
ROCKY MOUNTAIN
INSTITUTE

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At the Royal Institute of British Architects, 66 Portland Place, London

Nuclear power: competitive economics and climate-protection potential

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Rocky Mountain Institute, www.rmi.org

Documentation is at www.rmi.org/sitepages/pid171.php#E05-14, summarized …-15

Q. How is climate protection like the Hubble Space Telescope?

A. Both were spoilt by a sign error

Global corporate leadership in profitable climate protection

- STMicroelectronics (#7 in the world)
  - Zero net carbon emissions by 2010, 1990 chips ×40
  - CO_2/chip –92% profitable now, –98–99% soon
  - kWh/wafer –6%/y 1994–2002, +$50M, 2.5-y payback
- IBM cut CO_2 emissions 5.7%/y, 1998–2004
- DuPont (worldwide), 2000–2010 goals
  - Revenue +6%/y, energy use at worst constant
  - 1/10 of energy, 1/4 of feedstocks renewable
  - 2010 greenhouse gas = 1990 – 65%
  - –2004: 1990–*72%*, output +30%, en. –7%, +$2b
- BP: met 2010 CO_2 goal (1990 – 10%) in 2002 at a net "cost" of –$0.65 billion
- *Every* firm or state/local government seeking to cut CO_2 via energy efficiency has reported a profit

The climate problem is caused by one percentage point

(after Hoffert *et al.*, *Nature* **395**:881–884 (1998))

The "Kaya identity" (Kaya Youichi-sensei) shows that:

Emitted CO_2/y = N × GDP/N × $\dot{E}_{primary}$/GDP × C/$E_{primary}$

1990–2100 %/y: +0.69 +1.6 −1.0 −0.26 = +1.0

That +1%/y causes C growth from ~6 to ~20 Gt/y

Supply-siders debate the −0.26%/y (no-C energy) term

But let's examine the 4× bigger energy-intensity term… because *−1%/y → −2%/y flattens CO_2 emissions* (or saves ~30 TW of no-C supply required for 550 ppm), and reducing energy intensity slightly faster than 2%/y would stabilise Earth's climate…still at a profit

So how plausible is a profitable 2%/y, or even faster, reduction in energy used per dollar of GDP?

How quickly have various economies cut energy intensity (primary energy consumption/$ real GDP at PPP)?

Av. –%/y compound; ***prices***	*1977–2001* ***varying***	*1981–1986* ***high***	*1997–2001* ***low***
California	*2.8*	*4.5*	*3.5*
USA	*2.0*	*3.4*	*2.7*
EU	1.3	1.2	1.4
Japan	0.8	1.1	~0
China (>5 for >20 y)	*5.1*	*4.8*	*5.3*
world	1.0	1.3	1.3

Data sources: CA and USA from USEIA, others from IEA

Reducing energy intensity

- Thus attentive advanced economies can sustain several %/y reduction over many years
- Major firms profitably sustain 6%/y reduction
- Many ways to reduce energy intensity
  - Shifts in composition of output
  - More sensible land-use (spatial planning)
  - More mindful individual behaviour, even lifestyle change
  - More efficient energy conversion and distribution
  - More efficient energy end-use (very big, very profitable)
- So reducing global intensity by not 1.0%/y (1977–2001) or 1.3%/y (recent) but ≥2%/y doesn't look difficult, let alone costly

Nuclear power and oil are unrelated

- <3% of US electricity is oil-fired, <2% of US oil makes el., both ↓; UK, 1.3% and 0.8%; worldwide, both ~7%; displacing oil-fired el. happens just once
- Only ~10% of the oil that makes that 3% of US electricity is distillate; ~90% is gooey residual oil
- Most oil-fired power plants run only briefly, whilst nuclear plants must run steadily
- Most oil-fired utilities (and developing-country grids) are too small for standard nuclear plants
- Nuclear could free some gas—but not competitively
- Fortunately, there's a far better oil solution
- Power plants release only 2/5 of US & world CO_2, 30% of UK, so an all-sectors approach saves 2.5× (UK: 3.4×) as much CO_2 as electricity-only approach

Independent, peer-reviewed

Transparent, uncontested

DoD-cosponsored

For business/mil. leaders

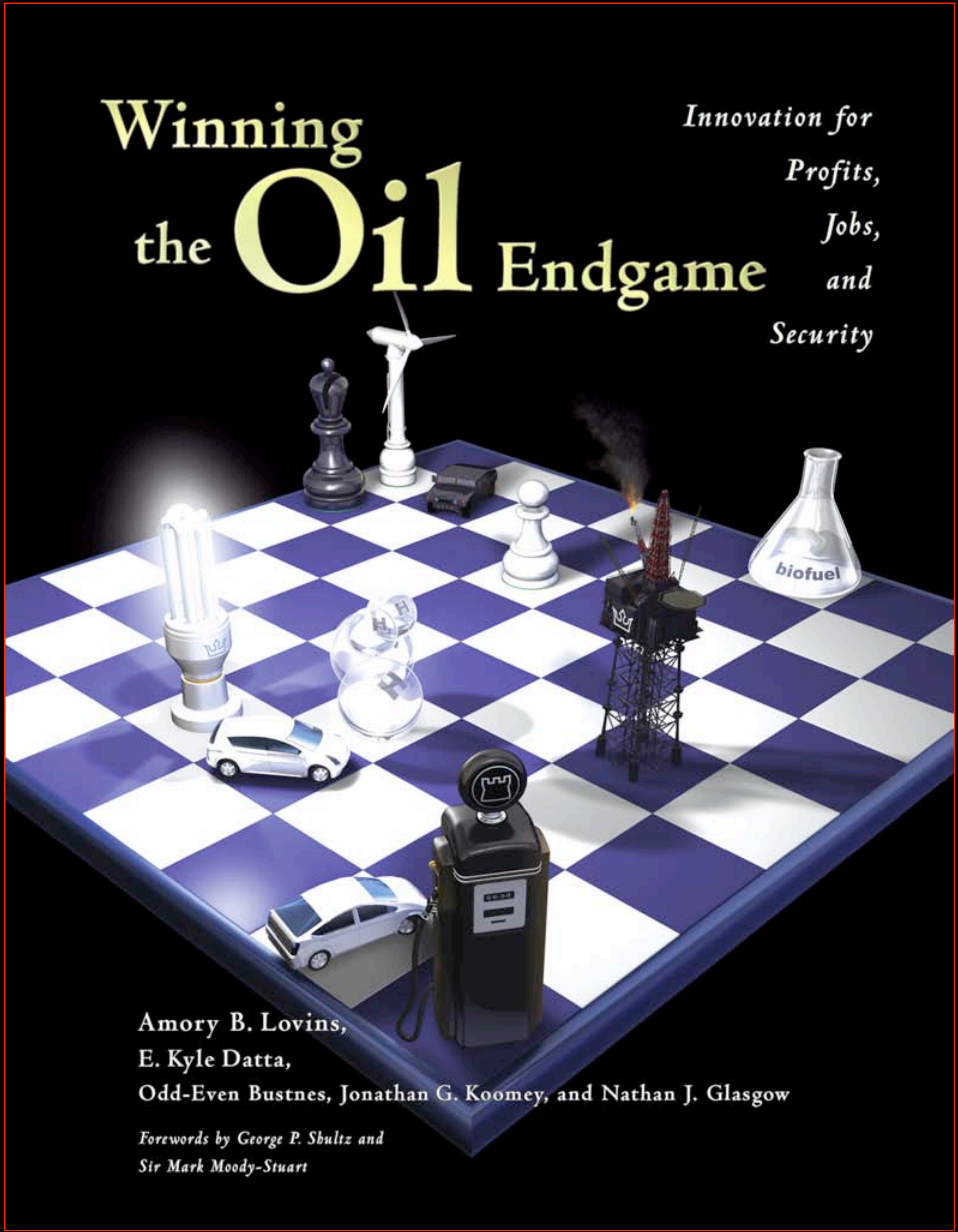
Based on competitive strategy cases for cars, trucks, planes, oil, military

Book and technical backup are free at:

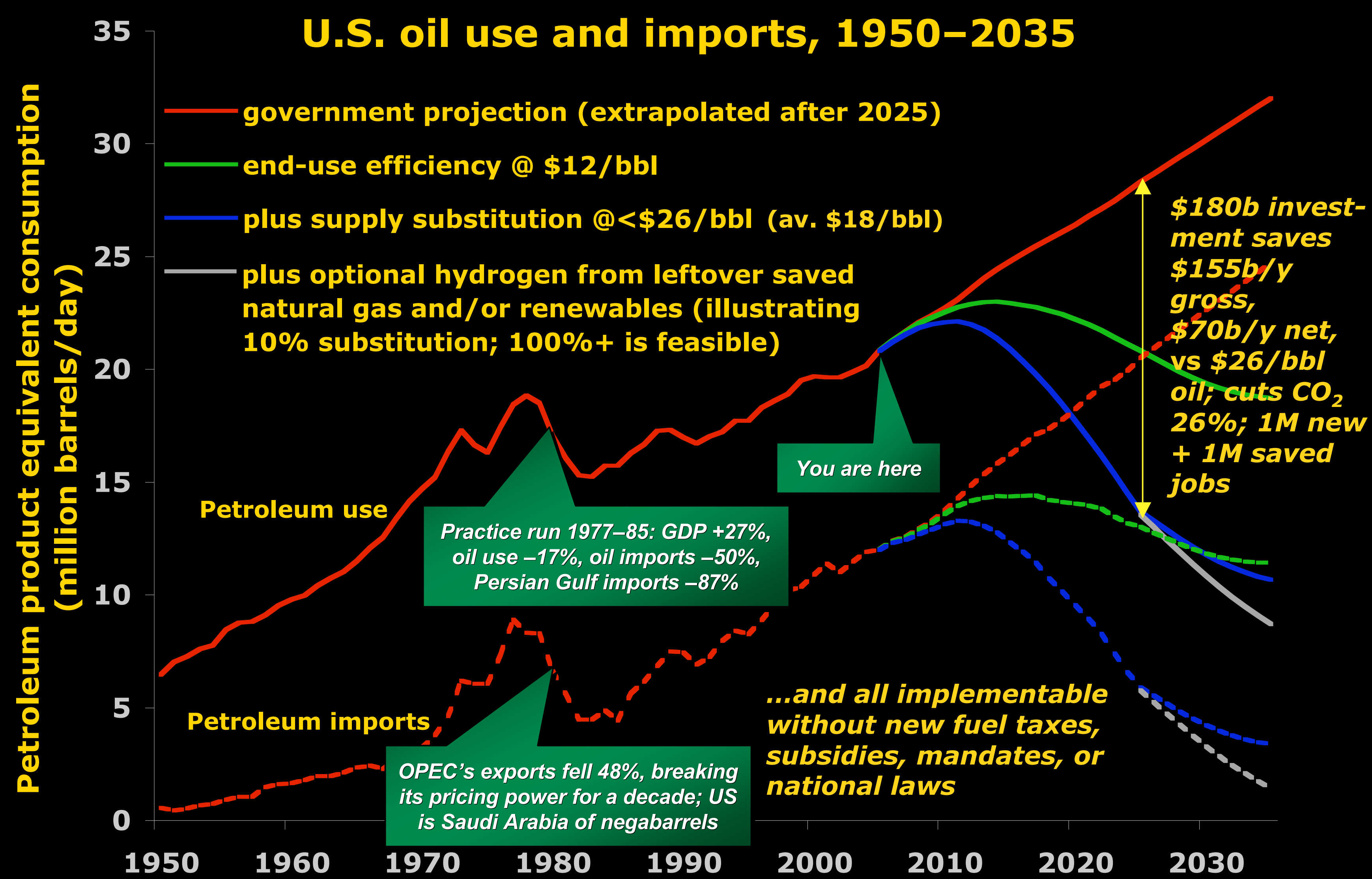
www.oilendgame.com

Chatham House 1300 13 May

Over the next few decades, the US can eliminate its use of oil and revitalize its economy, led by business for profit (and probably UK too)



A profitable US transition beyond oil (with best 2004 technologies)



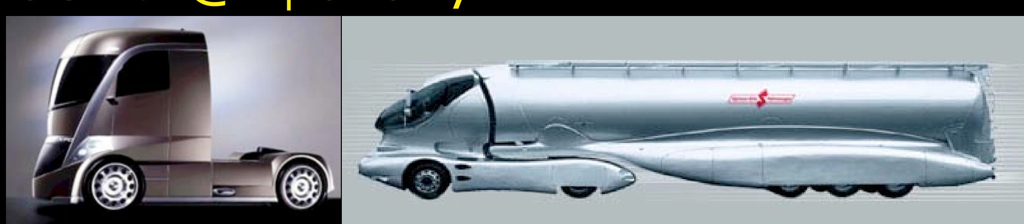
Vehicles use 70% of US oil, but integ-rating low mass & drag with advanced propulsion saves ~2/3 very cheaply

CARS: save 69% at $0.15/L

Surprise: ultralighting is ***free* —** offset by simpler automaking and the 2× smaller powertrain

250 km/h, 2.5 L/100 km

TRUCKS: save 25% free, 65% @ $0.07/L



PLANES: save 20% free, 45–65% @ ≤$0.12/L

BLDGS/IND: big, cheap savings; often *lower* capex

Technology is improving faster for efficient end-use than for energy supply

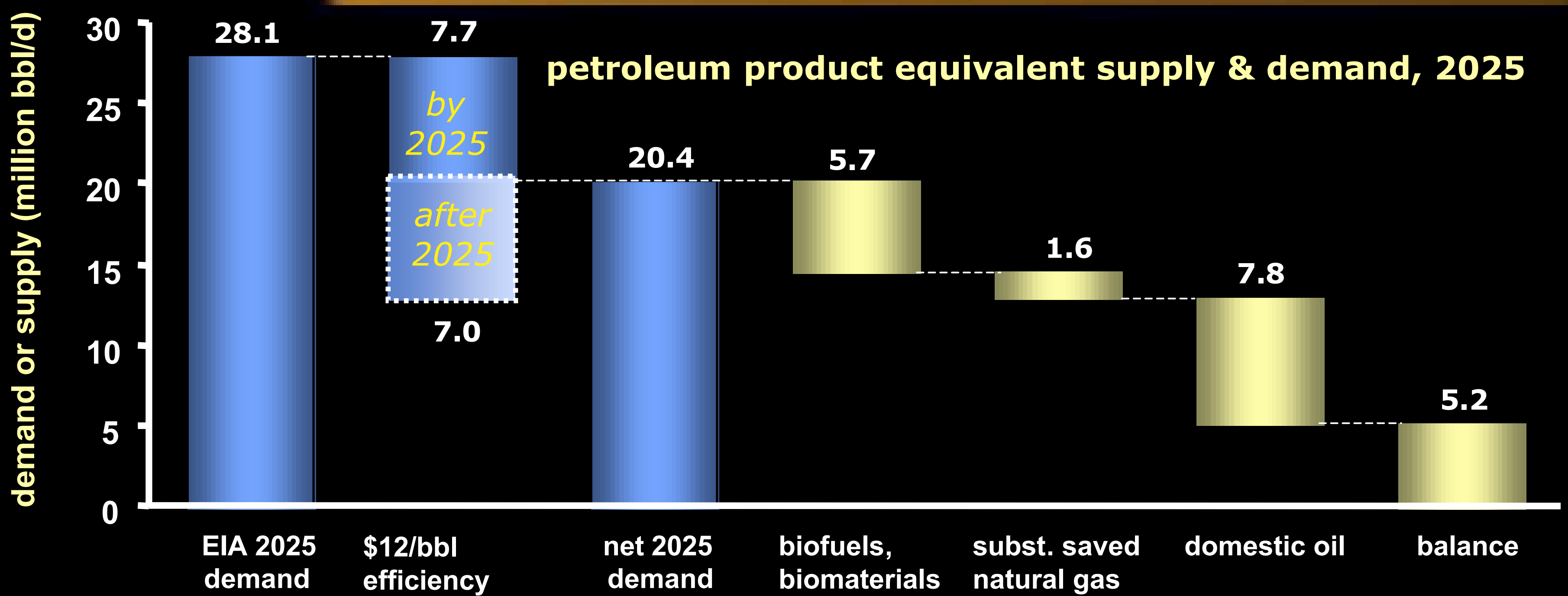
Midsize 5-seat* Revolution concept *SUV (2000)
Ultralight (857 kg) but ultrasafe
0–100 km/h in 8.3 s: 2.06 L/100 km (136 mi/UKgal) w/ fuel cell
0–100/7.2 s: 3.56 L/100 km (80 mi/UKgal) with petrol hybrid

"We'll take two."
— *Automobile* magazine

World Technology Award, 2003

Show car and a complete virtual design, uncompromised, production-costed, manufacturable with a $2,510 higher retail price (as hybrid)

2025 US oil demand-supply integration



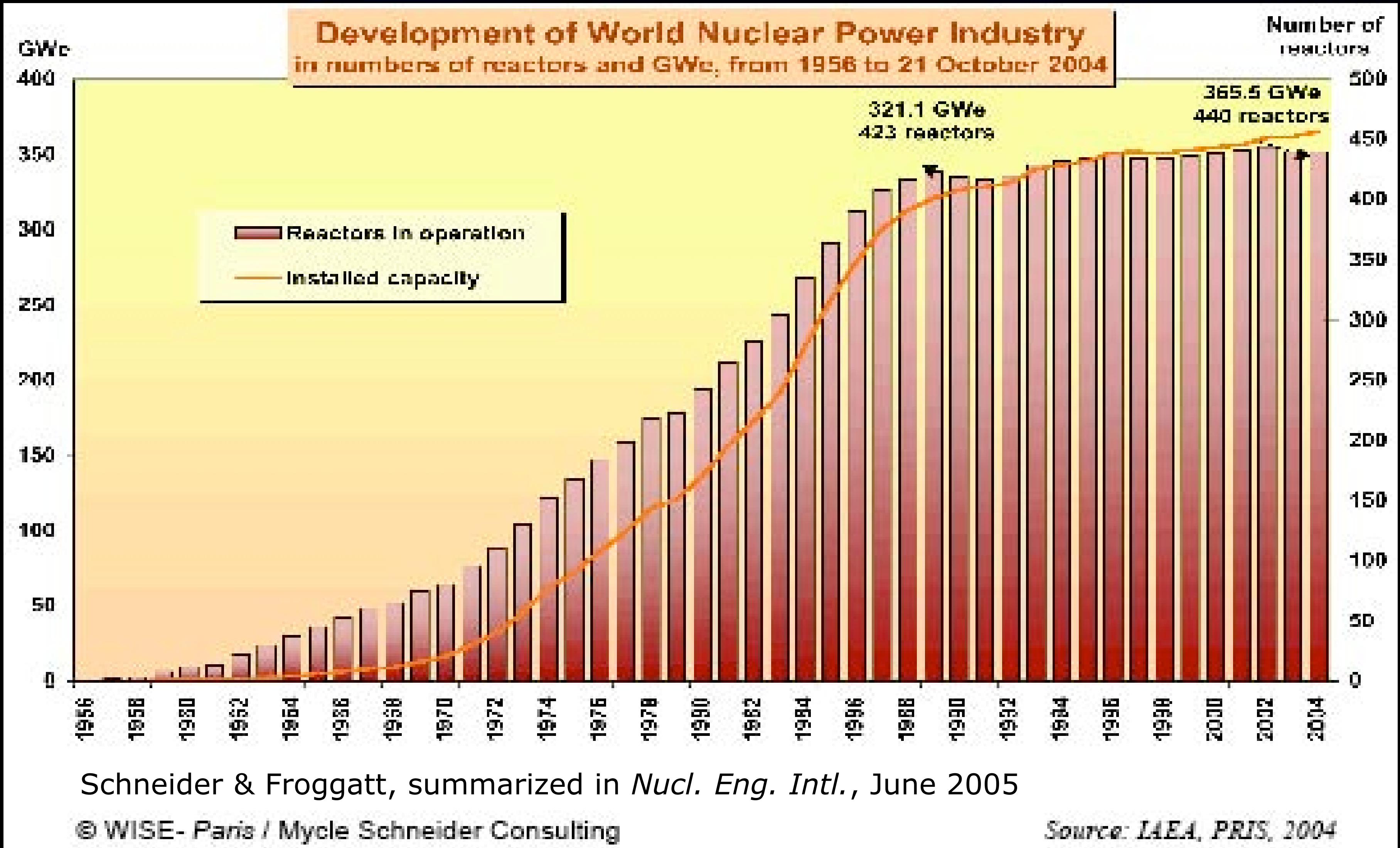
Great flexibility of ways and timing to *eliminate* oil in next few decades

- **Buy more efficiency (it's costing only half as much as the oil it replaces)**
- **Efficiency is only half captured by 2025—7 Mbbl/d still in process**
- **"Balance" can import crude oil/product (can be all N. Amer.) or biofuels**
- **Or saved US natural gas @ $0.9/GJ can fill the "balance"…or**
- **H_2 from saved US natural gas can displace "balance" *plus* domestic oil**
- **Not counting other options, *e.g*. Dakotas windpower—50 MT/y H_2 source**

Two 1989 climate-strategy cases that scope the world's conditions

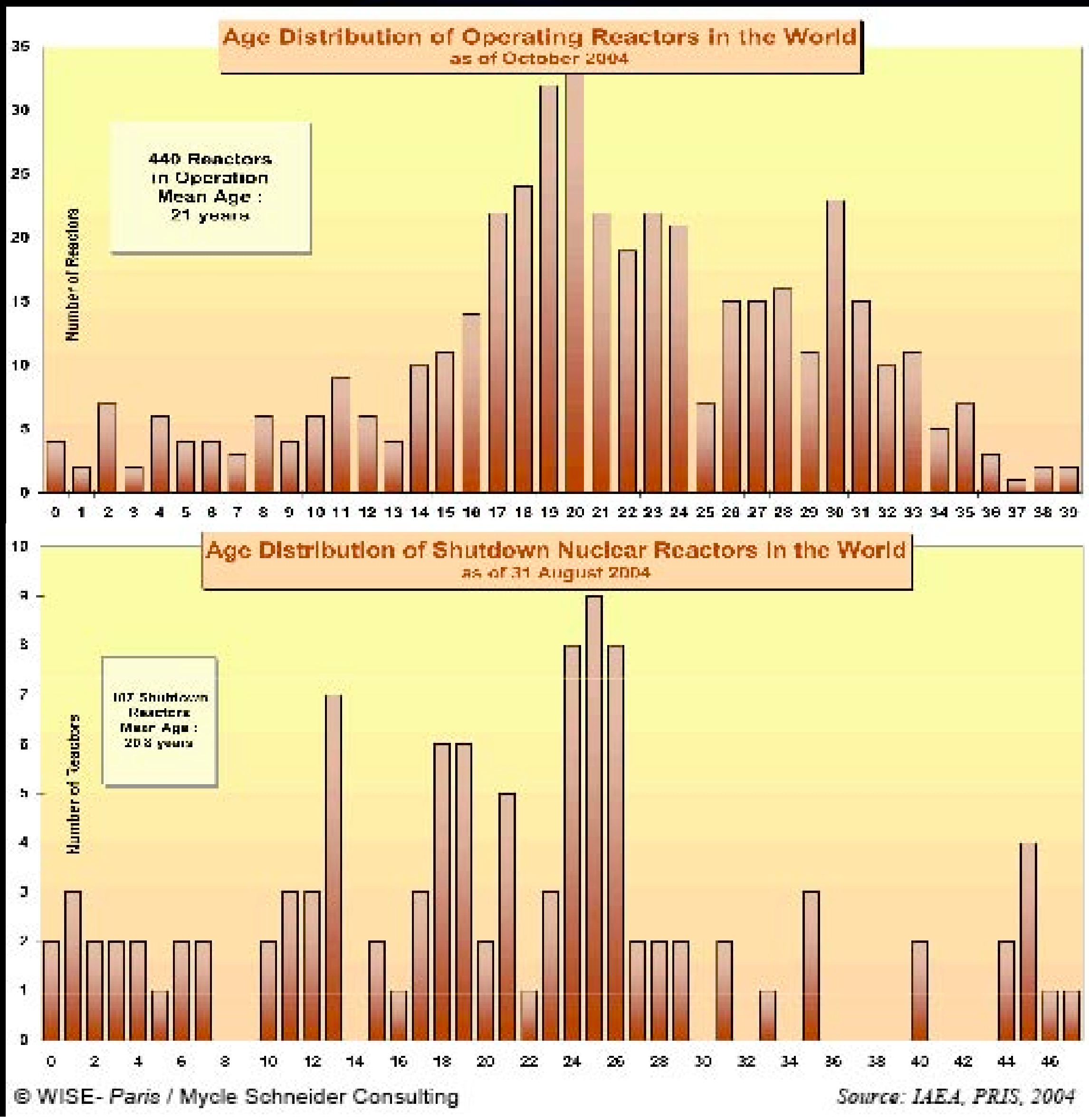
- Sweden: Vattenfall, "The Challenge of Choices"
  - Cold, cloudy, far north, heavily industrialized, relatively efficient
  - Half of Swedish el. saveable at 78% lower cost than making more
  - Least-cost strategy (doubled el. end-use eff. + some fuel-switching + environmental dispatch) could achieve forecast 54% GDP growth 1987–2010, shut down nuclear half of el. supply, reduce heat-and-power-sector CO_2 emissions by 1/3, cut el. service cost $1b/y
  - CEO ordered disclaimer removed, but report little-known, ignored
- India: Amulya Reddy, roadmap for Karnataka state
  - A little efficiency & natural gas, bagasse CHP, biogas/producer gas, solar water heaters, small hydro—far from comprehensive mix
  - Would achieve far greater and faster economic development
  - Would have 3/5 lower el. demand, 2/3 lower cost, and 99.5% less fossil-fuel CO_2 than utility's official plan (*both* plans were rejected)
- Both: efficiency more than pays for renewables, making major carbon savings better than free
- All with 1980s technologies and no design integration

Global nuclear expansion is coasting to a halt



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

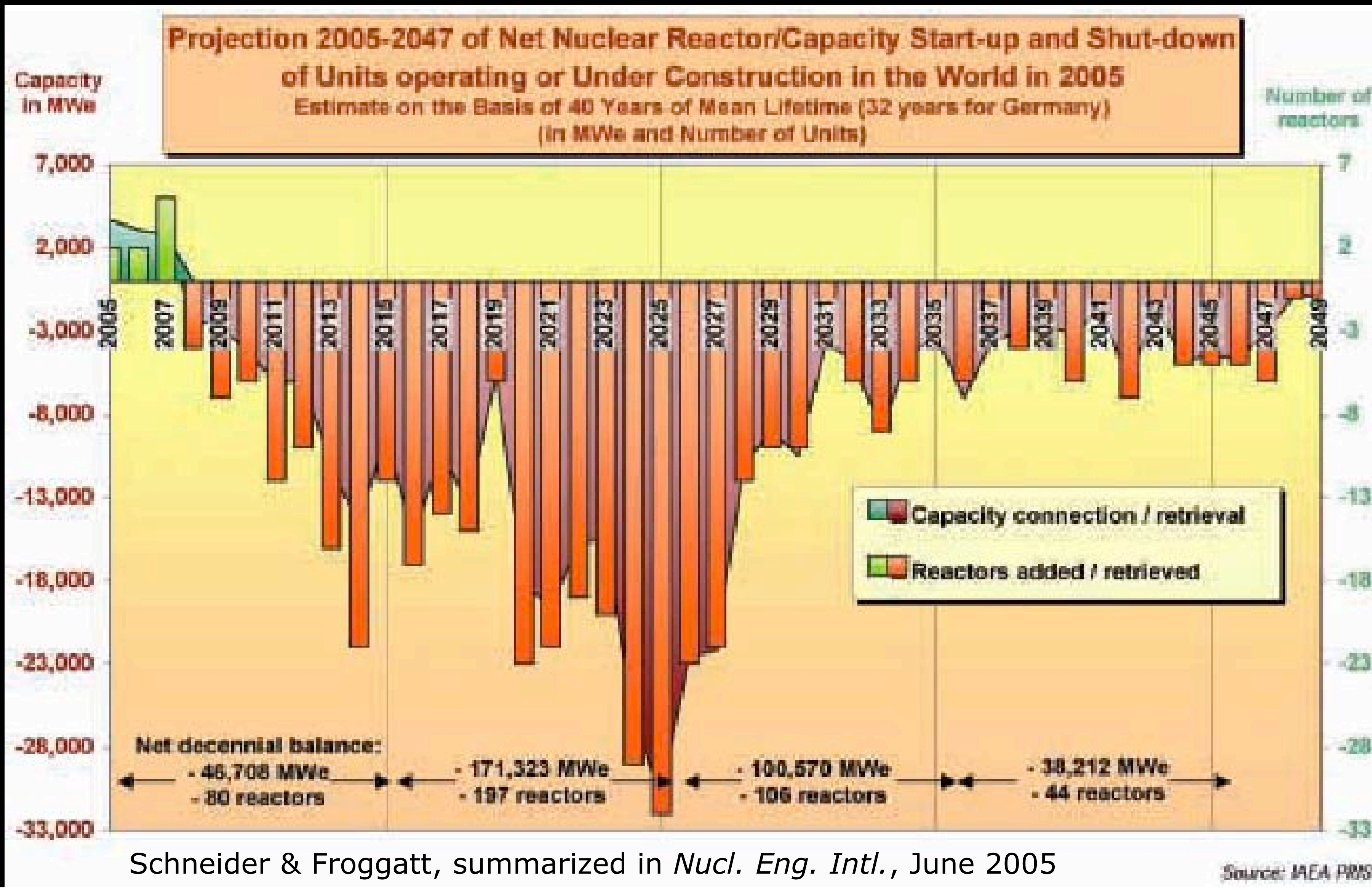
Average reactor in 2005 was 21 years old—as was av. unit permanently retired



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

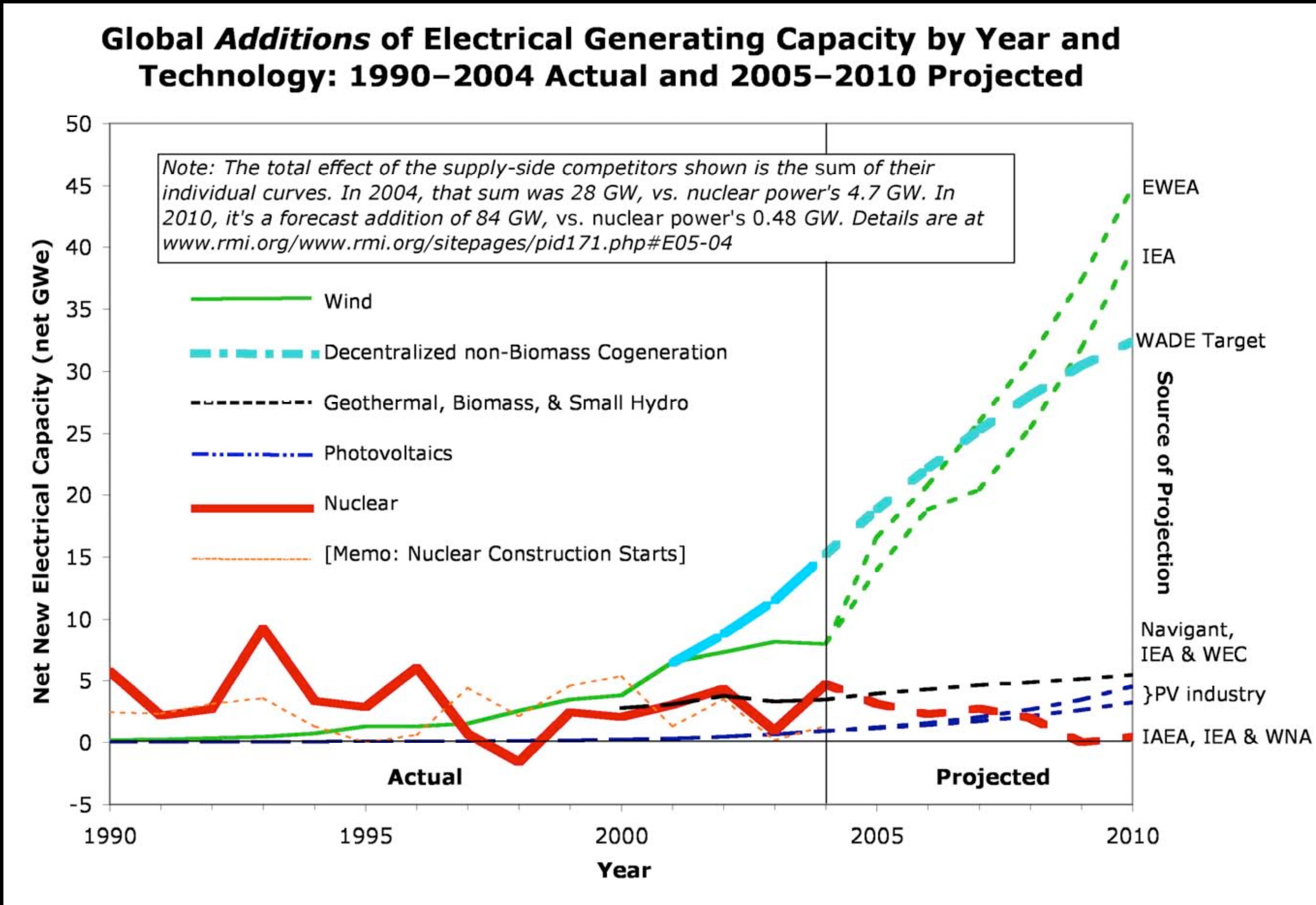
If China built 32 new units to 2020 (extremely ambi-tious), it'd cover hardly over 10% of plants reaching age 40 worldwide

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

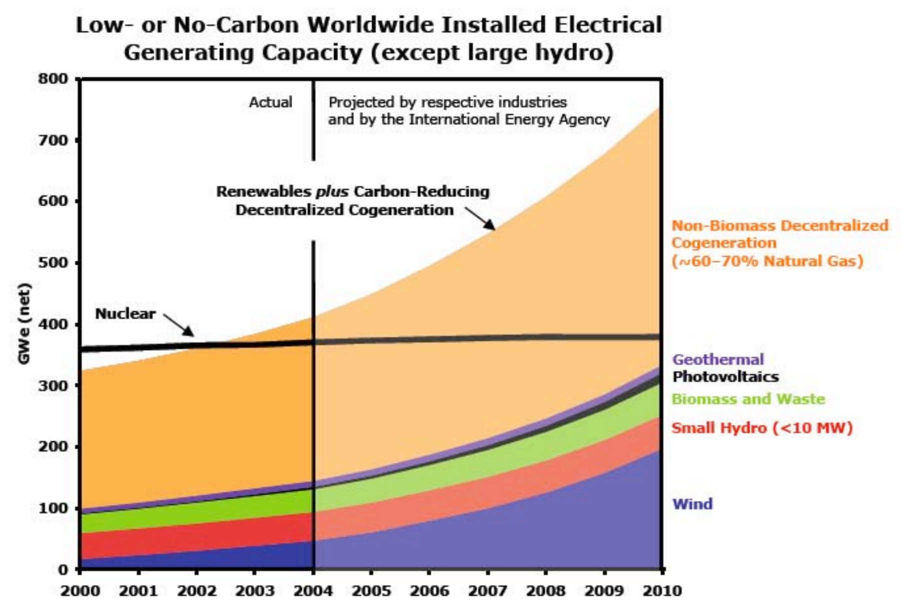


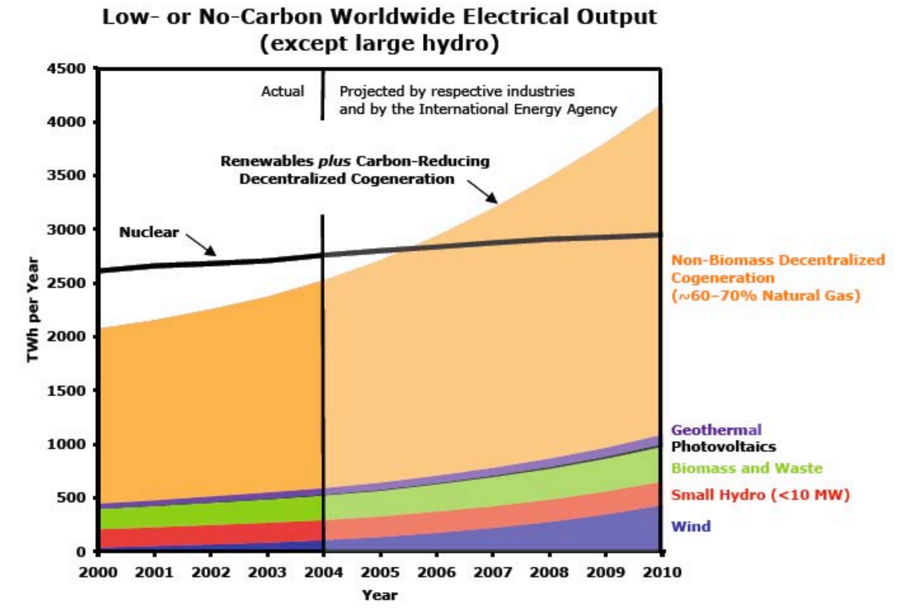
Schneider & Froggatt, summarized in *Nucl. Eng. Intl.*, June 2005

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



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





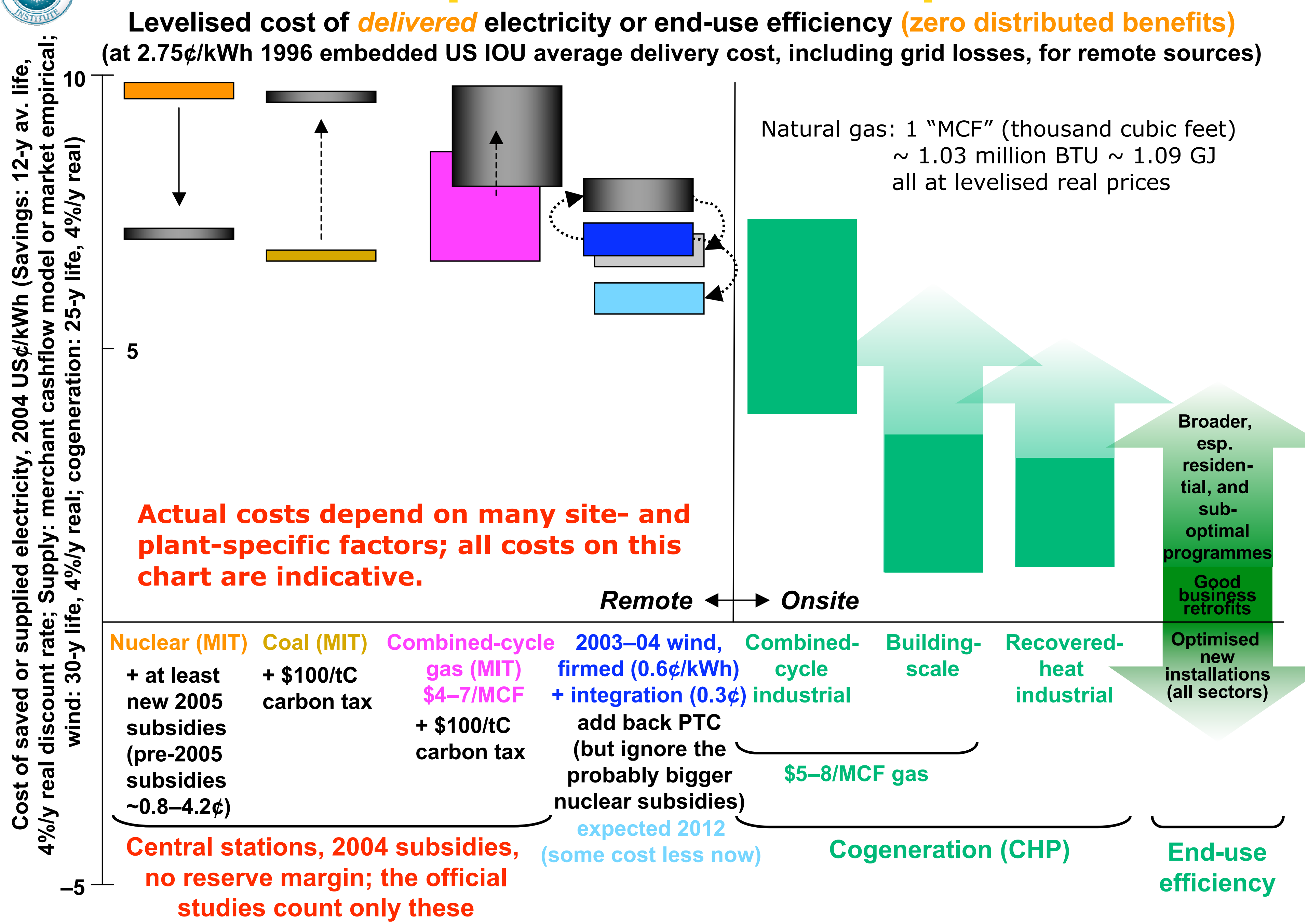
RMI analysis: www.rmi.org/sitepages/pid171.php#E05-04

- Two-thirds combined-heat-and-power (cogeneration)*, ~60–70% gas-fired, ≥50% CO_2 reduction

*Gas turbines ≤120 MWe, engines ≤30 MWe, steam turbines only in China

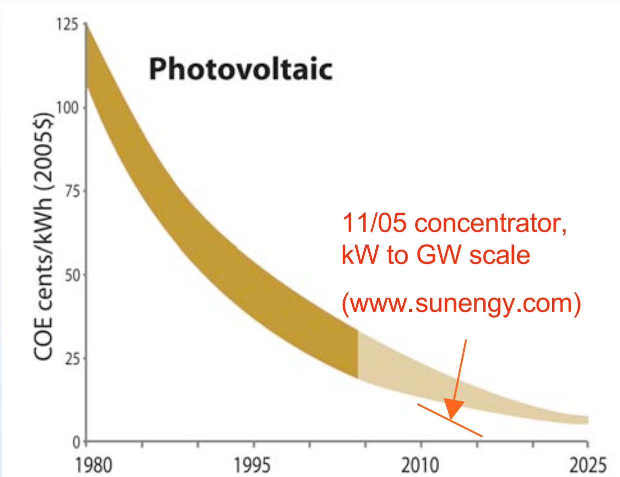
- One-third renewable (hydropower only up to 10 MW_e)
- In 2004, these low- or no-carbon options added *2.9× as much output and 5.9× as much capacity* as nuclear power did
- Their projected 2010 capacity addition is *136–184× nuclear's*
- Demand-side additions are probably bigger…but no data!
- *Total* decentralised cap. addns. in 2004 were ≥10× nuclear's
- Not due to carbon taxes/trading

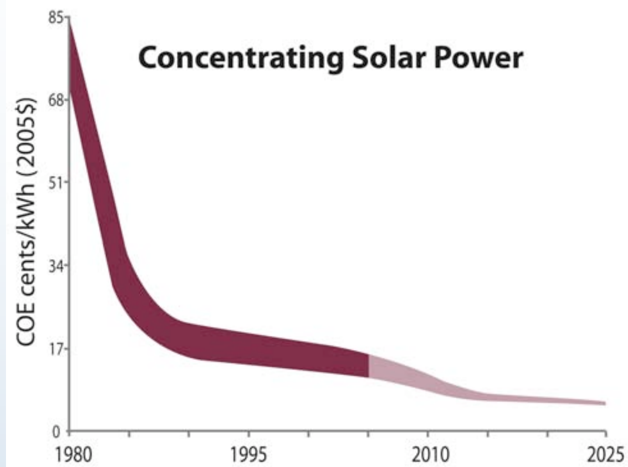
Nuclear power's fatal competitors

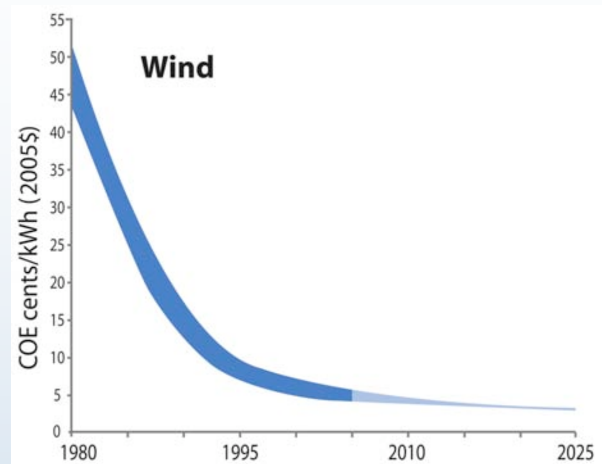


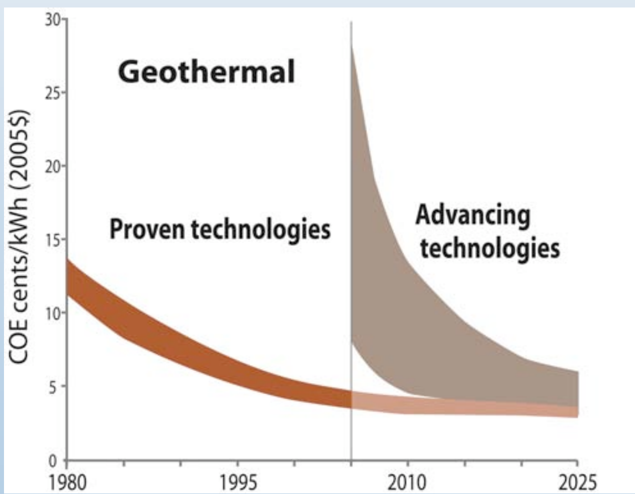
Renewable Energy Cost Trends

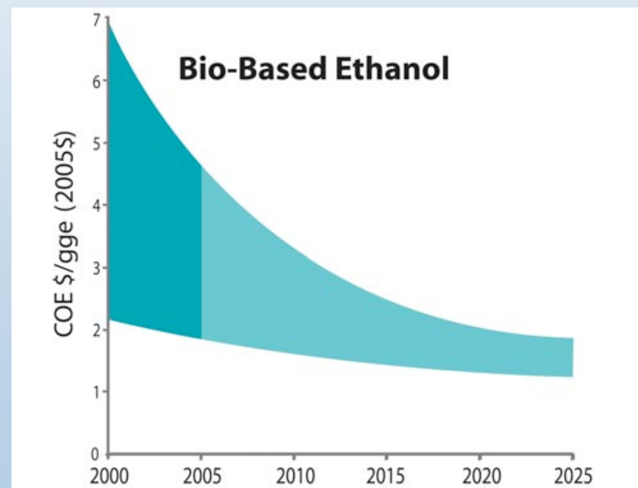
Levelised sent-out cost of energy in constant 2005 US$, excluding subsidies[1]











Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2005.ppt)

[1]These graphs are reflections of historical cost trends NOT precise annual historical data. DRAFT November 2005

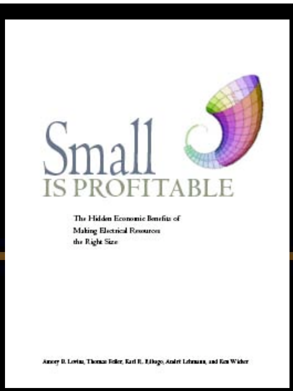
EAO Energy Analysis Office
Understanding Energy Issues

NREL National Renewable Energy Laboratory

Electricity supply (and more): what's the right size for the job?

- ~1880–1980: power stations costlier & less reliable than the grid, so must be shared via the grid
- ~1980– : power stations cheaper and more reliable than the grid, so really cheap and reliable supply must be at/near customers, *i.e.*, 'distributed'
- Central thermal power plants stopped becoming more efficient in the 1960s, bigger in the 1970s, cheaper in the 1980s, and bought in the 1990s
- Distributed generators made 52% of the 2004 electricity used in Denmark, 39% in Holland, 37% in Finland, 31% in Russia, 18% in Germany, 16% in Japan and Poland, 15% in China, 14% in Portugal, and 11% in Canada…because they're faster, cheaper, and have lower financial risk

"Distributed benefits" change the game



- *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (RMI, 8/02)
  - www.smallisprofitable.org
  - One of *The Economist*'s top three business/economics books of 2002
- Codifies and quantifies 207 'distributed benefits' that collectively increase the economic value of decentral-ised generation by typically ~10× (but site-specific)
- Four kinds: financial economics, electrical engineering, miscellaneous, externalities
- 'Cleaner Energy, Greener Profits' (www.rmi.org, 2001) shows how this approach can make fuel cells profitable even at handicraft prices ($3,000/kWe)

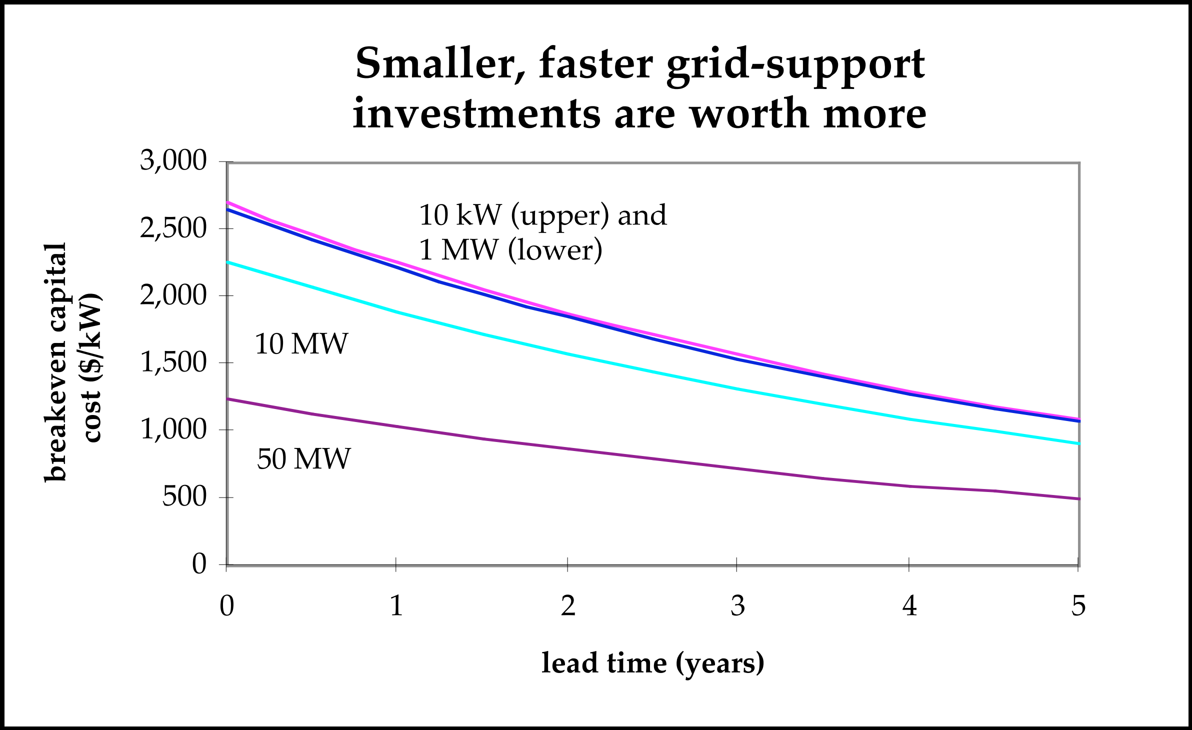
Whence the order-of-magnitude typical value increase?

- Financial-economics benefits: often nearing ~10× renewables, ~3–5× others
- Electrical-engineering benefits: normally ~2–3×, far more if the distribution grid is congested or if premium power reliability or quality is required
- Miscellaneous benefits: often around 2×, more with thermal integration
- Externalities: indeterminate but may be important; not quantified here

207 Distributed benefits: ~10× value

(Actual value is very technology- & site-specific)

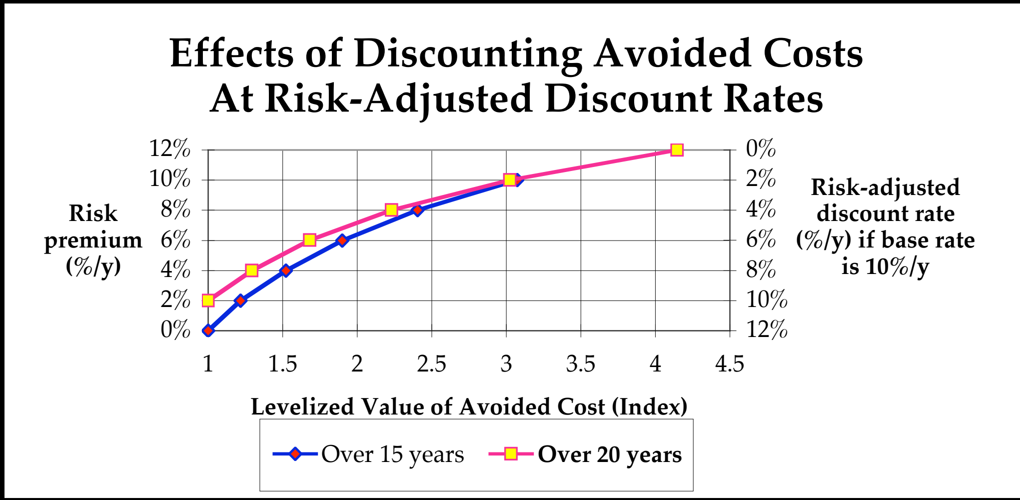
- ~10¹×: Minimizing regret (financial economics)
  - Short lead times and small modules cut risk
    - Financial, forecasting, obsolescence
    - Overshoot and 'lumpiness'



Tom Hoff's analytic solution shows that it's worth paying ~2.7× more per kW for a 10-kW overnight resource than for a 50-MW 2-y resource

Financial-economics benefits (cont'd)

- Portable resources are redeployable
  - Benefits' expected value rises, risk falls
- Rapid learning, mass-production economies
- Constant-price resources *vs.* volatile prices
  - Risk-adjusted discounting can nearly double the present value of a gas cost stream for fair comparison with windpower



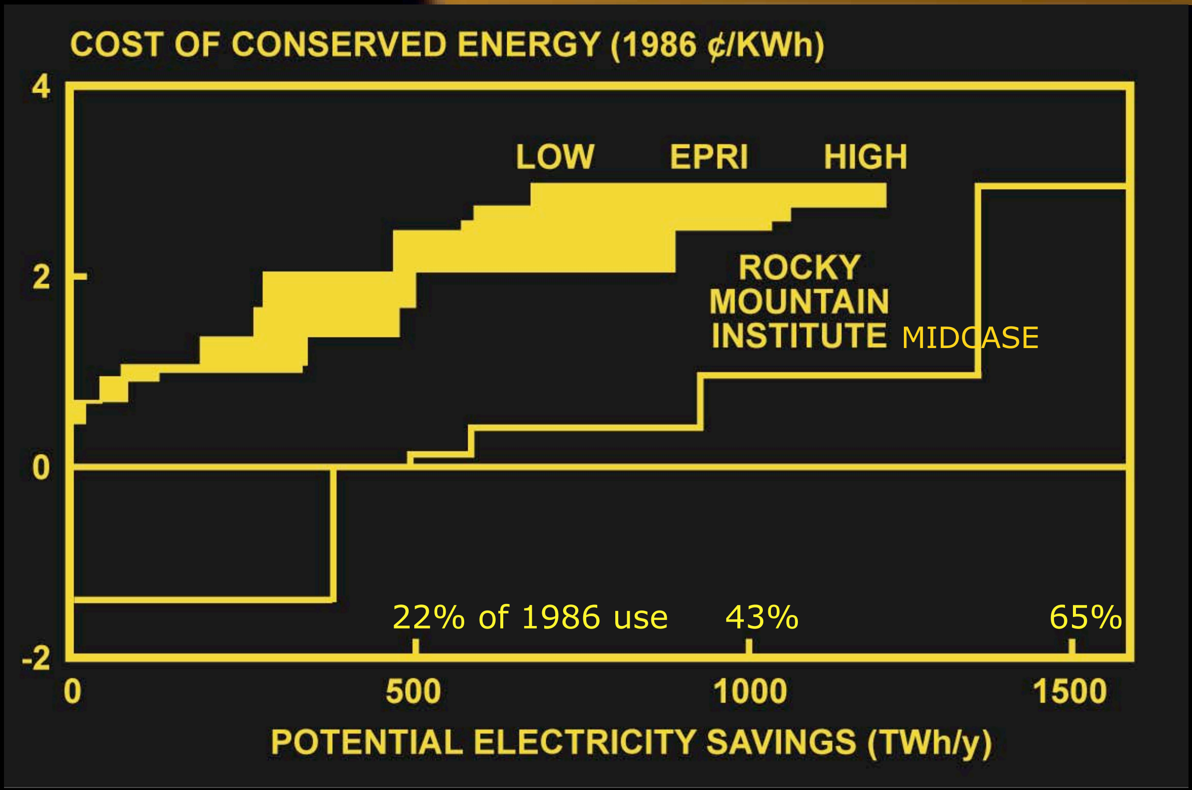
- Genuinely diversified supply portfolios
- 'Load-growth insurance' of CHP and efficiency

The US gas price's risk premium was ~5–6 percentage points in 2002 but is probably higher now.

Most of the world's energy is wasted (could be saved at far lower cost)

- Halved US E/GDP since '75 just scratches the surface
- Unbought efficiency is becoming bigger and cheaper
- Official stats focus ~99% on supply, which fueled just 22% of the 1996–2005 rise in US energy services
- Government energy policy uses *economic* paradigm
  - If more efficient use were worthwhile, it'd have been bought
  - Choices must be interpreted and influenced through price
  - Market failures and technological progress are unimportant
  - Obvious wastes—<1% of cars' fuel moves the driver, ~3% of power-plant fuel lights the incandescent-lit room, US power plants discard heat equivalent to 1.2× Japan's total energy use—are OK
- So the biggest, cheapest, fastest, most benign energy option is the least visible, least understood, and most neglected…persistently and globally

Two 1990 supply curves for saved US electricity (ORNL/CON-312, 1991)



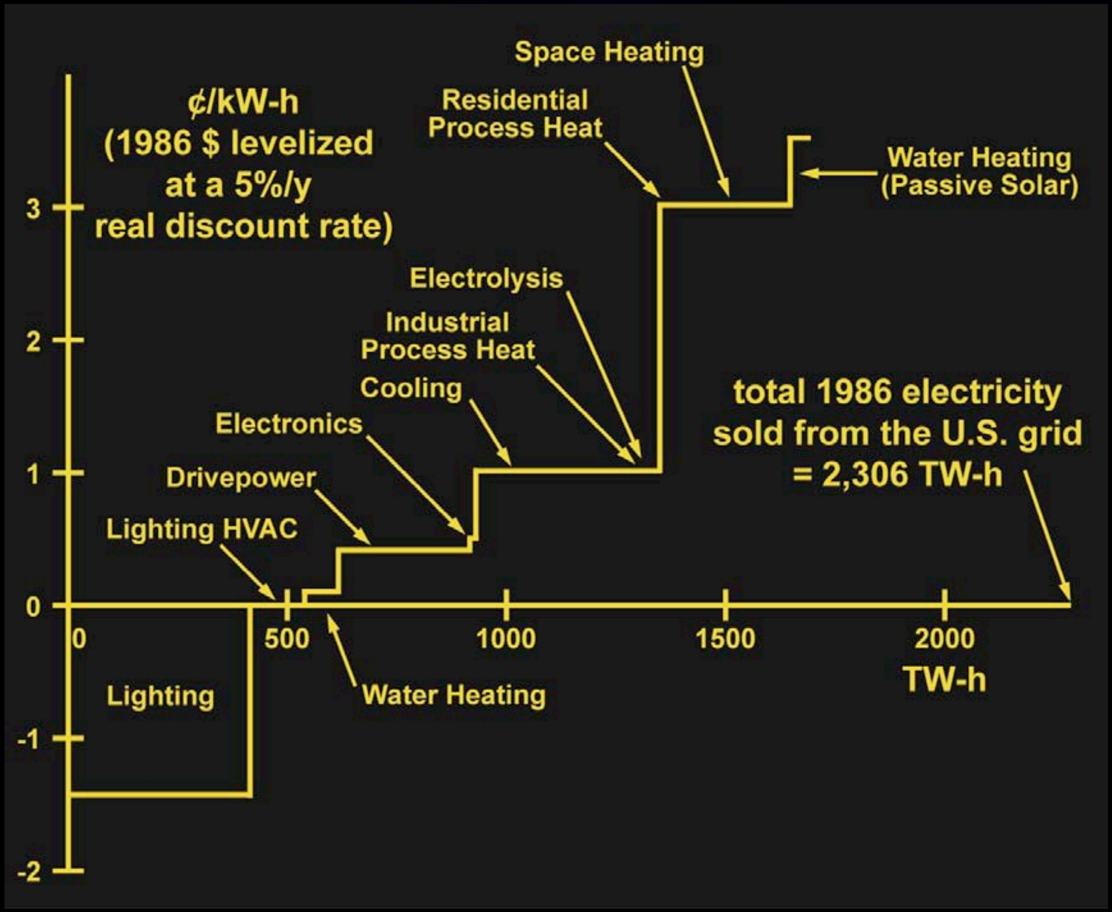
◇ EPRI: potential savings by 2000, *excluding* 9–15% add'l savings expected to occur spontanteously

◇ RMI: full long-term potential retrofit savings

◇ Difference is largely methodological, not substantive

- ○ EPRI excludes, RMI includes saved maint. cost, so commercial lighting retrofit costs +1.2 *vs* −1.4¢/kWh
- ○ EPRI assumes drivepower savings 3× smaller & 5× costlier than EPRI agrees *id*. (*Sci. Amer*. Sept 1990)

1989 supply curve for saved US electricity (*vs.* 1986 frozen efficiency)



Best 1989 commercially available technologies, retrofitted wherever they fit in the 1986 US stock of buildings & equipment

Savings keep getting bigger and cheaper faster than they're being depleted

Similar S, DK, D, UK…

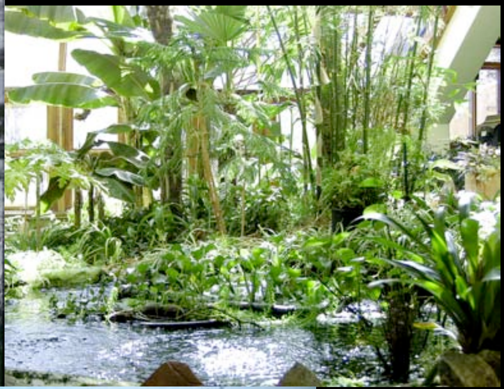
Measured technical cost and performance data for ~1,000 technologies (RMI 1986–92, 6 vol, 2509 pp, 5135 notes)

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!

−44 to + 46°C with no heating/cooling equipment, *less* construction cost

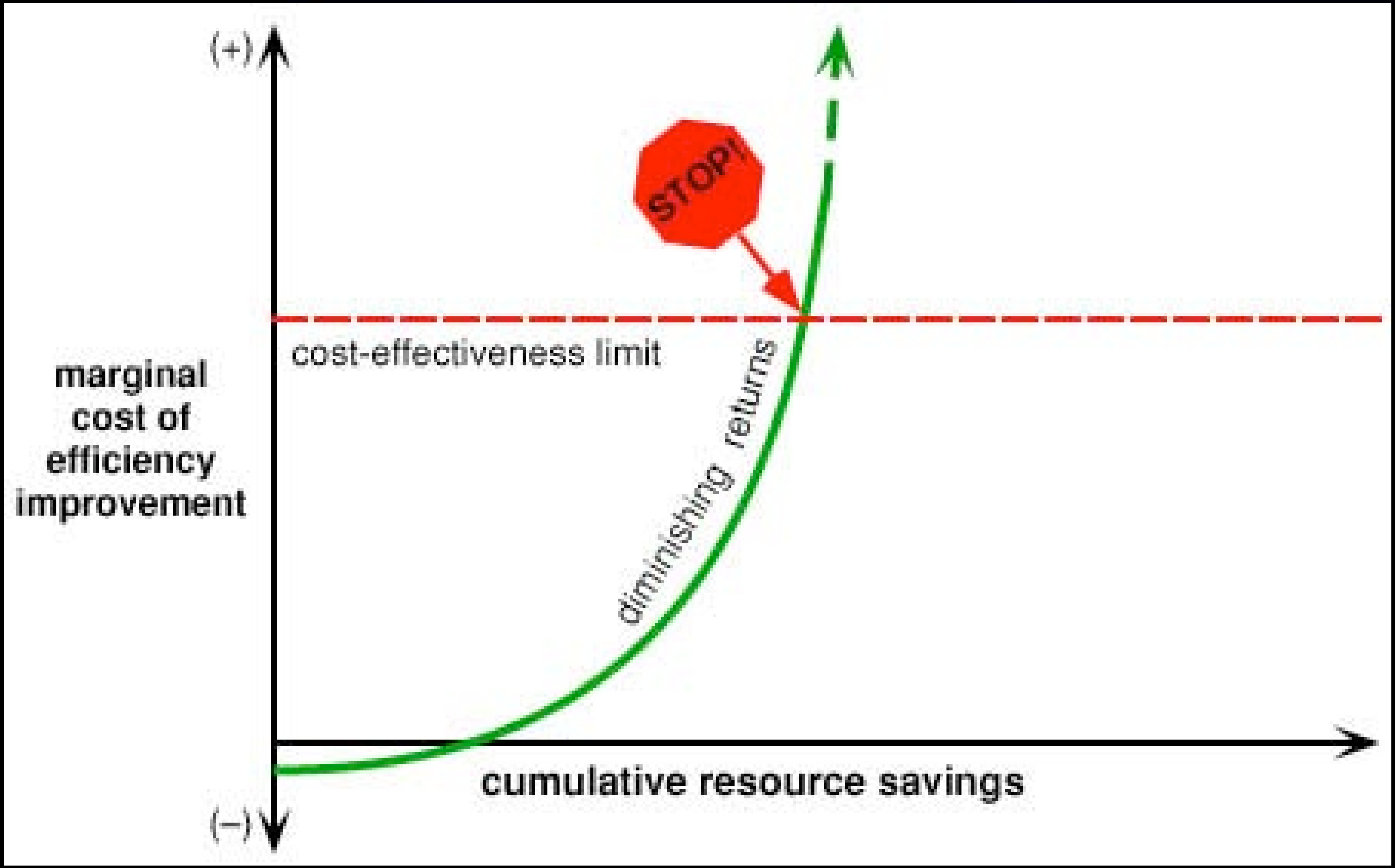
2200 m, frost any day, 39 days' continuous midwinter cloud…yet 28 banana crops with no furnace



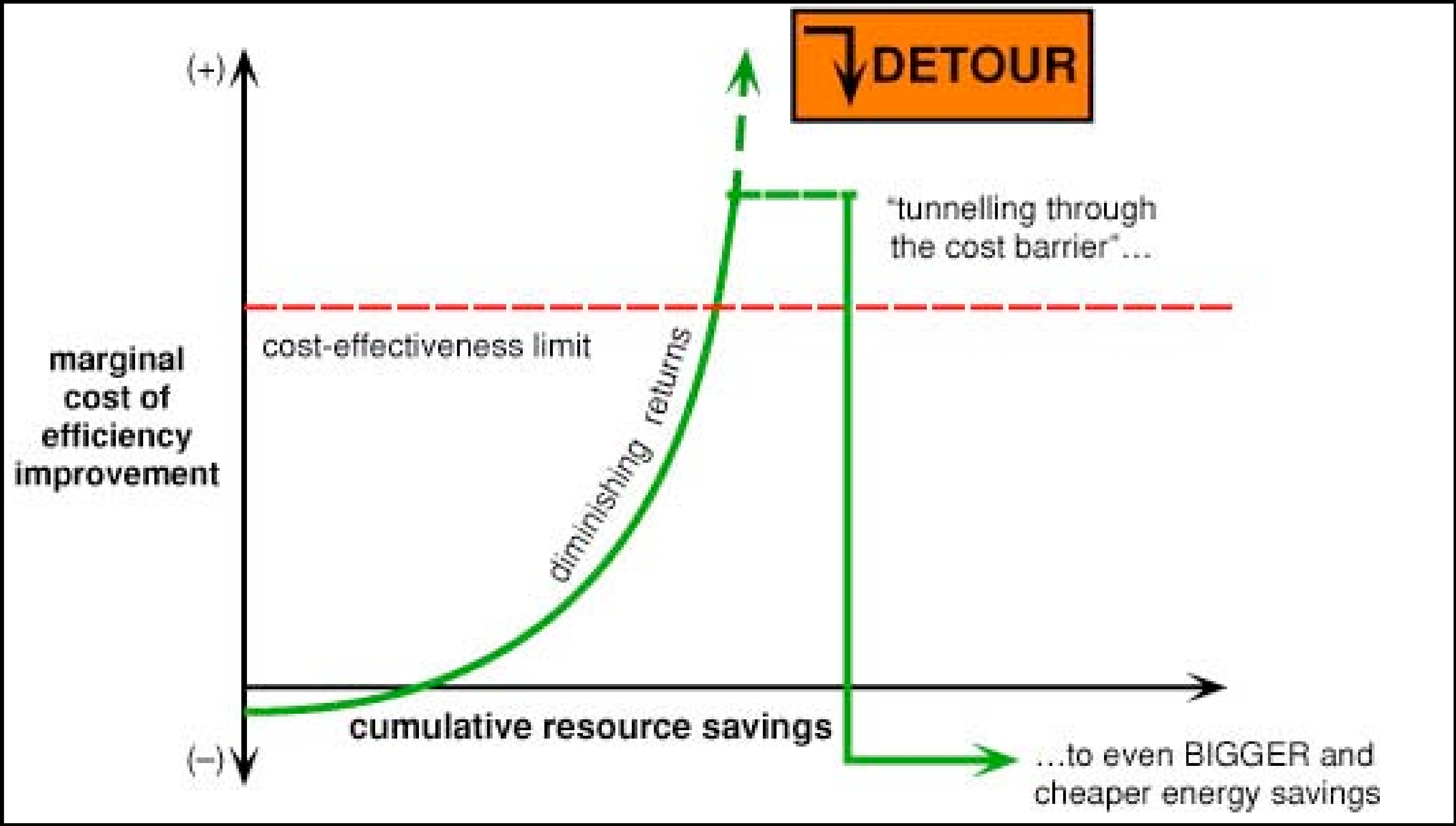
Key: integrative design—multiple benefits from single expenditures

- Lovins house / RMI HQ, Snowmass, Colorado, '84
  - Saves 99% of space & water heating energy, 90% of home el. (372 m^2 use ~120 W_{av} costing ~\$5/month @ \$0.07/kWh)
  - 10-month payback in 1983
- PG&E ACT², Davis CA, '94
  - Mature-market cost –\$1,800
  - Present-valued maint. –\$1,600
  - 82% design saving from 1992 California Title 24 code
- Prof. Soontorn Boonyatikarn house, Bangkok, Thailand, '96
  - 84% less a/c capacity, ~90% less a/c energy, better comfort
  - No extra construction cost

Old design mentality: always diminishing returns...



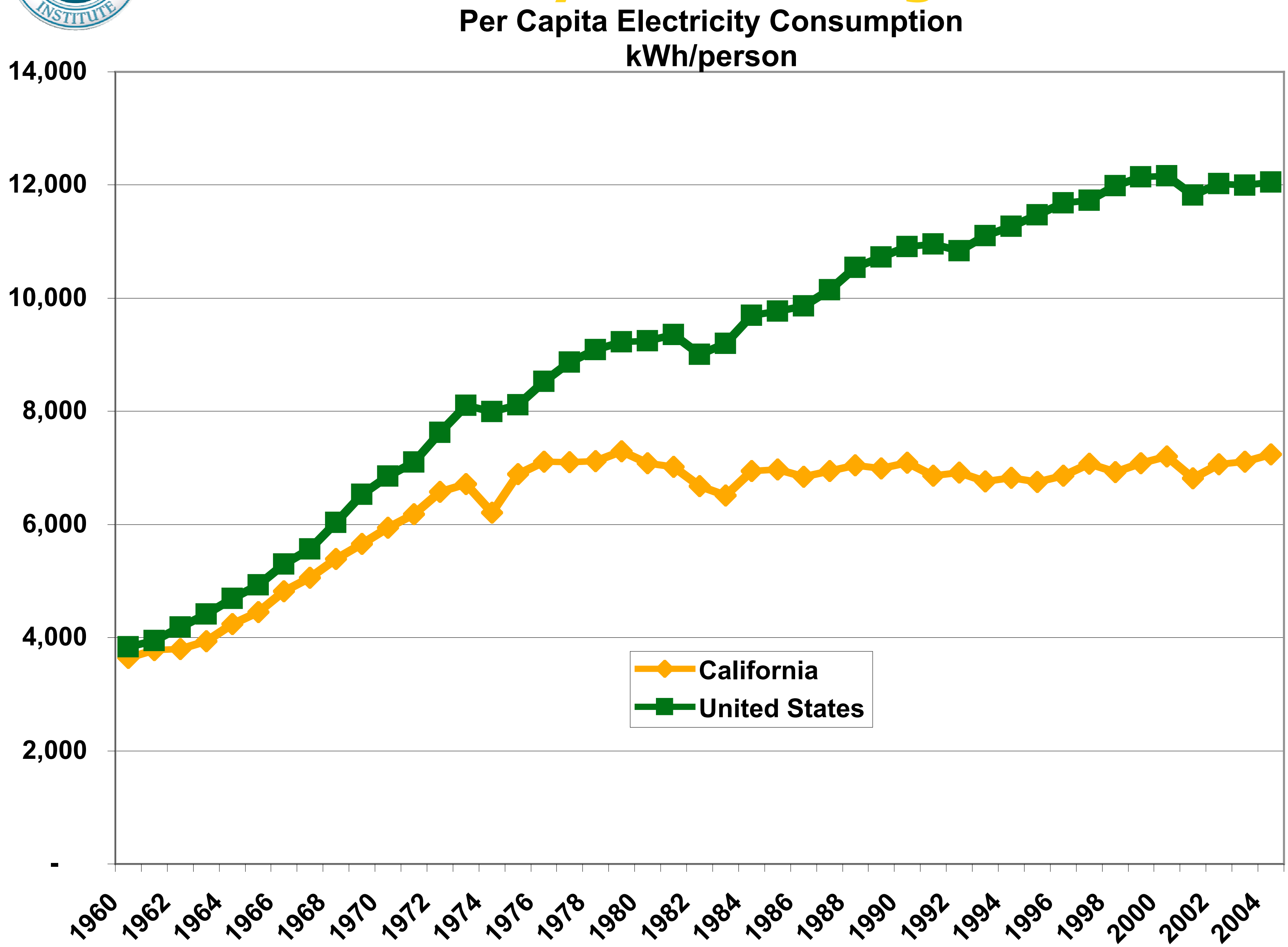
New design mentality: expanding returns, "tunneling through the cost barrier"

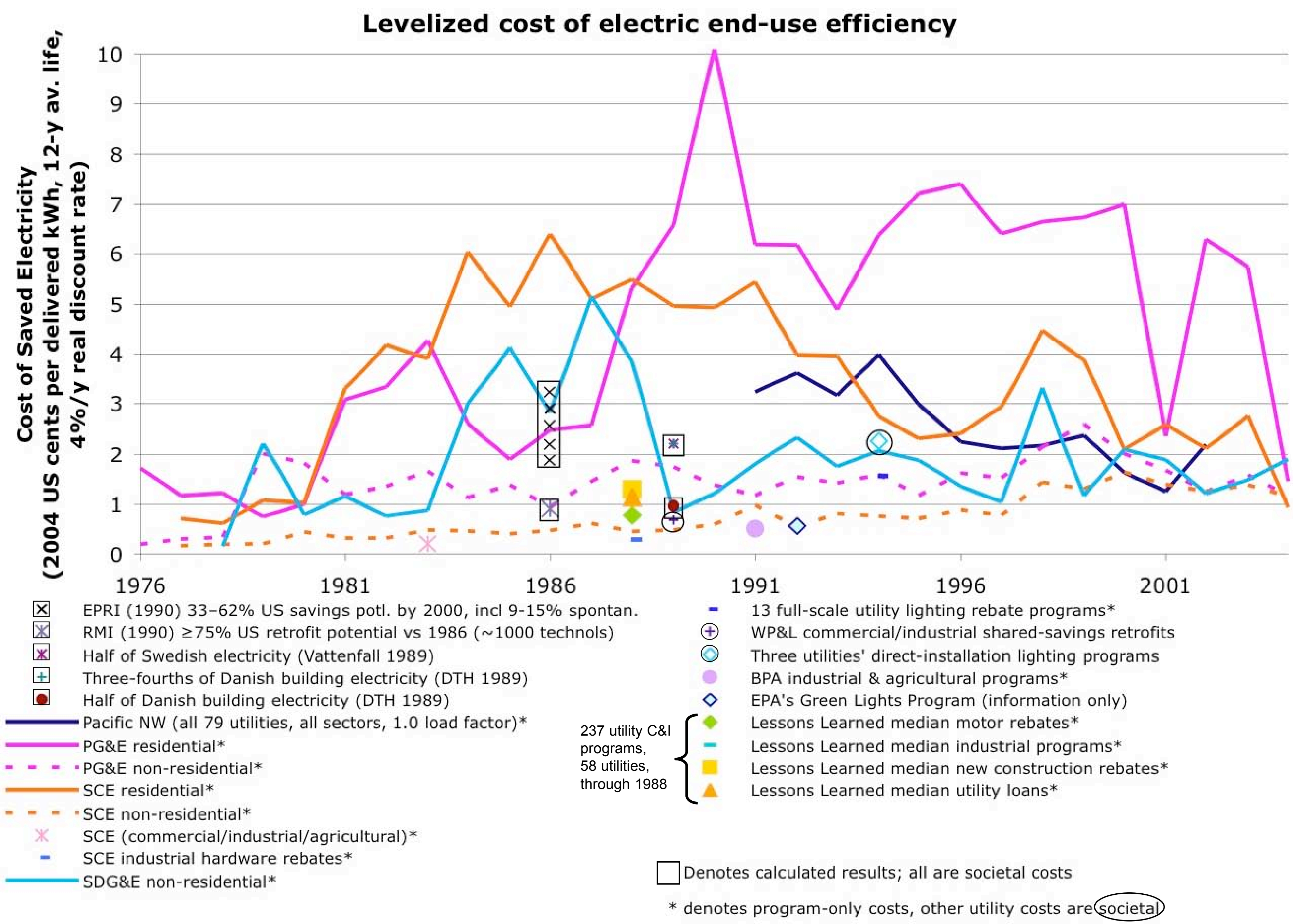


Examples from RMI’s industrial practice (>$20b of facilities)

- Save half of motor-system electricity; retrofit payback typically <1 y
- Similar w/ >50% retrofit savings of chip-fab HVAC power; new fab: 20% savings with –30% capex; next should save >50%, cost even less
- Retrofit very efficient oil refinery, save 42%, ~3-y payback
- Retrofit North Sea oil platform, save half the electricity, get the rest from wasted energy streams
- Redesign $5b gas-to-liquids plant, –$1b capex, save >50% energy
- Retrofit big LNG plant, ≥40% energy savings; ~60%? new, cost less
- Redesign giant platinum mine, 43% energy savings, 2–3-y paybacks
- Redesign new data centre, save 89%, cut capex & time, improve uptime
- Redesign supermarket, save 70–90%, better sales, ?lower capex
- Redesign new chemical plant, save ~3/4 of electricity just in auxiliaries, cut construction time and cost by ~10%
- Now add process change, microfluidics, biomimetics, dematerialisation/longevity/closed loops…and there is no end to major industrial energy efficiency gains for a *very* long time

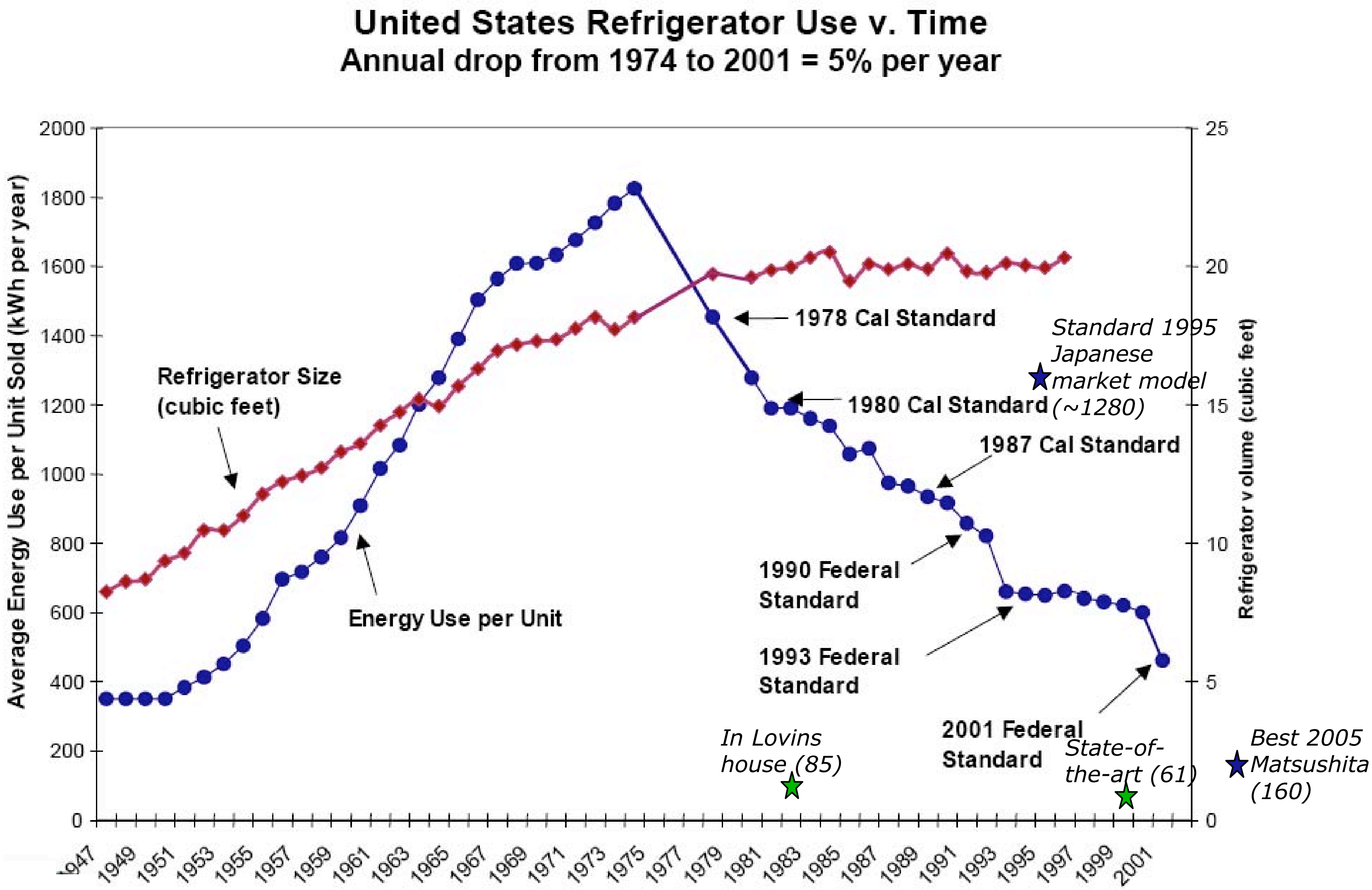
Efficiency works in California… and similarly in New England (not shown)





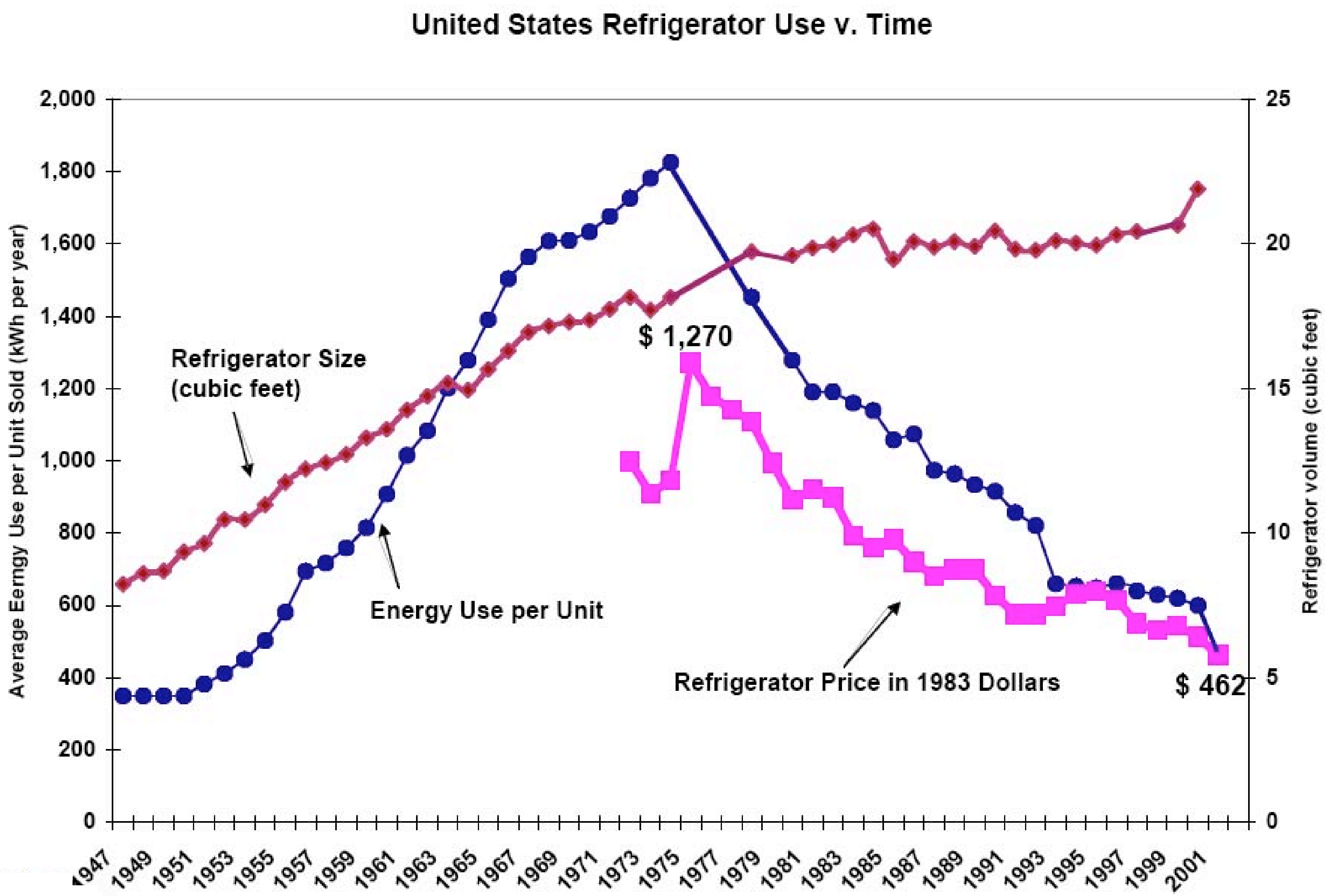
Levelized cost of electric end-use efficiency
Cost of Saved Electricity
(2004 US cents per delivered kWh, 12-y av. life, 4%/y real discount rate)
10
9
8
7
6
5
4
3
2
1
0
1976
1981
1986
1991
1996
2001
EPRI (1990) 33–62% US savings potl. by 2000, incl 9-15% spontan.
RMI (1990) ≥75% US retrofit potential vs 1986 (~1000 technols)
Half of Swedish electricity (Vattenfall 1989)
Three-fourths of Danish building electricity (DTH 1989)
Half of Danish building electricity (DTH 1989)
Pacific NW (all 79 utilities, all sectors, 1.0 load factor)*
PG&E residential*
PG&E non-residential*
SCE residential*
SCE non-residential*
SCE (commercial/industrial/agricultural)*
SCE industrial hardware rebates*
SDG&E non-residential*
13 full-scale utility lighting rebate programs*
WP&L commercial/industrial shared-savings retrofits
Three utilities' direct-installation lighting programs
BPA industrial & agricultural programs*
EPA's Green Lights Program (information only)
237 utility C&I programs, 58 utilities, through 1988
Lessons Learned median motor rebates*
Lessons Learned median industrial programs*
Lessons Learned median new construction rebates*
Lessons Learned median utility loans*
Denotes calculated results; all are societal costs
* denotes program-only costs, other utility costs are societal

Efficiency is a rapidly moving target



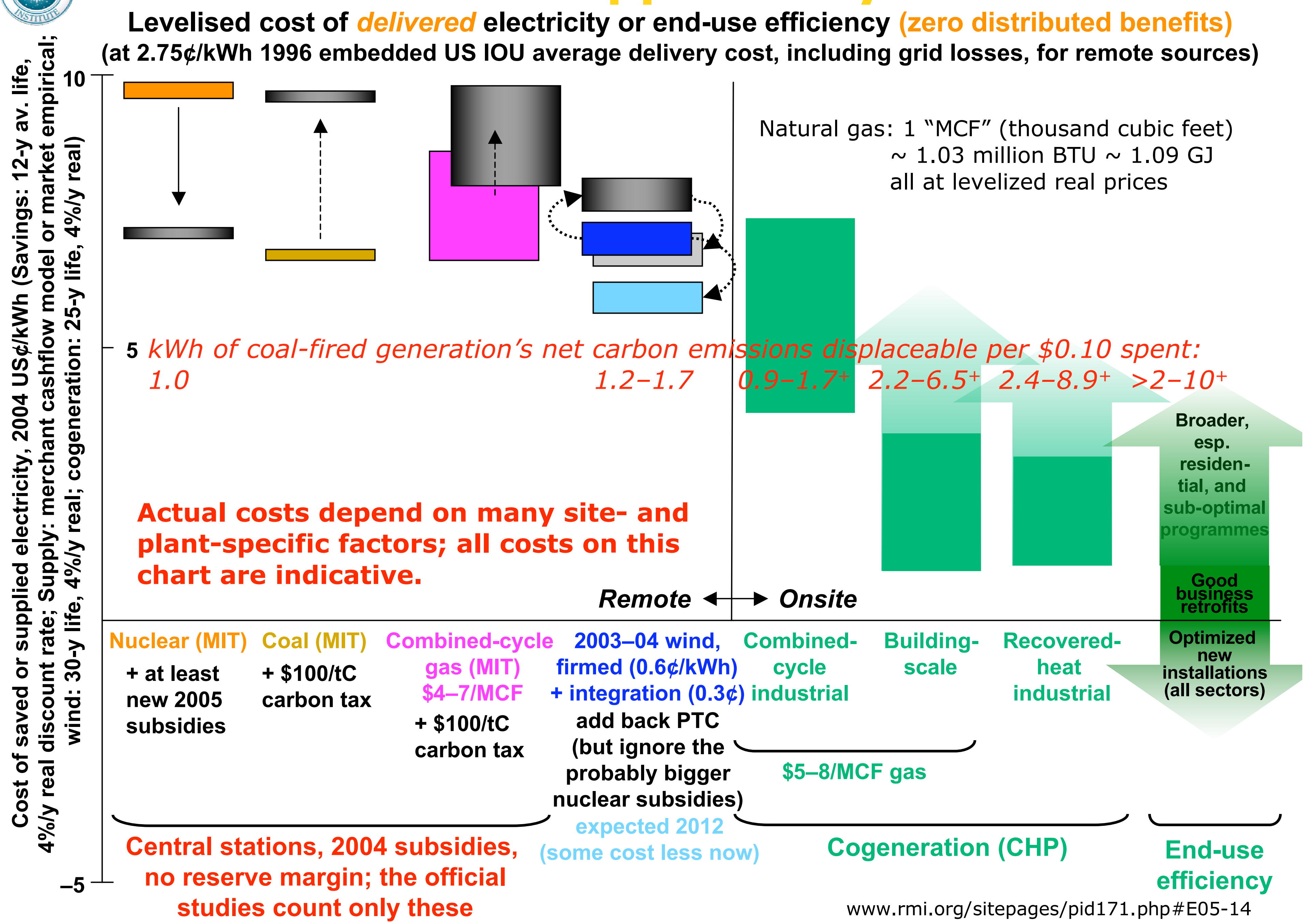
Japan's standards aim to cut el. use 30% from ~1997 levels for refrigerators, 16% for TVs, 83% for PCs, 14% for air conditioners,…; all can go much lower

Efficiency standards needn't raise costs



Source: David Goldstein

Climatic opportunity cost



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

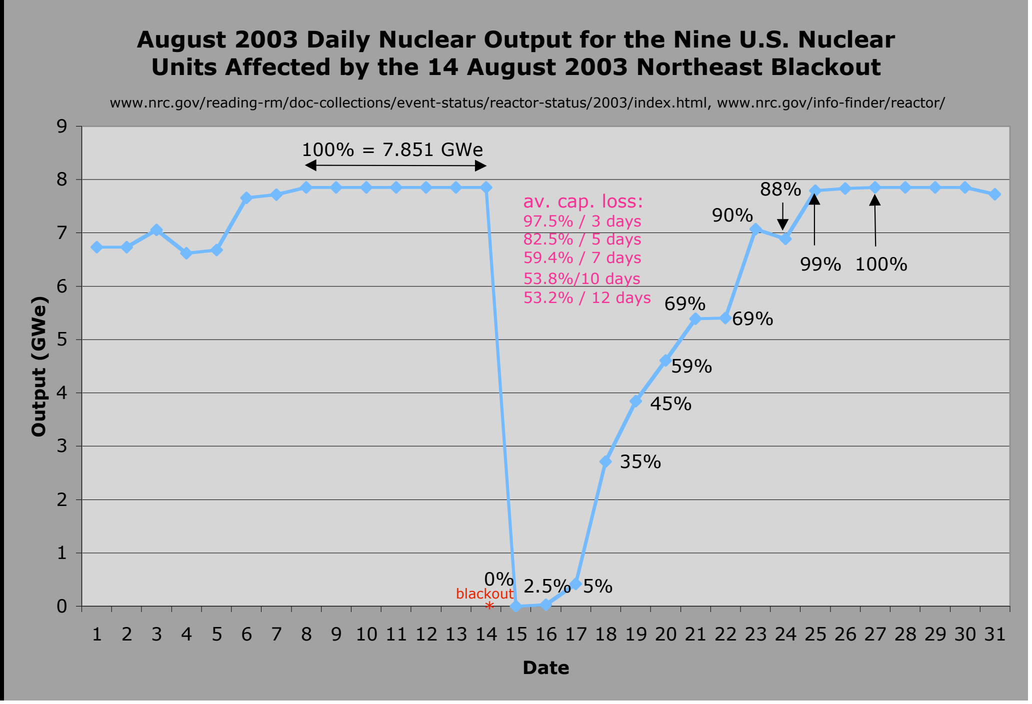
- California's 1982–85 fair bidding with roughly equal subsidies elicited, *vs.* 37-GW 1984 load:
  - 23 GW of contracted electric savings acquisitions over the next decade (62% of 1984 peak load)
  - 13 GW of contracted new generating capacity (35% of 1984 load), most of it renewable
  - 8 GW (22%) 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
- Ultimate size of alternatives also dwarfs nuclear's
  - El. end-use efficiency: ~2–3× (EPRI) or 4–5× nuclear's 20% US share at below its *short*-run marginal delivered cost
  - CHP: industrial alone is comparable to nuclear; + buildings CHP
  - Wind: ≥2× US & China electricity use, 9× global electricity use
  - Other renewables: collectively even larger, PVs almost unlimited
  - Diverse, dispersed, forecast, and integrated deployment makes variability & land-use concerns unimportant (*all* sources are variable/intermittent, differing in why, how big/long, predictability)

"Baseload" ≠ "big thermal plant" (*cf.* telephony and computing)

◇ Arithmetically, one 1-GWe unit or a thousand 1-MWe units or a million 1-kWe units are equivalent

◇ But in practice, many small units are *more* reliable than a few big ones even if all are equally reliable—and those near customers are more reliable than faraway units (98–99% of US outages originate in the grid)

◇ Anyhow, not only wind arrays can lose output for an extended period: *av*. US nuclear outage is 37 days every 17 months, and many units can fail simultaneously and without warning…

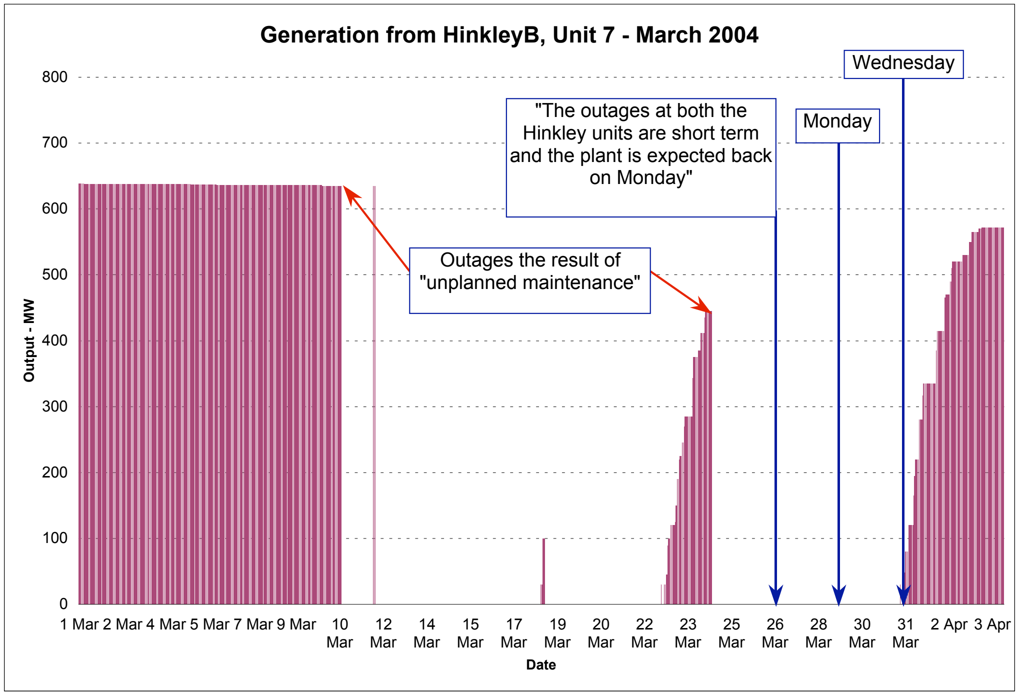


Same for UK reactors

◇ UK reactors' availability varies widely; cap.-weighted lifetime capacity factor averaged 73.6% through 2004

◇ *All* central stations are intermittent (US fossil units' forced outage rate ~8%, UK reactors' recently ~9.4%)

◇ Hinkley, scheduled for decommissioning in 2011, averaged 75.6% cumulative cap. factor –2004, when…



◇ UK windfarms don't have such long outages

◇ What is the 'balancing cost' for *this* resource?

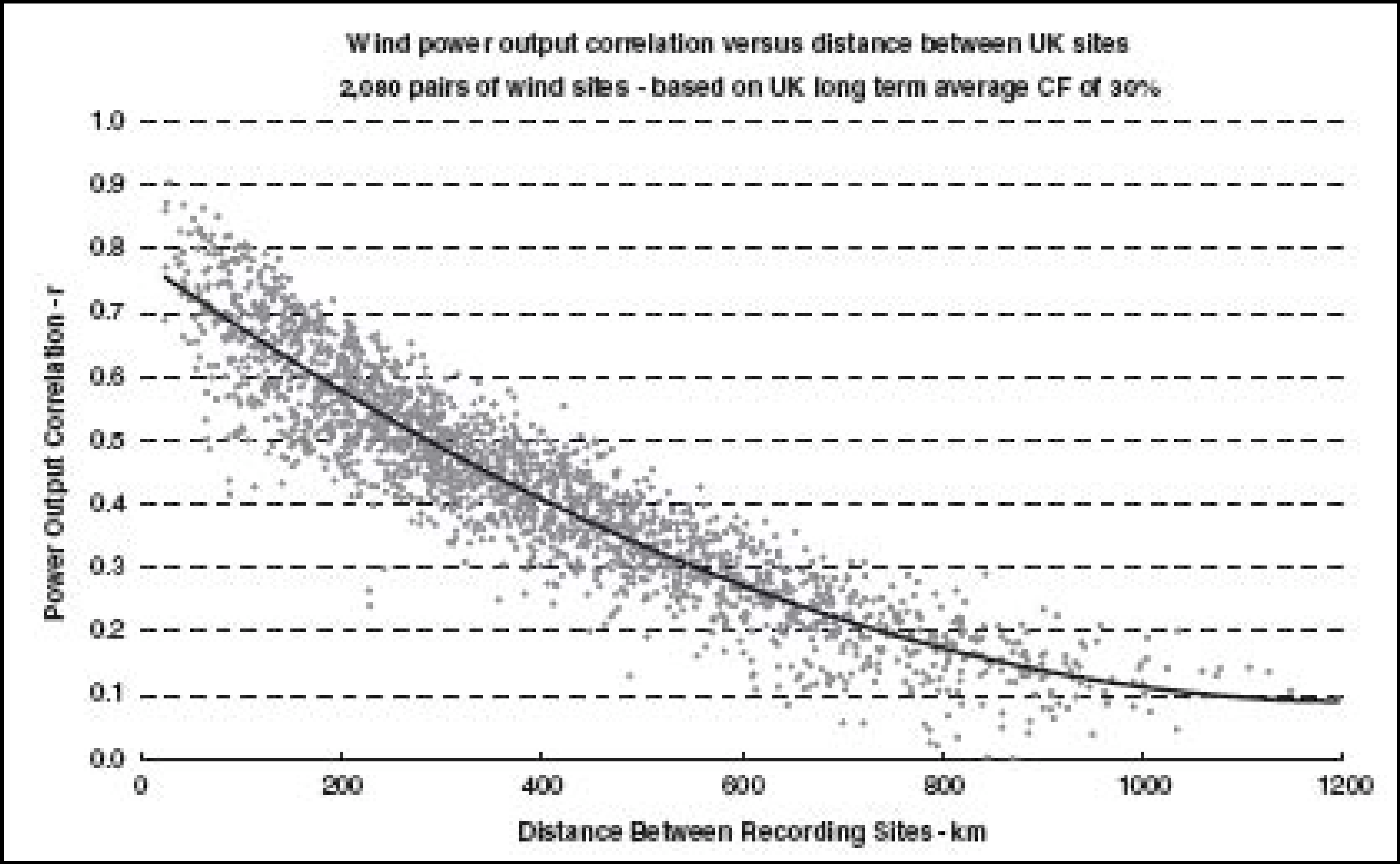
◇ It's not zero; better to be approximately right than precisely wrong

34 years of UK wind data from 66 onshore sites (>15M site-h)

(Graham Sinden, *En. Pol.*, in press, 2006, www.eci.ox.ac.uk)

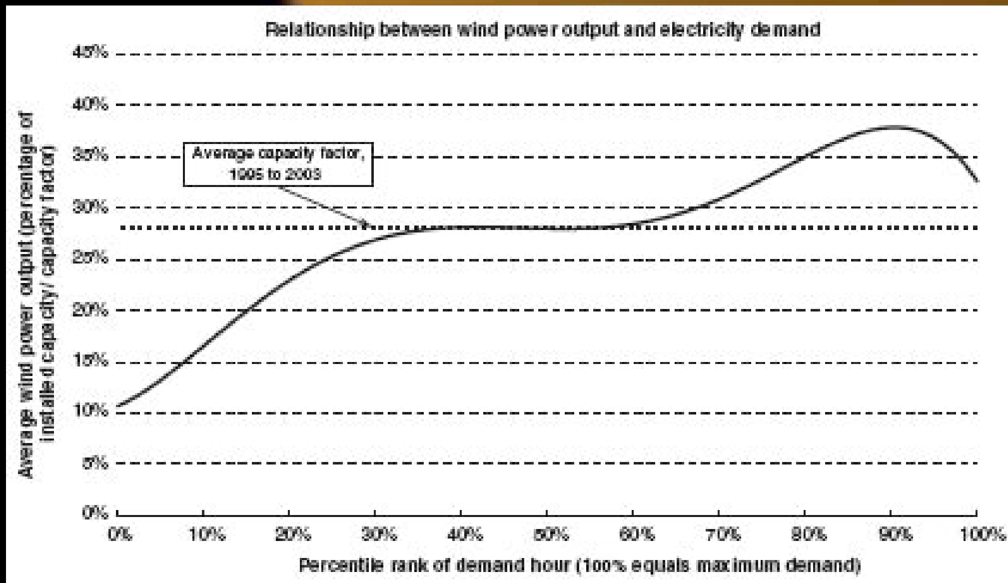
- Realistic long-term capacity factor is encouraging
  - 0.30 at current stage of UK wind development, higher later
  - 1970–2004 annual range 0.241–0.357, σ = 7.4% of production/y
- Seasonal and diurnal variations correlate with loads
  - Dec–Feb = ~1/3 of annual output, Jun–Aug ~1/6
  - Stronger in the daytime than at night
- Correlation between sites' output falls with distance
  - So diversifying sites smoothes output; this can be maximised
- Extreme conditions are not problematic
  - Not for a single hour was the whole UK becalmed—nor too windy
  - Of the ~20% of a given site's zero-output hours, ~99% are due to underspeed (<4 m/s), ~1% to overspeed (>25 m/s)
  - Underspeed affects >50% of UK for <10% of all hours, ≥75% for 0.8% (0.2% winter), >90% for only 1 h/y, <20% for >60% of h
  - Most extreme overspeed affects 43% of UK for ~1 h in 30 y; overspeed for >30% of UK at once is always during very low load
  - Strong winds affect <0.1% of UK at any one time

Correlation between output from UK windpower sites falls with distance



UK wind resource matches loads well, increasing its dependability & value

(Graham Sinden, *En. Pol.*, in press, 2006, www.eci.ox.ac.uk)



These data are for a subset of years in which average capacity factor was 0.28, not the long-run average of 0.30

- Windpower output correlates well with electric loads
- Capacity factor during highest-demand hours is nearly 3× higher than during lowest-demand hours
- In highest-10%-demand hours, ~82% of sites work
- Low windspeed correlates well with low load, so annual-average metrics understate windpower’s capacity value for meeting peak loads

Diversifying renewables beyond just windpower (Graham Sinden, 9/05, 'Diversified renewable energy portfolios for the UK', www.eci.ox.ac.uk)

- Wavepower is even more load-correlated than wind
- They're 42% correlated with each other, but tidal-current power is only 1% correlated with either
- A diversified portfolio of all three, meeting 20% of UK electricity demand, can serve the same load with the same reliability using 76 GW of conventional capacity, *vs.* 79 GW with wind-only or 84 GW with no renewables (Dale *et al.* 2004)
- The portfolio also cuts wind-only balancing cost from £2.85/MWh to £1.80/MWh (Millborrow)
- Diversification by technology and site reduces variability, raises capacity credit, & cuts balancing cost

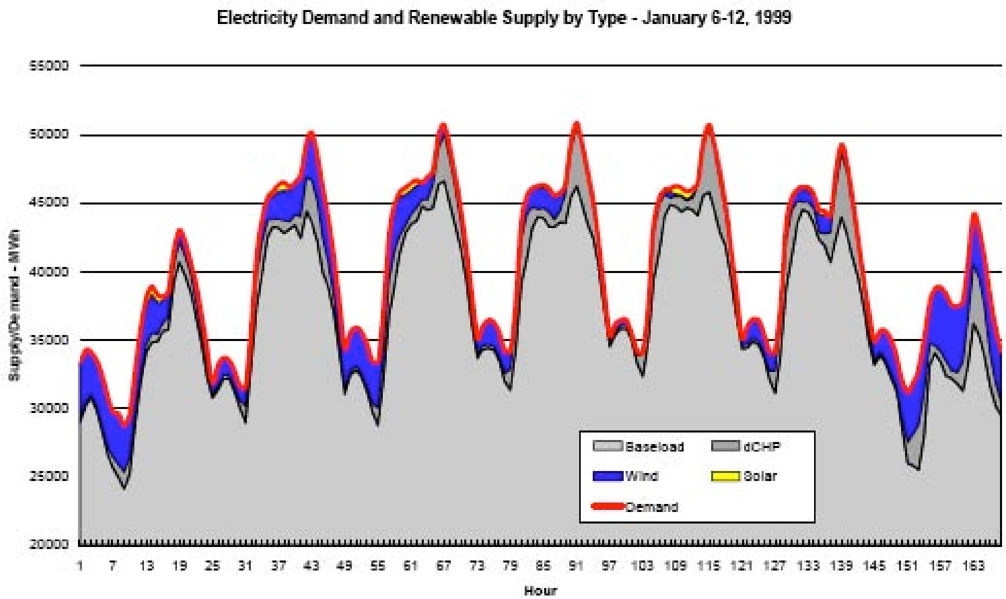
Or combine offshore wind, PVs, and domestic CHP (65/10/25%)

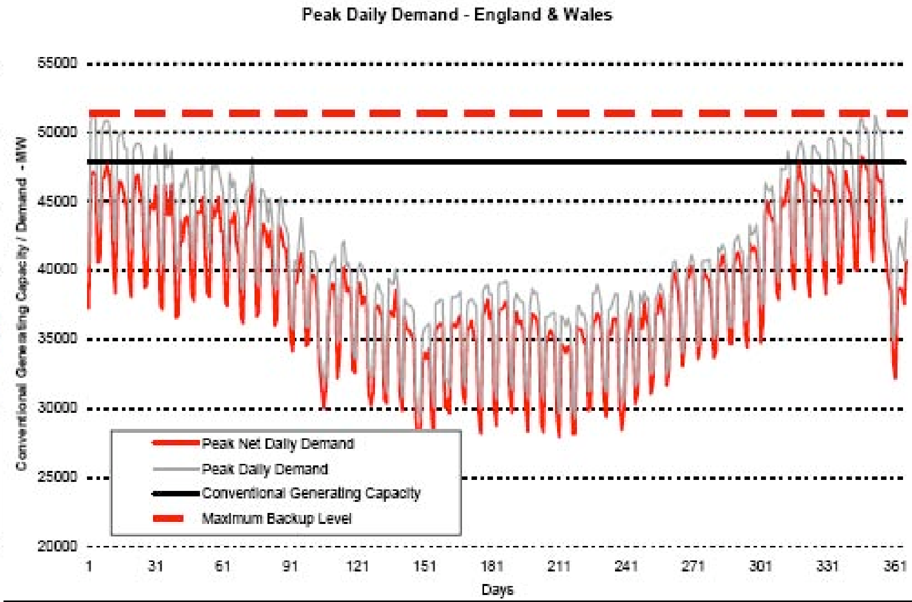
(Graham Sinden, House of Lords Sci&Tech Select Comm., 2004)

- To provide 10% of England & Wales TWh/y (~11.2% onpeak, ~8.8% offpeak); runs *every* hour
- Additional backup capacity is needed only when variable sources are weak *and* demand is high
  - The 1980–2000 peak load, 51,364 MW, could have been met with 47,864 MW of available conventional capacity if variable resources displace ~3,500 MW of conventional capacity
  - That worst-case hour would have needed only 400 MW of additional conventional capacity…to serve peak load two hours in 21 years; that backup would be used on average for just one hour every five years, and zero hours in four out of five years
  - All-offshore-wind (~10 GW) would instead need 3,135 MW of backup, so three-source integration reduces this by 87%
- More diverse types/sites would reduce backup more
- So would counting grid's *existing* backup capacity
- 20% variable supply needs ~2 GW backup 1 h/y, again not counting already existing backup capacity

A 10%-variable-generator scenario in the 1980–2000 UK peak period

(Graham Sinden, House of Lords Sci&Tech Select Comm., 2004)





A combination of 65% offshore wind, 25% domestic CHP, and 10% PV, meeting 10% of annual el. needs in England and Wales, is diverse enough to produce continuously. Meeting the most extreme condition of low variable-source output plus high demand needs additional backup capacity 0.78% as big as peak load—far below reserve margin already on the grid

Even photovoltaics show UK promise

(Barnham, Mazzer & Clive, *Nature Materials* 5:161 (3/06))

- Japan and Germany boosted PV production by nearly 2/3 during 2003–04 as they completed their 70,000- and 100,000-solar-roof programmes
  - UK cancelled its 3,500-roof programme halfway; BP Solar, the world #3 PV maker in 2004, no longer manufactures in the UK
- Japan plans to have installed ~100 GW PV by 2030; past 12 y of German PVs implies 12 GW in 2011–12
- 'If the average trend of the past 12 years continues, Germany will have installed more PV capacity than the entire current UK nuclear contribution well before the [next UK reactor] has produced a single kWh.'
- UK buildings' solar incidence is ≥7× their electricity use, so nuclear could be replaced by 13%-eff't PVs on ~1/3 of roof & S-facing wall areas; the latest cells get >30% and can be integrated into light-diffusing windows, making a S-facing London office self-sufficient in el. with ~2-y payback, given EU feed-ins

What about nuclear power's commonly discussed issues?

- Investors and the public are concerned about such issues as proliferation of nuclear bombs, vulnerability to terrorism, major accidents, waste management and decommissioning, fuel-cycle releases and risks, common-mode shutdowns, etc. ***(S. Kidd [WNA],* Nucl. Eng. Intl.*, 9/05)***
- But here we consider economics first, so such issues 'are not a minor counterweight to enormous advantages but rather a gratuitous supplement to enormous disadvantages' ***(A.B. & L.H. Lovins & L. Ross,* Foreign Affairs*, Summer 1980)***
- If nuclear power is unnecessary and uneconomic, we needn't debate its safety

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, technologies, know-ledge, skills); 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 UK and US examples are critical to the world

Nuclear power: policy questions

- 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 £ and per year?
- Why divert further public resources from market winners to the already very subsidised market loser?
  - 2004 global vendor revenues were ~$30b for renewable el. eqt., probably more for CHP & efficiency, *far* smaller for nuclear
  - How can new nuclear build's clear need for public subsidies thread between market liberalisation principles and EU anti-subsidy rules?
- If you think 'we need everything' (no choices):
  - What is 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)

Nuclear power: more policy questions

- What exactly is 'keeping the nuclear option open'?
  - 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 $447b of 2003 revenues, won't commit from their own funds?
    - Koplow estimates pre-2005 subsidies at 0.8–4.2¢/kWh (levelised 2004 $), plus new 2005 subsidies of 3.4–4¢/kWh for next 6 GW
  - Heroic life-support measures to try to divert more private investment where it wouldn't otherwise go—and away from competitors?
  - What is the opportunity cost—what other options are thus foregone?
- 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 desubsidise the entire energy sector—themselves *and* their rivals?

Nothing can save nuclear power from its dismal fundamental economics

- Not regulatory change—the USA has tried that for 25 years (so did France)
- Not new reactor types: even if the reactor were *free*, the balance-of-plant would still cost too much
- Not a carbon tax: it equally (or largely) advantages nuclear's main competitors
- Not hydrogen: nuclear is a hopelessly uneconomic way to make it, electrolytically or thermolytically
- Not the 2005 >$13b increase in already-large US subsidies: S&P concluded those new subsidies wouldn't materially raise builders' credit ratings
- Markets ultimately prevail
- Historically, policy favouritism hurts nuclear power

"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 true 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
- The market agrees: private capital is financing huge growth in micropower, but zero nuclear projects: those are bought only by central planners
- 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

Documentation is at www.rmi.org/sitepages/pid171.php#E05-14, summarised at www.rmi.org/sitepages/pid171.php#E05-15 — "Mighty Mice," *Nucl. Eng. Intl., pp. 44–48 (Dec. 2005)*

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