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Predictability of Technological Change

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Physics offers both opportunities and limits on new technologies; but predicting winners can be hazardous. For example:

There has been a great deal said about a 3,000 mile high angle rocket. In my opinion such a thing is impossible for many years. The people who have been writing these things that annoy me, have been talking about a 3,000 mile high-angle rocket shot from one continent to another, carrying an atomic bomb and so directed as to be a precise weapon which would land exactly on a certain target, such as a city.

I say, technically, I don't think anyone in the world knows how to do such a thing, and I feel confident that it will not be done for a very long period of time to come . . . I wish the American Public would leave that out of their thinking.

Vannevar (not George) Bush, Head of US scientific WW II effort (in 1945)

Arthur C. Clarke's Laws of Technological Prophecy

- When a distinguished but elderly scientist states that something is possible he is almost certainly right. When he states that something is impossible, he is very probably wrong.

- The only way of discovering the limits of the possible is to venture a little way past them into the impossible.

- Any sufficiently advanced technology is indistinguishable from magic.

The Kaya Identity:

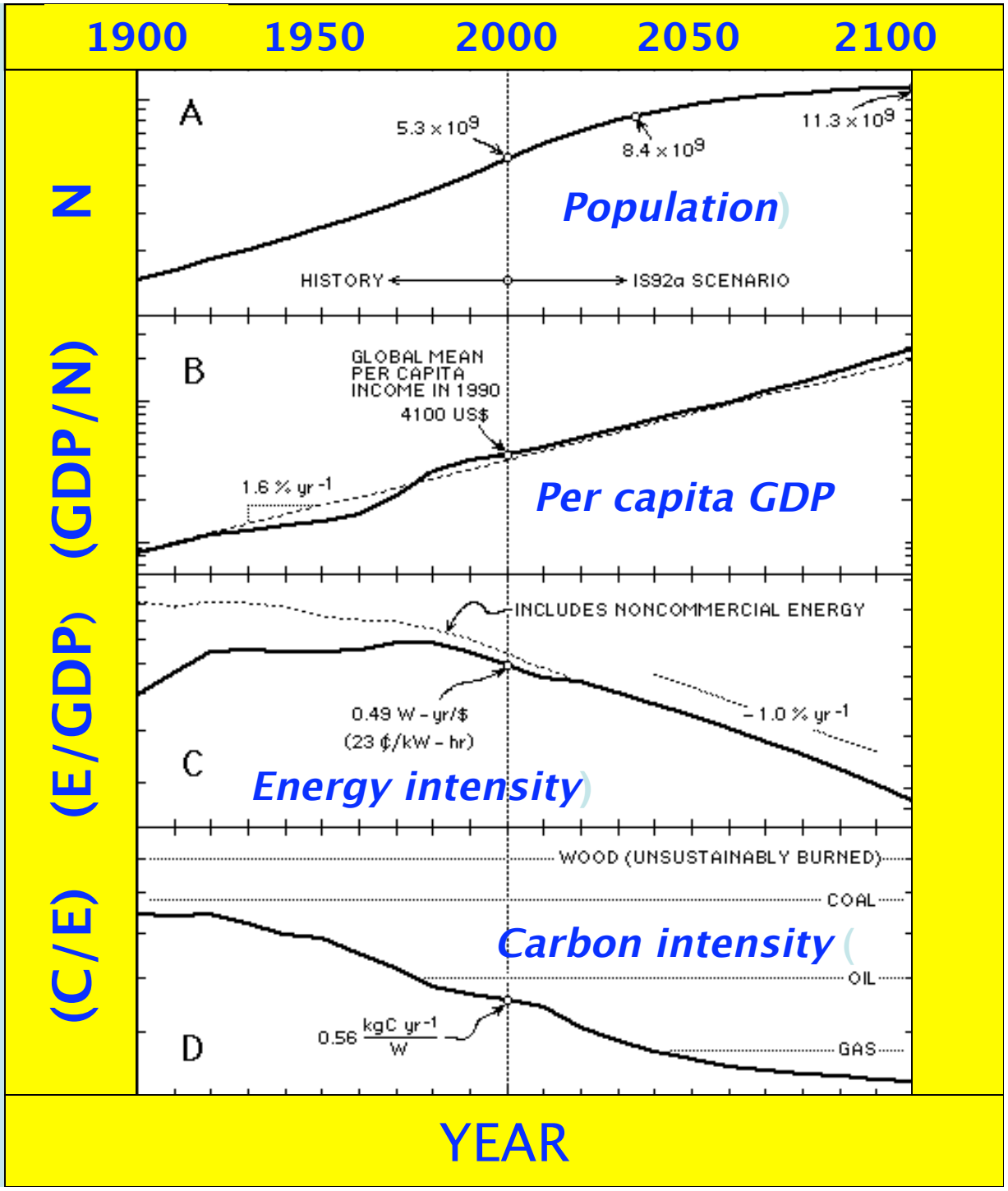
CO_2 Emissions

= N x (GDP/N) x (E/GDP) x (C/E)

= GDP x (E/GDP) x (C/E)

= GDP x (C/GDP)

IPCC IS92a "Business as usual" scenario assumptions

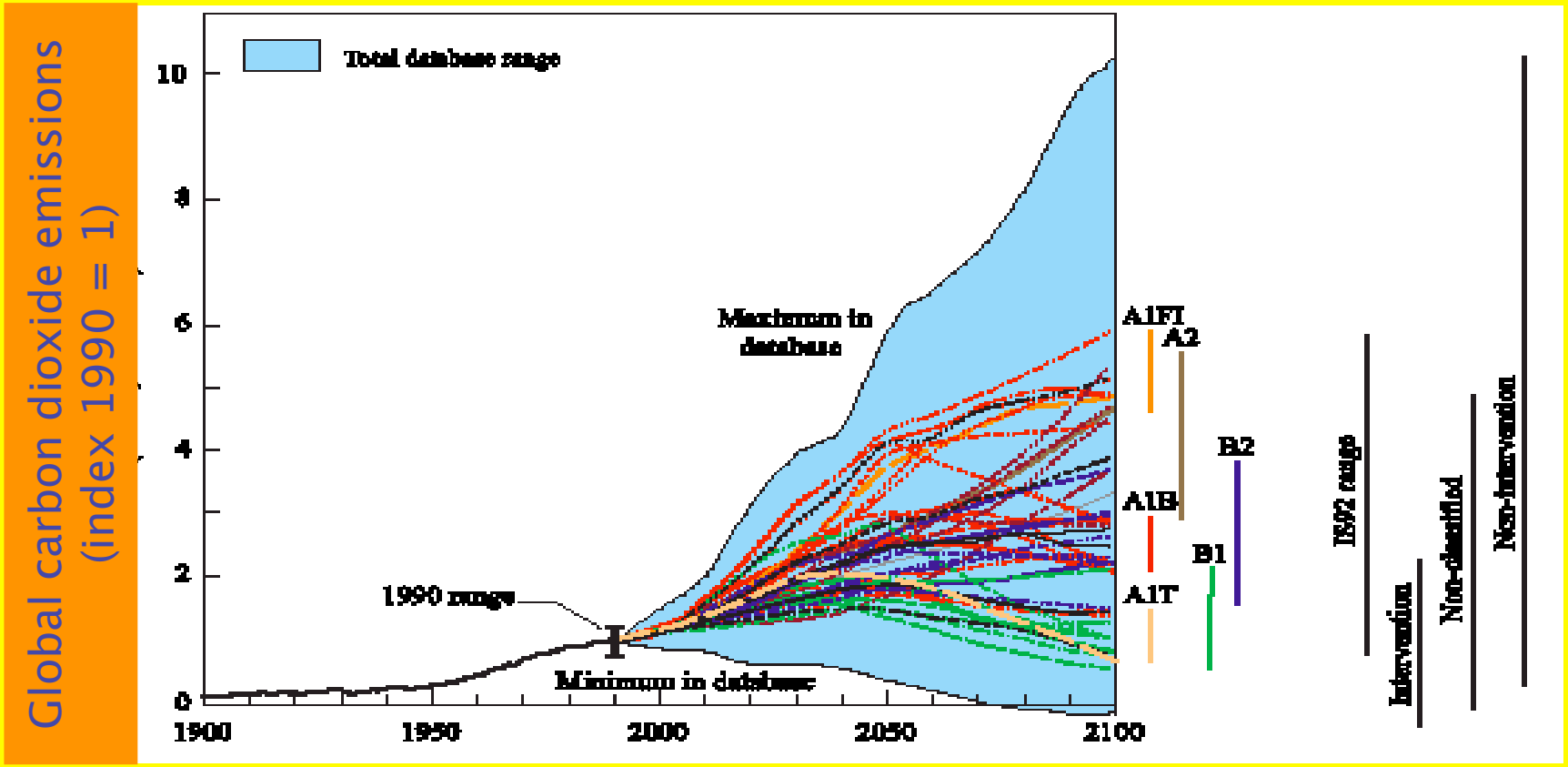


Percent change in Kaya Identity terms and carbon emssions disaggregated by region 1980-1999

	Average Annual Percent Change 1980-1999				
Region	Population	Standard of Living	Energy Intensity	Carbon Intensity	Carbon Emissions
Africa	2.54%	-0.58%	0.82%	-0.01%	2.77%
Australia	1.36%	1.98%	-0.37%	0.00%	2.98%
Brazil	1.61%	0.76%	1.83%	-0.80%	3.43%
China	1.37%	8.54%	-5.22%	-0.26%	4.00%
East Asia	1.78%	5.00%	0.92%	-0.70%	7.10%
Eastern Europe	0.44%	-1.91%	-0.14%	-0.61%	-2.21%
India	2.04%	3.54%	0.27%	0.03%	5.97%
Japan	0.41%	2.62%	-0.57%	-0.96%	1.47%
Middle East	2.98%	0.04%	2.45%	-1.14%	4.34%
OECD	0.68%	1.73%	-0.88%	-0.58%	0.94%
OECD Europe	0.53%	1.74%	-1.00%	-1.06%	0.18%
United States	0.96%	2.15%	-1.64%	-0.21%	1.23%
World	1.60%	1.28%	-1.12%	-0.45%	1.30%

Data from
http://sequestration.mit.edu/carbon_emissions_data/index.html

What does the SRES emission uncertainty range mean ?

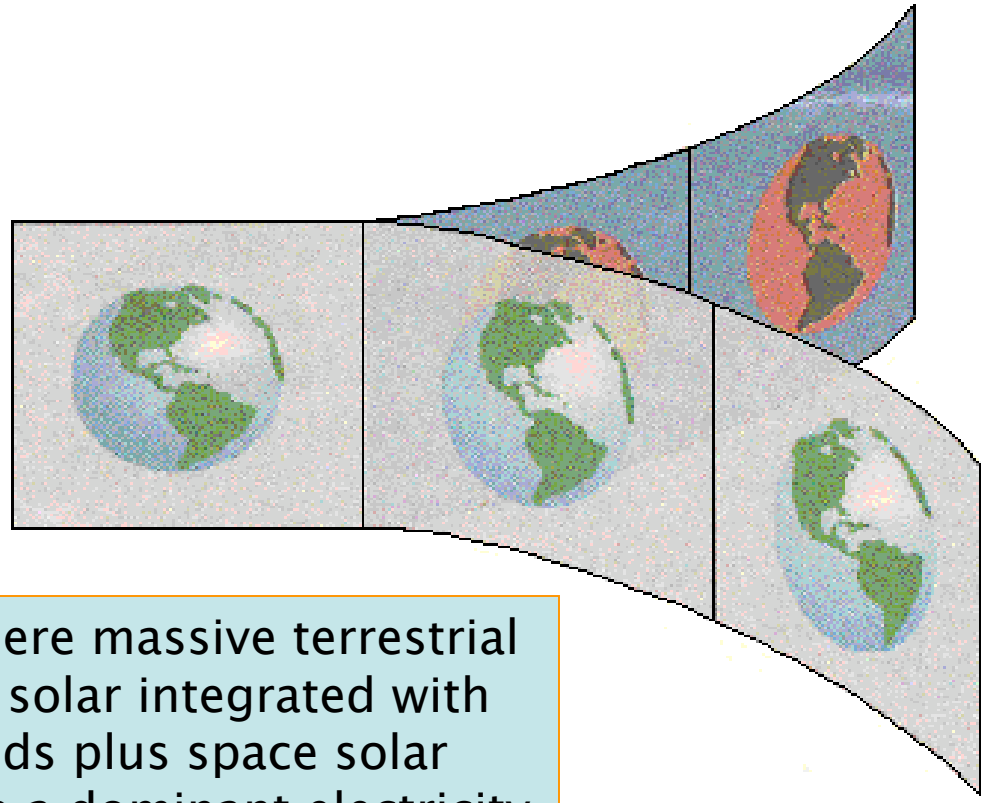


Global carbon dioxide emssions related to energy and industry from 1900 to 1990 and for 40 SRES scenarios from 1990 to 2100, shown as an index (1900 = 1). Colored lines are individual SRES scenarios. The area shaded in blue is the range of scenarios in the literature documented in the SRES database.

Many Worlds?

A popular hypothesis of cosmology and quantum mechanics is that universe's continually split into infinite parallel versions, with outcomes covering every possible situation. Their probabilities are described by wavefunctions, much a as an electron's position is. If we only knew them for the 40 SRES scenarios. . .

A world Splits . . .



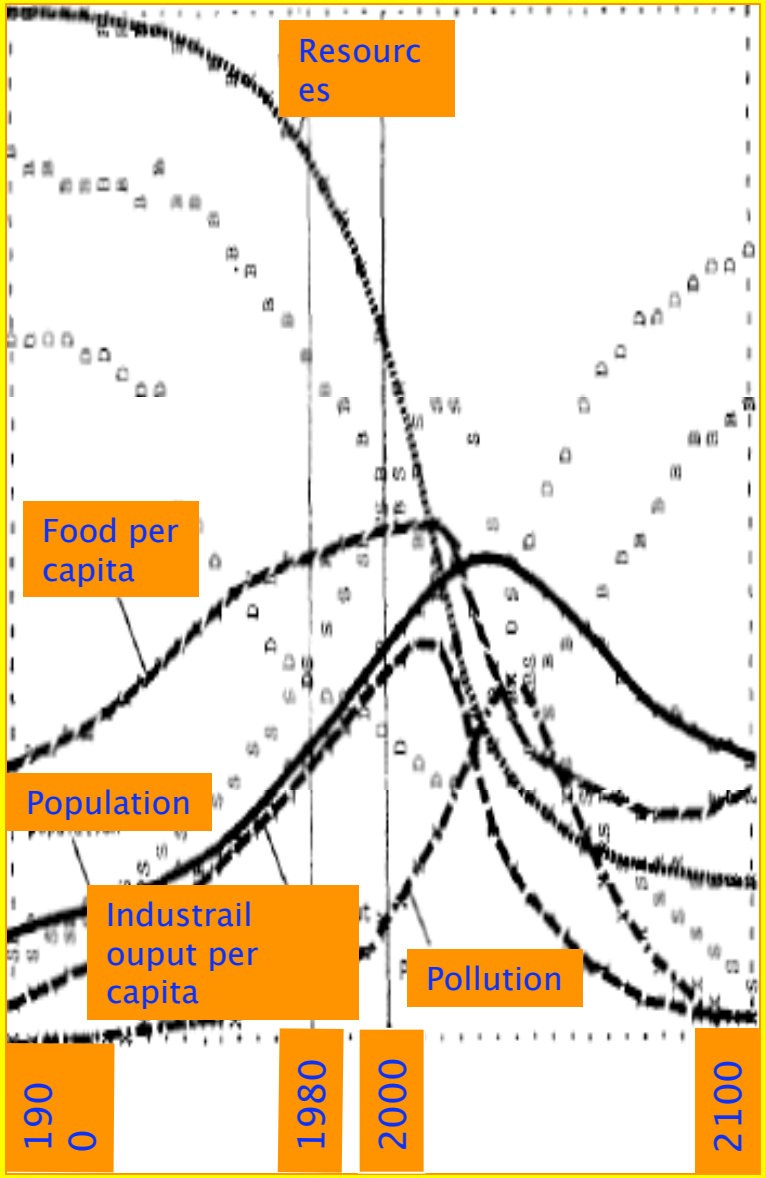
. . . and here coal-fired power plants with CO2 sequestered are a dominant electricity source in 2050

. . . and here massive terrestrial wind and solar integrated with global grids plus space solar power are a dominant electricity source in 2050

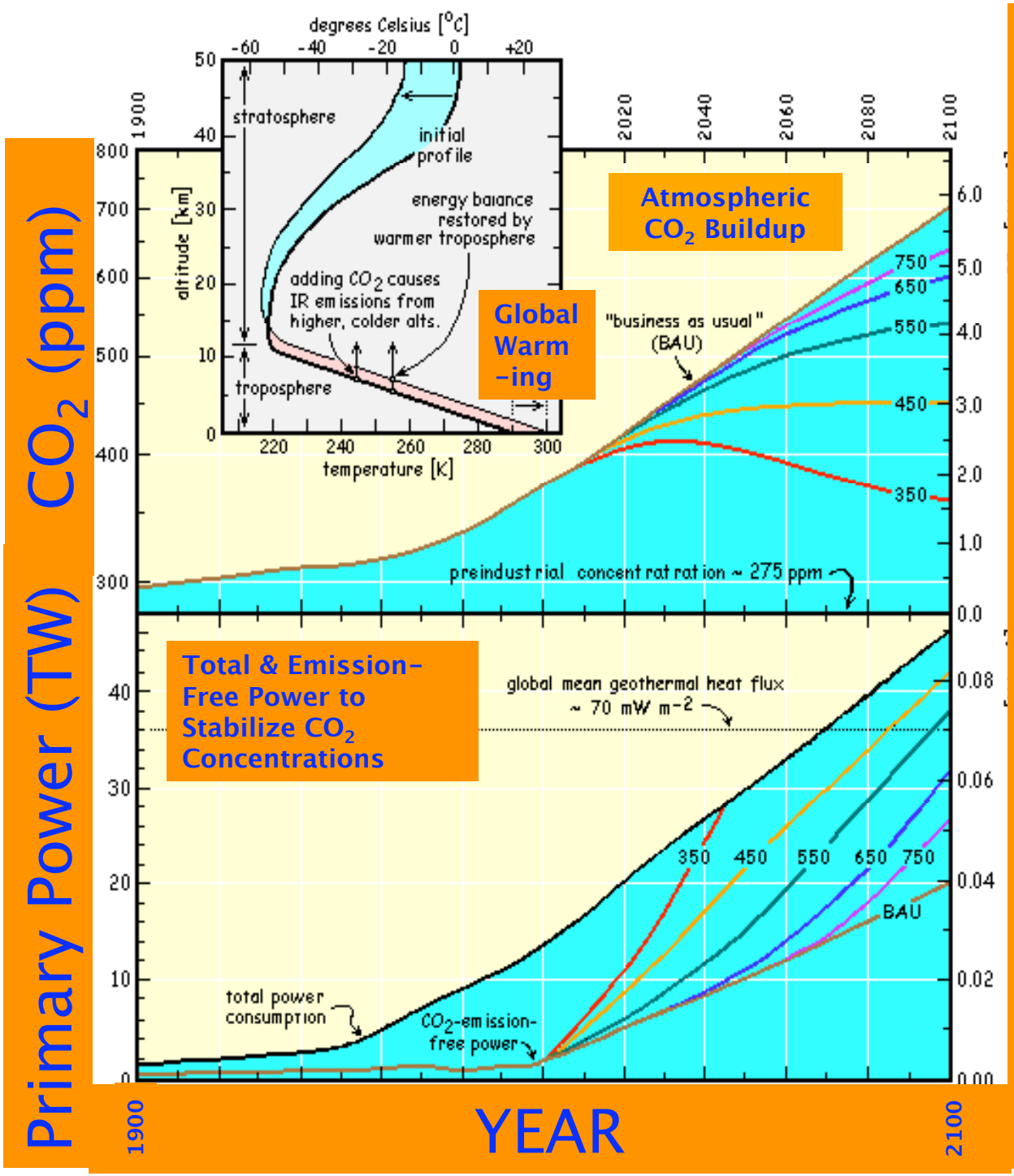
Will civilization crash this century?

Plots are the "standard world model " run from Meadow's (1974) "Limits to Growth" sponsored by the Club of Rome which assumed no major change in physical, economic or social relationships that have historically governed the devlopment of the world system. All variables follow historical values from 1900 to 1970. Food, industrial output, and population grow exponentially until the rapidly diminishing resource base forces a slowdown in industrial growth. Because of natural delays in the system, both population and pollution continue to increase for some time after the peak of industrialization. Population growth is finally halted by a rise in the death rate due to decreased food and medical services.

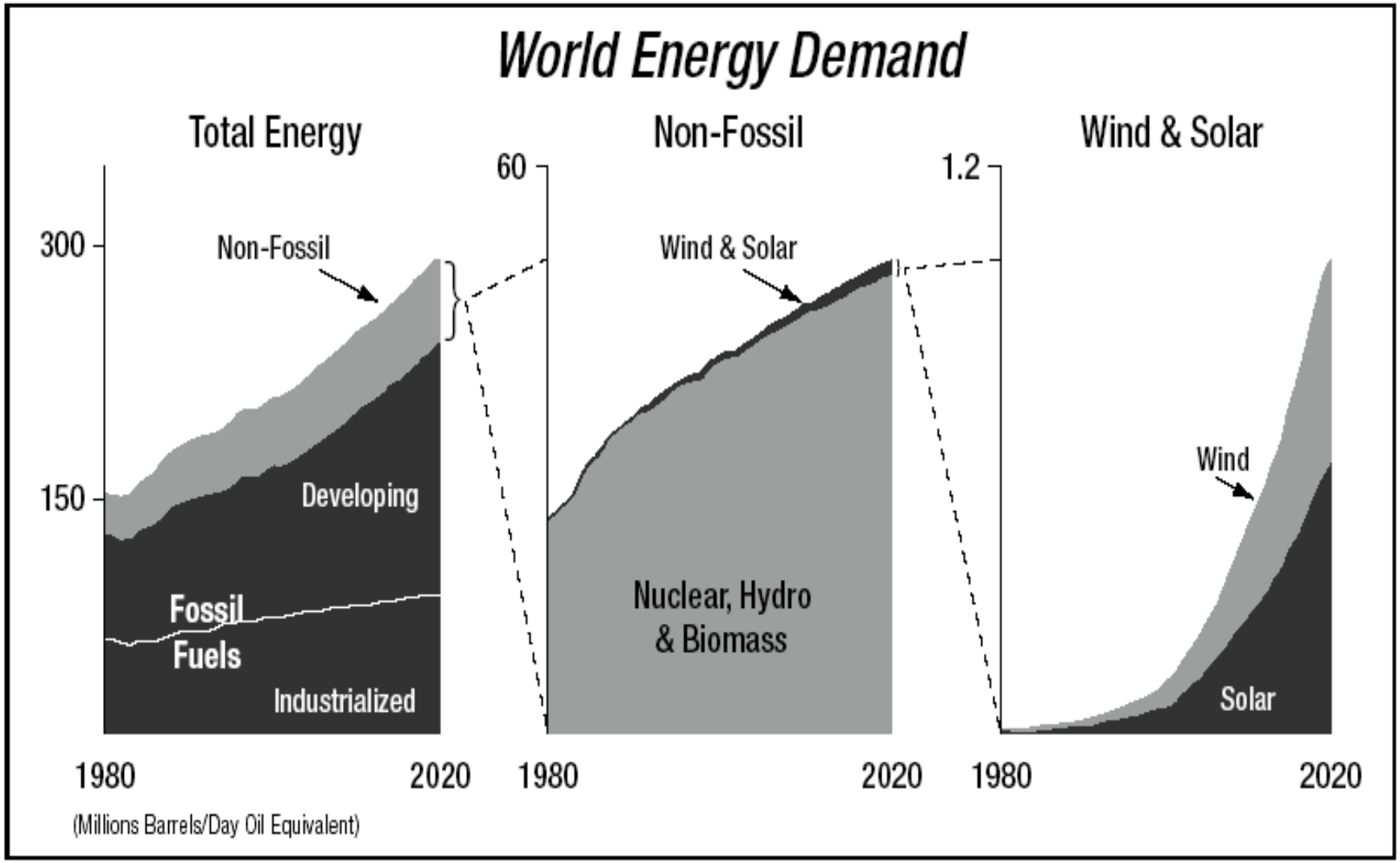
That resource scarcity limits economic growth as embodied in this model is fundamentally opposed by the boundless growth paradigm of market economics embodied in IPCC SRES scenarios.

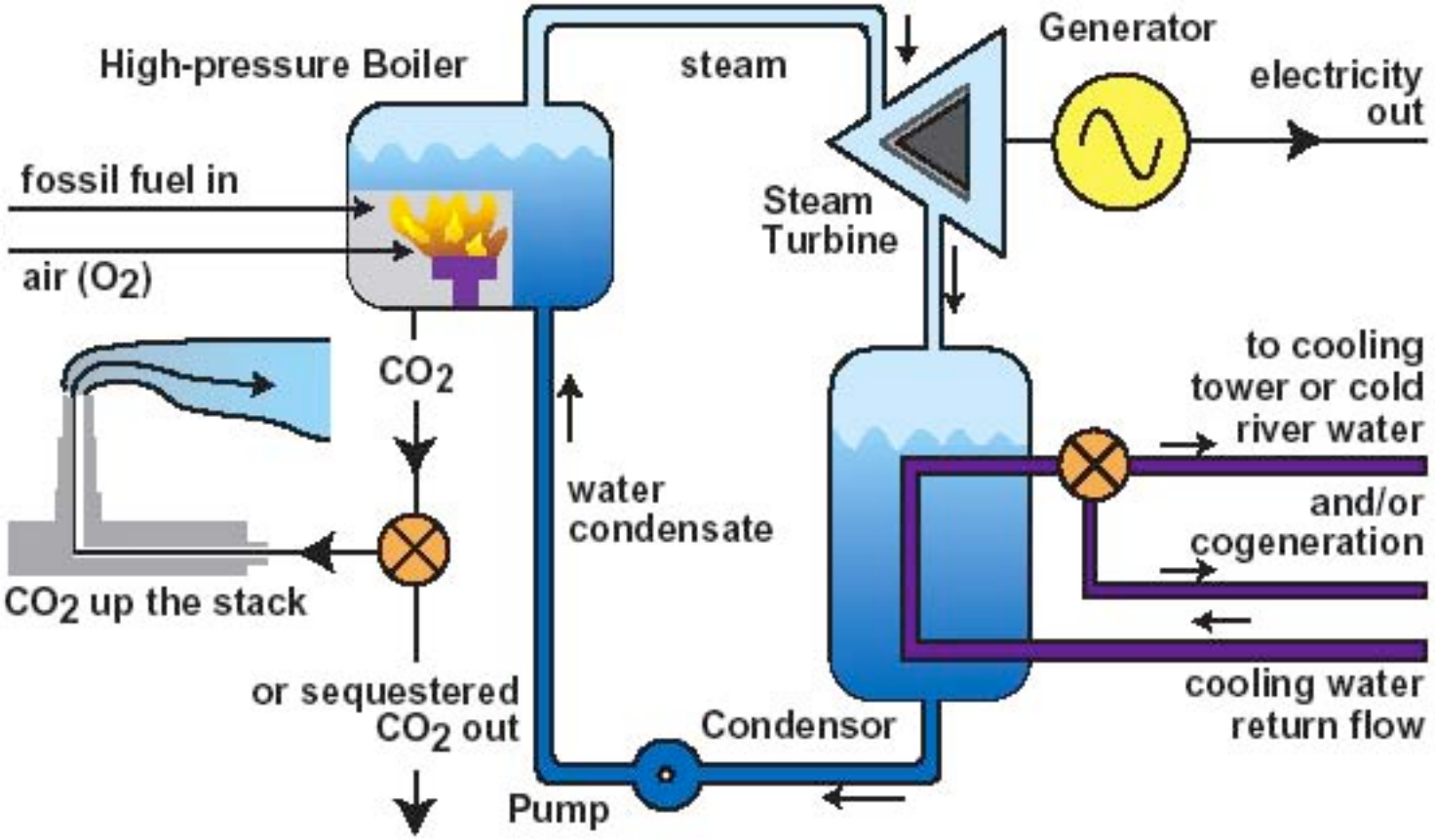


The Challenge: Fossil Fuel CO_2 and Primary Power Buildup: 1900–2100



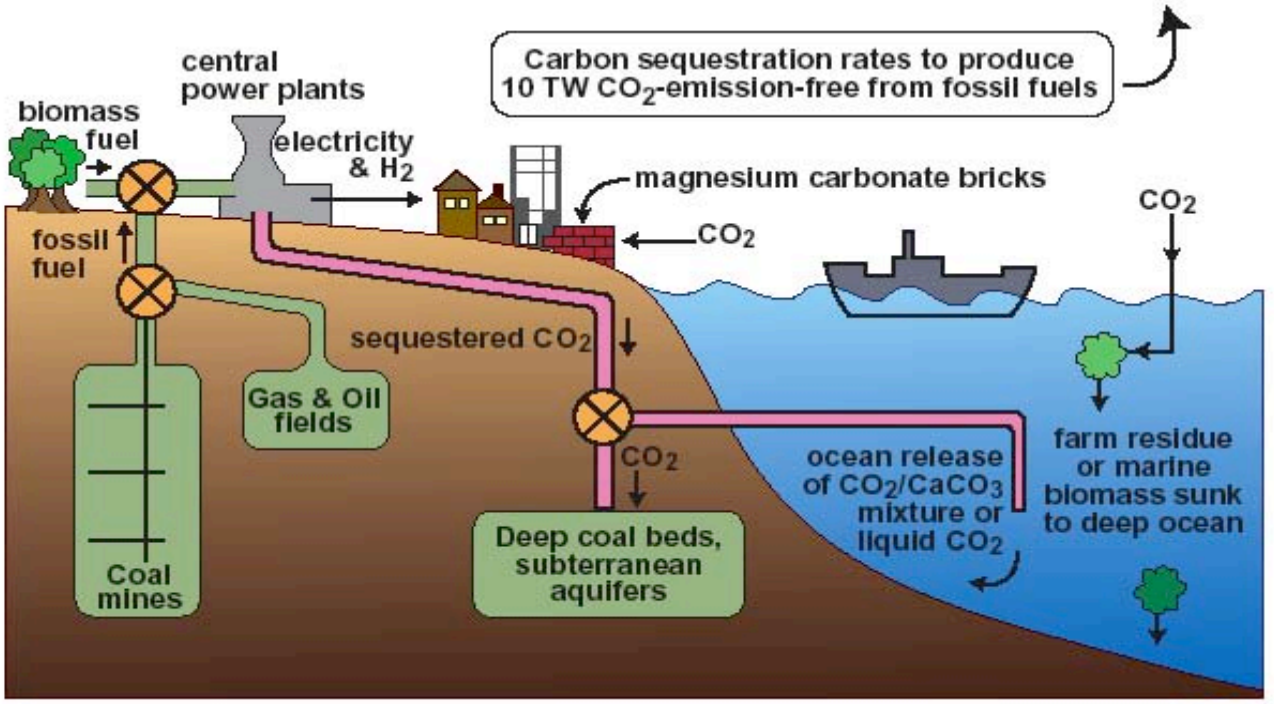
ExxonMobil Energy Projections



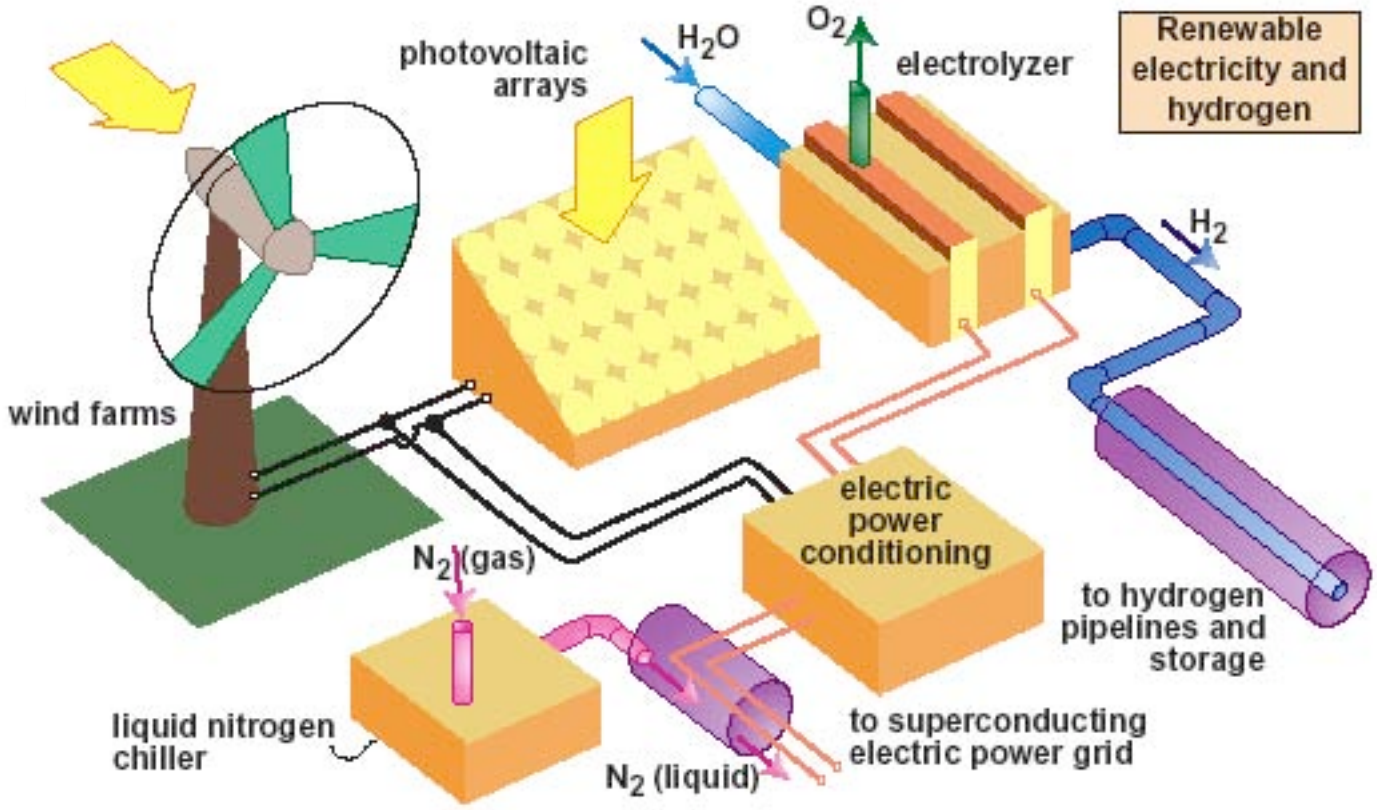


Fossil fuel electricity from steam turbine cycles

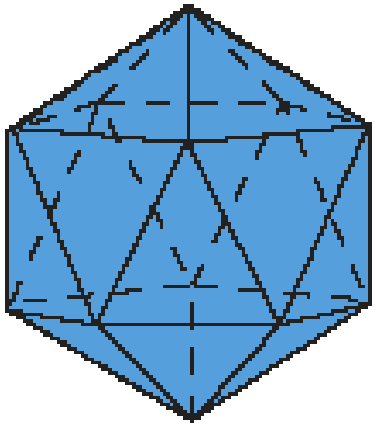
Fossil fuel	Energy content [TW-yr]	Carbon content [GTC]	(E_{fuel}/C) [TW-yr/GtC]	(E/C) [TW-yr/GtC]	Sequestration rate [GtC/yr]
Gas	1200	570	2.1	1.9 - 1.6	5 - 6
Oil	1200	750	1.6	1.4 - 1.2	7 - 8
Coal	4800	3690	1.3	1.2 - 1.0	9 - 10



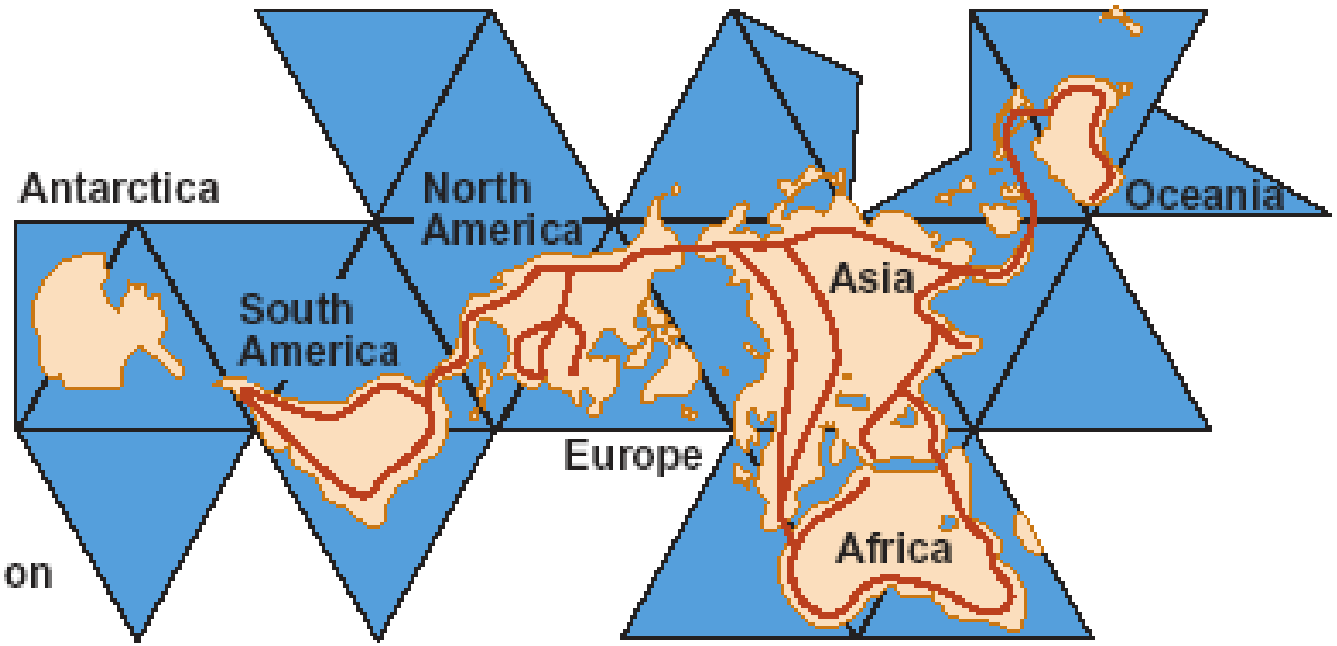
Fossil fuel CO_2 sequestration ideas and burial rates to generate 10 TW emission-free



Mass-produced widely distributed PV arrays and wind turbines may eventually generate 10-30 TW emission-free

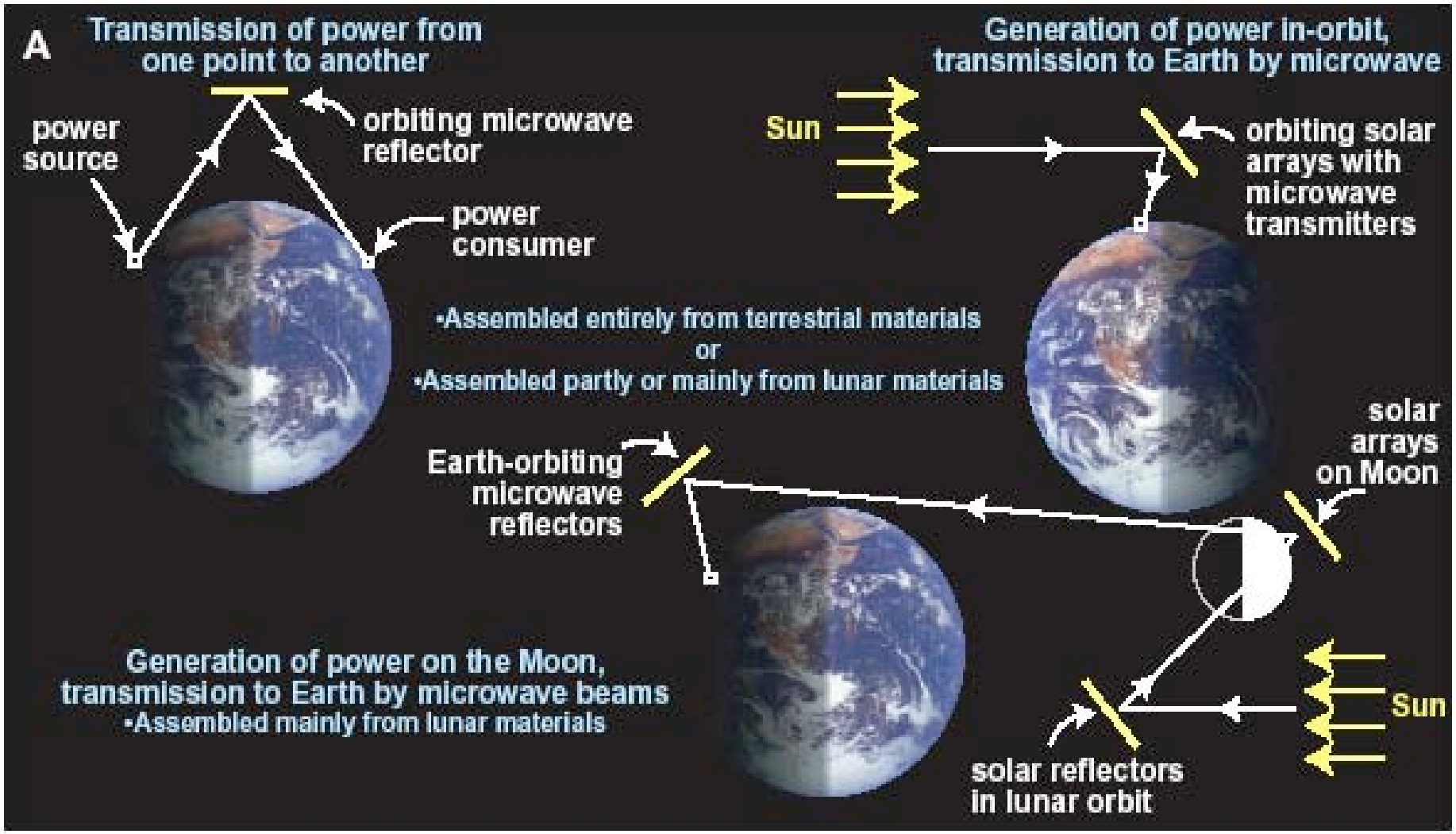


Icosahedron: An equilateral-triangle-faced solid that reduces map projection errors

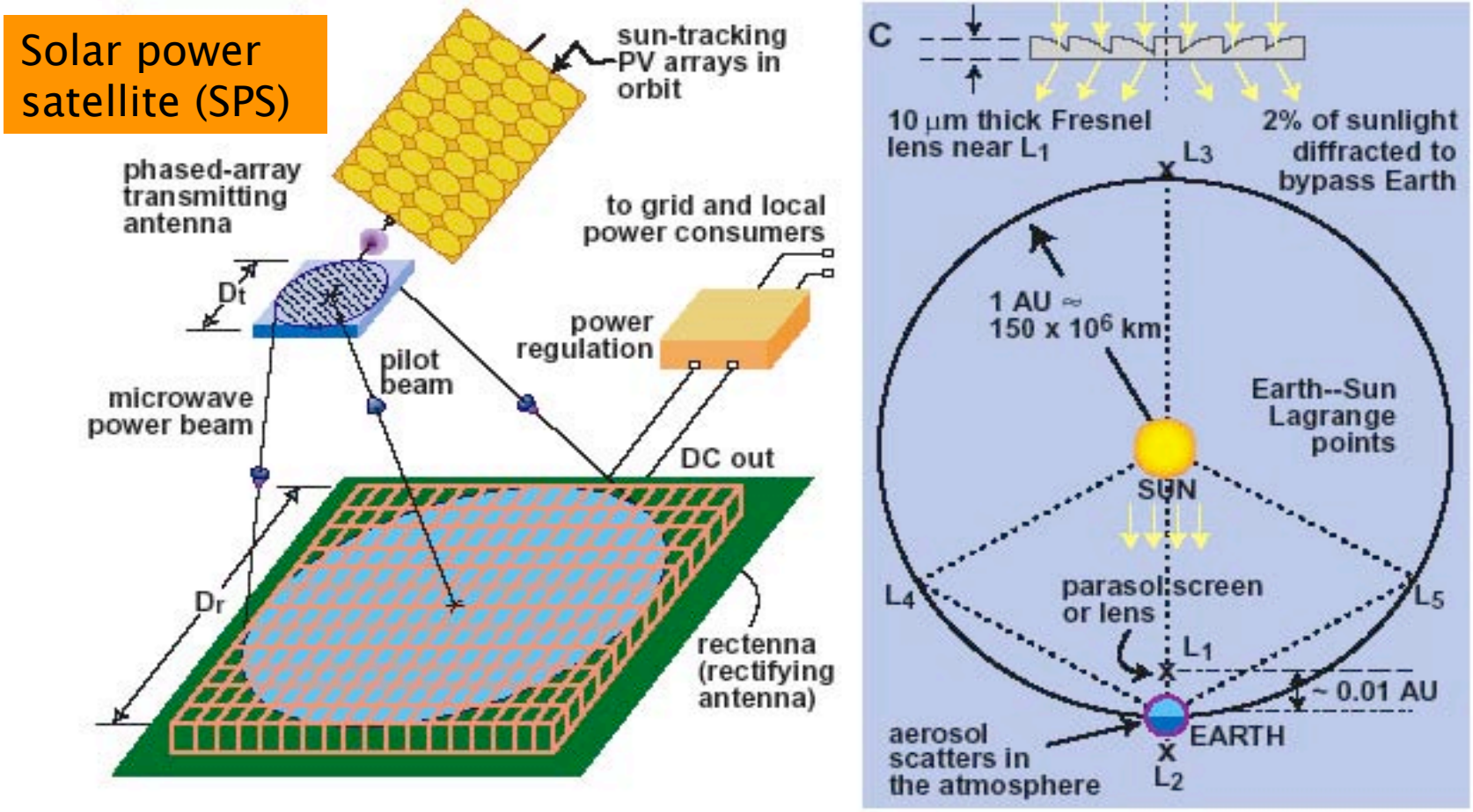


Buckminster Fuller's Global Electrical Grid

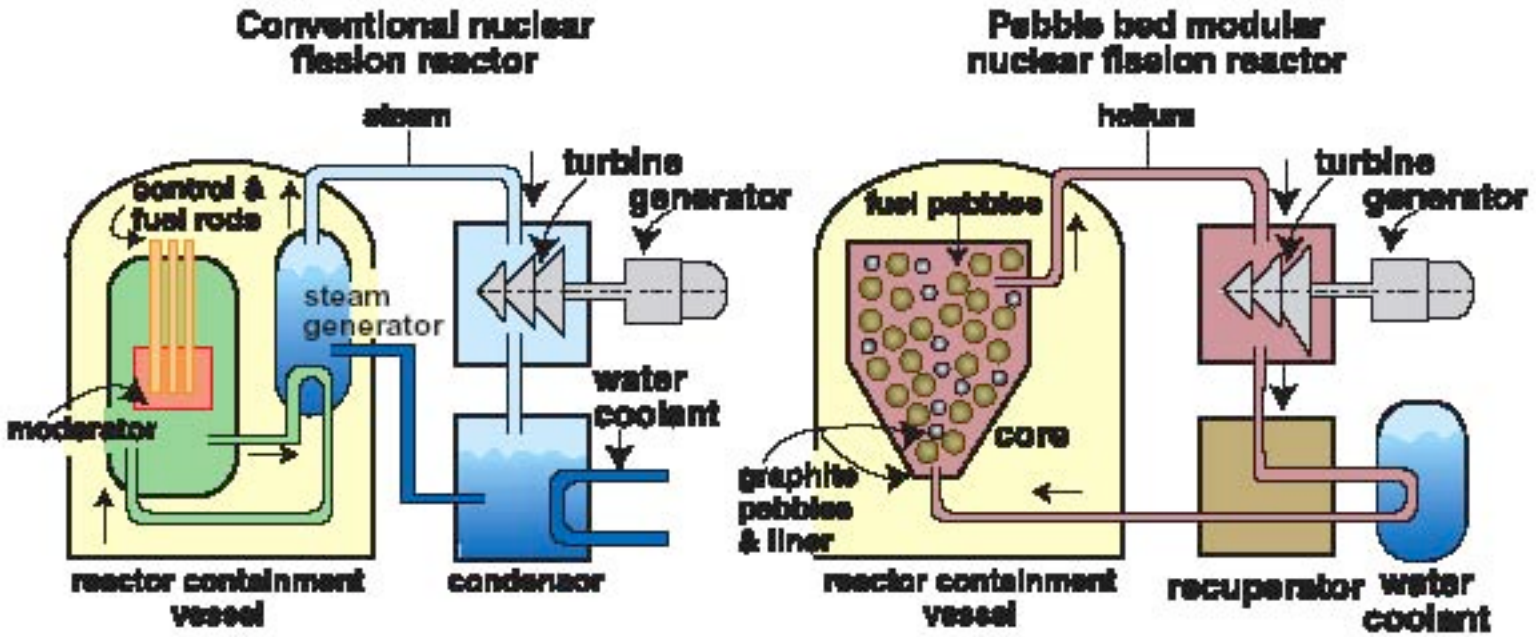
"Bucky" Fuller's global electrical grid proposed in the 1970s augmented with computerized load management and high-temperature superconducting (HTS) cables could transmit electricity from day to night locations and foster low-loss distribution from remote, episodic or dangerous power sources. The resistivity of copper oxide HTS wires vanishes below the 77 K boiling point of liquid N_2 available from air. ***Could HTS nanotubes do the job someday?***



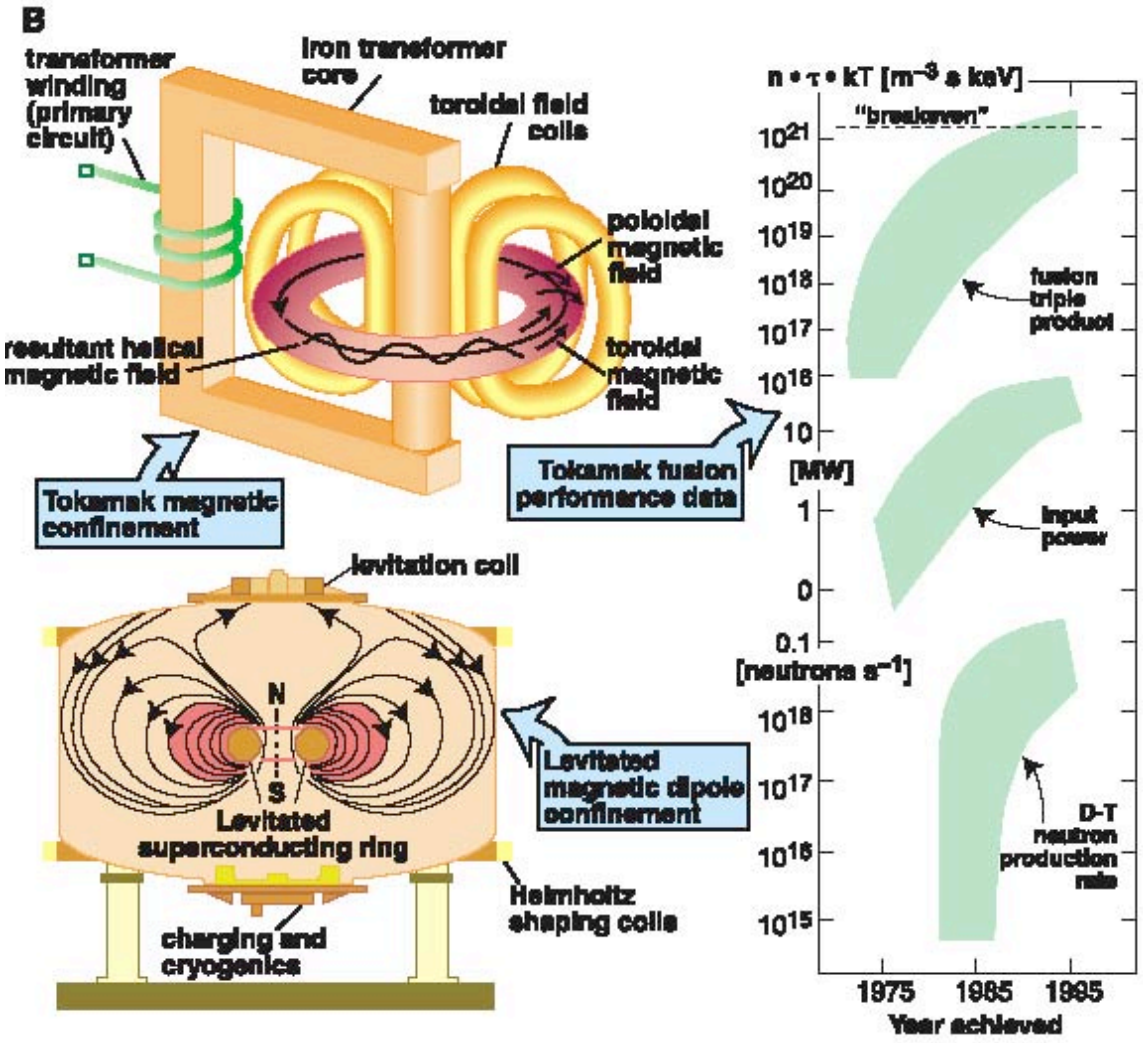
Capturing and controlling space solar power



(Left) Wireless power from space could enable developing nations to avoid fossil-fuel-based industrialization. Ultralight large SPS aperture antennas and other components could be fostered by nanotechnology. ***(Right) Deflecting sunlight*** with a 2000 km flat lens at the L_1 Lagrange point or intentional aerosol injections to the stratosphere are potential "worst case" mitigators of global warming.



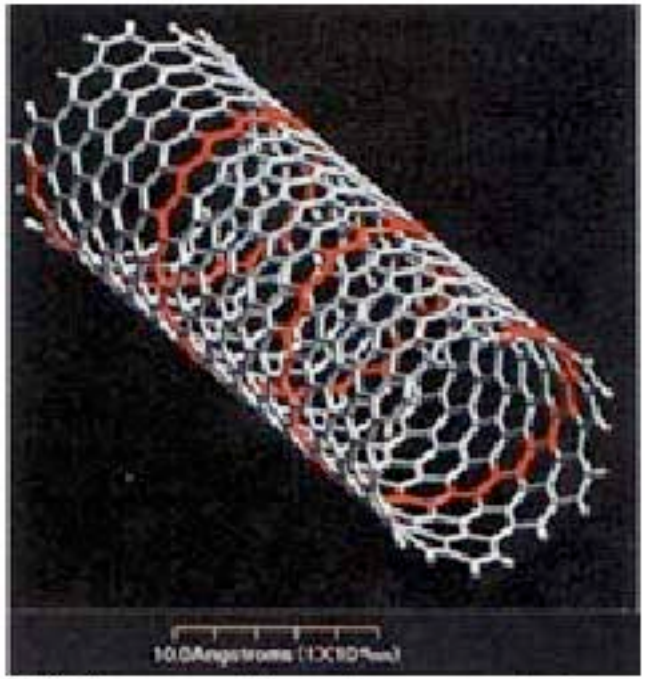
(LEFT) The conventional light water reactor (LWR) employs water as both coolant and working fluid. (RIGHT) The helium-cooled, graphite-moderated, pebble bed, modular nuclear fission reactor is theoretically immune to loss of coolant (TMI) and criticality (Chernobyl) accidents.



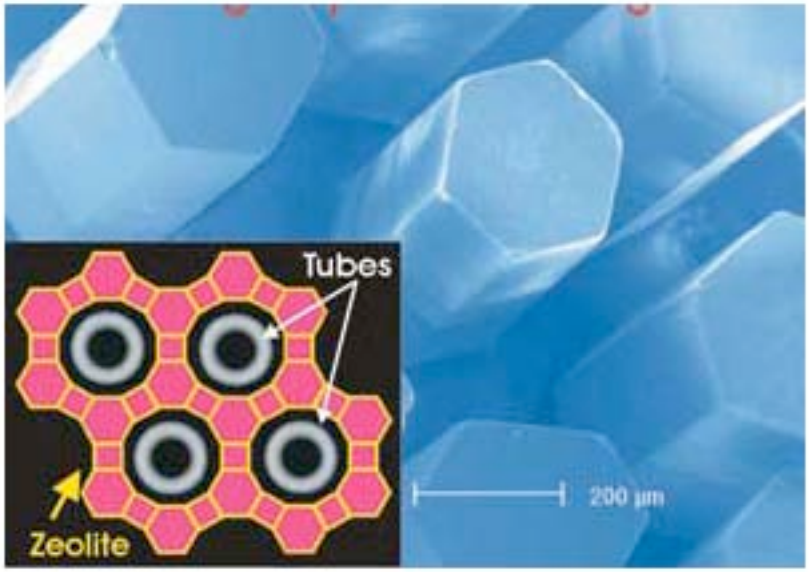
FUSION PATHS

The most successful approach to fusion so far has been has been confining a D-T plasma (in purple) with complex magnetic fields in a "bagel-shaped chamber (a ***tokamak***).

"***Breakeven***" requires that the plasma triple product (= number density X confinement time X temperature) attain a critical value; as it has nearly done in recent experiments. A fusion-fission hybrid breeder based on tokamak research may be feasible prior to a fully fusion power reactor. Experiments on advanced fusion fuel cycles and simpler designs are also needed -- like the ***levitated dipole experiment*** at MIT shown above.



CG image of carbon nanotube.



TINY TUBES Superconducting nanotubes inside zeolite pores (inset), against backdrop of zeolite crystals.
COURTESY OF PING SHENG & NING WANG

Energy Applications of Carbon Nanotubes

(Left) Hydrogen Storage: High H2 sorption may result from polarization inside tubes enhanced by dopants

(Right) Superconductivity: So far, electron-hole doped fullerenes superconduct at temps < 52 K

Nanotube-Enabled Space Elevators

Climbing into space on ultrastrong tethers -- possibly carbon nanotubes -- a ***space elevator*** could provide cheap access to orbit someday. This visualization appeared in an article by T. Ferris in the NY Times Magazine 28 Nov. 1999, where the price of carbon nanotubes was estimated at ~ $1000/gm. Cost breakthroughs could enable this technology, as well as large aperture microwave antennae and ***solar polar satellites*** even sooner.

Global Warming: Early Signs?

(Left) Coral Reefs: Marine ecosystems like the blue coral areas around the Bahamas shown are already stressed worldwide.
(Right) West Antarctic Ice Sheet: Catastrophic breakup is possible in the long run raising sea level ~ 50 m. Satellite image shows the Larson B ice shelf which shattered and separated 21 March 2002. Much larger breakups may occur Earth warms.

Research and Demonstrations

- ***An Apollo-like program in alternate energy*** is needed over a broad spectrum of mitigation technologies. US should provide leadership. Goal is to provide options capable of transforming global energy system to one that can generate 10-30 TW primary power CO_2-emission-free by 2050.
- ***Strategic technologies need to be identified*** and demonstrations conducted in user-friendly, energy-efficient renewably-powered communities, "zero-emission" fossil-fueled plants with CO_2 sequestered, "air capture' of CO_2, hydrogen storage, global scale and "smart" electrical transmission grids, operationally safe and proliferation resistant fission reactors & breeders, wireless power transmission and space solar power, fusion power, fission-fusion & particle accelerator hybrids.
- ***Near-term emphasis on "leapfrog" technologies*** for alternate industrialization paths (i.e., solar power satellite demonstration collaborative project of US/NASA, IPCC, developing nations).
- ***Nanotech can be major player if cost barriers fall***. Are molecular assemblers ("Engines of Creation") real or SF?