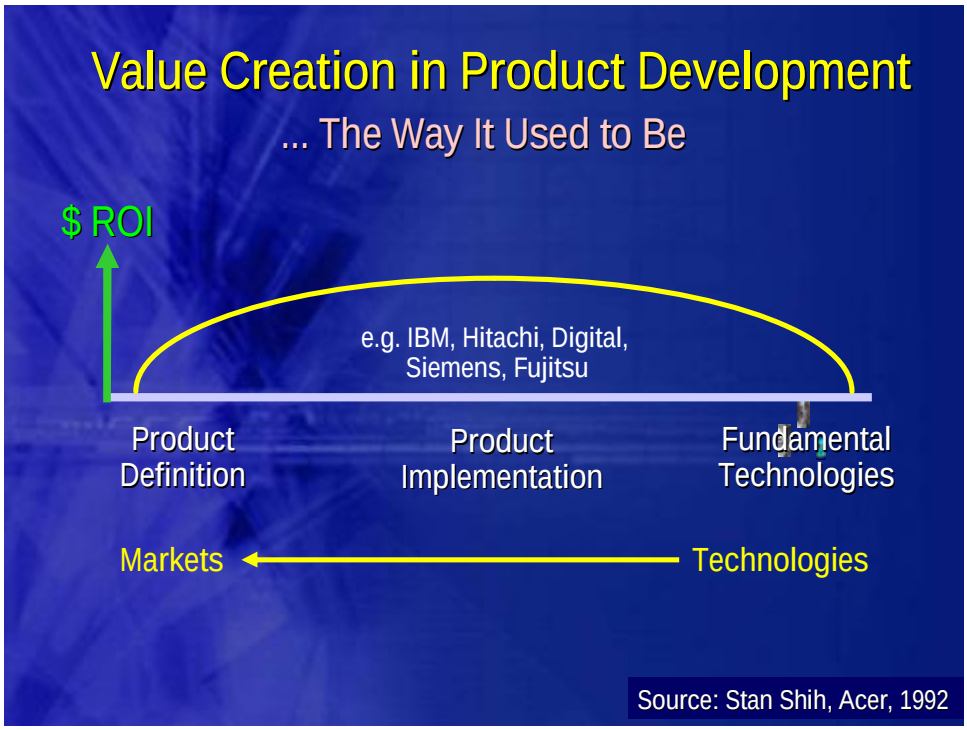
- "Use Inspired Basic Research" as a Framework for Implementation
  - Energy—e.g. Nanoengineered solar cells
  - Education—e.g. ICT for the Developing World
  - Disease—e.g. Curing malaria with synthetic biology
- The Research University Network
  - Role as the "DMZ of Research"
  - Next Steps

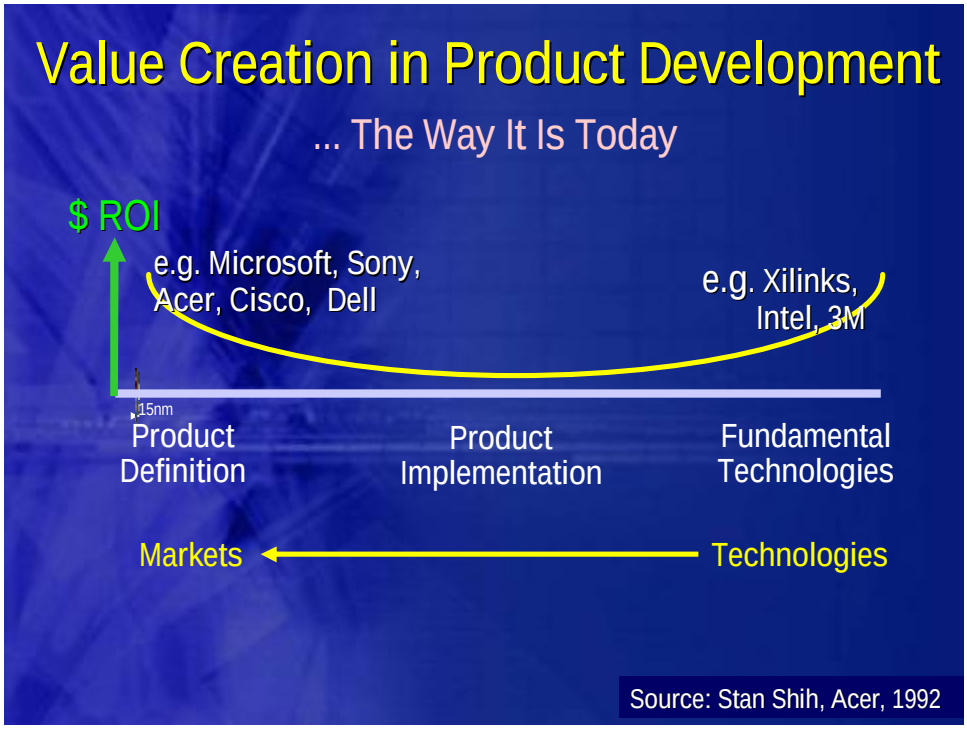
The Bottom of the Pyramid

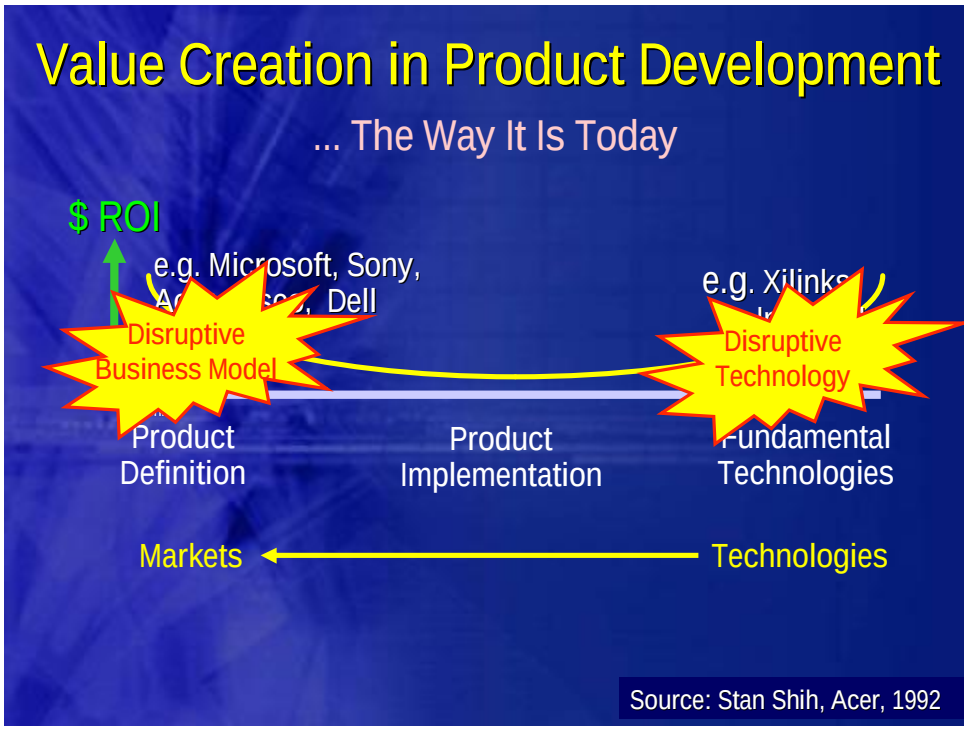


Source: Prahalad & Hammond, Harvard Business Review, Vol. 80, Issue 9 (Sep. 2002), pp48-58


The Bottom of the Pyramid
Annual Purchasing Power Parity (PPP) in $US
Population In Millions
> $20,000
Wealthy Nations
100
adjacent
We Can Build Large and Sustainable Businesses Based on These Markets
< $2,000
4,000
Earning less than $2,000/year
Source: Prahalad & Hammond, Harvard Business Review, Vol. 80, Issue 9 (Sep. 2002), pp48-58


Value Creation in Product Development
... The Way It Used to Be
$ ROI
e.g. IBM, Hitachi, Digital, Siemens, Fujitsu
Product Definition
Product Implementation
Fundamental Technologies
Markets
Technologies
Source: Stan Shih, Acer, 1992


Value Creation in Product Development
... The Way It Is Today
$ ROI
e.g. Microsoft, Sony, Acer, Cisco, Dell
e.g. Xilinks, Intel, 3M
15nm
Product Definition
Product Implementation
Fundamental Technologies
Markets
Technologies
Source: Stan Shih, Acer, 1992


Value Creation in Product Development
... The Way It Is Today
$ ROI
e.g. Microsoft, Sony,
Disruptive Business Model
Disruptive Technology
Product Definition
Product Implementation
Technologies
Markets
Technologies
Source: Stan Shih, Acer, 1992

Great Works as an Organizing Principal

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  - Education—e.g. ICT for the Developing World
  - Disease—e.g. Curing malaria with synthetic biology
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  - Role as the "DMZ of Research"
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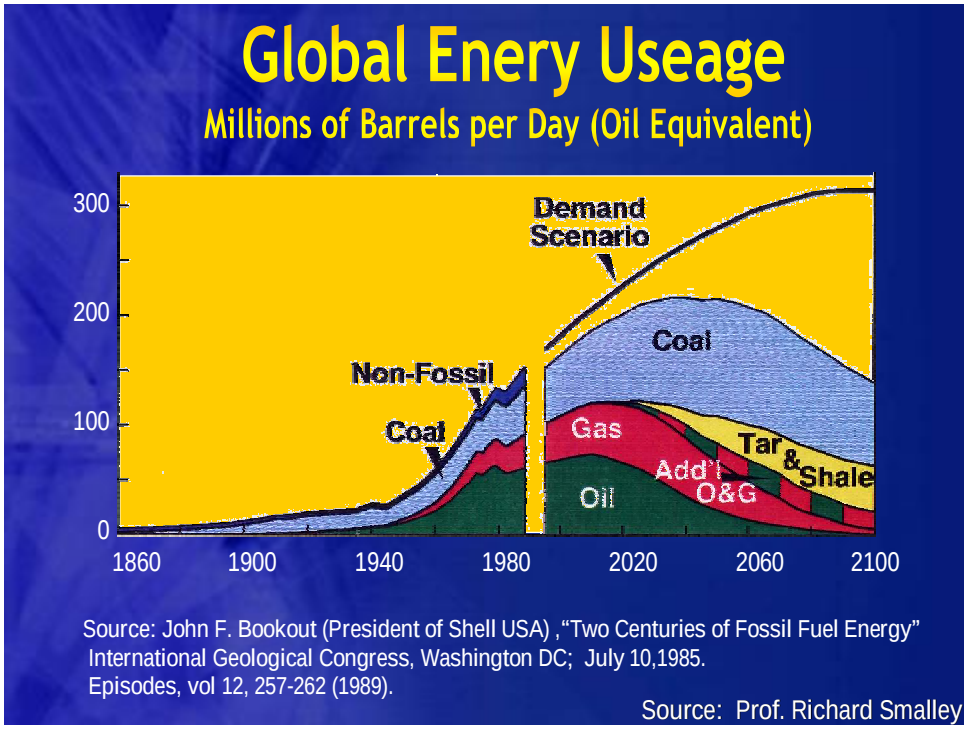
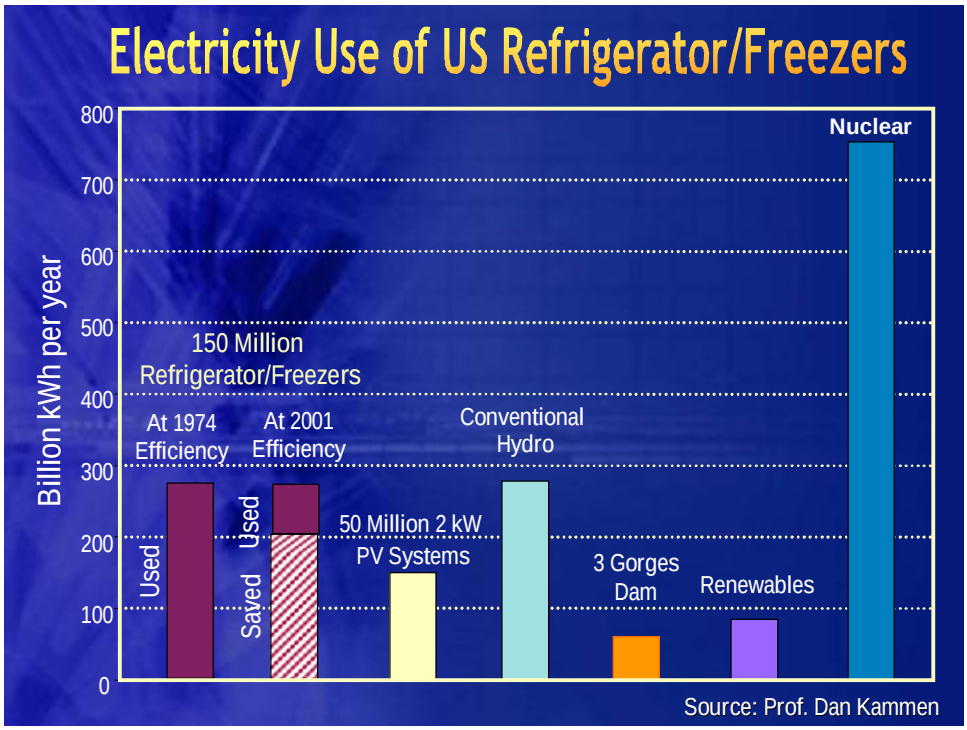
The Two Energy Philosophies

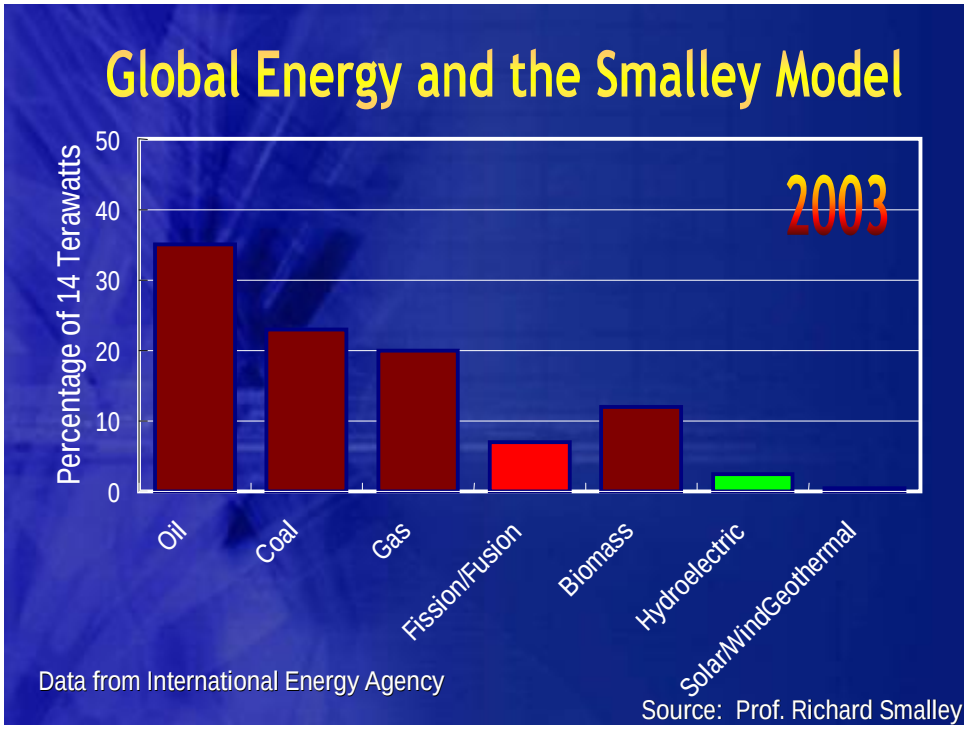
Consume Less!

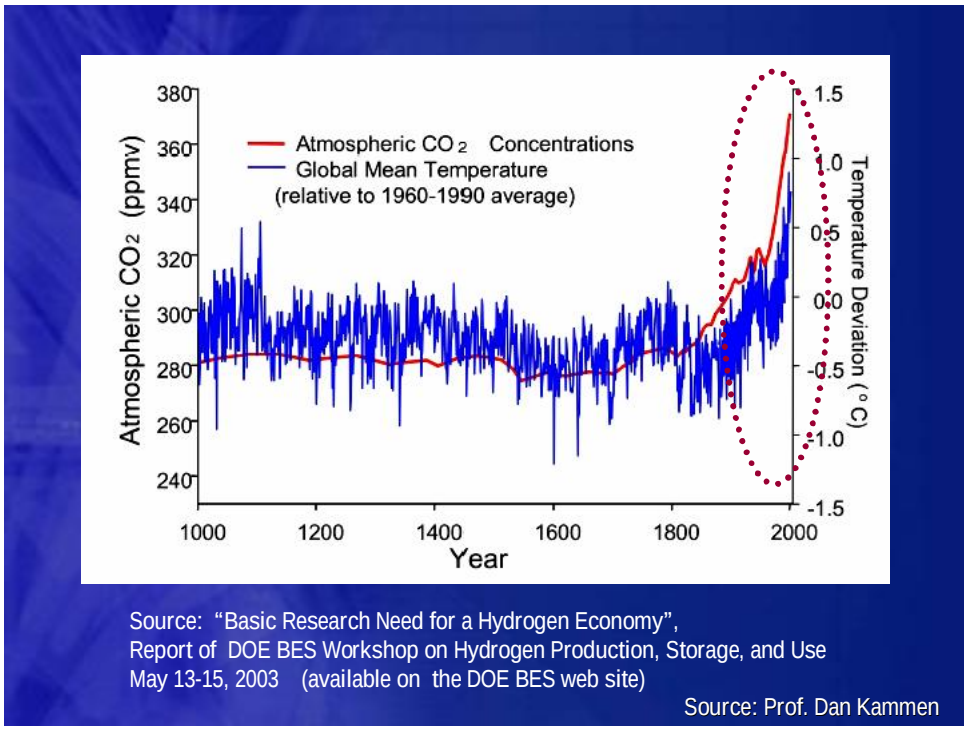
Generate More!

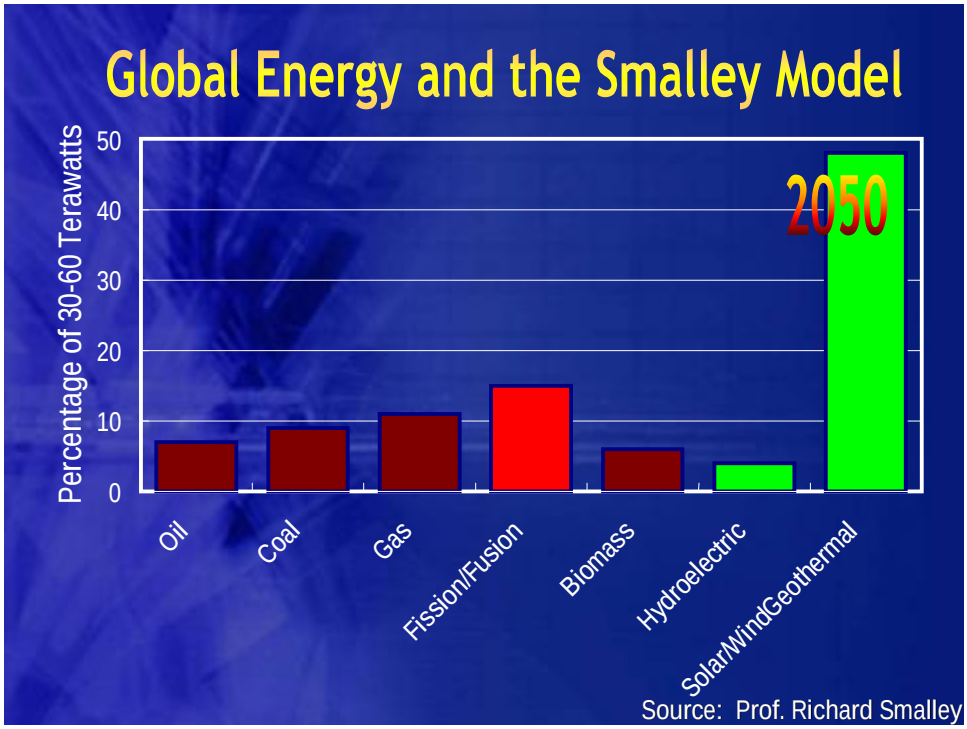
Source: Prof. Richard Smalley

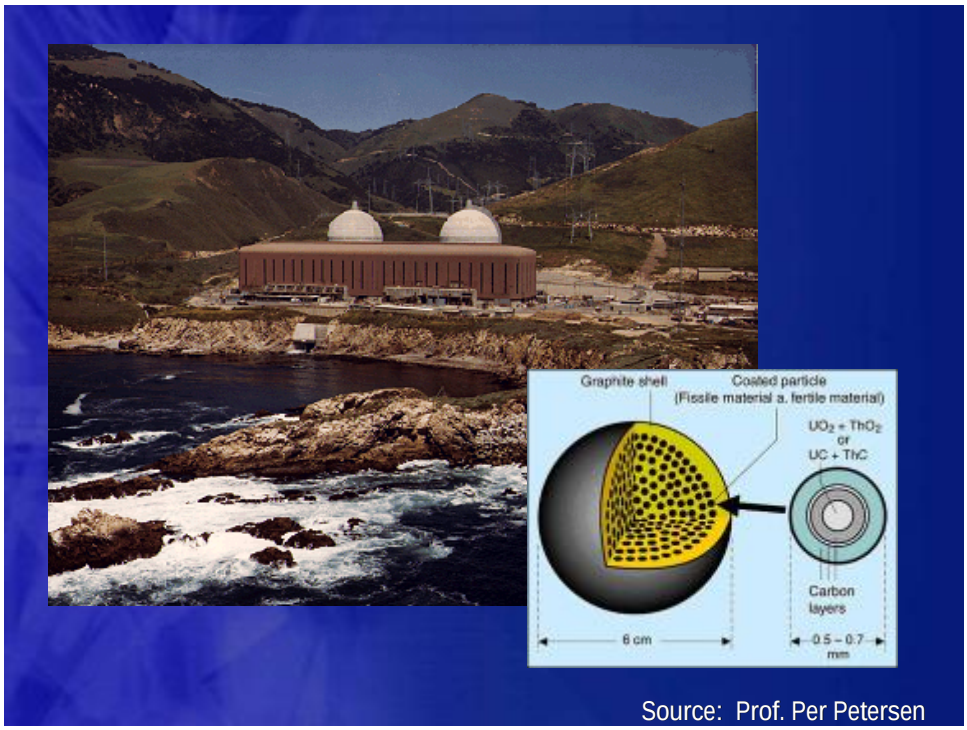

Global Enery Useage
Millions of Barrels per Day (Oil Equivalent)
300
200
100
0
1860
1900
1940
1980
2020
2060
2100
Demand Scenario
Coal
Non-Fossil
Coal
Gas
Tar & Shale
Add'l O&G
Oil
Source: John F. Bookout (President of Shell USA) ,"Two Centuries of Fossil Fuel Energy" International Geological Congress, Washington DC; July 10,1985. Episodes, vol 12, 257-262 (1989).
Source: Prof. Richard Smalley


Electricity Use of US Refrigerator/Freezers
Billion kWh per year
800
700
600
500
400
300
200
100
0
Nuclear
150 Million Refrigerator/Freezers
At 1974 Efficiency
At 2001 Efficiency
Used
Used
Saved
Conventional Hydro
50 Million 2 kW PV Systems
3 Gorges Dam
Renewables
Source: Prof. Dan Kammen

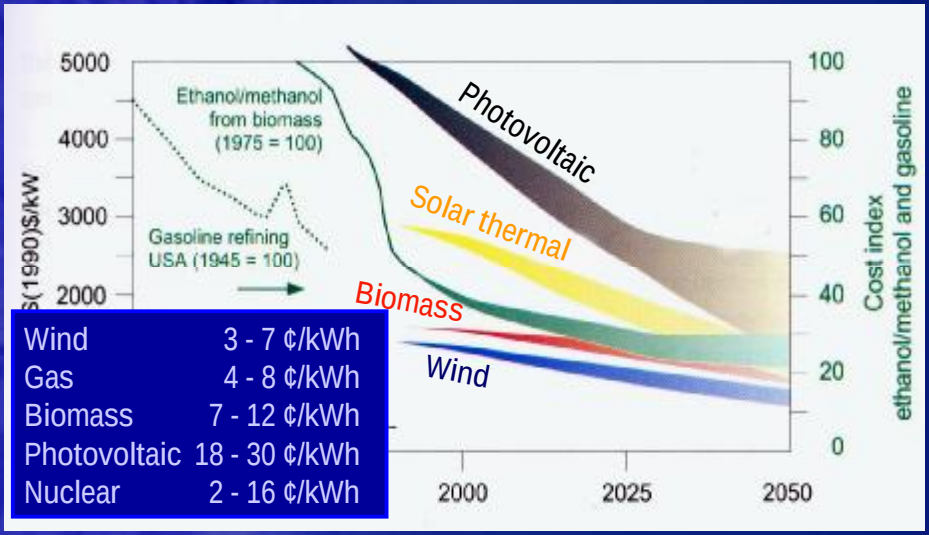

Global Energy and the Smalley Model
2003
Percentage of 14 Terawatts
50
40
30
20
10
0
Oil
Coal
Gas
Fission/Fusion
Biomass
Hydroelectric
Solar/Wind/Geothermal
Data from International Energy Agency
Source: Prof. Richard Smalley


Atmospheric CO2 Concentrations
Global Mean Temperature
(relative to 1960-1990 average)
Atmospheric CO2 (ppmv)
380
360
340
320
300
280
260
240
Temperature Deviation (°C)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1000
1200
1400
1600
1800
2000
Year
Source: "Basic Research Need for a Hydrogen Economy",
Report of DOE BES Workshop on Hydrogen Production, Storage, and Use
May 13-15, 2003 (available on the DOE BES web site)
Source: Prof. Dan Kammen


Global Energy and the Smalley Model
Percentage of 30-60 Terawatts
50
40
30
20
10
0
2050
Oil
Coal
Gas
Fission/Fusion
Biomass
Hydroelectric
Solar/WindGeothermal
Source: Prof. Richard Smalley


Graphite shell
Coated particle
(Fissile material a. fertile material)
UO2 + ThO2
or
UC + ThC
Carbon
layers
6 cm
0.5 – 0.7
mm
Source: Prof. Per Petersen

Dramatic Cost Reductions with Use



Wind	3 - 7 ¢/kWh
Gas	4 - 8 ¢/kWh
Biomass	7 - 12 ¢/kWh
Photovoltaic	18 - 30 ¢/kWh
Nuclear	2 - 16 ¢/kWh

Learning is dynamically driven by market opportunity

Source: Prof. Dan Kammen

Windmills: Incredible Growth in Size & Dramatic Cost Decreases

50–200 kW | 100–400 kW | 1,500–4,600 kW

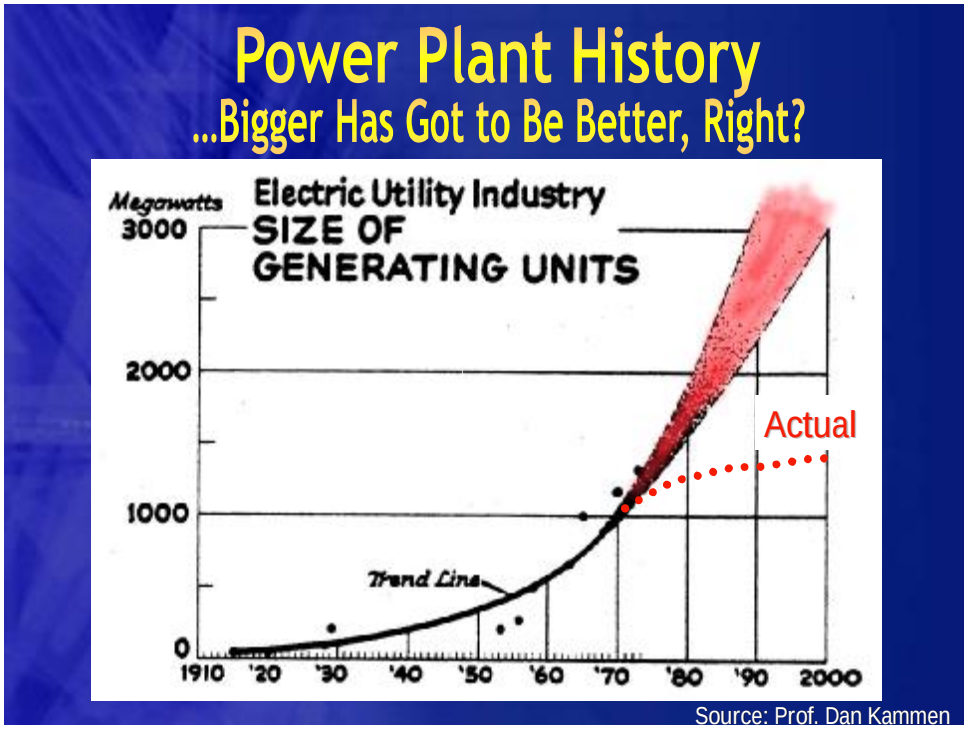
Eff_{max} = 16% | Eff_{max} = 30% | Eff_{max} = 45%

Berkeley

Source: Prof. Dan Kammen

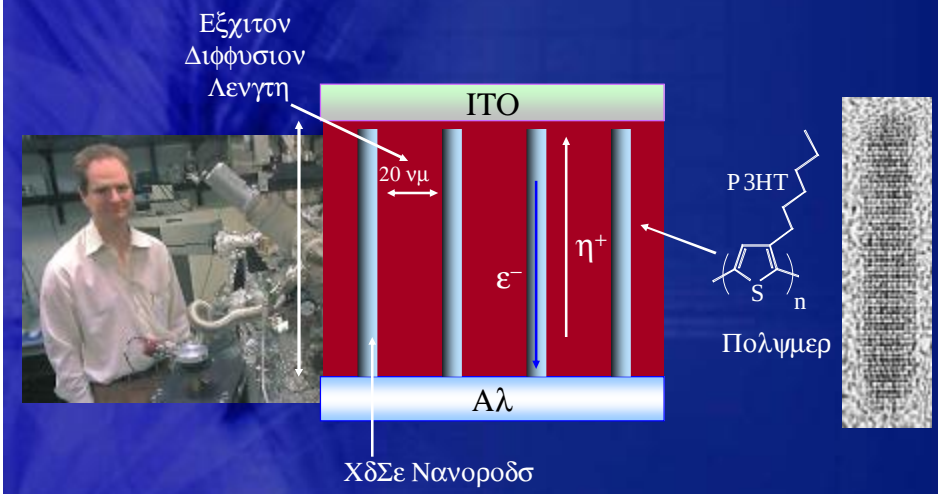
Dean Richard Newton
newton@coe.berkeley.edu


NORTH AMERICA
EUROPE
ASIA AND RUSSIA
AFRICA
SOUTH AMERICA
AUSTRALIA AND OCEANIA
6 Boxes at 3.3 TW Each = 20 TW
Source: Prof. Richard Smalley


Power Plant History
...Bigger Has Got to Be Better, Right?
Megawatts
Electric Utility Industry
SIZE OF
GENERATING UNITS
3000
2000
1000
0
Trend Line
Actual
1910
'20
'30
'40
'50
'60
'70
'80
'90
2000
Source: Prof. Dan Kammen


Moscone Center, San Francisco, CA: 675,000 W
Source: Professor Dan Kammen

Plastic Film Solar Cells - No Silicon!

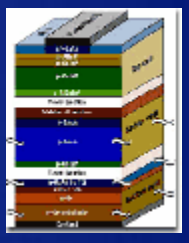


Peng, X. G.; Manna, L.; Yang, W. D.; Wickham, J.; Scher, E. Kadavanich, A. P. Alivisatos, *Nature* **2000**, *404*, 59-61.

Source: Prof. Paul Alivisatos

Our Best Result So Far!

- Low end silicon tandem cells, 12% power efficiency
- High end multi-band gap tandems 34%
- Key considerations:
  - Thermalization to band edge
  - Processing methods



AM 1.5 Efficiency

Power Conversion: 1.7%

Short Circuit Current: 5.8 mA/cm^2

Fill Factor: 0.42

Voc : 0.67 V

Source: Prof. Paul Alivisatos

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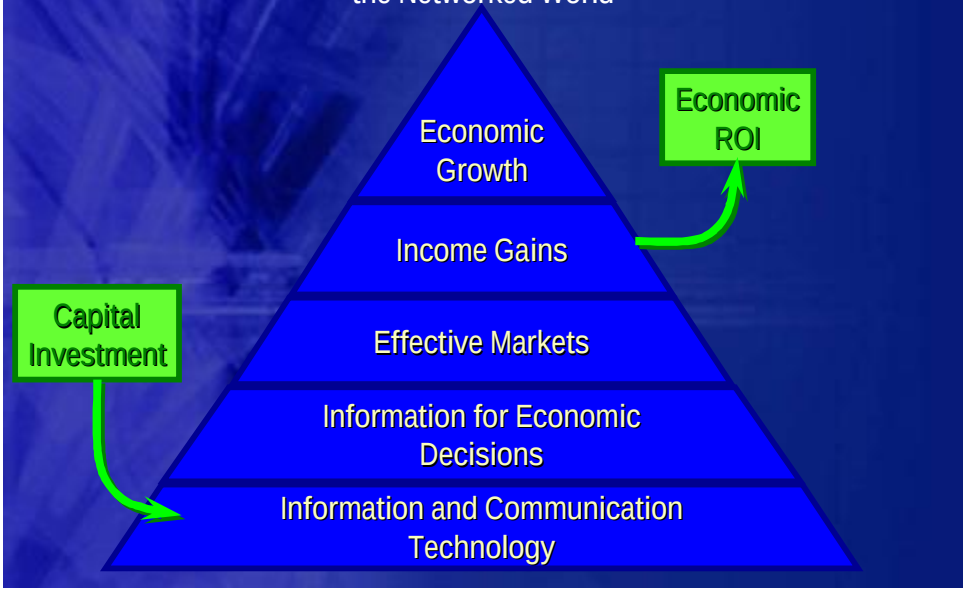
The Digital Provide

Global Information Technology Report 2001-2002:Readiness for the Networked World



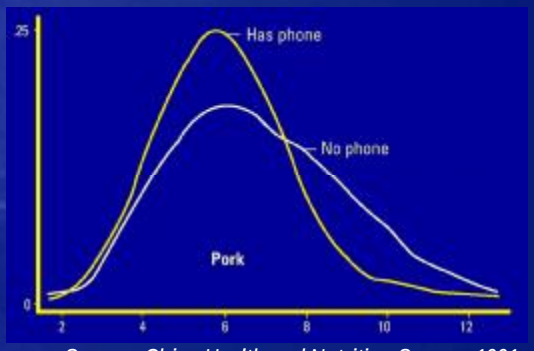
Benefits and Applications

- Price discovery—rural farmers able to double incomes by discovering price of their crops in the capital city
- Improved exports to developed country markets
- Transfer of dollars from diaspora—networked diaspora as a development resource
- Coordination of transportation and distribution (e.g. crops to markets)
- Natural disaster mitigation—early warning of floods, monsoons, etc.

ICT for Improving Market Efficiencies

"Price dispersion is a manifestation—and, indeed, it is the measure—of ignorance in the market" (Stigler, 1961)

- Badiane and Shively (1998) studied monthly maize prices in Ghana from 1980 to 1993: "…the estimated time to fully transmit a price shock to each of two outlying markets is about four months."



Source: China Health and Nutrition Survey, 1991

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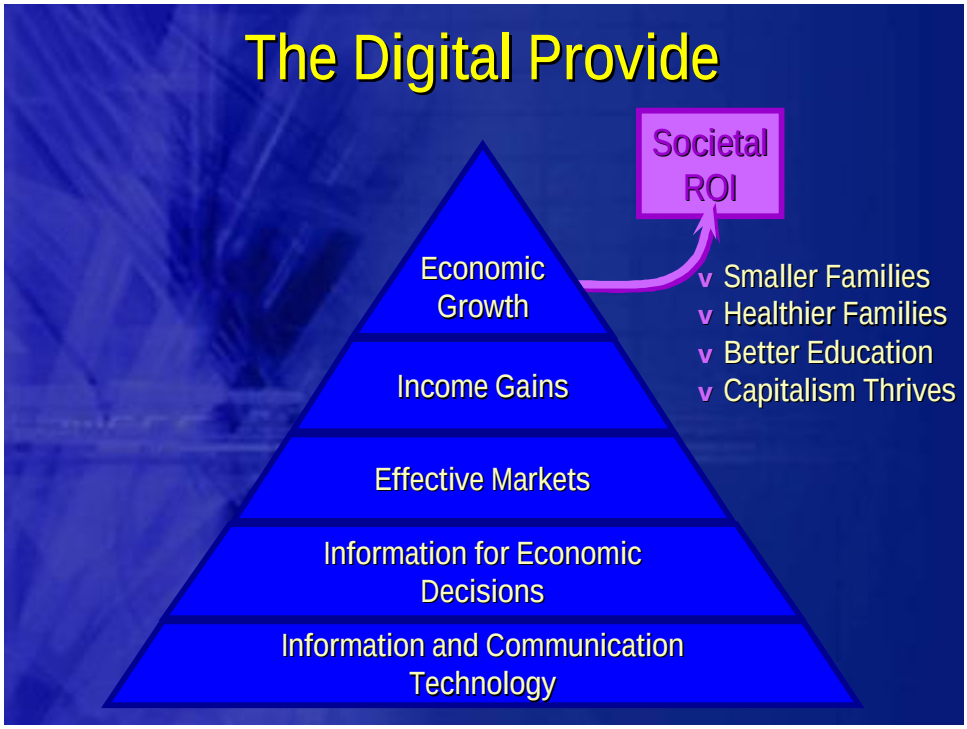
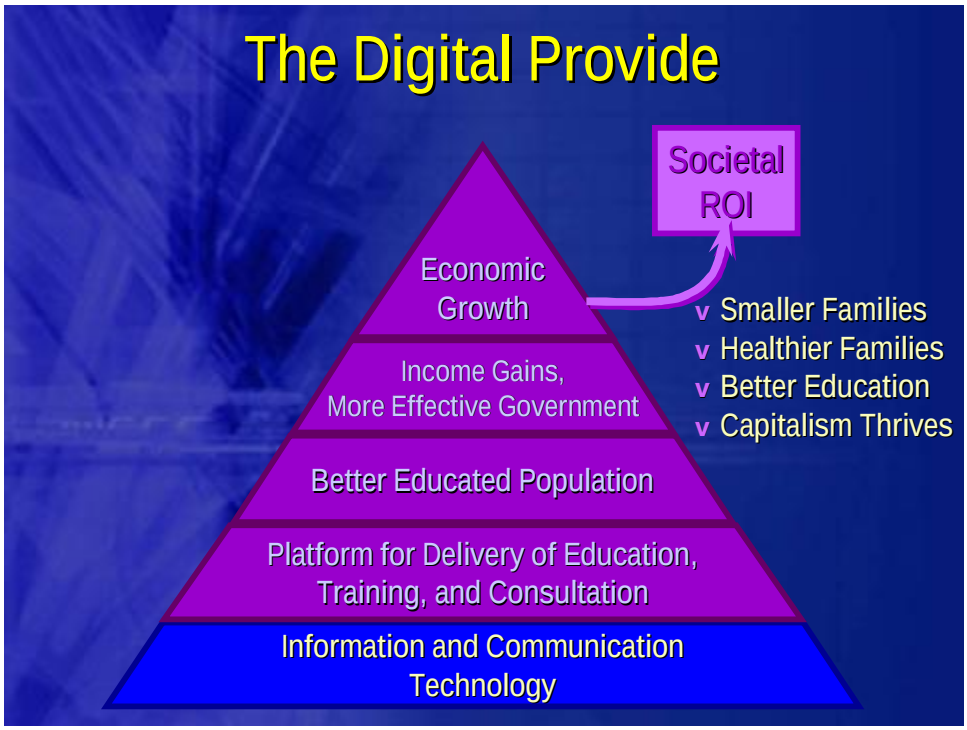
ICT Empowers Women

"We get our freedom from the Internet, since in our society girls are not allowed to go wherever we want…the Internet takes us out to other people, places and realities…it is our way of escaping from our closed society. It is vital to us, it gives us liberty."

A young Muslim girl from Mauritania, Global Information Technology Report 2001-2002: Readiness for the Networked World





Dean Richard Newton
newton@coe.berkeley.edu

Benefits and Applications

- A Platform for Education, Training and Consultation
- Job creation (jobs like data entry that can be shifted to developing countries—inexpensive IT workforce)
- Reducing corruption from increased transparency (e.g. e-gov for transfer of land titles)
- Entertainment
- E-health (health information, remote consultation using digital cameras, public health networks)
- Developing country "communities of practice"
- Preservation and global sharing of local culture

Open, Standards-Based Global ICT Platform: Infrastructure and Basic Services

- Very Low Cost, Operates Off the Power Grid, Designed for Intermittent Connectivity, Supports Low Literacy and Multiple Languages, Reliable in Extreme Environments, Supports Shared Access, Private and Secure
- Must support telephony (synchronous and asynchronous) & data communication
- Must support sensor networks (potentially millions of sensors/application)

Network access feels just like power grid access in a developed community: You simply "plug in" (wirelessly, of course!)

Asynchronous Two-Way Communication

- The telephone system was developed when memory and storage was expensive
- Semi-interactive, but potentially much less expensive…
- Savings:
  - No need for dedicated resources
  - Can "store-and-forward" data (like real mail)
  - Can hide problems (e.g. power out) by waiting or redundancy
- Examples: voice messaging, SMS/MMS, correspondence classes, medical diagnosis (non-emergency), coordinating money transfers, e-commerce (e.g. catalogs), e-mail

Source: Prof. Eric Brewer

Light-Weight Audio SMS

What have the TIER TPC Researchers Accomplished this Summer?

- We are working with M. S. Swaminathan Research Foundation (MSSRF), Aravind Eye Hospital, and the Akshaya (e-gov) project in Kerela
- This summer, we got towers up and set up two links: one from Aravind to one of the MSSRF villages (only 3km) and a 10km link that reconnects that village with the hub
  - It had a connection that was broken, but we reused the towers and antennas
- We showed videoconferencing between the hospital and the villages (sufficient for basic telemedicine)
- We collected 30 samples of Tamil speech for our speech recognizer
- We set up and left a proxy cache that sits in front of the VSAT (which is the only connection from the villages to the outside Internet)

Source: Prof. Eric Brewer


What is the most effective
power architecture for rural users?

Why ICT for Developing Regions Now?

- Cumulative price-performance advances in technologies are bringing ICT within reach of the global poor
- Emergence of successful business models has spurred commercial interest in these unconventional but large markets
- Many successful pilot applications have demonstrated the positive impact of ICT on global sustainability and quality-of-life
- And many of the very best ICT researchers from throughout the world are passionate about this challenge!

Source: Prof. Eric Brewer

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Systems Biology

- Systems biology seeks to uncover the design and control principles of cellular systems through
  - Comparative genomic analysis
  - Functional genomic and high-through phenotyping of cellular systems
  - Mathematical modeling of regulatory networks and interacting cell populations.
- Systems biology builds upon our modern understanding of genetics, our latest high-throughput instrumentation and analysis tools, and advanced computer modeling to explain how simple living systems work (e.g. yeast, e-coli)

Synthetic Biology

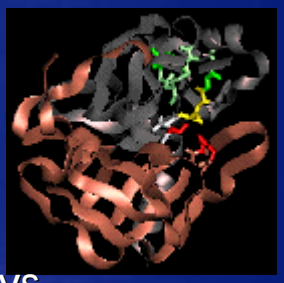
syn•the•sis *n.* 1.a. the combination of separate elements to form a coherent whole.

- Synthetic biology seeks, through understanding, to design biological systems and their components to address a host of problems that cannot be solved using naturally-occurring entities
- Enormous potential benefits to medicine, environmental remediation and renewable energy
- Need the ability to write a 'blueprint'

Source: Prof. Jay Keasling

What Might We Want to Design?

- Enzymes
- Biomaterials
- Metabolic pathways
- Genetic control systems
- Signal transduction pathways

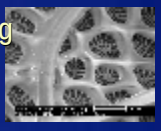


- … eventually whole cells

Source: Prof. Jay Keasling

Why Do We Need Synthetic Biology?

- Synthesis of molecules in an environmentally friendly way
- Synthesis of complicated molecules not found in nature
  - Designer enzymes
  - Designer cells with designer enzymes or existing enzymes
- New materials
  - Designer soft biomaterials
  - Designer hard biomaterials
- Chem/Bio threat detection and decontamination
  - New hydrolytic reactions
  - New metabolic pathways for complete degradation
  - New cells that will swim to the threat and decontaminate it



Source: Prof. Jay Keasling

Why Synthetic Biology Now?

- Advances in computing power
- Internet
- Genomic sequencing
- Crystal structures of proteins
- High through-put technologies, including DNA synthesis
- Biological databases
- Repositories of cell parts (genes)

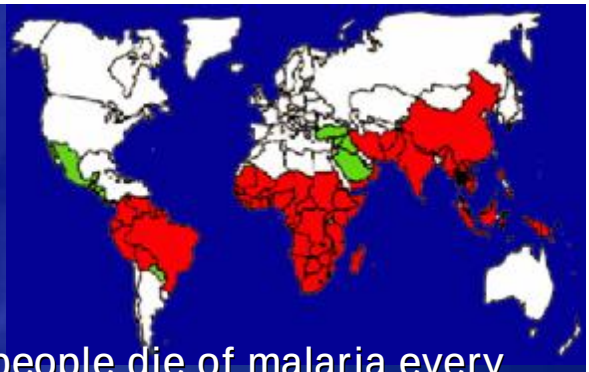
Source: Prof. Adam Arkin

Building a System With Off-the-Shelf Parts

Design → Off-the-shelf parts → System → Application

Source: Professor Jay Keasling

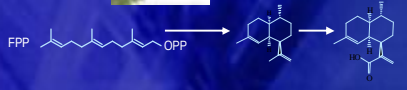
Malaria

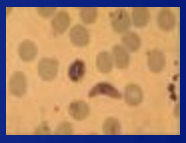


- 1.5-2.7 million people die of malaria every year
  - 90% of the victims are children
  - 40% of the world's population is at risk
- Economists have proposed that malaria decreases the GDP of affected countries by as much as 50%.

Building an Anti-Malarial Drug Producer with Parts

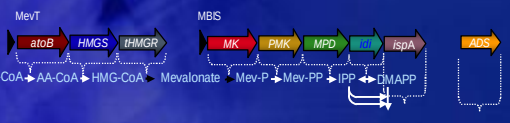
Artemisia Annua

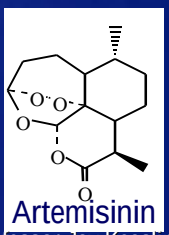




Malaria

Design → Off-the-shelf parts → System (existing cells) → Application





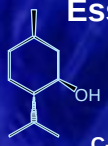
Artemisinin

Source: Professor Jay Keasling

Terpenoids

> 50,000 known molecules

Essential oils

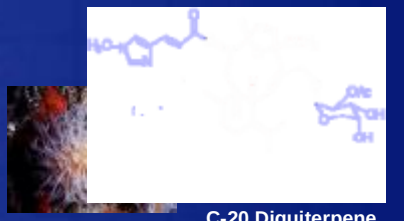


Menthol
C-10 Monoterpene

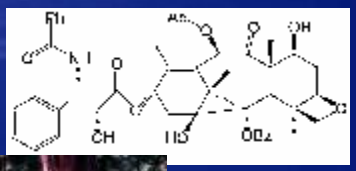
Carotenoids

Lycopene
C-40 Tetraterpene

Chemotherapeutics



C-20 Diquiterpene

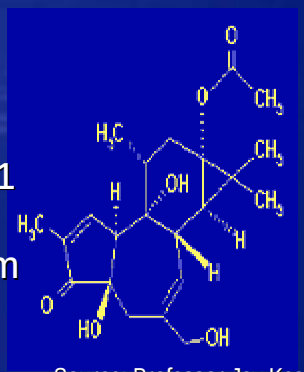


Taxol
C-20 Diterpene

Source: Professor Jay Keasling

Prostratin

- Protein kinase C activator
- Isolated from the stems of the small Samoan tree ***Homalanthus nutans***



- Inhibits human immunodeficiency virus type 1 (HIV-1) infection yet up-regulates viral expression from latent proviruses

Source: Professor Jay Keasling

Risk: Creation of New Risks?

- Standard Biological Parts
  - Current component libraries seem below the noise level of existing conventional risk
  - Open distribution of particular classes of parts may need to be considered on a case-by-case basis.
- Coordinated Fabrication & DNA Synthesis
  - Engineers ordering DNA already has a modest positive impact on risk landscape.
  - Coordination implies community, community in engineering also implies ethical standards and codes of conduct.

Great Works as an Organizing Principal

- "Use Inspired Basic Research" as a Framework for Implementation
  - Energy—e.g. Nanoengineered solar cells
  - Education—e.g. ICT for the Developing World
  - Disease—e.g. Curing malaria with synthetic biology
- The Research University Network
  - Role as the "DMZ of Research"
  - Next Steps

Pasteur's Quadrant

Donald E. Stokes

Quest for Fundamental Understanding?	Considerations of Use? NO	Considerations of Use? YES
YES	Pure Basic Research (Bohr) 	*Use-Inspired* Basic Research (Pasteur) 
NO		Pure Applied Research (Edison) 

The Xerox Palo Alto Research Center (PARC): The end of a critical institution!

Such approaches must be global and should include partnerships among universities, industries, and governments

We must find new approaches to effective collaborative research management in an era of hyper-development

Aerial view of Bell Labs, Murray Hill, New Jersey: A shadow of its former self…

Great Works as an Implementable Vision

- Can we create a collaborative network of great research universities from throughout the world to act as "home" for such an initiative?
- Can we reach agreement with a set of national governments and international agencies to collaborate on this project?
- Can we identify a collection of national and multinational corporations willing to collaborate on specific research and development goals?
- As a community, can we create a common vision, a set of priorities, and a research framework for their pursuit?
- Finally, and most importantly, can we find a source of funds sufficient to make this vision a reality?

Great Works as an Organizing Principal

- "Use Inspired Basic Research" as a Framework for Implementation
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  - Disease—e.g. Curing malaria with synthetic biology
- The Research University Network
  - Role as the "DMZ of Research"
  - ***Next Steps… Discussion***