Singapore, 23 May 2008

Next-Generation Electricity:
The Emerging Negawatt and Micropower Revolutions

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US energy/GDP already cut 48%, to very nearly the 1976 "soft path"

FOREIGN AFFAIRS



but that just scratches the surface, especially for electricity

Of all energy options, end-use efficiency is by far the …

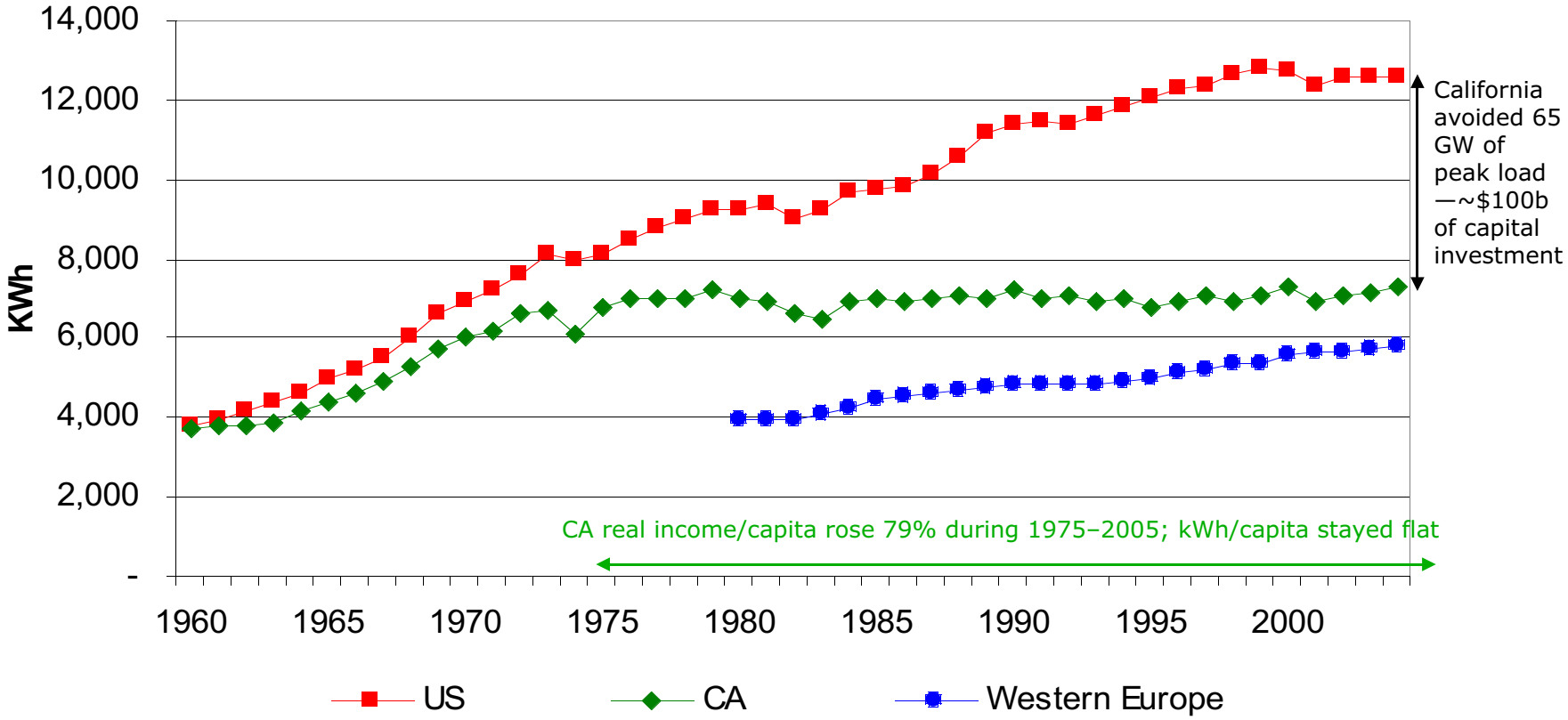
- Biggest
- Cheapest
- Fastest
- Most benign
- Least visible
- Least understood
- Least well measured (in most places)
- Most neglected in policy
- Most underinvested-in
- Most overlooked when assessing the competitive landscape on the supply side

What has reduced energy intensity already done? What more can it do?

- During 1975–2006, the US made a dollar of real GDP with 48% less total energy, 54% less oil, 64% less direct natural gas, 17% less electricity
  - Despite stagnant light-vehicle efficiency for >20 years, and perverse incentives rewarding electricity sales in 48 states
  - Nobody noticed: they haven't paid attention since the mid-1980s
- Full use of today's best end-use efficiency techniques would deliver the same or better services but save half the oil and gas, and ≥75% of the electricity
- Investing to achieve those savings over several decades would cost 8× less than buying the energy, and would make energy prices lower and less volatile
- Supply-side investors tacitly bet little eff. will happen —and lately wrote off US$100b for unneeded CCGTs
- No competitive economy can long ignore efficient use

Policy matters: electric efficiency is far faster in California and New England than in the rest of the United States

Annual electricity use per capita



Source: California Energy Commission

CA savings came* roughly half from appliance and building efficiency standards, half from rewarding utilities for cutting customers' bills—not for selling more energy

*Total may be subject to big adjustments, says Jim Sweeney, for changes in household size and composition of output

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

Both got spoilt by a sign error ("+" *vs.* "–")

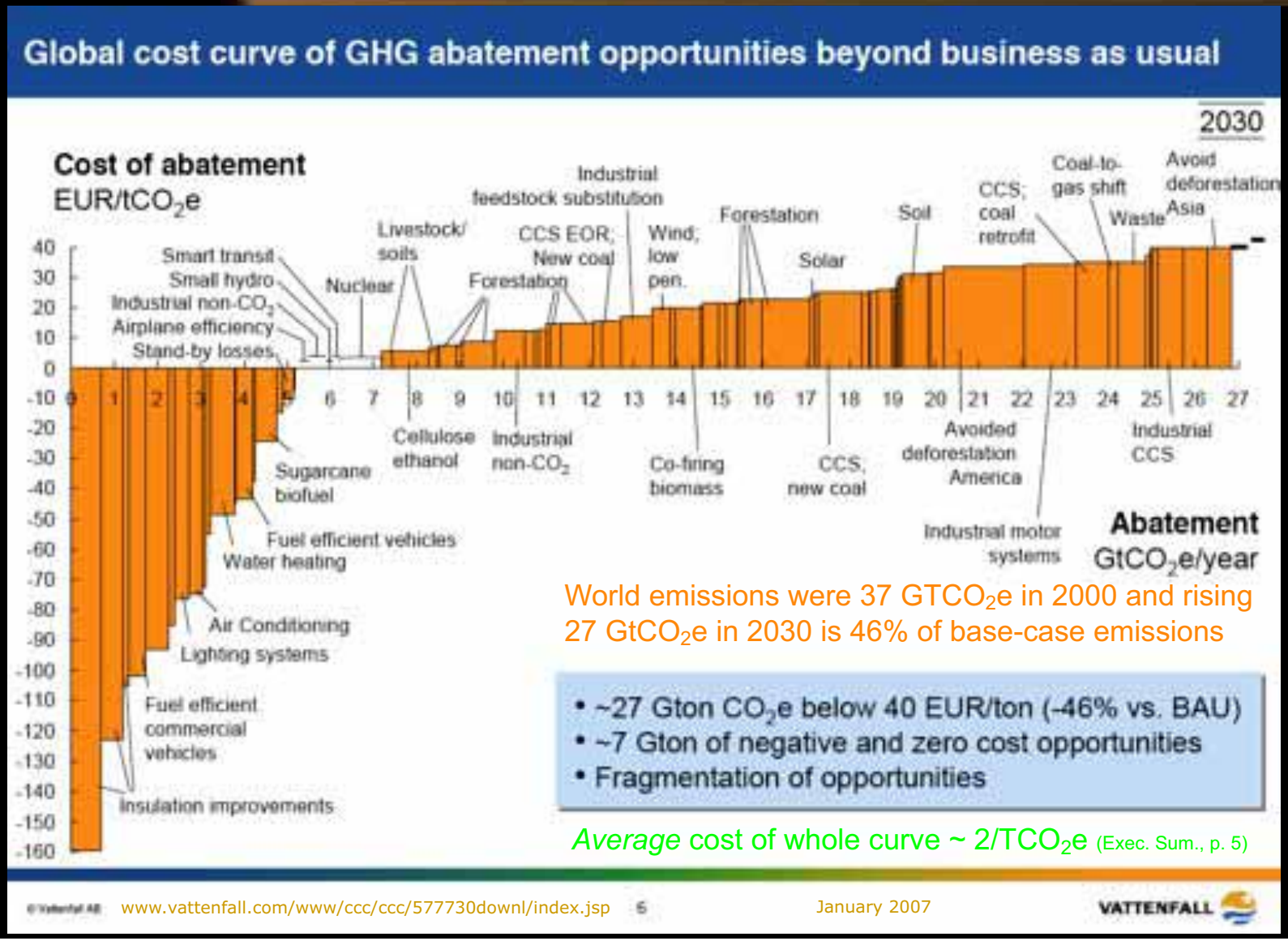
The incorrect but almost universal *assumption* that climate protection will be costly is the biggest obstacle to climate protection…and reduces wealth

Saving energy is cheaper than buying it, so climate protection is profitable even if you don't think it's necessary

- IBM and STMicroelectronics
  - CO_2 emissions –6%/y, fast paybacks
- DuPont's 2000–2010 worldwide goals
  - Energy use/$ –6%/y, add renewables, cut absolute greenhouse gas emissions by 65% below 1990 level
  - By 2006: actually cut GHG 80% below 1990, $3b profit
- Dow: cut E/lb 22% 1994–2005, $3.3b profit
- BP's 2010 CO_2 goal met 8 y early, $2b profit
- GE pledged 2005 to boost its eff. 30% by 2012
- Interface: 1994–2006 GHG –60% (–9.2%/y)
- TI new chip fab: –20% en., –35% water, –30% capex
- McKinsey found 46% of projected global GHG emissions in 2030 can be abated at av. cost ~ 2/TCO_2e

2007 Vattenfall/McKinsey supply curve for abating global greenhouse gases

(technologically *very* conservative, esp. for transport)



Profitable climate protection

- Global CO_2 emissions will triple by 2100 if we reduce E/GDP by 1%/y; level off if 2%/y; and drop—stabilizing the Earth's climate—if ~3%/y. Is that feasible?
- The U.S. spontaneously saved >2%/y since 1997; 3.4%/y 1981–86; 3.2%/y in '01 & '05; *4.0%* in '06
- California was ~1 percentage point faster; its new homes use 75% less energy; savings accelerating
- China did even better—saved >5%/y for >20 y, 7.9%/y 1997–2001; energy efficiency is top priority
- Attentive corporations routinely save ~6–9%/y
- Even Japan, with 2–3× lower energy intensity than U.S., can profitably save 2/3 of *its* energy
- Oil causes 42% of all CO_2 emissions, electricity 40%

Business-based oil *solution*

Independent, detailed, peer-reviewed, transparent

Cosponsored by USDoD

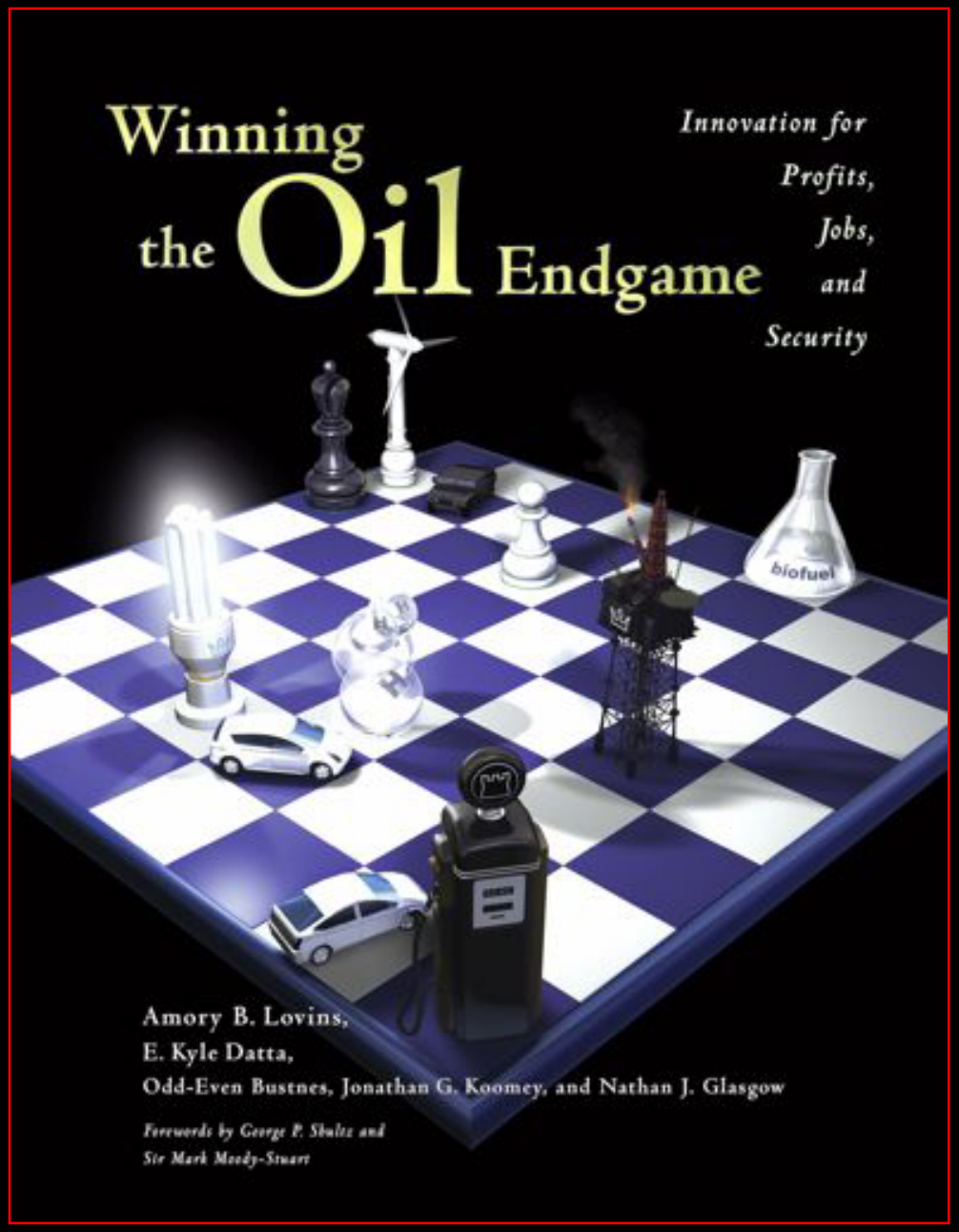
For business & mil. leaders, built on business cases

Book and technical backup are free at:

www.oilendgame.com

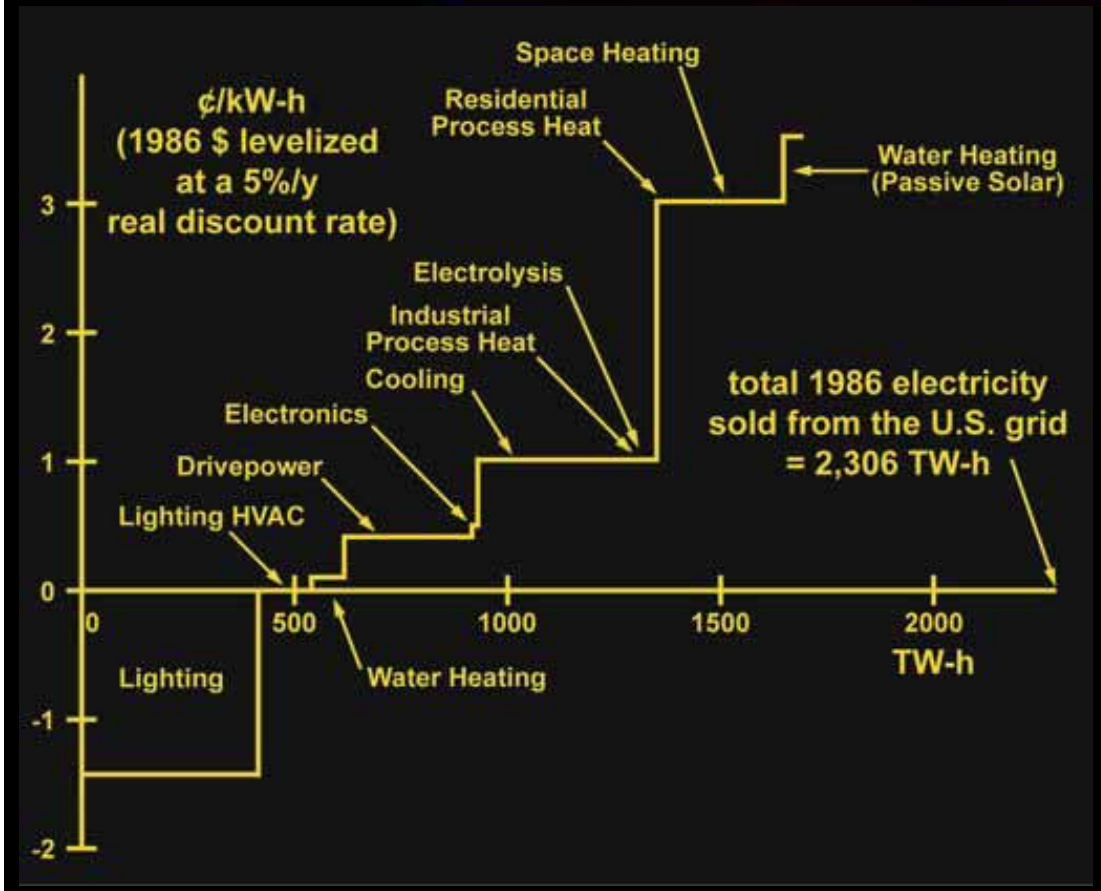
Over the next few decades, the US can* eliminate *its use of oil and revitalize its economy, led by business for profit

(Singapore probably can too)



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3/4 of US electricity can be saved, at an average cost ~1/8 of its price



Best retrofittable 1989 technologies, but *no whole-system design*

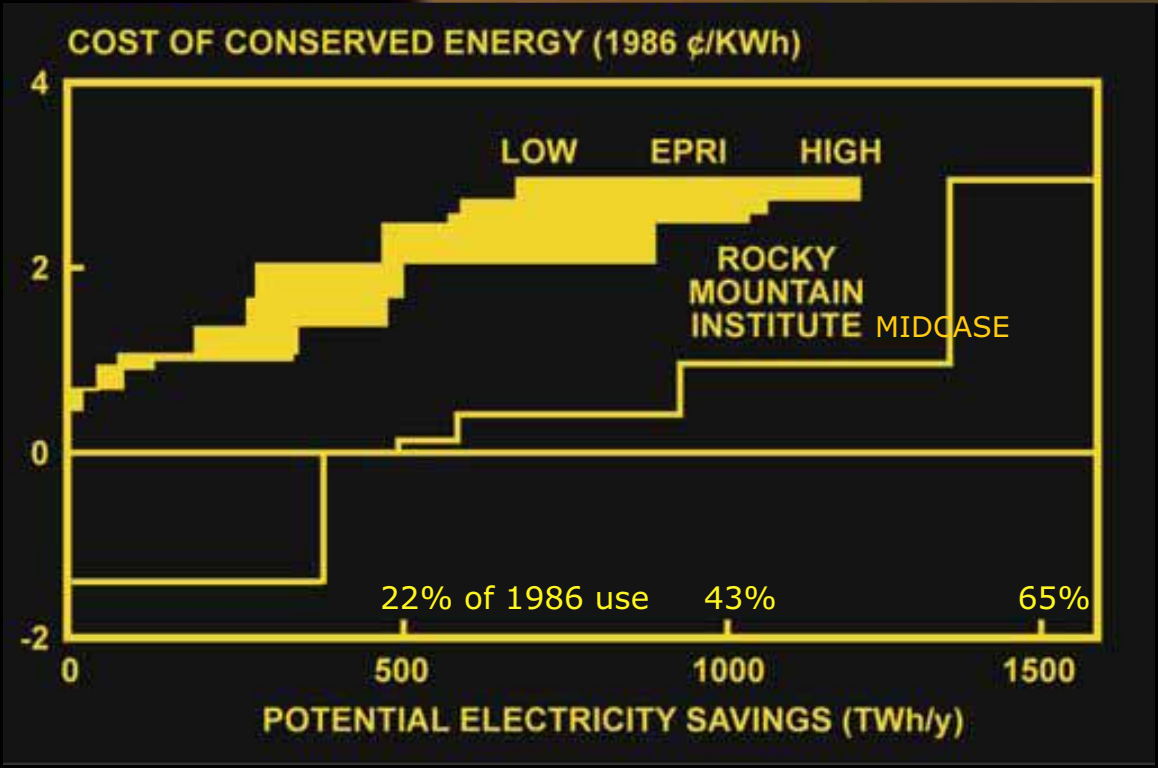
Similar S, DK, D, UK…

EPRI found 40–60% saving potential

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

Measured technical cost and performance data for ~1,000 technologies (RMI 1986–92, 6 vol, 2,509 pp, 5,135 notes)

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 spontaneously

◇ 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)

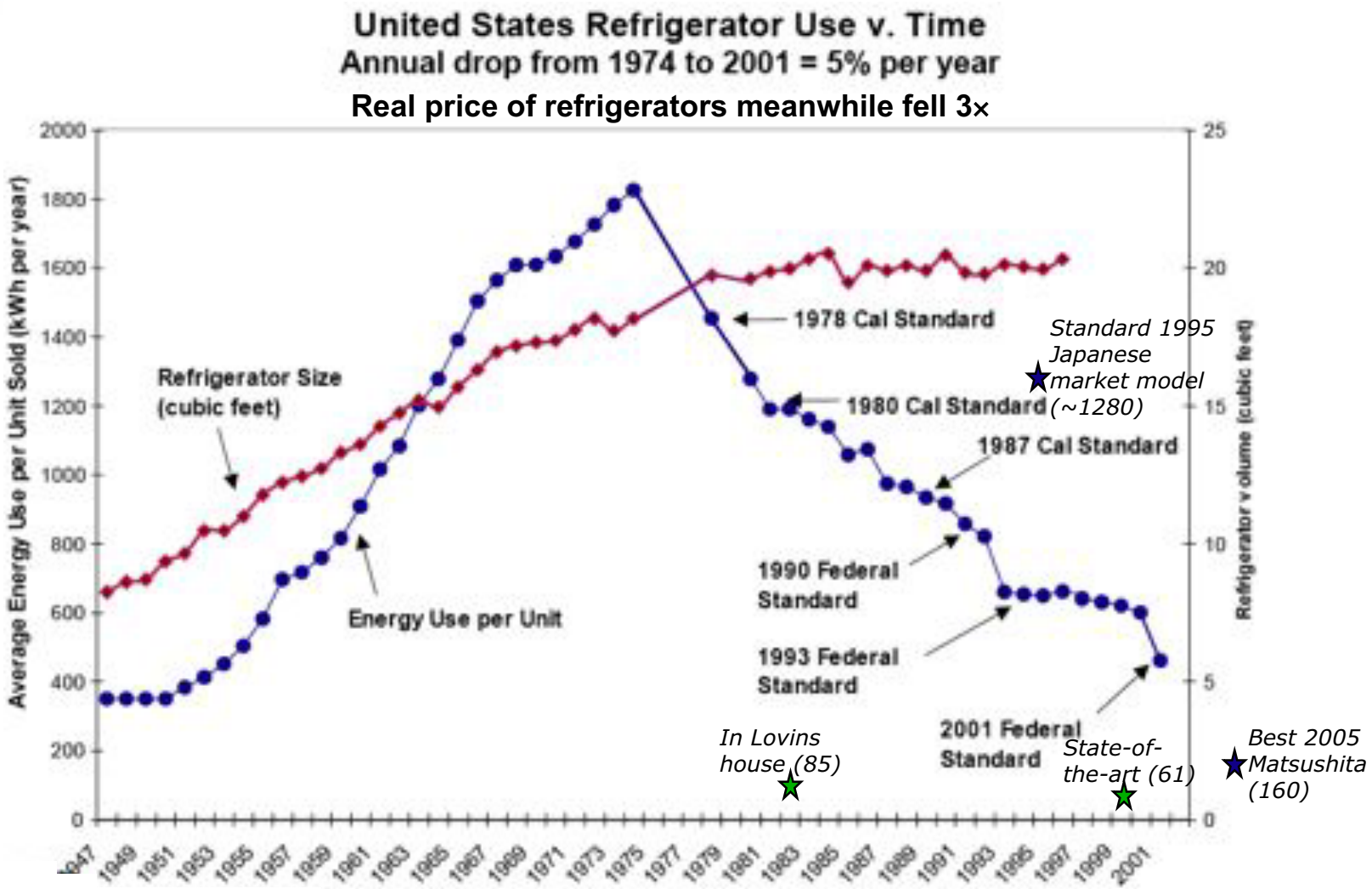
The efficiency resource is getting bigger and cheaper faster than we use it

- 1984–89: negawatt potential ×2, real cost ÷3 (RMI)
- Since 1990, add mass production (often offshore), cheaper electronics, competition, better technology

  Thanks to James K. Rogers PE for most of these examples, which I've converted to constant dollars

  - Compact fluorescent lamps: 85–94% cheaper 1983–2003 (>1b/y)
  - Electronic T8 ballasts: >90% cheaper 1990–2003 (& lm/W up 30%)
  - Direct/indirect luminaires: gone from premium to cheapest option
  - Industrial variable-speed drives: ~83–97% cheaper since 1990
  - Window a/c: 69% cheaper than 1993, 13% more efficient, digital
  - Low-E window coatings: ~84% 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!

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

–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







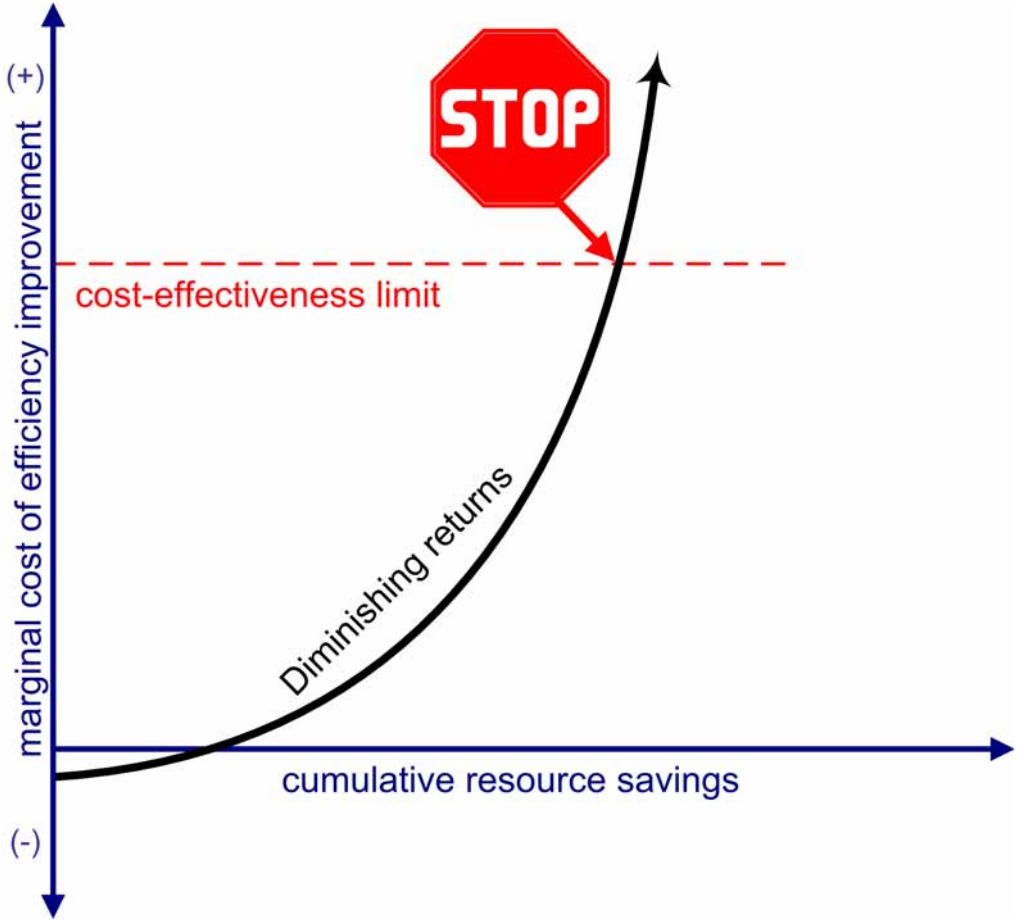
Key: integrative design—multiple benefits from single expenditures

- 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 ~US$5/month @ US$0.07/kWh)
  - 10-month payback in 1983
- PG&E ACT^2, Davis CA, '94
  - Mature-market cost –$1,800
  - Present-valued maint. –$1,600
  - 82% design saving from best 1992 std., ~90% from US norm
- Prof. Soontorn Boonyatikarn house, Bangkok, Thailand, '96
  - 84% less a/c capacity, ~90% less a/c energy, better comfort
  - No extra construction cost

Rocky Mountain bananas with no furnace?



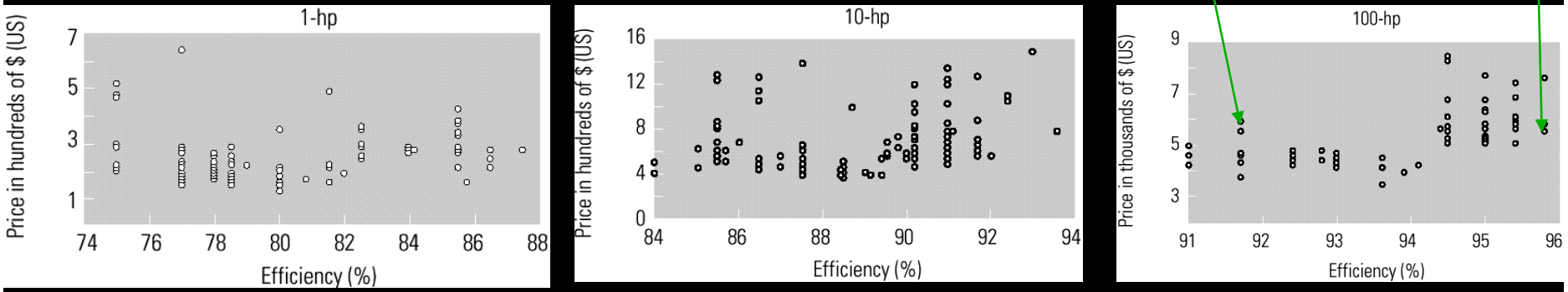
Old design mentality: always diminishing returns…



High efficiency doesn't always raise even *components'* capital cost

- Motor Master database shows no correlation between efficiency and trade price for North American motors (1,800-rpm TEFC Design B) up to at least 220 kW

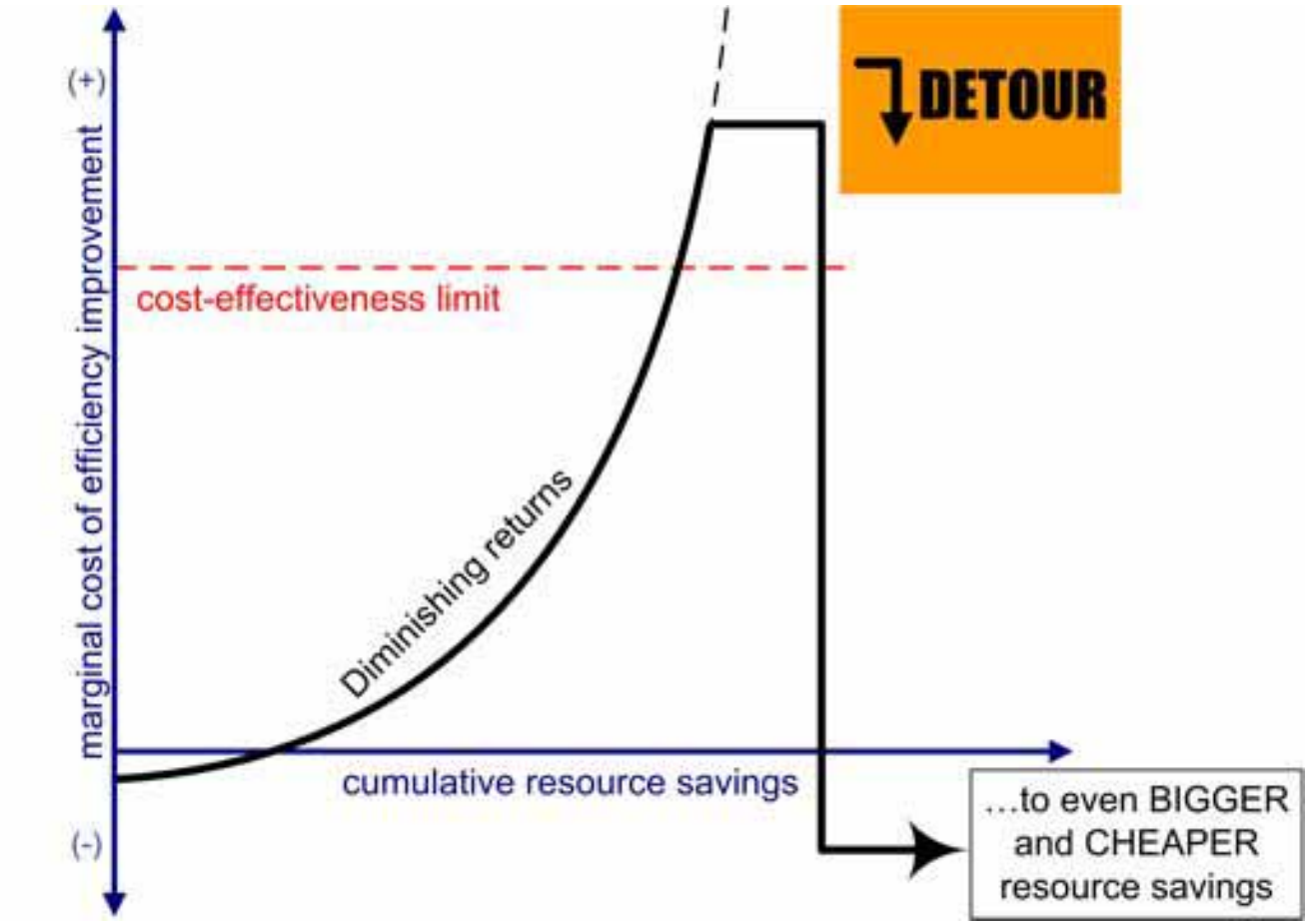
Buying this motor instead of this motor can cost you >US$20,000 present value



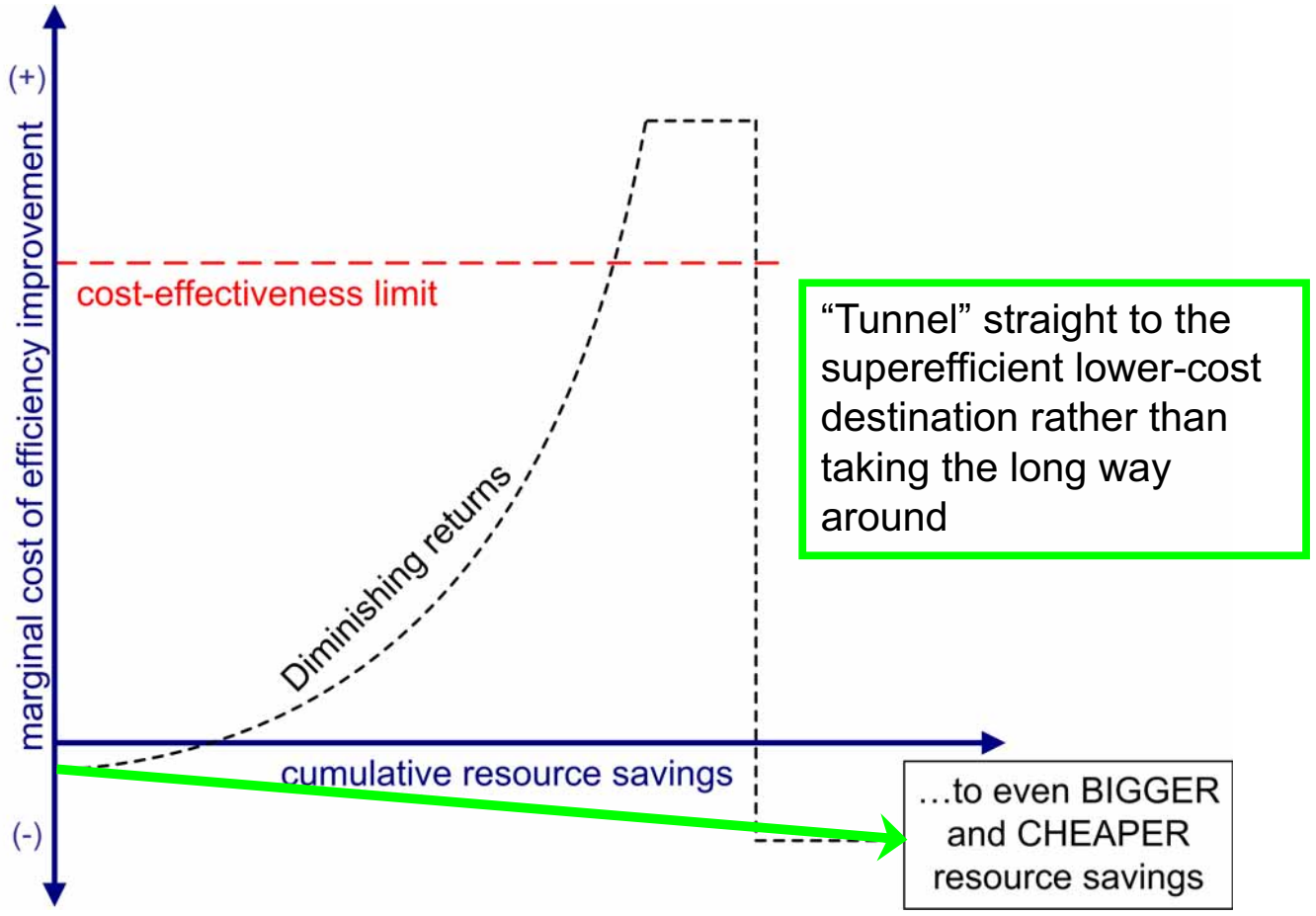
E SOURCE (www.esource.com)* Drivepower Technology Atlas*, 1999, p. 143, by permission

- Same for industrial pumps, most rooftop chillers, refrigerators, televisions,…
- "In God we trust"; all others bring data

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



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



Tunneling through the cost barrier through integrative design: Grand Forks (ND) office

Incremental costs

Windows	$67,500
Daylighting	$18,000
Insulation	$17,200
Lighting	$21,000
HVAC	-$160,000
Total	-$36,300

Energy savings: $75,000/year



Cost can be negative even for retrofits of big buildings



- 19,000-m^2, 20-year-old curtainwall office near Chicago (hot & humid summer, very cold winter)
- Dark-glass window units' edge-seals were failing
- Replace not with similar but with superwindows
  - Let in nearly 6× more light, 0.9× as much unwanted heat, reduce heat loss and noise by 3–4×, cost \$8.4/m^2_{glass} more
- Add deep daylighting, plus very efficient lights (3 W/m^2) and office eqt (2 W/m^2); peak cooling –76%
- Replace big old cooling system with a new one 4× smaller, 3.8× more efficient, \$0.2 million cheaper
- That capital saving pays for all the extra costs
- 75% energy saving—*cheaper* than usual renovation

The right steps in the right order: space cooling

0. Cool the people, not the building
1. Expand comfort envelope
2. Minimize unwanted heat gains
3. Passive cooling
   - Ventilative, radiative, ground- / H_2O-coupling
4. Active nonrefrigerative cooling
   - Evap, desiccant, absorption, hybrids: COP >100
   - Direct/indirect evap + VFD recip in CA: COP 25
5. ~~Supereff't refrigerative cooling: COP 8.6 (Singapore)~~
6. Coolth storage and controls
7. Cumulative energy saving: ~90–100%, better comfort, lower capital cost, better uptime

A worthy long-term goal: eliminate refrigerative air conditioning, including big commercial; easy in most of U.S., practical and worthwhile everywhere

Whole-system design



Most people think efficient systems are about energy-efficient equipment and expensive gadgets

This is like saying that using the best ingredients will ensure a tasty dish

Efficient systems are actually the result of *whole-system design*



Even the finest and rarest ingredients won't make our dish tasty unless:

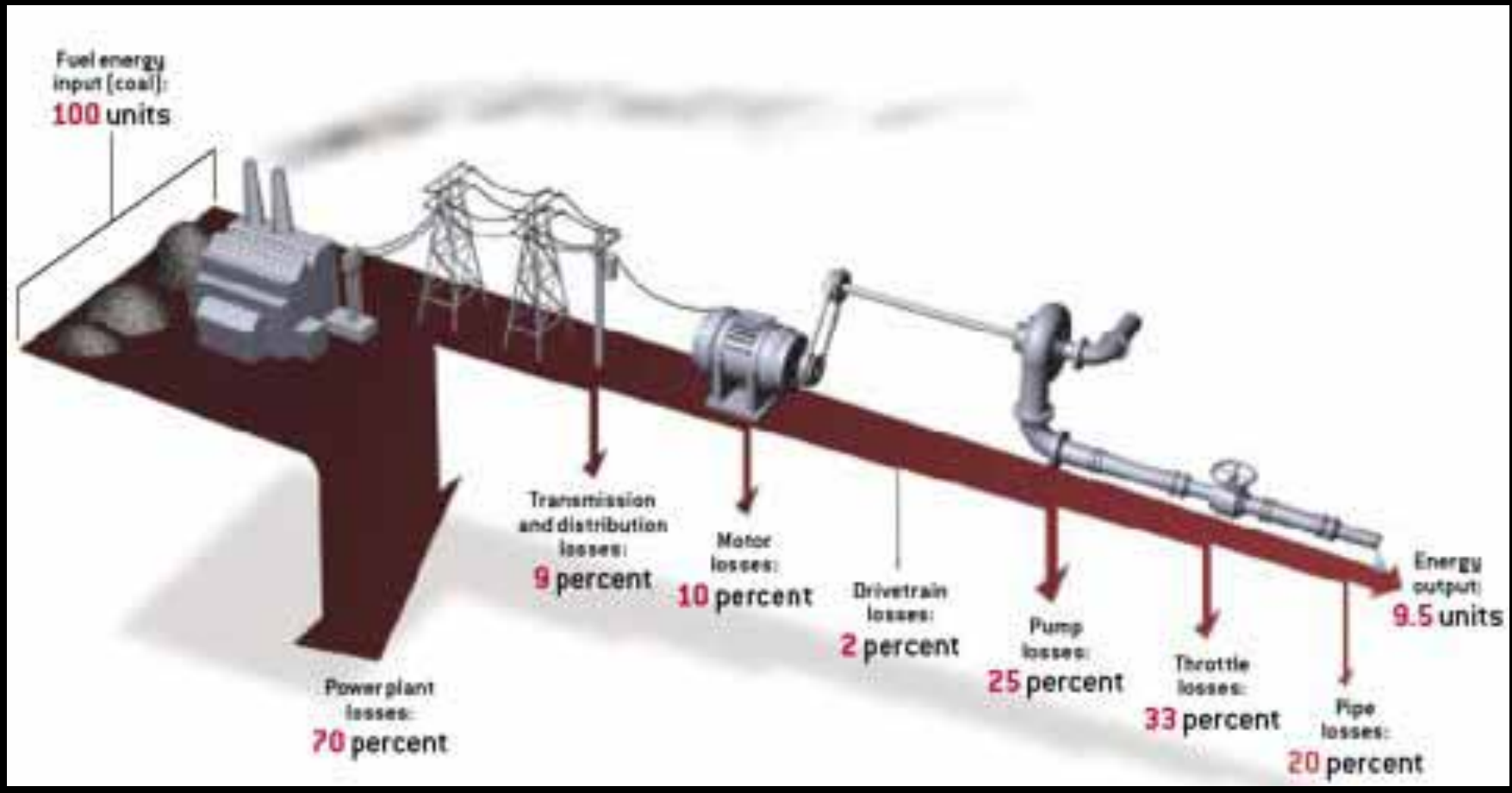
- we use a good recipe,
- combining the right ingredients,
- in the right sequence, manner, and proportions

New design mentality



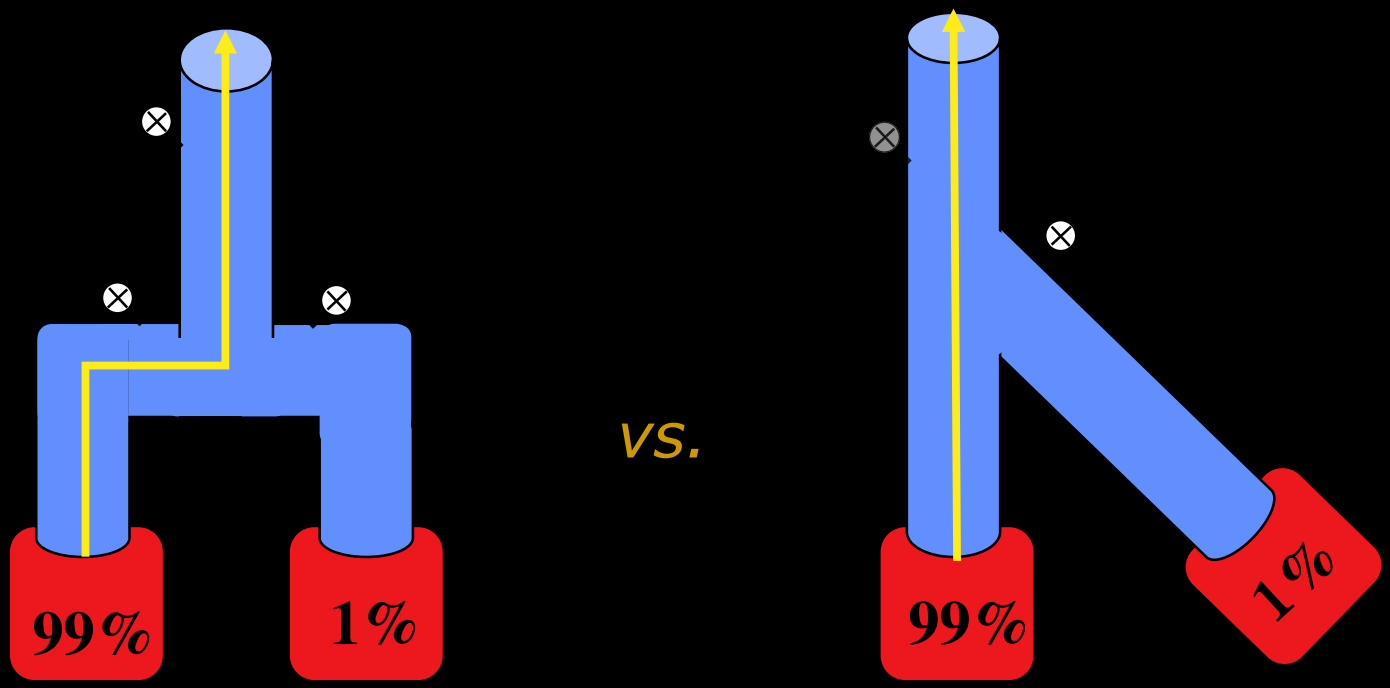
- Pumps and fans use half of motor energy; motors use 3/5 world electricity
- Redesigning a standard (supposedly optimized) industrial pumping loop cut its power from 70.8 to 5.3 kW (–92%), cost less to build, and worked better
- Just by specifying fat, short, straight pipes—not (as usual) thin, long, crooked pipes!
- Even better design could have saved ~98% and cost even *less* to build
- This example is archetypical

Compounding losses…or savings…so start saving at the *downstream* end to save ten times as much energy at the power plant



Also makes upstream equipment smaller, simpler, cheaper

Bends cause friction



Boolean pipe layout

hydraulic pipe layout

High-efficiency pumping / piping retrofit

(Rumsey Engineers, Oakland Museum)



Notice smooth piping design – 45°s and Ys

downsized CW pumps, ~75% pumping energy saving

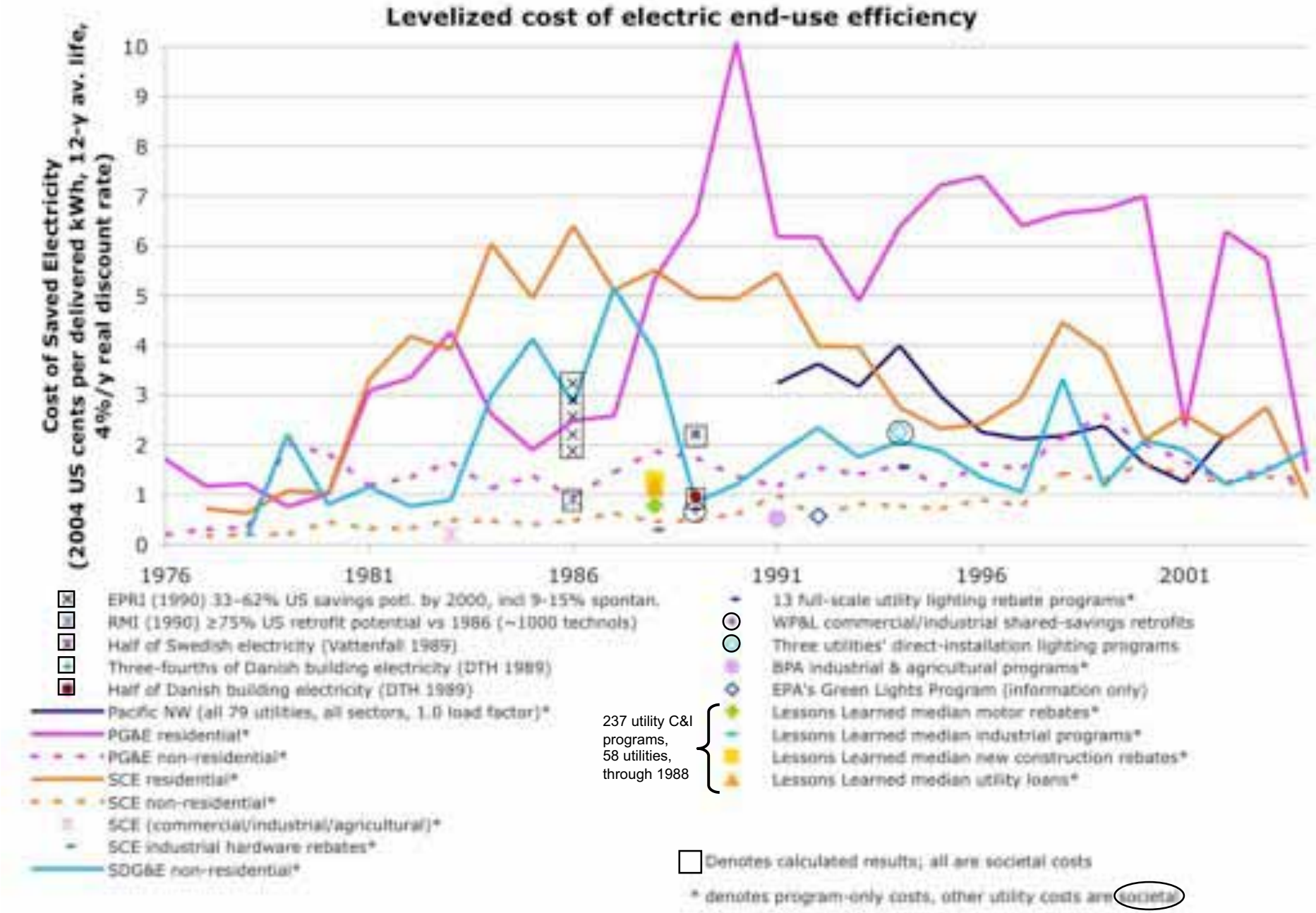
Examples from RMI's industrial practice (>$30b of facilities)

- Retrofit eight chip fabs, save 30–50+% of HVAC energy, ~2-y paybacks
- Retrofit very efficient oil refinery, save 42%, ~3-y payback
- Retrofit North Sea oil platform, save 50% el., get the rest from waste
- Retrofit huge LNG plant, ≥40% energy savings; ~60% new, cost less
- Retrofit giant platinum mine, 43% energy savings, 2–3-y payback
- Redesign $5b gas-to-liquids plant, save >50% energy and 20% capex
- Redesign next new chip fab, eliminate chillers, save 2/3 el. & 1/2 capex
- Redesign new data center, save 89%, cut capex & time, improve uptime
- Redesign new mine, save 100% of fossil fuel (it's powered by gravity)
- Redesign supermarket, save 70–90%, better sales, ?lower capex
- Redesign new chemical plant, save ~3/4 of auxiliary el., –10% capex
- Redesign cellulosic ethanol plant, –50% steam, –60% el, –30% capex
- Retrofits save ~30–60% w/2–3-y payback; new ~40–90% w/less capex
- "Tunneling through the cost barrier" now observed in 29 sectors
- None of this would be possible if original designs had been good
- Needs engineering pedadogy/practice reforms; see www.10xE.org (RMI's plot for the nonviolent overthrow of bad engineering)

10xe FACTOR 10 ENGINEERING

Negawatts can be fast, even with old implementation methods

- In ~1975–85, most new U.S. end-use devices—cars, buildings, refrigerators, lighting systs., etc.—doubled in efficiency (~7%/y)
- In 1983–85, 10 million people served by Southern California Edison Company (then the #3 US investor-owned utility) were cutting its 10-years-ahead forecast peak load by $8^1/_2$% *per year*, at a tiny fraction of the cost of adding supply
- In 1990, New England Electric System got 90% of a small-business retrofit pilot program's market (1.5× target) in 2 months
- PG&E got 25% of its 1990 new-commercial-construction market in 3 months, raised its 1991 target, and got it all during 1–9 Jan.
- Even without helpful policy (in all but a few states), the U.S. has cut electric intensity >2%/y in 6 of the past 10 y (av. 1.7%/y)
- New delivery methods are even better—not just marketing negawatts but making markets *in* negawatts, thus maximizing competition in who saves and how—and marketing efficiency for its side-benefits, not only for cutting energy costs



In general, these utility programs don't dive nearly as deep as RMI's assessment of potential, and most utilities and states haven't yet done much on the demand side as some did in the 1980s

Negawatts' marketable side-benefits are often worth $10^{1-2}\times$ more than lower bills

- Efficient buildings raise labor productivity ~6–16%
  - A typical 2005 office paid ~164× as much for people as for energy
- Efficient lighting systems improve visibility & beauty
  - 20–26% faster learning (per test scores) in well-daylit schools
  - 40% higher retail sales/ft^2-y in well-daylit stores
- Efficient motors are more reliable, quiet, controllable
- Efficient hospitals have faster healing, less pain, fewer infections, better financials
- Efficient refrigerators keep food fresher, longer
- Efficient supermarkets sell more and safer food
- Side-benefits more than double industrial efficiency's returns and savings

Schools in Curitiba, Paraná, Brazil



- Of the two classroom window units on the top right, the second has a light shelf inside and outside





Curitiba Retrofit Experiment

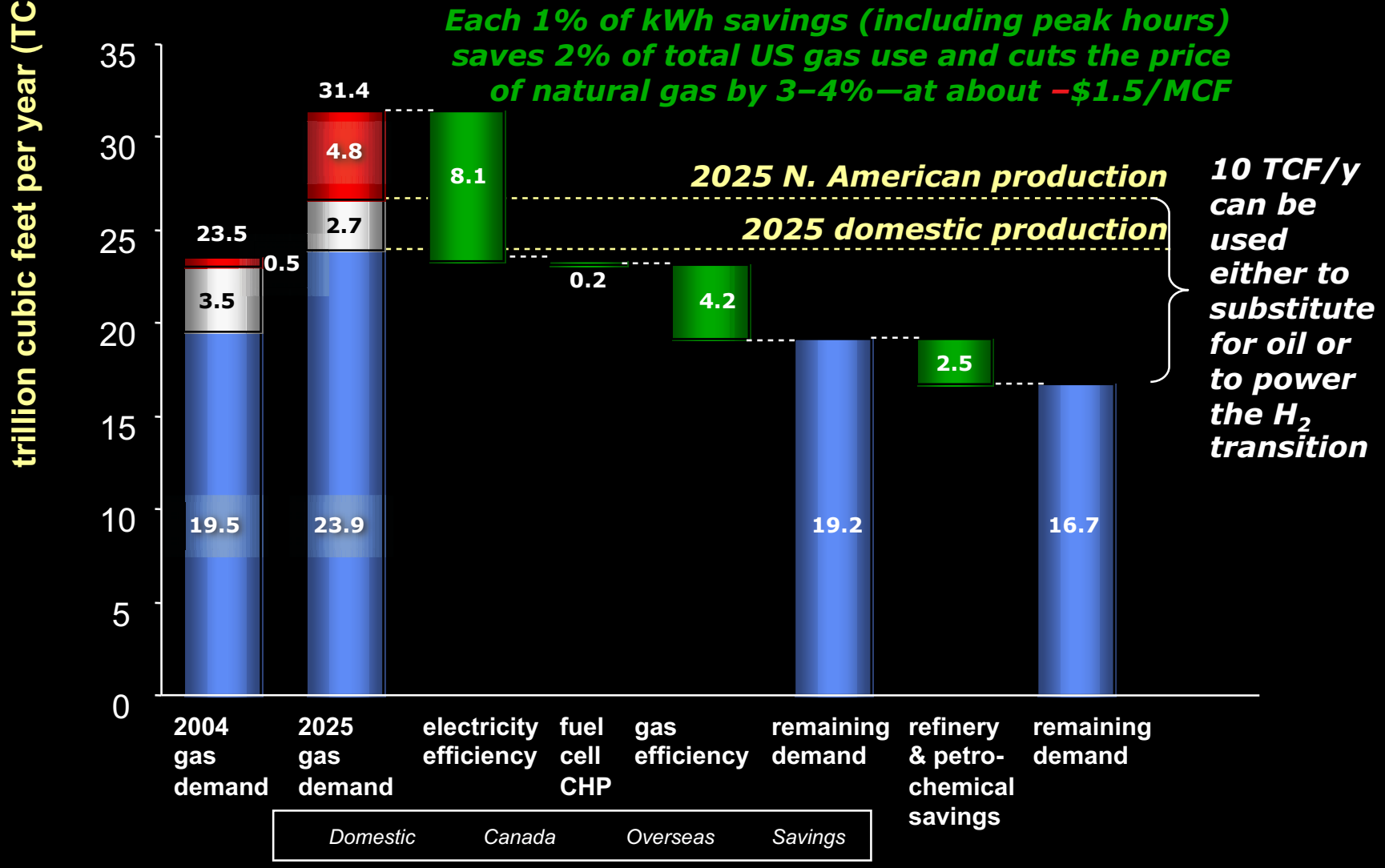
- Top classroom with no lightshelf has high luminance ratios, making the room feel dark compared to the bright window
- Bottom classroom under same condition but with lightshelf appears bright with moderate luminance ratios
- No electric lights are on in either photo
- The lower room saves 75% of electricity, so that class can afford to buy books
- Students also learn ~20–26% faster in well-daylit classrooms
- What's the multiplier from education to national development?



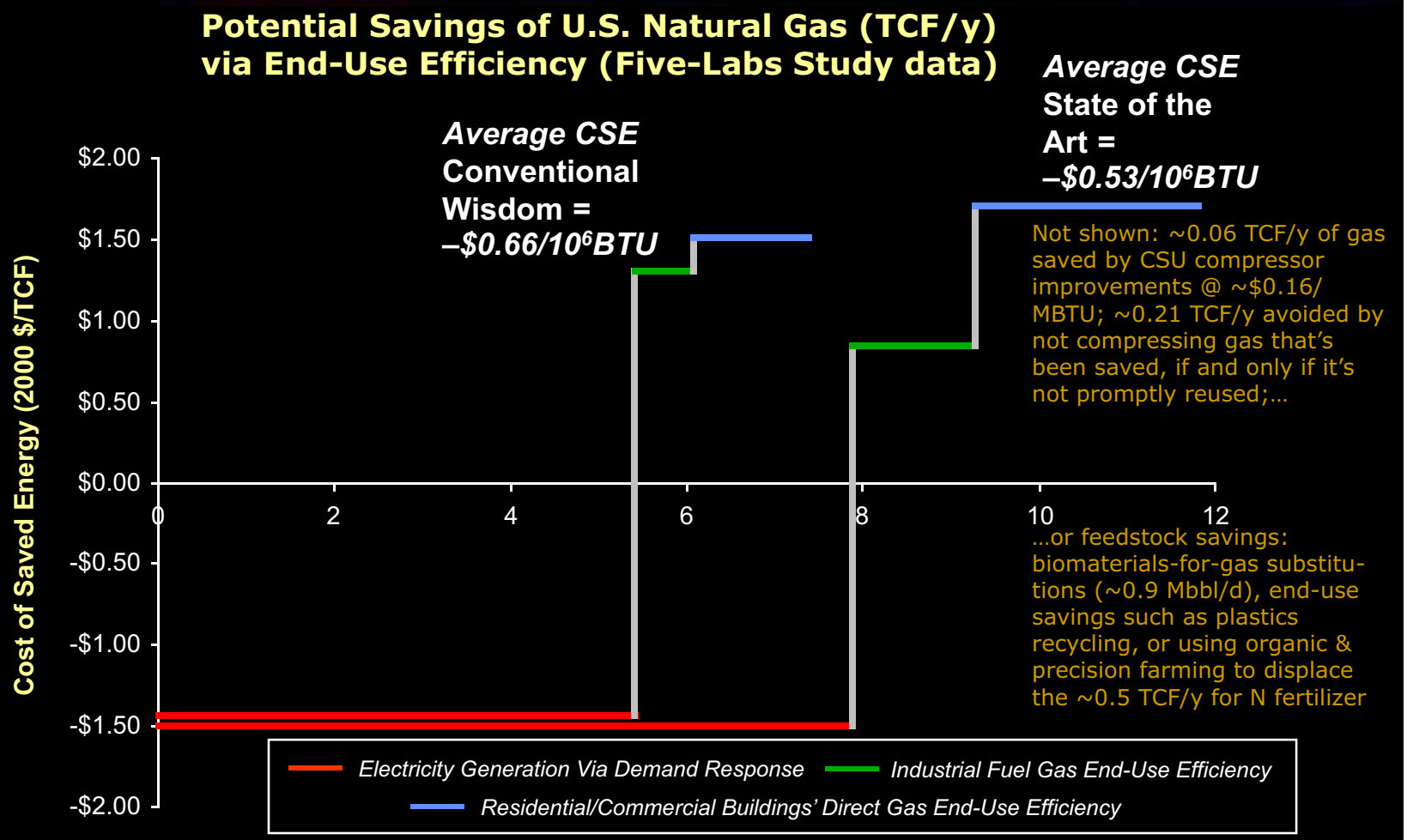


Courtesy of Greg Franta FAIA, RMI/ENSAR Built Environment, Boulder, Colorado

>12 TCF/y of US natural gas could be saved by efficiency, at an average cost ~$0.9/MCF (<1/10th recent price)



Saving U.S. natural gas



Five-Labs (CEF) Study's conservative costs of saving electricity, less avoided onpeak gen. cap. & deferred grid cap., saves electricity at –1.6¢/kWh. Converted at the appropriate heat rates, that can save 25% of total 2025 gas use at –$1.5/10⁶BTU.

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…hardly a small, slow, futuristic activity! In fact, it's taking over the global market…

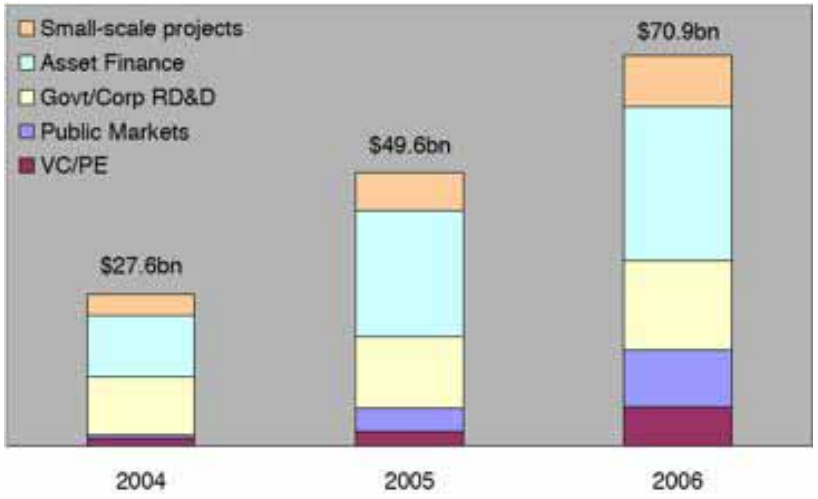
Distributed generation technologies

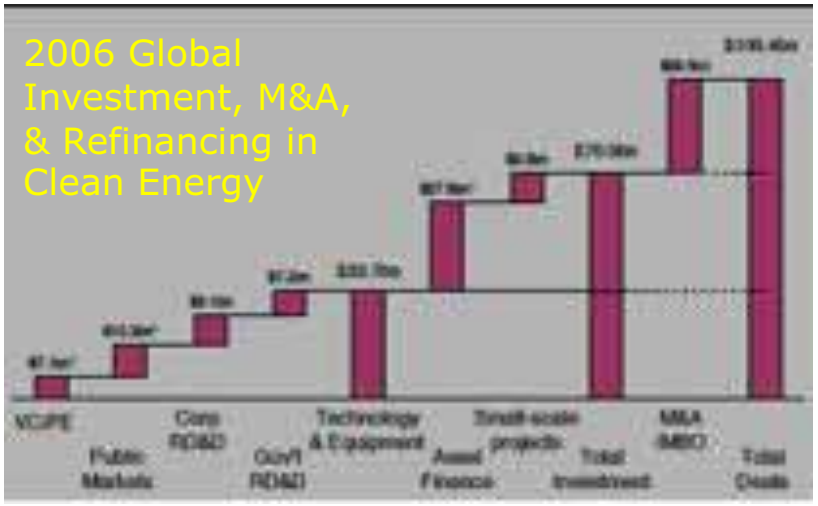
- Reciprocating engines (diesel, gas)
- Small turbines and microturbines
- Fuel cells (PAFC, PEMFC, MCFC, SOFC)
- Combined heat & power (biomass, biogas, landfill gas, fossil fuel,…)
- Thermal cooling (absorption, desiccant, hybrids)
- Solar thermal electric (concentrator, solar pond, byproduct of flat-plate,…)
- Solar photovoltaic (if coincident)
- Storage (batteries, flywheels, etc.)
- Can be sited at distribution substation or end of feeder line for grid support, or at customer load for (C)CHP





Global new investment in clean energy: US$71b in 2006, ~US$117b in 2007



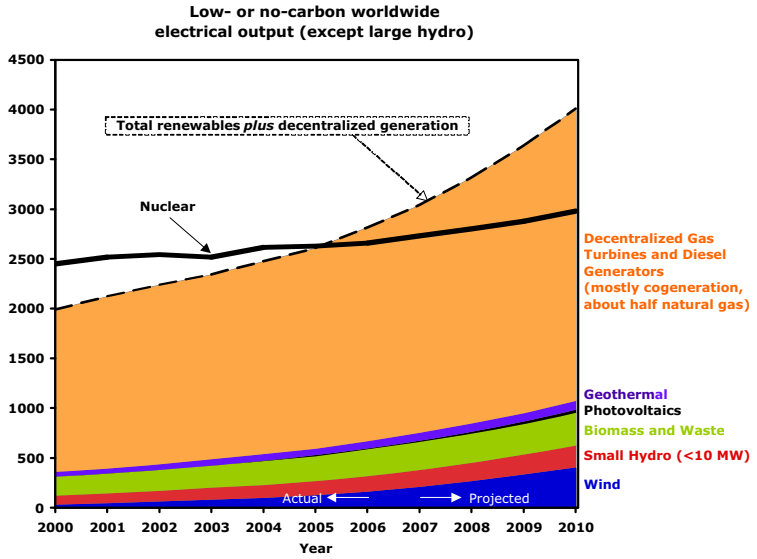


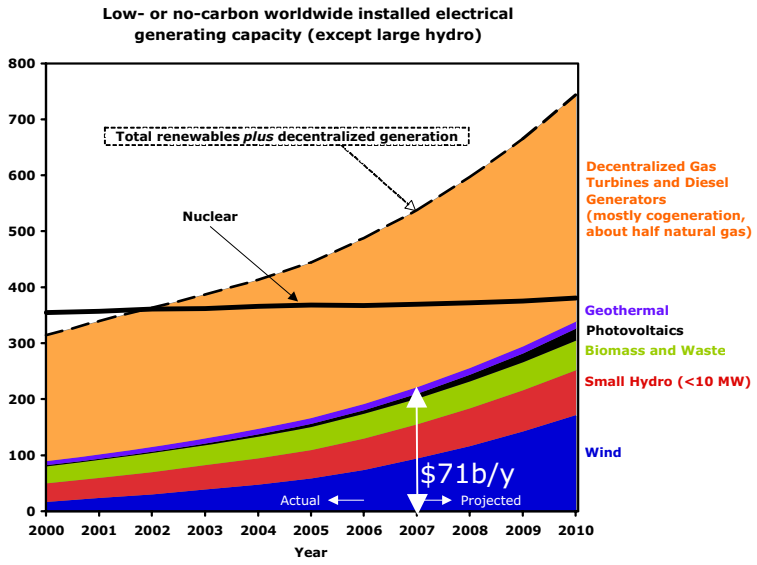
- Clean-energy investments grew 80% in 2005, 43% in 2006, ~65% in 2007
- 2006 new investments included $31b wind, $12b solar, $8b biomass & waste [to el.], $3b other [el.] renewables, $6b other renewables, $15b biofuels; total for distributed renewable power equipment ~$56b (*vs.* ~$38b in 2005)
- 12/2006 quoted companies' market cap: $154b wind, $95b solar, $74b biomass/biofuels (much non-el.), $61b other renewables, $53b demand-side efficiency
- WilderHill New Energy Global Innovation Index (NEX) grew 29.3%/y compound in 2002–05, 33.3% in 2006, but 2006 performance weak to negative in non-Kyoto-ratifying countries, strong in others; outperformed AMEX Oil; >80% better than NASDAQ or S&P 500

Bottom-up, transaction-by-transaction 3/07 data: Michael Liebreich, New Energy Finance, London

Electric shock: low-/no-carbon decentralized sources are eclipsing central stations

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





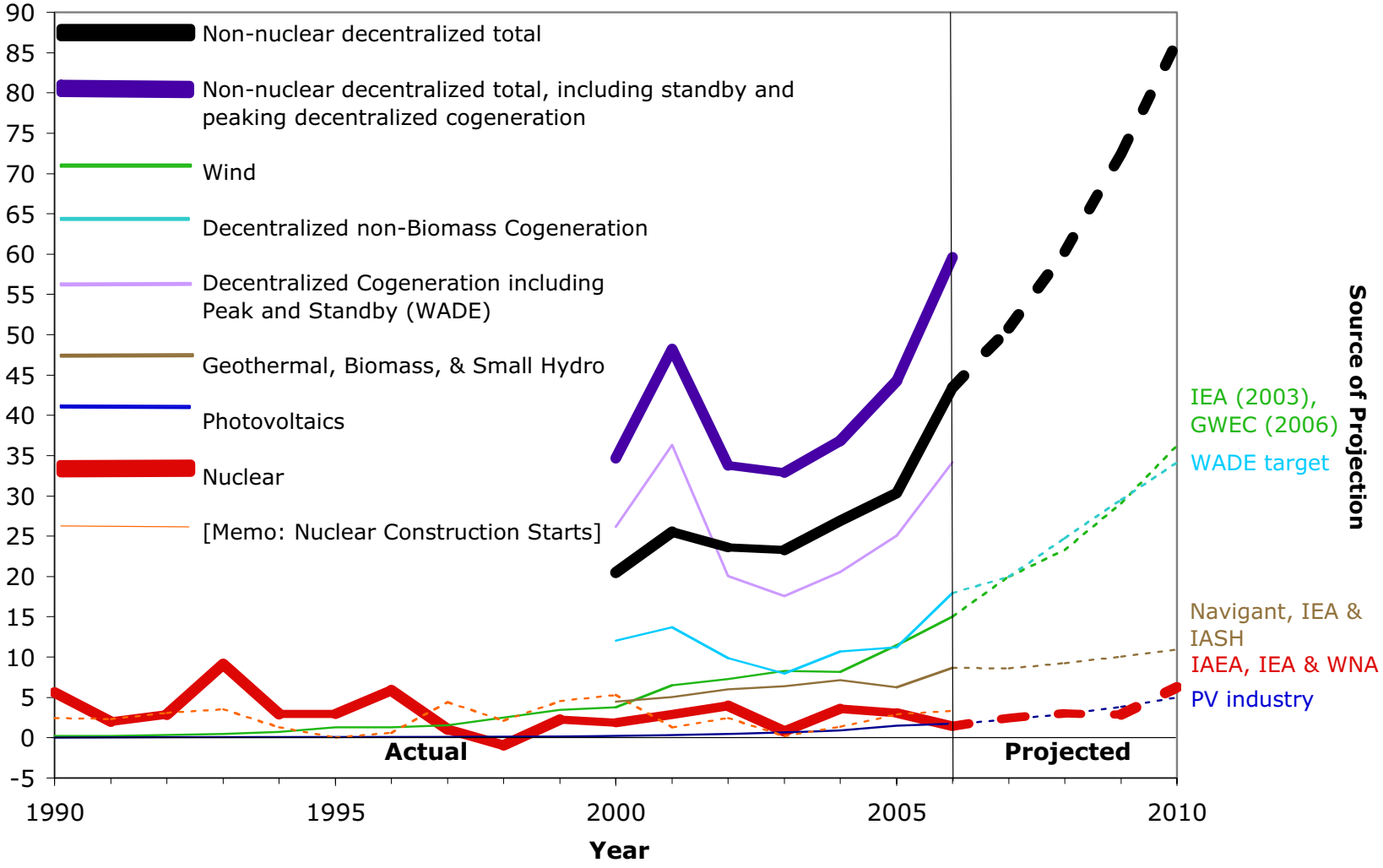
- Two-thirds combined-heat-and-power (cogeneration)*, ~50% gas-fired, ≥50% CO_2 reduction

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

- One-third renewable (excluding hydropower >10 MW_e)
- In 2006, micropower added 3× as much output and 30× (incl peaking & standby units, 41×) as much capacity as nuclear power added
- Micropower now makes *1/6 of all el, 1/3 of new el.*, 1/6 to >1/2 of all el. in a dozen industrial nations
- Negawatts comparable or bigger; central plants have <1/2 of market!
- Micropower is winning due to lower costs & financial risks, so it's financed mainly by private capital (only central planners buy nuclear)

Micropower is the world's top source of new electricity

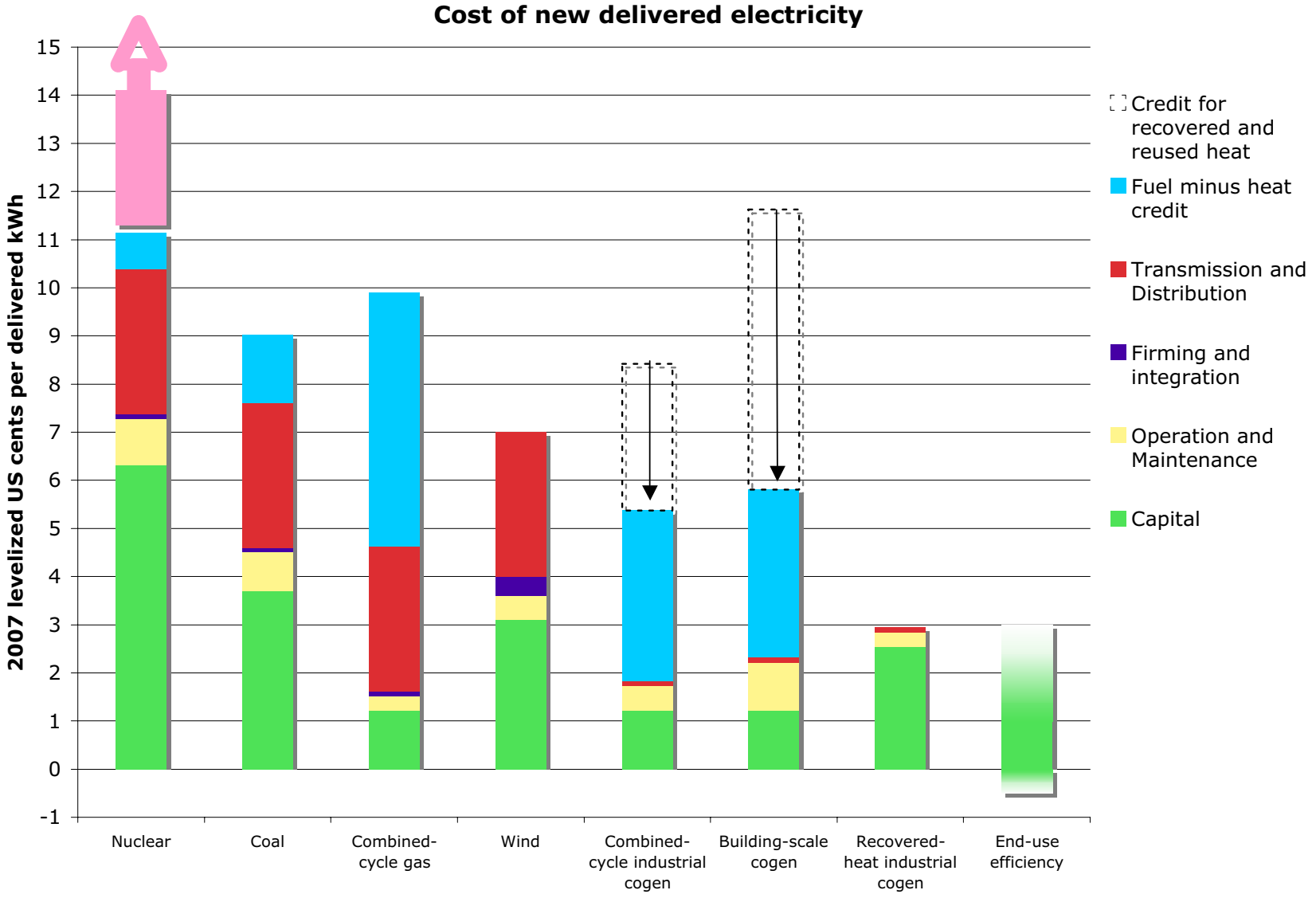
Global *Additions* of Electrical Generating Capacity by Year and Technology: 1990–2006 Actual and 2007–2010 Projected



Worldwide in 2006 …

- New nuclear capacity was smaller than solar PV additions, or 1/10th of windpower additions
- Nuclear retirements exceeded additions, but upratings boosted net nuclear capacity by 1.44 GW; micropower added 43–60 net GW
- Micropower surpassed nuclear power in total annual electricity production (16% of total)
- Distributed renewables got $56b of private risk capital; nuclear, as always, got zero
- China's distributed renewables reached 49 GW—7× nuclear capacity—and grew 7× more
- And in 2007, nuclear added less world capacity than China or Spain added windpower

Nuclear is the costliest of the low- or no-carbon resources

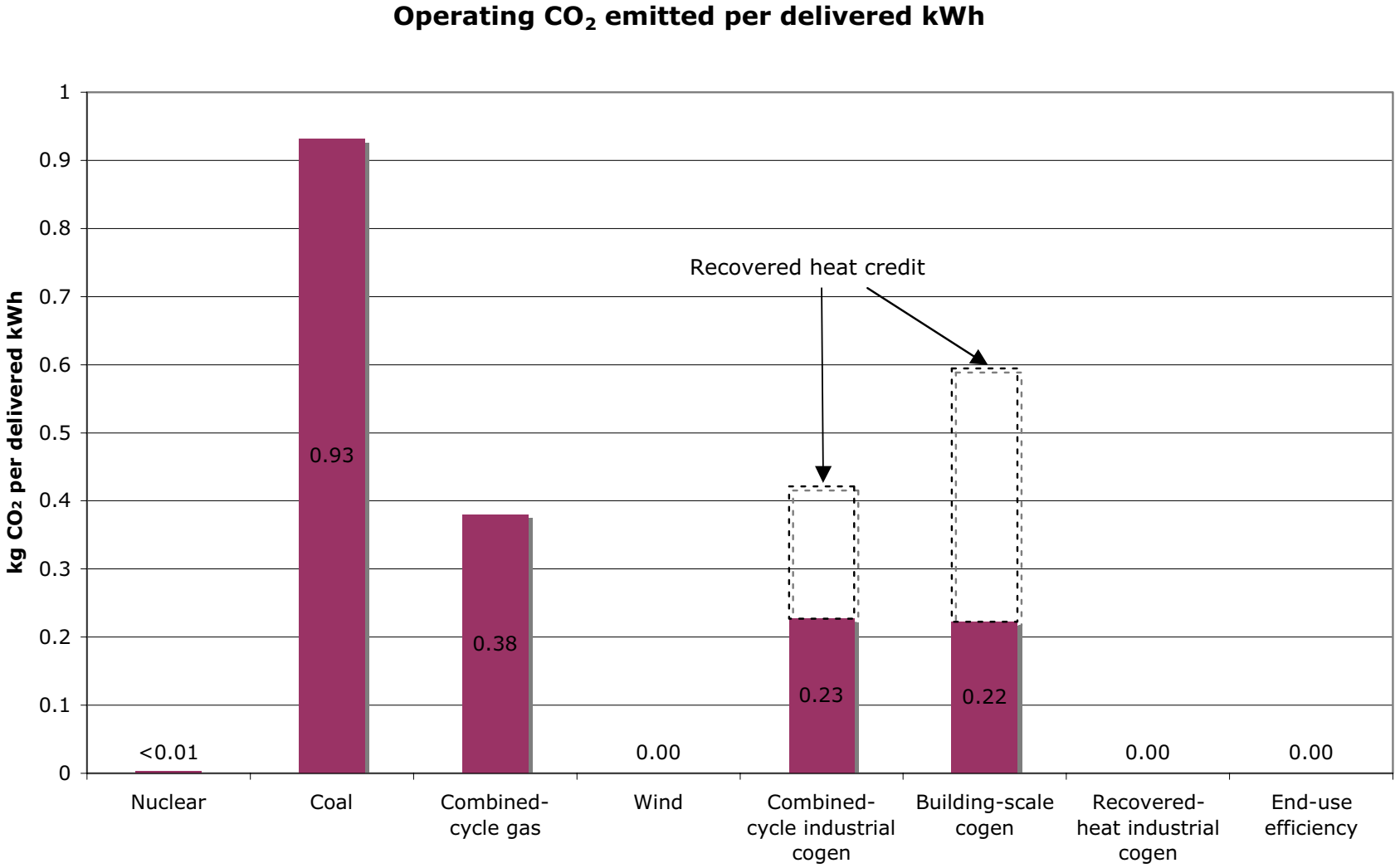


Cheaper options deliver more electrical services per dollar

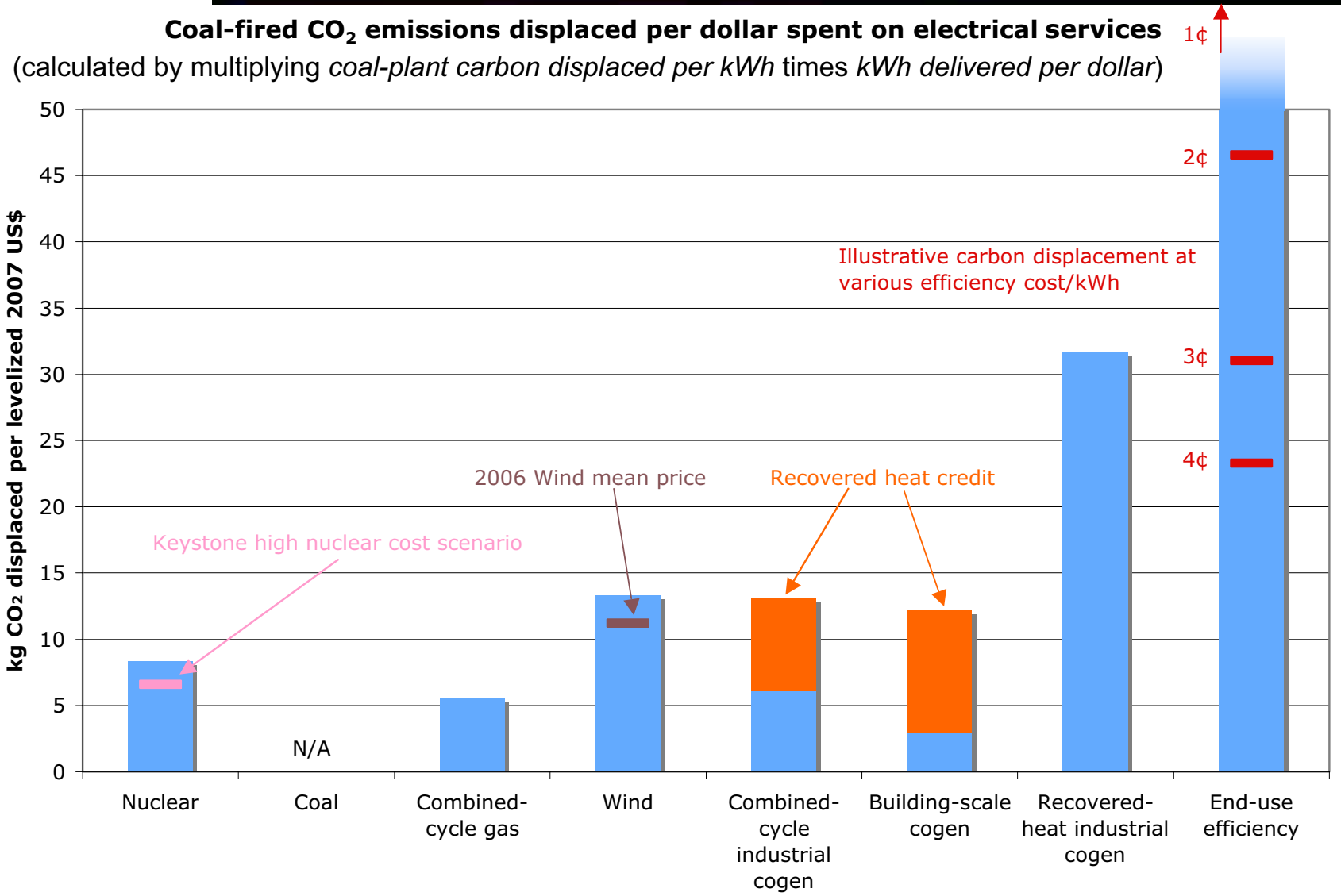
Representative kWh delivered per dollar spent to make or save electricity



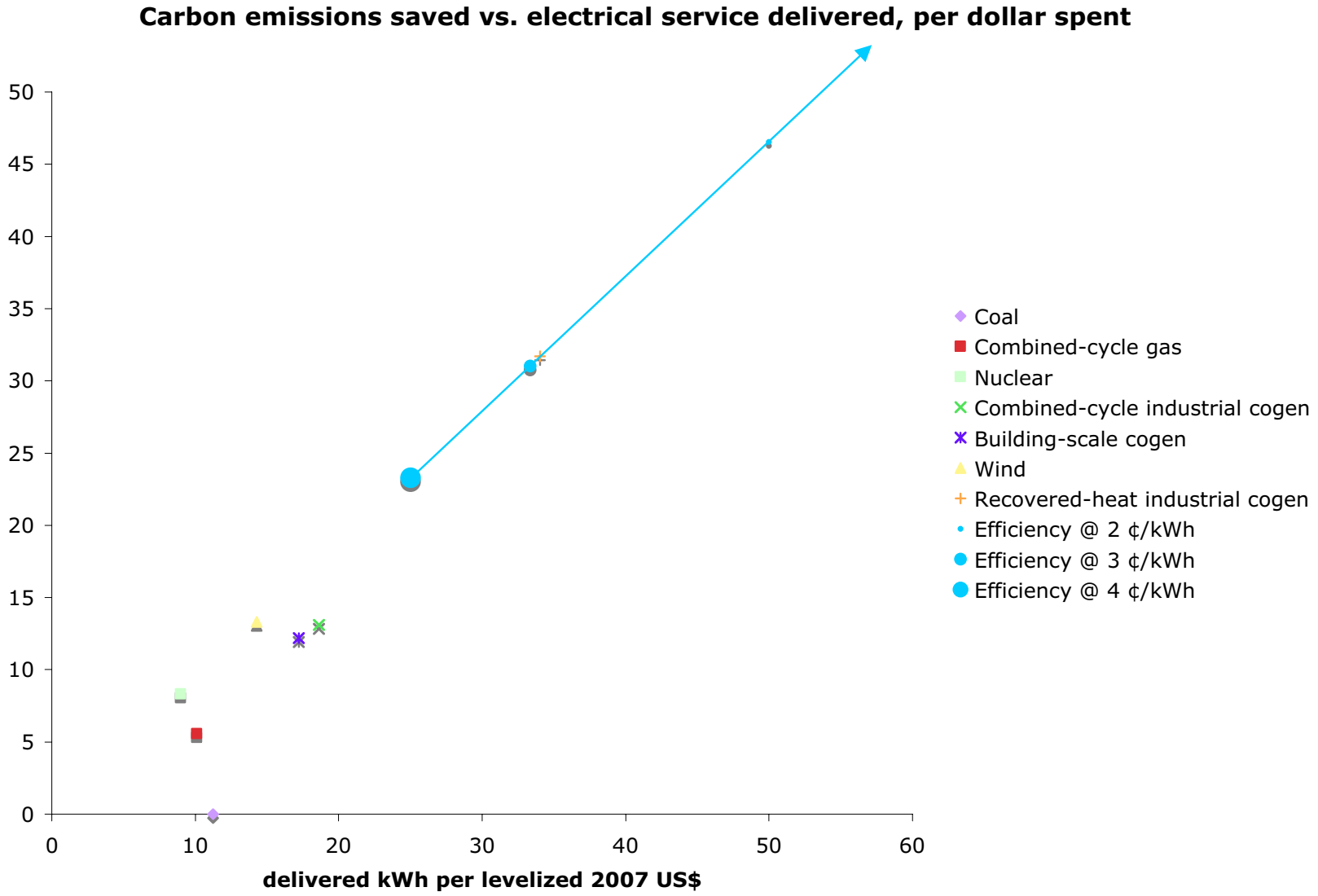
Various resources emit different amounts of carbon



Cheapest and lowest-carbon sources save the most C per $



Buying the most climate solution and energy service per $



Nuclear power's market collapse is *good* for climate and security

Lovins *et al.*, *Foreign Affairs*, Summer 1980; Lovins, *Scientific American*, Sept. 2005

- Buy 1.5–11× more climate protection per $, faster
- Free up money and attention for superior alternatives—~$10^{3–4}$× macroeconomic leverage to fund other needs (development/health/education/water…)
- Inhibit spread of nuclear bombs (Iran, N. Korea,…) by removing ambiguity & smoking out proliferators
- How? Just let all ways to save or produce energy compete fairly—no matter which they are, what technology they use, where they are, how big they are, or who owns them
- More prosperity, stronger democracy, safer world

AEP says 2003–07 *real* cost escalation in U.S. heavy construction was 7.8%/y (last line)

in nominal dollars…

Commodity	Esc 86–03	Esc 03–07	Ratio *vs.* History
Nickel	3.8%/y	60.3%/y	15.9×
Copper	3.3%/y	69.2%/y	21×
Cement	2.7%/y	11.6%/y	4.3×
Iron/steel	1.2%/y	19.6%/y	16.3×
Heavy construction	2.2%/y	10.5%/y	4.8×

This and following slide's data and analysis courtesy of Jim Harding, NPEC–Carnegie speech, November 2007

This implies capex 2–3× higher for nuclear, 1.7–2.0× for coal

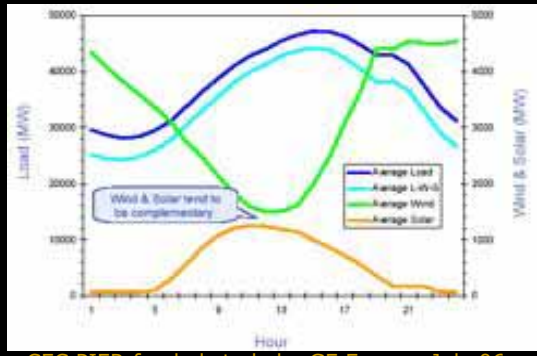
Cap Cost	Keystone	Moody's	S&P	Historical
Nuclear	$3600–4000	$5000–6000	$4000	$2000–2500
Coal	NA	$2500–2900	$2500	$1500
IGCC	NA	$3300–3700	$2800	NA
Gas CC	NA	$700–900	$700	$500–750

Same escalation in 2003– for a nuclear plant with 2007 construction start and 5–6-y lead time (both optimistic) would imply a $5,600/kW real discounted capital cost—much higher than Keystone or S&P but consistent with Moody's—and a levelized busbar cost (2007 $) ~12–15¢/kWh; equivalent coal busbar cost is probably >9¢ without carbon capture and sequestration, which S&P estimates at 6.2¢/kWh extra

Central renewable energy: wind and solar—a hedge against cost and risk of fuel and CO_2

- **Windpower: onshore and offshore**
  - >100 GW installed worldwide through 1Q08, 20.6 GW of it added in 2007
  - >8 GW in India, 5 GW in China (could install 122 GW by 2020—4× wind and 3× nuclear target)
  - EU expects 80 installed GW to be achieved ~2009, then even faster growth
  - But wind must be "firmed" by hydro, gas, storage, dispatchable demand response, or…*wind* (using the geographical diversity of the wind resource)





CEC PIER-funded study by GE Energy, July 06

- **Central solar thermal power: troughs, dish, power towers**
  - After 10+ years, SEGS generates 354 MW_e reliably in California; can be firmed with thermal storage or gas (or with demand response—"virtual peakers")
  - New projects under development worldwide typically include overnight thermal storage



9 recent US studies show wind integration costs <0.1–0.5¢/kWh at capacity shares ≤31% of regional peak demand

Table 6. Key Results from Major Wind Integration Studies Completed 2003-2006

Date	Study	Wind Capacity Penetration	Cost ($/MWh)				
			Regulation	Load Following	Unit Commitment	Gas Supply	TOTAL
2003	Xcel-UWIG	3.5%	0	0.41	1.44	na	1.85
2003	We Energies	4%	1.12	0.09	0.69	na	1.90
2003	We Energies	29%	1.02	0.15	1.75	na	2.92
2004	Xcel-MNDOC	15%	0.23	na	4.37	na	4.60
2005	PacifiCorp	20%	0	1.6	3	na	4.60
2006	CA RPS (multi-year)	4%	0.45*	trace	na	na	0.45
2006	Xcel-PSCo	10%	0.2	na	2.26	1.26	3.72
2006	Xcel-PSCo	15%	0.2	na	3.32	1.45	4.97
2006	MN-MISO 20%	31%	na	na	na	na	4.41**

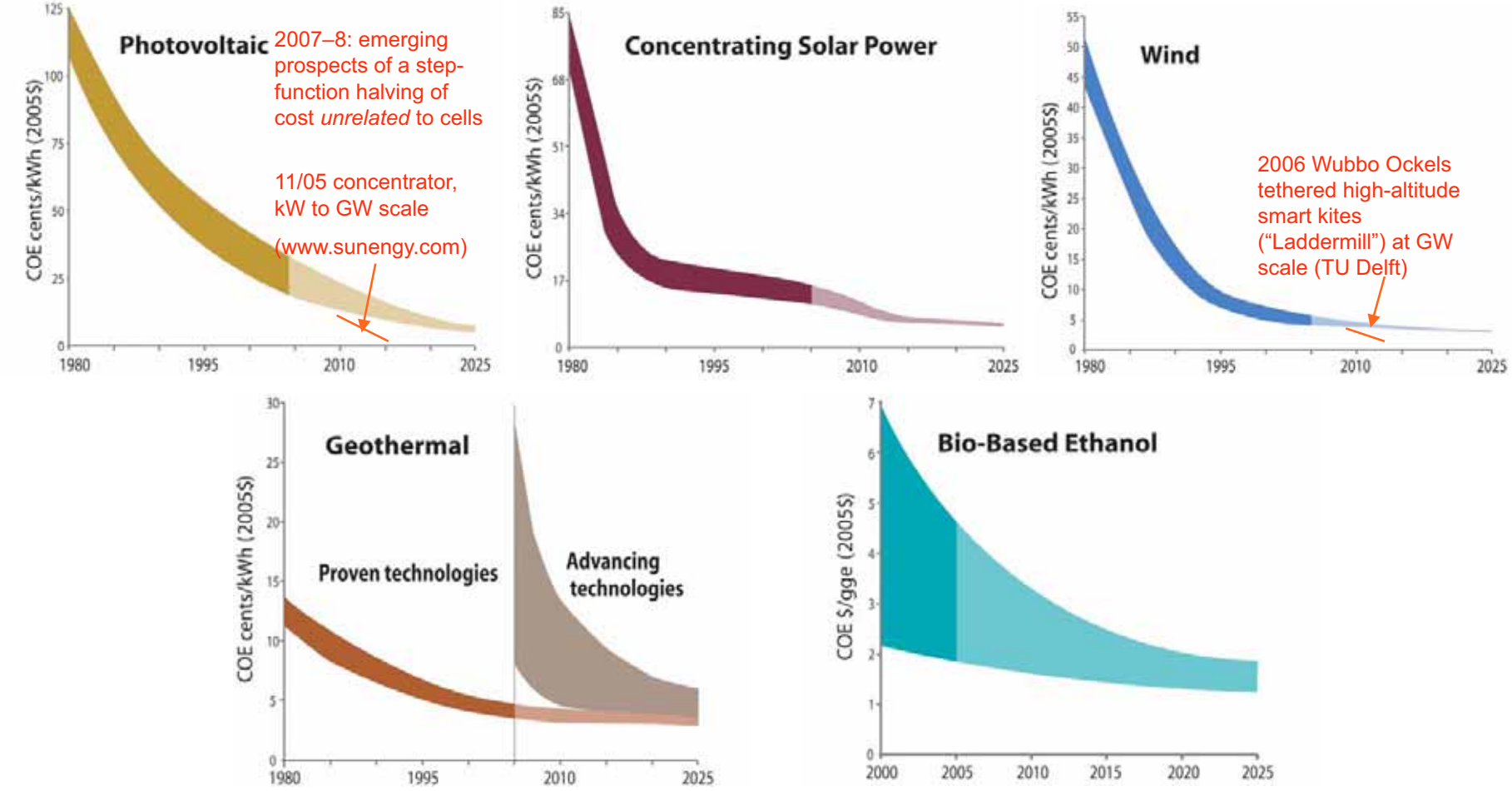
* 3-year average ** highest over 3-year evaluation period

Source: National Renewable Energy Laboratory

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

Renewable Energy Cost Trends

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

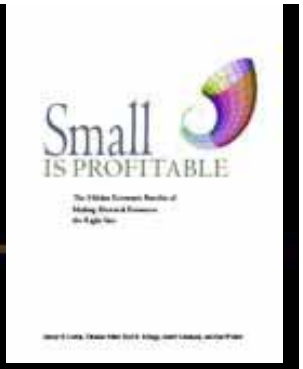


Illustrative Lovins additions, 12/06

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

"Distributed benefits" further change the game



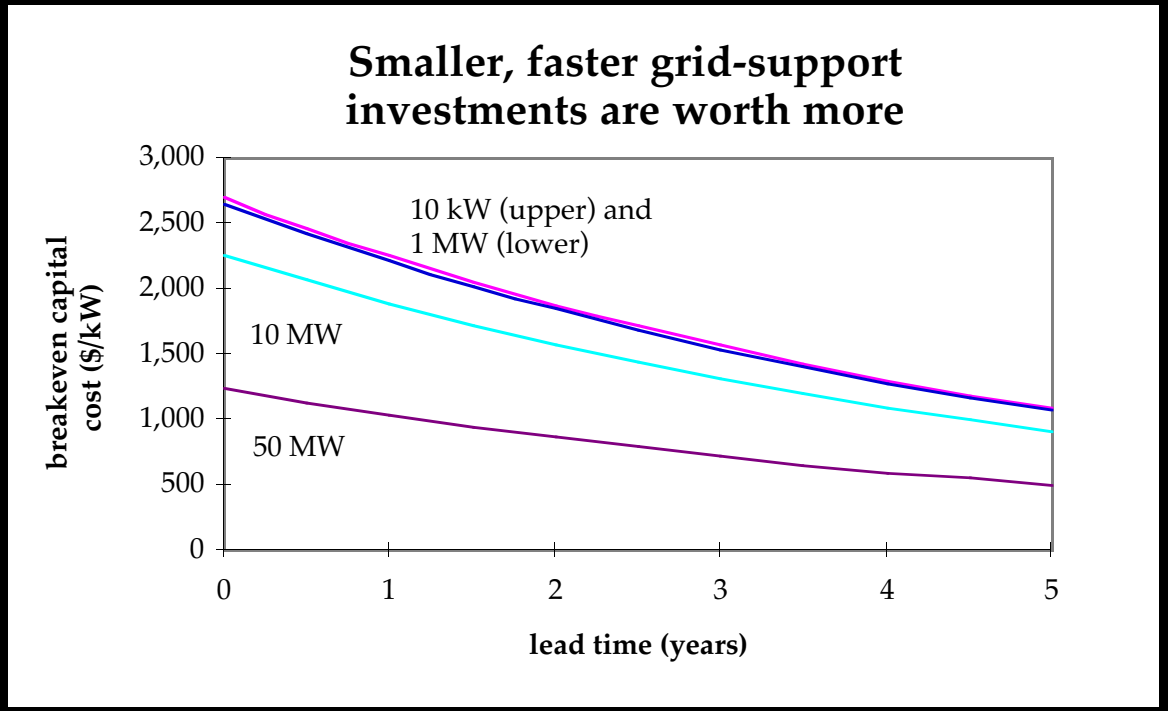
- *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (RMI, 8/02)
  - www.smallisprofitable.org
  - One of *The Economist*'s top three business/economics books of 2002
- Codifies and quantifies 207 "distributed benefits" that collectively increase the economic value of decentralized 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 ($3,000/$kW_e$)

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
- *All these apply to end-use efficiency as well as to decentralized supply!*

207 Distributed benefits: ~10× value
(Actual value is very technology- & site-specific)

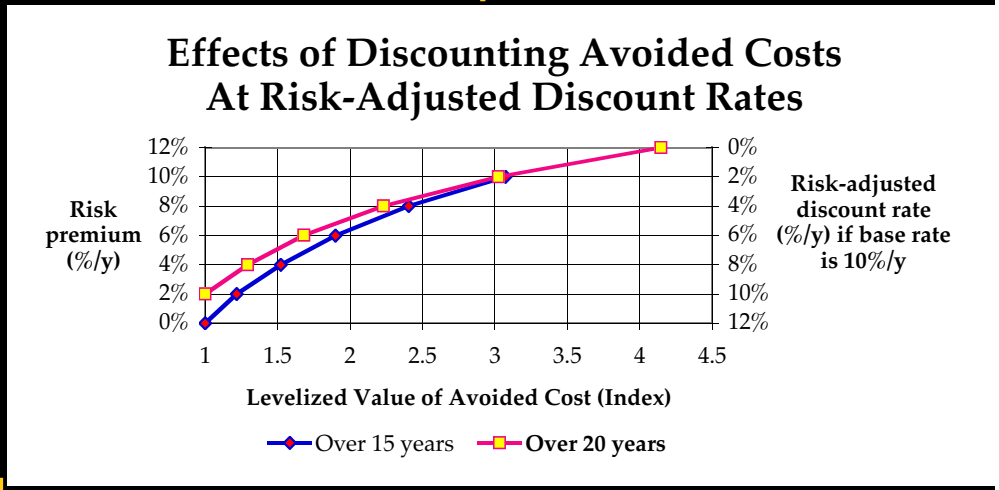
- ~10^{1}×: Minimizing regret (financial economics)
  - Short lead times and small modules cut risk
    - Financial, forecasting, obsolescence
    - Overshoot and "lumpiness"



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 ~500–600 basis points in 2002 but is probably higher now, as the market has become far more volatile

Four Times Square, NYC

(Condé Nast Building)

- *149,000 m^2, 47 storeys*
- *non-toxic, low-energy materials*
- *40% energy savings/ft^2-y despite doubled ventilation rates*
- *Gas absorption chillers*
- *Fuel cells*
- *Integral photovoltaics in spandrels on S & W elevations*
- *Ultrareliable power helped recruit premium tenants at premium rents*
- *Fiber-optic signage (signage required at lower floor(s))*
- *Experiment in Performance Based Fees rewarding savings, not costs*
- *Market average construction cost*



Bundling PVs with end-use efficiency: a recent example





- Santa Rita Jail, Alameda County, California
- PowerLight 1.18 MW_p project, 1.46 GWh/y, 1.25 ha of PVs
- Integrated with Cool Roof and ESCO efficiency retrofit (lighting, HVAC, controls, 1 GWh/y)
- Energy management optimizes use of PV output
- Dramatic (~0.7 MW_p) load cut
- Gross project cost US$9M
- State incentives US$5M
- Gross savings US$15M/25 y
- IRR >10%/y (Cty. hurdle rate)
- Works for PVs, so should work better for anything cheaper

My banana farm's efficiency-and-photovoltaic electric power system



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



- Lovins house / RMI HQ, Snowmass, Colorado, 1984
  - 372 m^2 use ~120 W_{av}, costing ~ $5/month @ $0.07/kWh
  - So ~3 m^2 of solar cells can run the building (or ~1 m^2 with 2007 not 1983 efficiency technology!)
  - That costs less than just *con-necting* to the grid a few m away
- Ing. Kees Daey Ouwens, Utrecht, 1980s
  - A similarly efficient small house used only ~50 W_{av}
  - Even at the high solar-cell prices of that time, it was cheaper to make solar power than to connect to the grid right by the house
  - So he provided efficiency plus solar power for an Indonesian village, rather than connecting to the power line running past it
  - With 10-y finance at utility's cost of money, the villagers had a positive cashflow from day one—as can ≥2 billion other people!
  - So with very efficient end-use, breakeven distance from grid drops to ~0!

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
  - Lesson: real, full competition is more likely to give you too many attractive options than too few!
- Ultimate size of alternatives also dwarfs nuclear's
  - El. end-use efficiency: ~2–3× (EPRI) or 4× (RMI) nuclear's 19% US share, at below its *short*-run marginal delivered cost
  - CHP: industrial alone is comparable to nuclear; + buildings CHP
  - On-/nearshore wind: >2× US & China el., ~6× UK, ~35× global*
  - Other renewables: collectively even larger, PVs almost unlimited
  - Land-use and variability *not* significant issues

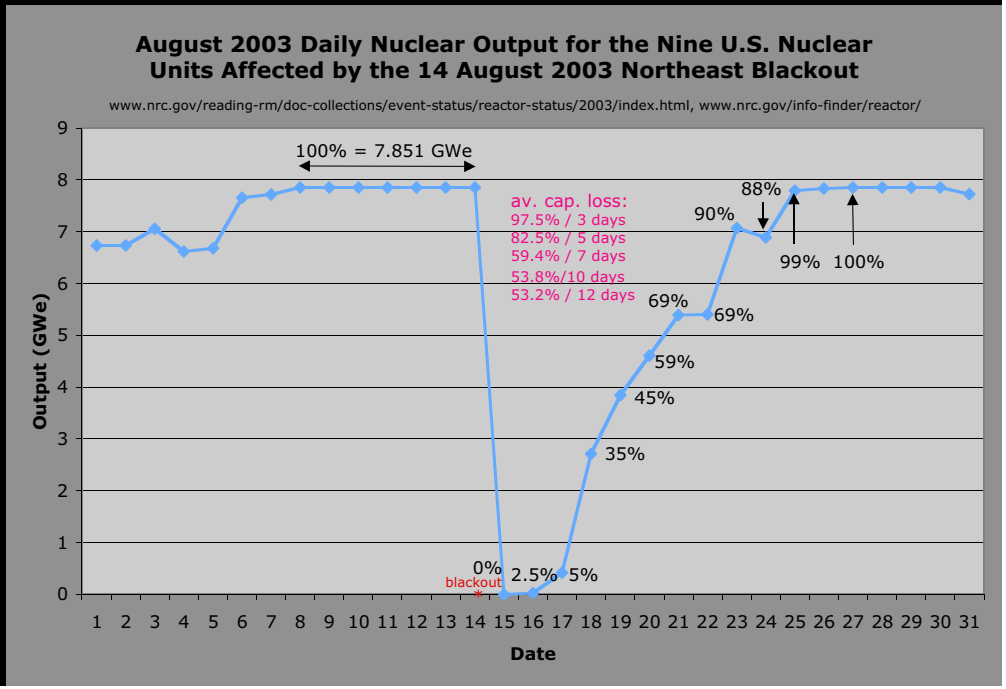
* www.stanford.edu/group/efmh/winds/global_winds.html, on- and nearshore sites with annual mean windspeeds ≥6.9 m/s at 80m hub, ~72 TW

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

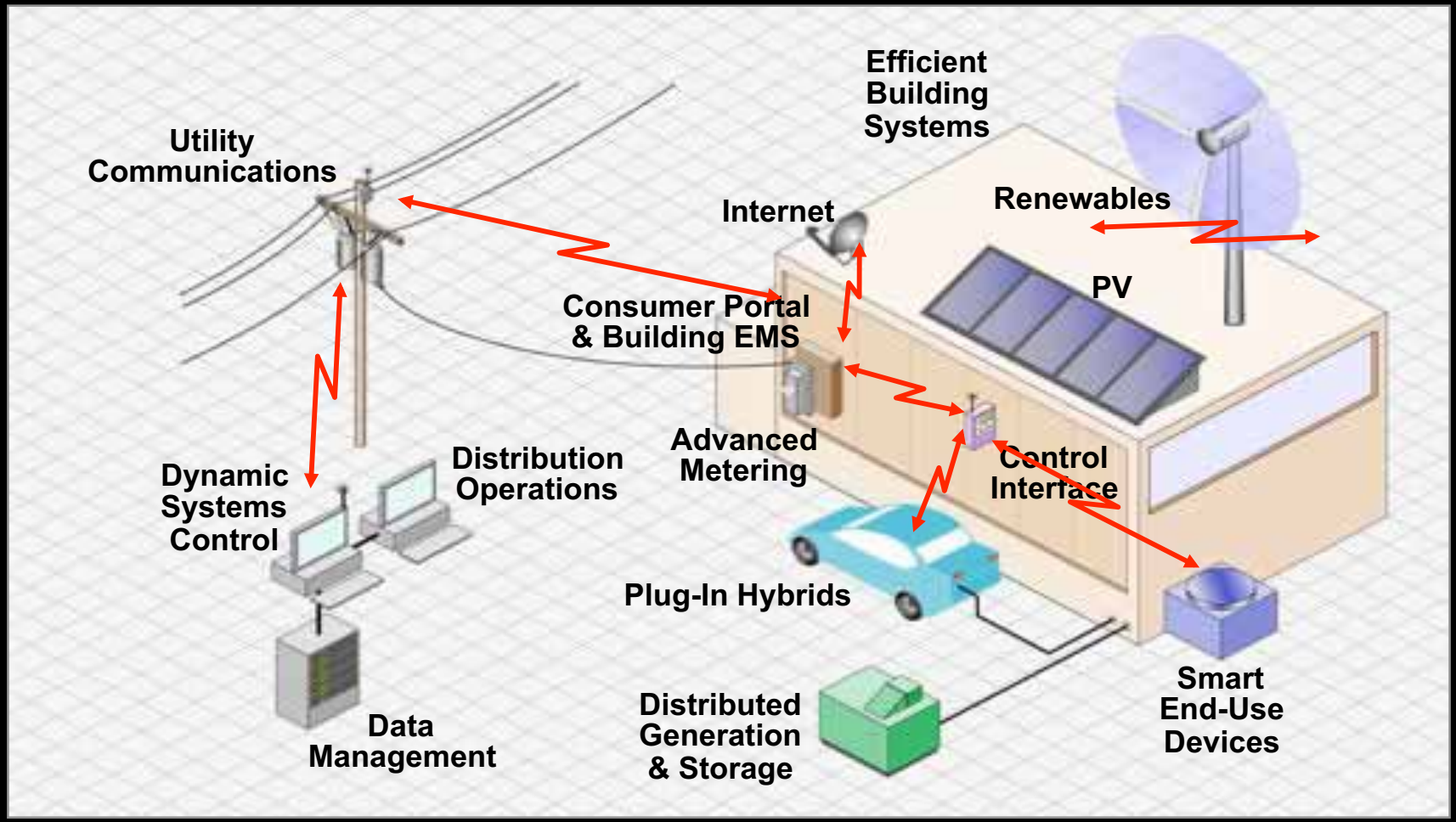
◇ Arithmetically, one 1-GWe unit or a thousand 1-MWe units or a million 1-kWe units are equivalent

◇ 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 & solar 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 (unlike renewables)…

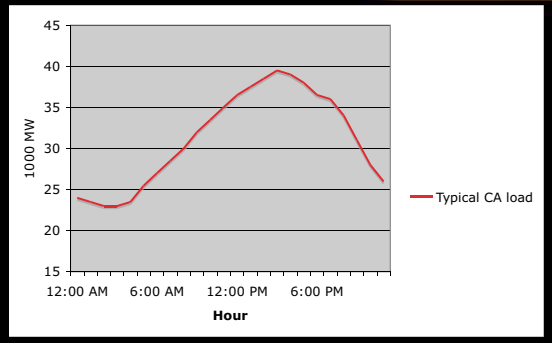


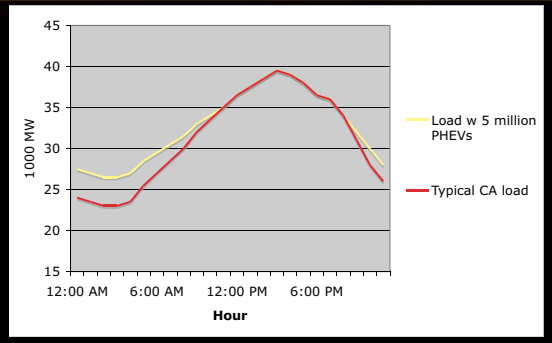
Utilities' emerging distributed-resources portfolio (EPRI vision)

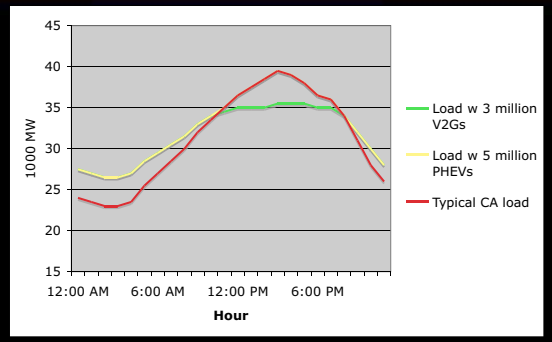


Graphic by Hank Courtright, Senior VP, Electric Power Research Institute, courtesy of Johnson Controls

Smart vehicle-to-grid (V2G) interface could be important







The grid could recharge PHEVs with previously spilled night windpower, then lop daytime peak

- Cars are parked ~96% of the time (or think about school buses!)
- PHEV batteries or FCEV fuel cells in a superefficient U.S. light-vehicle fleet have ~6–12× total U.S. electric generating capacity, so even modest V2G *displaces all coal and nuclear plants*
- First ~2 million US drivers selling that capacity back to utility where/when most valuable could earn back entire car cost
- Utilities love G2V: offpeak el. sales, ratebasing grid expansion, el.→transport GHG shift, battery finance, hi-tech customer bundle
- RMI and Tier One partners are engaged in a serious effort to bring profitable PHEVs, then "smart garages," to the U.S. market soon

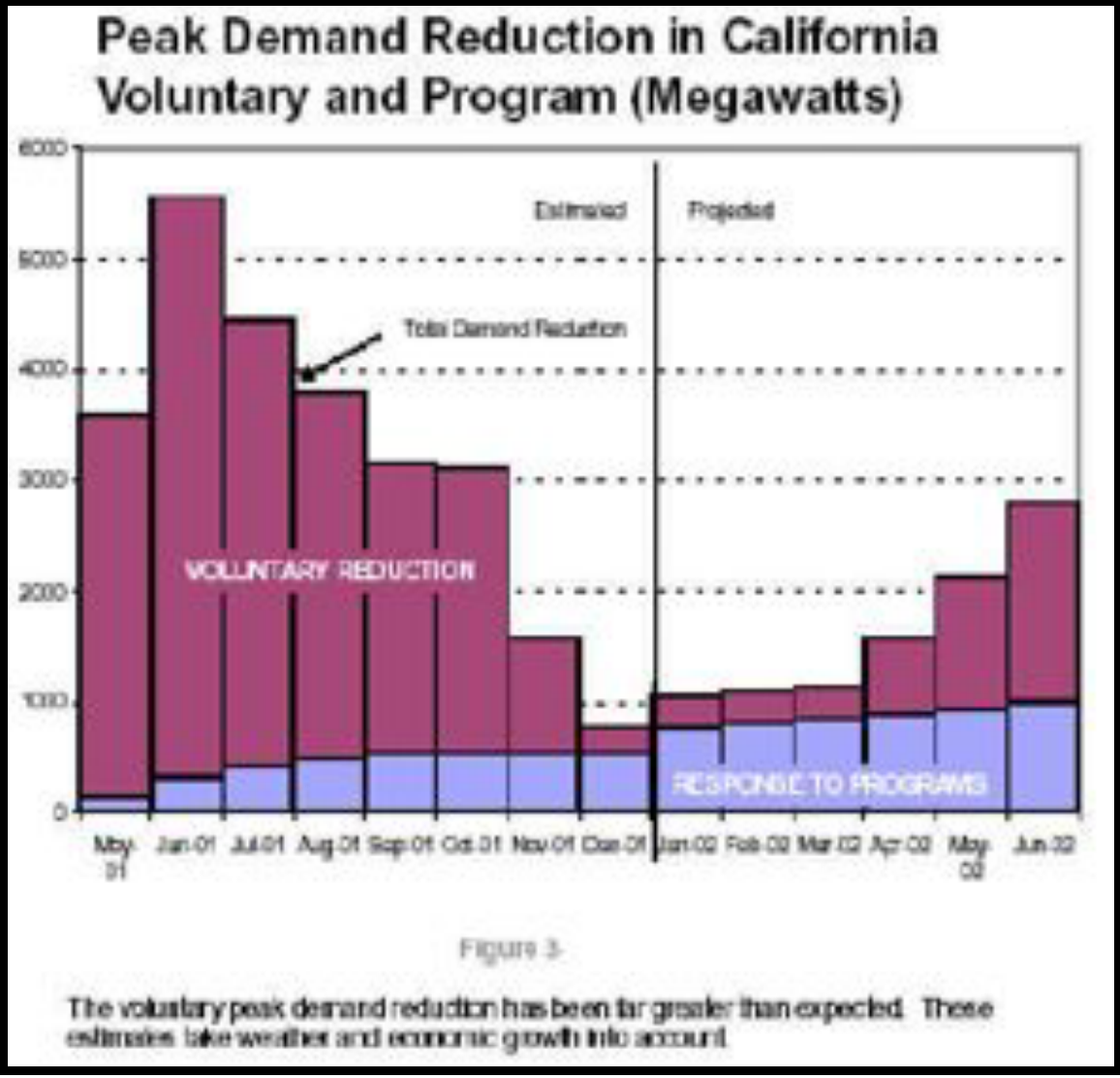
Strategy focused on the customer in each distribution planning area

- Traditional: forecast demand, build generation, size grid to deliver output to customers
- Customer-focused: start with end-uses
  - In each distribution area that's about to invest…
  - Target DSM on key end-uses driving load growth there
  - Augment as necessary with distributed generation, reactance control, other minor grid improvements
  - In short, work from end-uses towards upstream assets
- When tried at PG&E and Ontario Hydro…
  - Generation and (usually) tx expansion proved unnecessary
  - All needs were met more reliably and quickly
  - *Required capital investment fell by about tenfold*

California's 2000–01 electricity crisis: media myths *vs*. realities

- Demand didn't soar — normal, CEC correctly forecast
- California didn't stop building capacity in the '90s
  - CA added 4–5 GW of distributed generation (> nuclear capacity)
- There was not a physical shortage of capacity
- Nutty restructuring (disaster designed by committee)
  - Sold utilities' fossil-fuel plants to a small number of buyers
  - Seven firms controlled 2/3 of bidding space; each could move mkt.
  - Each made more profit selling less electricity at a higher price
  - ≥10 GW called in sick; efficient use defunded and disincentivized
  - So a system that had met a 53-GW load in summer 1999 crashed on a 29-GW load in January 2001 (but munis were generally OK!)
- ~20 other linked causes, many linked to natural gas
- Customers undid 5–10 y demand growth in 1–2Q01
- That plus long-term contracts put out the fire
- Supply then overshot, as regionally and nationally

Dissolving California's 2001 power crisis



California customers' stunning 14% drop in weather-corrected peak el. load/GDP in the first half of 2001 (*before* price signals hit outside San Diego) was mainly voluntary & temporary, but permanent technological savings then rose rapidly

— CEC Cons. Rpt., Feb. 2002

What can negawatts do in Singapore?

- The potential is clearly huge, in all sectors, because:
  - Very little has been done to capture savings or to bust barriers; it's hard to think of a single really efficient building in Singapore (high Green Mark ratings don't equate to very high energy efficiency!)
  - The policy framework is not balanced between supply- and demand-side investments, rewards, or attention
  - The public sector is not yet leading innovation as it has done in *e.g.* setting a goal for halved desalination energy intensity
  - Awareness of modern technical potential is generally sparse
  - Some old policies may be unhelpful or even counterproductive
  - New proposals tend to fall far short of modern profitable practice
- The absence of measured data is striking
  - Well-established and rigorous ways to measure the performance of buildings and processes are seldom being applied, except by a few private practitioners for private-sector clients
- Negawatts (like micropower) can't yet compete fairly

Between the idea / And the reality / Between the motion / And the act / Falls the Shadow

—T.S. Eliot

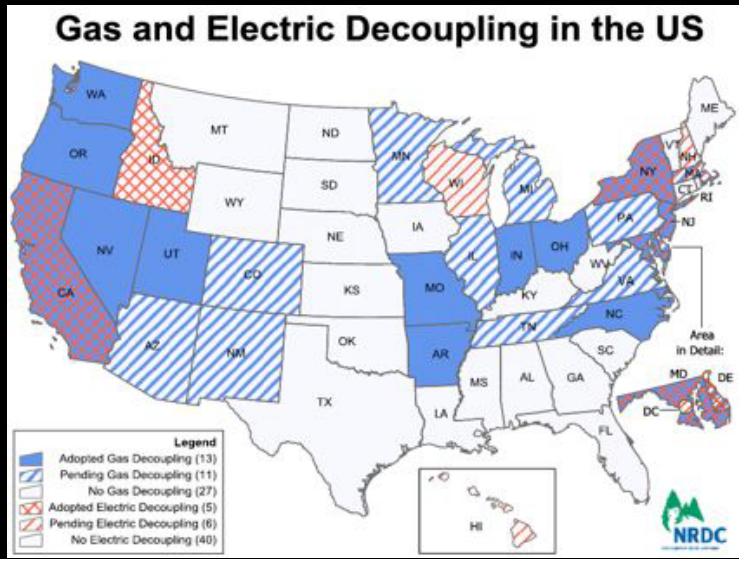
- There are ~60–80 specific market failures* of 8 types
  1. Capital misallocation
  2. Value-chain risks
  3. Organizational failures
  4. Informational failures
  5. Regulatory failures
  6. Perverse incentives
  7. False or absent price signals
  8. Absent markets
- **Proven methods can turn each of these obstacles into lucrative business opportunities**
- ***Barrier-busting* should top the policy agenda and animate efficiency businesses' strategy**

*"Climate: Making Sense *and* Making Money," RMI, 1977, pp. 11–20

The biggest public-policy lever to support the business logic

- Aligning suppliers' with customers' incentives is always a sound practice in any business—but most utilities still live in contradiction
- Utility regulators should reward electricity and gas distribution companies for reducing customers' bills, not for selling more energy
  - Decouple profits from sales volumes using a balancing account
  - Let the distributor keep a small part of the savings it achieves for its customers (CA just adopted a powerful sliding-scale incentive structure to spur overperformance)
  - Unanimously endorsed by U.S. state utility regulators (NARUC) 7/88, adopted in ~7–9 states, derailed by restructuring, now surging with strong AGA & EEI support
  - NRDC & Energy Foundation lead reforms; www.raponline.org helps Commissions

By early October 2007, electric decoupling was adopted in 5 states and pending in 6; gas decoupling was adopted in 13 and pending in 11. This trend could cover most US private utilities within a few years—leapfrogging ahead of EU policy, which is still about kWh commodity *prices*



What are we waiting for?
We are the people we have been waiting for!

"Only puny secrets need protection.
Big discoveries are protected
by public incredulity."

—Marshall McLuhan



Your move…

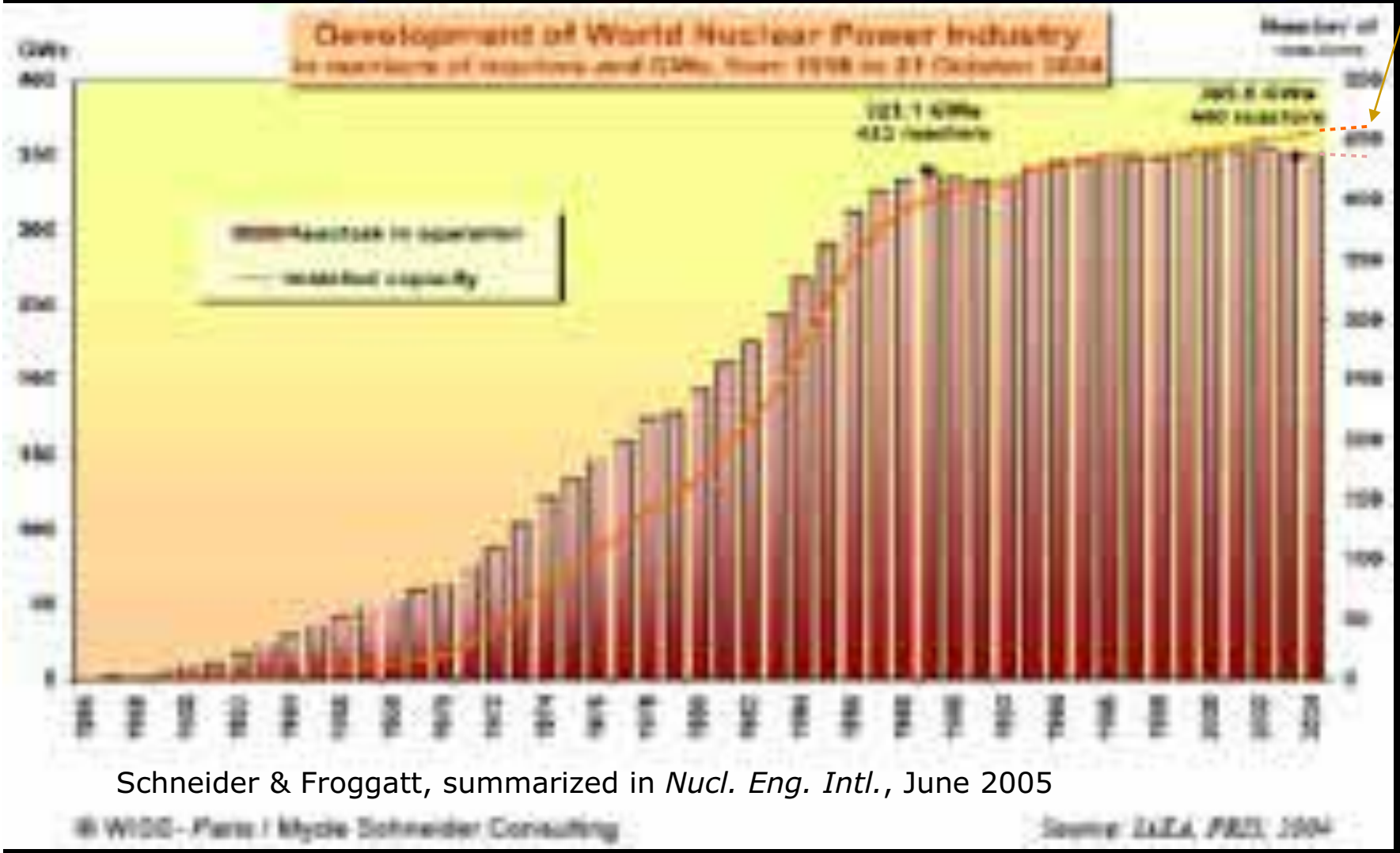
www.oilendgame.com,

www.fiberforge.com,
www.rmi.org (Publ'ns.),

www.rmi.org/stanford,
www.natcap.org

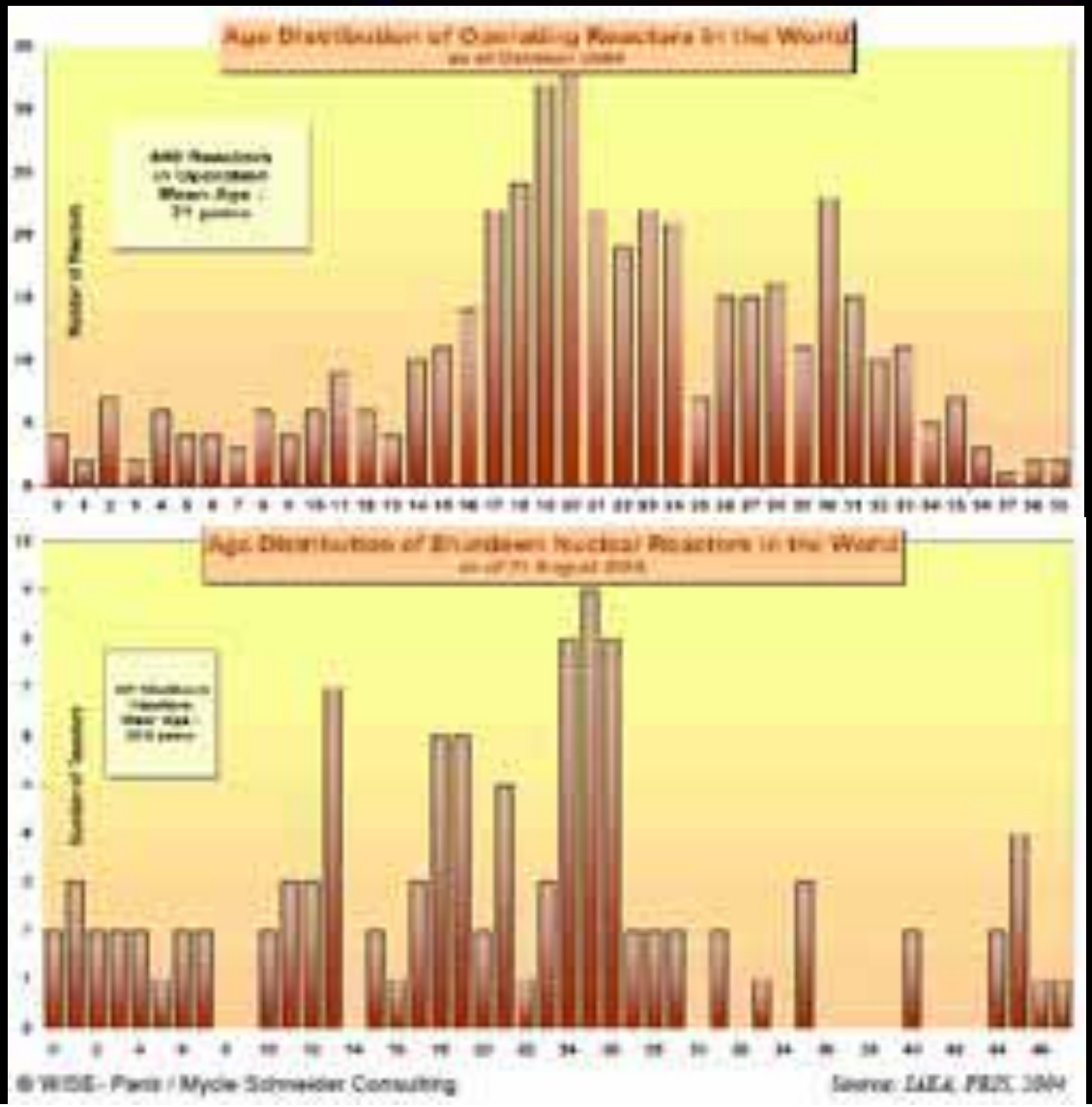
Global nuclear expansion is coasting to a halt

At end 2006 per IAEA:
435 units, 368.2 GWe



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

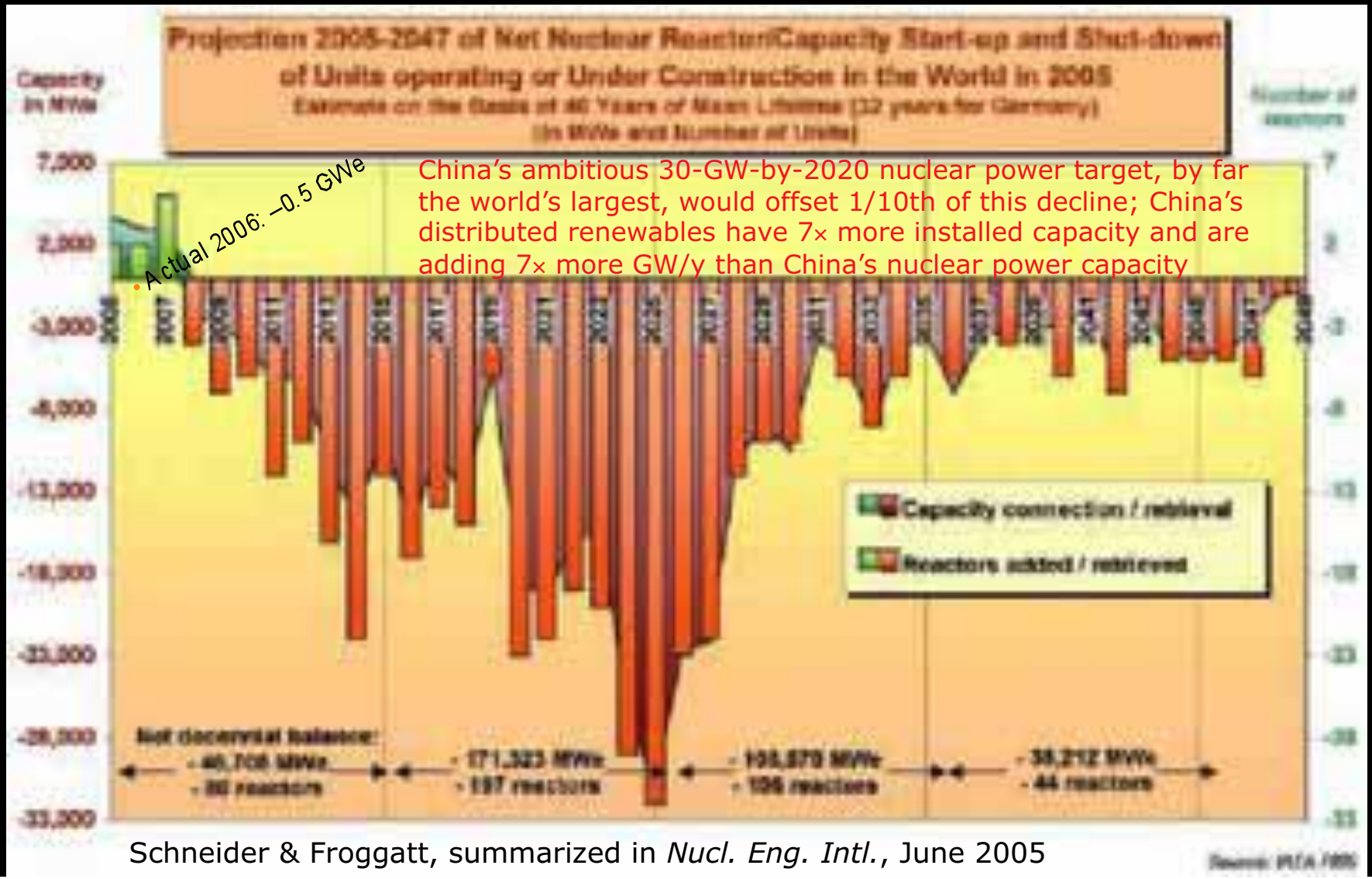
Average reactor in 2004 was 21 years old—as was av. unit permanently retired



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

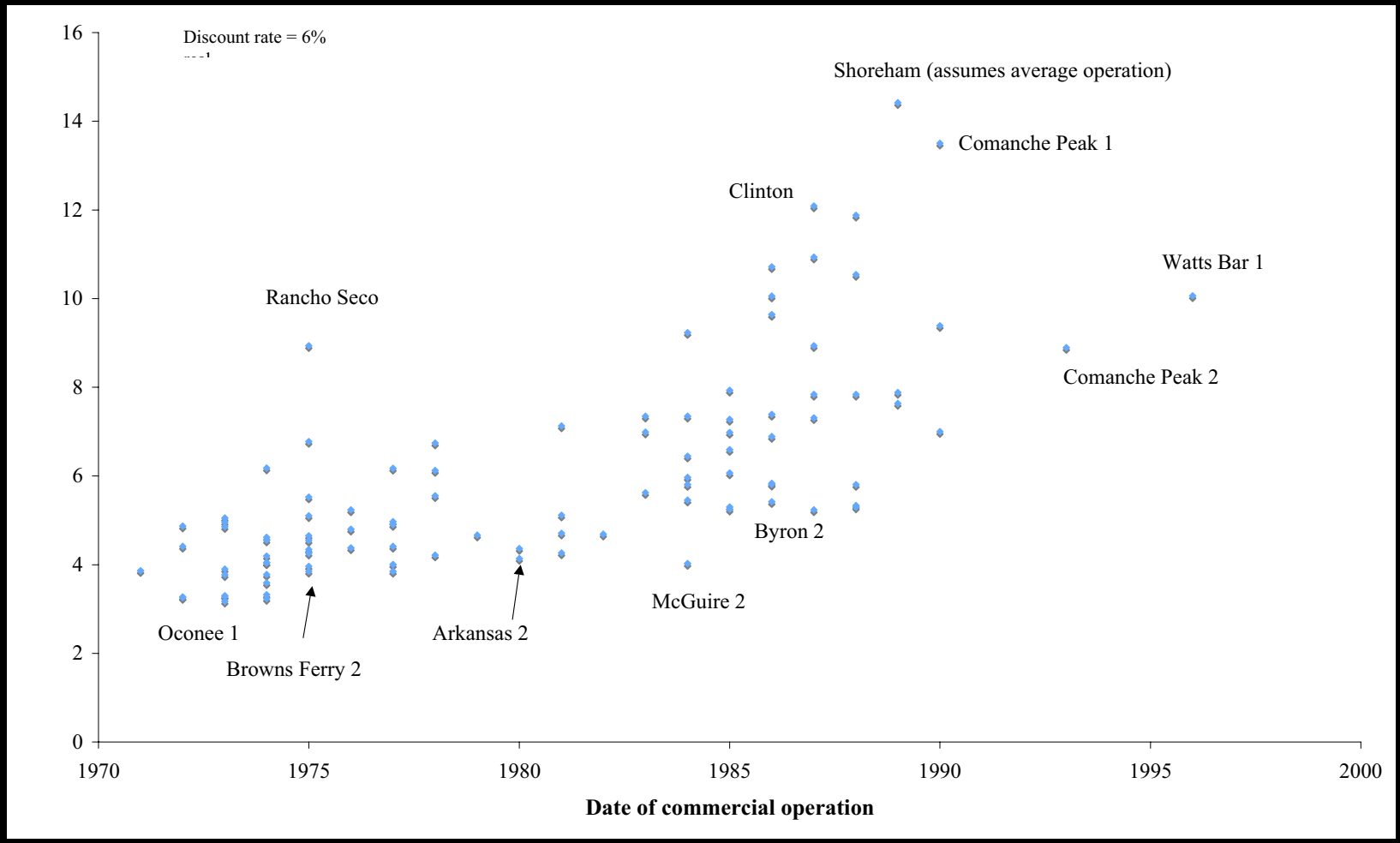
If China built 32 new units to 2020 (extremely ambitious), it'd cover hardly over 10% of plants reaching age 40 worldwide

Global nuclear capacity will decline just by its demographics



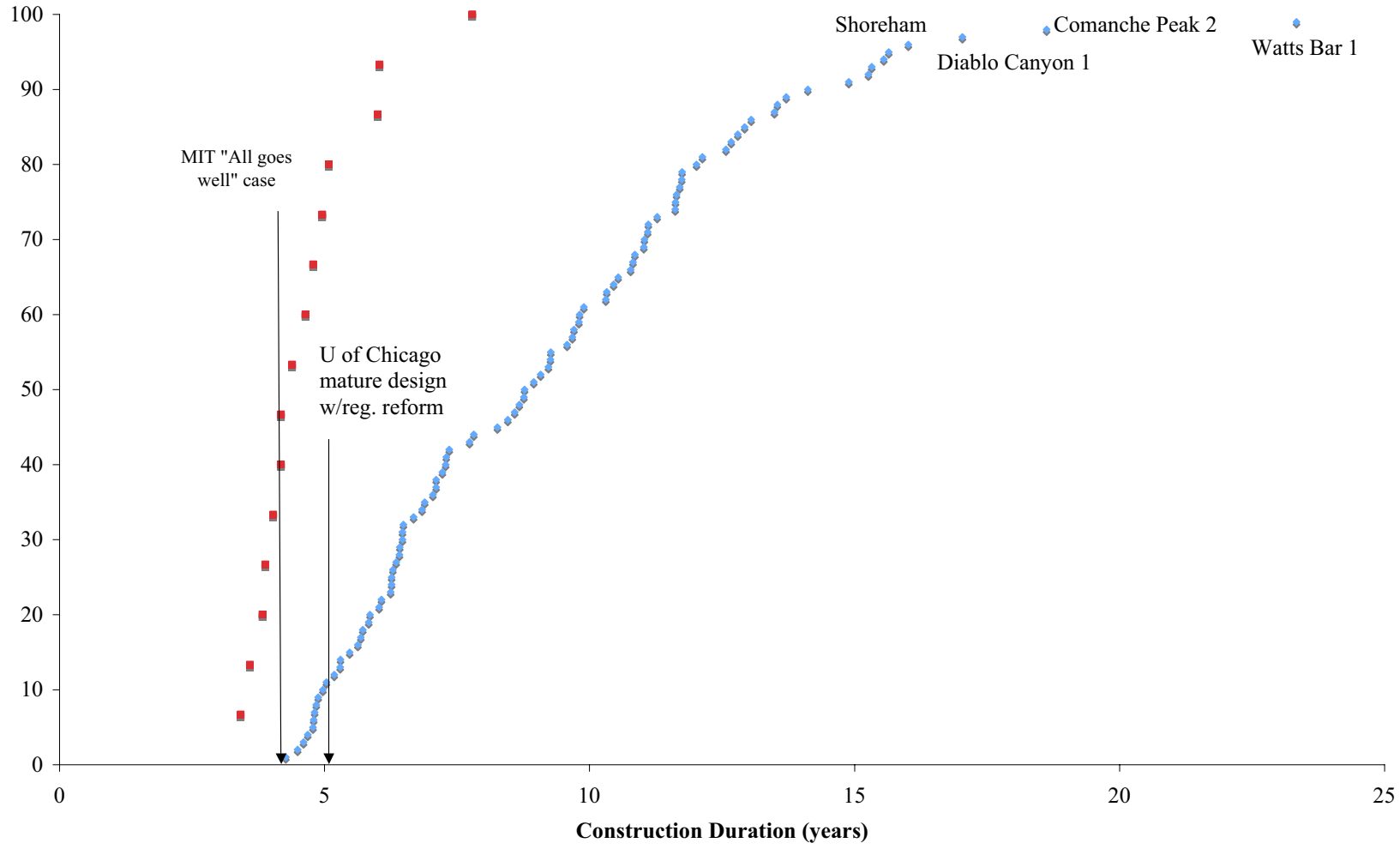
Schneider & Froggatt, summarized in *Nucl. Eng. Intl.*, June 2005

Busbar costs of power from 99 historical US nuclear plants



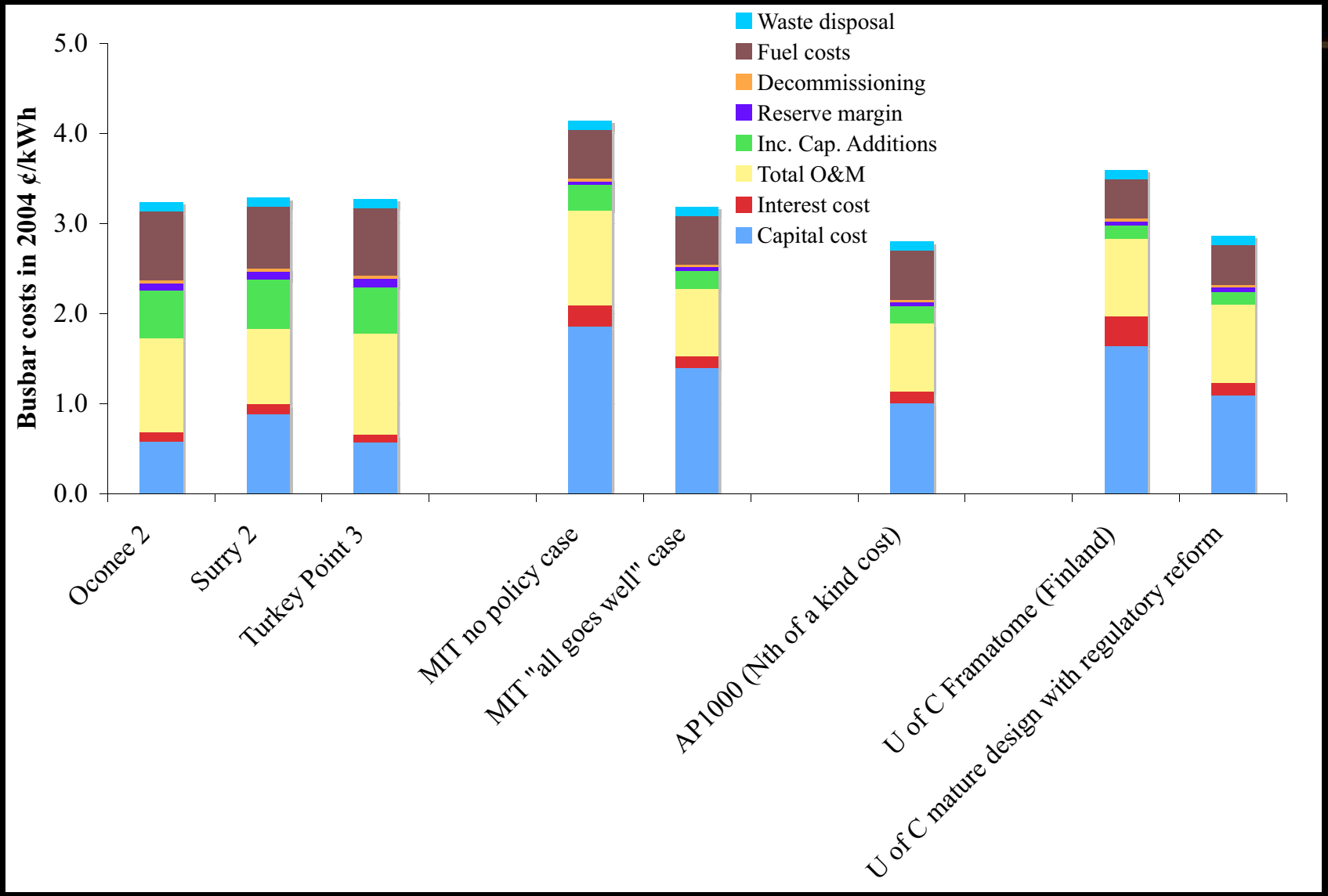
Koomey, Jonathan, and Nate Hultman. 2007. "A reactor-level analysis of busbar costs for U.S. nuclear plants, 1970-2005." Submitted to *Energy Policy*. January.

Ranked construction duration of 99 historical US nuclear plants



Koomey, Jonathan, and Nate Hultman. 2007. "A reactor-level analysis of busbar costs for U.S. nuclear plants, 1970-2005." Submitted to *Energy Policy*. January.

Comparative nuclear busbar costs



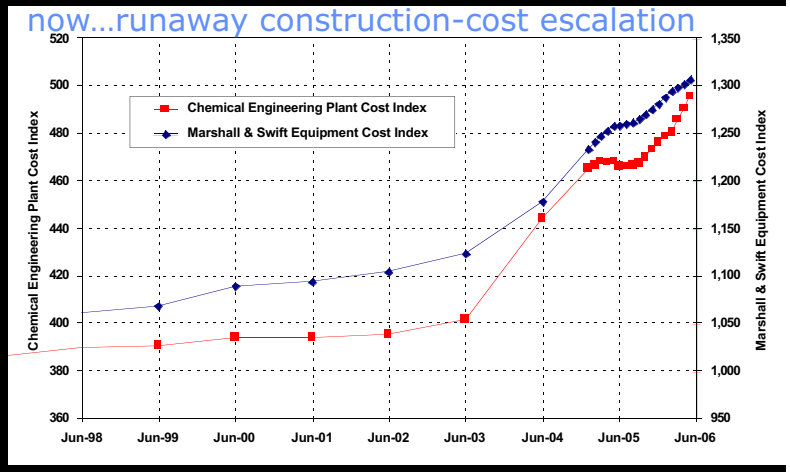
Koomey, Jonathan, and Nate Hultman. 2007. "A reactor-level analysis of busbar costs for U.S. nuclear plants, 1970-2005." Submitted to *Energy Policy*. January.

Update: nuclear capital and fuel costs are going through the roof

- Pre-MIT studies simply quoted industry hopes and wishes, and each other—no honest empiricism
- MIT evidence-based 2003 study derived ~$2,000/kW (2002 $); FPL now guesses ~$3,500/kW ('07?$)
- 8 recent Asian plants look to end up ~$4,000/kW (~2007 $) *before* recent construct'n-cost escalation
- Looming fuel (U & SWU) crises will raise MIT's 0.5¢/kWh fuel cost to ~1.2–1.7¢ open, ~2.1–3.5¢ closed
- Big manufacturing bottlenecks too
- Realistic busbar cost 7→*11*¢/kWh

99 historical US nuclear plants: ranked real capital cost, including Interest During Construction at 6%/y real

now…runaway construction-cost escalation

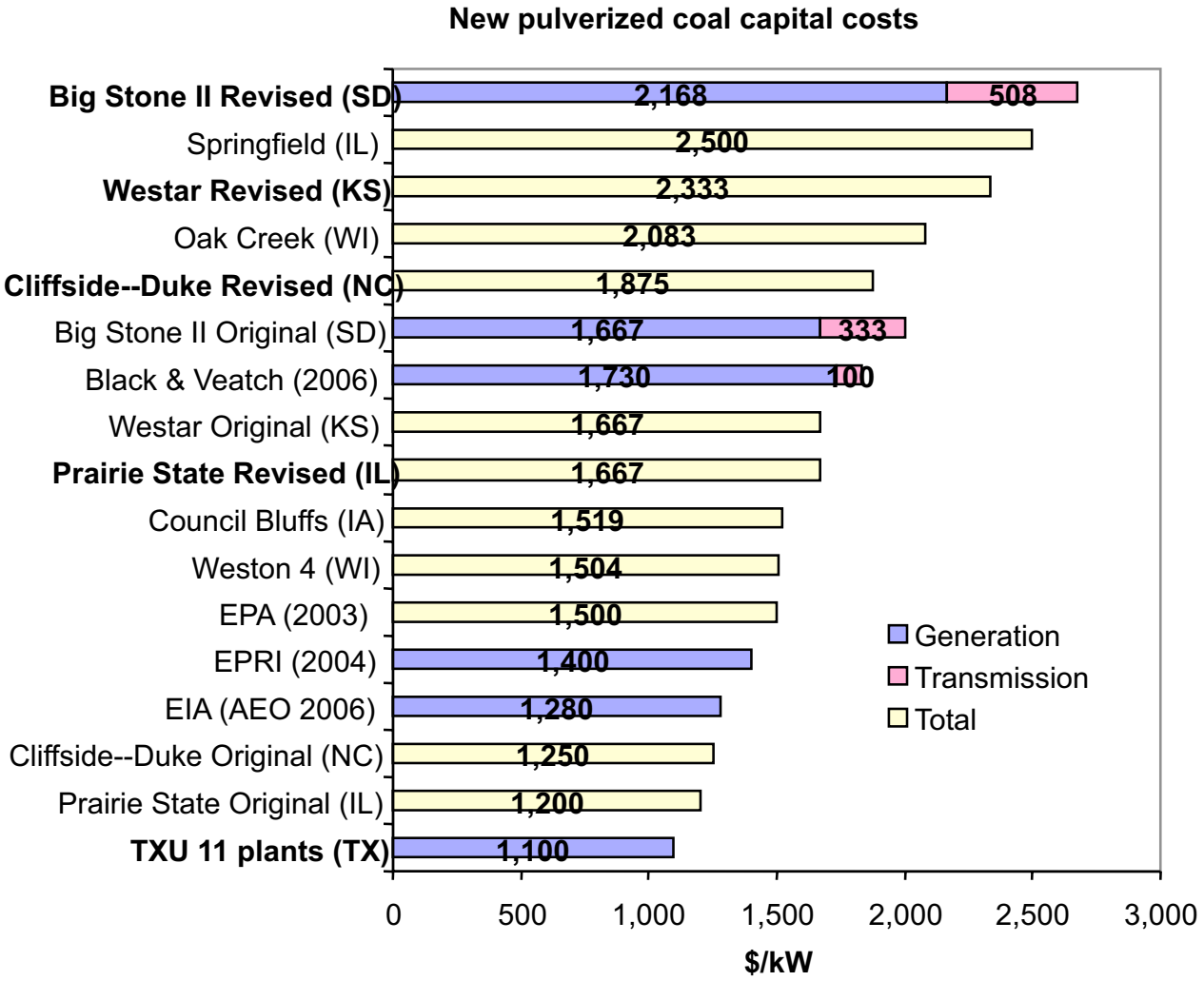


J.G. Koomey & N. Hultman, "A reactor-level analysis of busbar costs for U.S. nuclear plants, 1970–2005," submitted to *En. Pol.*, Jan 07

J. Harding, "Seven Myths of the Nuclear Renaissance," Euratom 50th Anniv. Conf., European Parliament (Brussels), 7 March 2007

Union of Concerned Scientists

Costs for new pulverized coal plants are on the rise



- **US and global coal rush creating supply constraints for equipment and skilled labor**
- **At least 4 plants have announced 30-50% capital cost increases in the past year**

Source: Steve Clemmer, UCS, "Gambling with Coal," National Wind Technology Center, 26 February 2007

Notes: EIA, EPRI, EPA, and Black & Veatch estimates are overnight costs and don't include interest during construction (IDC). It's not clear whether the other estimates include IDC. Most of the estimates are in 2005$ for a supercritical PC plant.

US busbar prices for windpower average ~3.5¢/kWh (2006 $)

- Lowest in ~2003, rose 2005–06 (steel prices, turbine short-ages,…), and will probably rise in ’07
- Still very competitive

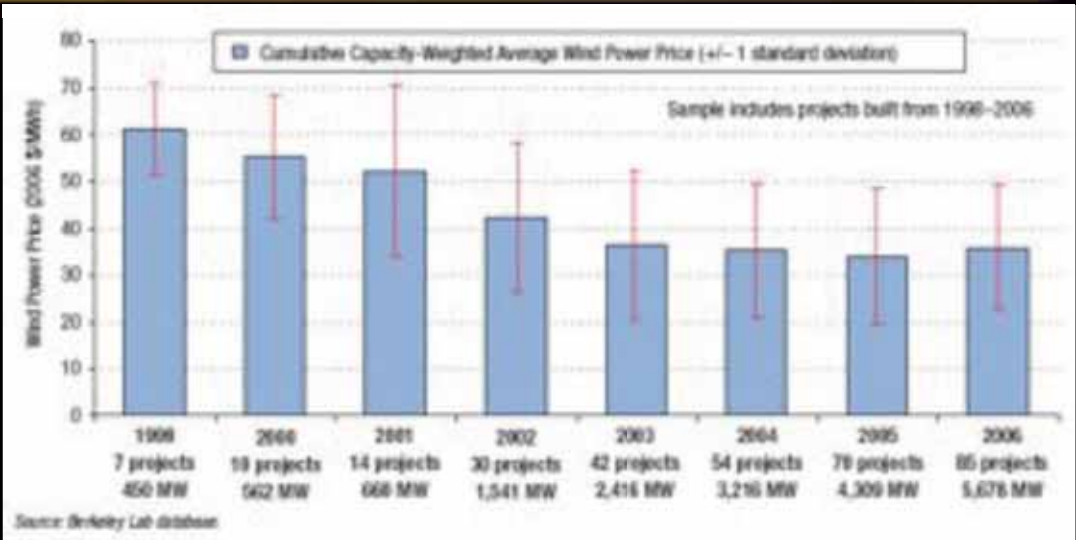


Figure 9. Cumulative Capacity-Weighted Average Wind Power Price over Time

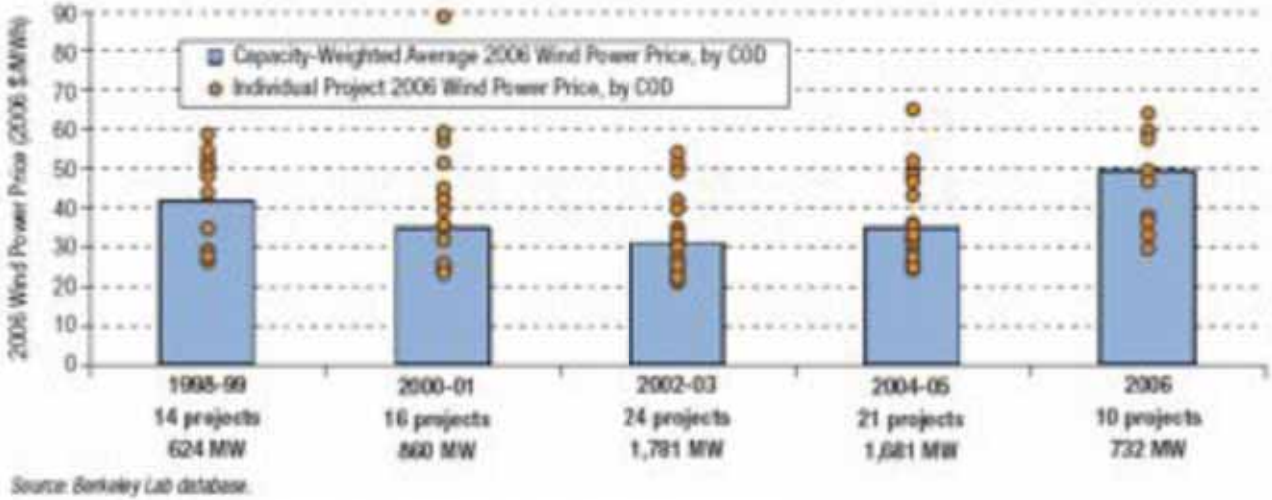
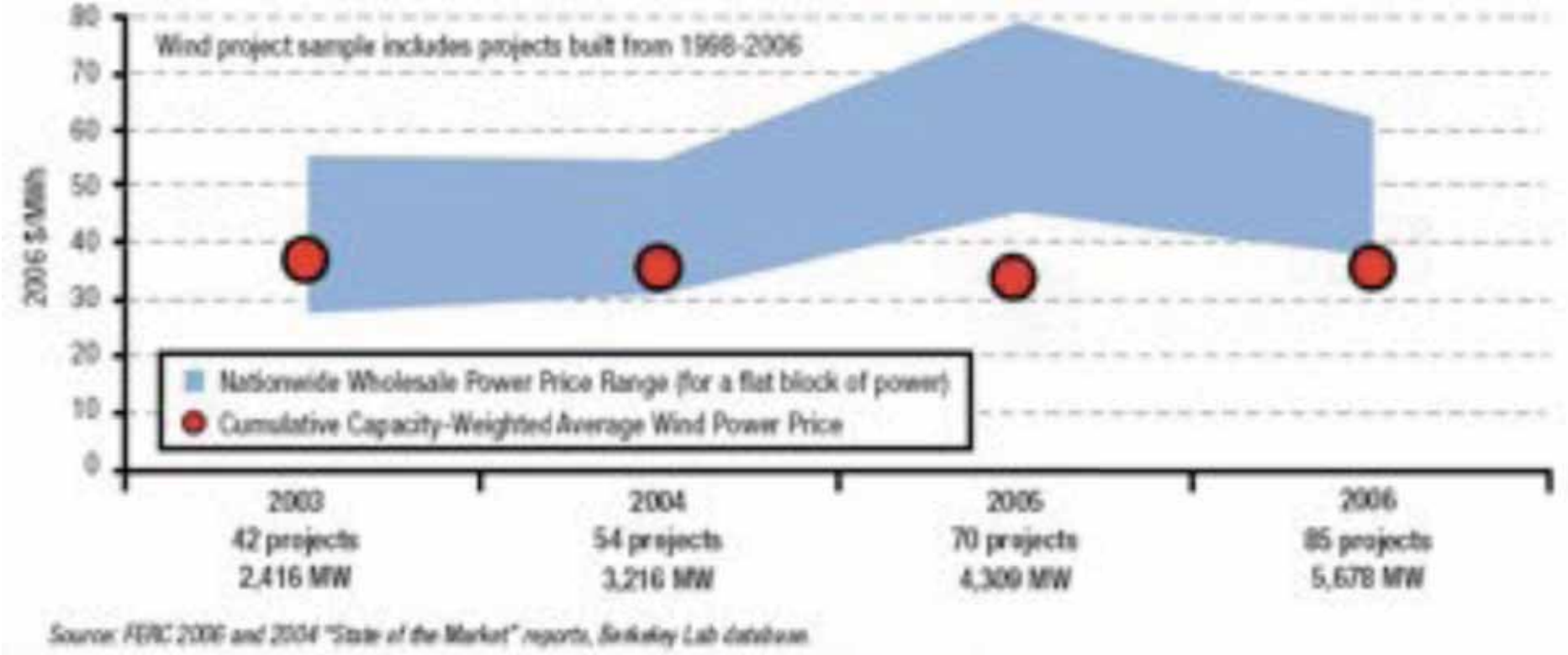


Figure 10. 2006 Wind Power Price by Commercial Operation Date (COD)

R. Wiser & M. Bolinger, “Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006,” USDOE/EERE, LBL-41435, May 2007

Windpower's price (av. ~3.5¢/kWh after PTC) has stayed generally competitive with wholesale power



Source: FERC 2006 and 2004 "State of the Market" reports, Berkeley Lab database

Figure 13. Average Cumulative Wind and Wholesale Power Prices over Time

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

Considerable cost scatter and regional variation among contemporaneous wind projects

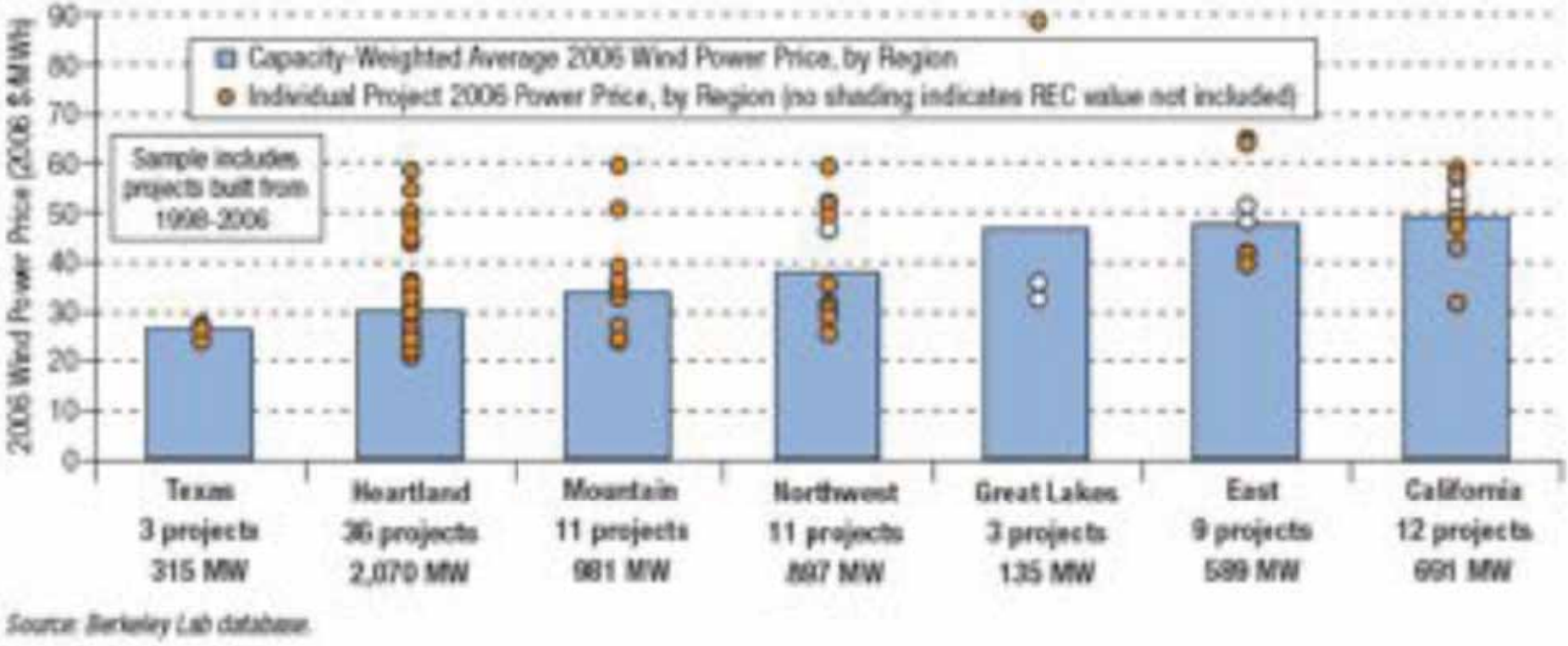


Figure 11. 2006 Wind Power Price by Region

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

Wide variations in power price (siting, timing, unit size, etc.)

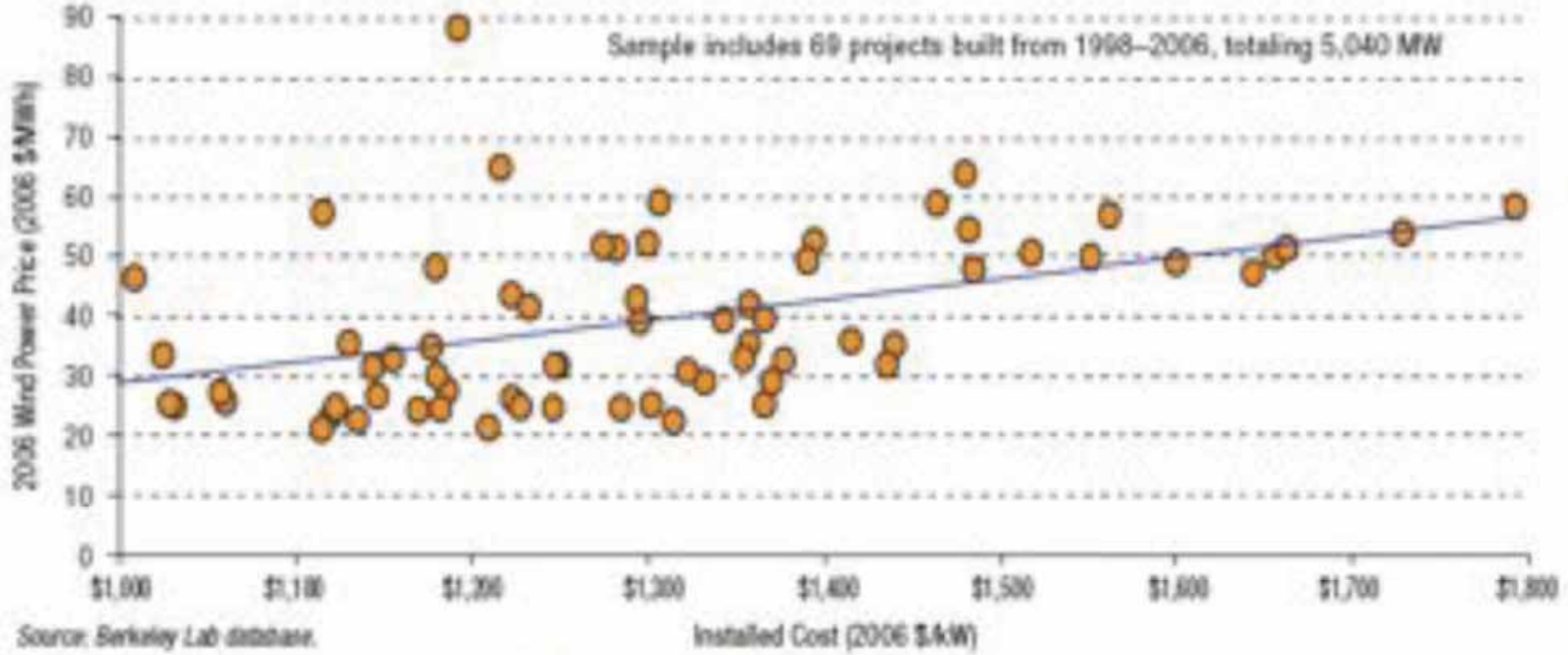


Figure 16. 2006 Wind Power Price as a Function of Installed Project Costs

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

Projects with high capacity factors naturally produce cheaper power

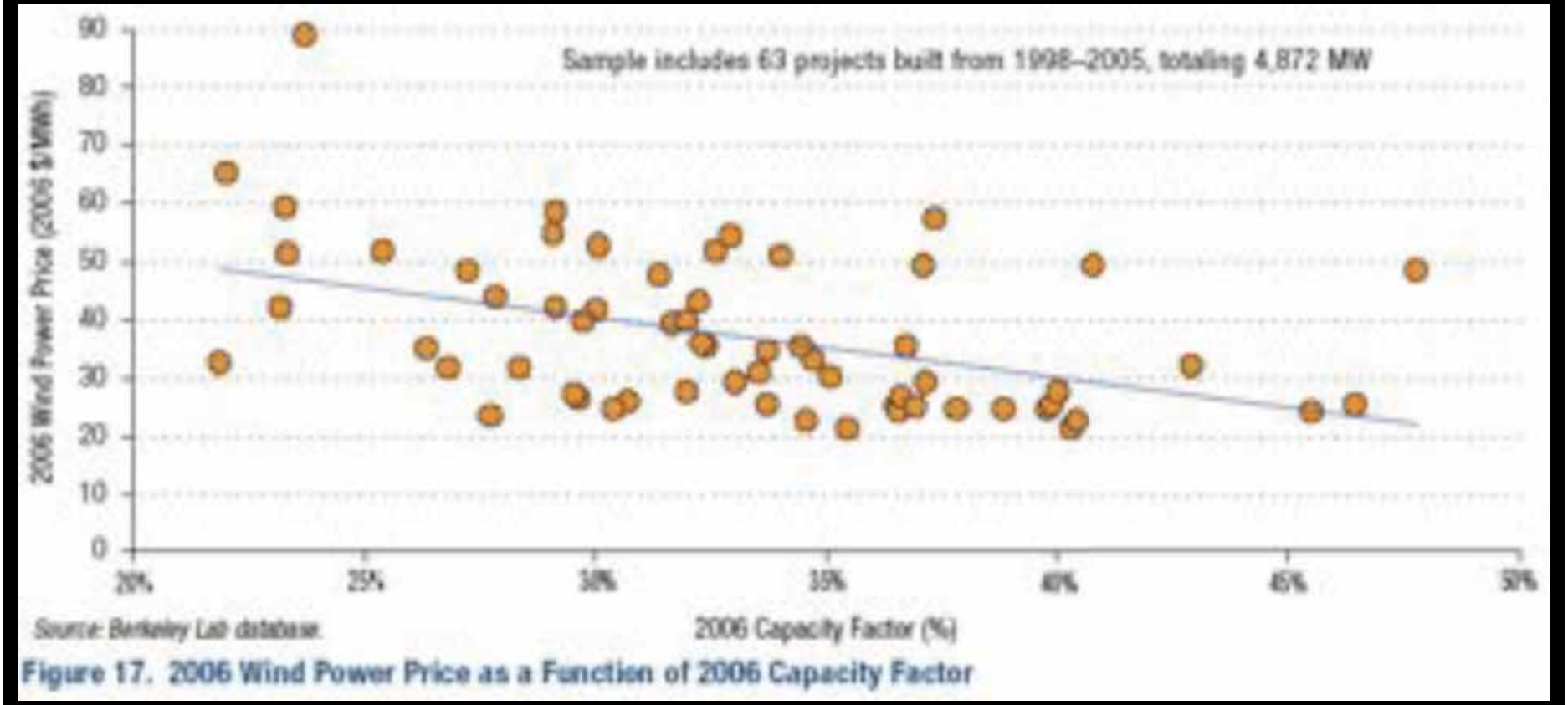


Figure 17. 2006 Wind Power Price as a Function of 2006 Capacity Factor

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

Long-term downward price trend, then 2005–6 uptick

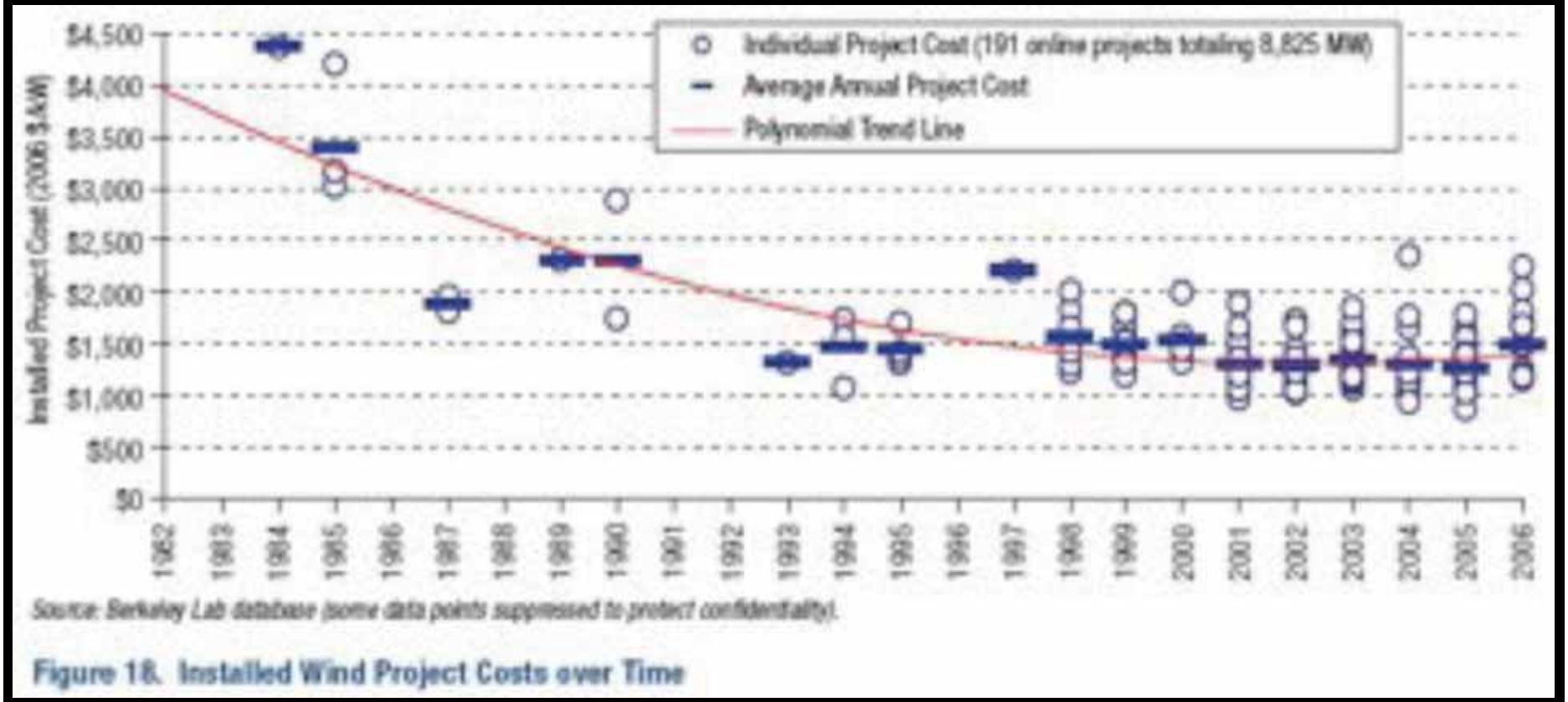


Figure 18. Installed Wind Project Costs over Time

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

World-leading 2005–6 US installation rate raised prices

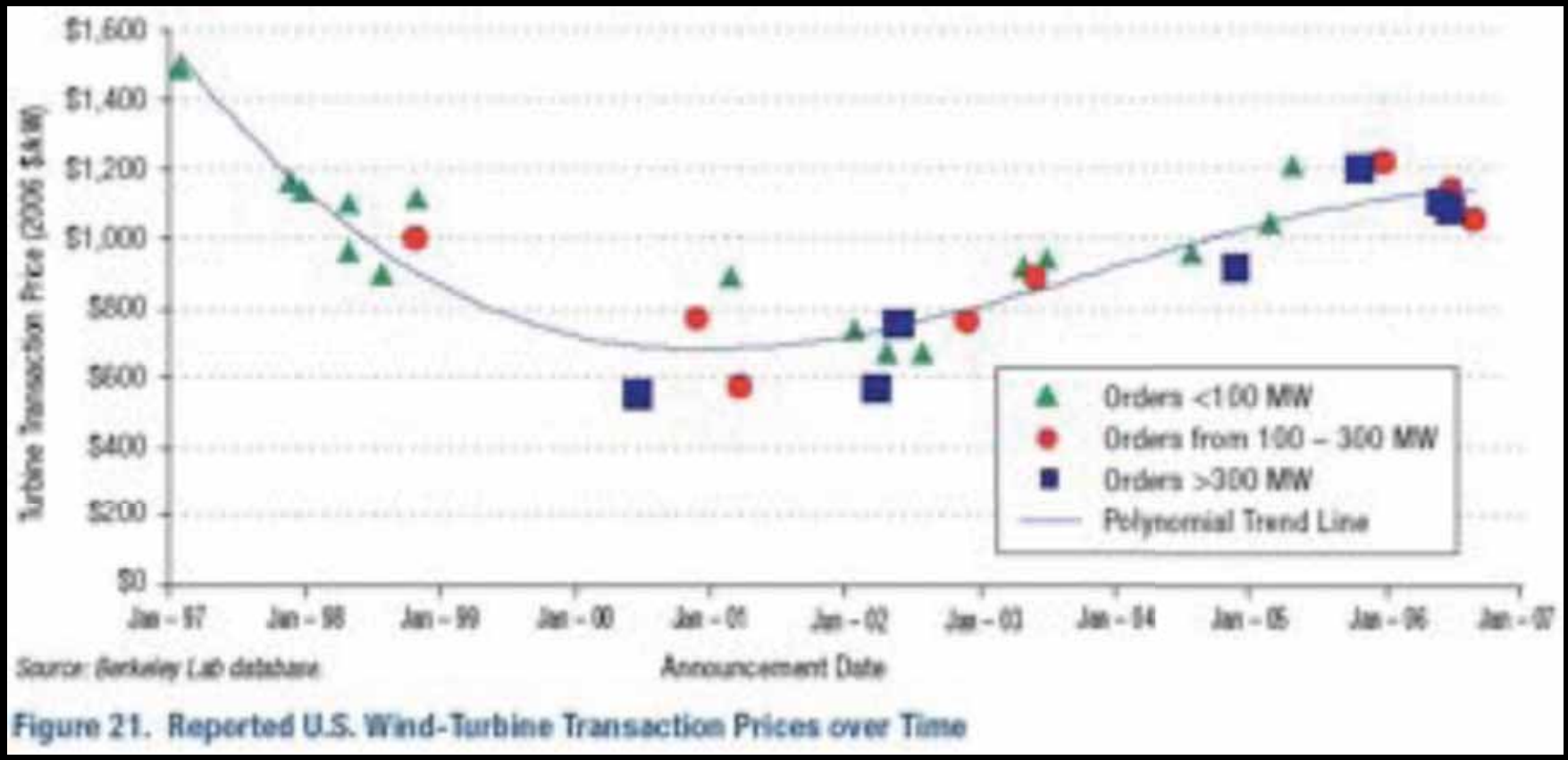


Figure 21. Reported U.S. Wind-Turbine Transaction Prices over Time

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

Project capacity factors are improving (now average ~35%)

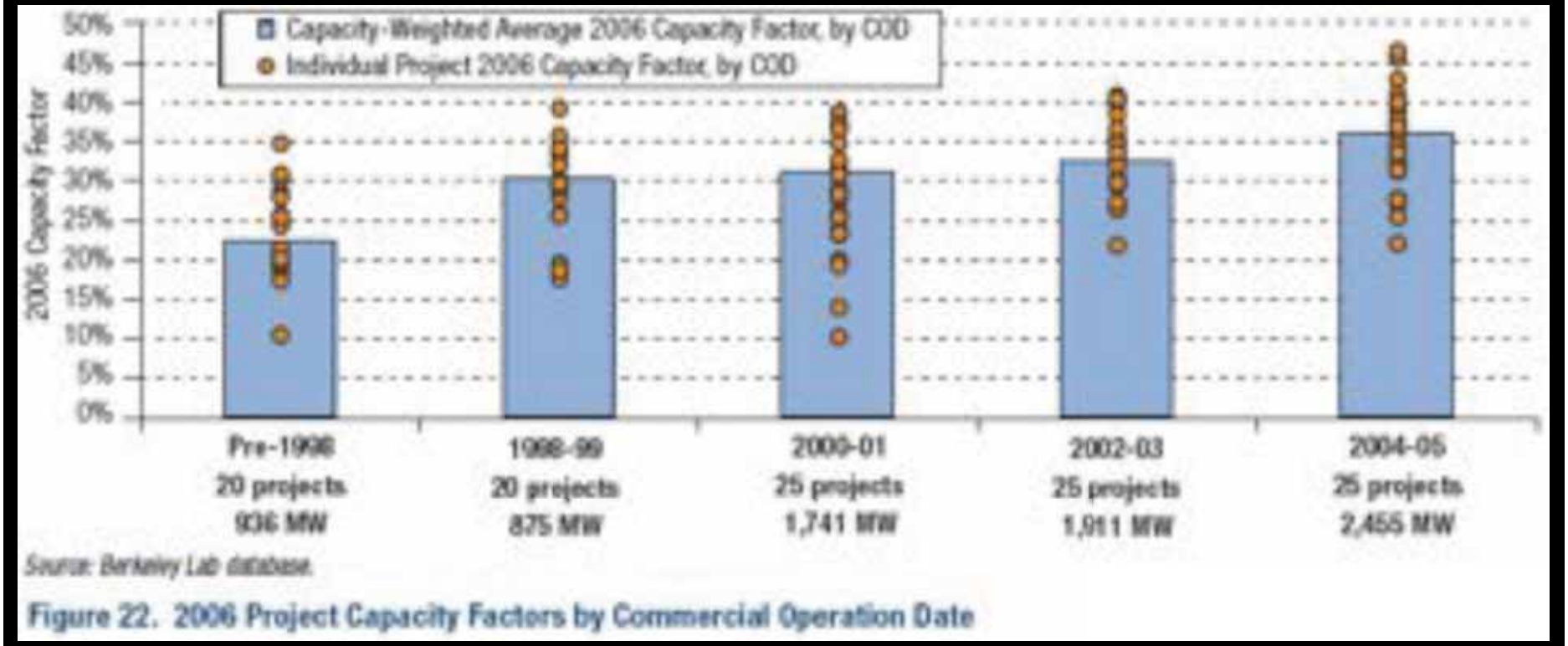


Figure 22. 2006 Project Capacity Factors by Commercial Operation Date

R. Wiser & M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," USDOE/EERE, LBL-41435, May 2007

Adopting renewables for energy security

- Urban strategy, *e.g.*, San Francisco's $100M bond
- Project developers, *e.g.*, windfarms (on/offshore)
- Real-estate developers, *e.g.*, Durst, Real Energy, Astro-Power/Shea, Beazer Homes "Powerhouse"
  - Different-colored "ultrareliable" wall sockets; expandable kW
  - Resilient, gracefully/reversibly islandable inverters
- Commercial/industrial PV retrofits, *e.g.*, PowerLight
- Military applications (facilities and in-theater)
- Regional and state policy / diversified portfolios
- Supportive state utility/interconnection policies
- Efficiency-*plus*-renewables is the big winner…

Key to rapid renewables deployment: efficient end-use

- Enables renewables to take a bigger share of the reduced market, sooner, more visibly
- Renewables work better technically with efficient use (*e.g.*, PV lighting, solar water htg.)
- Easier integration of intermittent el. sources
- Bundling efficiency with renewables can radically improve the economics of the package
- Special security benefits of combining the two
- Renewables providers should focus on integrated solutions, not single technologies

Infrastructure enablers

- Communication and control on end uses is the critical enabler for demand response
  - Which network configuration will prove to be least cost?
- If we invest in new meters, shouldn't we be looking forward into the future of the end uses they are metering?
  - Smart appliances are coming (Carrier, Whirlpool)
  - H_2–Hypercar® integration — sell power and ancillary services back to the grid when and where they're most valuable
  - Onsite storage (ultracapacitors, superflywheels, reversible fuel cells, flow batteries,…) will further increase DG's value
  - Demand responsiveness can add spectacular value to an integrated bundle of end-use efficiency plus onsite generation — all already delivered, bypassing any grid constraints
- Omnidirectional-web distribution automation

Some instructive PV applications (*Small Is Profitable*, pp. 252–262)

- LCRA did PV warning beacons on a cooling-water dam…a few hundred m from a 1.5-GW plant
- PG&E saved $200k w/PV strobes on 58-m tx towers
- PV home walkway lights beat burying a wire
- West Kendall FL in ‘91 (!) beat utility-pwrd street lts
  - Kept running through 33-h utility outage after Hurricane Andrew
  - Modern superefficient PV-integrated street lights are MUCH better
- SMUD saved ~1/6 on downtown Sac’to alley lights, counting energy cost at zero, or ~2/5 @ actual rate
- In Eindhoven in 1991 (!), a 50-av-W house yielded a ~10-y payback vs. hookup to grid a few m away
- Eff. + PVs in Indonesian village gave pos. cashflow

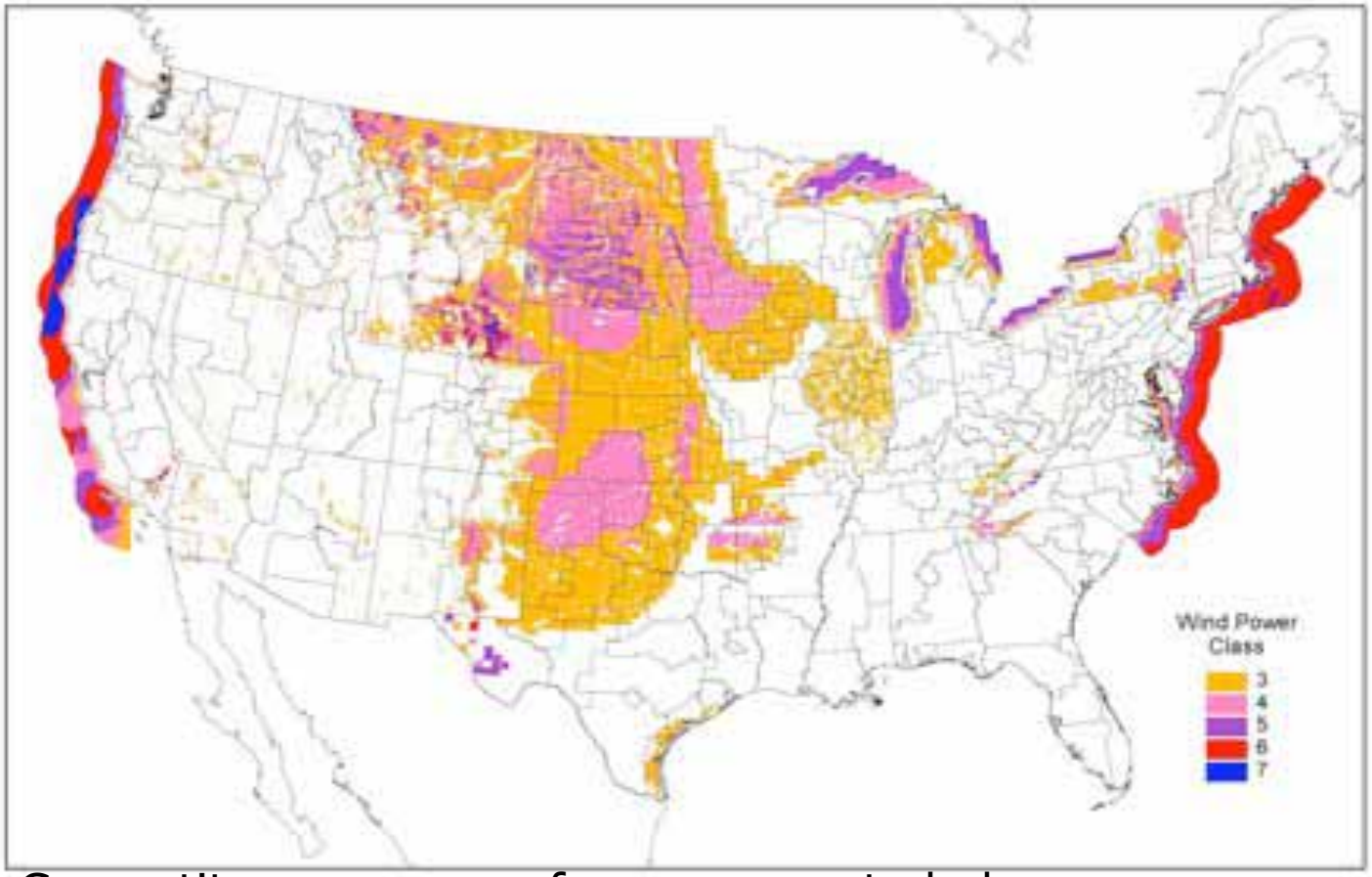
Seven fundamentals (no matter what your scale or risk appetite)

- Even after recent shifts from fossil & nuclear fuels to renewables and toward more appropriate scale, most (>90%?) energy capital remains misallocated
  - *E.g.*, by 1990, the U.S. misallocated ~$1 trillion just for ~200 million tons of air conditioning + its ~200 GW of power supplies
- Energy efficiency's untapped potential is far bigger and cheaper than widely assumed, is getting more so, and will for at least another century or so
- Biggest underinvestments are in saving el. and oil
- Improving technology is important—but much less important than *design to apply existing* technology
- Policy & marketing are as innovative as technology
- Some big leapfrogs assumed to need policy drivers will actually be driven by competitive strategy
- For starters, we must *track* efficiency, in J and $!

Issues of a more aggressive approach to DSM or cogeneration by a G&T cooperative

- How is the practice of *least-cost planning* to be interpreted in the context of resource planning and customer rates?
- What is the potential to market, implement, and finance DSM programs for energy efficiency, load management and cogeneration with direct customers, as well as the customers of municipal and other utility customers?
- What is the role of such program options as financial incentives, rate modifications, direct installation, and competitive bidding approaches?
- Will there be a problem with stranded generation assets?
- These are issues that require further study in the context of a supply coop serving munis and distribution coops
- Any distribution coop (or G&T) buying bulk power can require the supplier to indemnify against carbon risks

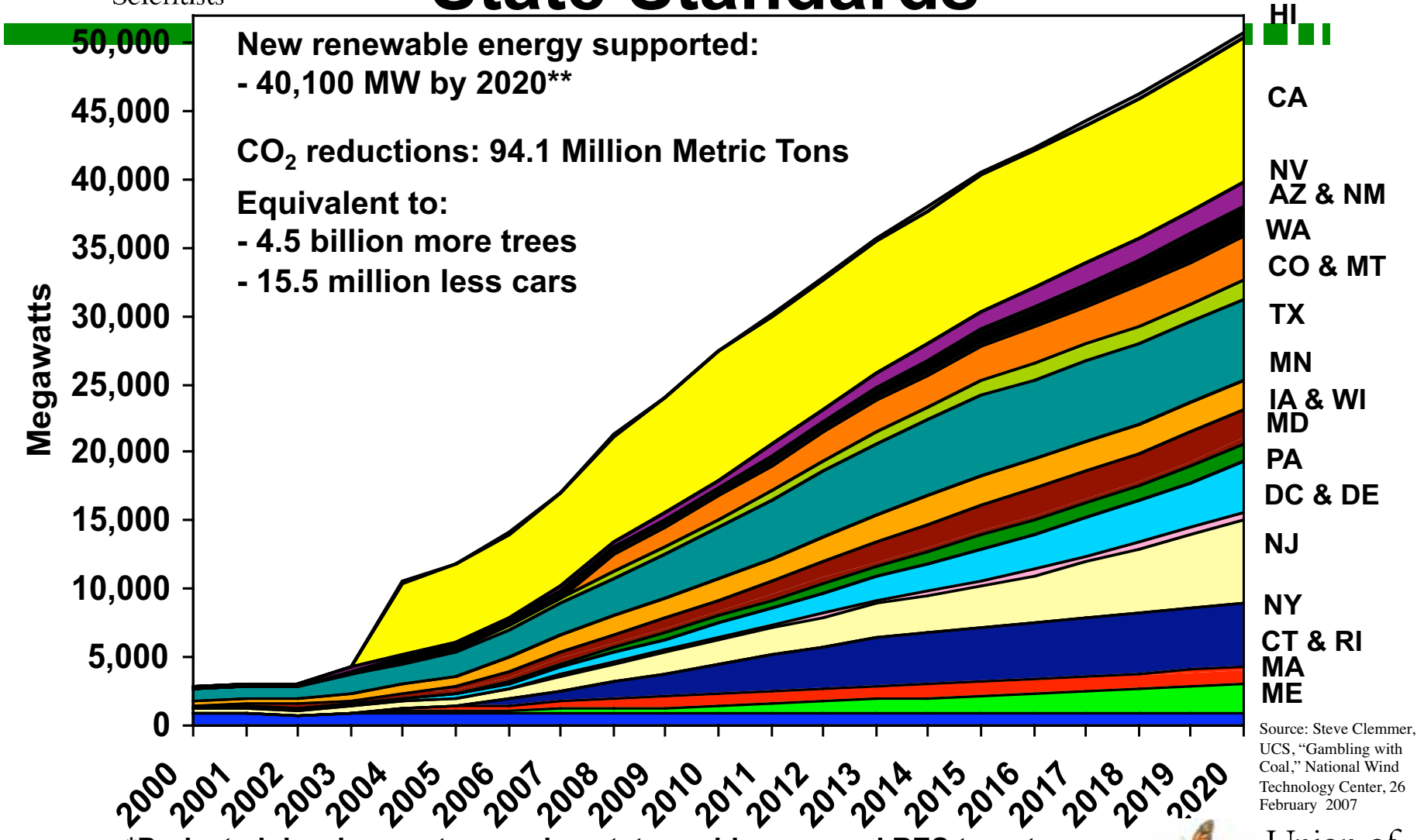
Wind resources in WinDS (NREL model) show strong resources, closer to most big load centers than coal is



Competitors can come from unexpected places: *e.g.*, NREL estimates a 50%-plug-in hybrid car fleet in 2050 could increase installed windpower by ~230 GW and save more coal-fired electricity than total U.S. use today

Renewable Energy Expected From State Standards*

Union of Concerned Scientists



Source: Steve Clemmer, UCS, "Gambling with Coal," National Wind Technology Center, 26 February 2007

*Projected development assuming states achieve annual RES targets.

**If achieved, IA, IL, ME and MN goals would support an additional 6,200 MW by 2020.

Union of Concerned Scientists

Initial steps in carbon risk management for electricity sector

- Characterize risk of CO_2 charges—range & uncertainties of future values
- Evaluate the potential for overcoming barriers to local options for energy efficiency and for generation on the customer side of the meter
- For local options, apply a comprehensive marginal cost and benefit analysis, subjecting each measure to the standard utility resource cost test
- Evaluate external offset options begins by ranking options' expected range of costs and reductions, also counting less tangible criteria, including:
  - Risk/reliability and permanence/persistence of the offset investments
  - Measurability and certainty of offset certification
  - Potential revenue upside (e.g., Clean Development Mechanism credits fungible in Europe)
  - Institutional barriers and potential transaction costs
  - Location (domestic *vs*. international, proximity to service territory)
- Compare the offset options with the local reduction options, comparing their magnitude, cost per ton of CO_2 reductions, and other criteria
- Assemble a portfolio of options to balance total cost against criteria, and determine a timing strategy to prioritize investments to implement first
- Make bulk power or fuel suppliers indemnify you against carbon costs
- Be sure you form retail prices in a way that rewards lower customer bills!

Examples of public utilities' advanced strategy and supply/demand integration

City of Palo Alto Utilities (CPAU)

- RMI is assisting the implementation of Energy Resource Portfolio Planning
- CPAU's WAPA contract expiration exposes the utility to volatile power markets
- Available local resources include efficient use and customer-sited distributed generation
- Utility-owned trigeneration has attractive technical and economic potential

City of San Francisco PUC (Hetch Hetchy Water and Power)

- RMI developed an Energy Resource Investment Strategy (ERIS) for the City
- An initial scenario analysis showed a proposed central power plant was unnecessary
- ERIS provides a blueprint for efficiency, distributed generation, & transmission solutions
- The strategy addresses local environmental justice, economic development and jobs

Nebraska Public Power District (NPPD)

- RMI performed a supply risk analysis, comparing reliability and economic impacts
- Under carbon constraints, for example, fuel price feedbacks negate any advantage of gas *vs.* coal
- Emissions can be reduced via renewable sources, customer efficiency, and cogeneration, or by traded carbon offsets
- For a G&T, an important challenge is how to advance energy efficiency with end-use customers: can buy it from distributors, as Metro Water District of S.Ca. did for water