# Beyond Fossil Fuels

Land Use and the Environment
17th Annual Rocky Mountain Lan
Use Institute Conference

Thursday, March 6, 2008, 8:45
AM, University of Denver Sturm
College of Law, 2255 East Evans
Avenue, Denver, CO 80208

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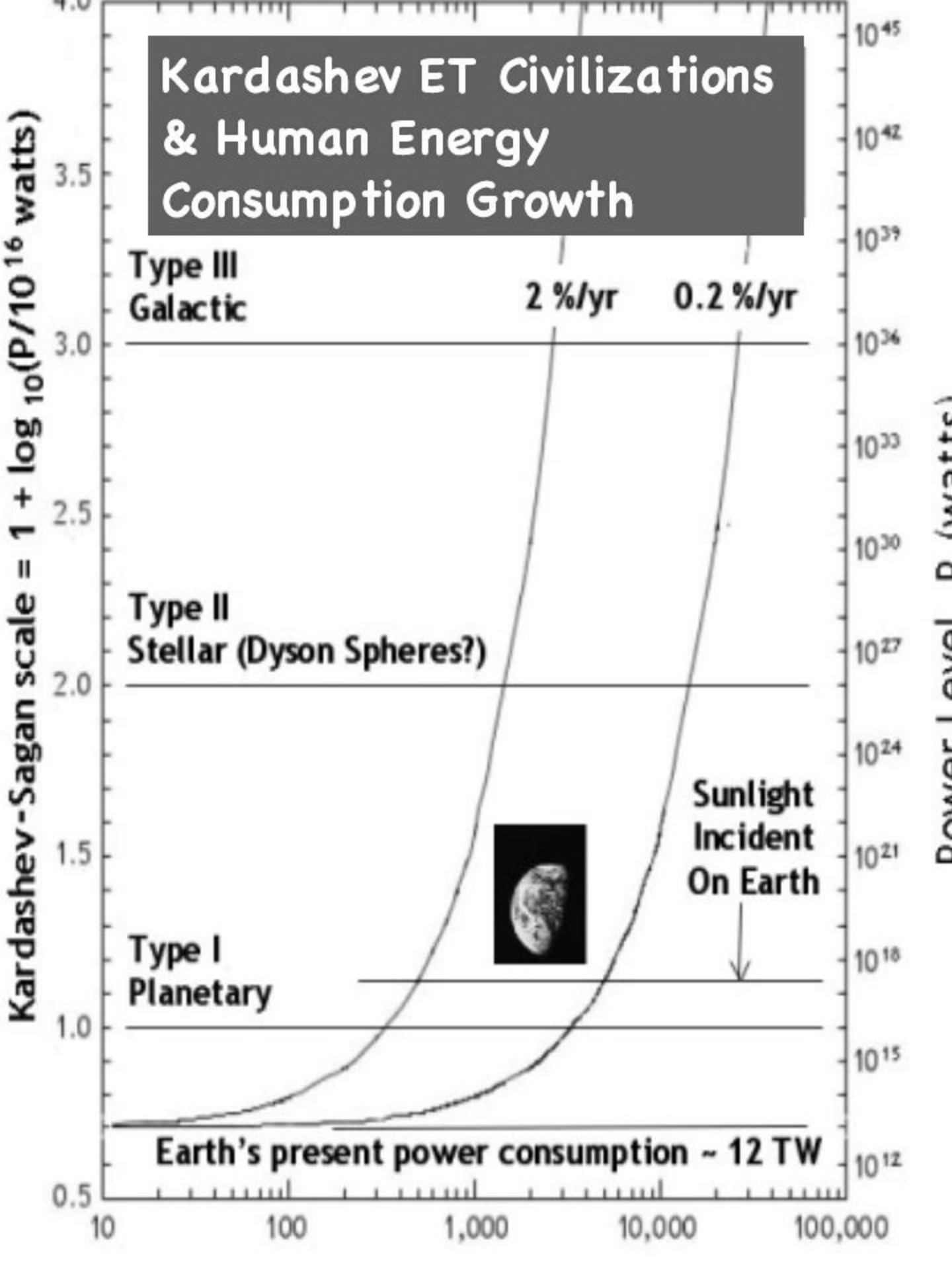
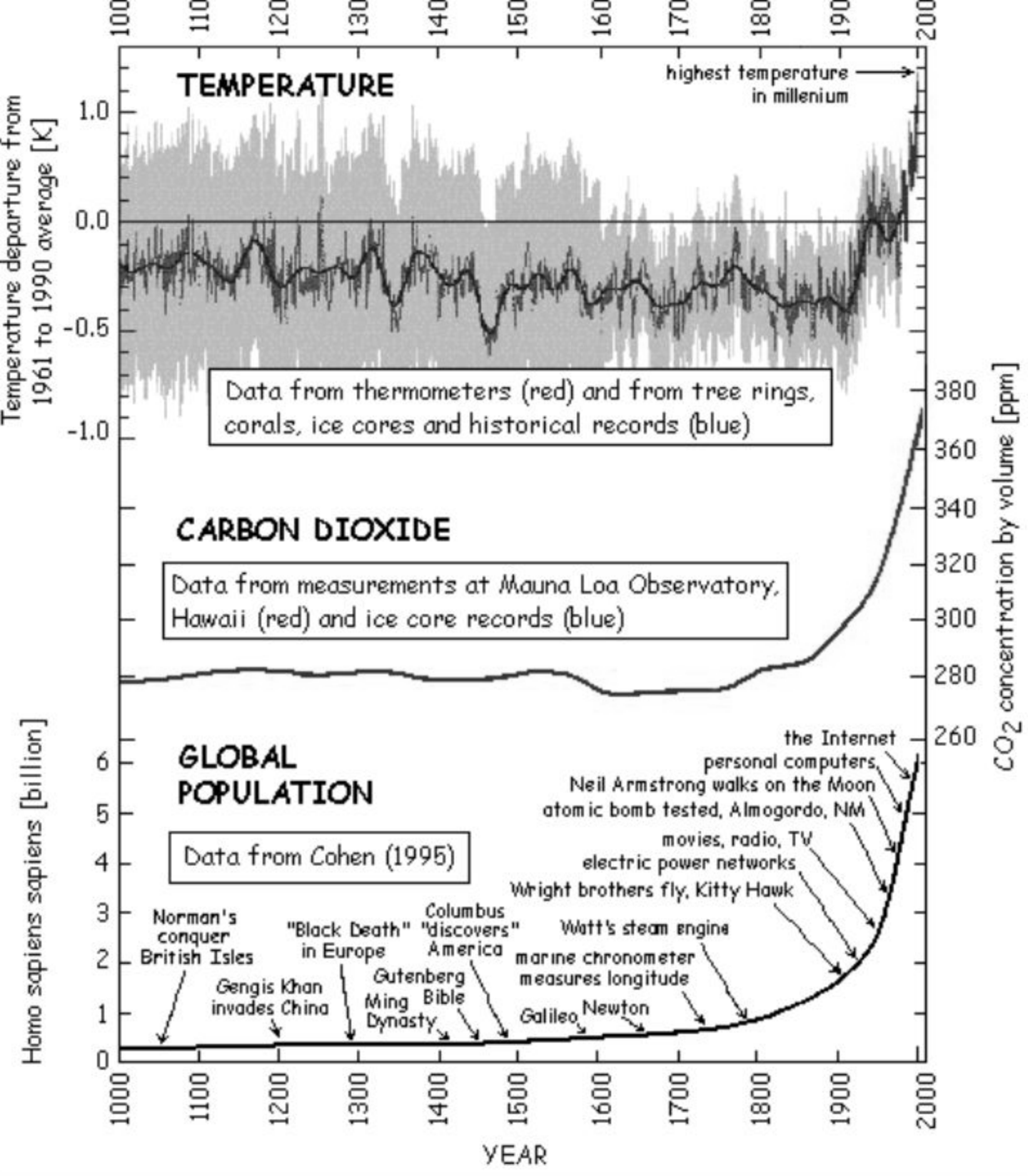

Kardashev ET Civilizations & Human Energy Consumption Growth
Type III Galactic
2 %/yr
0.2 %/yr
Type II Stellar (Dyson Spheres?)
Sunlight Incident On Earth
Type I Planetary
Earth's present power consumption ~ 12 TW
Kardashev-Sagan scale = 1 + log 10(P/10 16 watts)
Power Level, P (watts)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
10
100
1,000
10,000
100,000
10 12
10 15
10 18
10 21
10 24
10 27
10 30
10 33
10 36
10 39
10 42
10 45




# Crossing the Greenhouse Threshold: Fossil Fuel $CO_2$ & Human Population Growth Trigger Recent Explosive Emergence of Global Warming

# Is *Homo sap.* High-Tech Civilization Viable on Earth Long Term?

## Many Calls for Action
## But What to Do?

# Strange Greenfellows

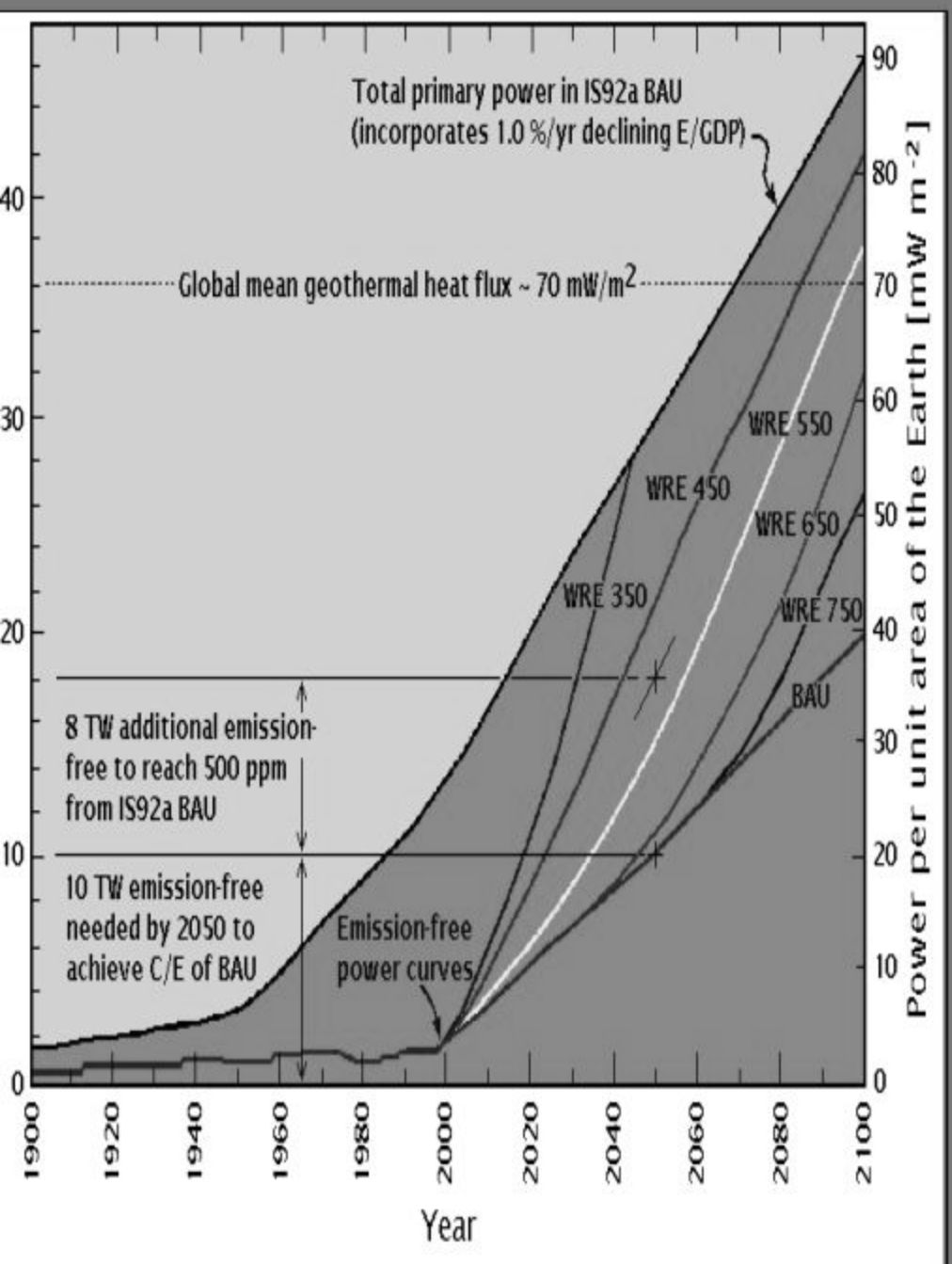
From longtime global warming warriors to recent converts, the over-50 figures calling for action include an ideologically diverse mix, to say the least.

**1.** Senator John McCain (R-AZ) **2.** Ellen Mosley-Thompson, of Ohio State University (OSU), has studied climate change for over 30 years **3.** Bonnie Raitt **4.** Pat Robertson **5.** Warren Washington, head of climate-change research at the National Center for Atmospheric Research **6.** Governor Arnold Schwarzenegger (R-CA) **7.** Martin I. Hoffert, an NYU professor and energy-research proponent **8.** Senator Barbara Boxer (D-CA) **9.** Senator Joe Lieberman (ID-CT) **10.** One-time skeptic Rupert Murdoch **11.** Tony Blair **12.** Sheila Watt-Cloutier, an Inuit leader and Nobel Peace Prize nominee **13.** Sir Richard Branson **14.** Lonnie Thompson, a prominent OSU climate researcher (and Mosley-Thompson's husband; see 2) **15.** Al Gore **16.** Wangari Muta Maathai, Kenyan founder of the Green Belt Movement **17.** Susan Solomon; she pulled together the Intergovernmental Panel on Climate Change (IPCC) report concluding that humans are the main force behind global warming **18.** Rajendra K. Pachauri, chairman of the IPCC **19.** Newt Gingrich **20.** Robert F. Kennedy Jr. **21.** Ed Begley Jr.

## Climate Bills in Congress

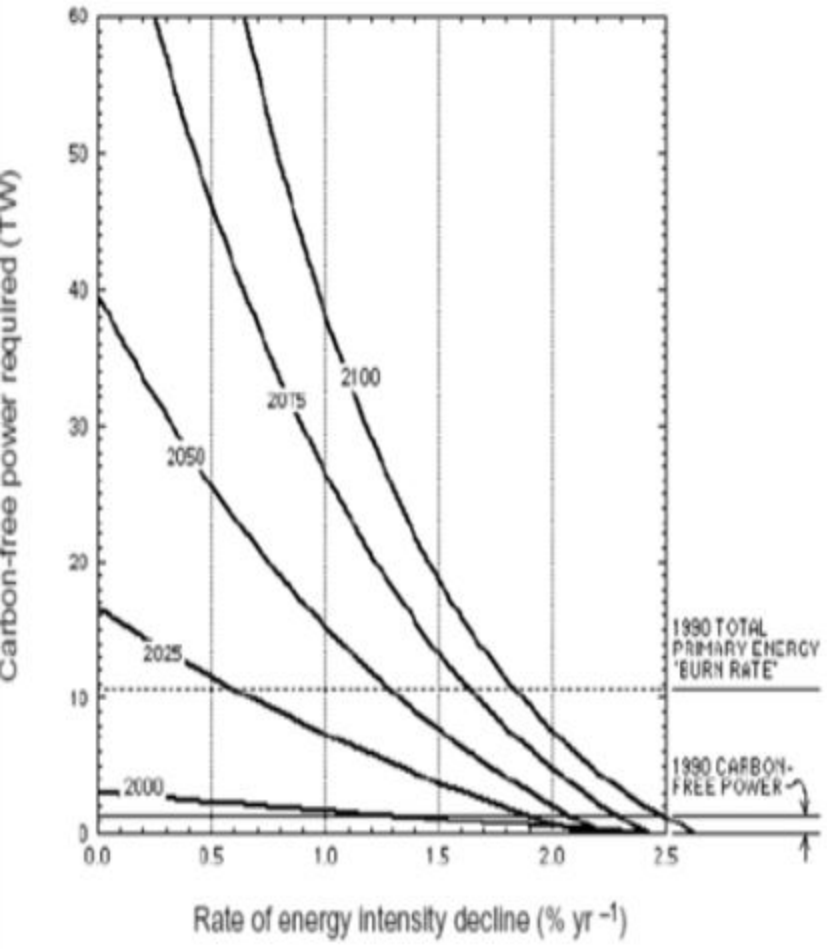
| ovisions | Sponsors | | | | |
|---|---|---|---|---|---|
| | Bingaman-Specter | Lieberman-McCain | Sanders-Boxer | Feinstein* | Kerry-Snowe |
| nission rget 2050 | 60% below 2006 levels — provided other countries play ball | 60% below 1990 levels | 80% below 1990 levels | Cut expected levels for 2020 by 25%; 1.5% annual reductions thereafter | 65% of 2000 levels |
| rbon owance | 53% to industry; 24% for auction; 9% to states; 14% to others | Allowances distributed across sectors and to a new 'Climate Change Credit Corporation' | Awarded to those most affected by transition to a carbon-free economy | Allowances based on means of electricity generation | To be determined by the president |
| chnology pport | Creates fund for research into low-carbon technologies and vehicles. Supports carbon capture and storage | Climate Technology Finance Board backs public-private research partnerships. Climate Change Credit Corporation supports low-carbon technologies | Grants for carbon capture and storage projects. Recommends boosting R&D for low-carbon technologies by 100% a year for a decade | Climate Action Trust Fund established to commercialize new low-carbon technologies | Recommends boosting R&D by 100% a year for a decade. Creates programme to assist with adaptation to climate variation |

**THE REAL PROBLEM:** To maintain 2-3%/yr
GDP growth in this century, some combination of new
carbon-emission-free primary power sources (100-30
present fossil fuel ones by 2050) & efficiency-
improving technologies will be needed, to also keep
global warming < 2 degrees Celsius* ($CO_2$ < 500 ppm)




*2 deg C is a nominal global warming target proposed by Tony Blair above which humans "dangerously interfere with climate system" -- interference that the UN Climate Treaty and the Kyoto Protocol process is intended to avoid.

# Growth Will Require Massive Low-Emitting ower Sources AND Massive Efficiency Gain

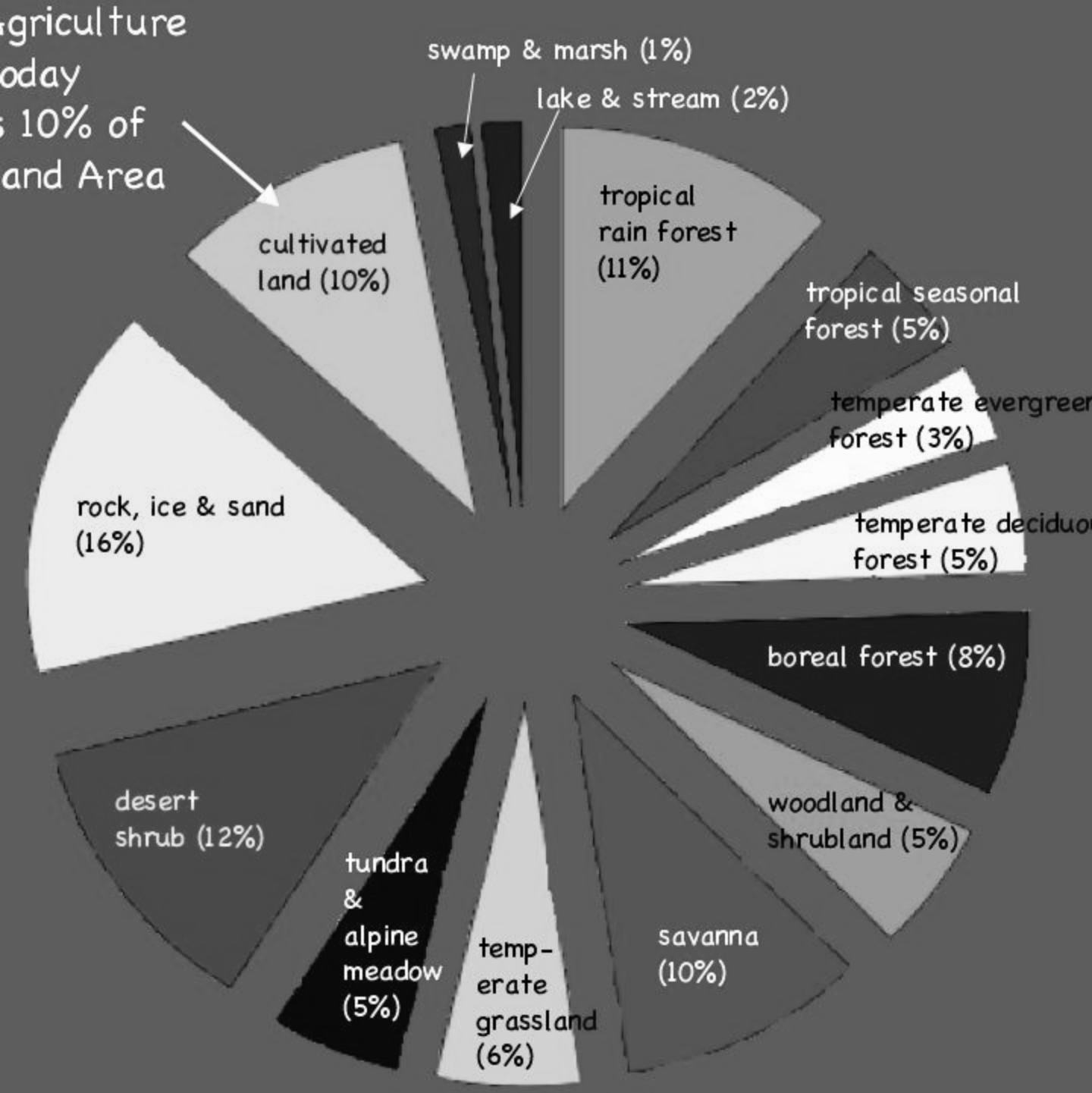



• Twenty-first century tradeoff between emission-free carbon-free primary power supply and energy intensity decline rate to stabilize atmospheric carbon dioxide at 550 ppm as the world GDP grows 2.9 %/yr to 2025, 2.3%/yr thereafter [from Hoffert et al., *Nature* 395, 881-884 (1998)]. Energy intensity is the ratio of primary energy consumption to gross domestic product, (E/GDP).

• Tens of terawatts from supply & tens of "nega-terawatts" from demand reduction are *both* needed by 2050 to stabilize climate with continued GDP growth; with much more needed by 2100.

• MIH arguing (debating?) that energy suppy vs. demand reduction is a "false dichotomy" with Amory Lovins (with pocketed banana) at *Technosphere Conference*, Synergia Ranch, Santa Fe, NM, Oct. 2005.

# LAND USE BY ECOSYSTEMS ON PLANET EARTH



# LAND REQUIREMENTS OF SOLAR MODULES & BIOFUEL

## BASIC DATA

- Agricultural area of Earth = $15 \times 10^{12}$ $m^2$ = 1,500 million ha (10% land area)
- Mean long-term solar flux at earth's surface = 200 $W/m^2$ (1/5 calibration intensity at which PV modules are rated)
- Typical commercial solar module efficiency (sunlight to DC) = 15%
- Chemical energy/carbon mass of cellulose (wood) = 35 MJ/kgC = 1.1 W-yr/kgC
- Mean net primary productivity of ag crops = 0.29 kgC/$m^2$-yr
- Present US primary power consumption for all end use sectors (electricity, transportation, buildings & industry) = 3.35 TW (1/4 world).

## SOLAR CELL LAND CONSTRAINT

- Area needed to generate ALL present US primary energy power (not just electricity) by solar modules at the surface = $11.2 \times 10^{10}$ $m^2$ = 112,000 $km^2$ = 11.2 million ha (< 0.1% earth's land area).

- Still a huge area to cover with high-tech panels -- equivalent to a square 334 km on a side -- but less than half the 28 million ha of the Southwestern Sonora and Mojave deserts combined. And it doesn't address major storage and transmission issues. But doable in principle.

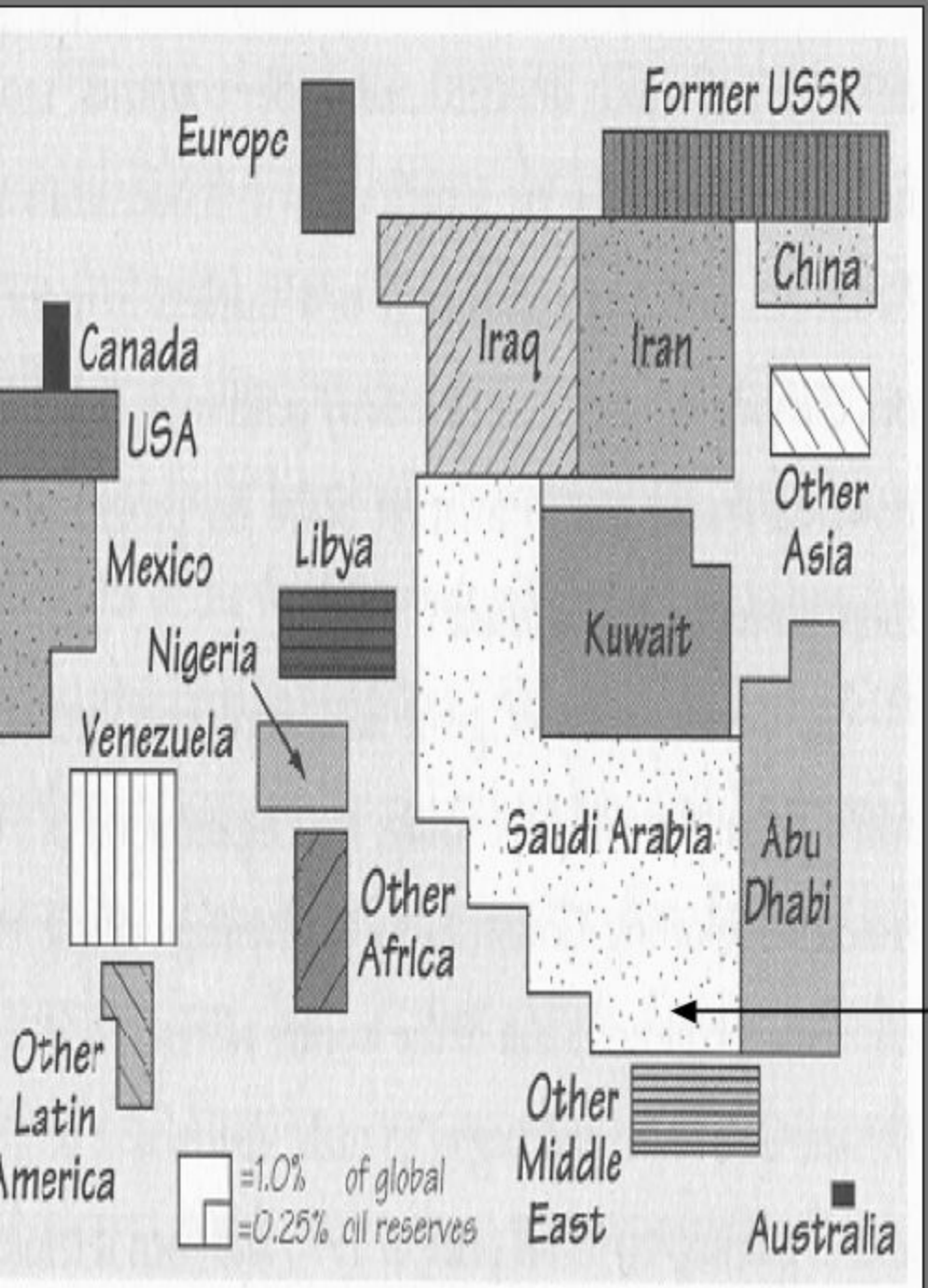
## BIOFUEL LAND CONSTRAINT

- On chemical energy per unit area of crops is produced at the rate = 0.29 kgC/$m^2$-yr X 1.1 W-yr/kgC = 0.31 $W/m^2$

- It follows that energy conversion efficiency of crop photosynthesis (sunlight-to-chemical energy) = [(0.31 $W/m^2$)/(200 $W/m^2$)] X 100% = 0.12 % -- 100 times less than PV cells (hence 100 times more area needed)!

- Even if ALL THE WORLD's cropland were devoted to cellulosic biofuels with 50% crop-to-fuel energy efficiency -- an unrealistically favorable assumption for many reasons, including the need for 6 billion+ *Homo sapiens* to eat -- the best we could do is generate 2.23 TW as biofuels, far less than the 10-30 TW of carbon neutral power needed worldwide by 2050. It only get worse with time.

# CRISIS: The geochemistry of oil formed ove hundreds of millions of years profound affects today geopoliti

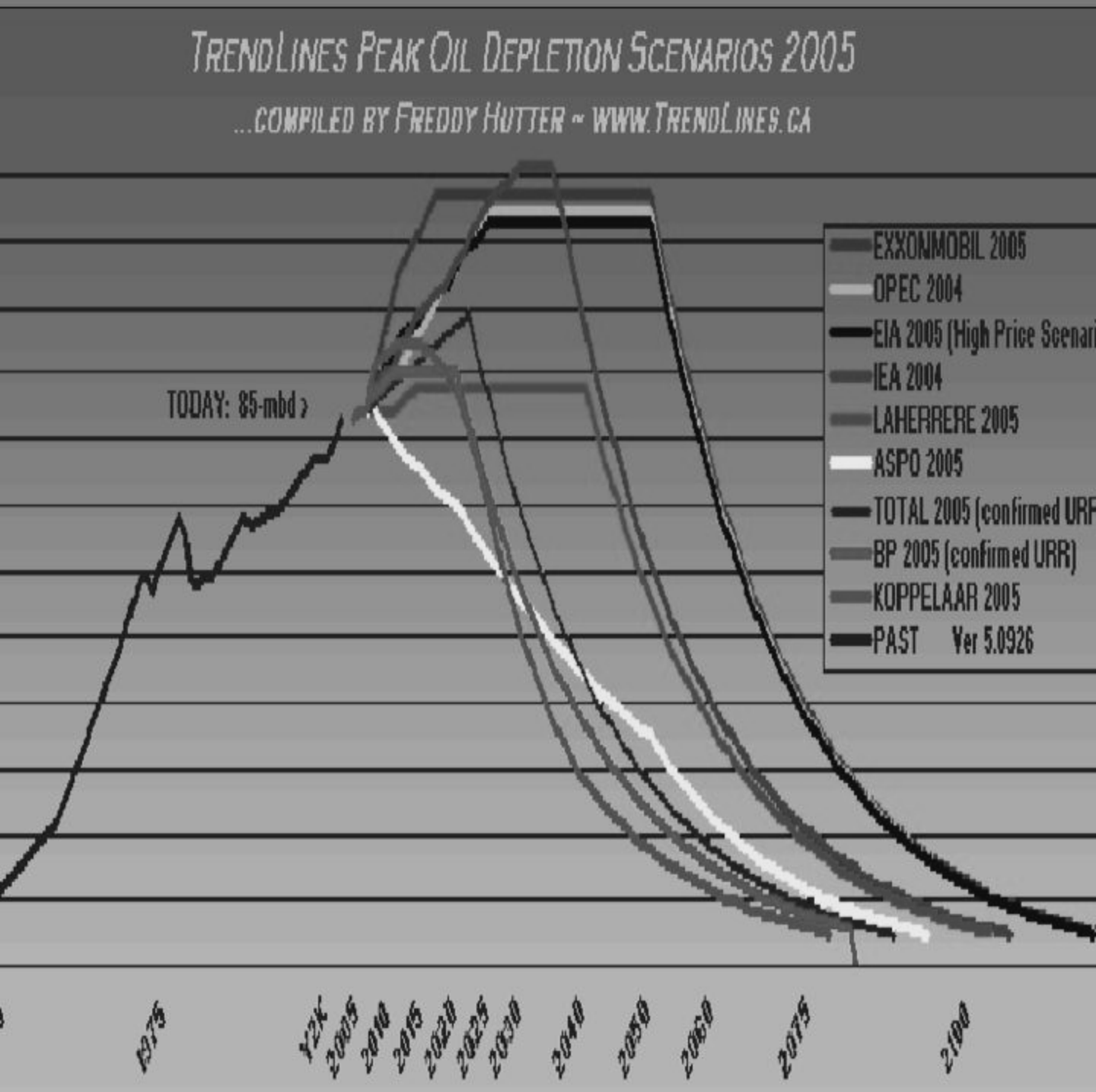



Shares of global crude oil reserves in 1995 are shown by proportionate areas of national or continental territories.

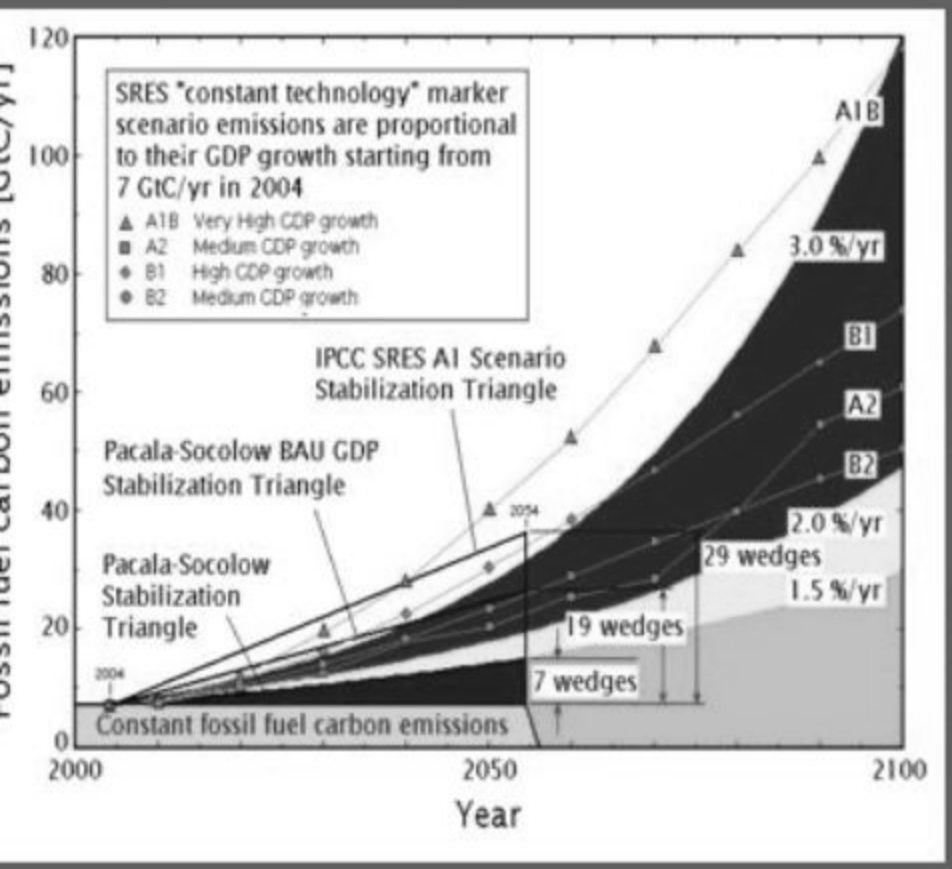
The overwhelming majority of global crude oil reserves reside in 6 Islamic nations of the Persian Gulf (data from V. Smil, *Energies* (MIT Press, 1999), p. 139.

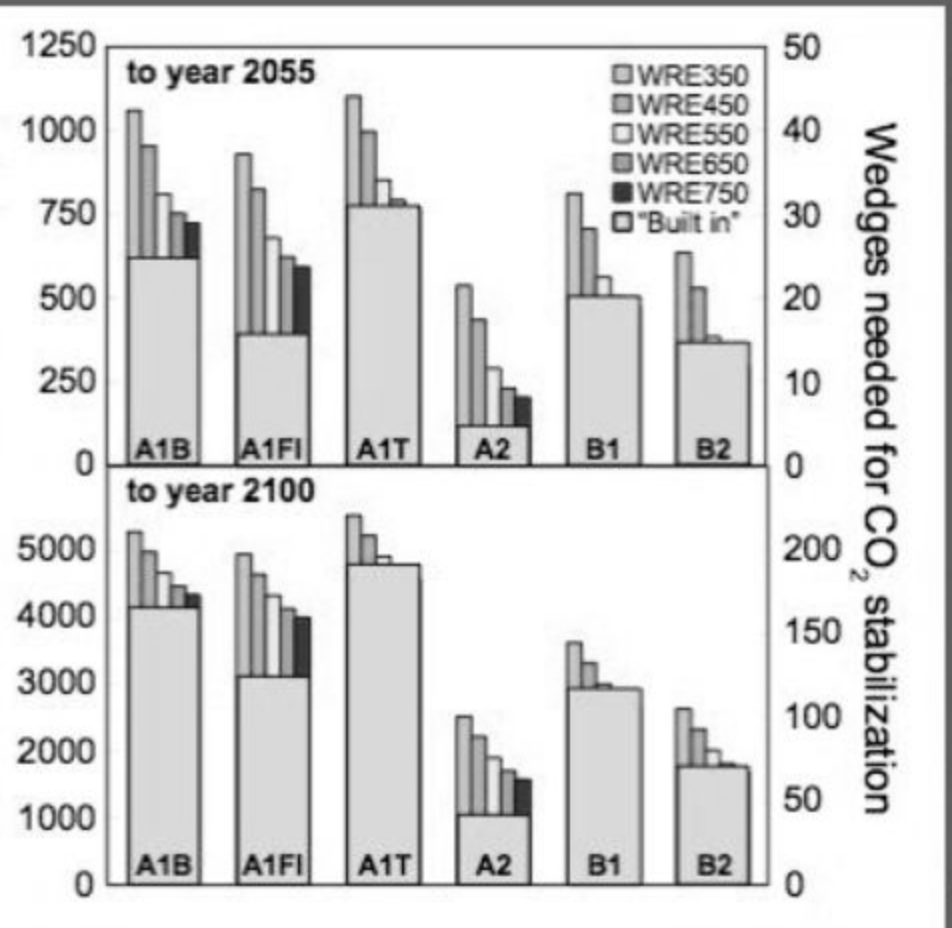
AS?"

n about 100 years; but Hubbert curves for "cheap oil" oduction rates estimated by various sources all peak tween "now" & mid-century (likewise for cheap natural ).



# ...Many Wedges!



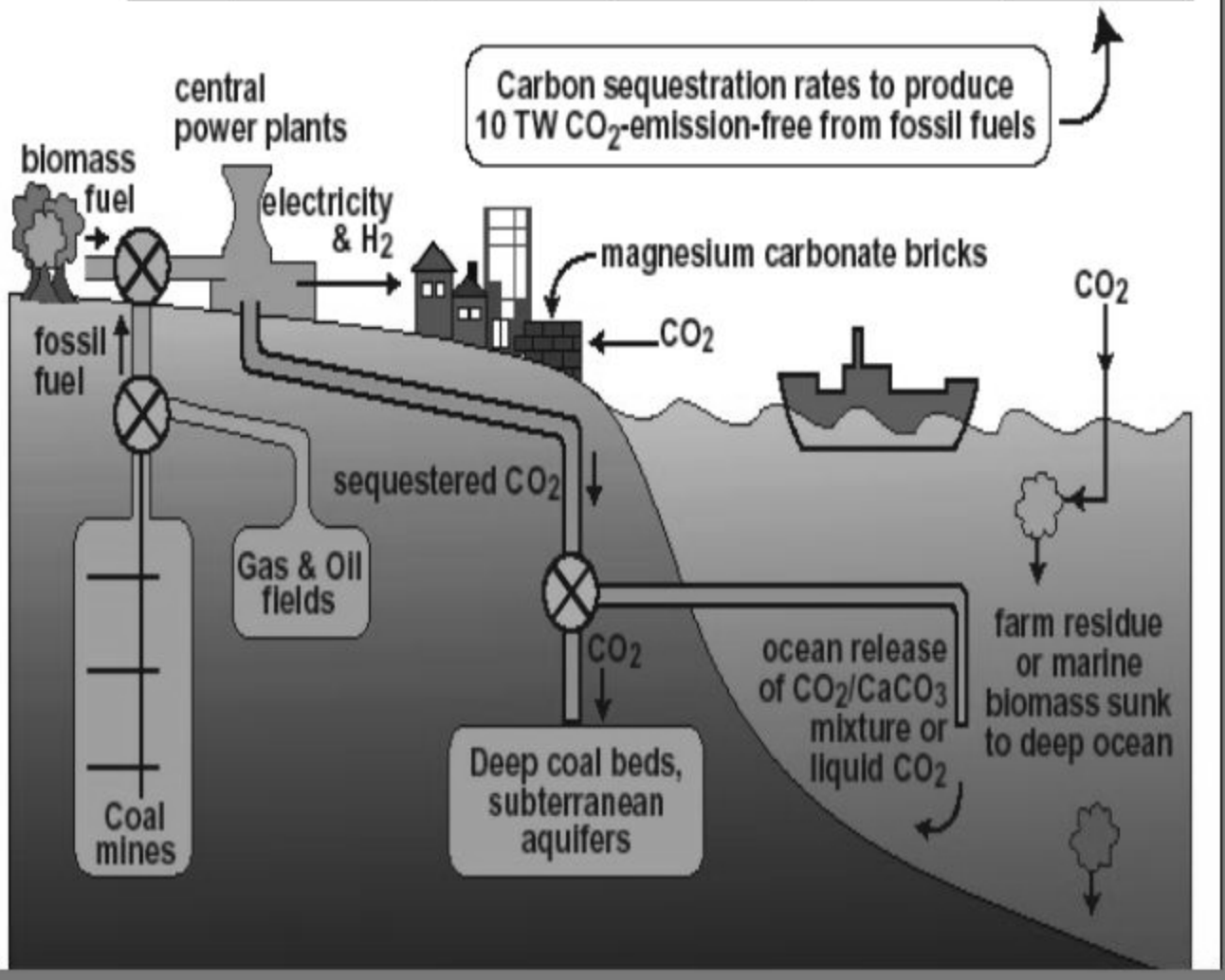

**If:** 1 "wedge" = 25 billion tonnes less carbon emitted over 50 years from carbon-neutral or energy efficient technology,

**Then:** 19 wedg are needed for Pacala-Socolow Scenario: 12 "virtual"wedges to g from 3%/yr GDP growth to 1.5%/yr emission growth + 7 to get from 1.5%/yr to zer emission growth for 50 yr.

## Even More Important:

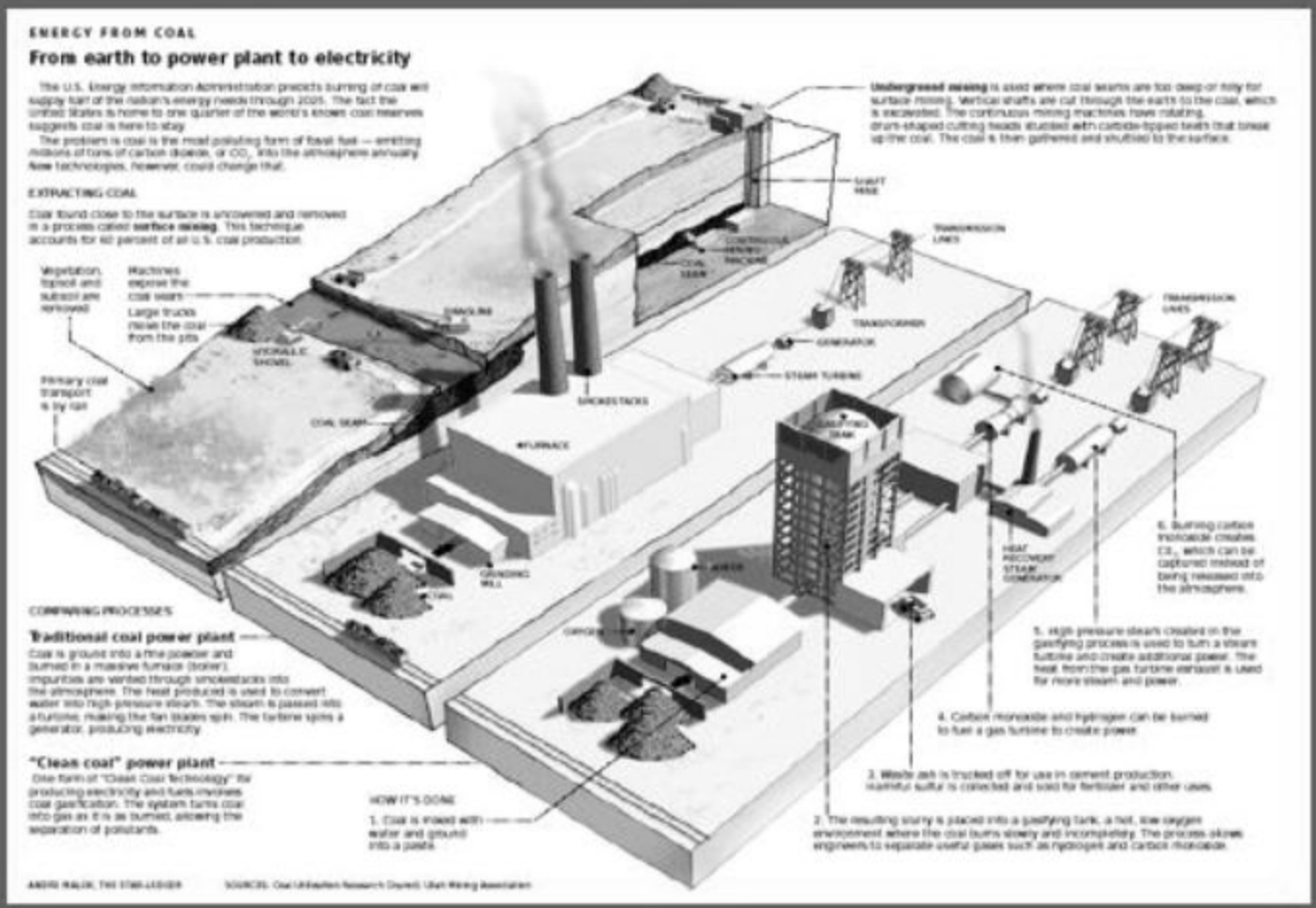
The wedge count becomes huge in the 2nd half of the 21st century. We need to target this now. (Tom Wigley

| 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 |

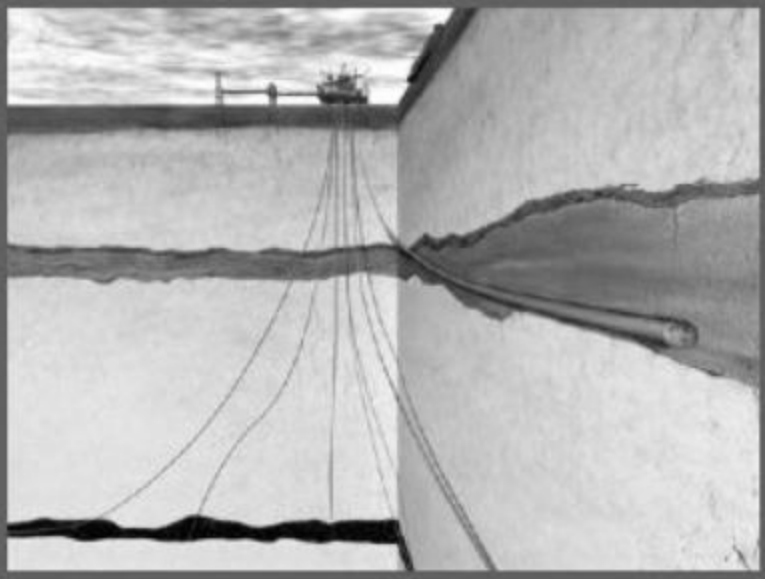


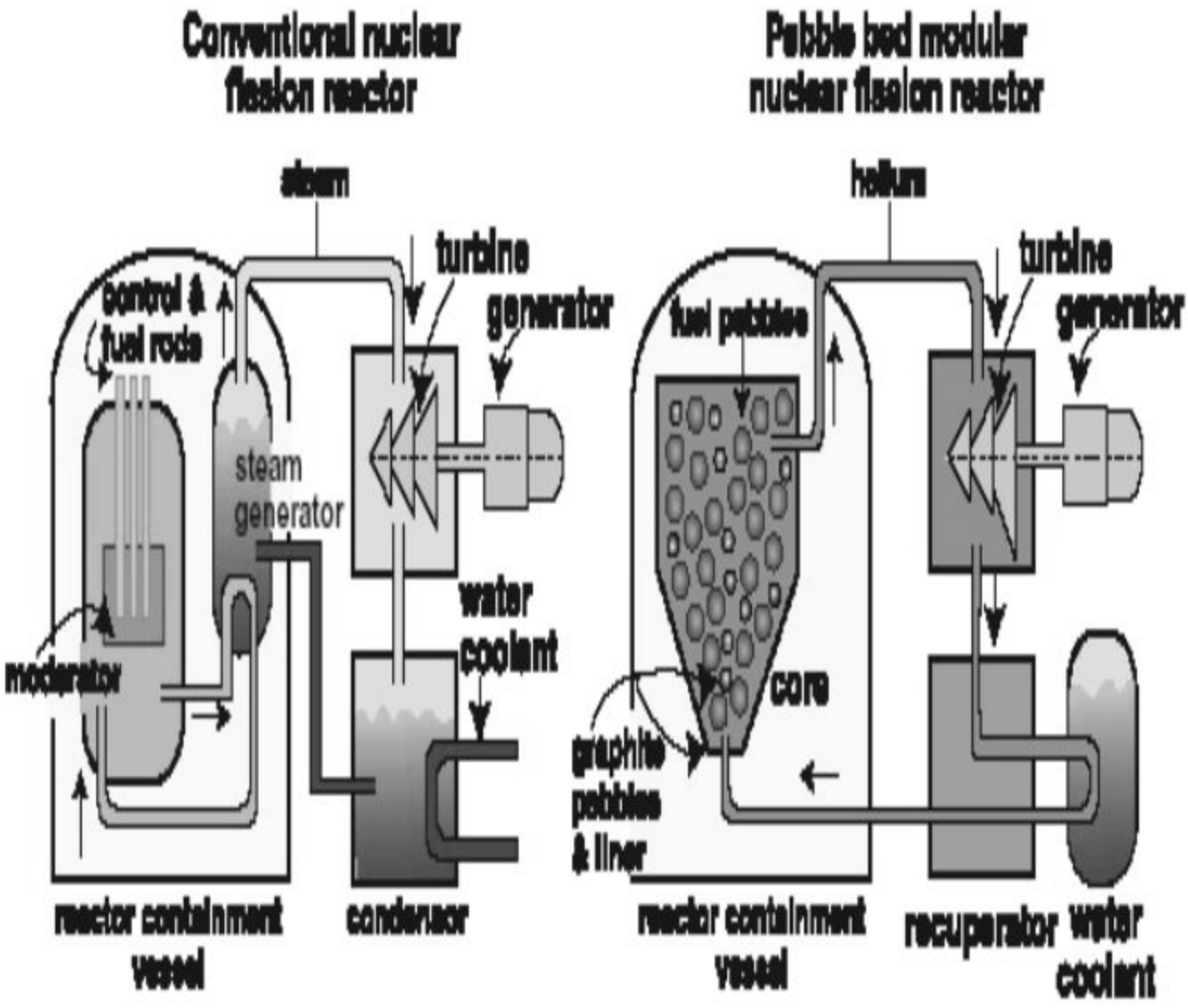

# Fossil fuel $CO_2$ sequestration concepts & burial rates needed, to generate 10 TW carbon-emission-free

# "FutureGen" coal-gasifier driving combined cycle (steam & gas turbines) for electricity generation and fuel cell grade H2 with carbon capture & storage



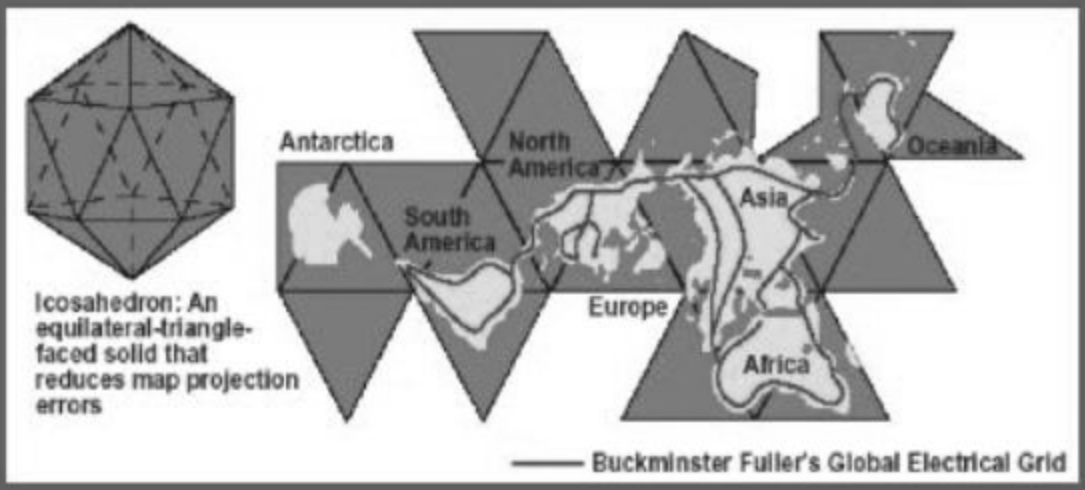

- $CO_2$ storage demo under Norwegian Statoil's Sleipner North Sea

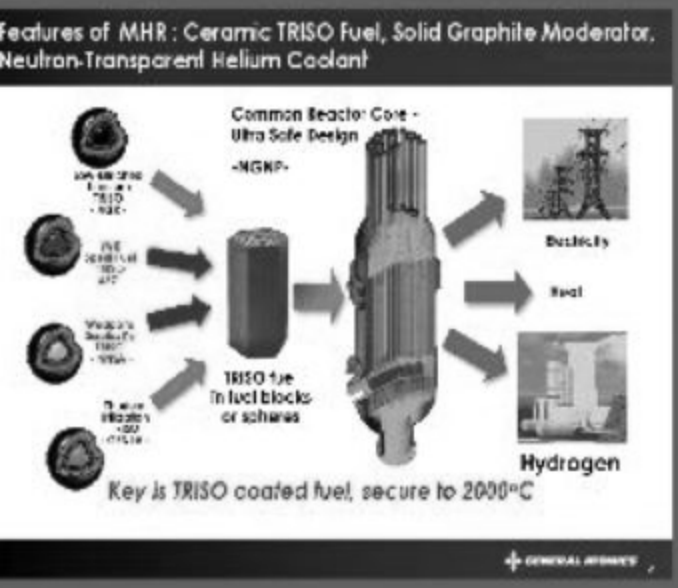





(LEFT) The conventional light water reactor (LWR) employs water as both coolant and working fluid. (RIGHT) The helium-cooled, graphite-moderated, pebble bed, modular nuclear fission reactor is theoretically immune to loss of coolant (TMI) and criticality (Chernobyl) accidents.

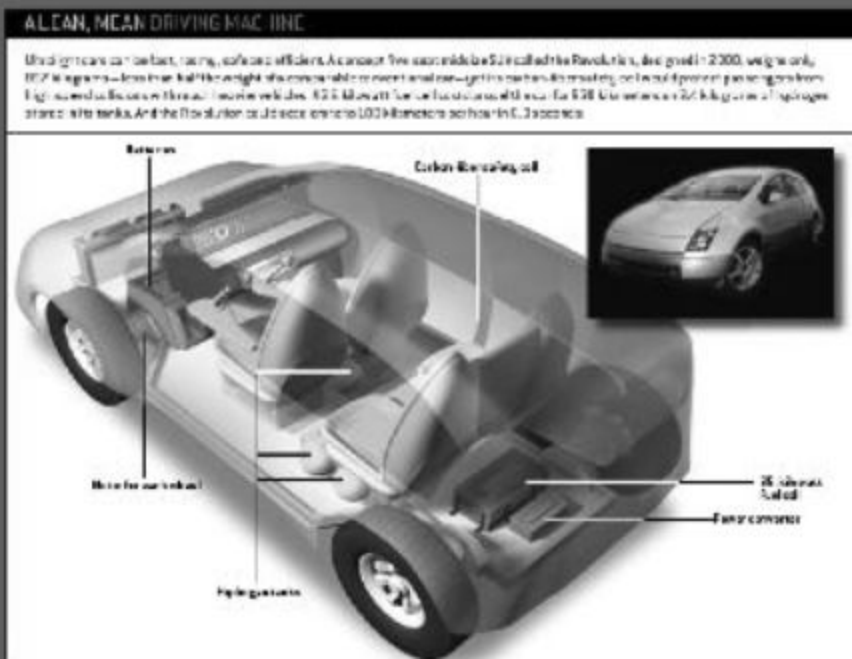
• Global Superconducting electric power grid




• Safer, gas-cooled, graphite- moderated reactors making electricity & hydrogen could burn U-233 bred from thorium

• Ultralight, low-drag plug-in hybrid cars & trucks rechargeable with wind and solar electricity

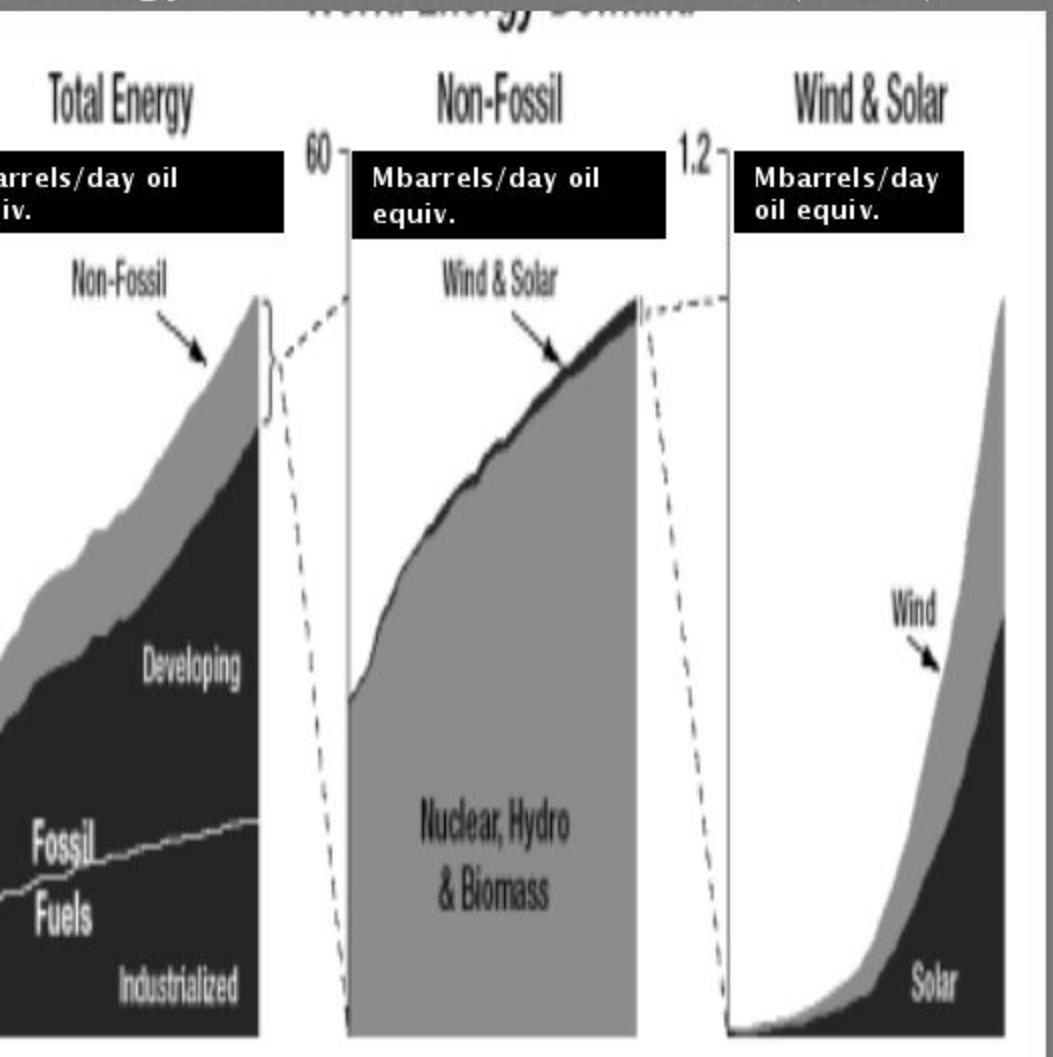


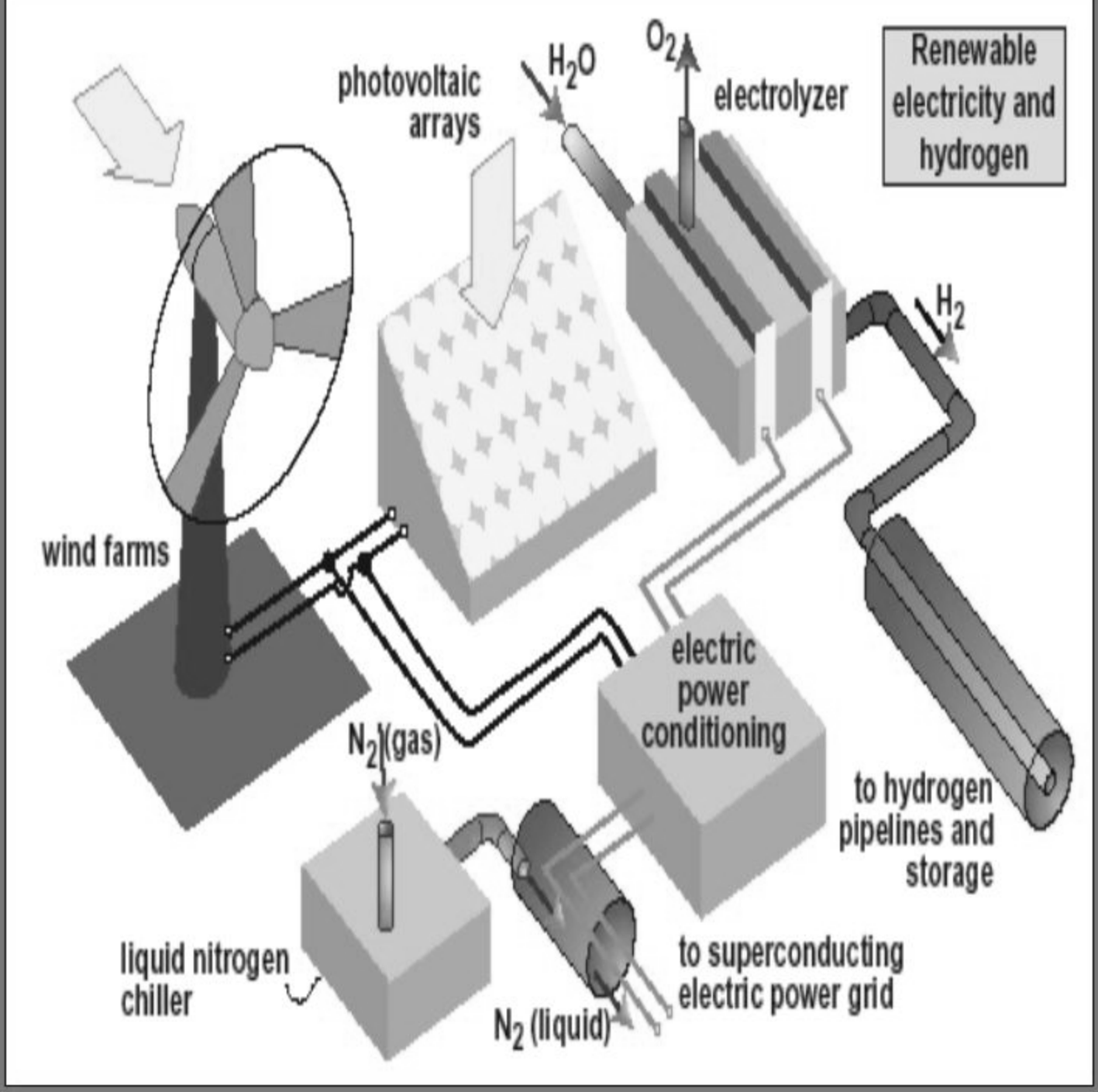
# NERGY:

ome critics claim we will never power civilization with
newable energy.

act: Wind & solar are fastest-growing primary power sources,
ut are unlikely to grow from present ~ 1% of supply to 10% by
025 and >30% by 2050 without major incentives, R & D and
emonstration of enabling technologies. There are no known
ow-stoppers

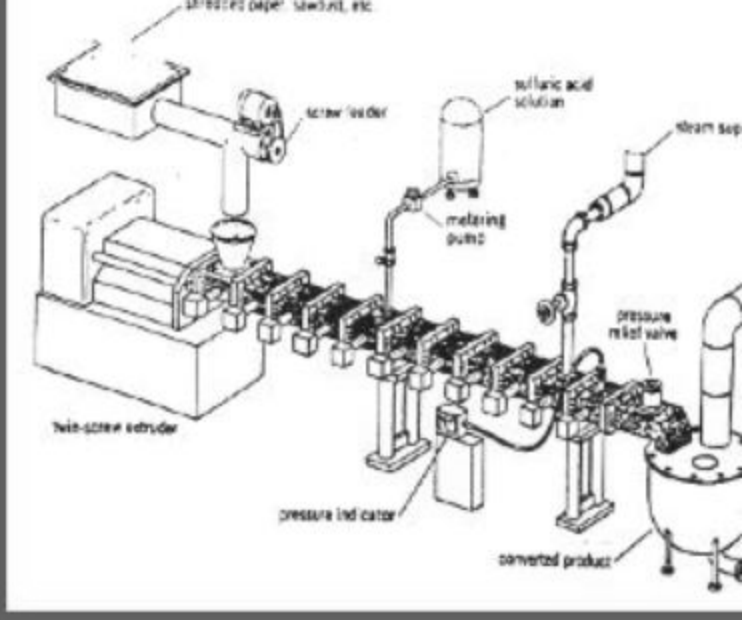
## Energy Demand 1980-2020 (BAU)




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

Biofuels need large
reas, energy inputs &
ellulose converters
or large-scale use.
YU acid hydrolysis
echnology (cellulose -
sugar -> ethanol) of
70s is shown

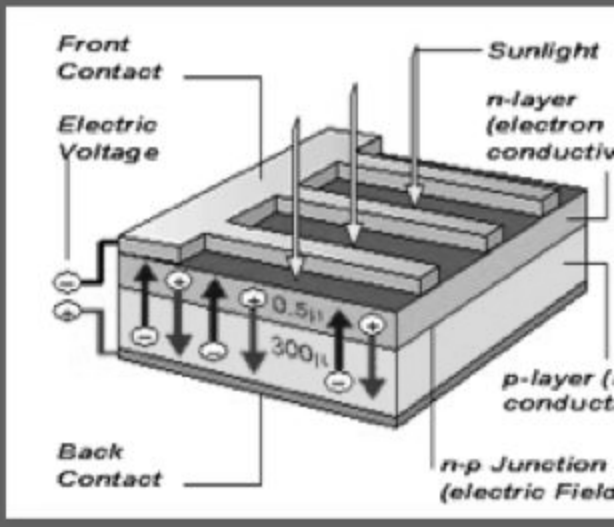



• Original Daniel Libeskind Freedom Tower design for WTC site shown had wind turbines inside open upper story tensioned lattices to provide 20% of the building's electricity

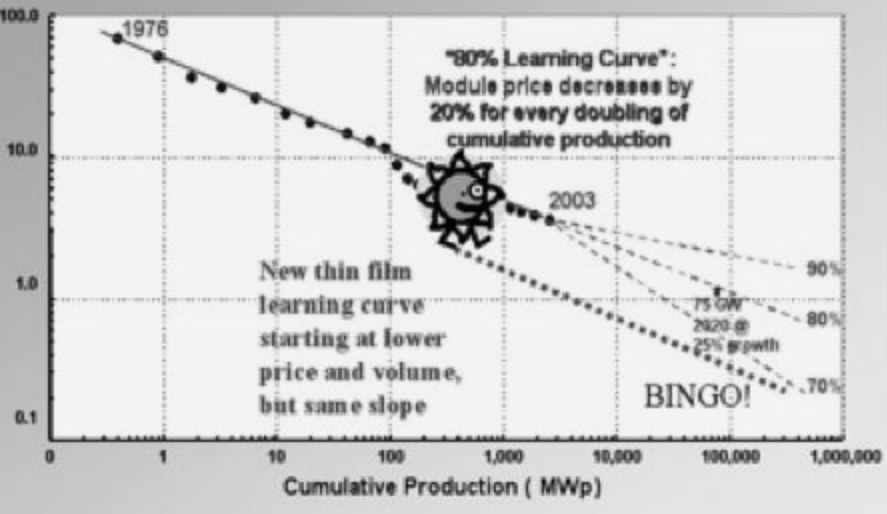
• Solar Hydrogen Home on LI by NY Institute of Technology & USMMA with PV electrolysis,


• High-altitude tethered autogiros could tap high kinetic energy in jet streams

Photovoltaic (PV) cells onvert photons more nergetic than emiconductor band gaps to C electricity. Dominant echnology today is rystalline Si modules




**PV Module Cost Versus Cumulative Production in peak megawatts: History & projected "Learning by Doing" & by celerated R & D curve for thin films (from Ken Zweibel, NREL)**




• Exotic thin fil (GaAs $CuInSe_2$, CdTe, amorphou Si) promise cost breakthroughs. An alternate approach is sola concentrators focused on smal

# ower Quanta & Carbon Footprints

Average amt.
mitted per
ilowatt-hr of
lectricity
onsumed in the
JS in the year
000

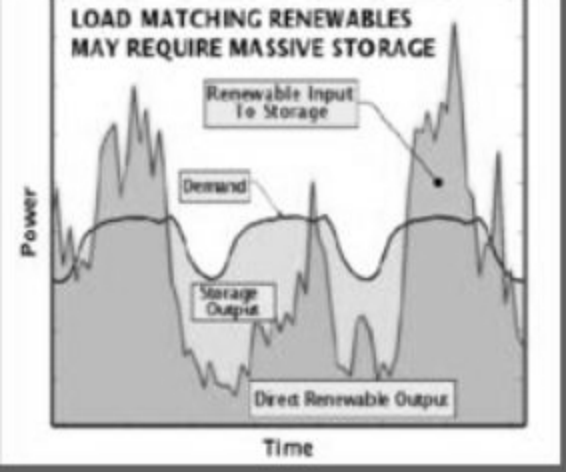
1.340 lb
O2/kWe-hr

0.365 lb
/kWe-hr

0.166 kg
/kWe-hr

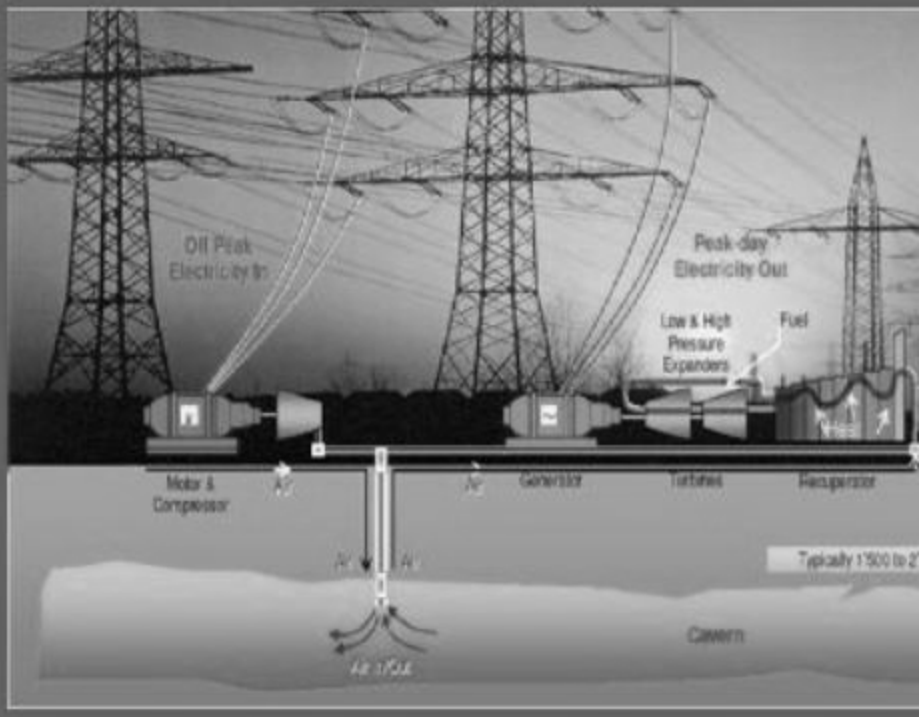

• Therefore, even a home wit
0.8 kWe mean solar power
input (at least 20 square
meters of solar panels) using
electricity at a mean rate o
7.8 kWe as in the example
above would cause CO2 to b
emitted at the power plant
the rate 7.8 kWe x 0.166 k
C/kWe-hr = 1.3 kg/hr

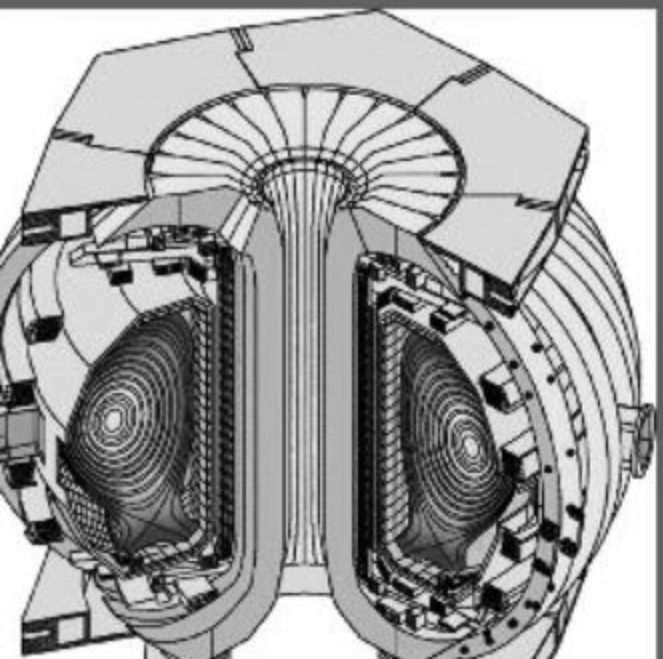
• In one year (8760 hr) the
carbon emitted would be
11,400 kg C, or 11.4 metric
tonnes.




• Large-scale solar and wind will need energy storage, transmission and power management technologies to match supply & demand

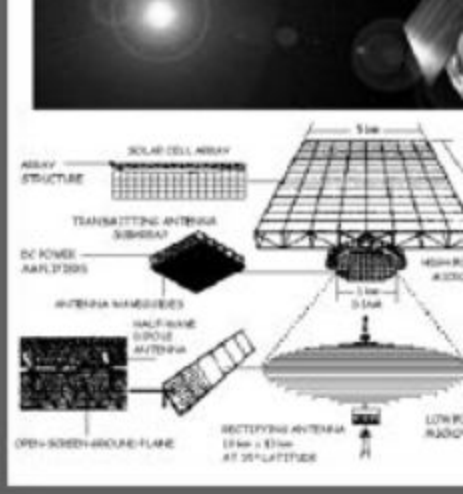
• Compressed air energy storage (CAES) is one promising approach for the US where pumped hydro is limited



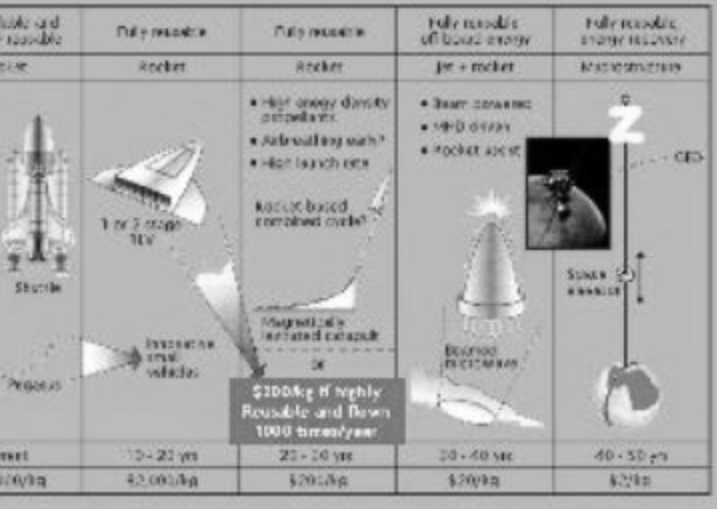



• Pure fusion is the Holy Grail (the ITER tokamak is shown). But early implementation of fusion neutrons to breed fissionable U-233 from thorium in burner-breeders should perhaps

wer continuously available in
O 5-10 times surface intensity
beamed to Earth for base
ad. The NASA-DoE design of
e 70s employing microwave
amers is shown

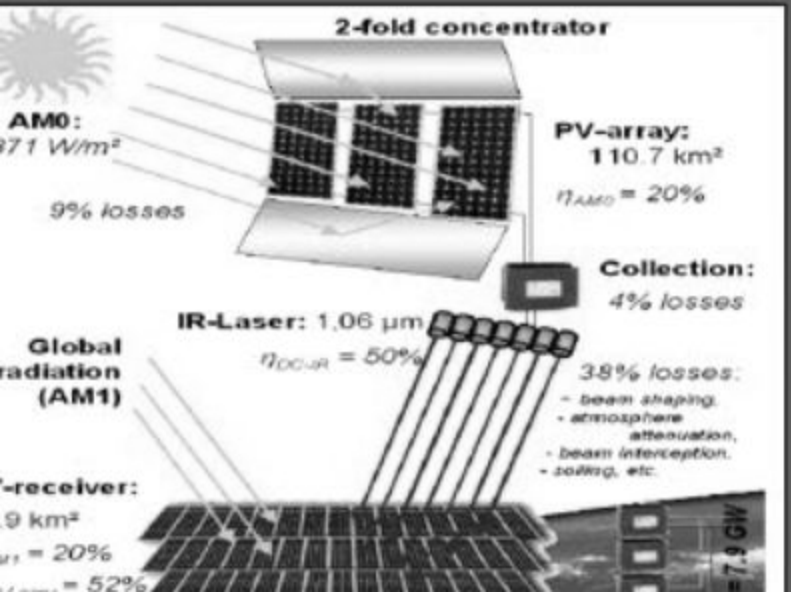


LAUNCH COST EVOLUTION: $20,000/kg -> $2/kg
d from I. Bekey, *Advanced Space System Concepts and Technologies 2010-2030*, Aerospace Press, El Segundo, CA, 2004, p.54)




- Launch costs could potentially drop from the present Shuttle $20,000/kg to $2/kg, comparable to "Moore's Law" as shown

Relay mirror laser demo of '90s --->

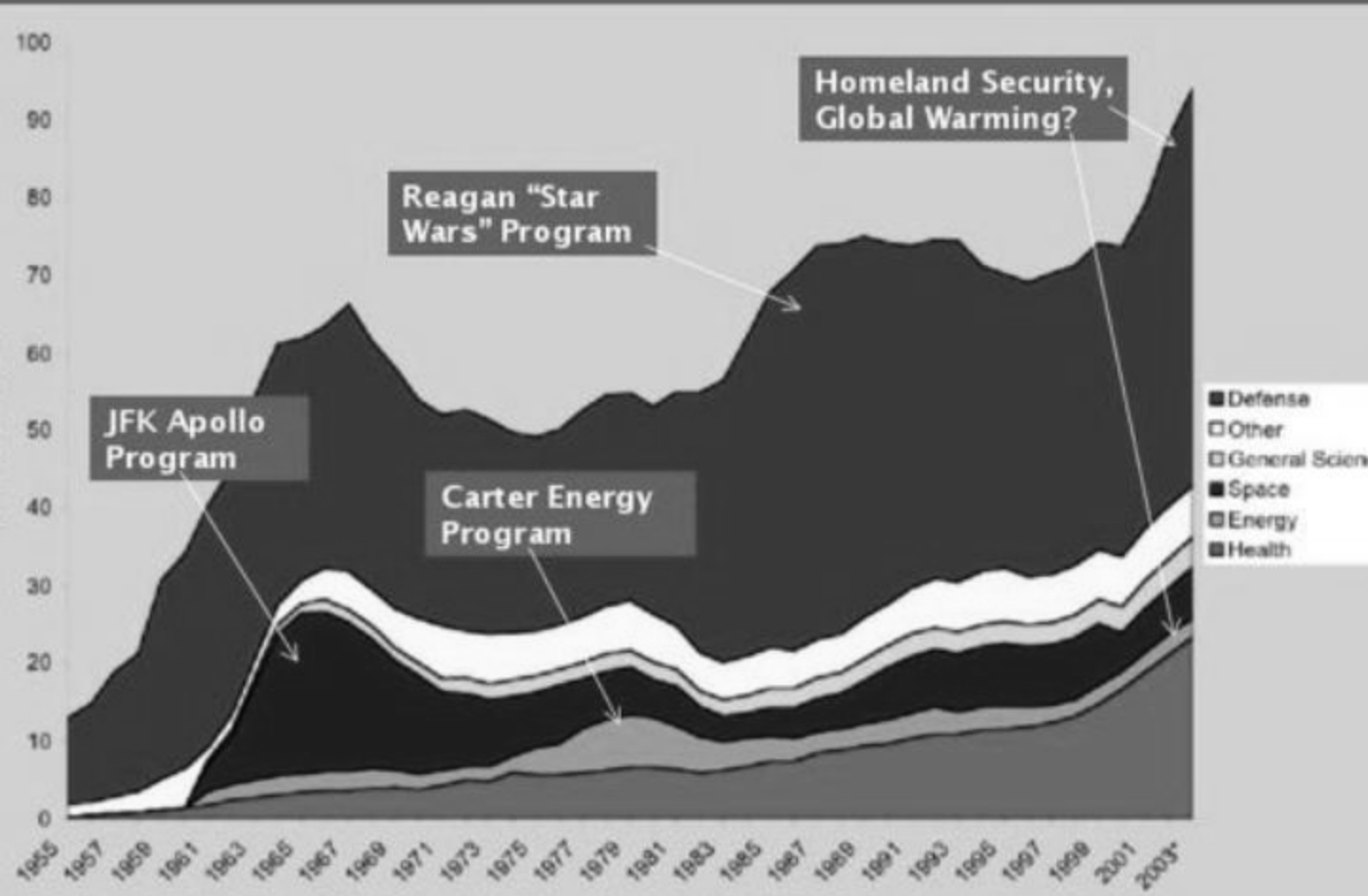



- Laser diode SSP beaming to PV modules in Sahara could supply load curve of Europe according to recent study

oney?

Or by failure of imagination?

# HISTORY OF US FEDERAL GOVERNMENT R &




*ource: National Science Foundation, Federal R&D Funding by Budget Function, Fiscal Years 2001-03.*
*2002 figures are preliminary, 2003 figures are proposed.*

We can well afford "Apollo Programs" in
stainable alternative energy research,
velopment, demonstration & global deployment

What we can't afford is collapse of our high-

# Does Economics Trump Technology?

# Or: Does Technology Create New Economic Realities?