Maximizing and Speeding Net Positive Impact of Emerging Technology:

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The Talk

- High Impact Technology Overview
- Ruminations on collectively achieving significant net positive impact
- Speculation on Timing 2015, 2020, 2030

High Impact Technology

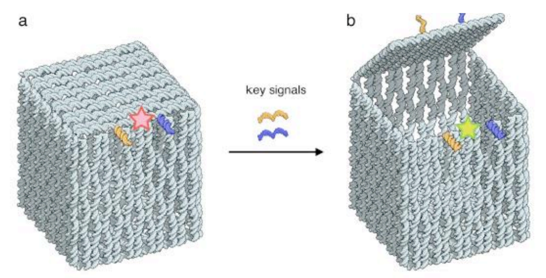
- Various types of Nanotechnology
- Hardware for AI and Sensors for AI input
- Quantum Computers and Quantum Technology
- Beyond Moore Law Candidates
- Hyperspeed Communication
- Superconductors
- Nuclear Fusion

Best Near Term

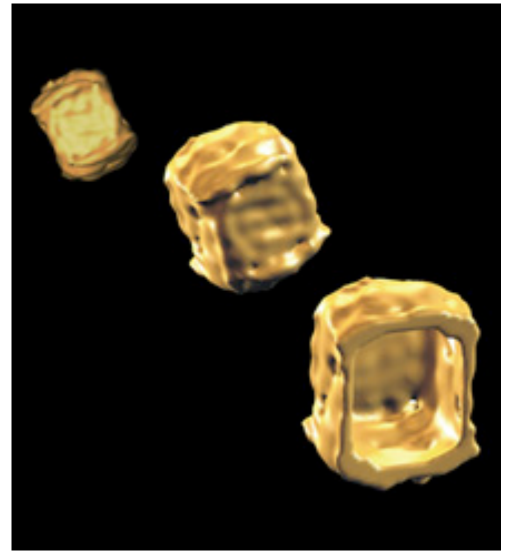
- 3D DNA Nanotechnology
- Graphene
- Carbon nanotubes
- Self Assembly
- Nanoscale enhancements of printable electronics and additive manufacturing
- Fab in a Box

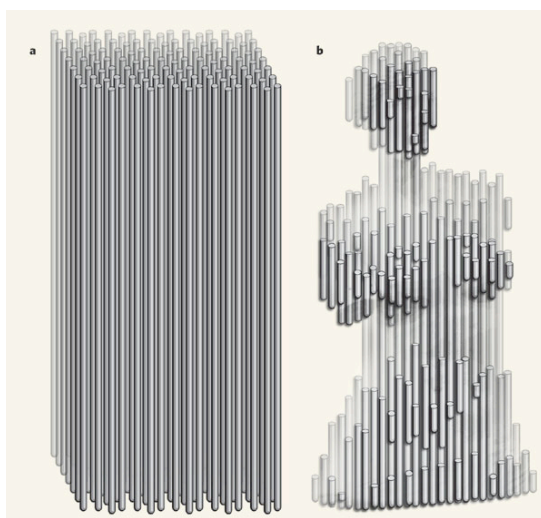
3d DNA Nanotechnology

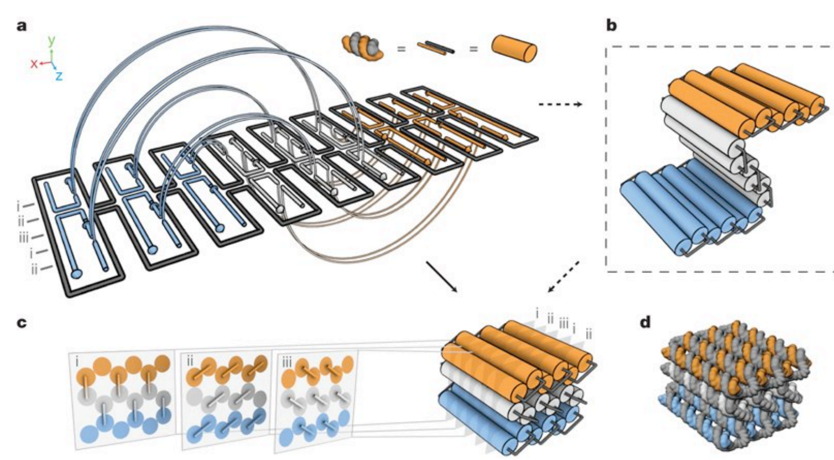
- DNA boxes
- DNA tubes and other shapes



Supplementary Figure 1. Mechanism for signal-induced opening of the DNA box. **a**, An atomic model of the DNA box held closed by "locks" (orange and blue) that are double helices formed by two short strands protruding from the lid and the main box, respectively. Each "lock" has a small sticky-end where a "key" sequence signal can bind and open the "lock" by strand displacement. If both "locks" are opened the lid of the box is effectively opened (b). The reporter system for detecting the lid opening is a Cy3-Cy5 FRET system. In the closed state the two fluorophores are in close proximity resulting in FRET emission from Cy5 (red star) when Cy3 is excited. In the open state







Graphene

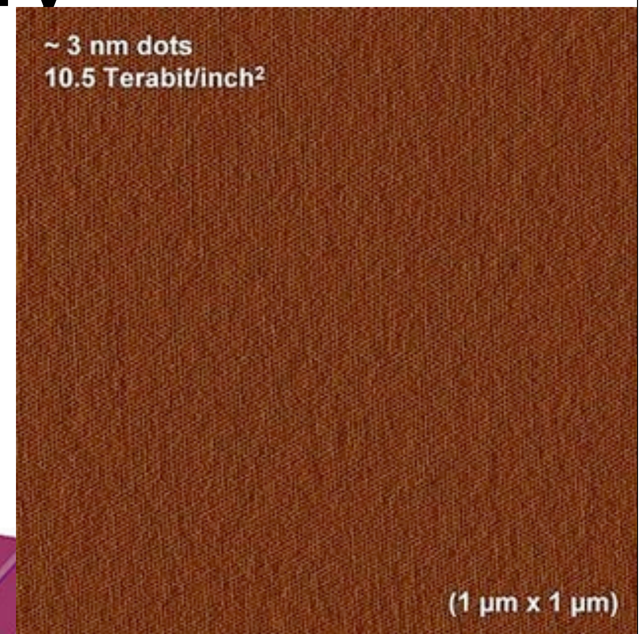
- electrons travel up to 100 times faster in graphene than silicon.
- 1000 Gigahertz electronics
- Graphene Energy: Ultracapacitors with twice the storage capacity of commercially available ultracapacitor in the lab by end of 2009 ($500K seed funded)
- a few" startups working on large-scale graphene production, as well as several big chemical companies that are trying to develop graphene production processes.
- Nanostripes

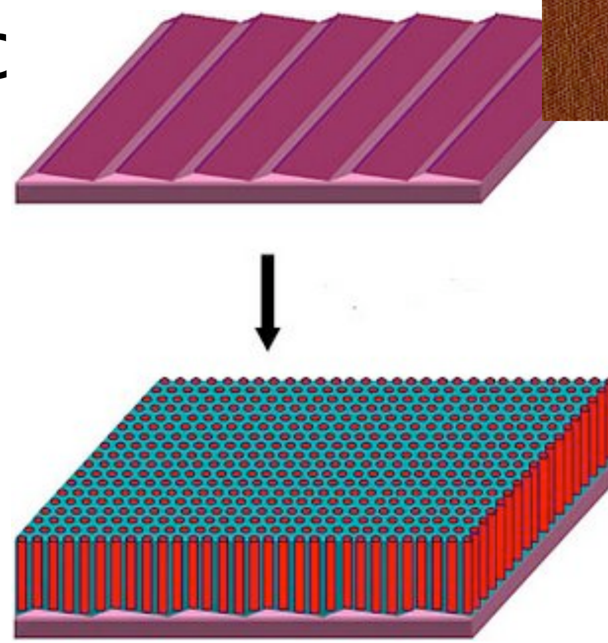
Nanocomp

- High Strength – spun conductive yarns exhibit breaking strengths up to 3 GPa expressed or in other terms: 1.5 Nt/Tex or 450,000 psi and with fracture toughness that is higher than aramids (such as Kevlar or Twaron). CNT sheets have breaking strengths, without binders, that range from 500 MPa to 1.2 GPa depending upon tube orientation. Aluminum breaks at 500 MPa, carbon steel breaks around 1 GPa.
- Electrical Conductivity – Capable of carrying more current than copper and are also more conductive than copper at high frequencies.
- Thermal Conductivity – Capability to transfer more heat than copper or silver on a per weight basis.
- Thermoelectric behavior – Demonstrate a Seebeck coefficient of greater than 60 μV/ºK and power greater than 1 watt/gram.
- Extremely Lightweight – Less than half the weight of aluminum
- Over three years enough to retrofit EMI shielding in all commercial jets.

Self Assembly

- Guided Self-assembly
- Surface topography
- Surface wetting
- Electrostatic force
- Magnetic forc





sawtooth ridges formed by cutting and heating a sapphire crystal serves to guide the self-assembly of nanoscale elements

Aerojet Printing and Printable

- Printing carbon nanotubes for electronics and computing and solar cells
- Optomec, a leading rapid manufacturing company, has an all-printed CNT-TFT (carbon nanotube-thin film transistor) on a polyimide substrate
- all-aerosol-jet-printed process eliminates the need for lithography, vacuum processing, and metallization procedures and thus provides a promising technology for low-cost, high-throughput fabrication of large-area high-speed flexible electronic circuits on virtually any desired flexible substrate.
- 10 microns wide, 5 Ghz, 200 meters/s
- Aerosol Jet systems are used in the

development of next generation printable c

such as solar cells, fuel cells, embedded se

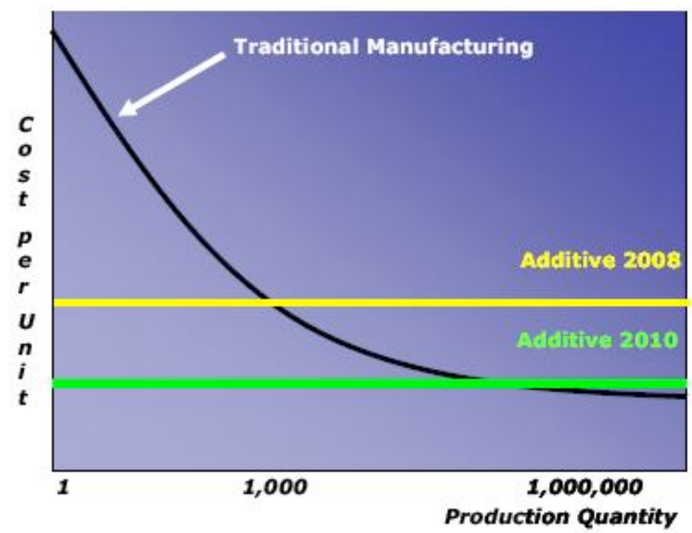


Figure 12. The Aerosol Jet process provides a cost effective solution for low to moderate volume production runs or where mass customization is required. The cost per unit for Direct Write technology is flat regardless of volume.

Fab in a Box

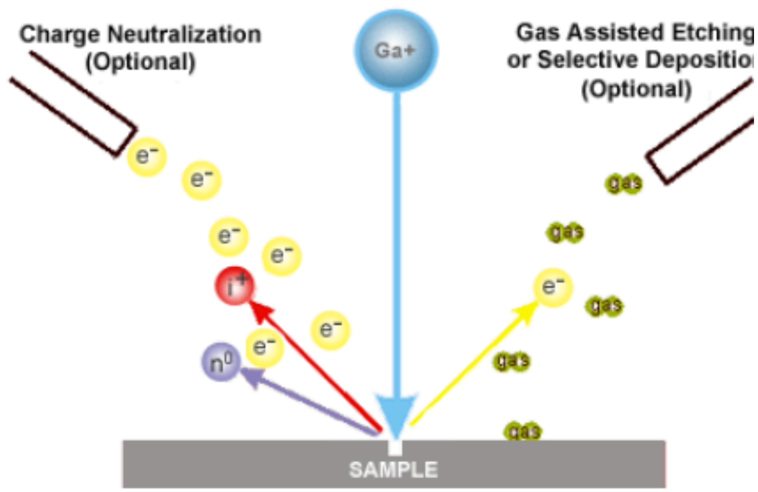
Focused Ion Beam (FIB)

FIB functions

1. Milling materials from a local area (~several nm)
2. Deposition of materials including Pt, SiO_2,etc.

General Applications

1. Device modification (mask, pad, etc.)
2. TEM sample preparation
3. Section analysis
4. Direct write



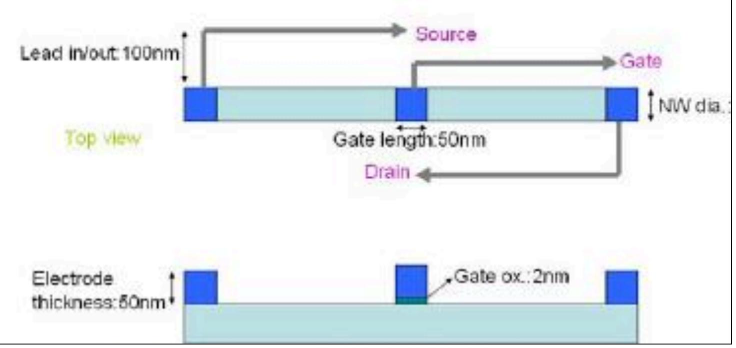
http://www.fibics.com

ther fabrication methods

	Pre FIB process	FIB process	FIB volume (um^3) / transistor	FIB time(s)/ transistor	FIB time(s) /10^14 transistor	Cost($)/ transistor	Cost($) /400million transistors	Cost($)/ Avogad number transist
D hole device brication by B	None	Whole parts (Metal, Oxide, SC)	9.01E-01	5.41E-6	5.41E+08	8.59E-08	3.44E+01	8.59E+
D B assisted ndom anowire circuit	VLS, solution nanowire synthesis	Interconnect oxides	1.50E-01	9.00E-07	9.00E+07	1.43E-08	5.72E+0	1.43E+
D B assisted NA tile circuit	DNA tile synthesis	Interconnect	1.50E-01	9.00E-07	9.00E+07	1.43E-08	5.72E+0	1.43E+
D B assisted anowire ynthesis and rcuit fab	None	Catalysts (metal)	1.25E-04	7.50E-10	7.50E+04	1.19E-11	4.76E-03	1.19E+

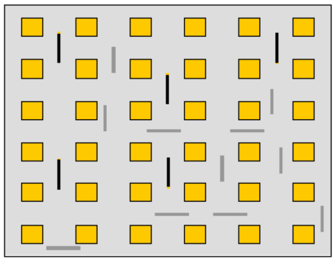
Assumption:

1. **One 1000 x 1000 multiple FIB beam**
2. **Design: simple MOSFET with 50nm gate**

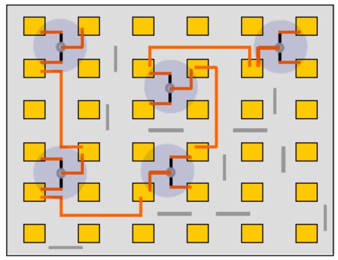


Fab in a Box

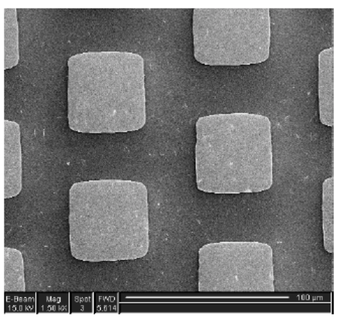
Prototype of error correction fabrication by FIB

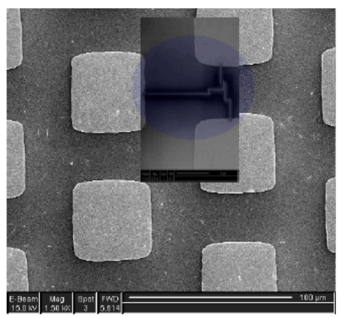


Extreme errors by random arrangement of nanowires

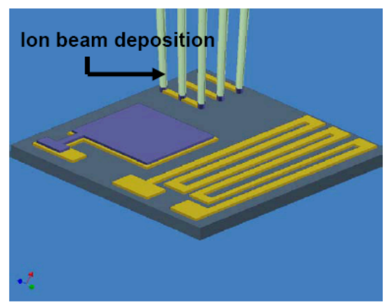


Transistor fabrication by error correction tool





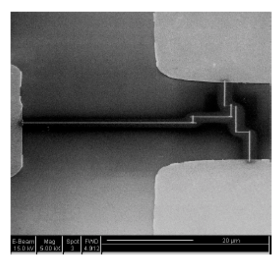
How to increase the speed of the fabrication?



< 20 nm Resolution

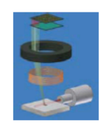
Novel 3 Dimensional Computer Architectures

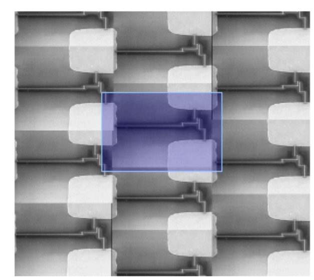
10^{12} Devices in << 24 hrs



Prototype circuit fabrication with error correction

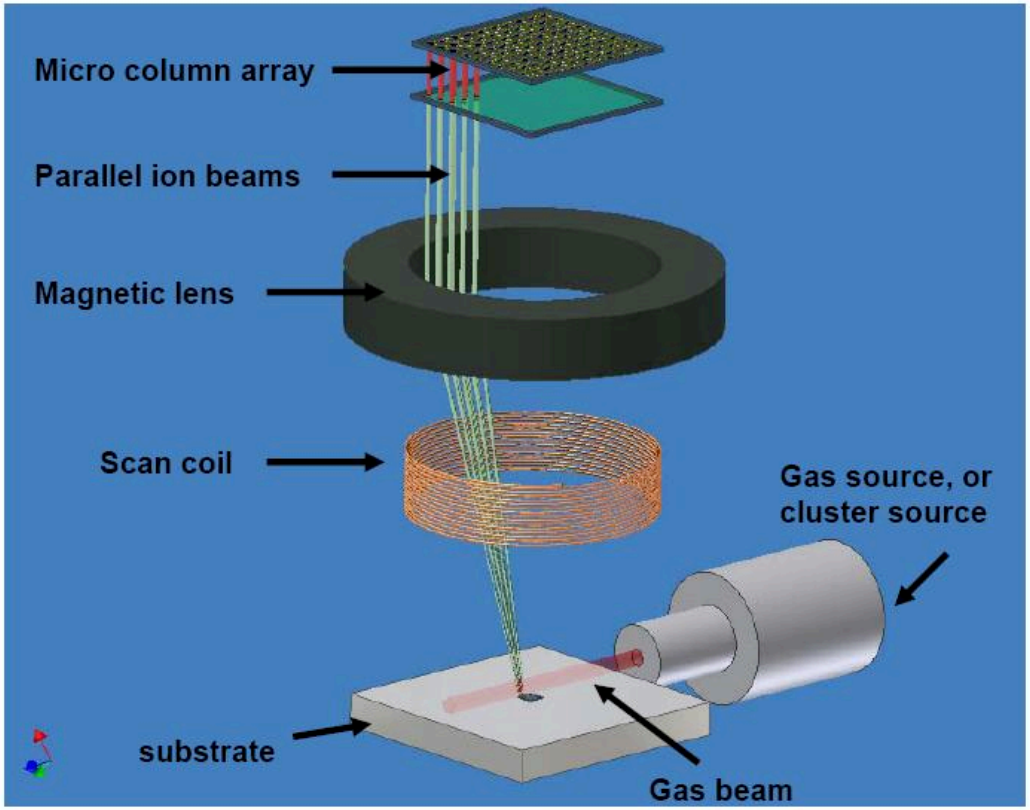
Parallel beam





Parallel Error Correcting Feedback Fabrication

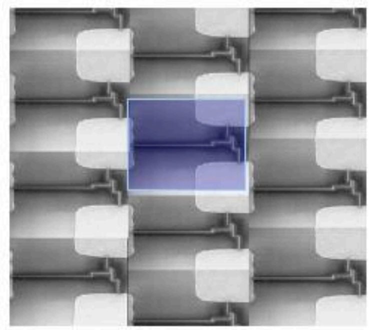
Parallel Focused Ion Beam (FIB)



Schematic of Moleographic Systems Showing Multiple Beam Fabrication with Feedback

Unique Features

- **Ultrafast Highly Parallel Direct Fabrication**
- **On-The-Fly Molecular Scale Error Correction**
- **nm Inorganic Semiconductor Building Blocks**



Hardware for AI and Sensors for AI input

- Getting a massive hardware acceleration sooner will help to AGI goal
- Massive amounts of sensors and satellites (high-res imaging) feeding AIs for semi-omniscience
- Memristors have synapse characteristics
- Could make memristors at 30nmX 30nm X 2 nm

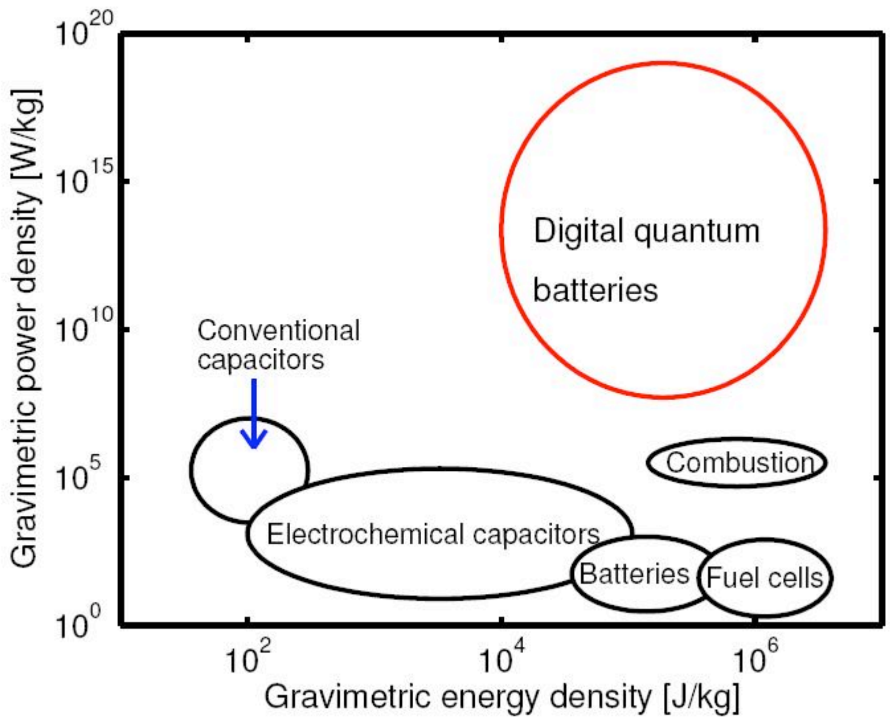
Beyond Moore's Law

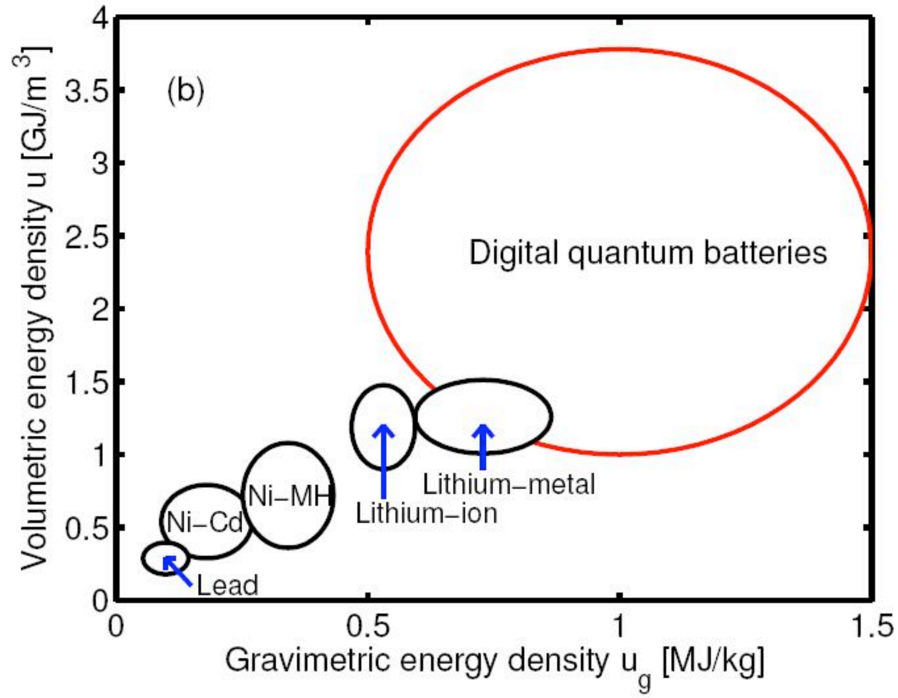
- Plasmonic computing (maybe zettaflops instead of exaflops by 2020)
- Graphene for 1000 GHz
- Universal memory that is superfast and lower energy use would be a general speed boost
- GPGPUs are improving faster than Moore's law
- Quantum dot cellular automata
- Massive distributed computing bound by a

Quantum Computer

- **Grover's algorithm** – search database with N entries in $O(N^{1/2})$ time and using $O(\log N)$ storage space
- Quantum algorithms for linear and differential equations
- Quantum simulations of molecular systems

Quantum Digital Batteries – Nano vacuum tube arrays



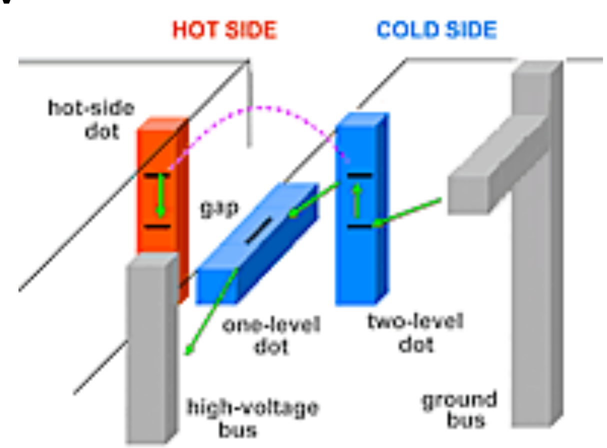


Alfred Hubler also proposes Atomic Neural Nets (billion nodes per neuron, more energy efficient than brain) and digital wire (wire utilizing quantum effects)

Quantum dot/Nano Gap Heat to

- the ideal thermal-to-electric converter using quantum dots, **Quantum-coupled single-electron thermal to electric conversion scheme**
- Thermal diodes demoed at 40% efficiency but could reach 90%
- Need to make a lot of the quantum dot devices which need to be perfected. Pre-nanofactory nanotechnology
- Peter Hagelstein MIT and Micron-gap Thermal Photo-Voltaics (MTPV Corp/ Robert DiMatteo)
- Microgap thermophotovoltaics take advantage of evanescent waves to obtain higher throughput, with the power per unit area limited by the internal blackbody, which is n^2 higher. Higher power per unit area can be achieved by taking

placing a high-temperature surface extremely close (~5 nm) to a low-temperature surface, and cover the surfaces with arrays of carefully structured quantum-dot components. With the use of small quantum dots, the scheme becomes very efficient theoretically, but will require advances in technology to fabricate.



Hyperspeed Communication

- Near term 60 GHz wireless for 7-12.5 Gbps. Range can be extended with antennas
  - High Gain antennas can boost the range to 1000 meters with 99% availability.
  - Metamaterial antennas, nanoantennas
- Terahertz communication by 2020 for 2-20 times more speed than 60 GHz
- Terabit optical chip (CUDOS australia)
- More speed from better laser

Superconducting Transformers

- 40 percent of the USA's total grid energy losses are from aging conventional transformers and that the use of superconducting transformers could reduce energy losses on the grid by one-third
- A transformer with superconducting wire can eliminate up to half the energy losses of transformers wound with conventional copper wire and results in a device that is about one-half the physical size and weight of a conventional transformer

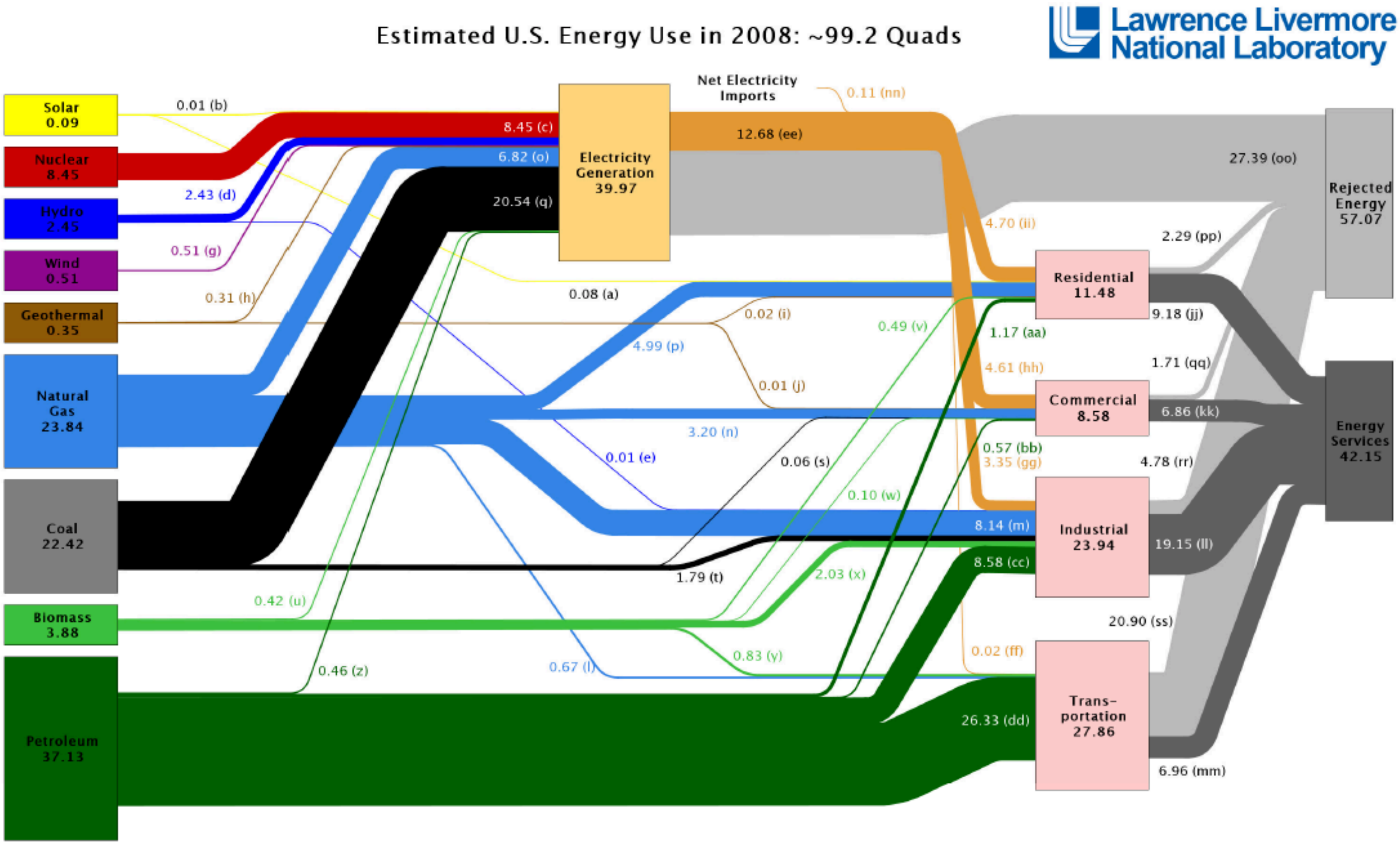
Table 4. National transformer statistics (best engineering estimates)

	Voltage range (kV)	Power range (MVA)	Number	Average age
Large Power	115–765	200–1200	2500	40+
Medium Power	65–345	10–100	45000	35+
Low Power	35–69	1–10	5000	25+
Mobile Power	35–245	1–100	600	20+

Transmission Efficiency

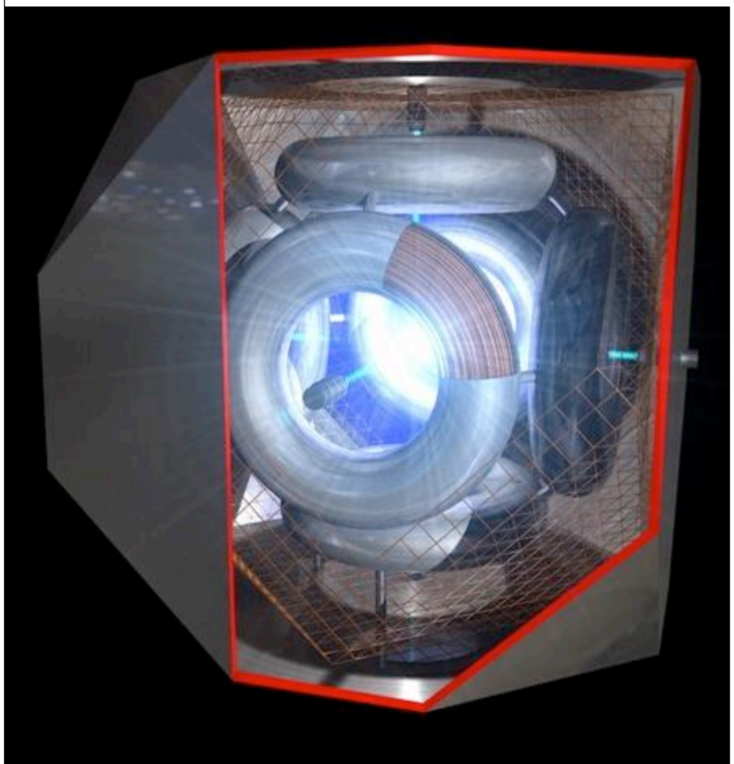
- Transmission
  - Superconductors
    - 1/3 of the power losses (3% instead of 9%)
    - 24 times less land (25 ft wide instead of 600 ft wide)
    - $8-13 million per mile
  - Ultra high Voltage Alternating Current
    - Transmission line losses about ¼ vs EHV lines
    - 1/3 to 1/2 vs standard extra high voltage (EHV) lines.
  - Carbon nanotubes could also be used to

US Energy Use 2008



Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Fusion



IEC fusion uses magnets to contain an electron cloud in the center. Then they inject the fuel (deuterium or lithium, boron) as positive ions. The positive ions get attracted to the high negative charge at a speed sufficient for fusion. Speed and electron volt charge can be converted over to temperature. The electrons hitting the TV screen can be converted from electron volts to 200 million degrees.

The old problem ions would collide with grid (2% losses minimum).

magnets on the outside 100,000 times less losses

Could prove out within 2 years and then commercial before 2020

Space 40 to 1000 times cheaper and energy about 5 times cheaper.

Fusion

- Focus fusion – Dense Plasma Focus Fusion ($1.2 million 2009-2010 to prove it out) Use billion gauss fields from plasmoids.
- If it works as expected up to 50 times reduction in energy costs
- General fusion
- Field reversed configuration (colliding beam) – Tri-alpha energy and Helion

Fusion for Space is Easier

Table 4. Differences in Applying Fusion to Electric Generation and to Propulsion

Terrestrial Electric Power	Space Propulsion
Fusion energy valued for a few cents per kW-hr	Fusion energy valued for \$10's to \$100's per kW-hr
Conversion to electricity mandatory	Conversion to thrust directly.
Cost of electricity is a physics driver	Specific jet power is a physics driver
Neutrons cherished for their energy, but accentuate reactor material engineering challenge	Neutrons are worse than useless and are vented out freely to space, alleviating the reactor material problems
Years of low-maintenance operation – inherently favors steady-state fusion approaches	Months of operating duty cycle between major overhauls – open the doors for pulsed fusion approaches
Terrestrial environment where creating a clean, high vacuum is a non-trivial engineering burden	Space environment where a near perfect clean vacuum is readily available.

Fusion to Assist in Deep Burn Fission is Easier

Parameter	Transmutation	Electric Power
Confinement H(y,2)	1.0	1.5-2.0
Beta β_N	< 2.5	> 5.0
Power Amplification Qp	< 2	≥ 50
Bootstrap Current Fraction f_{bs}	0.2-0.4	0.9
Neutron wall load (MW/m^2)	< 1.0	> 4.0
Fusion Power (MW)	≤ 200	3000
Availability (%)	≥ 50	90

Positive Deflection of Global Trends

- Challenge to go beyond regular improvement
  - 8+% GWP growth (no inflation, 5-7% best BAU)
  - Beyond Moore's law or other tech trends
  - Creative combinations to significantly accelerate an important development (make a sweet spot)
- Productivity Enhancement
- Exec Management enhance

Global growth

Year	2006	2007	2008	2009p	2010f
World	5.1	5.2	3.0	-1.1	3.1
Advanced economies	3.0	2.7	0.6	-3.4	1.3
Euro area	2.9	2.7	0.7	-4.2	0.3
USA	2.7	2.1	0.4	-2.7	1.5
Developing countries	7.9	8.3	6.0	1.7	5.1

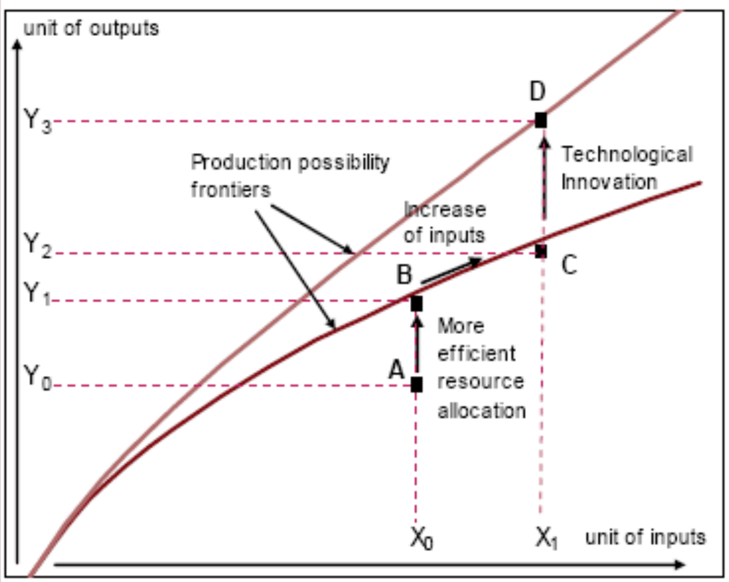
Goldman Sachs Analysis of Increasing India's GDP

Average growth (% chg yoy)

	GDP	TFP	Capital Stock	Employment	Education Attainment
Agriculture					
1981-1990	3.5	0.5	2.1	1.1	2.3
1992-1996	4.7	1.8	2.0	1.2	2.0
1997-2001	2.0	-0.4	1.3	0.6	2.3
2002-2004	1.3	-1.0	1.5	0.4	2.2
Industry					
1981-1990	7.0	0.5	7.5	3.4	2.3
1992-1996	7.3	1.2	9.0	2.0	2.0
1997-2001	**4.5**	**-1.2**	5.4	3.7	2.3
2002-2004	**7.7**	**1.9**	3.9	4.7	2.2
Services					
1981-1990	6.7	1.6	3.3	3.5	2.3
1992-1996	7.5	2.2	4.7	3.2	2.0
1997-2001	8.2	2.8	4.2	3.3	2.3
2002-2004	8.5	3.0	5.8	2.8	2.2

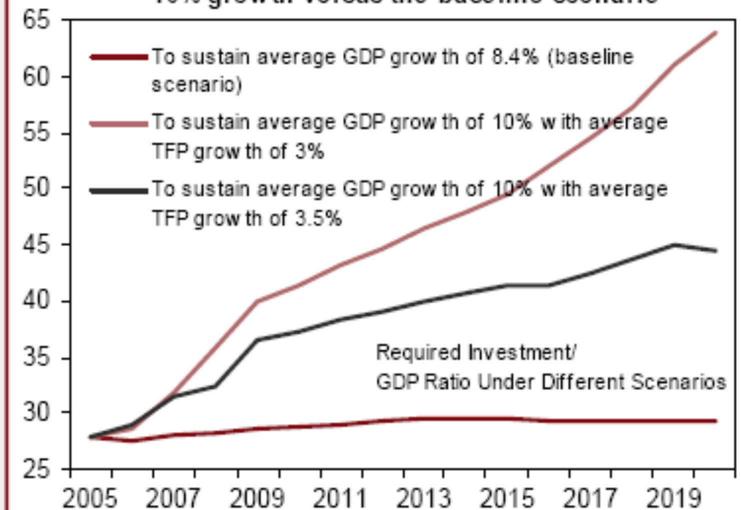
Source: Central Statistical Organisation of India, Goldman Sachs Economic Research.

Production function and the Sources of Growth



Source: Goldman Sachs Economic Research.

Required investment/GDP ratio to sustain 10% growth versus the baseline scenario



Source: Central Statistical Organisation of India, Goldman Sachs Economic Research.

Creativity in Faster, Sooner and

- Enhancing humans, companies, cities, regions, regulation, governments
  - Computational Governance
    - Real time business census
    - Timely and accurate
    - Sensors feeding models
    - Not big brother but competent partner and tracking systems affordable and usable for all (parallel private and public systems)
    - Wikipolicy, wiki-public plans, X-plan competitions
    - Pre-test and track effectiveness of policies and plans
  - Ubiquitous testing, validation and simulation
    - Scientific method to government (historical data tests, compare competing approaches, field trials etc…)

Historic Global GDP Gains

- Agricultural Productivity
- Industrialization
- Urbanization
- Container Shipping (Transportation & Trade)
  - Before that ships, car, rail – efficiently moving stuff
- Services
- Information Technology (including internet)
- Telecom
- Efficient capital and financial markets
- Organization and Processes

Quantify and compare multiplier effects

Future New Economy

- Re-examine all of the historic ones to get more out of them
- Even more products and services (more choices/customized)
- Do the same things faster (pick up the pace)
  - More transactions in a year
  - X years of growth in one year
- Inventions and creative combos
- Space expansion
- Robots, agents & multipliers

Re-examine historic GDP

- Agricultural Productivity
  - Genetically modified food (more and healthier food)
- Industrialization
  - Additive manufacturing, reel-to-reel printable electronics, nanofactories
- Urbanization
  - Re-invent cities with supertech for hyper-productivity
- Transportation & Trade
  - Magnetic pipelines
  - Sub-orbital hypersonic transport
- Services
  - No future shocked left behind

Re-examine historic GDP

- Information Technology (including internet)
- Telecom
  - Get faster communication sooner
- Efficient capital and financial markets
- Organization and Processes
- Population and Geographic Expansion
  - Everyone involved and productive
    - Catchup everyone in Africa, Asia etc…
    - Contribute and consume

Future New Economy

- Radical Health improvement
  - Life extension
  - Regeneration
  - Nanomedicine
- New services
  - Helping people adapt and stay connected to civilization changed by new technology
  - Business models where people work with robots and AI

More from Less Matter &

- Efficiency
  - More GDP per kWh
  - Lighter products and less movement of things
    - Stronger materials can make big things from less tonnage (GDP/ton)
- More matter & energy
  - Reel to reel production and Nanotechnology and other ways to ramp up production
  - Nuclear fusion
  - Access to space
    - Asteroids have $100 billion of resources for every person

Basic drivers

- More and cheaper Energy
- More efficient and productive use of energy and materials
- Faster Communication
  - Broadband, ultrabroadband and beyond
  - Better antennas can increase range of fast local wireless
- Mobile Productivity
- Put new technology together to revamp cities

Business as Usual is Powerful

- What will people actually buy ?
  - Dayjet – failed air taxi service
    - Would save hours driving to airport, hours at security checks, cost about business class ticket
      - Concord to Torrance, San Carlos to Corona
    - Change in booking the ticket for the individual
    - Narrow service area
    - Company HR/procurement has allow it
  - Roadable planes
    - Only 250,000 pilots in the USA
- Market acceptance, training issues
  - AI assistant and automation could address training issues
- Japan culture early adopts gadgets, China good at adopting and implementing nation scale change

Barriers in the Mind to Substantially Faster Progress

- I don’t believe it, that is why you fail
  - If scientists reject then few try
  - Journalists will mock it and try to “expose the waste”
  - If business people reject then funding problems
- High Risk, high payoff in few institutions
  - DARPA and who else ?

Can Supertech break barriers

- The first shock the world innovation could change the mindset
- Proto-AGI could help people and businesses adapt
- Transform regulatory processes
  - FDA - Biomarkers, adaptive clinical trials
  - EPA - environmental impact studies
  - Engineering - NRC, civil engineering
    - Integrate the design validation and regulatory approval and proving it is safe

What if a Supertech is Late

- How do we achieve goals anyway or sooner with an earlier and weaker version ?
- AI not good enough for fully robotic car system?
  - Deploy better GPS and sensors to reduce AI requirements
  - Make a system that works anyway
    - Roadtrains - 6 cars follow a better lead driver
- Full Fledged Quantum computing and

Full Nanotech Late

- Maximize use of low volume molecular precision
  - Utilize quantum effects
    - Quantum computers
    - More precise clocks and lasers
      - Better clocks, better GPS
      - Better lasers for faster communication and better sensors
  - Chipscale and smaller
    - Atomic clocks everywhere
    - Small accelerators everywhere
    - Superphysics out of the lab and into personal and business products

Open Entirely new Areas

- Otherwise what is the reason for taking a big financial risk on something different ?
- How do you displace what is good enough ?
- Problems for business as usual ➔ Opportunity
  - Greenhouse gas problem
  - Peak Oil
    - ➔Some openness to new energy solutions

Status of the current mix

- Impactful Convergence: GPGPU, FPGAs, Higher speed communication (onchip, between chips, distributed)
- Working and building to impact: Mathematically error-free OS kernel, solid state memory, Quantum Computers, Memristors
- Understanding Concrete from Molecular Level up (MIT)
- Convergence enhancers - antennas, additive manufacturing
- Setting the stage with some payoff and changes (Change significant for those outside but not singularity scale)

2010-2015

- DNA nanotech matures (structures, switches)
- Synthetic biology for biofuels
- Stem cells and gene therapy
- Supercheap medical tests, early detection and treatment
- Early life extension technology emerging
- Graphene, carbon nanotubes have some significant commericialization (big impact 2015-2019+, electronics and material related products)
- Enabler = harvested power, even faster wireless communication
- Super smartphones, tablets, ebooks
- Gigapixel and more imaging - with low power usage and constant surveillence
- Myostatin inhibitors, SARM steroids, exoskeletons emerge
- 2^{nd} gen cognitive enhancers
- Validation of new nuclear fusion methods - moving to

2015

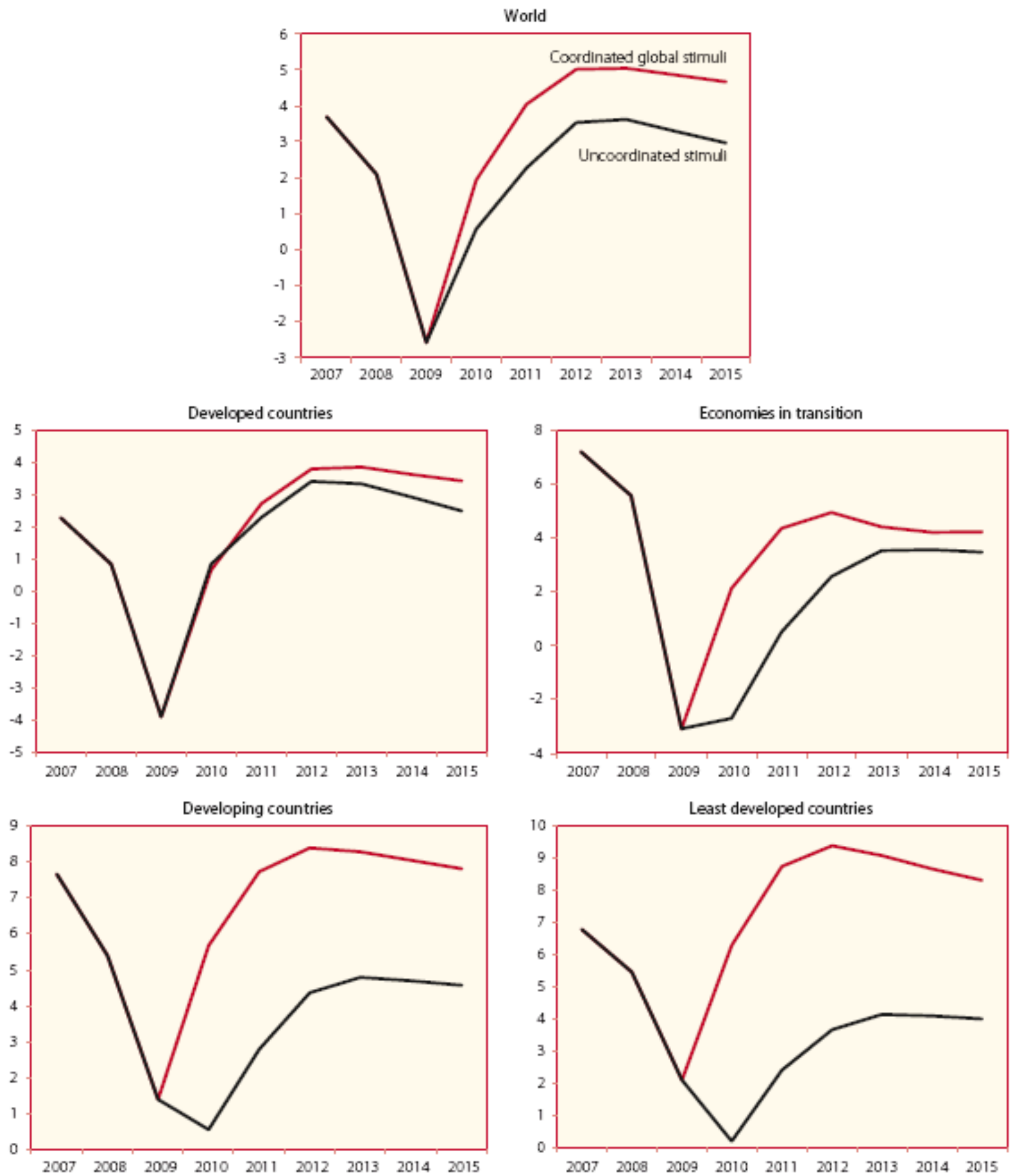
- Possibly the first exaflop supercomputer. Distributed systems have exascale by 2012
  - Terabit internet and cloud computing OS likely to reshape the resourcing of computers 2012-2020
  - 100,000+ supercompute nodes: Need to have hotswapping and instant connect and compute

How Much 2015 ?

1. Economic abundance
   - Regular World GDP projection
     - 74.7 trillion GDP, 93 trillion PPP (end of 2014)
     - 60.6 trillion GDP, 73 trillion PPP 2010
     - GDP growth 4-5% per year
2. Radical life extension
   - +10 years for some and up to 80% reduction in cancer fatality and 30% in heart disease, +2 yrs generally
3. Physical and Cognitive enhancement
   - Myostatin inhibition, SARM Steroids
4. Automation, Robots, exoskeletons
   - HULC, sarcos

UN Global
ɔdel to 2015

Economic recovery under coordinated and uncoordinated global stimulus, 2009-2015



Source: UN/DESA, based on policy stimulations with the UN Global Policy Model.

How Much 2015 ?

5. Super-materials
- Carbon Nanotubes: 1000 tons/yr now, 10k tons 2011
- Carbon Nanotubes: 40K-100K tons/year by 2015, $1-5/lb
- Graphene
- 3.5 billion tons of cement, 2.2 billion tons of steel, 17 million tons of copper

6. Open Access to space
- Space hotels 2012-2013
- SpaceX and other new rockets
- VASIMR

7. Pollution elimination (still slowing growth)
8. Computer/Intelligence Advancement
   - Quantum computing, quantum dots, universal memory, memristors, graphene - high frequency chips

2016-2020

- Proving and initial commercializing nuclear fusion and a combined systems for factory mass produced deeper burn fission - (build out will get to meaningful levels in 2020-2030 +)
- Super smartphones and network of super accessories- continue
- smarts in cars and buildings

2016-2020 part 2

- OLED and Printable Electronics
  - Roadmap
- Superconductors Cheap and Ramping Deployment
- Solar electric sail, VASIMR
- Significant volumes [tens of thousands of tons] of carbon nanotubes, superconducting wire, graphene

How Much 2020?

1. Economic abundance
   - Regular World GDP projection
     - 150 trillion GDP, 200 trillion PPP, GDP growth 6% per year
     - +35% GDP growth over ten years with Gigabit broadband
     - Nanoantennas ?
2. Radical life extension
   - +10-15 years for more and up to 99% reduction in cancer fatality and 80% in heart disease, +4 years generally
3. Physical and Cognitive enhancement
4. Automation, Robots, exoskeletons

How Much by 2020 ?

5. Super-materials
- Carbon Nanotubes: 200-300 kt or breakthrough to megatons
- Graphene
- 4 billion tons of cement, 3 billion tons of steel, 17 million tons of copper

6. Open Access to space
- More Space hotels, bigger and cheaper new rockets
- Megawatt VASIMR

7. Pollution elimination
8. Computer/Intelligence Advancement
9. Towards programmable matter
    - Claytronics

2021-2030

- 2020-2030 Big Payoff and supertech comes together
- Infrastructure light change -
- Early - robotic cars, leader following road trains, modular cars etc...
- Wearable computers and robotics
- Terapixel and more imaging - with low power usage and constant surveillence
- Sensors imaging and superfast quantum search.
- Hardware and energy - less heroics from the software.

Energy 2015, 2020, 2030

More nuclear is just China and some other countries hitting stated targets. Like China 86GW in 2020 and 160-200 GW for 2030
And some adoption of better uprates (dual cooled fuel)

Fusion and Nanotech has double economic growth from 2020-2030 and more nuclear and renewables. Better manufacturing can make everything max uprated and higher efficiency turbines fully deployed

Total World - high oil price case EIA

	2006	2010	2015	2020	2030	
Liquids	172.4	174.5	169.0	169.5	181.7	0.2
Natural	108.1	118.3	132.2	147.0	167.0	1.8
Coal	127.5	140.4	149.9	162.2	192.2	1.7
Nuclear	27.8	29.0	32.0	35.7	40.4	1.6
Other	36.8	45.7	55.0	63.5	74.5	3.0
Total	**472.4**	**507.8**	**538.1**	**577.9**	**655.8**	**1.4**

Total World - High Growth case EIA

	2006	2010	2015	2020	2030	
Liquids	172.4	175.2	188.1	203.5	235.5	1.3
Natural	108.1	119.2	135.1	149.6	173.2	2.0
Coal	127.5	141.2	153.5	168.0	207.8	2.1
Nuclear	27.8	29.0	31.9	35.7	41.5	1.7
Other	36.8	45.9	55.4	63.3	75.4	3.0
Total	**472.4**	**510.5**	**564.1**	**620.2**	**733.4**	**1.8**

Total World - modified more nuclear

	2006	2010	2015	2020	2030
Liquids	172.4	175.2	188.1	203.0	225.0
Natural	108.1	119.2	135.1	149.6	173.2
Coal	127.5	141.2	153.5	154.0	177.0
Nuclear	27.8	29.0	31.9	50.7	93.0
Other	36.8	45.9	55.4	63.3	75.4
Total	**472.4**	**510.5**	**564.1**	**620.2**	**733.4**

Total World - modified fusion and nanotech

	2006	2010	2015	2020	2030
Liquids	172.4	175.2	188.1	203.0	203.0
Natural	108.1	119.2	135.1	149.6	173.2
Coal	127.5	141.2	153.5	154.0	154.0
Nuclear	27.8	29.0	31.9	50.7	200.0
Other	36.8	45.9	55.4	63.3	130.0
Total	**472.4**	**510.5**	**564.1**	**620.2**	**860.2**

How Much 2030 ?

1. Economic abundance
2. Radical life extension
3. Physical and Cognitive enhancement
4. Automation, Robots, exoskeletons
5. Super-materials
6. Open Access to space
7. Pollution elimination
8. Computer/Intelligence Advancement
9. Towards programmable matter

Unleash super innovation

Enabling the Near Impossible

- Super-dielectrics for Mach Effect Propulsion
- Room temperature superconductors
- Magnetic ground launch
- 200+ Tesla superconducting magnets
  - Test Heim hyperdrive
- Quantum Digital Batteries
- Catalyze Ultradense deuterium
  - Make nuclear fusion 100,000 times easier
- Trillion+ qubit quantum computers

End of Talk

- Extra slides follow

Goldman Sachs Projections

Rank	Country	2010	2015	2020	2025	2030
1	United	14,535,000	16,194,000	17,978,000	20,087,000	22,817,000
2	Japan	4,604,000	4,861,000	5,224,000	5,570,000	5,814,000
3	Germany	3,083,000	3,326,000	3,519,000	3,631,000	3,761,000
4	China	4,667,000	8,133,000	12,630,000	18,437,000	25,610,000
5	United	2,546,000	2,835,000	3,101,000	3,333,000	3,595,000
6	France	2,366,000	2,577,000	2,815,000	3,055,000	3,306,000
7	Italy	1,914,000	2,072,000	2,224,000	2,326,000	2,391,000
8	Canada	1,389,000	1,549,000	1,700,000	1,856,000	2,061,000
9	Brazil	1,346,000	1,720,000	2,194,000	2,831,000	3,720,000
10	Russia	1,371,000	1,900,000	2,554,000	3,341,000	4,265,000
11	India	1,256,000	1,900,000	2,848,000	4,316,000	6,683,000
12	South Korea	1,071,000	1,305,000	1,508,000	1,861,000	2,241,000
13	Mexico	1,009,000	1,327,000	1,742,000	2,303,000	3,068,000
14	Turkey	440,000	572,000	740,000	965,000	1,279,000
15	Indonesia	419,000	562,000	752,000	1,033,000	1,479,000
16	Iran	312,000	415,000	544,000	716,000	953,000
17	Pakistan	161,000	206,000	268,000	359,000	497,000
18	Nigeria	158,000	218,000	306,000	445,000	680,000
19	Philippines	162,000	215,000	289,000	400,000	582,000
20	Egypt	129,000	171,000	229,000	318,000	467,000
21	Bangladesh	81,000	110,000	150,000	210,000	304,000
22	Vietnam	88,000	157,000	273,000	458,000	745,000
		43,107,000	52,325,000	63,588,000	77,851,000	96,318,000
		75,000,000	91,037,998	110,634,004	135,449,579	167,579,511

GDP Determinants Since

Table 1 Proximate and Measurable Determinants of Growth since 1820

	UK	USA	Japan	UK	USA	Japan
	Gross Stock of Machinery & Equipment Per Capita (1990$)			Gross Stock of Non-Residential Structures Per Capita (1990 $)		
1820	92	87	n.a.	1,074	1,094	n.a.
1870	334	489	94 a	2,509	3,686	593a
1913	878	2,749	329	3,215	14,696	852
1950	2,122	6,110	1,381	3,412	17,211	1,929
1973	6,203	10,762	6,431	9,585	24,366	12,778
2001	16,082	30,600	32,929	22,176	36,330	57,415

	UK	USA	Japan	UK	USA	Japan
	Primary Energy Consumption Per Capita (tons of oil equiv.)			Average Years of Education* Per Person Employed		
1820	.61	2.45b	0.20	2.00	1.75	1.50
1870	2.21	2.45	0.20	4.44	3.92	1.50
1913	3.24	4.47	0.42	8.82	7.86	5.36
1950	3.14	5.68	0.54	10.60	11.2	9.11
1973	3.93	8.19	2.98	11.66	14.58	12.09
2001	3.94	8.00	4.10	15.45	20.21	16.61

	UK	USA	Japan	UK	USA	Japan
	Land Area Per Capita (hectares)			Exports Per Capita (1990 $)		
1820	1.48	48.1	1.23	53	25	n.a.
1870	1.00	23.4	1.11	390	62	1.5
1913	0.69	9.6	0.74	862	197	33
1950	0.48	6.2	0.44	781	283	42
1973	0.43	4.4	0.35	1,684	824	875
2001	0.41	3.3	0.30	5,447	2,843	2,696

	UK	USA	Japan	UK	USA	Japan
	Hours Worked Per Head of Population			GDP Per Man hour (1990 $)		
1820	1,153	968	1,598	1.49	1.30	0.42
1870	1,251	1,084	1,598	2.55	2.25	0.46
1913	1,181	1,036	1,290	4.31	5.12	1.08
1950	904	756	925	7.93	12.65	2.08
1973	750	704	988	15.97	23.72	11.57
2001	704	770	883	28.59	36.29	23.42

	UK	USA	Japan	UK	USA	Japan
	Capital-Output Ratio Machinery & Equipment/GDP			Capital-Output Ratio Non-Residential Structures/GDP		
1820	.05	.07	n.a.	.63	.87	n.a.
1870	.11	.20	.10a	.79	1.51	.59a
1913	.18	.52	.24	.65	2.77	.61
1950	.31	.64	.72	.49	1.80	1.00
1973	.52	.64	.93	.80	1.46	1.12
2001	.80	1.09	1.59	1.10	1.30	2.77

	UK	USA	Japan	UK	USA	Japan
	Labour Productivity			Total Factor Productivity		
	(annual average compound growth rates)					
1820-70	1.10	1.10	0.18	0.15	-0.15	n.a.
1870-1913	1.22	1.93	2.00	0.31	0.36	-0.05c
1913-50	1.66	2.47	1.79	0.81	1.62	0.20
1950-73	3.09	2.77	7.75	1.48	1.75	5.12
1973-2001	2.10	1.53	2.55	0.69	0.54	0.49

a) 1890; b) 1850; c) 1890-1913; *) in equivalent years of primary education. Source: Appendix K of MADDISON, MONITORING THE WORLD ECONOMY (1995,PP. 252-55), amended and updated.

Detailed Analysis That Considers Capital Expenditure and Generation Costs and Build

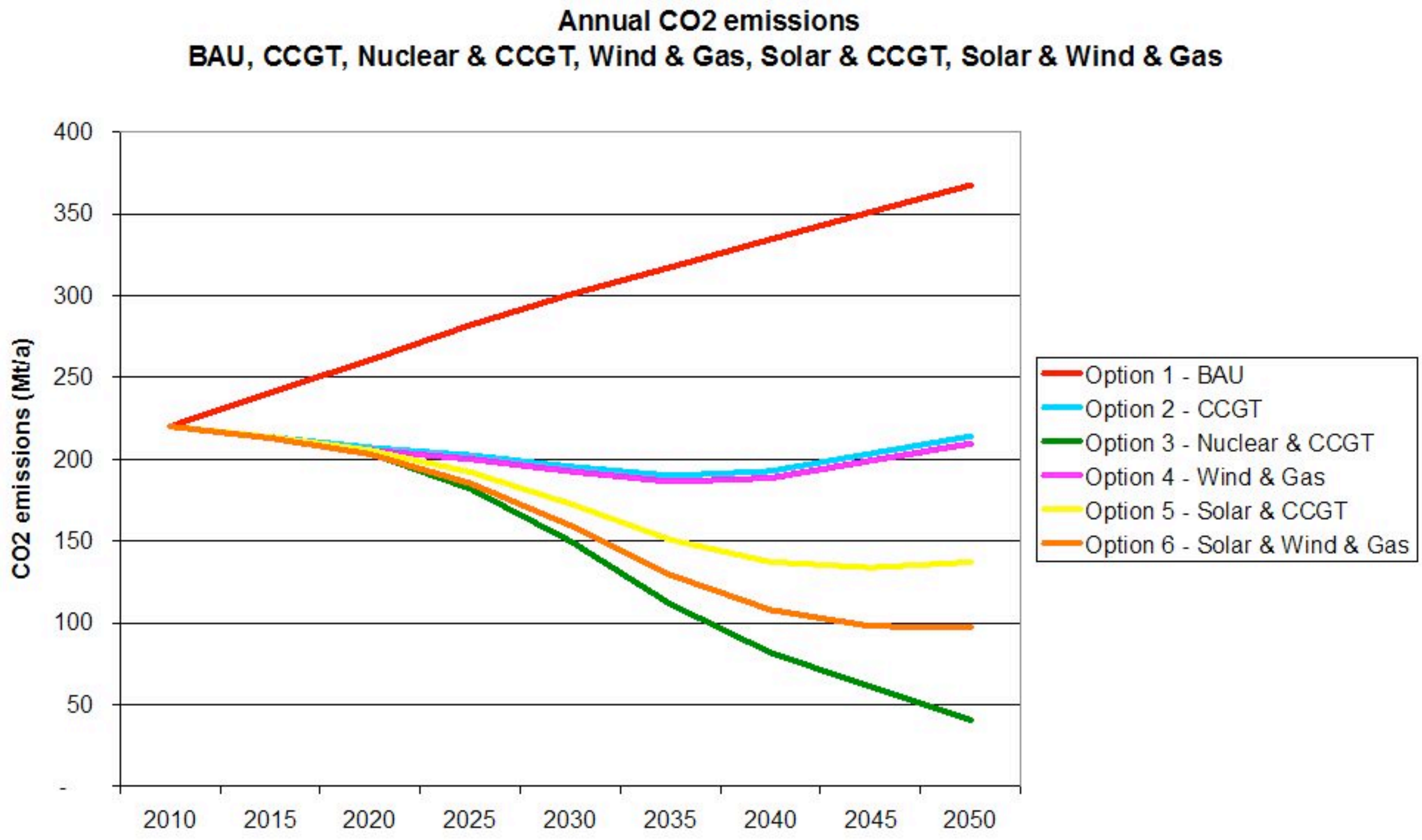
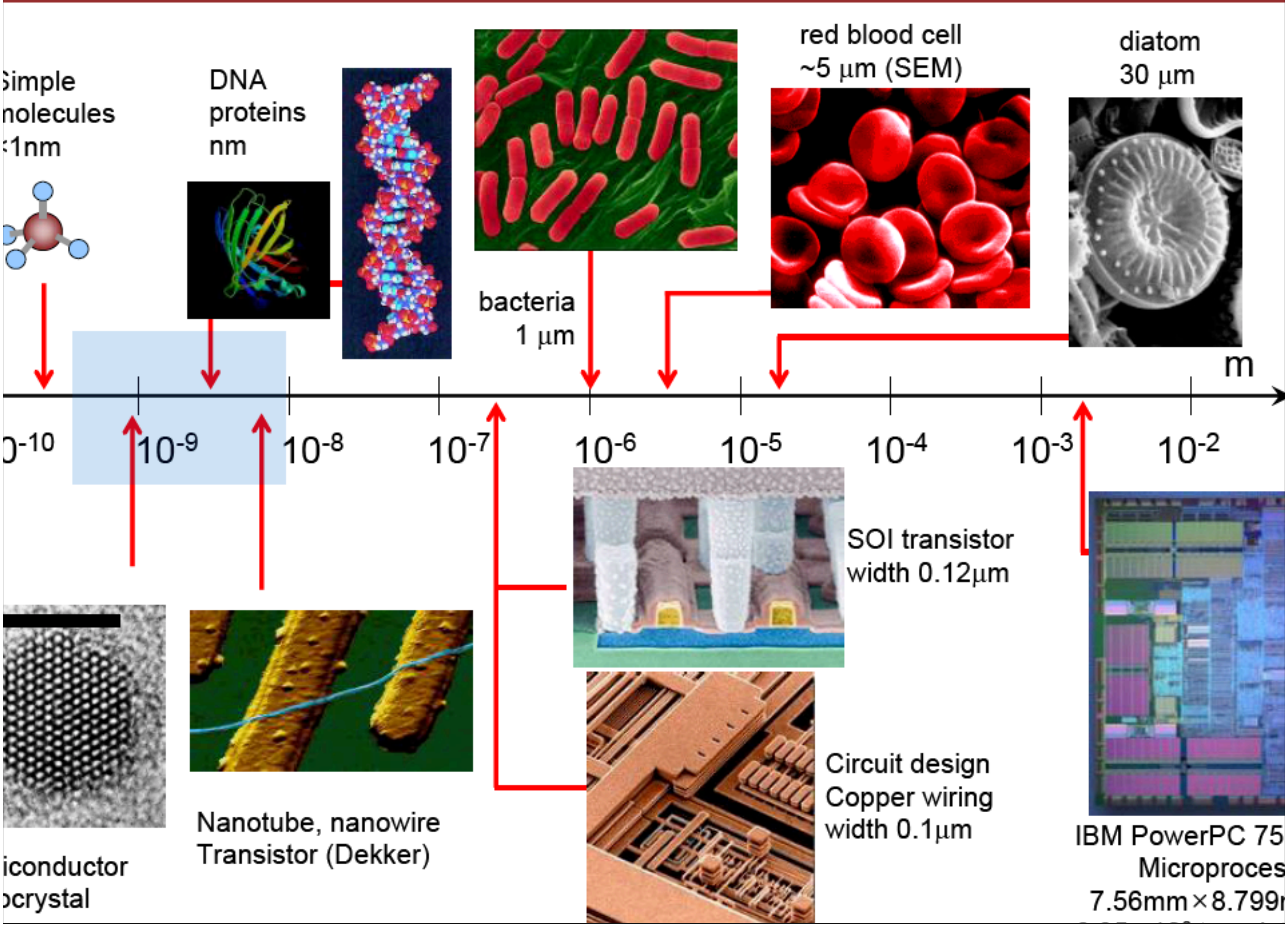


Figure 7: CO_2 emissions per year for the six options

Accelerate Convergence

- Takes Creativity to work around a bottleneck
  - FDA delays : Better use of already approved
  - FDA delays : Medical tourism
  - Low Volumes of carbon nanotubes
    - Increase volumes or use as additives
  - Fully Robotic driving is tough, maybe 2030+
    - Make super cruise control, platoon cars to follow skilled driver (deploy partial solutions

omplexity comparison (Biology vs. current Fab)



Advanced Lithography and

Mainstream: lithography, nanoparticles for medicine and more, carbon nanotubes and other nanotech and nanostructured materials, Scanning Probe Microscopy and other microscopy, aerojet printing, arrays of dip pens, MEMS/NEMS, nano-enhanced regular tech, better sensors, detection devices and tests

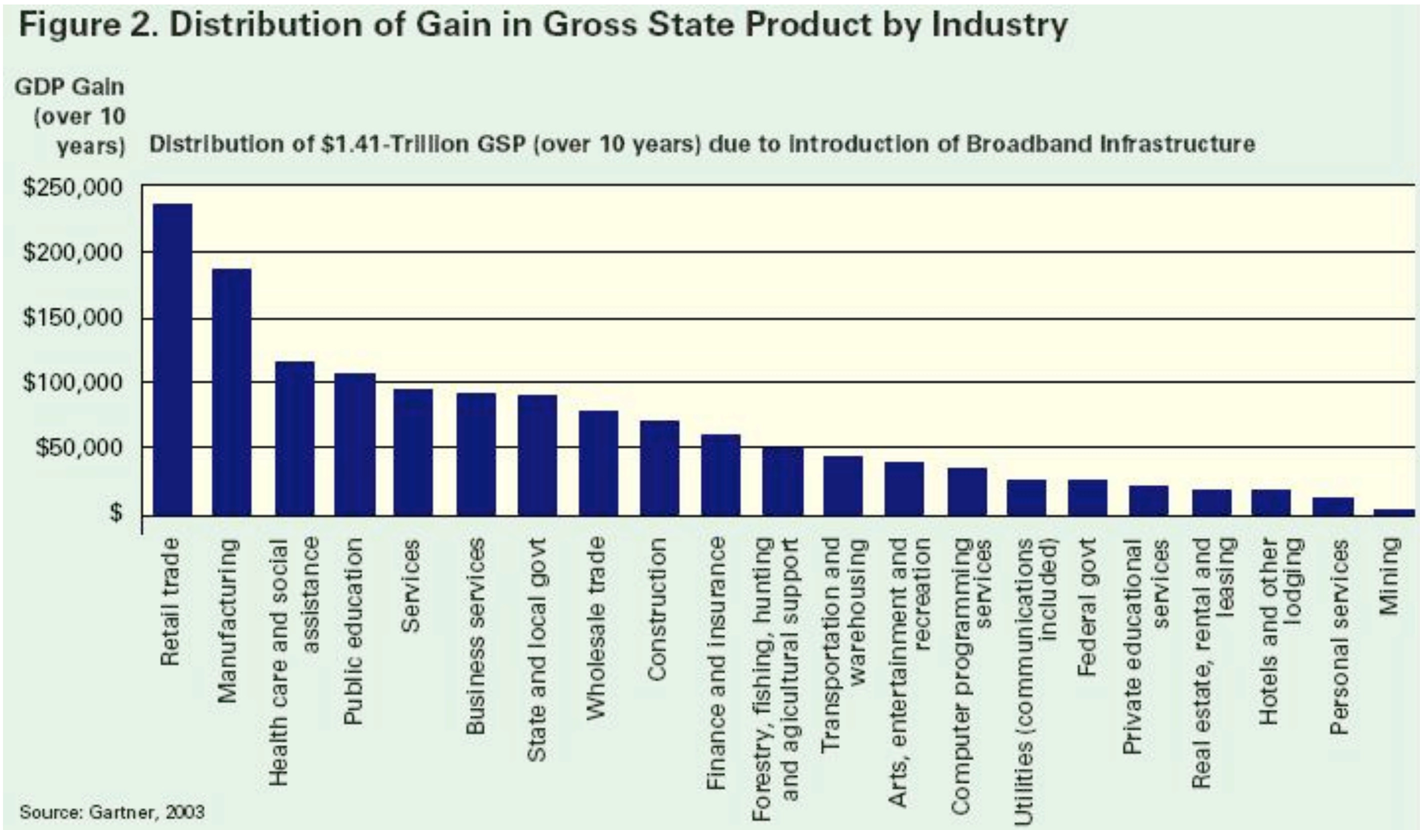
Enabling: Computational Chemistry, Superlenses, Lab on a chip

Progressing: DNA nanotechnology, self assembly, graphene electronics, quantum dots, quantum computing, nanostructures for tissue engineering, nanomembranes/nanofiltration, nanophotonics, molecular electronics, spintronics, plasmonics

Basic capabilities and funded development: atomic layer expitaxy and deposition, mechanosynthesis

Other: RNA, DNA, proteins, avogadro scale computing,

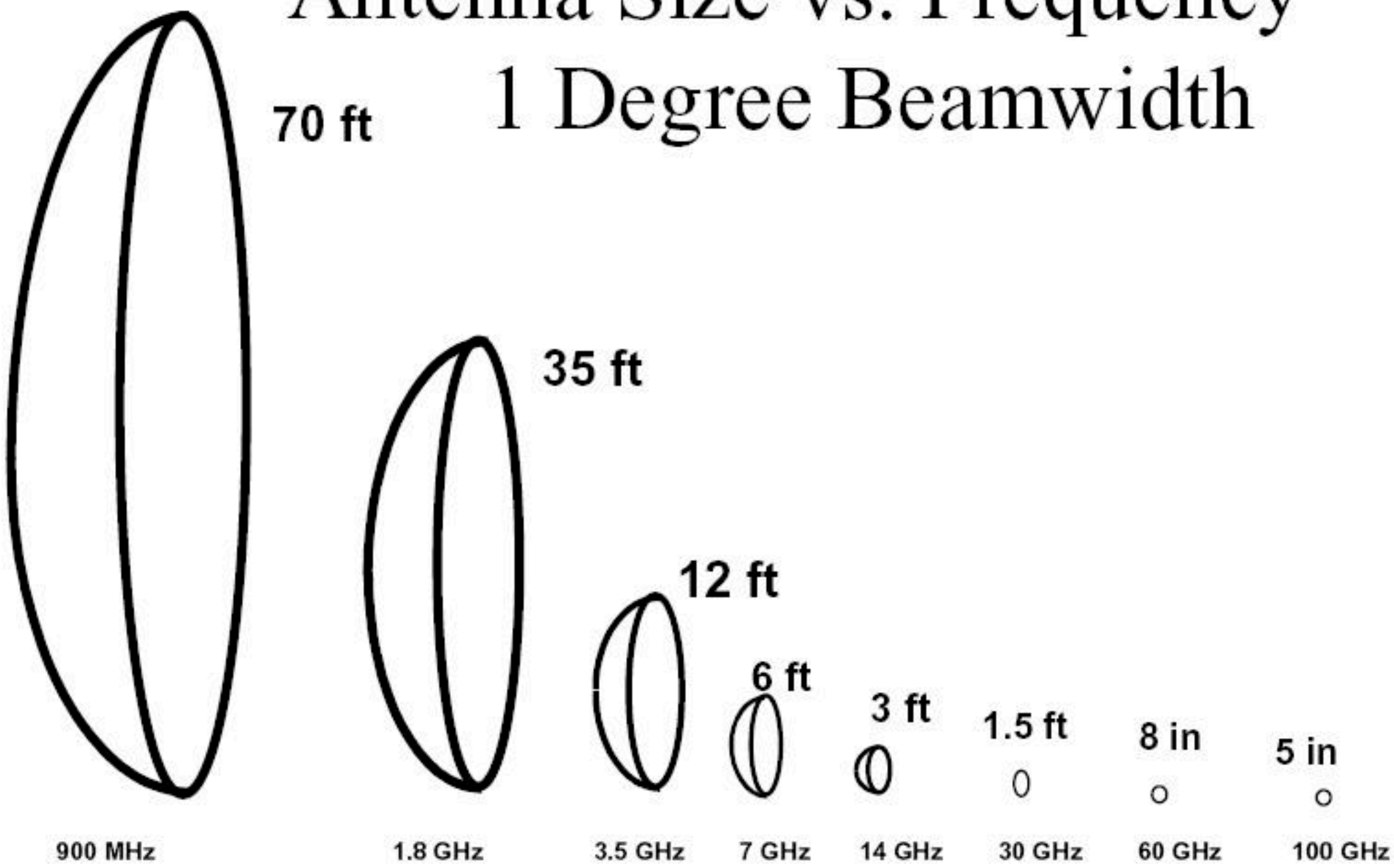
Gains from Broadband



Fiber Trenching Costs

- $25 – $50 K per mile in open farm land
- $250 K to $ 3 Million per mile in urban areas
- Boring
- Trenching
- Encasement
- Splice Points
- Map inaccuracies
- Hand digging zones
- Permits and easements
- Fiber Cuts
- 0.018 per mile per year probability – 15 mile link, 2.4 Hours downtime per year on average

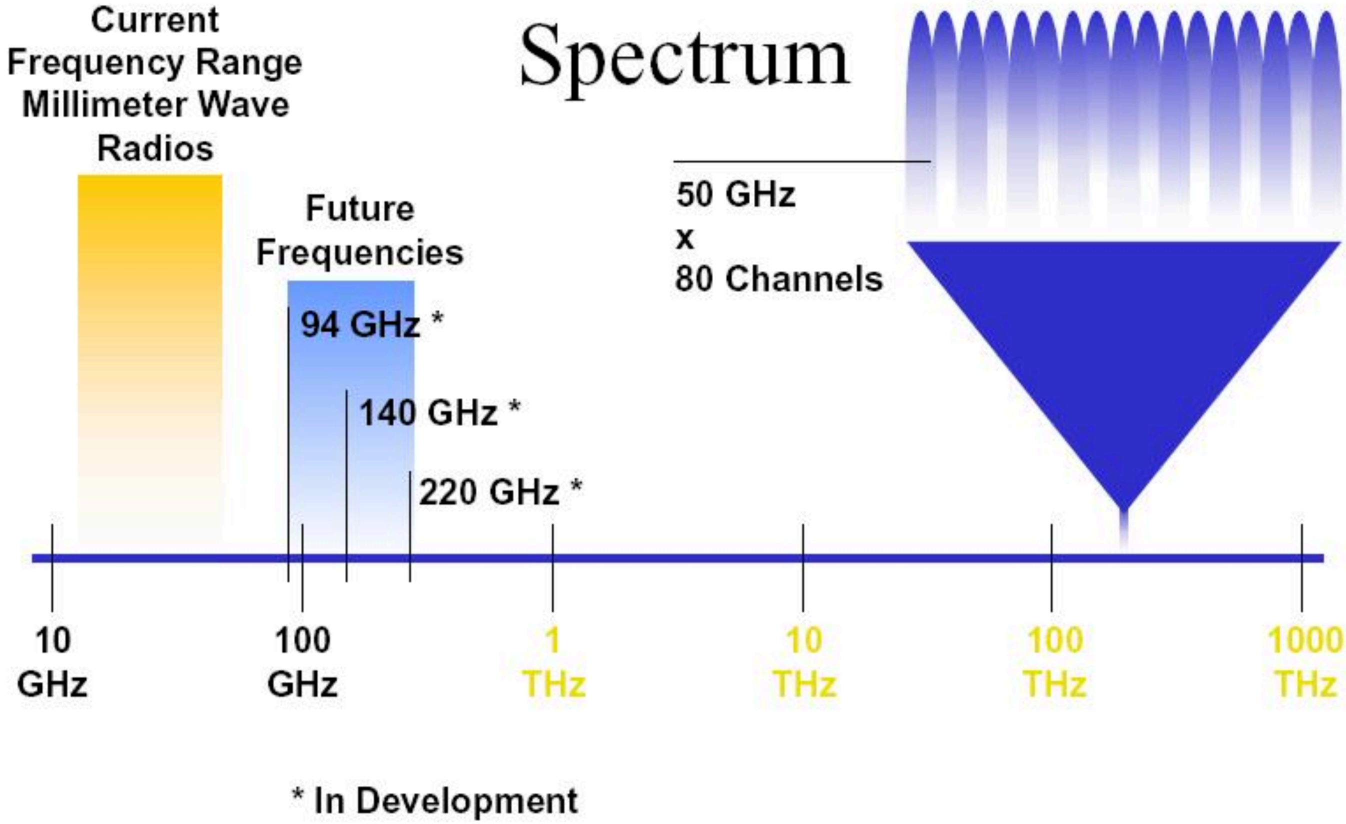
Antenna Size vs. Frequency
1 Degree Beamwidth



Antenna Gain — the Most Cost Effective Link Margin Increase on the Planet

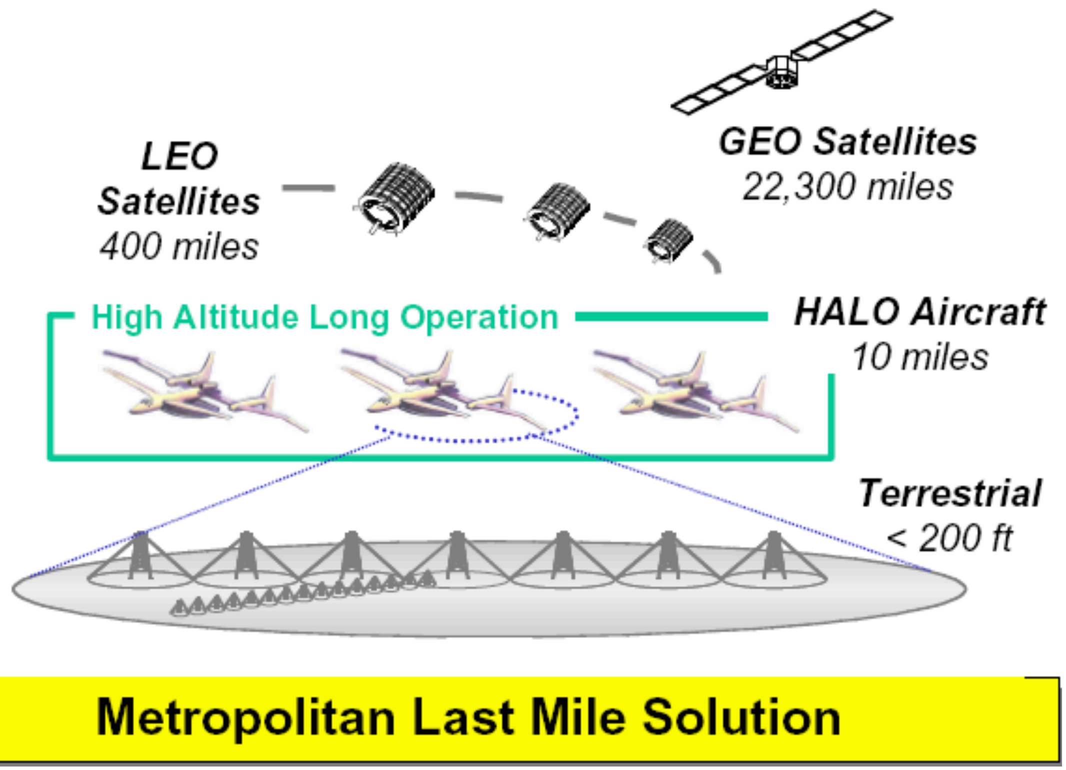
- Conference Room Engineering
- Antenna size in the conference room
- Antenna size on the roof
- Double diameter, multiply the link margin by almost 20X (12dB)
- This is the same as a 1 watt amplifier doing the work of a 20 watt amplifier

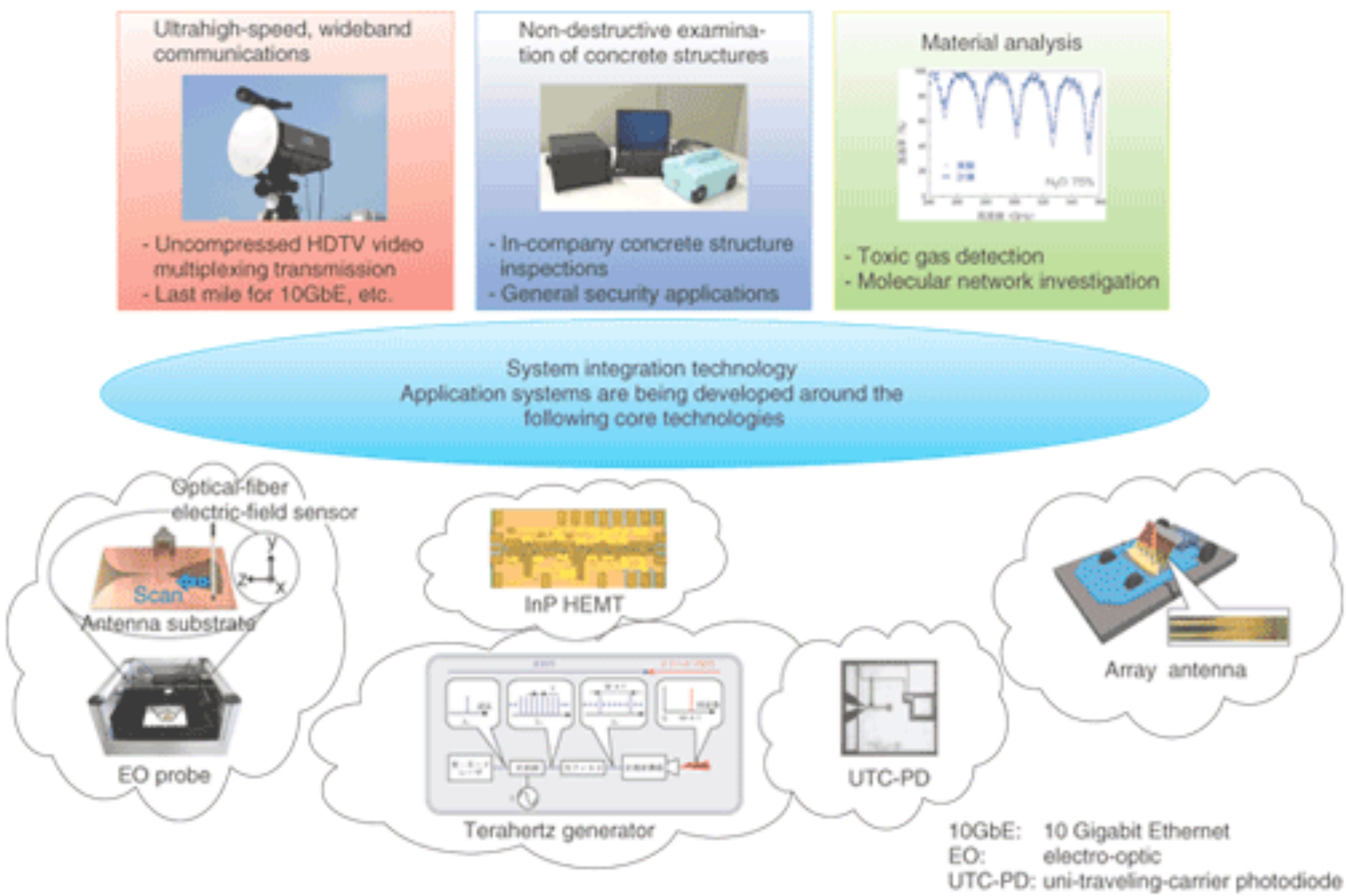
Millimeter Wave & Optical Spectrum



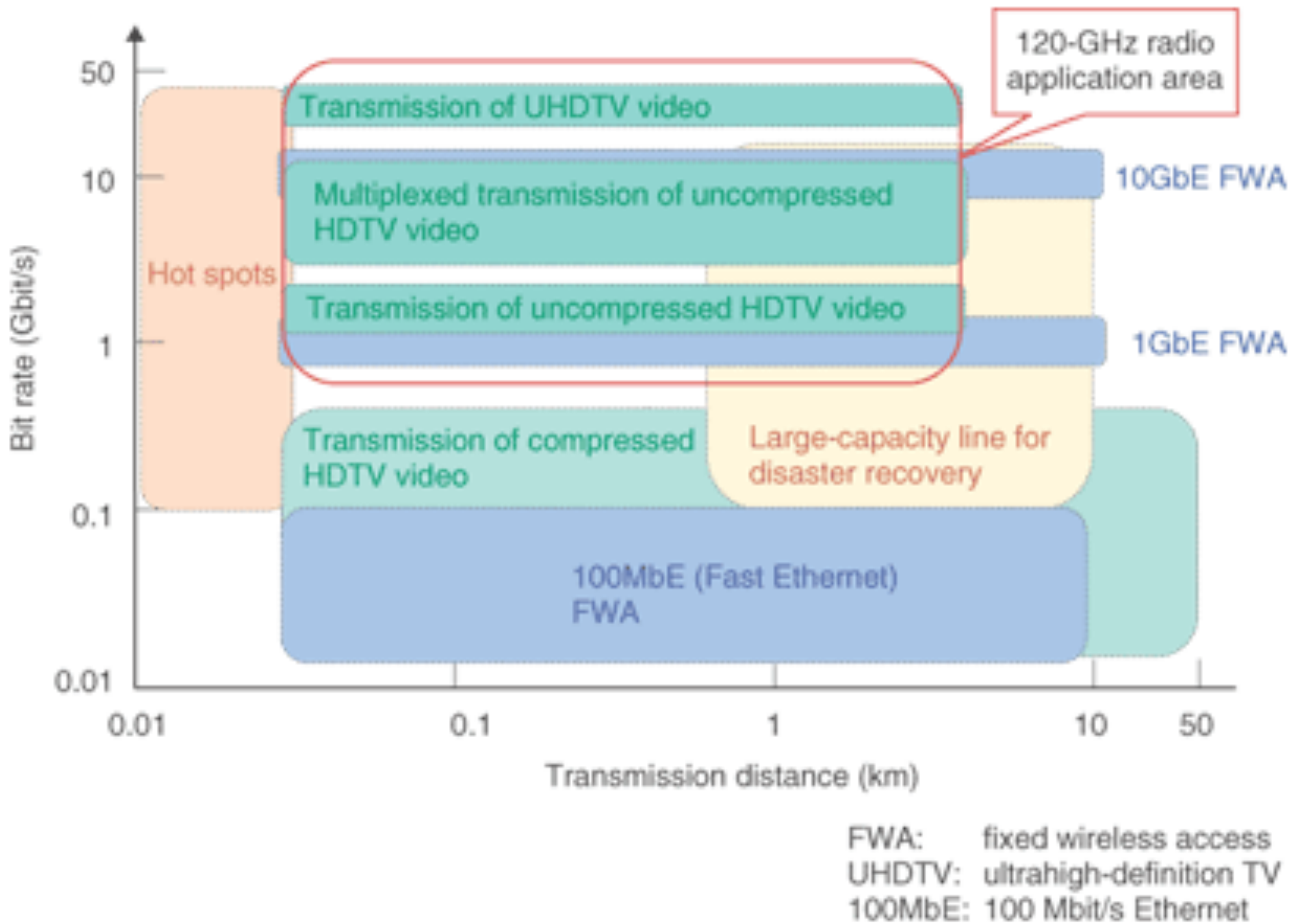
Classic Metro Solutions

Stratospheric, Satellite and Terrestrial Platforms





Ultrahigh-speed, wideband communications
- Uncompressed HDTV video multiplexing transmission
- Last mile for 10GbE, etc.
Non-destructive examination of concrete structures
- In-company concrete structure inspections
- General security applications
Material analysis
- Toxic gas detection
- Molecular network investigation
System integration technology
Application systems are being developed around the following core technologies
Optical-fiber electric-field sensor
Scan
Antenna substrate
EO probe
InP HEMT
Terahertz generator
UTC-PD
Array antenna
10GbE: 10 Gigabit Ethernet
EO: electro-optic
UTC-PD: uni-traveling-carrier photodiode


120-GHz radio application area
50
10
1
0.1
0.01
Bit rate (Gbit/s)
Hot spots
Transmission of UHDTV video
Multiplexed transmission of uncompressed HDTV video
Transmission of uncompressed HDTV video
10GbE FWA
1GbE FWA
Transmission of compressed HDTV video
Large-capacity line for disaster recovery
100MbE (Fast Ethernet) FWA
0.01
0.1
1
10
50
Transmission distance (km)
FWA: fixed wireless access
UHDTV: ultrahigh-definition TV
100MbE: 100 Mbit/s Ethernet

High Impacts Convergence

Nanotech and Physical Tech

- DNA Nanotech
- Carbon Nanotubes
- Graphene
- Boron Nitride Nanotubes
- Quantum Dots

AI, AGI, Info and Software

- GPGPU
- Exaflop Supercomputers
- Quantum Computers

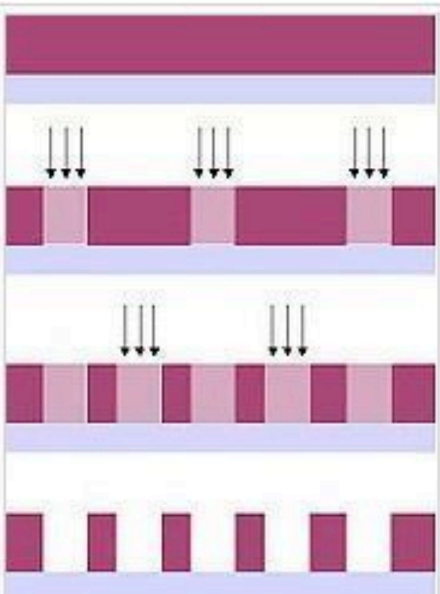
Other High Impact Tech

- Energy
- Fusion Energy
- Superconductors

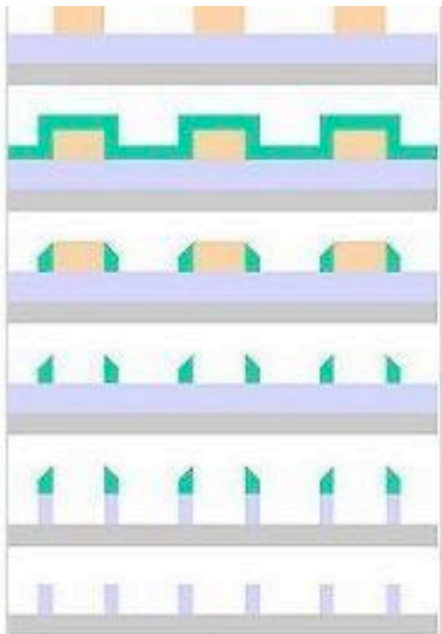
Advanced Lithography

- Double, triple and quadruple patterning (down to 11 nm)
- Computational lithography
- EUV (with quadruple patterning down to 5 nm)
- Nanoimprint (13nm now ➔1-2 nm with CNT)
- Self assembly (down to 2 nm)
- E-beam
- Plasmonic lithography
- Resolution augmentation through photo-induced deactivation (RAPID) lithography 40 nm now (10nm)
- Ion beams

Double, Triple, Quad Litho

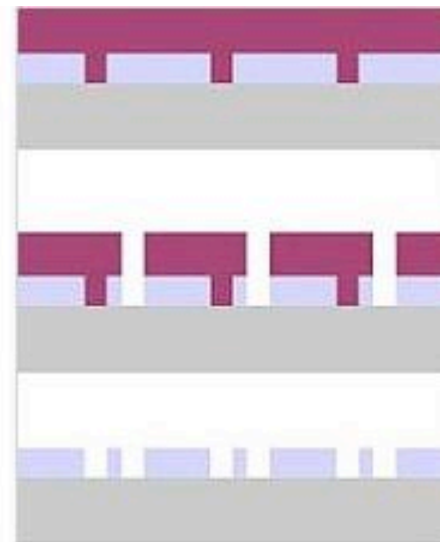


Double exposure: photoresist coating; first exposure; second exposure; development



Spacer mask: first pattern; deposition; spacer formation by etching; first pattern removal; etching with spacer mask; final pattern

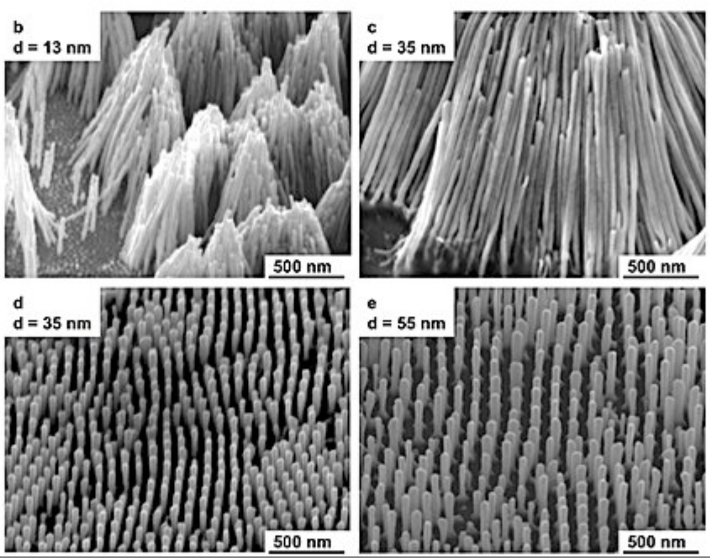
Double Expose, Double Etch (lines): Photoresist coating over first pattern; photoresist features between previous features; etching; mask removal

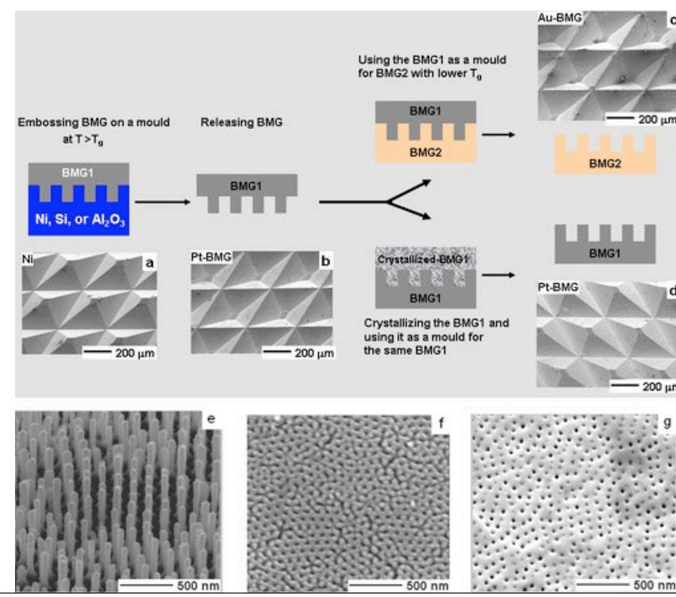


Double Expose, Double Etch (trenches): Photoresist coating over first pattern; etching adjacent to previous features; mask removal

Nanoimprint

- metallic-glass molds can be used millions of times to pattern materials, including polymers like those used to make DVDs. Schroers Yale group used the molds to create three-dimensional microparts such as gears and tweezers, as well as much finer structures. Feb 2009 Journal nature paper : molds with features as small as 13 nanometers.
- Theoretic size limit is the size of a single atom for the metallic-glass molds. Yale researchers hope to make molds that can form even finer structures by controlling the surface chemistry of the





Beyond CMOS

Emerging Research Device Technology Candidates are being evaluated. A list of devices being considered to go beyond CMOS.
- Nano-electro Mechanic Switches
- Collective Spin Devices
- Spin Torque Transfer Devices
- Atomic Switch / Electrochemical Metallization
- Carbon-based

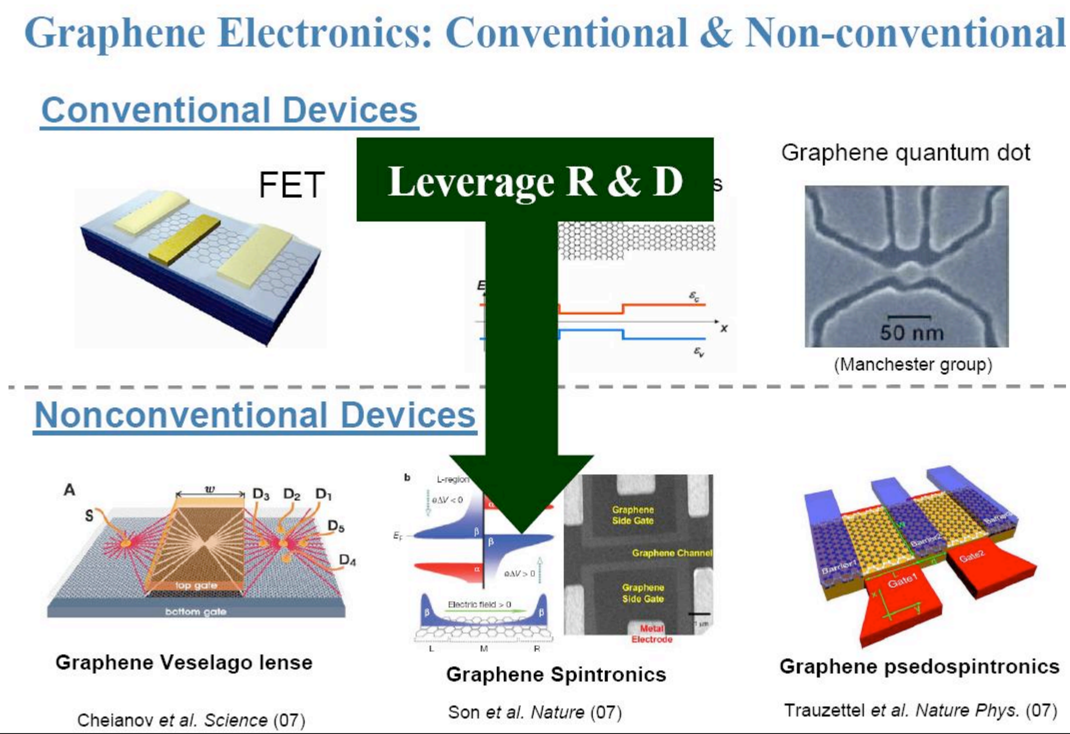
2007 ITRS ERD

Emerging Research Logic Devices Evaluated

Device							
		FET Extension					
	FET [A]	*1D structures*	*Channel replacement*	*SET*	*Molecular*	*Ferromagnetic logic*	*Spin transistor*
Typical example devices	Si CMOS	CNT FET NW FET NW hetero-structures Nanoribbon transistors with graphene	III-V compound semiconductor and Ge channel replacement	SET	Crossbar latch Molecular transistor Molecular QCA	Moving domain wall M: QCA	Spin Gain transistor Spin FET Spin Torque Transistor

ITRS 2008 Summer

- **Carbon-based Nanoelectronics to include carbon nanotubes and graphene**
- **For additional resources and detailed road mapping for ITRS as promising technologies targeting commercial demonstration in the**



Nano-enhanced Regular

- Concrete and metal
  - Research on the nanoscale that provides insight into improved control of the properties
  - Nanograins for metal, almost no-creep concrete
- Hydrophobic sand
  - Desert sand made hydrophobic by additive SP-HFS 1609
  - The large rolls sandwich the sand between layers of polyethylene and can be produced in lengths of up to 50 metres. "The coating is done in 30 or 45 seconds," said Hareb. "We have the capacity of manufacturing 3,000 tonnes per day."
- Engineering properties : composites, polymers, doping

* Larger holes (4-5nm) in zeolite for more efficient oil refining. Crack larger molecules

* Cars, planes, buildings, subs

Nanoparticles

- Nanoparticles for diagnosis and delivery of medicine
- Tobacco mosaic virus is like a 18-nanometer wide straw, which can hold gene silencing RNA
- 2007 total market for nanotechnology-enabled drug

		Percentage siRNA delivery and RNAi response by cell type				
	Use	Less than 10%	Less than 25%	Less than 50%	Less than 75%	Greater than 99%
PTD-DRDB	Therapeutics, Screening & Target Validation				Neuronal cells	Primary cells Tumor cells B cells T cells Macrophage Stem cells Fibroblasts Melanoma Adenocarcinoma Carcinoma Glioblastoma Keratinocyte
Liposomes	Therapeutics		B cells T cells Macrophage Neuronal cells Stem cells Fibroblasts	Primary cells Melanoma	Tumor cells Adenocarcinoma Carcinoma Glioblastoma Keratinocyte	
Lipofection (e.g. Lipofectamine)	Screening & Target Validation	B cells T cells Macrophage	Neuronal cells Stem cells Fibroblasts Melanoma	Primary cells	Tumor cells Adenocarcinoma Carcinoma Glioblastoma Keratinocyte	

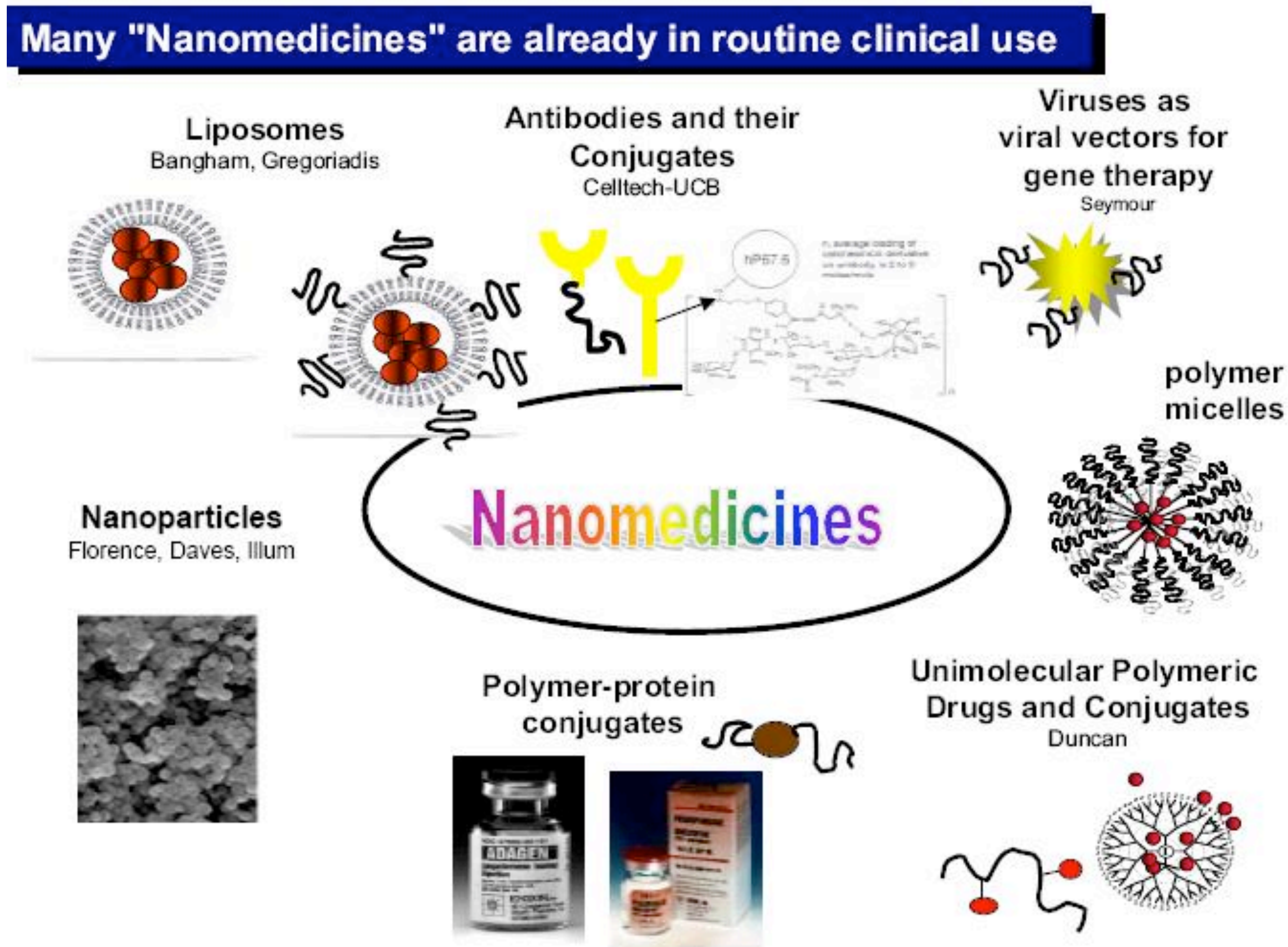
Table 1: PTD-DRBD vs. Liposome & Lipofectamine siRNA Delivery. Note that PTD-DRDB achieves RNAi response in greater than 99% of cells in virtually all cell types. Also note that Lipofection is the most broadly used agent for siRNA delivery in vitro, but is not viable for therapeutics delivery.

Nanomed today

Nanoparticles is a microscopic particle with at least one dimension less than 100 nm.

Liposomes is a spherical vesicle composed of a bilayer membrane. In biology, this specifically refers to a membrane composed of a phospholipid and cholesterol bilayer

Antibody conjugates
A conjugate vaccine is created by covalently attaching a poor antigen to a carrier protein, thereby conferring the immunological attributes of the carrier on the attached antigen. This technique for the creation of an effective immunogen is most often applied to bacterial polysaccharides for the prevention of invasive bacterial disease.



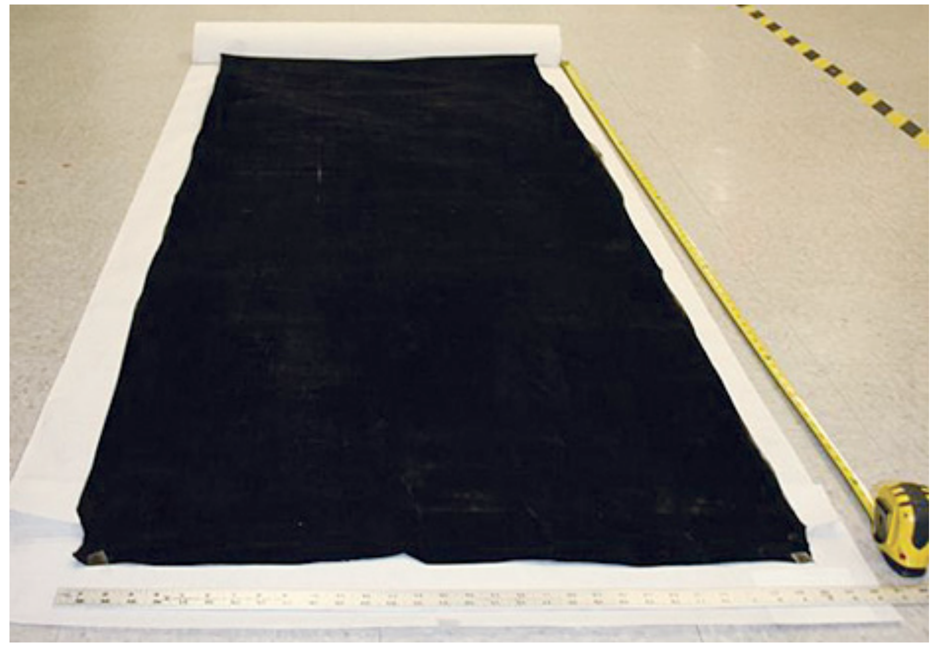
Carbon nanotubes

- 500 ton/year factory : Cnano Technologies
- Context (carbon fiber, kevlar, copper, steel, cement)
- Kevlar reinforced with carbon nanotubes
- Nanocomp Techologies
- CNT-reinforced aluminum is only around one third that of steel, but is as hard as steel (Bayer Materials work)
  - Could become cheaper than alloy method for making strong aluminum
- Lunar cement and concrete
  - 2.4-metre mirror like Hubble's, Peter Chen (NASA

Nanocomp Technologies

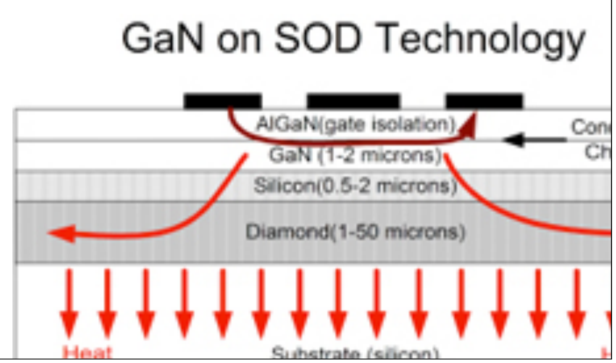
- Nanocomp's has high-volume production of very long CNTs (approximately one millimeter in length), and then processing the nanotubes into contiguous macrostructures (4ftx8ft mats). Over the past 18 months, the company has been distributing CNT yarn into the marketplace, recently delivering the 10 kilometer shipment to meet its customer's volume and performance specifications. Highly conductive products are lighter and stronger than aluminum, can be draped like a cloth or spun like a yarn or wire
- provide electrostatic discharge (ESD) and electromagnetic interference (EMI) shielding components.
- The electrical properties of the sheets are already superior to existing materials by weight for applications like radiation and electromagnetic shielding
- They can achieve the same electromagnetic shielding at one third to one half of the weight of traditional material (copper wires)
- Superior electrical properties already exist for antennas

CNT Yarn and Sheets



Diamond

- Switch higher frequencies (10-120 Ghz) and voltages for power chips (MESFET, rf, 100 watt x-bands)
- High power devices applications include satellite communications, telecoms base stations and compact, high resolution phased-array radars
- 2 tons of power electronics per railcar can be 50 pounds
- Great thermal conductivity, reaching 2,000 Wm-1°C-1 for mono-crystal, which is the highest of any solid material (4-5X higher than silicon carbide and copper)
- diamond is vastly better substrate
- Single crystal diamond across wafers much bigger than an inch and a half
- polycrystalline diamond films (5 nm grains of carbon, 20-30 atoms across)



Properties

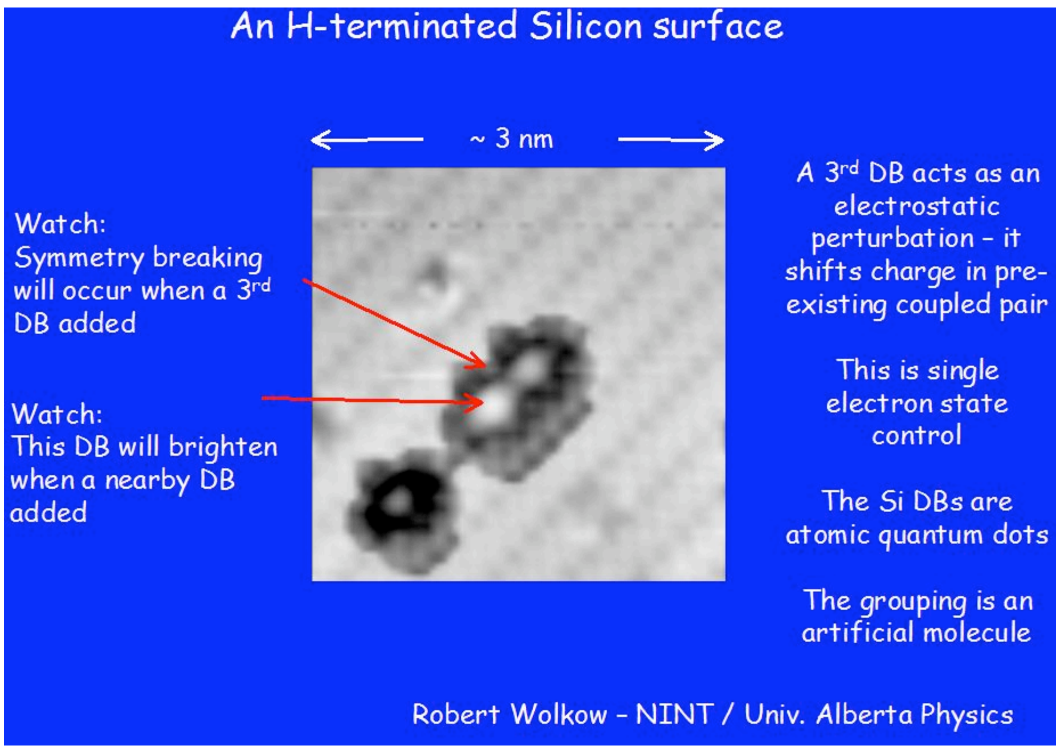
- Strength of materials
- Conductance
- Electron mobility
- Thermal properties
- Do more or better with less material (stronger, electrical properties)
- Do something completely new

Microscopy

- STM
- SPM
- AFM
- Superlenses
- Hyperlens
- Dip pen nanolithography
- Arrays of tips
- Zyvex/DARPA tip based research project

Quantum Dots

- Single molecule quantum dots
- Bulk production of quantum dots



Computational Chemistry

- **Computational chemistry** is a branch of chemistry that uses computers to assist in solving chemical problems
- Computing power and methods have advanced to where it is now possible to use molecular simulations to predict important engineering properties of real materials with a high degree of accuracy.
- Anton Supercomputer, Nvidia Tesla
- NanoEngineer-1 is an open-source (GPL) 3D multi-scale modeling and simulation program for nano-composites with special support for structural DNA nanotechnology.

DNA Nanotechnology

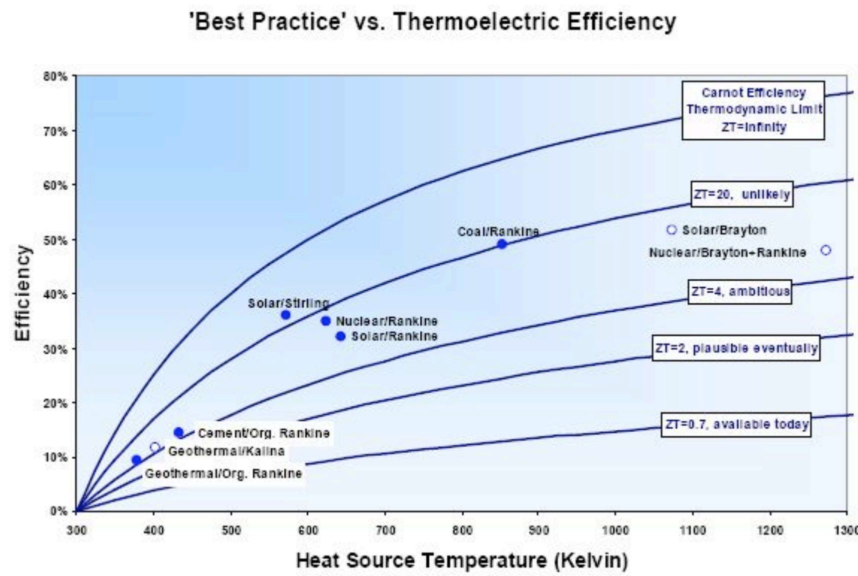
- DNA origami
- DNA movement and placement of nanoparticles and carbon nanotubes
- New bases and chemistry
- DNA separation of carbon nanotubes

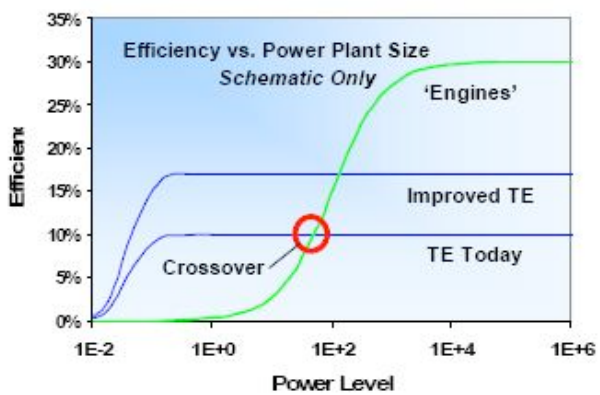
Nanopantography

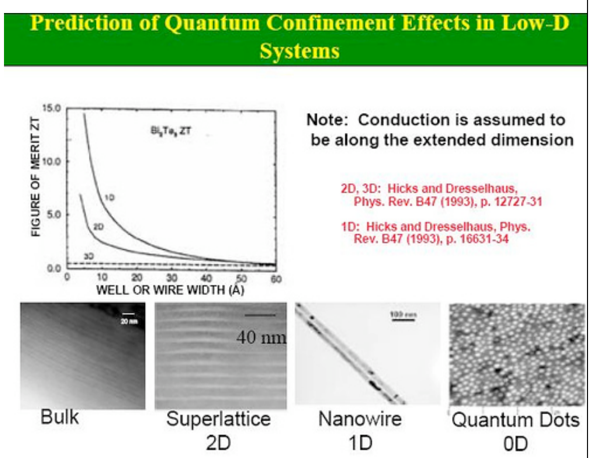
- Nanopantography uses microlenses placed on a substrate (the surface that is being written upon) to divide a single ion beam into billions of smaller beams, each of which writes a feature on the substrate for nanotech device production
- simultaneous impingement of an Ar^+ beam and a Cl_2 effusive beam on an array of 950-nm-diam lenses can be used to etch 10-nm-diam features into a Si substrate, a reduction of 95x.
- Simulations indicate that the focused “beamlet” diameters scale directly with lens diameter, thus a minimum feature size of 1 nm should be possible with 90-nm-diam lenses that are at the limit of current photolithography.
- We expect nanopantography to become a viable method for overcoming one of the main obstacles in practical nanoscale fabrication: rapid, large-scale fabrication of virtually any shape

Thermoelectric

- Silicon nanowires. ZT 0.6-1.0
- quantum wells that get 4.5ZT
- thallium-doped lead telluride ZT 1.5 ➔3.0
- Recover waste heat of cars and trucks
- Power passenger cooling and heating







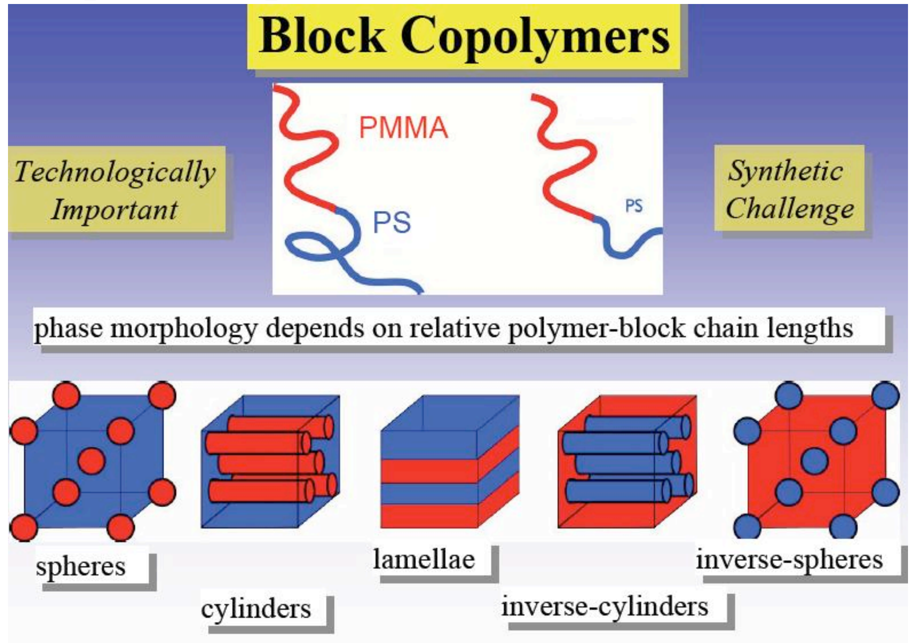
Roadmap

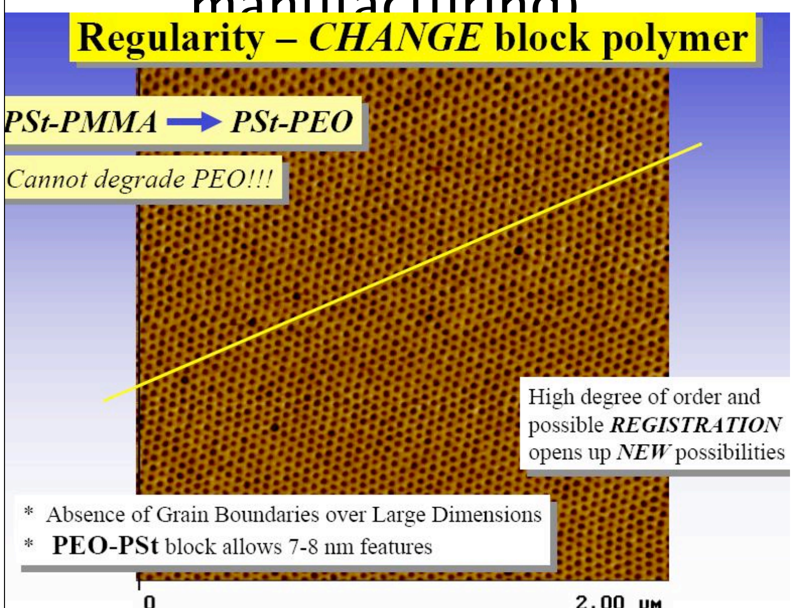
Development Area	Horizon I	Horizon II	Horizon III
Atomically Precise Fabrication and Synthesis Methods	• Bio-based productive nanosystems (ribosomes, DNA polymerases) • Atomically precise molecular self-assembly • Tip-directed (STM, AFM) surface modification • Advanced organic and inorganic synthesis	• Artificial productive nanosystems in solvents • Mechanically directed solution-phase synthesis • Directed and conventional self-assembly • Crystal growth on tip-built surface patterns • Coupled-catalyst systems	• Scalable productive subsystems in machine-phase environments • Machine-phase synthesis of exotic structures • Multi-scale assembly • Single-product, high-throughput molecular assembly lines
Atomically Precise Components and Subsystems	• Biomolecules (DNA- and protein-based objects) • Surface structures formed by tip-directed operations • Structural and functional nanoparticles, fibers, organic molecules, etc.	• Composite structures of ceramics, metals, and semiconductors • Tailored graphene, nanotube structures • Intricate, 10-nm scale functional devices	• Nearly reversible spintronic logic • Microscale 1 MW/cm^3 engines and motors • Complex electro-mechanical subsystems • Adaptive supermaterials
Atomically Precise Systems and Frameworks	• 3D DNA frameworks, 1000 addressable binding sites • Composite systems of the above, patterned by DNA-binding protein adapters • Systems organized by tip-built surface patterns	• Casings, "circuit boards" to support, link components • 100-nm scale, 1000-component systems • Molecular motors, actuators, controllers • Digital logic systems	• Complex systems of advanced components, micron to meter+ scale • 100 GHz, 1 GByte, 1 μm-scale, sub-μW processors • Ultra-light, super-strength, fracture-tough structures
Applications	• Multifunctional biosensors • Anti-viral, -cancer agents • 5-nm-scale logic elements • Nano-enabled fuel cells and solar photovoltaics, • High-value nanomaterials • Artificial productive nanosystems	• Artificial immune systems • Post-silicon extension of Moore's Law growth • Petabit RAM • Quantum-wire solar photovoltaics • Next-generation productive nanosystems	• Artificial organ systems • Exaflop laptop computers • Efficient, integrated, solar-based fuel production • Removal of greenhouse gases from atmosphere • Manufacturing based on productive nanosystems

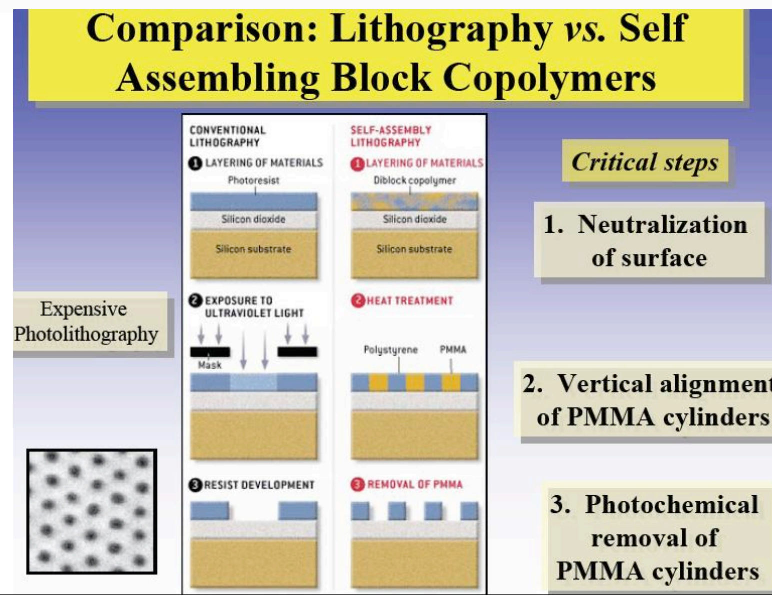
Block Co-polymers

- Block copolymers

UCSB claims self assembly block co-polymer features on silicon (5-20nm). Making improvements (like cross linking for faster manufacturing)







Plasmonic Lithography

Engineers at the University of California, Berkeley, are reporting a new way of creating computer chips that could enable commercial speed 5 nanometer optical lithography. It can also mean higher density hard drives and optical disks with 20 times the density of Blu-ray.

The 5 page research paper: Flying plasmonic lens in the near field for high-speed nanolithography, Published online: 12 October 2008; doi: 10.1038/nnano.2008.303.

The researchers designed an air bearing that uses the aerodynamic lift force created by the spinning to help keep the two surfaces a mere 20 nanometers apart.

Air bearings are used to create magnetic tapes and disk drives, but this is the first application for a plasmonic lens.

With this innovative setup, the engineers demonstrated scanning speeds of 4 to 12 meters per second.

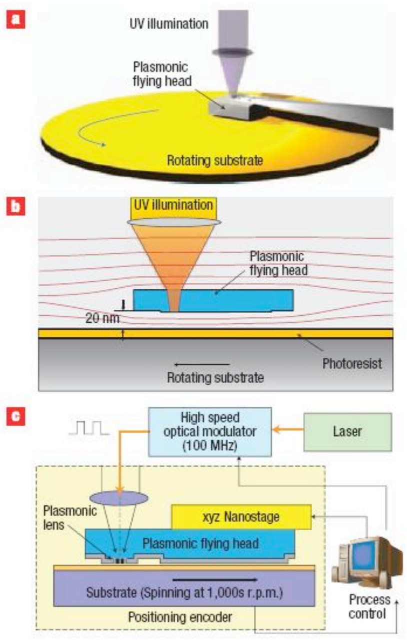
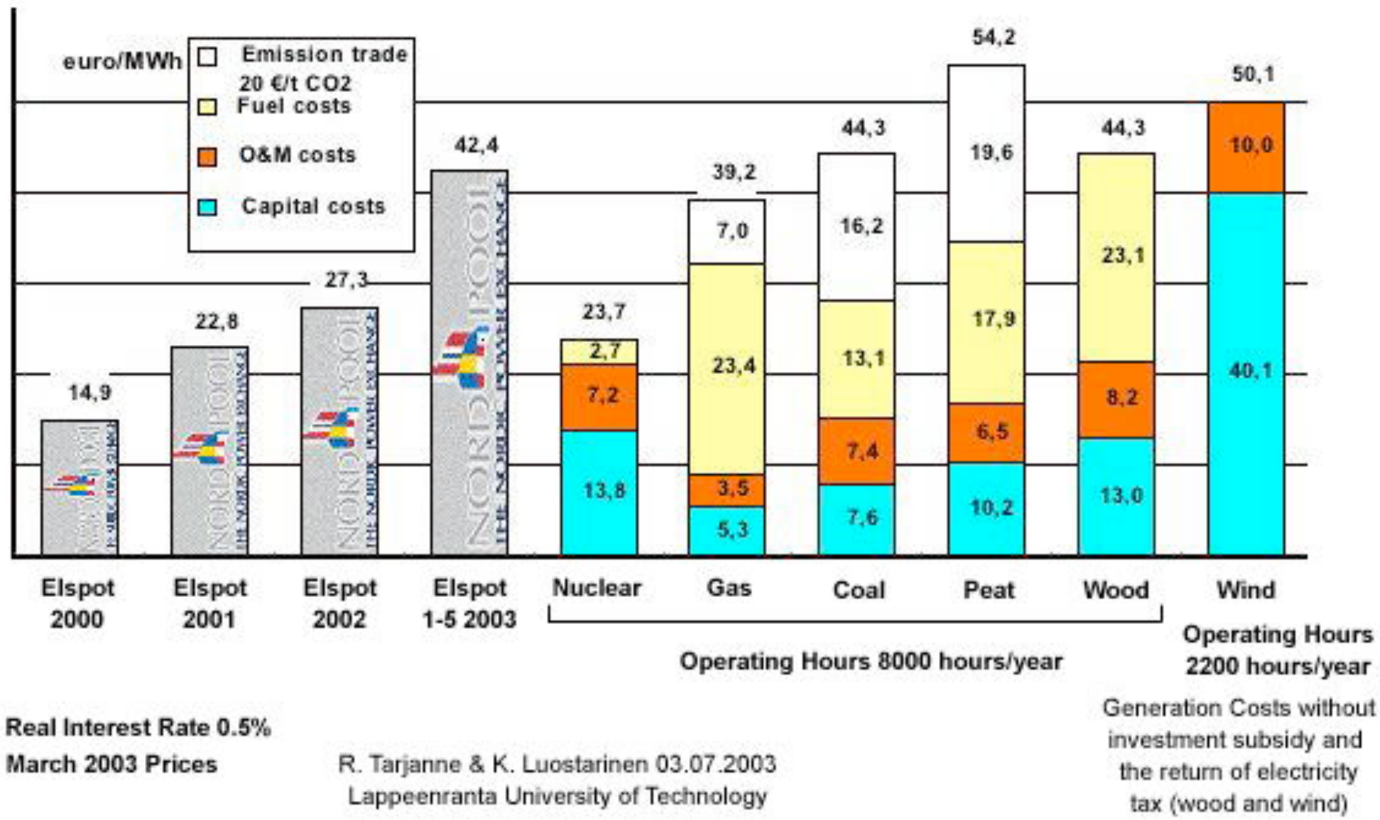


Figure 1 High-throughput maskless nanolithography using plasmonic lens arrays. a, Schematic showing the lens array focusing ultraviolet (365 nm) laser pulses onto the rotating substrate to concentrate surface plasmons into sub-100 nm spots. However, sub-100 nm spots are only produced in the near field of the lens, so a process control system is needed to maintain the gap between the lens and the substrate at 20 nm. **b**, Cross-section schematic of the plasmonic head flying 20 nm above the rotating substrate which is covered with photoresist. **c**, Schematic of process control system. The laser pulses are controlled by a high-speed optical modulator according to the signals from a pattern generator. The writing position is referred to the angular position of the disk from the spindle encoder and the position of a nano-stage along the radial direction.

Energy Costs



Nuclear plant: projected electrcity costs (c/kWh)

Overnight capital cost $/kW		1200	1500	1800
First unit	7 yr build, 40 yr life	5.3	6.2	7.1
	5 yr build, 60 yr life	4.3	5.0	5.8
4th unit	7 yr build, 40 yr life	4.5	4.5	5.3
	5 yr build, 60 yr life *	3.7	3.7	4.3
8th unit	7 yr build, 40 yr life	4.2	4.2	4.9
	5 yr build, 60 yr life *	3.4	3.4	4.0

* calculated from above data

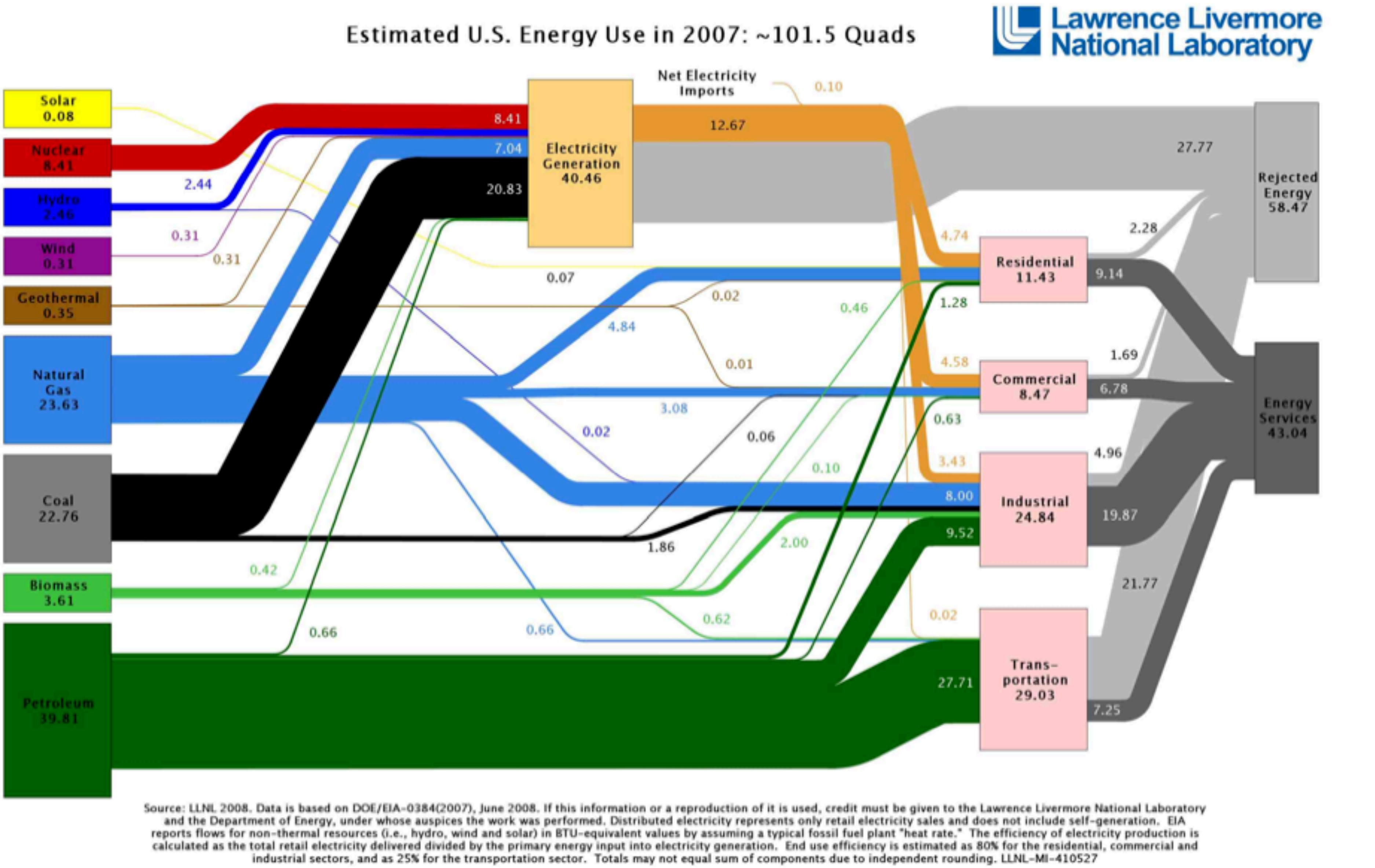
	Overnight capital cost (2008 $/kW)	Electricity cost (c/kWh)
nuclear	4038	8.34
supercritical coal	2214	8.65
supercritical coal +CCS	4037	14.19
IGCC	2567	9.22
IGCC + CCS	3387	12.45
gas combined cycle	869	7.60
gas combined cycle + CCS	1558	10.31

CCS = carbon capture & storage

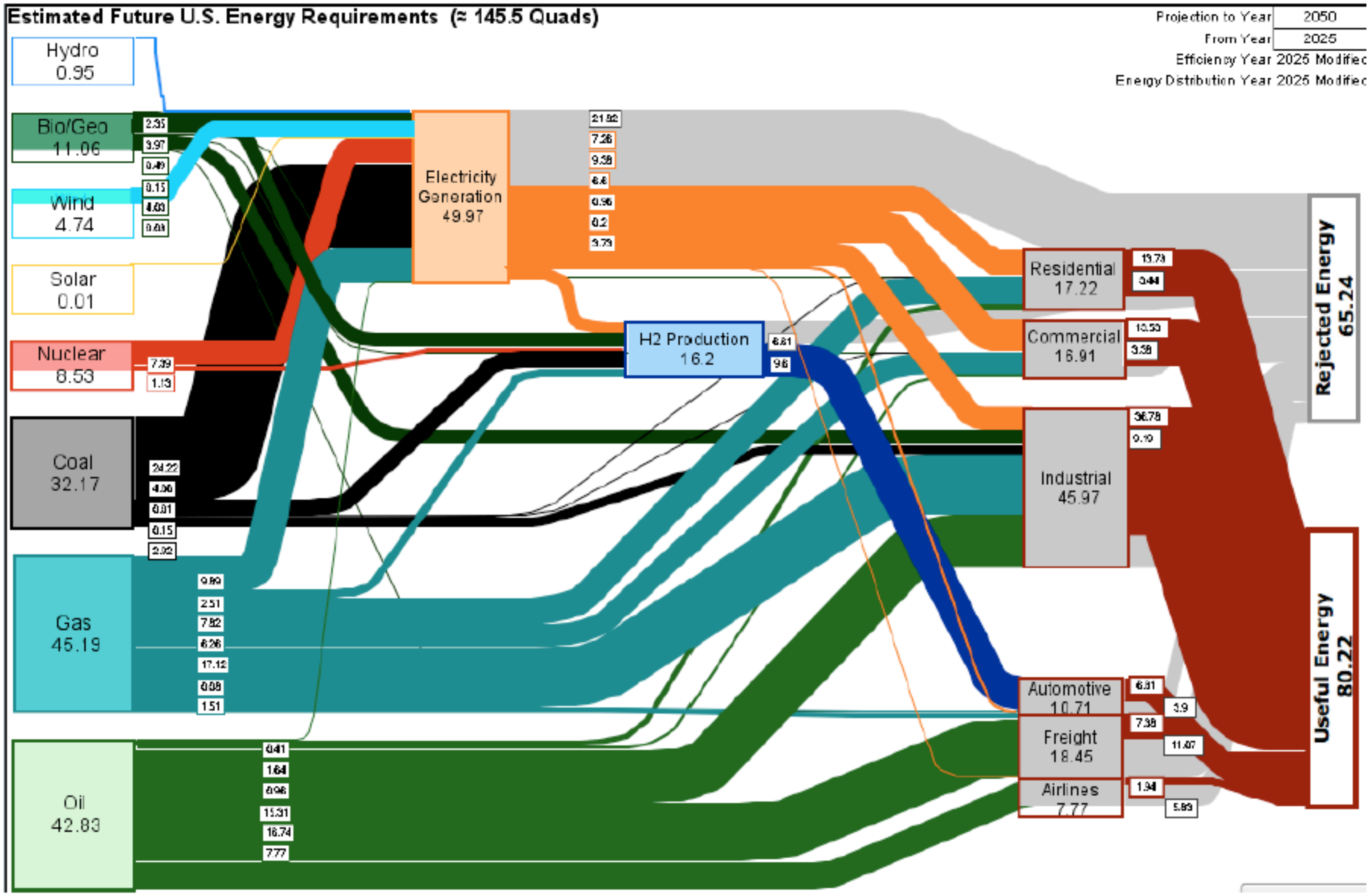
Uranium:	8.9 kg U_3O_8 x $53	US$ 472
Conversion:	7.5 kg U x $12	US$ 90
Enrichment:	7.3 SWU x $135	US$ 985
Fuel fabrication:	per kg	US$ 240
Total, approx:		US$ 1787

At 45,000 MWd/t burn-up this gives 360,000 kWh electrical per kg, hence fuel cost: 0.50 c/kWh.

Energy Use 2007

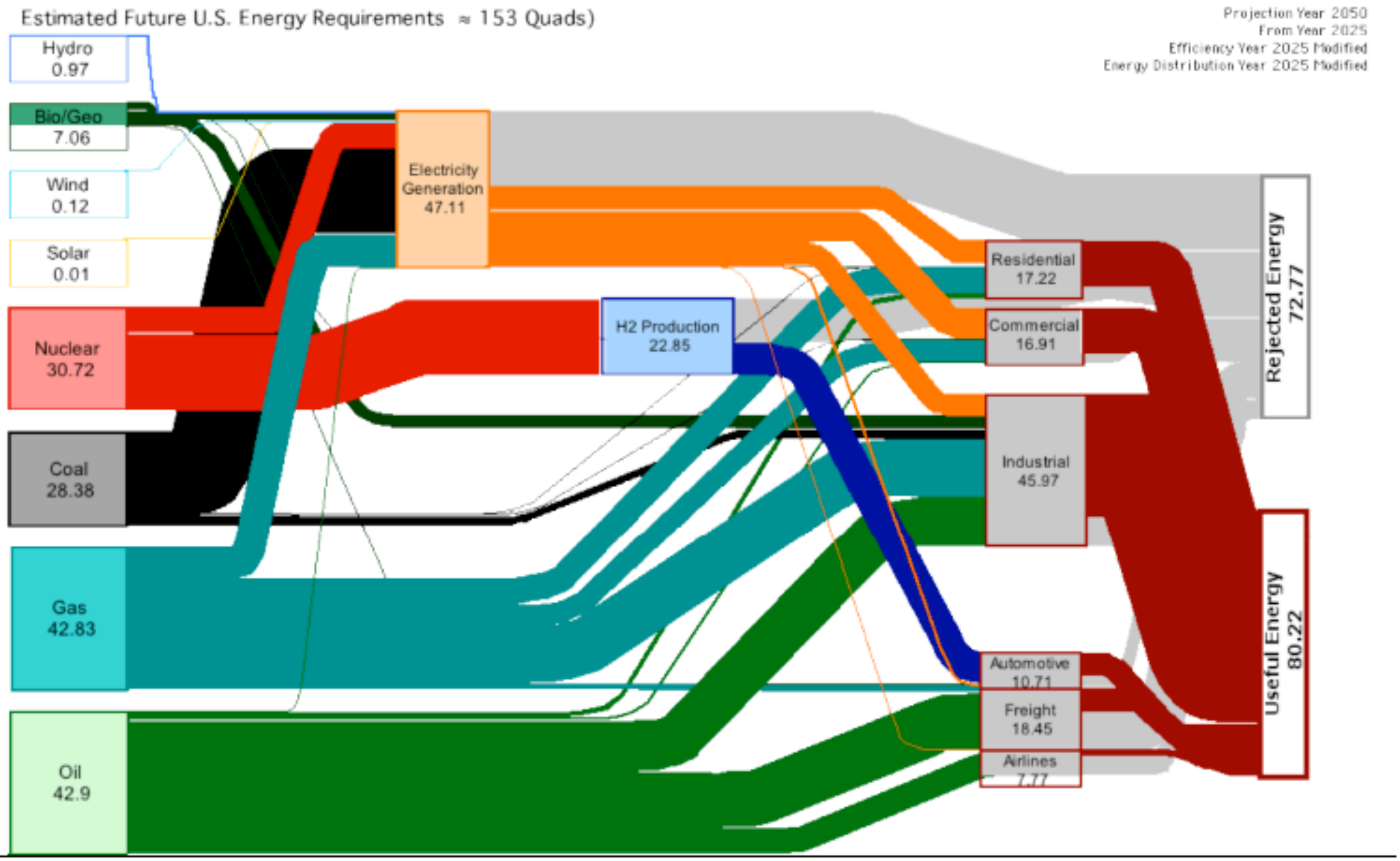


LLNL Scenario for 2050



U.S. Energy flow scenario for the year 2050, based on linear extrapolation of EIA 2025 reference projection modified to include a) 50% efficient electricity generation, and b) 318 million "80 mpg" H_2 fuel cell vehicles

2004 LLNL Nuclear Scenario for 2050



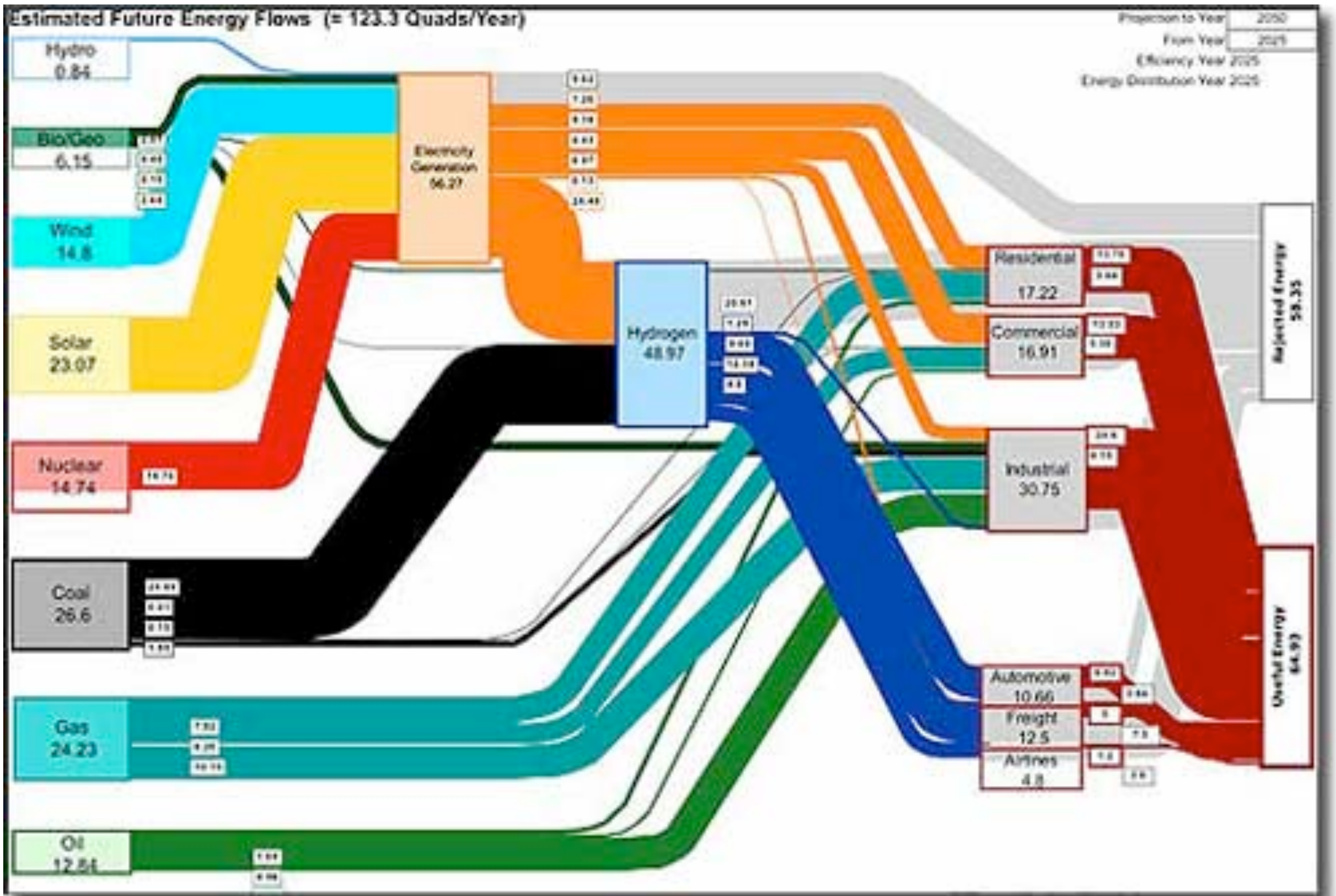
Scenario 12. The U.S. light-duty fleet transitions to "80 mpg" 10,000 psi compressed hydrogen (H_2) fuel cell vehicles by 2050. 23 Quads of nuclear fuel produce 100 million tonnes of H_2/yr with 42% efficiency (LHV basis) using the Sulfur-Iodine cycle.

Conventional Stretch

LLNL Stretch Energy Scenarios

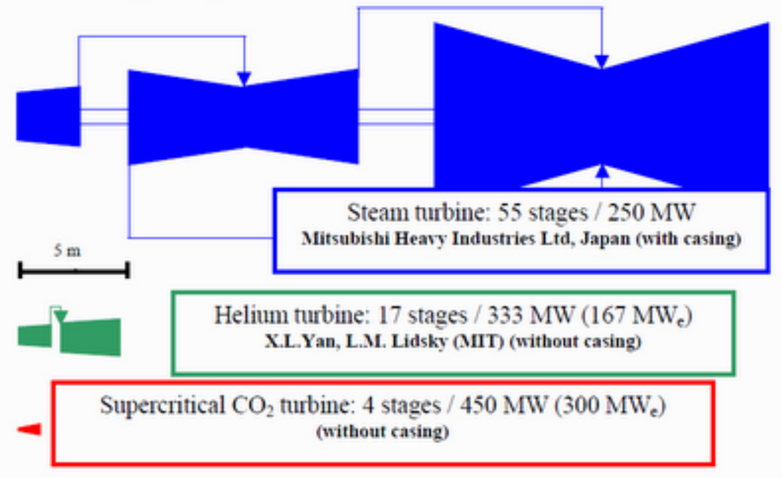
- All transportation, not just cars (airplanes, freight, boats, trains), running on hydrogen produced by non-carbon-emitting sources, with light-duty vehicles averaging 50 mpg
- Six new nuclear power plants going on line each year between now and 2050
- Renewable energy sources (solar, wind, biomass, geothermal, hydroelectric) generating 75 percent of the nation's electricity
- Coal used exclusively to produce hydrogen instead of electricity, making possible the capture and storage in the earth of 2.3 billion tons of carbon dioxide a year.
- Even in such a utopian energy economy, the chart shows, the nation would still be venting 2.3 billion tons of carbon dioxide a year – down from the current level of nearly six billion tons, but still a long way from carbon free.
- 120 quads per year case (2050). Required: a 50 percent improvement in electric generation, industrial, freight and aircraft efficiency; auto fuel economy averaging 50 miles a gallon; and

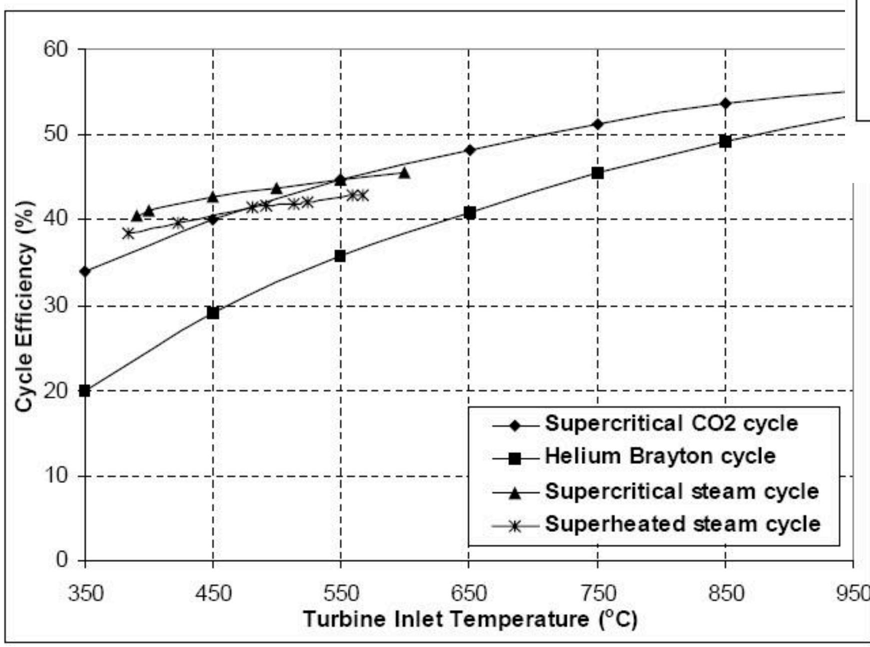
Conventional 2050 Projection



Thermal Efficiency

Fig. 51 Comparison of turbine sizes for steam, helium and CO_2





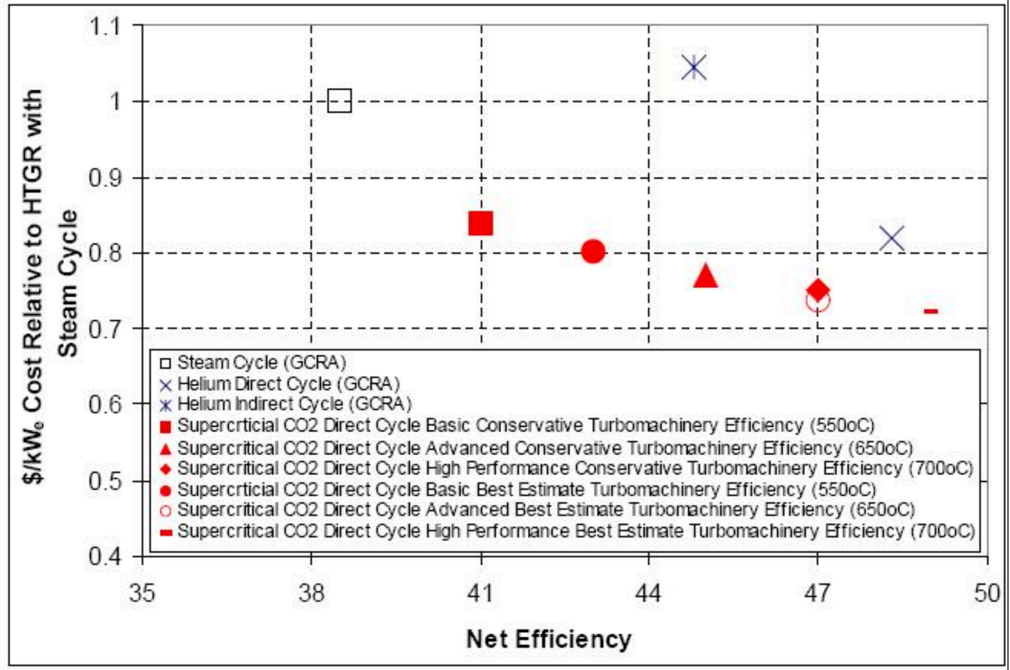


Figure 13.18 Net efficiency and relative costs for different power cycles ($/kWe)

Future Fossil Fuel Efficiency

- GE Pulse Detonation For 65% Efficient Natural Gas Power Generation Turbines
- integrated coal gasification fuel cell combined cycle (IGFC) provides 55%. Efficiency levels are 7% to 8% lower than that of natural gas-fired IGCC/IGFC.
- Advanced IGCC - generation efficiency of 57% and A-IGFC with fuel cells, is expected to provide a generation efficiency as high as 65%
- 33% now for coal and 40-46% for natural gas
- -A 10 percent increase in the thermal efficiency would raise the overall efficiency of the coal-fired power plant fleet from 32.5% to 35.8%