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California Energy Commission Integrated Energy Policy Report 2005, 04-IEP-1J

Committee Workshop on Issues Concerning Nuclear Power

Sacramento, California, 16 August 2005, slightly updated 13 September 2005

Nuclear power: economic fundamentals and potential role in climate change mitigation

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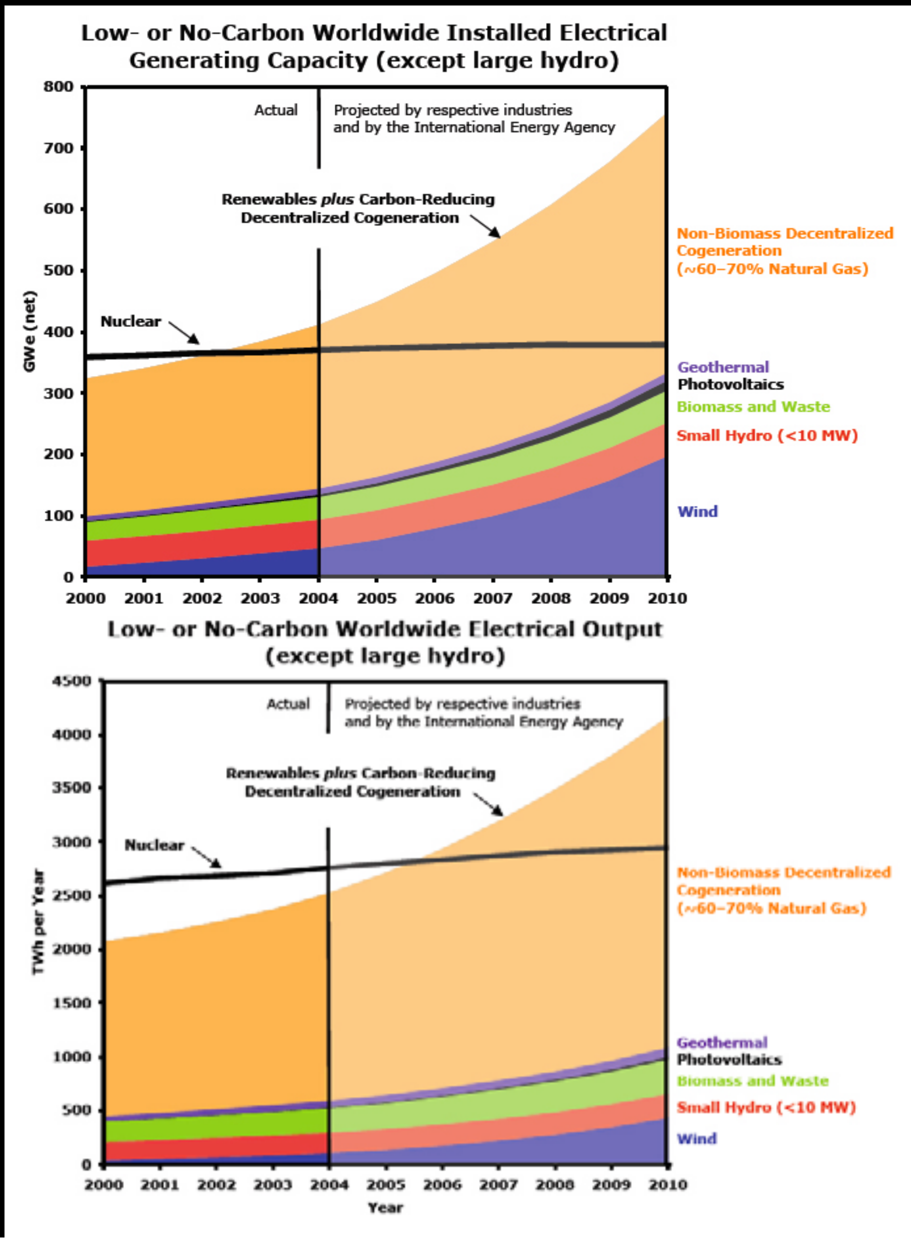
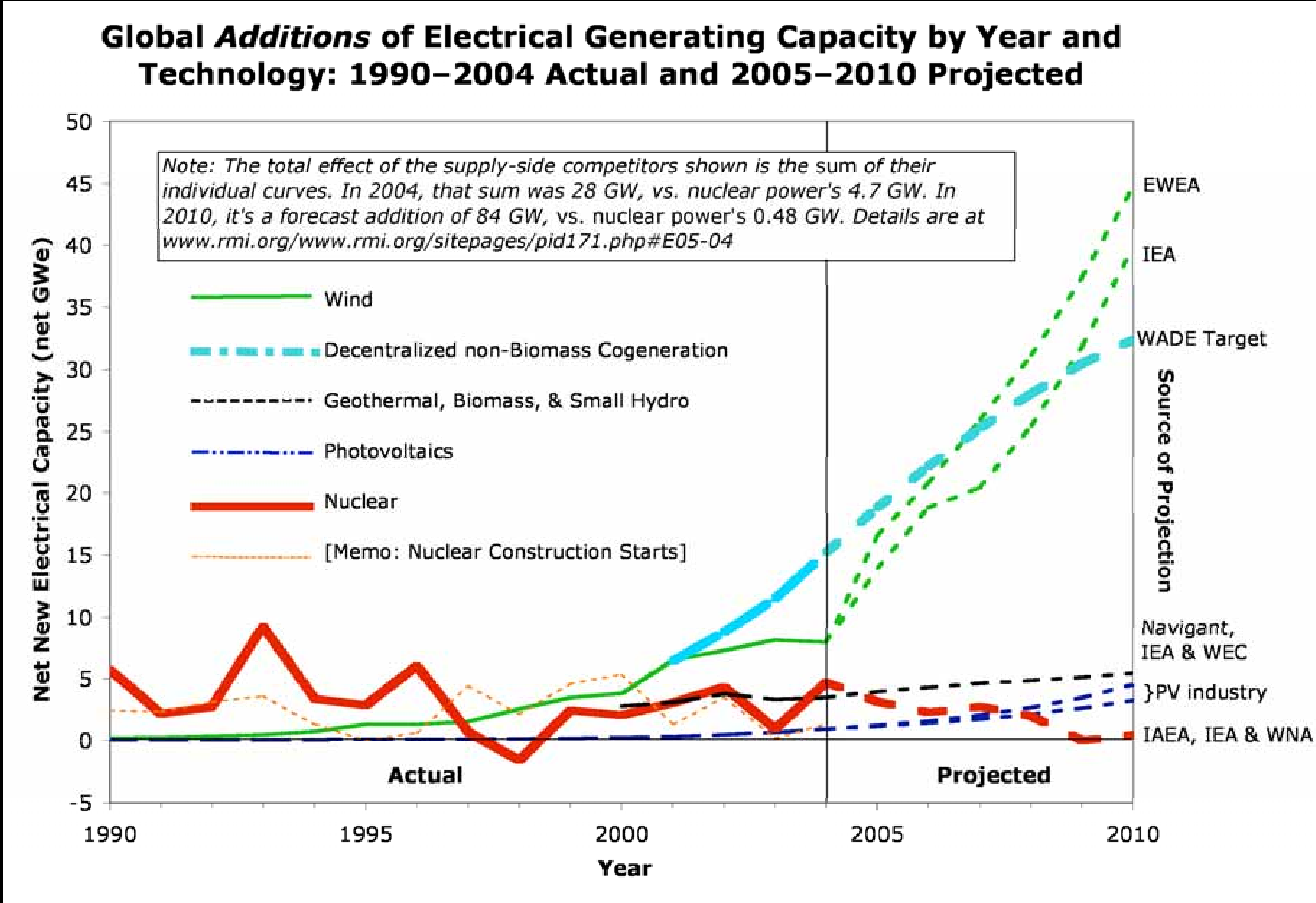
Market reality: low-/no-carbon decentralized sources have eclipsed nuclear power



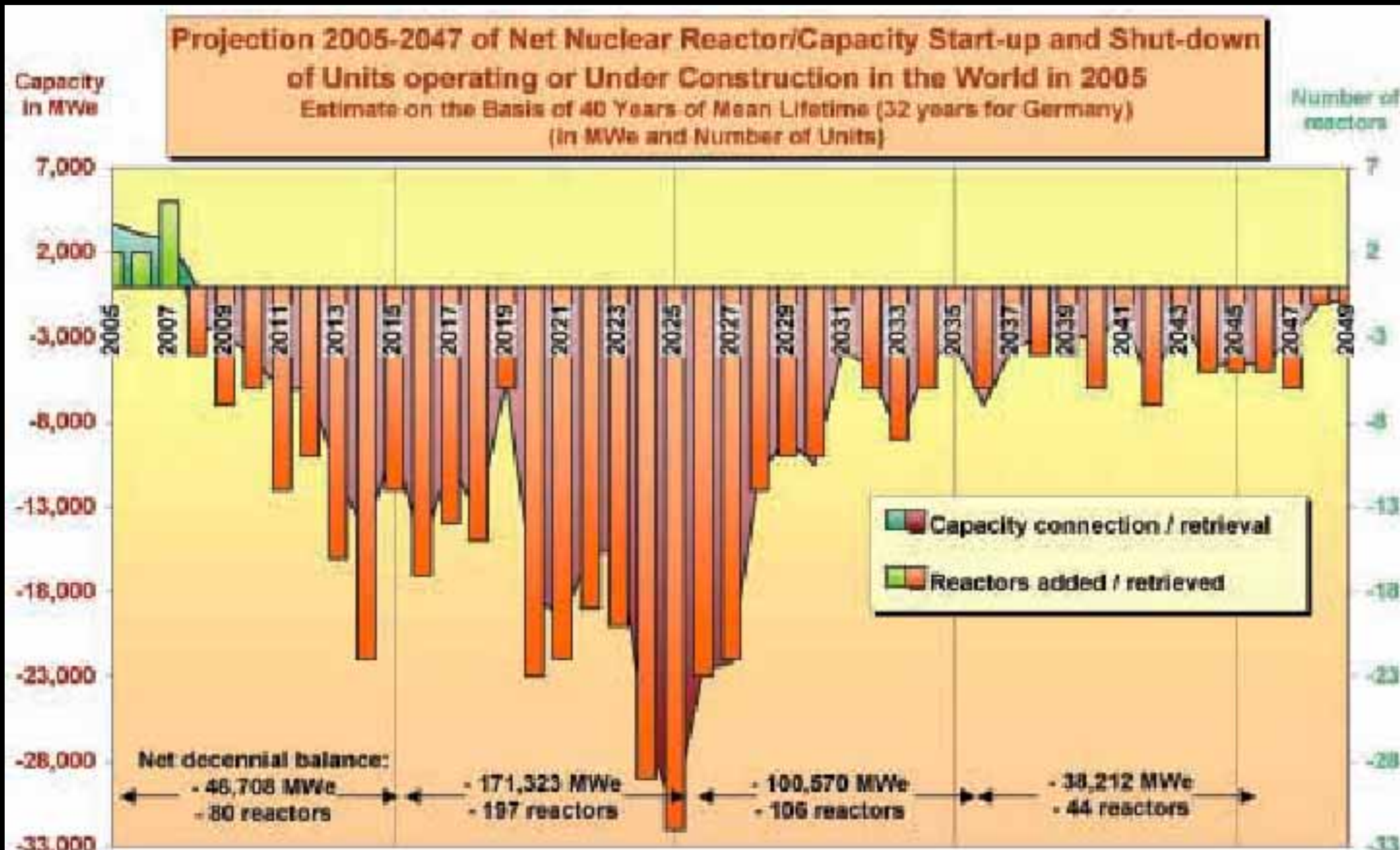
RMI analysis: www.rmi.org/sitepages/pid171.php#E05-04

- Two-thirds of the decentralized new capacity is combined-heat-and-power in industry and buildings, ~60–70% of it gas-fired
- The rest is renewable (hydro is included only up to 10 MW_e)
- In 2004, these low- or no-carbon options added *2.9× as much output and 5.9× as much capacity* as nuclear power did
- Their projected 2010 capacity addition is *~177× nuclear's*
- Demand-side additions are probably bigger…but no data! (Nearly all data focus on supply side…just 22% of increased U.S. energy services since 1996)

Nuclear's "small, slow" decentralized supply competitors are growing far faster



Global nuclear capacity is about to start a long, inevitable decline



Schneider & Froggatt, summarized in *Nucl. Eng. Intl.*, June 2005

Basic economics of new nuclear power plants

- Unfinanceable in the private capital market; the few orders are all in centrally planned
- That's because it's fundamentally electricity systems; never bid into an auction nor chosen by open process uncompetitive…
  - With the usual competitors (central coal, gas-combined-cycle) considered by MIT, U. Chicago, IAEA, IEA, and other studies
  - Far more importantly, with three durably fatal competitors that those studies consistently ignore: **end-use efficiency, gas-fired cogen/trigen, and windpower** (plus some other renewables)
- Nothing can save nuclear power from bad economics
  - Not regulatory change—we've tried that for 25 y (so did France)
  - Not new reactor types: it'd cost too much even if reactor were *free*
  - Not a carbon tax: it equally advantages nuclear's main competitors
  - Not hydrogen: a hopelessly uneconomic source of H_2
  - Not the just-increased U.S. subsidies: markets ultimately prevail

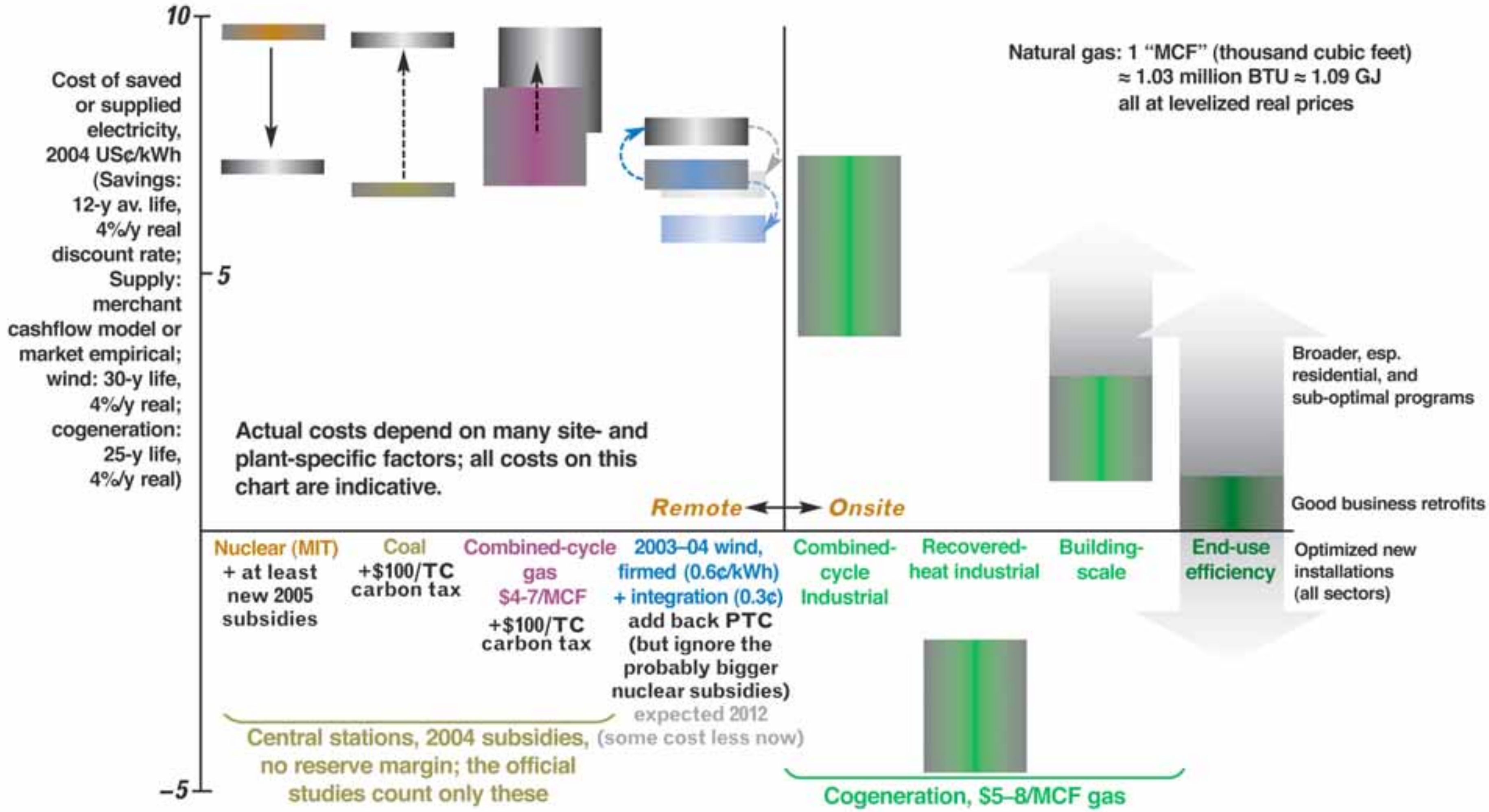
New-nuclear electricity busbar cost

0.85 capacity factor, 40-y life, levelized, merchant, 2004$ [= 2002$ × 1.0471 GDP implicit price deflator]

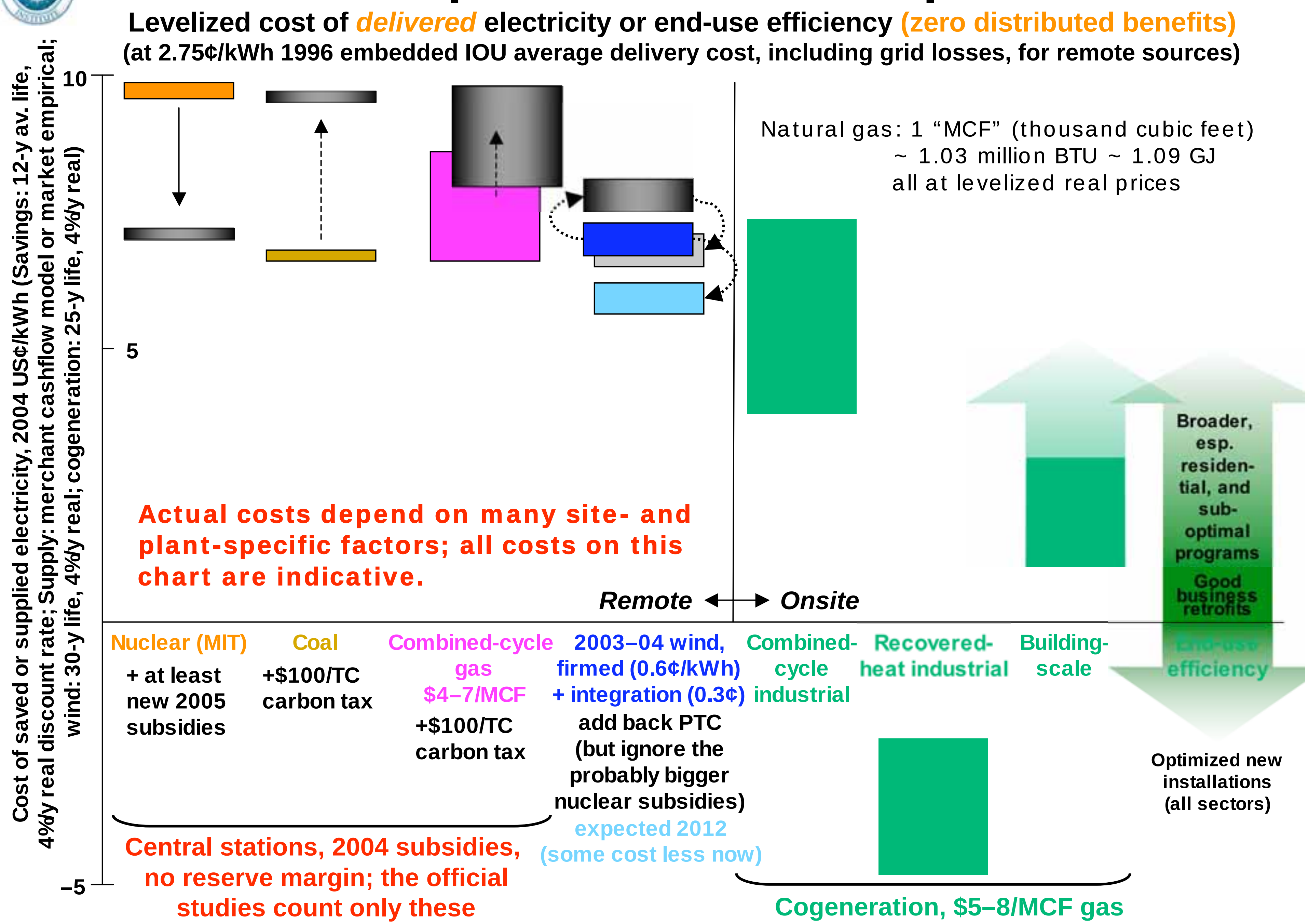
- MIT study 2003 (which I adopt): **7.0¢/kWh**, *vs.* 4.4¢ coal, 4.0–5.9¢ combined-cycle gas (@ $4–7/MCF)
  - Nuclear cost can drop to 5.8¢ if 25% cheaper than assumed overnight $2094/kW, to 5.6¢ if 1 y faster than assumed “optimistic” 5 y, and to 4.6¢ if no capital risk premium…but never beats coal
  - Carbon tax of (say) $50/TC raises 40-y coal-el. cost by 1.3¢/ kWh, gas-el. cost by 0.5¢/kWh; an actual tax might be 2–4× higher
  - So new nuclear plants can’t compete with new coal or gas plants, but might if nuclear got much cheaper or carbon were heavily taxed
- U. of Chicago study 2004: similar findings with more optimistic costs (nuclear $1232–1847/kW overnight)
- Caution: Finland’s [TVA-like] 1.6-GW plant was bought turnkey for ~€1875–2000/kW in 12/03—then worth ~$2500/ kW (2004 $), or ~$2200/kW overnight—and was a heavily subsidized loss-leader; an identical unit now proposed for France is to cost ≥25% more
- Big caution: coal and gas are the wrong competitors!

Nuclear power's fatal competitors

Levelized cost of *delivered* electricity or end-use efficiency (zero distributed benefits)
(at 2.75¢/kWh 1996 embedded IOU average delivery cost, including grid losses, for remote sources)



Nuclear power's fatal competitors

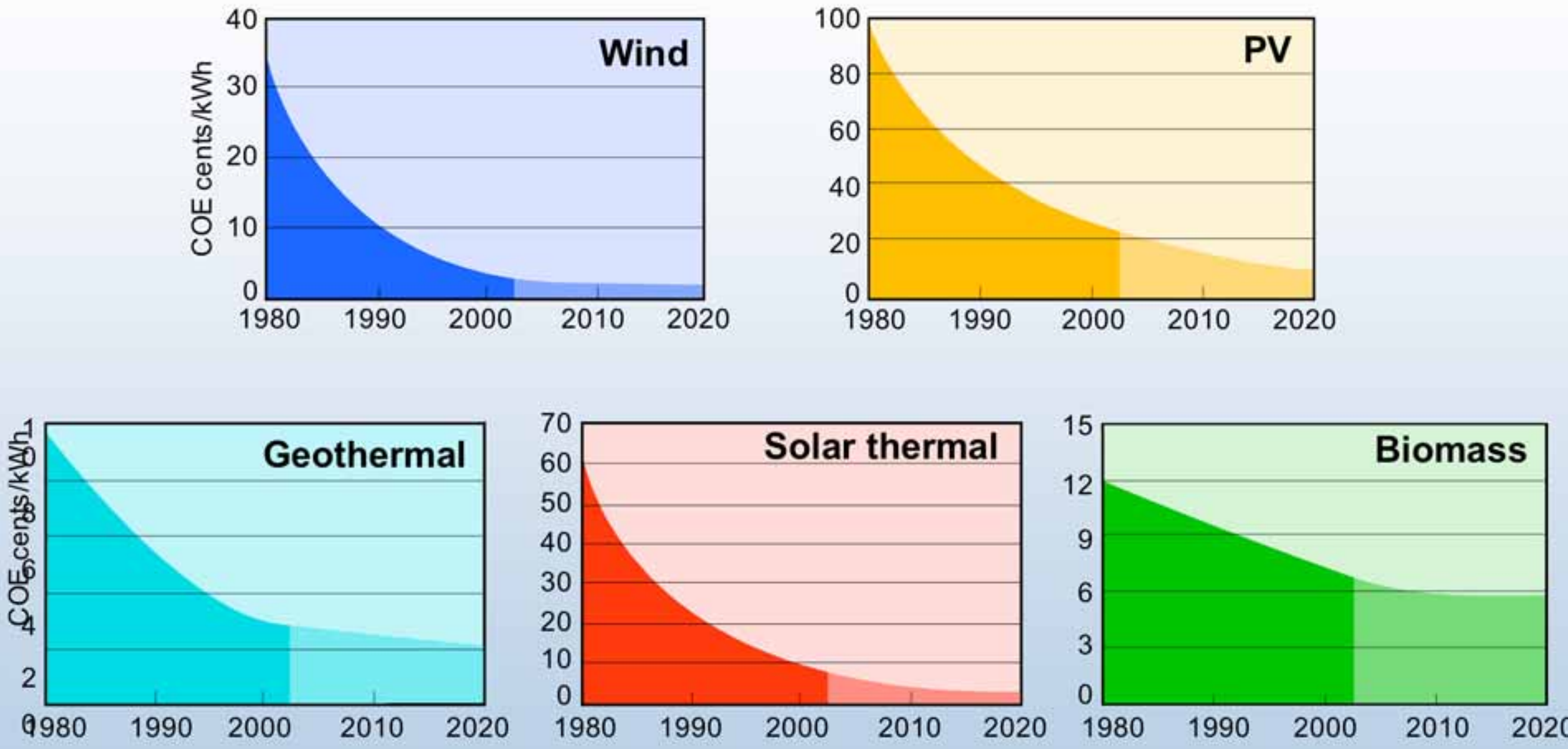


Why is the efficiency resource getting bigger and cheaper even as we use it up?

- Technologies: mass production (often offshore), cheaper electronics, competition, better tech (thanks to Jim Rogers PE for most of these examples, all in *nominal* dollars)
  - Compact fluorescent lamps: >$20 in 1983, $2–5 in 2003 (~1b/y)
  - Electronic T8 ballasts: >$80 1990, <$10 2003 (and lm/W up 30%)
  - Direct/indirect luminaires: gone from premium to cheapest option
  - Industrial variable-speed drives: ~60–70% cheaper since 1990
  - Window a/c: 54% cheaper than 1993, 13% more efficient, digital
  - Low-E window coatings: ~75% cheaper than five years ago
- Delivery: scaleup, streamlining, integration
  - *E.g.*, a NE lighting retrofit firm halves the normal contractor price
- Design integration: huge, least exploited resource
  - Hardly used yet...but typically makes very big savings cost <0!

Renewable Energy Cost Trends

Levelized cents/kWh in constant \$2000[1] [× 1.091 = 2004\$]



Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2002.ppt)
[1]These graphs are reflections of historical cost trends NOT precise annual historical data.
Updated: October 2002

NB: These graphs, and RMI's comparisons in this presentation, use engineering economics, and hence *ignore* the 207 "distributed benefits" that typically increase decentralized resources' economic value by ~10×...as markets are starting to recognize

Main (*i.e.*, normally ignored) competitors' potential US size dwarfs nuclear's

- El. end-use efficiency: ~2–4× nuclear's 20% share at below its *short*-run marginal delivered cost
- Cogen: industrial alone is comparable to nuclear: LBNL found 96 GW of low-to-negative-cost potent'l
- Wind: ≥2× US total el. use, or ≥10× 2004 nuclear
- Other renewables: collectively even larger
- Intermittence & land-use concerns are unfounded
- IEA (2004) estimated world long-term renewable potential at ~30,000 TWh/y (≈ total 2030 usage); clearly much larger with emerging PV innovations
- All these options are becoming bigger and cheaper…faster than nuclear potential is or could
- They also have inherently far shorter lead times

Neither of the main arguments for nuclear expansion withstands analysis

- Displacing oil
  - <3% of US el. is oil-fired (0.3% distillate), <2% of US oil makes el., both declining; worldwide, both are ~7%
  - Most oil-fired power plants are peaking or intermediate-load-factor, while nuclear plants must run steadily
  - Even “small” nukes are too big for most oil-fired systems
- Protecting climate
  - Buying a costlier option (nuclear) instead of a cheaper one (efficiency, cogen, wind,…) *displaces less carbon per $*
  - This opportunity cost is an unavoidable consequence of not following the least-cost investment sequence
  - If nuclear investments also have a longer lead time, they don’t only reduce but also retard carbon displacement
  - If climate matters, then ***we must buy the most solution, fastest, per dollar invested***

Nuclear power's climatic opportunity cost

- Based on the empirical costs graphed above, spending $0.10 could displace coal-fired electricity's emissions by buying the delivered equivalent of:
  - 1.0 kWh of nuclear power
  - 1.2–1.7 kWh of dispatchable windpower (no to 2004 subsidies, 2004 to 2012 costs)
  - 0.9–1.7+ of gas-fired or ~2.2–6.5+ kWh of building cogen (both adjusted for their carbon emissions)
  - ∞kWh of [negative-cost] recovered-heat industrial cogen
  - several to 10+ kWh of end-use efficiency
- Thus compared with best buys, a new nuclear plant is several- to manyfold *more* carbon-intensive than a new coal-fired plant!

All options face implementation risks; what does market behavior reveal?

- California's 1982–85 fair bidding with roughly equal subsidies elicited, *vs.* 37-GW 1984 load:
  - 23 GW of contracted electric savings acquisitions over the next decade (62% of 1984 peak load)
  - 13 GW of contracted new generating capacity (35% of 1984 load), most of it renewable
  - 8 GW (22%) of additional new generating capacity on firm offer
  - 9 GW of new generating offers arriving *per year* (25%)
  - Result: glut (143%) forced bidding suspension in April 1985
- U.S. 1979–85: more new capacity ordered from small hydro and windpower than from coal and nuclear plants, excluding their cancellations (>100 GW)…yet nuclear got (in FY1984) 24× the subsidy/kWh that nonhydro renewables got, and doesn't face their obstacles to fair interconnection
- A portfolio is safer than any single technology
  - But that doesn't mean the portfolio should include every option!

Nuclear power: policy questions

- Why divert further public resources from market winners to the already very subsidized market loser?
  - 2004 global vendor revenues were ~$30b for renewable el. eqt., probably more for cogen & DSM, and just a few $b for nuclear
- Why pay a premium to incur nuclear’s problems, including terrorism risk & “anti-peaker” unavailability?
- Why incur the opportunity cost of buying less climate solution per dollar (and slower)?
- If you think “we need everything” (no choices):
  - What’s your analytic basis for that belief?
  - How do you propose to pay for buying everything?
  - Since different choices have different prices, how do you avoid the “Chinese restaurant menu problem”? (Pick one item from each section, spend your money on a little bowl of shark’s-fin soup and other delicacies, run out of money to buy rice, go away hungry)
- How do nuclear’s dry-hole risks compare with those of its competitors’ *portfolio*? (*Cf.* market behavior)

Nuclear power: more policy questions

- What exactly is meant and entailed by "keeping nuclear energy on the table"?
  - Continued massive R&D investments for a "mature" technology?
    - OECD 1991–2001: 39% of $88b, *vs.* eff. 13%, rens. 8%
    - US 1948–98: 59% of $66b (1999 $), *vs.* eff. 7%, rens. 11%
  - Ever bigger taxpayer subsidies to try to attract the private investment that is so far lacking—and which the US proponents, with $437b of 2003 revenues, won't commit from their own funds?
  - Heroic life-support measures to try to divert more private investment where it wouldn't otherwise go—and away from competitors?
- We've been trying to make nuclear cost-effective for a half-century. Are we there yet? When will we know?
- Would nuclear advocates agree to desubsidize the entire energy sector—themselves *and* their rivals?
  - In principle, a state could do this by imposing taxes specifically designed to offset federal subsidies to each technology

Conclusion: "If a thing is not worth doing, it is not worth doing well" —Lord Keynes

- Nuclear power has died of an incurable attack of market forces, with no credible prospect of revival
- Current efforts to deny this reality will only waste money, and will reduce and retard CO_2 reductions
- Cheaper, faster, abundant alternatives are now bigger
- Since nuclear power is unnecessary and uneconomic, we needn't debate whether it's otherwise acceptable
- Simply let all ways to save or produce energy compete fairly, at honest prices, regardless of which kind they are, what technology they use, how big they are, or who owns them—and watch the climate, oil, and (mostly) nuclear proliferation problems fade away
- Climate protection needs best buys first, not the more the merrier—judicious, not indiscriminate investments
- California is on the right energy track; the US is not

FURTHER BACKGROUND SLIDES

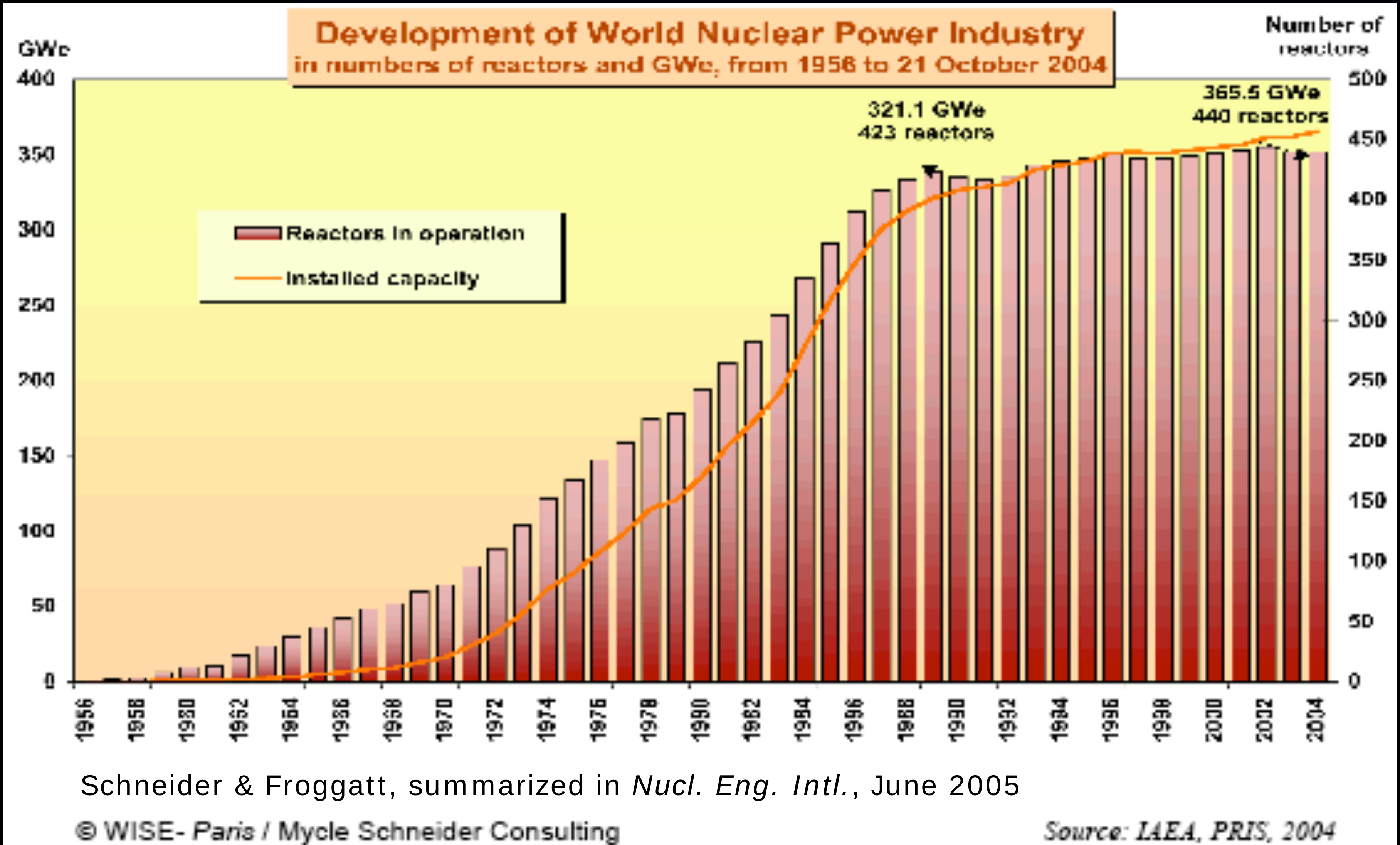
Rocky Mountain Institute

- Independent, entepreneurial, nonpartisan, nonprofit
- Founded 1982, ~50 staff
- Fosters the efficient and restorative use of resources to make the world secure, just, prosperous, and life-sustaining: in short, creates abundance by design
- Earns most of its $6–8 million annual revenue from programmatic enterprise, chiefly private-sector consultancy in energy & resources, buildings, and integrative design (heavy industry, vehicles,…)
  - Have served or been asked to serve >80 *Fortune* 500 firms
  - Redesigned ~$20b worth of major facilities in 22 sectors
  - Led for a decade probably the most detailed synthesis yet done of advanced electric end-use efficiency (COMPETITEK → E SOURCE)
  - Extensive global energy practice over three decades old
- I've been a student of nuclear issues for >40 years

Where's the nuclear power?

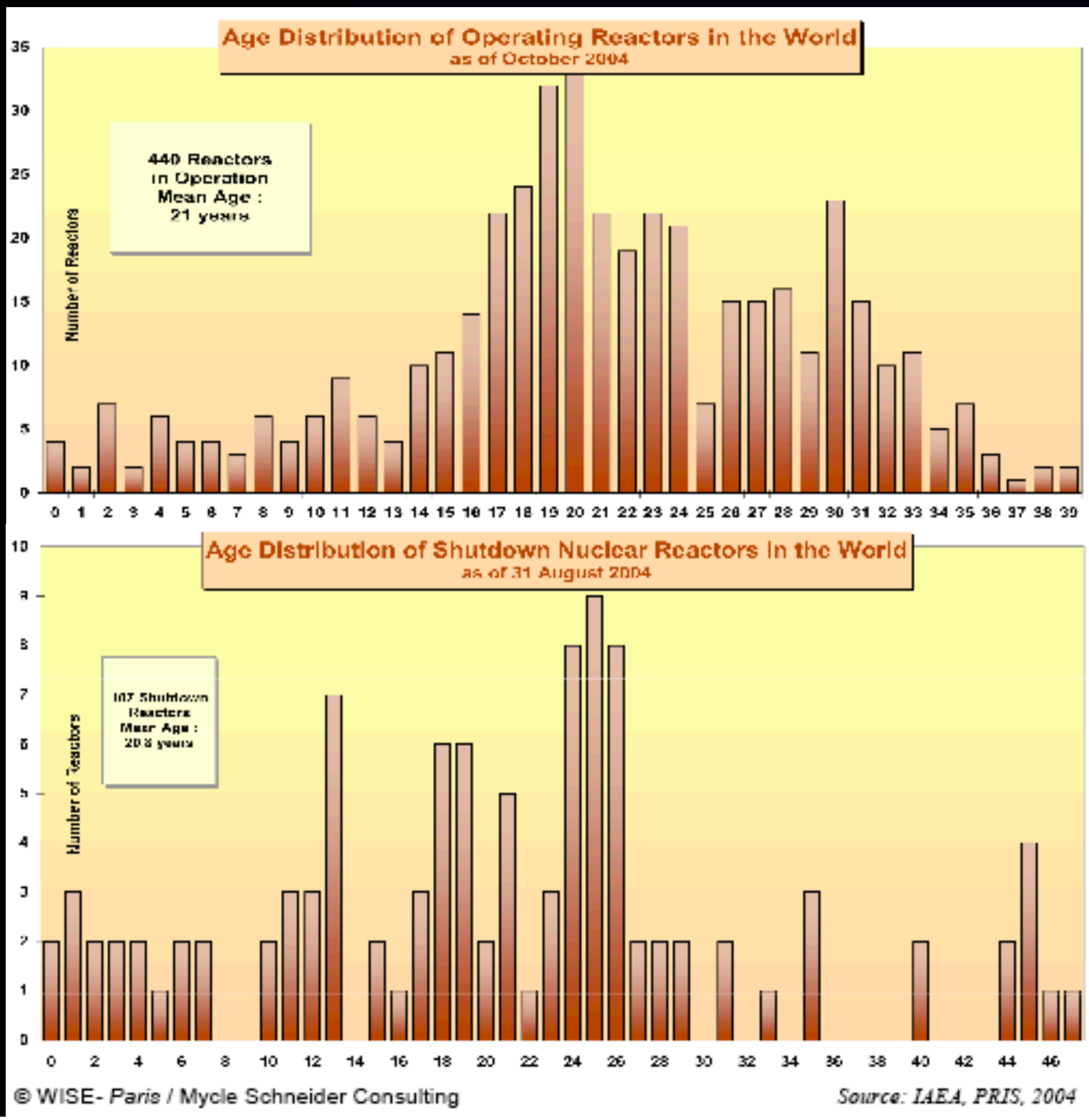
- Three-fourths of output is in the Big Six: US, France, Japan, Germany, Russia, S Korea
- Half the world's 31 nuclear countries, >1/2 the output, is in Western & Central Europe
- IAEA reports 22 of past 31 units built were in Asia, as are 18 of 27 now under construction, which "has virtually halted in Western Europe and North American countries"—where operating units (294) peaked in 1989, then fell

Global nuclear expansion is coasting to a halt



Schneider & Froggatt, summarized in *Nucl. Eng. Intl.*, June 2005

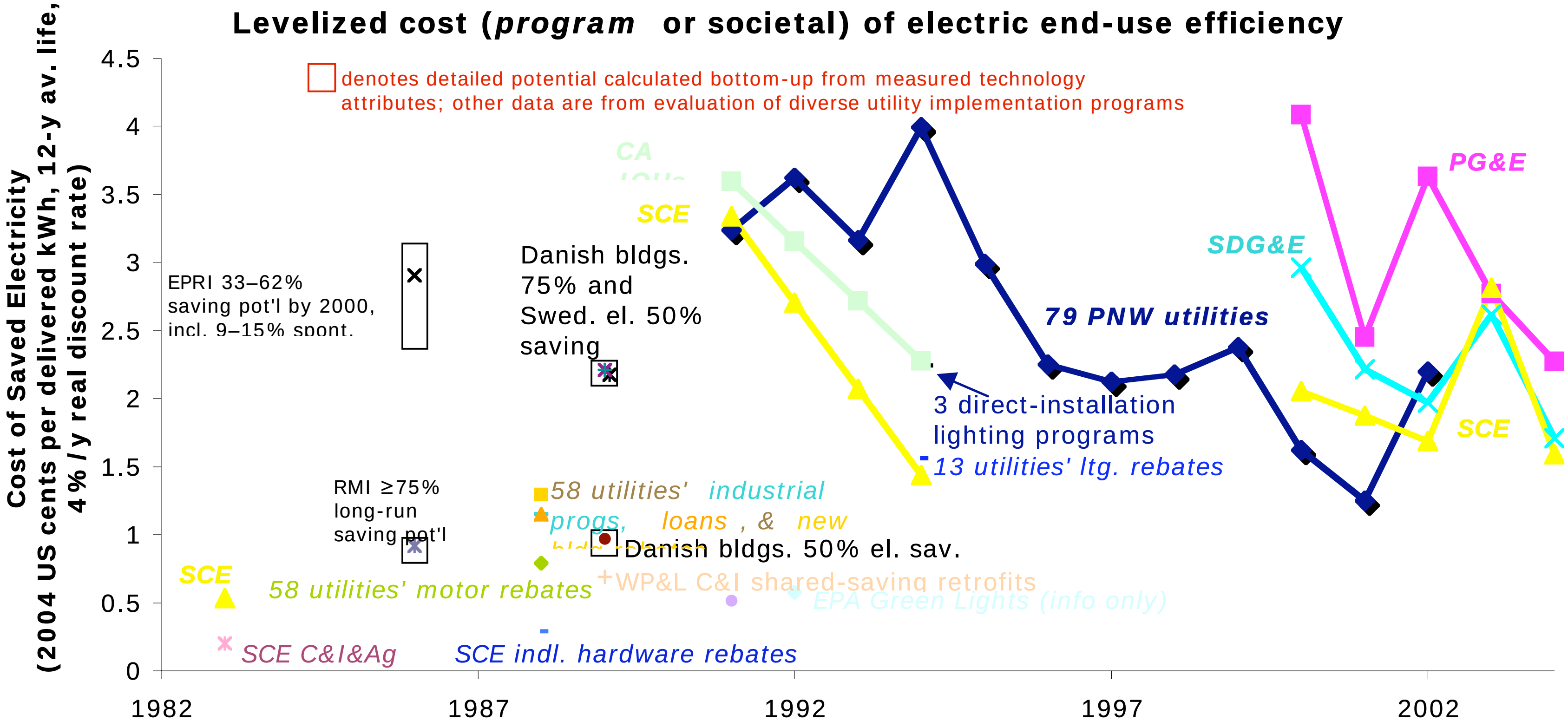
Average world reactor is 21 years old—as is the av. reactor permanently retired



To offset planned retirements to 2015, 73 reactors not yet planned (plus all now scheduled) would need to be built—virtually impossible

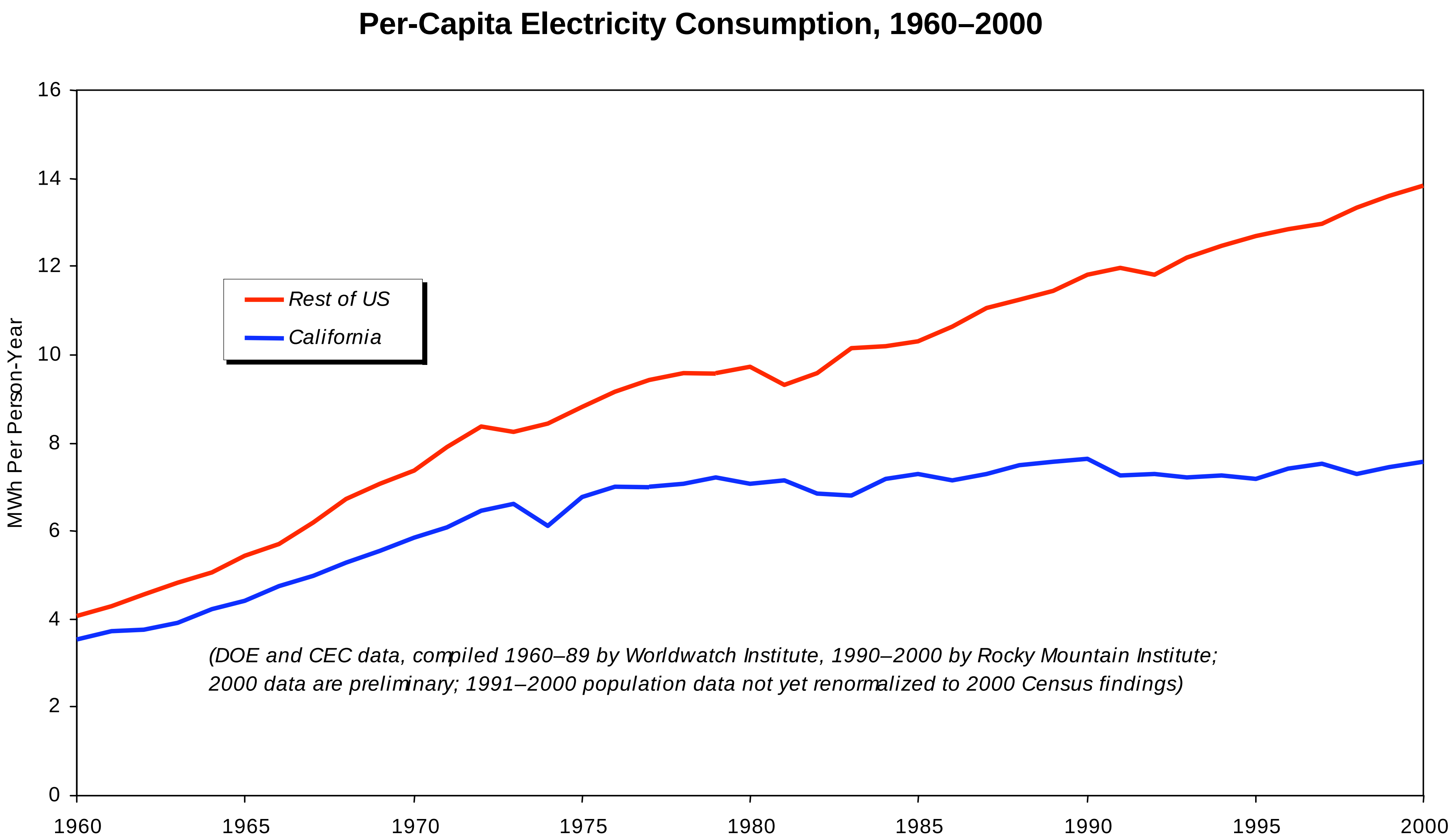
If China built 32 new units to 2020 (extremely ambi-tious), it'd cover hardly over 10% of plants reaching age 40 worldwide

Competition from end-use efficiency

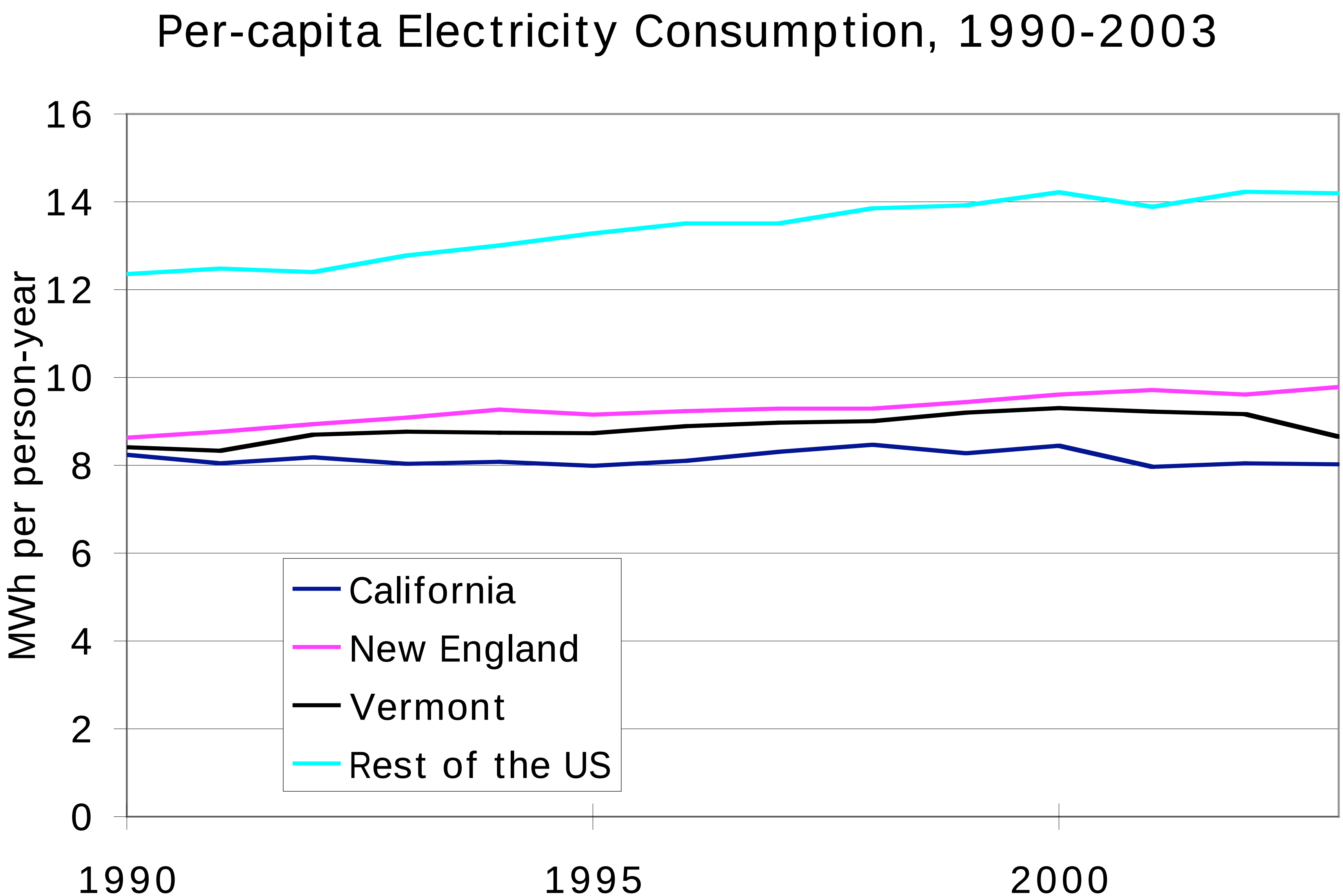


Key conservatisms: residential measures often cost far more than C&I savings; old technologies remain common; best programs often cost far less than averages; neither measured nor calculated savings capture modern design integration ("tunneling through the cost barrier"), which saves far more for far lower cost; no distributed benefits are counted here

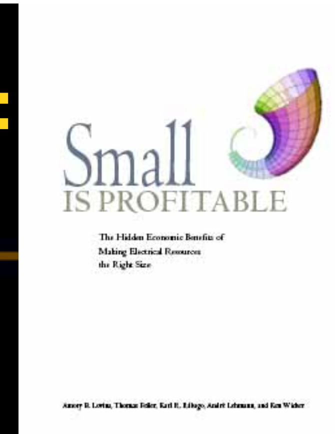
Policy works in California...



California isn't the only state that's stopped el. demand growth



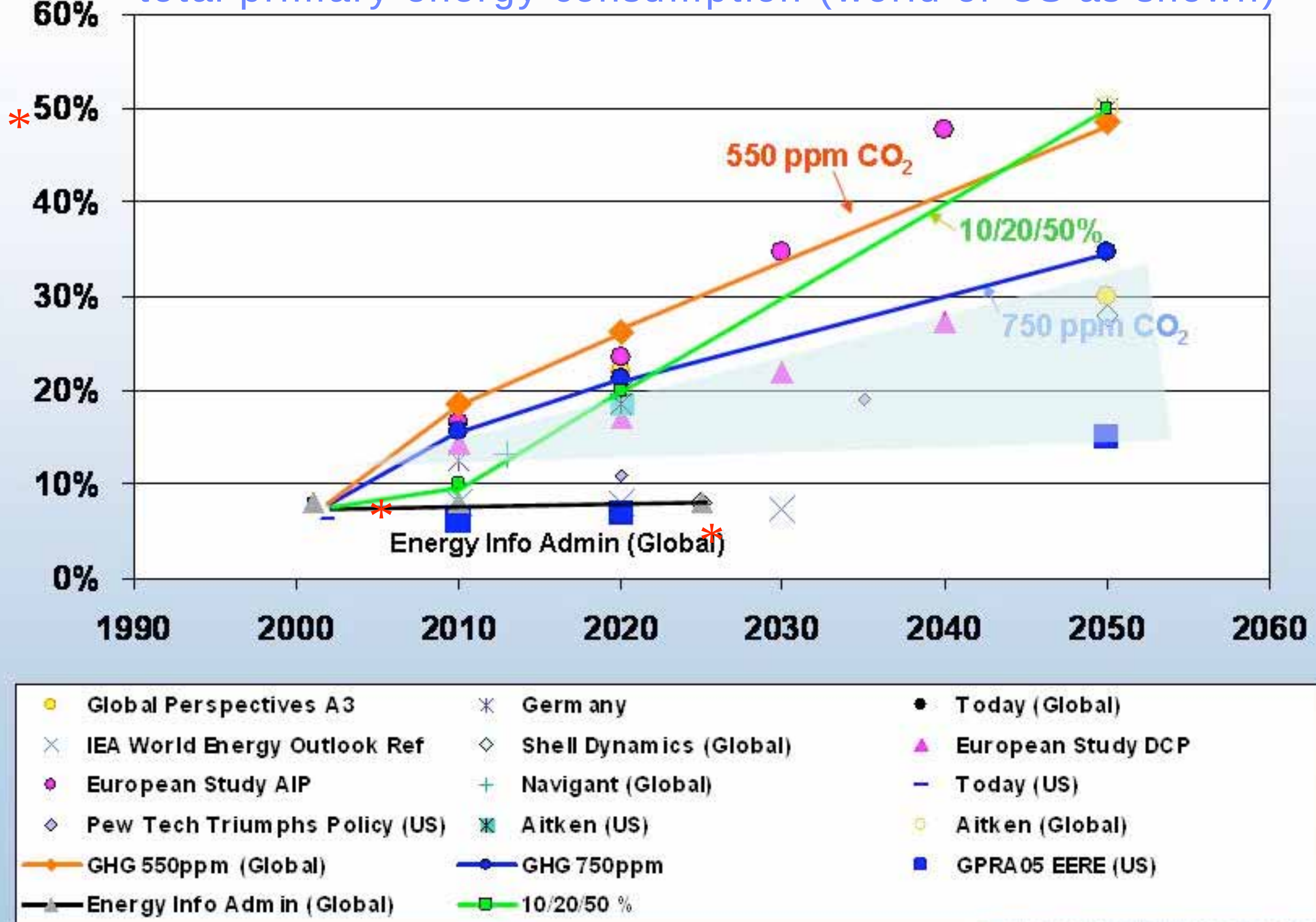
The next electric revolution: efficient and distributed



- In late 1980s, full best retrofit could save ~3/4 of U.S. el. @ av. ~0.6¢/kWh ('86$)
- Key technologies & delivery methods now far cheaper
- Biggest revolution: whole-system design integration yields *expanding* returns to efficiency investment
  - See *Encyc. of Energy* 2004 article; www.natcap.org
- Distributed electricity is often competitive *now*—even PVs when integrated with demand-side management
- But commodity ¢/kWh omits key "distributed benefits"
  - *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (www.smallisprofitable.org, 2002), an *Economist* book of the year
  - 207 distributed benefits boost typical economic value *by ~10×*; the biggest benefits come from financial economics, then el. engineering
  - "Cleaner Energy, Greener Profits" (www.rmi.org, 2001) shows fuel cells can often be profitably applied even at $2,000–3,000/kW

All Renewables Targets

Renewable and *global nuclear (EIA *IEO04*) fraction of total primary energy consumption (world or US as shown)



New subsidies ≠ nuclear "revival"

- Taxpayers pay 1/2 licensing + $3b "R&D" + unlimited 80% loan guarantees (if appropriated)
- Large operating subsidies rise by 1.8¢/kWh (for 6 GW for the first 8 y—*i.e.*, $5.7b or ~$842/kW)
- Liability capped at $11b for 20 y...largely evadable
- All waste taken for a small fee, w/penalty if late
- All offsite security costs borne by taxpayers
- Taxpayers pay $2b for any regulatory/legal delays
- New $1.3b tax break for decommissioning funds
- Total subsidy ~$13b...≈ total capital cost of 6 GW
- In short, taxpayers get virtually all remaining costs and risks; promoters pocket any upside
- Yet S&P concludes the nuclear promoters' credit won't improve much—their biggest risks persist

Adding 700 nuclear GW_e world-wide, operated 2050–2100, would…

- About double today's global nuclear capacity
- Add ~1,200 nuclear plants (if they last 40 y)
- Add 15 enrichment plants (each 8 MSWU/y)
- Create 0.97 million tonnes of spent fuel, requiring 14 Yucca Mountains, and containing ~1 million kg—hundreds of thousands of bombs' worth—of plutonium…or
- Require 50 reprocessing plants (each 800 TSF/y with 40-y life) to extract that plutonium
- Require ~$1–2+ trillion capital investment
- Cut ~0.2 C˚ from global av. temperature rise

SOURCE: Dr. Tom Cochran, NRDC (DC), 22 June 2005 NRDC Board mtg.

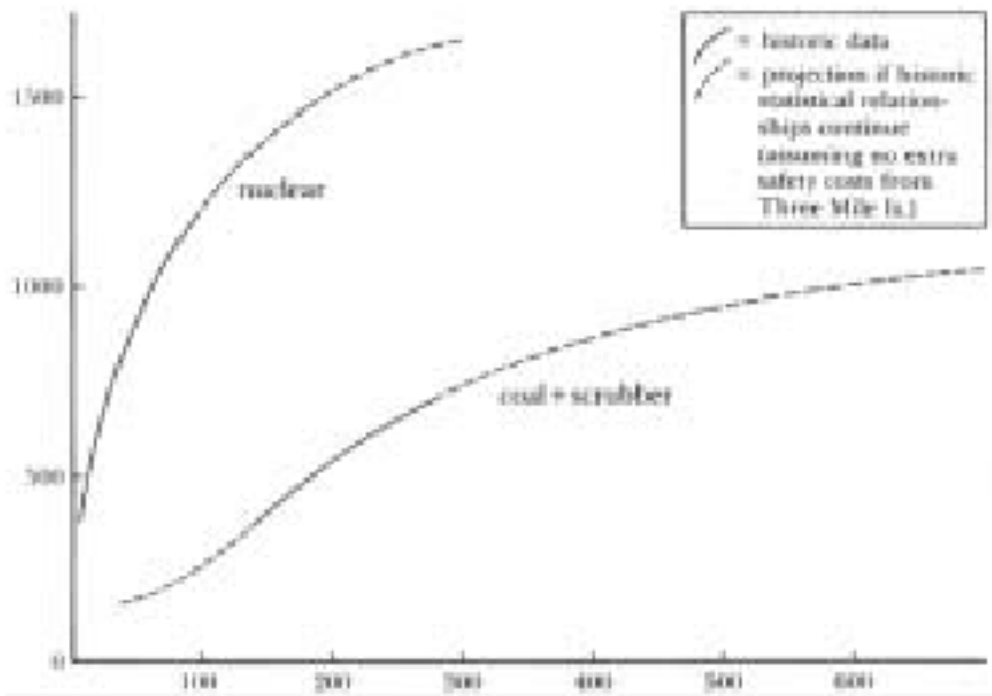
Nuclear power disguises & greatly facilitates nuclear proliferation

See Lovins *et al.*, *Foreign Affairs*, Summer 1980

- Nuclear power makes widely and innocently available all the key ingredients of do-it-yourself bomb kits (fissile materials and the technologies, knowledge and skills to produce and process them; new reactor types are much worse)
- Absent nuclear power, these ingredients would be harder to get, more conspicuous to try to get, and politically far costlier to be caught trying to get, because the reason for wanting them would be *unambiguously* military
- A world without significant nuclear commerce would make proliferation not impossible but vastly more difficult—and easier to detect timely
- The U.S. example is critical to the world

U.S. nuclear power historically has a "forgetting curve"

Figure A.3 Plant construction cost (1979 steam-plant dollars per net electric kilowatt of installed capacity, without interest during construction)



Thousands of megawatts of net electric capacity (of each type of plant) built or being built

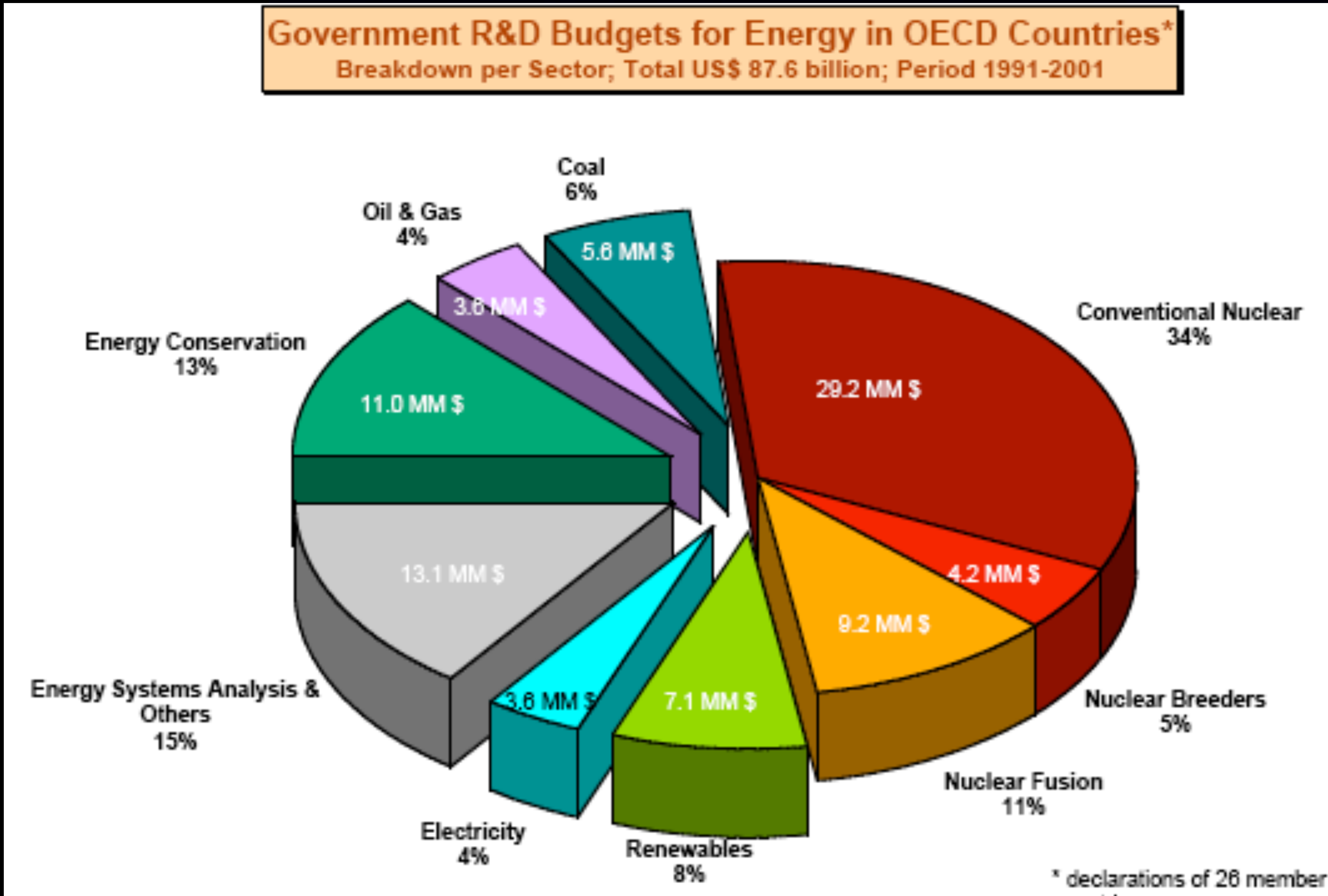
Nuclear:
n = 46
r^2 = 0.92

Coal:
n = 116
r^2 = 0.68

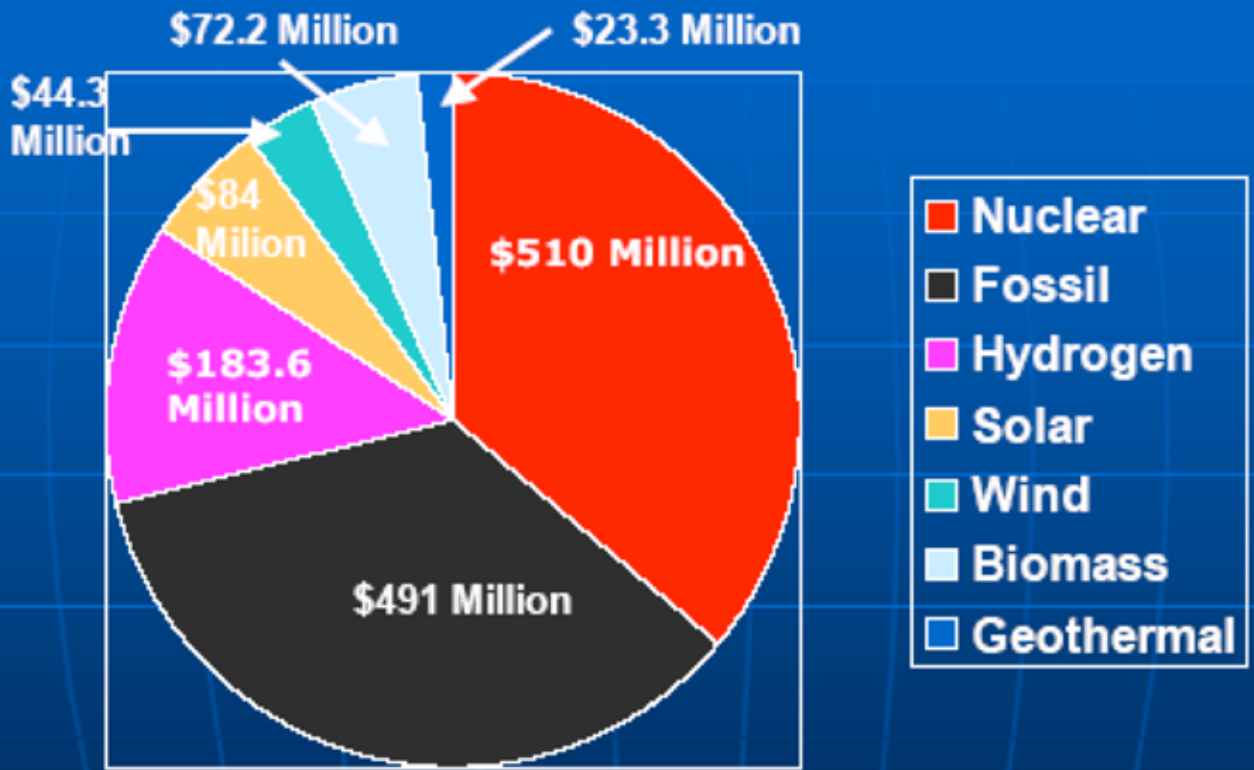
The reasons are funda-mental and durable!

A.B. & L.H. Lovins, *Brittle Power: Energy Strategy for National Security*, Brick House (Andover MA), 1981, now at www.rmi.org, p. 378. Underlying analysis by C. Komanoff, *Power Plant Cost Escalation*, 1981; see also W. Mooz (RAND), R-2304-DOE (1978) and R-2504-RC (1979).

Nuclear energy continues to get the lion's share of energy R&D $



Nuclear Energy gets the single largest R&D subsidy as a fuel source.



As an outcrop of the nuclear weapons program, between 1948 and 1998, 59% of R&D funding ($66 billion in constant 1999 dollars) went to nuclear power. During that time, 23% went to fossil energy ($26 billion), 11% to renewable energy ($12 billion), and 7% to energy efficiency ($8 billion). **Source: Sustainable Energy Coalition.**

Figure 1. World Electrical Generating Capacity of Nuclear Power Plants, 1960–2004

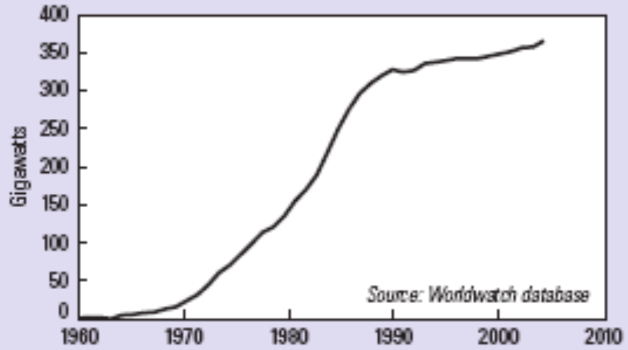


Figure 2. World Nuclear Reactor Construction Starts, 1960–2004

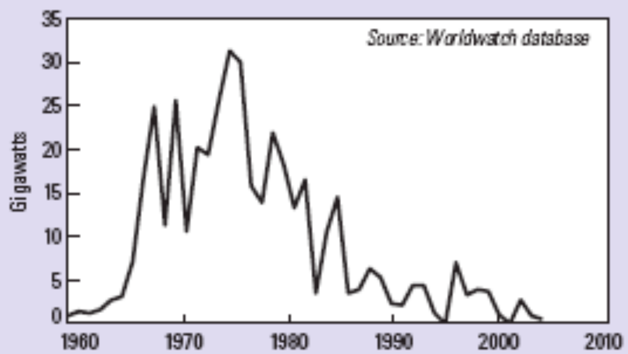
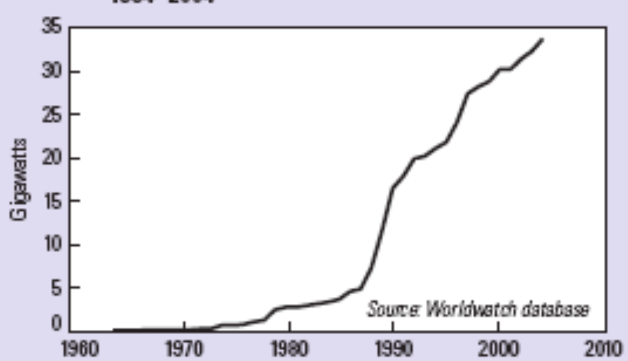


Figure 3. Nuclear Capacity of Decommisioned Plants, 1964–2004



2–3x more windpower than nuclear power is being added annually

From 2005, PVs add more GW/y than nuclear constr’n. starts

Within a few y, nuclear retire-ments will ex-ceed additions

Gas cogen/tri-gen over-whelms all else

Figure 1. World Wind Energy Generating Capacity, 1980–2004

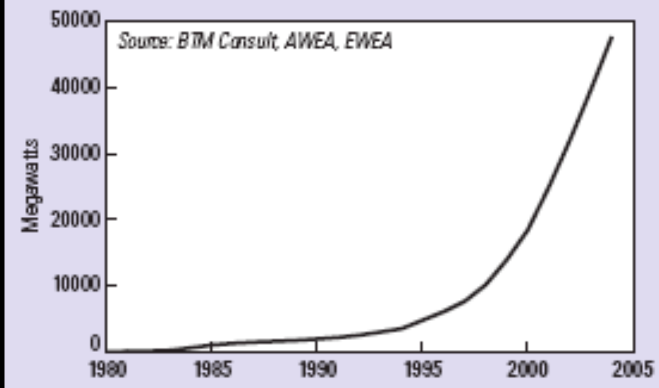


Figure 2. Annual Additions to World Wind Energy Generating Capacity, 1980–2004

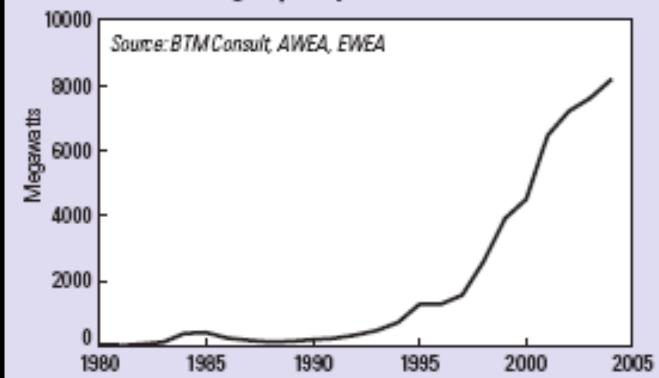


Figure 1. World Photovoltaic Production, 1971–2004