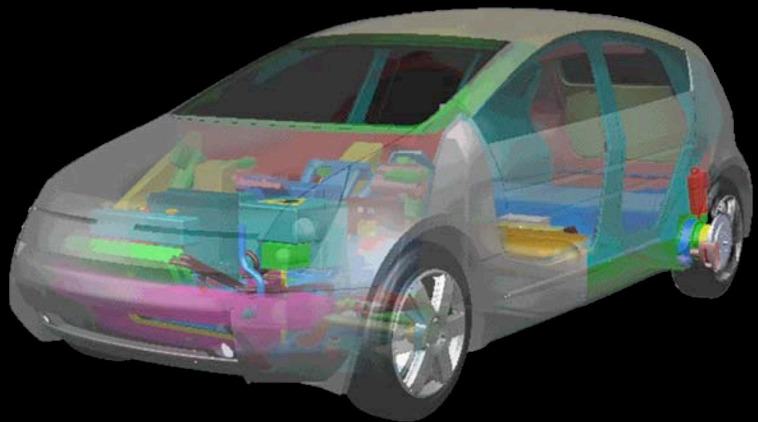

ROCKY MOUNTAIN
INSTITUTE

Fachtagung "Neue Atomkraftwerke in der Schweiz"

Schweizerische Energie-Stiftung, Zürich, den 12. Sept. 2008

Profitable Solutions to Climate Change, Oil Dependence, and Nuclear Proliferation



To be truly radical is to make hope possible, not despair convincing.

— Raymond Williams

Amory B. Lovins, Foreign Member Royal Swedish Acad. of Eng. Sciences, Hon. AIA, FRSA

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Energy policy: a multiple-choice test

Would you rather die of:

1. climate change?
2. oil wars?
3. nuclear holocaust?

The right answer, often left out, is:

4. none of the above

Let's just use energy in a way that saves money, because that will solve the climate, oil, and proliferation problems—not at a cost but at a profit

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

A. Both got messed up by a sign error ("+" *vs.* "–")

The incorrect *assumption* that climate protection will be costly is the biggest obstacle to doing it

Saving energy costs less than buying it, so firms are starting to buy energy efficiency *whether or not they worry about climate*

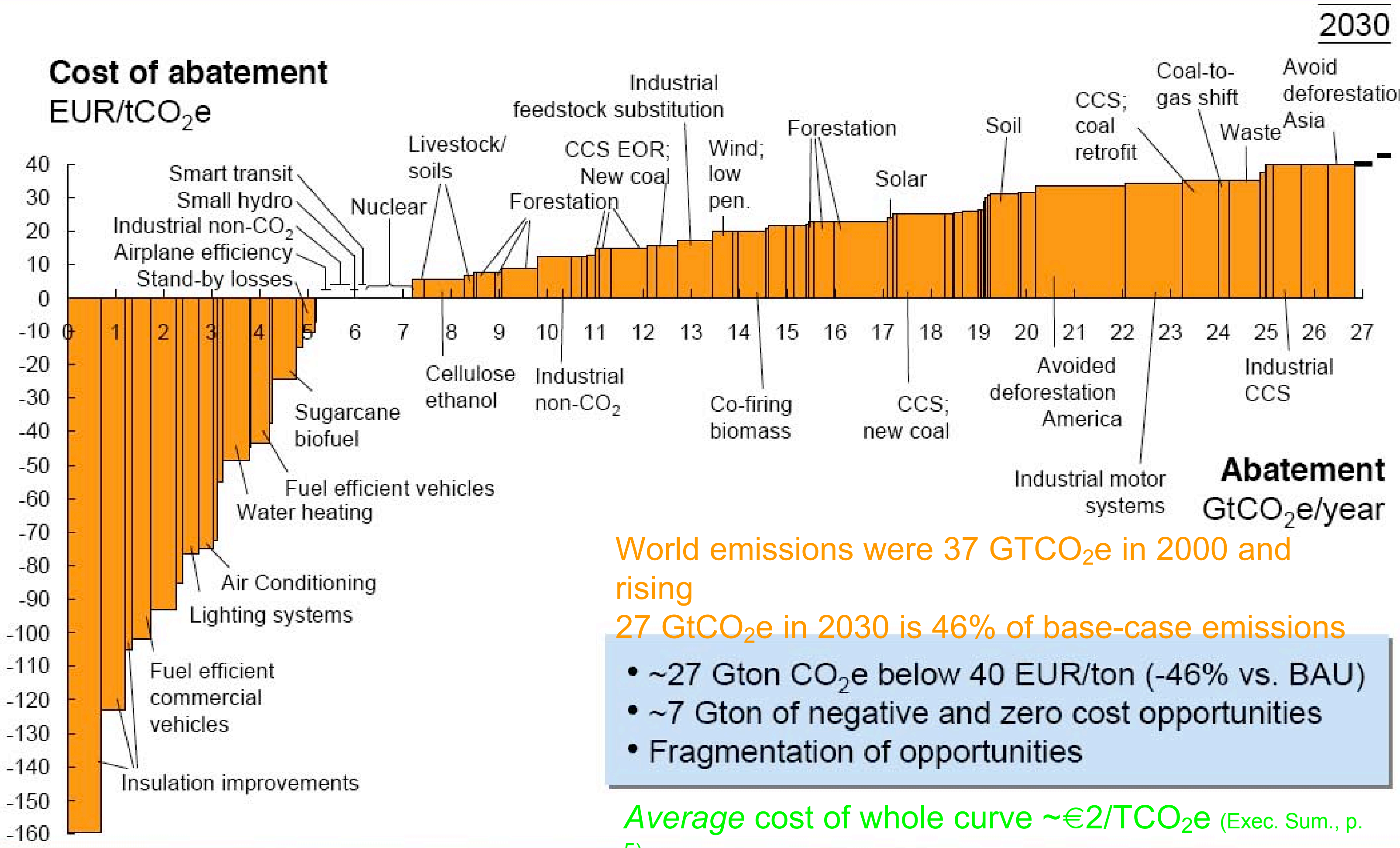
- IBM and STMicroelectronics
  - CO_2 emissions –6%/y, fast paybacks
- DuPont's 2000–2010 worldwide goals
  - Energy use/$ –6%/y, GHG = 1990 level –65%
  - By 2006: actually cut GHG 80% below 1990, $3b profit
- Dow: cut E/kg 22% 1994–2005, $3.3b profit
- BP's 2010 CO_2 goal met 8 y early, $2b profit
- GE pledged 2005 to boost its eff. 30% by 2012
- United Technologies cut E/$ 45% during 2003–07
- Interface: 1996–2007 GHG –82% (–16%/y)

- So while the politicians endlessly debate theoretical "costs," smart firms race to pocket real *profits!*

2007 Vattenfall/McKinsey supply curve for abating global greenhouse gases

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

Global cost curve of GHG abatement opportunities beyond business as usual



World emissions were 37 GTCO_2e in 2000 and rising

27 GtCO_2e in 2030 is 46% of base-case emissions

- ~27 Gton CO_2e below 40 EUR/ton (-46% vs. BAU)
- ~7 Gton of negative and zero cost opportunities
- Fragmentation of opportunities

Average cost of whole curve ~€2/TCO_2e (Exec. Sum., p. 5)

Profitable climate protection: how much can we do, how fast?

- 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. has spontaneously saved >2%/y since '97; 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; still saving much more
- China did even better—saved >5%/y for >20 y, 7.9%/y 1997–2001; energy efficiency is top priority
- Attentive corporations profitably save ~6–9%/y…so why should 3%/y be difficult or costly?
- Even Japan can profitably save 2/3 of *its* energy
- Oil causes 42% of all CO_2 emissions, electricity 40%

Independent, transparent, peer-reviewed, uncontested

DoD-cosponsored, Sept 04

For business & mil. leaders

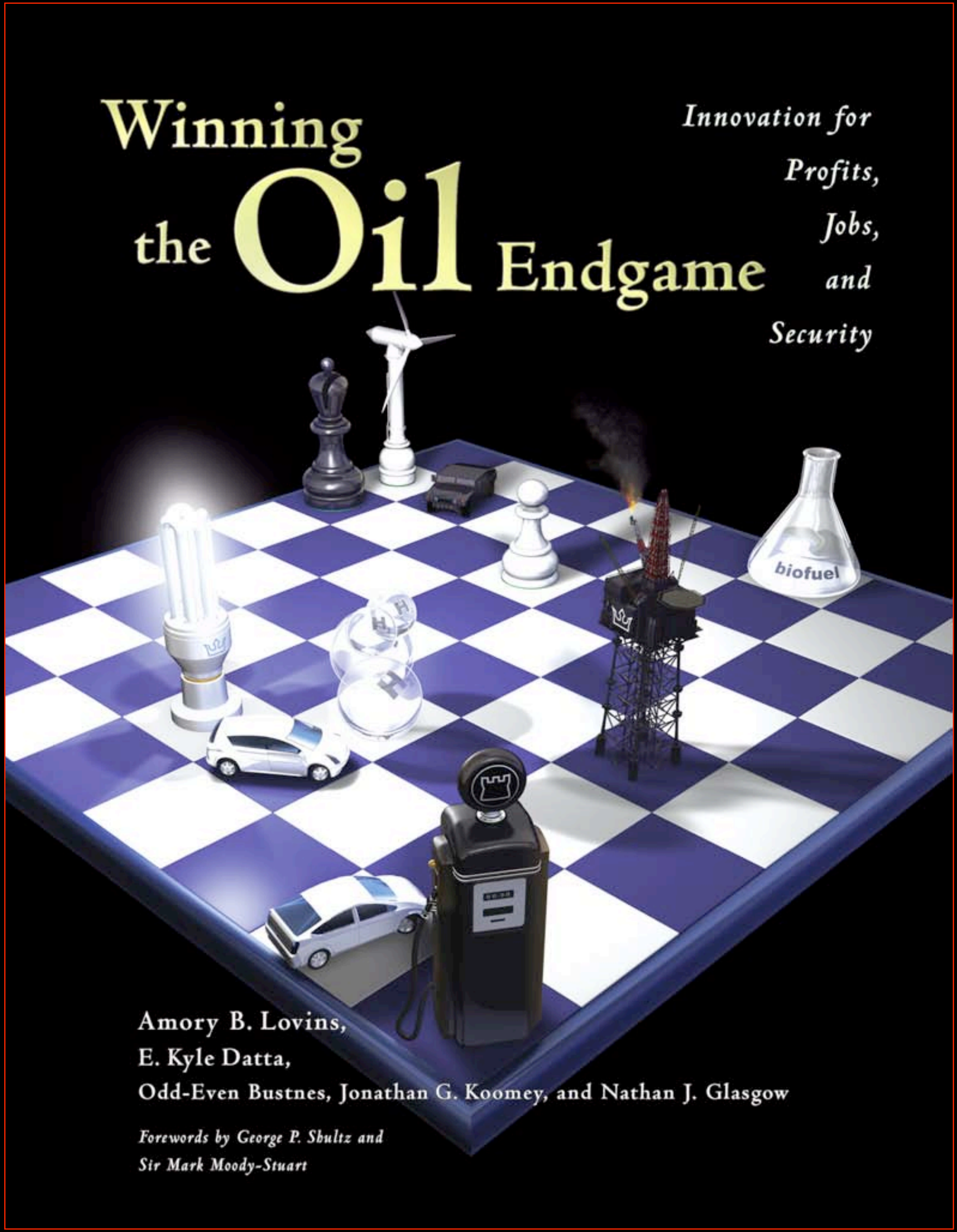
Based on competitive strategy cases for cars, trucks, planes, oil, military

Book and technical backup are free at:

www.oilendgame.com

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

So, very probably, can CH



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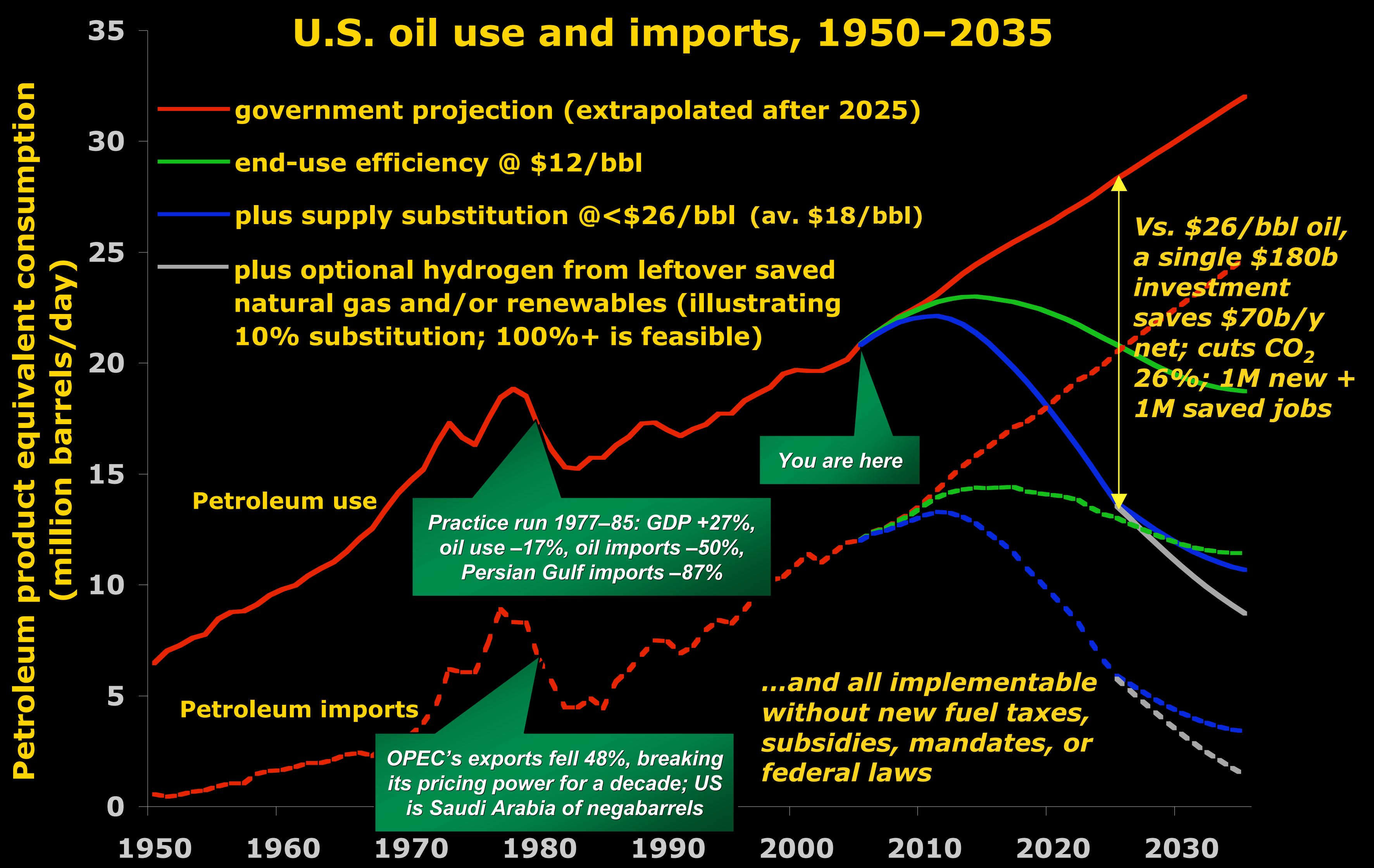
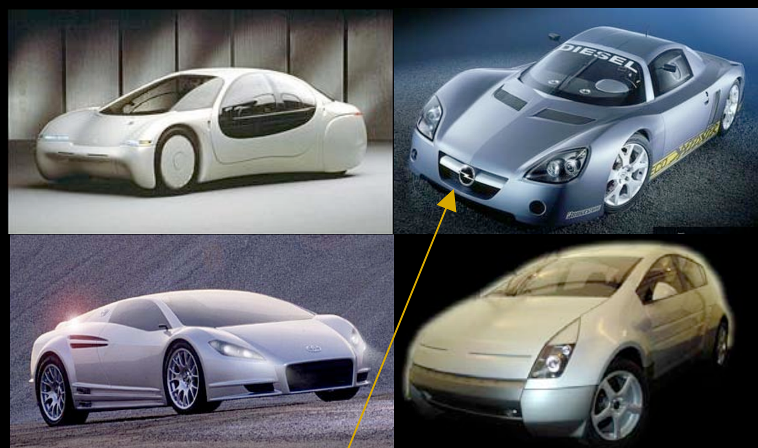
A profitable US transition beyond oil (with best 2004 technologies)



Tripled-efficiency cars, trucks, and planes by integrating ultralight, ultra-low-drag, and advanced-propulsion

CARS: save 69% at $0.15/L

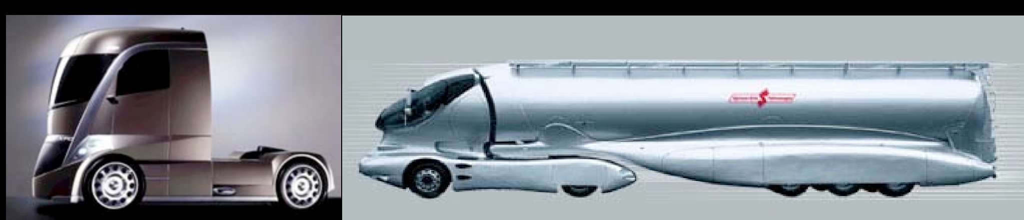
Surprise: ultralighting is ***free* —** offset by simpler automaking and 2–3× smaller powertrain!



250 km/h, 2.5 L/100 km

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

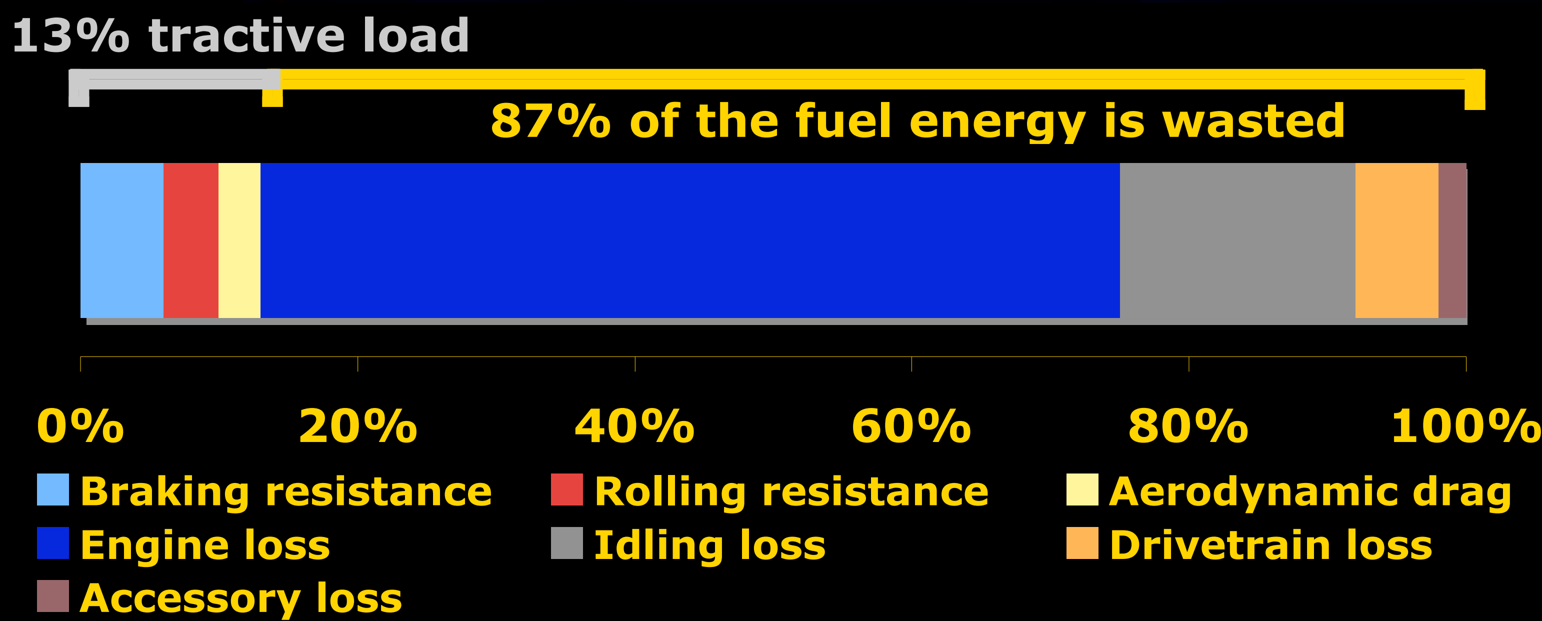
TRUCKS: save 25% free, or 65% @ $0.07/L



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

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

Each day, your car uses ~100× its weight in ancient plants. Where does that fuel energy go?



- 6% accelerates the car, ~0.3% moves the driver
- Three-fourths of the fuel use is weight-related
- Each unit of energy saved at the wheels saves ~7–8 units of gasoline in the tank (or ~3–4 with a hybrid)
- **So first make the car radically lighter-weight!**

Midsize 5-seat* Revolution concept *SUV (2000)
Ultralight (857 kg = steel – 53%) but ultrasafe
0–100 km/h in 8.3 s: 2.06 L/100 km with fuel cell
0–100/7.2 s: 3.56 L/100 km with gasoline hybrid

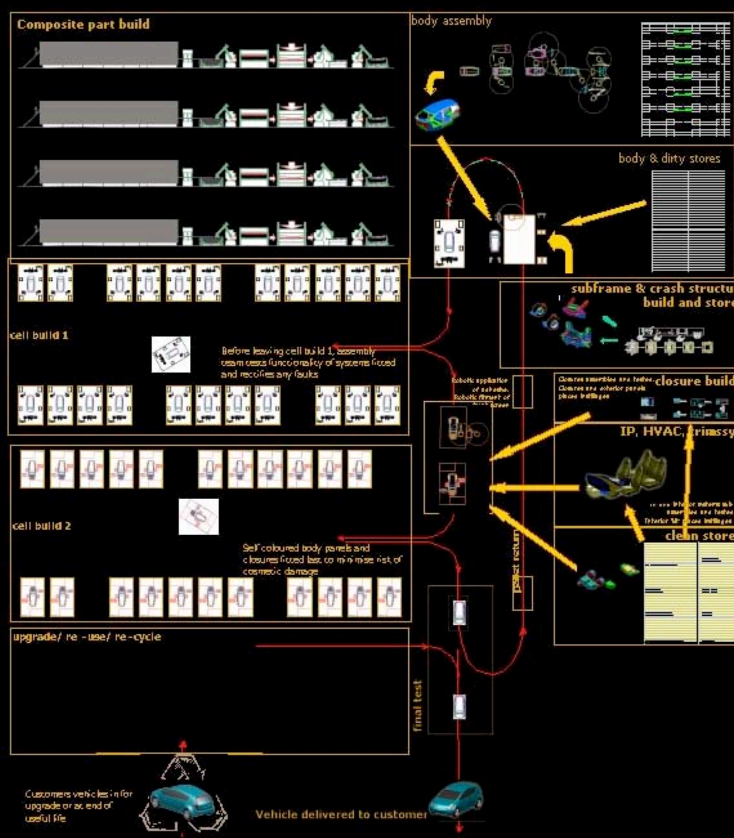
"We'll take two."
— *Automobile* magazine

World Technology Award, 2003

Show car and a complete virtual design, uncompromised, production-costed, manufacturable with a $2,511 higher retail price (as hybrid)

Radically simplified manufacturing

- Mass customization
  - *Revolution* designed for 50k/year production volume
  - Integration, modular design, and low-cost assembly
  - Low tooling and equipment cost



- 14 major structural parts, no hoists
- 14 low-pressure diesets (not ~10^3)
- Self-fixturing, detoleranced in 2 dim.
- No body shop, optional paint shop
- 2/5 less capital than leanest, 2/3 smaller

Toyota's Hypercar®-class *1/X* concept car (Tokyo Motor Show, 26 Oct 2007)

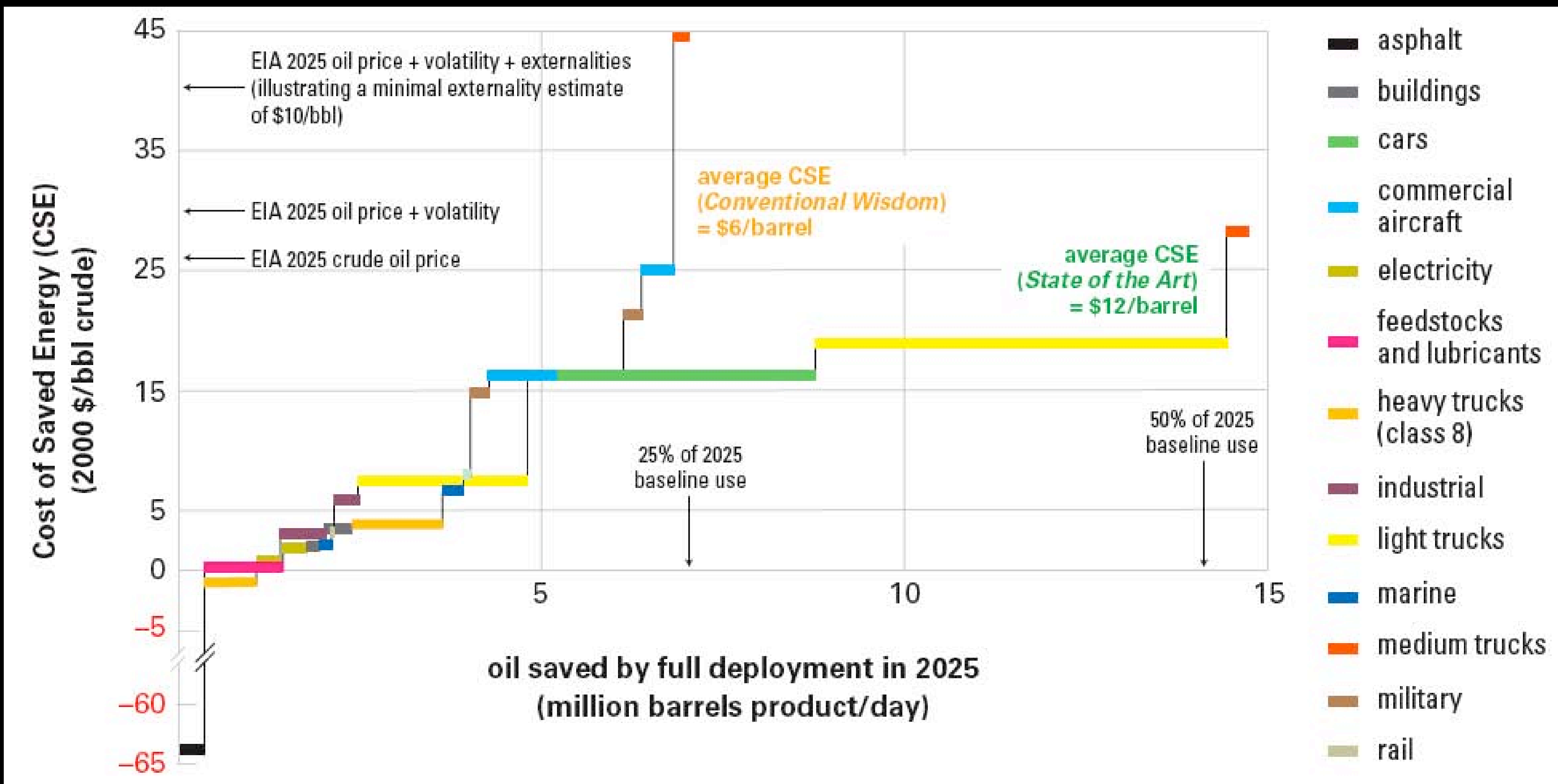
- 1/2 *Prius* fuel use, similar interior vol. (4 seats)
- 1/3 the weight (420 kg)
- carbon-fiber structure
- 0.5-L flex-fuel engine under rear seat, RWD
- plug-in hybrid-electric (if plain hybrid, 400 kg)

• One day earlier, Toray announced a ¥30b plant to mass-produce carbon-fiber autobody panels and other parts for Toyota, Nissan, …; in July 2008, similar Honda/Nissan/Toray deal announced too

• Nov 2007: Ford announced 113–340-kg weight cuts MY2012–20

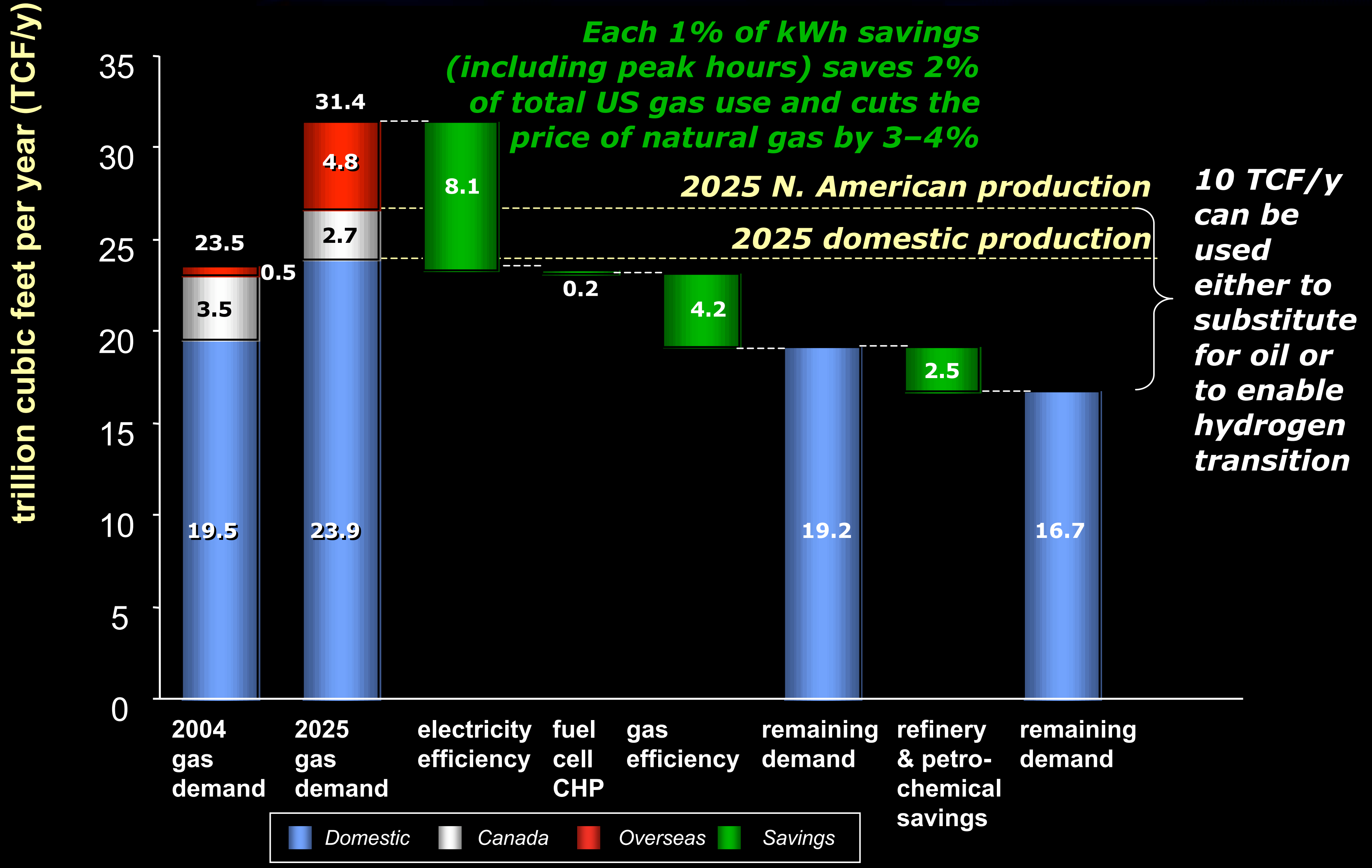
• Dec 2007: 15% av. weight cut in all Nissan vehicles by 2015; China formed auto lightweighting alliance targeting –200 kg 20*10*

It pays to be bold: saving half the oil for $12/bbl is better than saving a fourth at $6/bbl — else alt. supplies cost too much

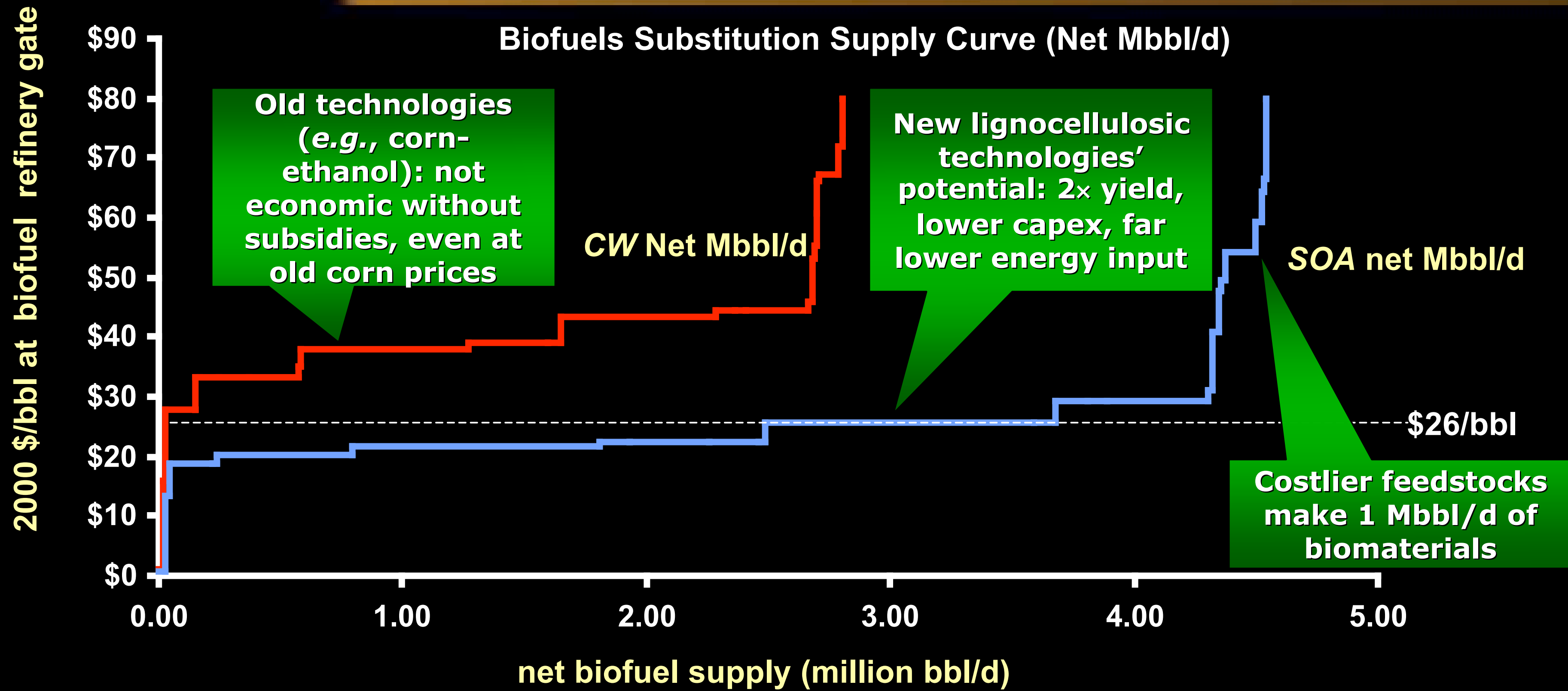


Hypothetically **assuming full deployment in 2025 (actually we realize half the savings by then); these curves assume no further invention in 2005–25**

>12 TCF/y of US natural gas could be saved by efficiency, at an average cost ~$0.9/MCF (<1/10th recent price); most gas eff. costs <0

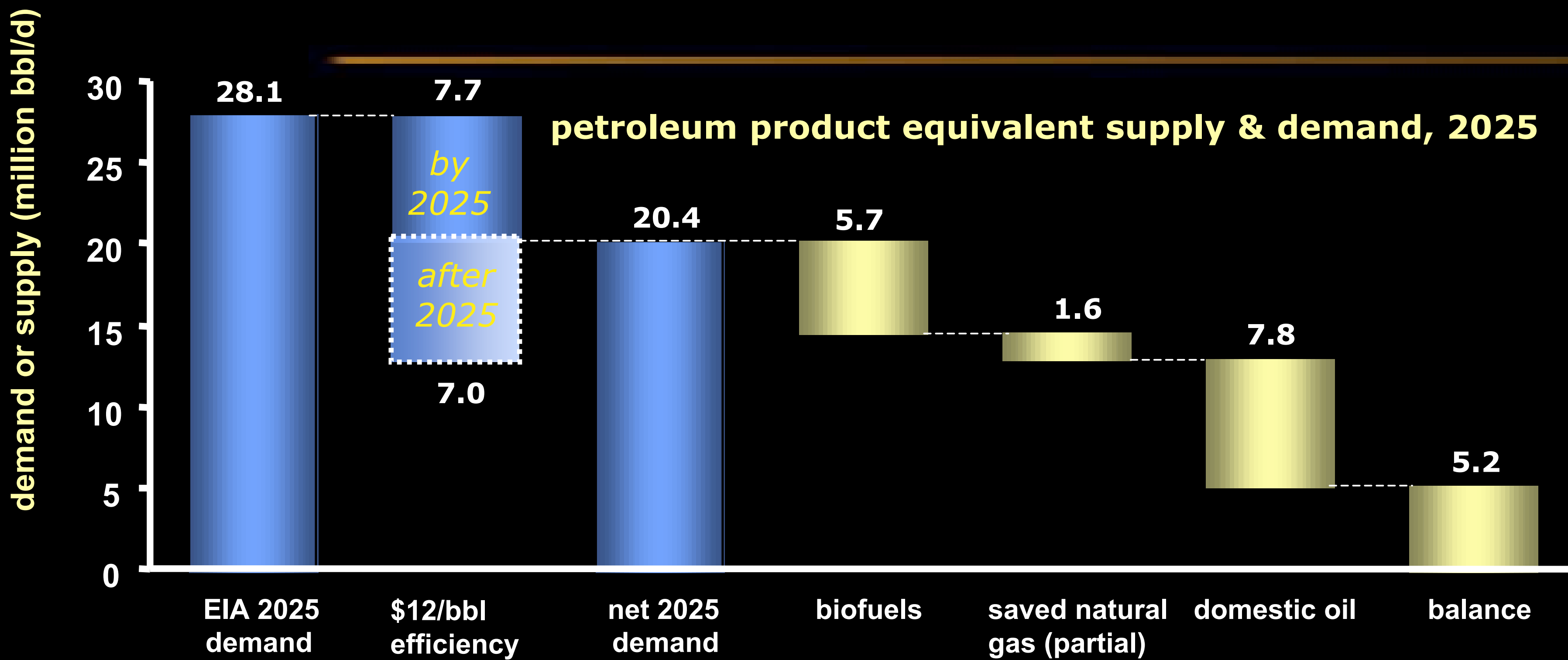


New biofuel technologies could provide 3.7 Mbbl/d cheaper than oil—without subsidies or crop/land/water problems



- Brazil has replaced 26% of gasoline with sugar-cane ethanol, competitive without subsidy (the startup subsidy has been recovered ~50× over)
- Sweden is going off oil by 2020–30 via cellulosic ethanol; anticipates H_2
- Europe in 2003 made 17× as much biodiesel as US: oil companies distribute >50%; shifts farmers from subsidy to revenue

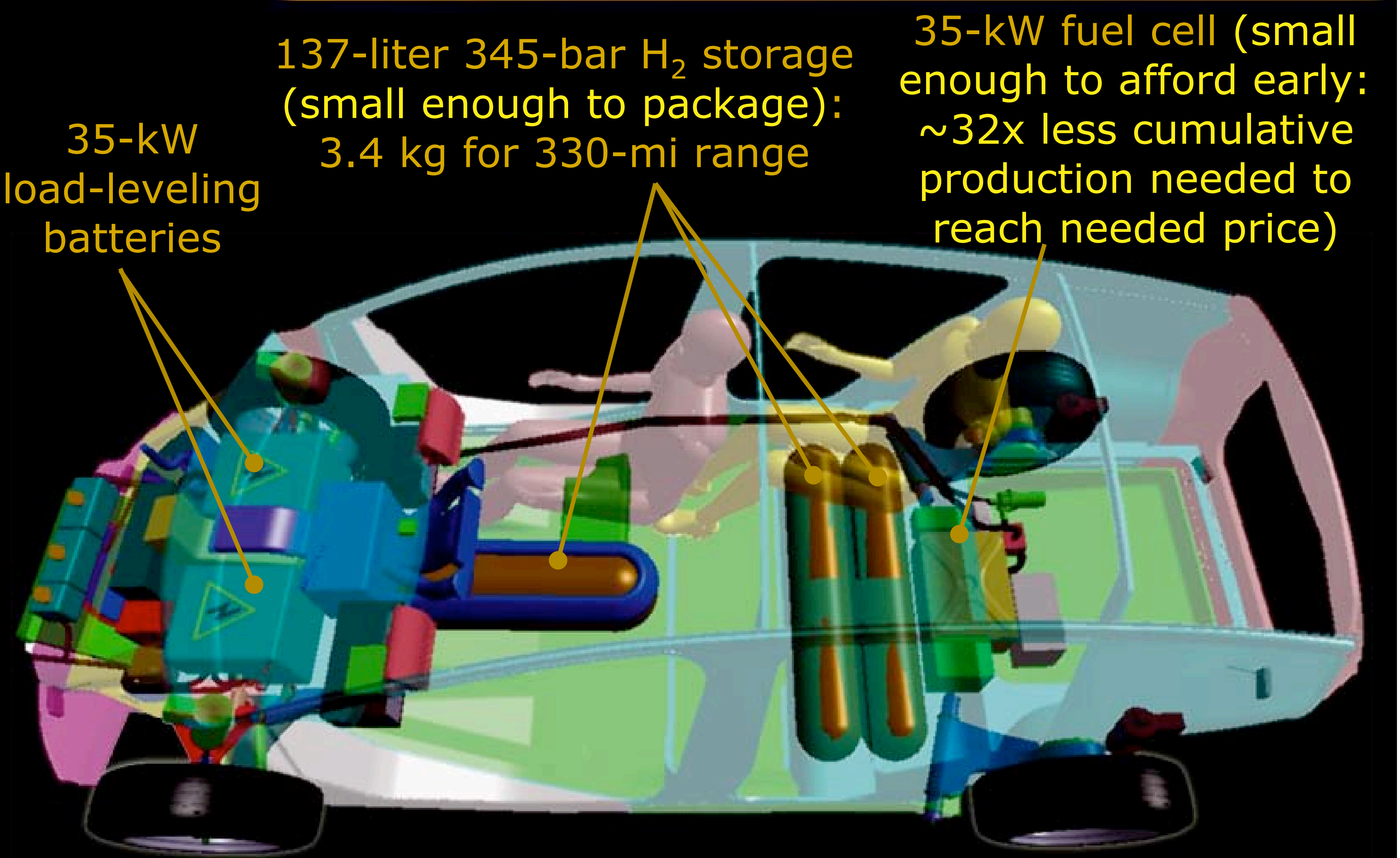
2025 demand-supply integration



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

- **Buy more efficiency (it's so cheap and rapidly improving)**
- **Wait for efficiency's other half — 7 Mbbl/d is still underway in 2025**
- **"Balance" can import crude oil/product (can be all N. Amer.) or biofuels**
- **Or saved U.S. natural gas @ $0.9/million BTU can fill the "balance"…or**
- **H_2 from saved U.S. natural gas can displace "balance" *plus* domestic oil**
- **Not counting other options, *e.g.*, ND+SD wind→H_2 to run all hwy vehicles**

1,889-lb curb mass (÷2), low drag, load ÷3, so 55 mph on same power as normal a/c, so ready now for direct hydrogen fuel cells



Big, fast changes have happened

- U.S. automakers switched in **six years** from 85% open wood bodies to 70% closed steel bodies—and in **six months** from making four million light vehicles per year to making the tanks and planes that won World War II
- In **eight years**, 1977–85, US cut oil/GDP by 5.2%/y—equivalent, at a given GDP, to a Gulf every 2.5 years; the 7.4-mpg (47%, 4.9%/y) gain in new US-made cars was the key
- Boeing launched *787* 4/04, scheduled in-service 1/09—built on prior work, but still all in the lab in 03; so a very complex and highly regulated product was transformed in **five years**
- GM's small team took *EV1* launch-to-street in **three years**
- Major technological transformations take **12–15 years** to go from 10% to 90% adoption in the product stock, but innovative business strategies and public policies can get to the first 10% years earlier, & greatly steepen adoption curve

Can an automaker use an efficiency-based strategy to transform itself?

- Boeing's crisis in 1997 was like Detroit's a decade later
- In 2003, Airbus for first time outproduced Boeing
  - "This is really a pivotal moment…could be the beginning of the end for Boeing's storied airplane business," said Richard L. Aboulafia, an aerospace analyst at Teal Group in 2003
- Boeing's bold, efficiency-led response: *787 Dreamliner*
  - >20% more efficient than comparable modern aircraft, *same price*
  - 80% advanced composite by volume, 50% by mass
    - Bigger windows, higher-pressure cabin
    - Many other important shifts, *e.g.* hydraulic→el.
  - 3-day final assembly (*737* takes 11 days)
  - 896 orders, 38 commitments, 434 rights & options
  - Sold out into 2018
  - Fastest order takeoff of any airliner in history
  - Boeing is now rolling out *787*'s radical advances to *all* models
- Airbus: Ultra-jumbo *A380* 2 years late, ~€5b over budget
  - Response? Ultraefficient, composite *A350*—probably too late

Implementation is underway via "institutional acupuncture"

- RMI's 3-year, $4-million effort is leading & consolidating shifts
- Need to shift strategy & investment in six sectors
  - Aviation: Boeing did it (*787 Dreamliner*)…and beat Airbus
  - Heavy trucks: Wal-Mart led it (25% fuel savings 2008, 50% soon)
  - Military: emerged Feb 2008 as the federal leader in getting USA off oil
  - Fuels: strong investor interest and industrial activity
  - Finance: rapidly growing interest/realignment will drive others
- Cars and light trucks: slowest, hardest, but now changing
  - Alan Mulally's move from Boeing to Ford with transformational intent
  - Workers and dealers not blocking but eager for fundamental innovation
  - Schumpeterian "creative destruction" is causing top executives to be far more open to previously unthinkable change
  - Emerging prospects of leapfrogs by China, India, ?new market entrants
  - RMI's two transformational projects and "feebate" promotion are helping
  - Competition, at a fundamental level and at a pace last seen in the 1920s, will change automakers' managers or their minds, whichever comes first

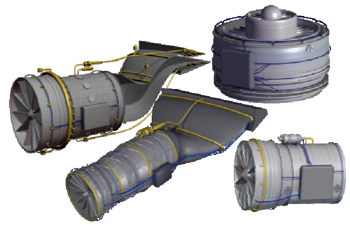
Military platform efficiency: dramatic gains available in combat effectiveness and energy efficiency almost everywhere, *e.g.*:

(from briefs to US Defense Science Board panel, 2/08, www.acq.osd.mil/dsb/reports/2008-02-ESTF.pdf)

(scaled-down wind-tunnel model)

BWB quiet aircraft: range & payload × ~2, sorties ÷ 5–10, fuel ÷ 5–9 (Σ 2–4)

SensorCraft (C4ISR): 50-h loiter, sorties ÷ 18, fuel ÷ >30, cost ÷ 2



VAATE engines: loiter × 2, fuel – 25–40%, far less maintenance, often lower capital cost

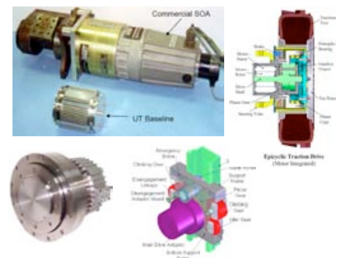
Optimum Speed Tilt Rotor (OSTR): range × 5–6, speed × 3, quiet, fuel ÷ 5–6

Re-engine *M1* with modern diesel, range × ≥2, fuel ÷ 3–4

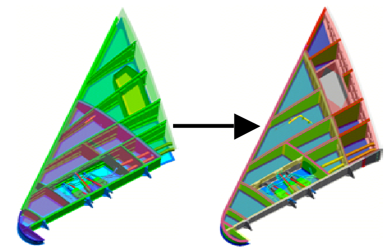
More lethal, highly IED-resistant, stable *HMMVV* replacement, weight ÷ 3, fuel ÷ >3

Hotel-load retrofits could save ~40–50% of onboard electricity (thus saving ~1/6 of the Navy's non-aviation fuel)

FOB uses 95% of gen-set fuel to cool desert; could be ~0 with same or better comfort

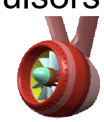
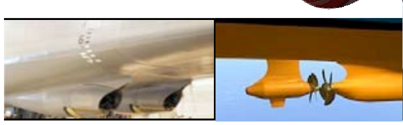
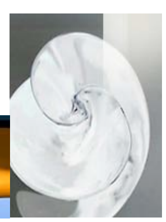


Actuators: performance × 10, fault tolerance × 4, size & mass ÷ 3–10



25% lighter, 30% cheaper advanced composite structures; aircraft can have ~95% fewer parts, weigh ≥1/3 less, cost less

Advanced propulsors can save much noise and fuel

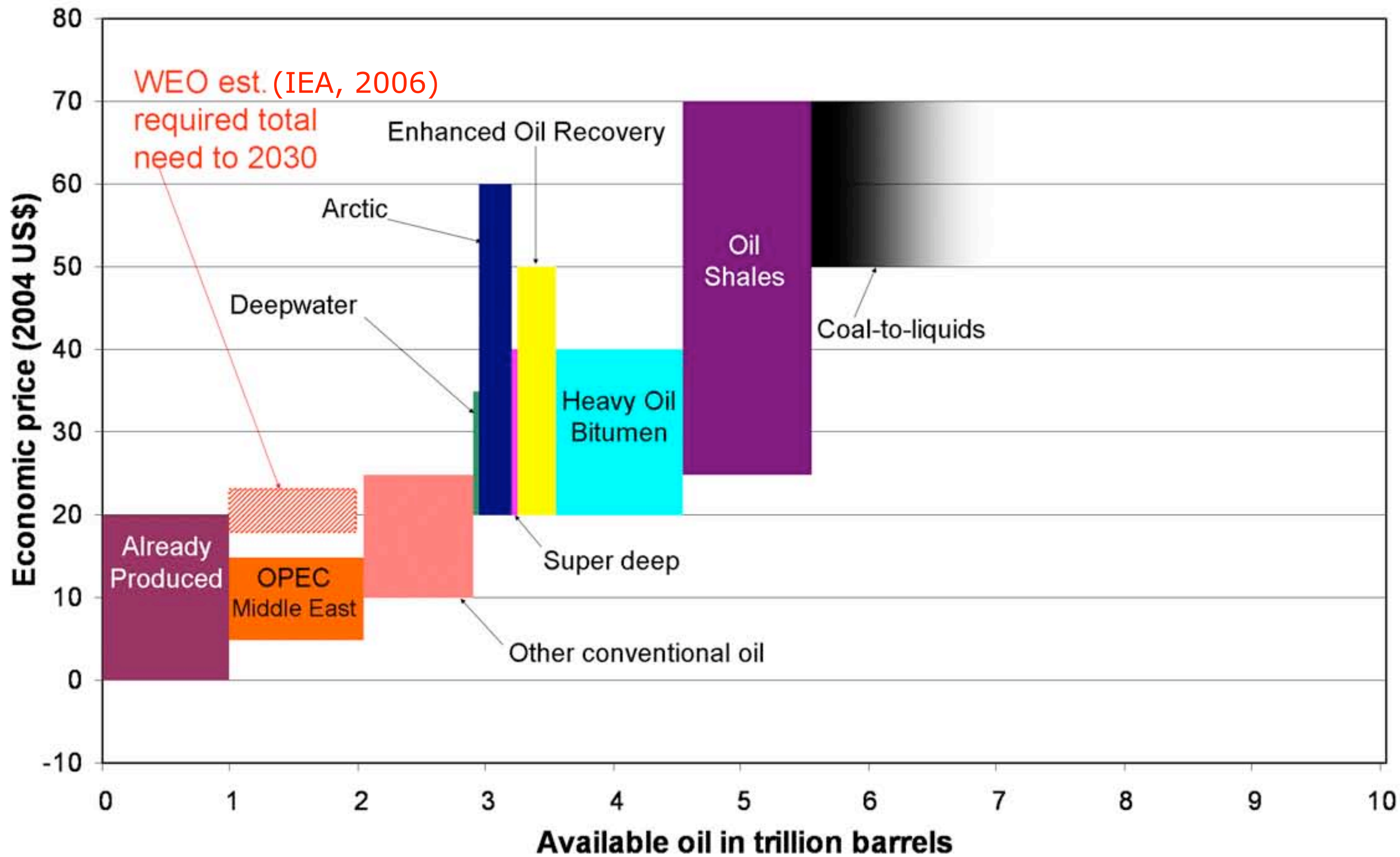




Rugged, 2.5-W PC, $150, solar + back-up crank

A zero-net-energy building (it's been done in –47˚–+115˚F at lower cost)

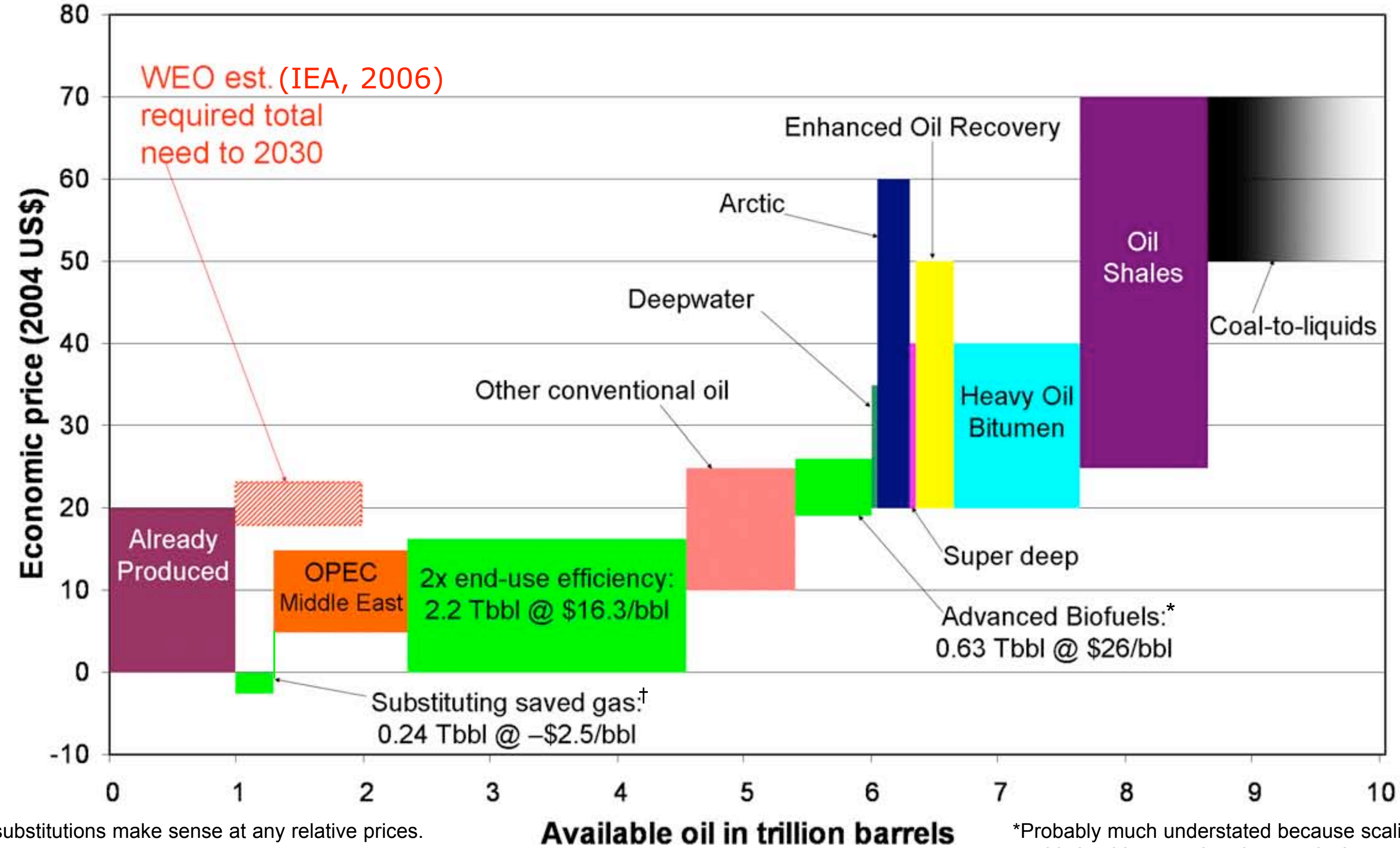
160-Gflops supercomputer, ultrareliable with no cooling at 87˚F, lifecycle cost ÷ 3–4

The oil industry’s conventional wisdom: approximate long-run supply curve for world crude oil and substitute fossil-fuel supplies



Source: BP data as graphed by USDoD JASON, “Reducing DoD Fossil-Fuel Dependence” (JSR-06-135, Nov. 2006, p. 6, www.fas.org/irp/agency/dod/jason/fossil.pdf), plus (red crosshatched box) IEA’s 2006 *World Energy Outlook* estimate of world demand and supply to 2030, plus (black/gray) RMI’s coal-to-liquids (Fischer-Tropsch) estimate derived from 2006–07 industry data and subject to reasonable water constraints. This and following graphic were redrawn by Imran Sheikh (RMI)

How that supply curve stretches ~3 Tbbl if the U.S. potential shown in *Winning the Oil End-game* scales, very approximately, to the world

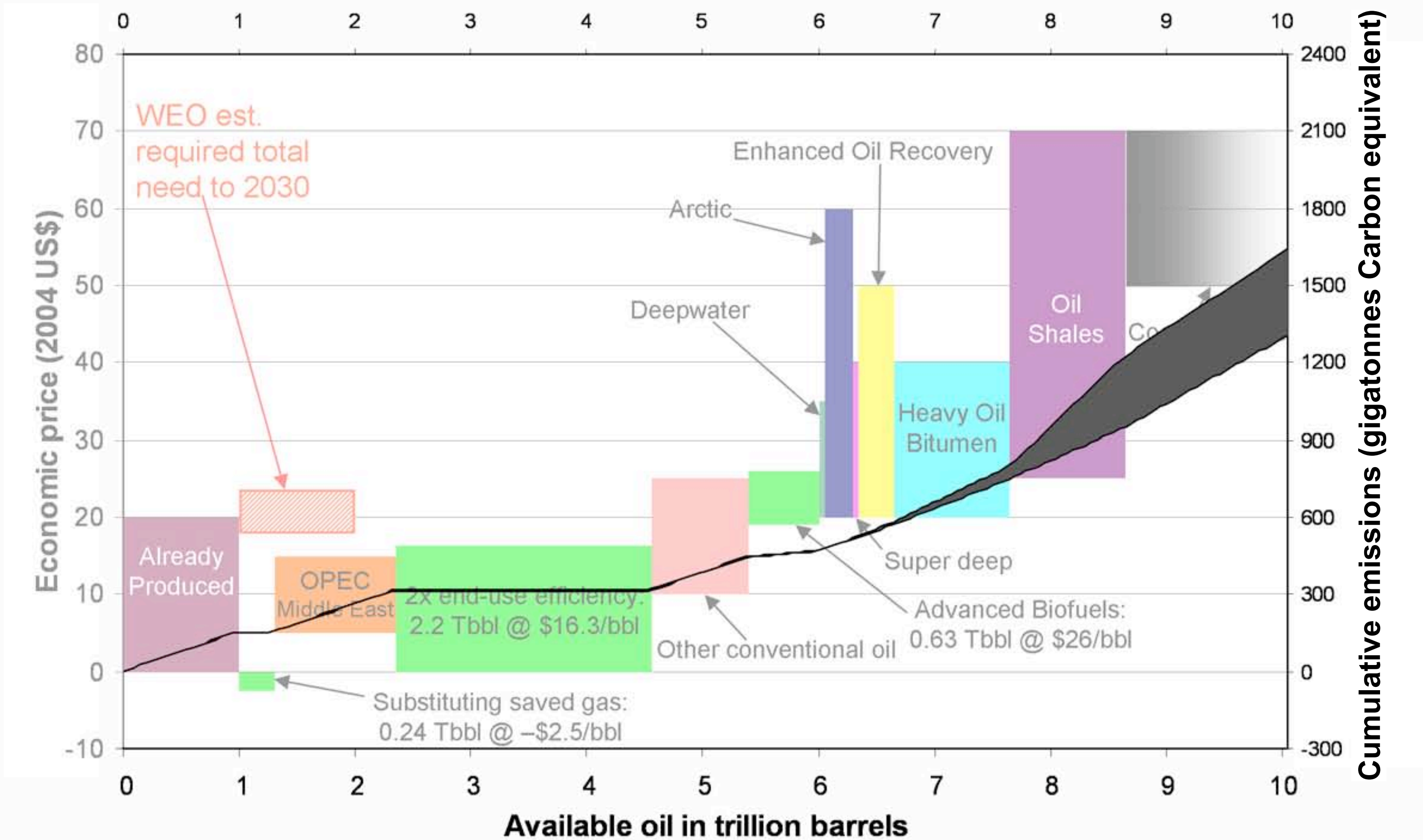


†These substitutions make sense at any relative prices. Depending on future prices, additional such substitutions several- to manyfold larger than shown are also available

*Probably much understated because scaling from U.S. to world should count abundant tropical cane potential; also, the estimate does not include emerging major options like algal oils

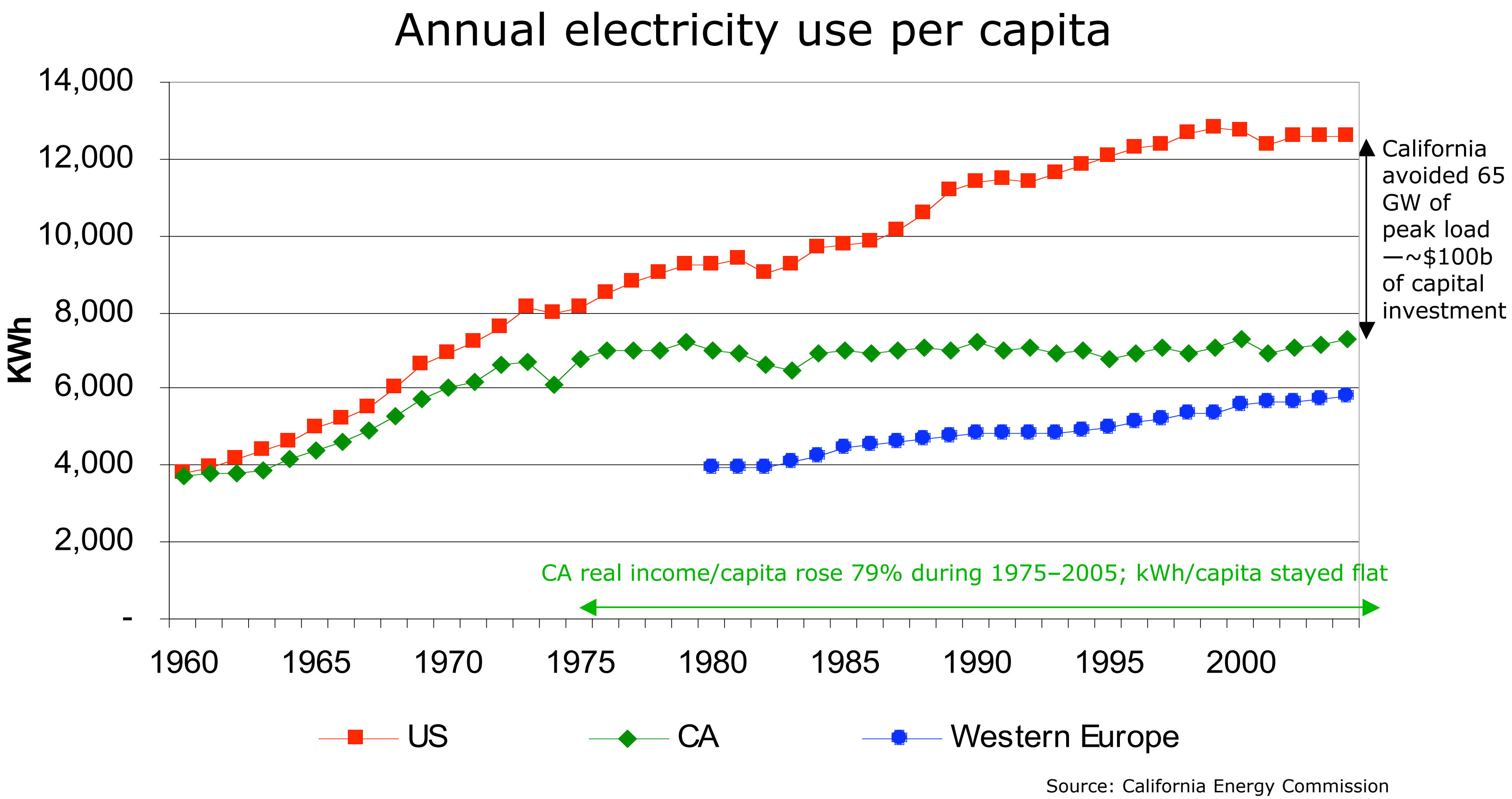
To scale from U.S. alternatives-to-oil potential in Mbbl/d achievable by the 2040s (at average cost $16/bbl in 2004 $: www.oilendgame.com) to world potential over 50 y, multiply the U.S. Mbbl/d × 146,000: 365 d/y × 50 y × 4 (for U.S.→world market size) × 2 (for growth in services provided). Obviously actual resource dynamics are more complex and these multipliers are very rough, so **this result is only illustrative and indicative.**

Stretching oil supply curve by ~3 trillion bbl averts >1 trillion tonnes of carbon emissions and tens of trillions of dollars + OPEC rent



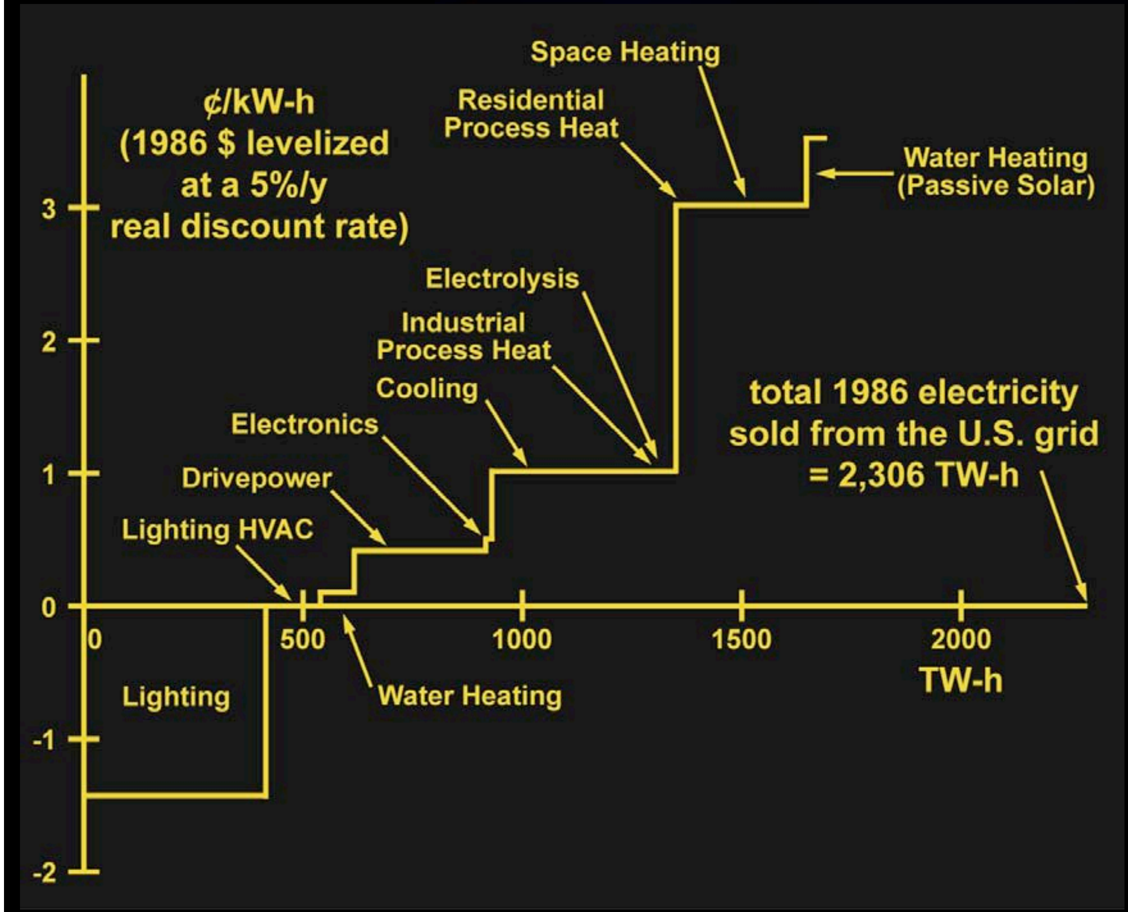
Nobody can know who's right about peak oil, but it doesn't matter

Saving electricity works—where allowed



California's electricity savings came roughly half from efficiency standards, half from rewarding utilities for cutting customers' bills—not for selling more energy

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



Best 1989 commercially available, retrofittable technologies

Similar S, DK, D, UK…

EPRI found 40–60% saving 2000 potential

Now conservative: 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)

–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

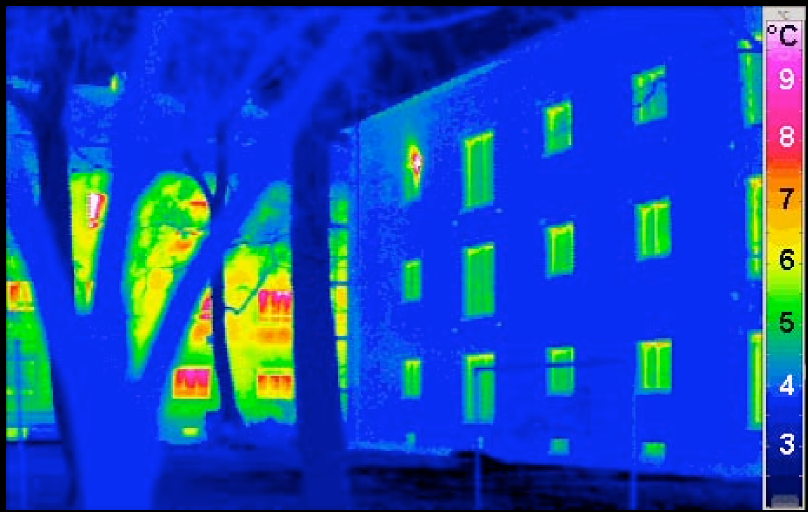
Key: integrative design makes very big energy savings cost *less* than small or no savings

- Lovins house / RMI HQ, Snowmass, Colorado, '84
  - Saves 99% of space & water heating energy, 90% of home el. (372 m² use ~$5/month worth @ 7¢/kWh, all made with solar)
  - 10-month payback in 1983
- PG&E ACT², Davis CA, '94
  - Mature-market cost –$1,800
  - Present-valued maint. –$1,600
  - Design energy 82% below strictest code, 90% below U.S. avg.
- Prof. Soontorn Boonyatikarn house, Bangkok, Thailand, '96
  - 84% less a/c capacity, ~90% less a/c energy, better comfort
  - No extra construction cost

Passive comfort in cold, cloudy climates like Germany (Passivhaus Institut)

http://en.wikipedia.org/wiki/Passive_house, www.passiv.de; Affordable Comfort Institute

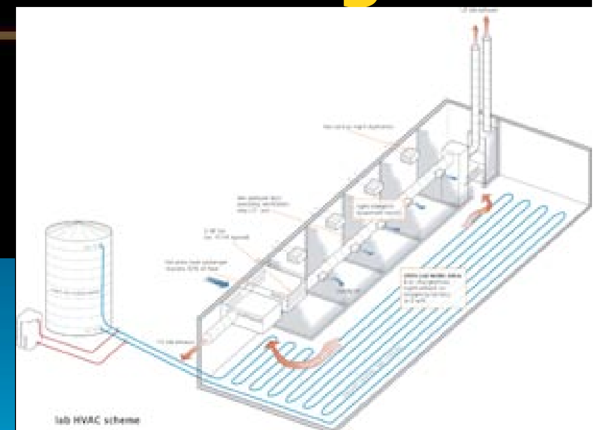
- No central heating system; can add small exhaust-air heat pump or solar panel if desired, but not necessary
- Total primary energy use ≤120 kWh/m²-y
- ≤15 kWh/m²-y & <10 W/m² heating energy—5–25% of U.S. allowables
- k-0.10–0.15 (k-0.066 roof in Sweden), airtight, high comfort, loses <0.5 C°/d w/ 0 el.
- >10k built in 5 EU nations; Vorarlberg (ÖS) standard
- *Zero marginal capital cost* (at least at <60°N lat)

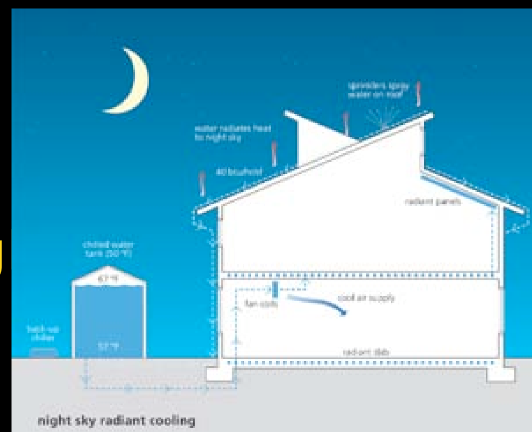


Infrared images of ordinary German apartment (L) and Passivhaus (R)

Stanford's Carnegie Institute for Global Ecology wet-lab building

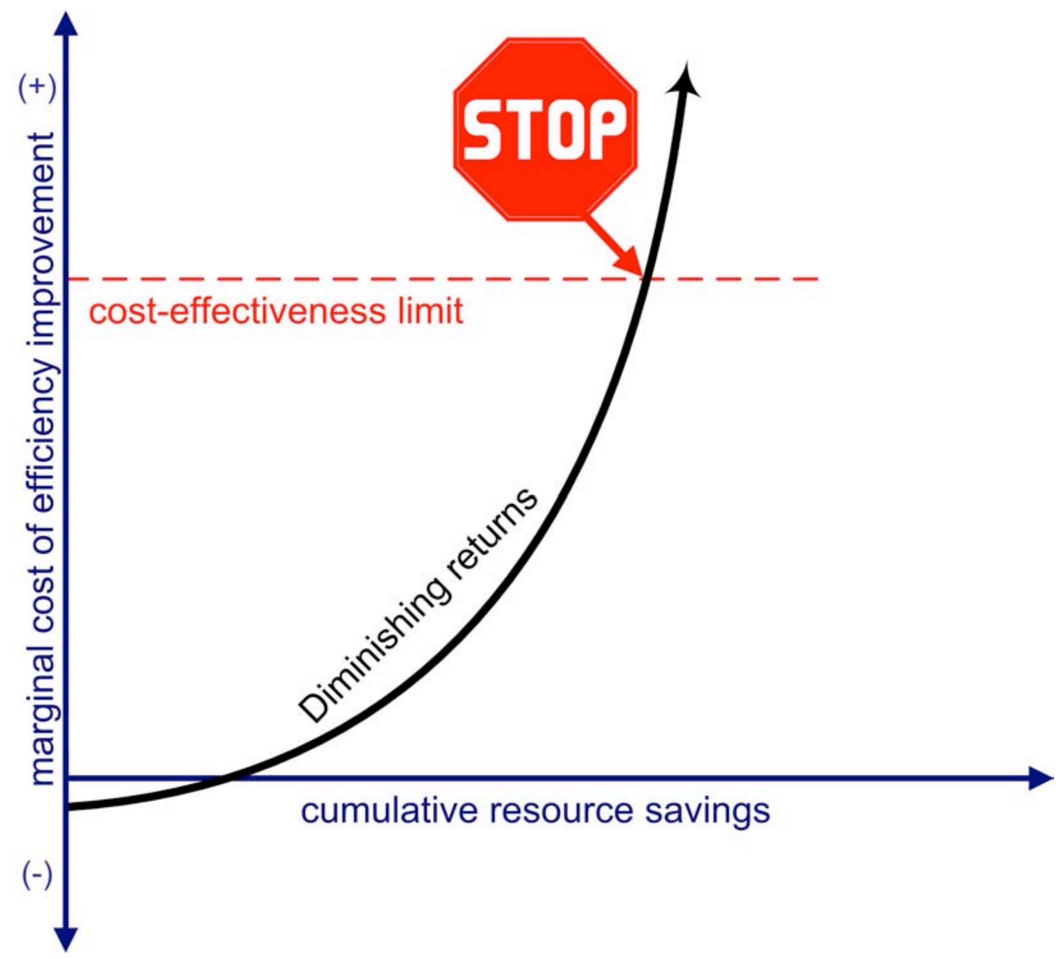
- NightSky (radiant roof spray), draft-tower, and air-economizer cooling, COP ≥50 (≤0.07 kW/t); wd improve with optimized pumping-system design
- Efficient shell, daylit, hig occupant satisfaction
- Normal capital cost
- ~1/5 normal energy use, despite peculiar safety rules requiring high-rate ventila-tion of empty, dark labs
- This usage excludes server farm, whose efficiency is the next logical target





1,012 m², \$4,002/m² in 2004—normal cost; energy data posted at http://globalecology.stanford.edu/DGE/CIWDGE/CIWDGE.HTML

Old design mentality: always diminishing returns…



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

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

Observed in >\$30b worth of projects in 29 sectors

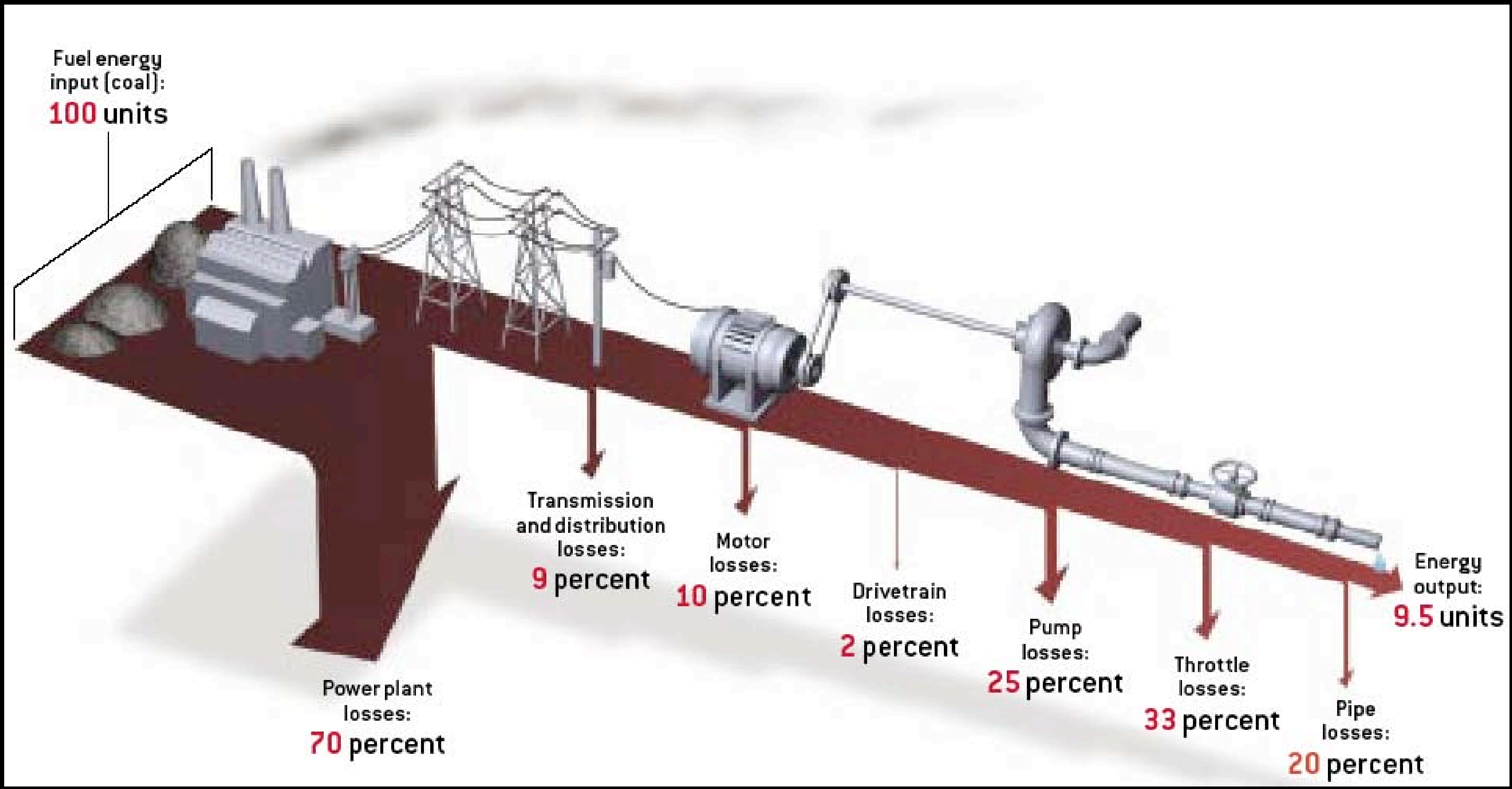
"Tunnel" straight to the superefficient lower-cost destination rather than taking the long way around

To see how, please visit www.rmi.org/stanford

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 70.8→5.7 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

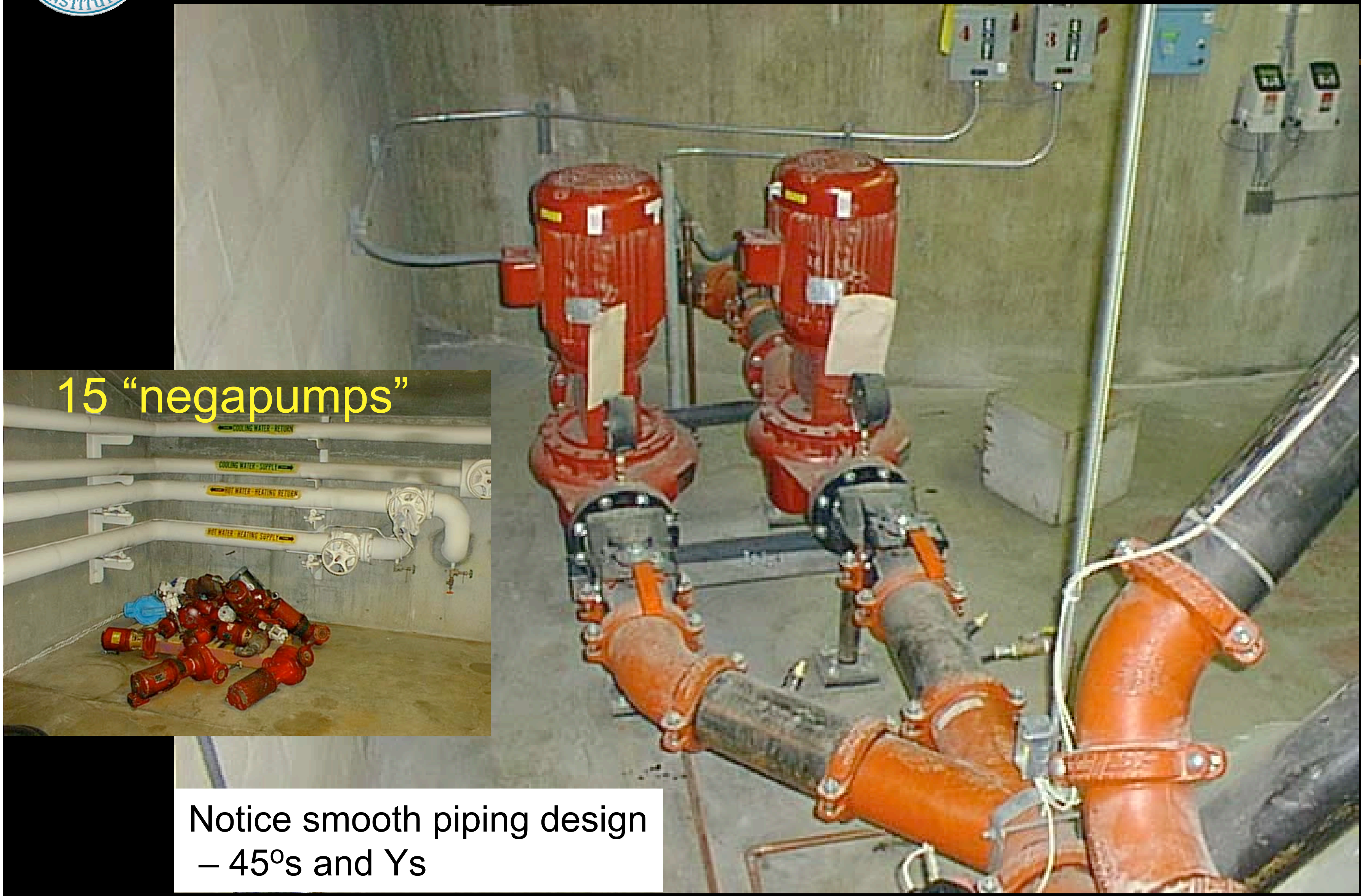
Compounding losses…or savings…so start saving at the *downstream* end to save ten times as much energy at the power plant



Also makes upstream equipment smaller, simpler, cheaper

High-efficiency pumping / piping retrofit

(Rumsey Engineers, Oakland Museum)



Notice smooth piping design
– 45ºs and Ys

Downsized condenser-water pumps, ~75% energy saving

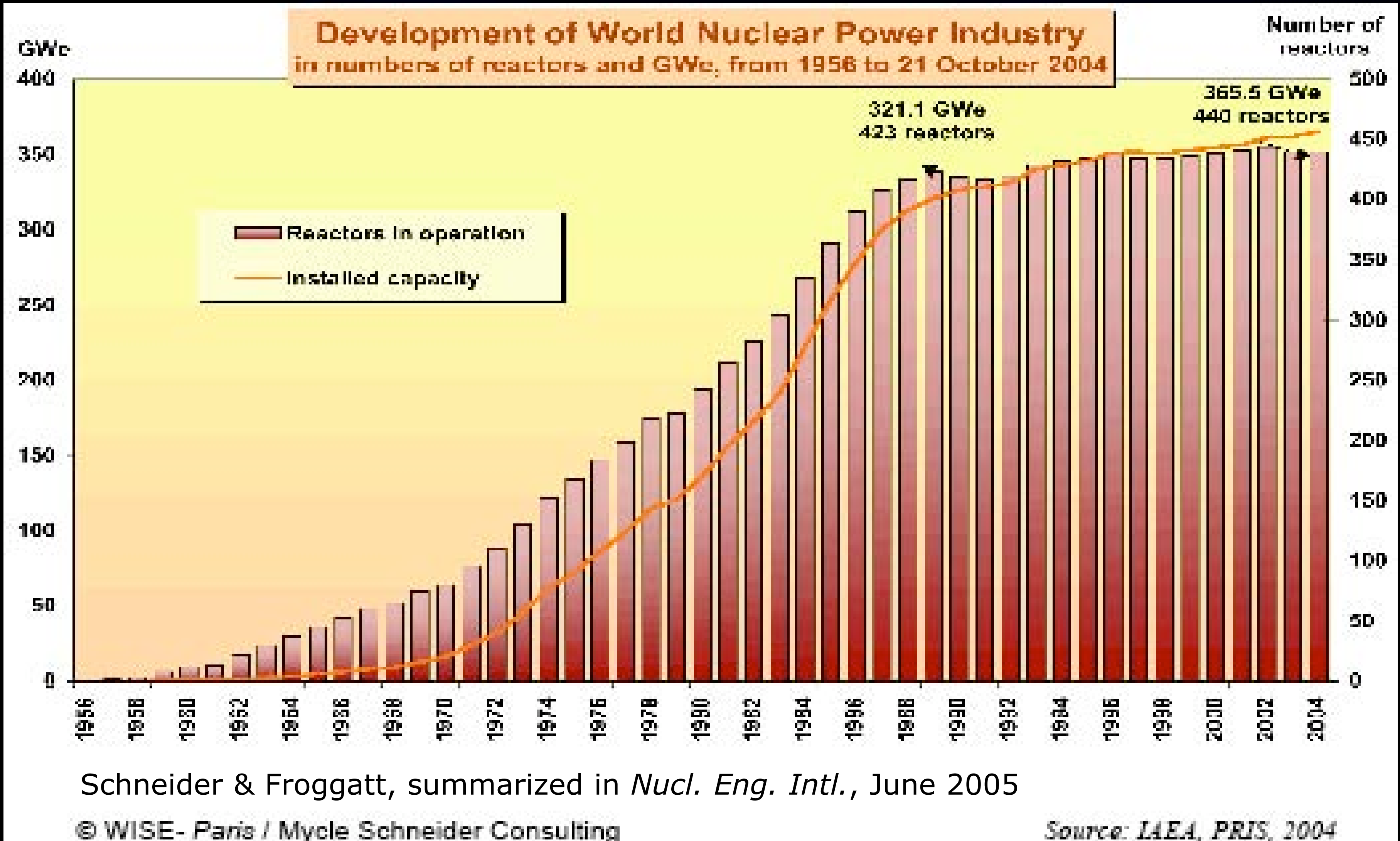
Examples from RMI's industrial practice (>$30b of facilities)

- Save half of motor-system electricity; retrofit payback typically <1 y
- Similar ROIs with 30–50+% retrofit savings of chip-fab HVAC power
- Retrofit very efficient oil refinery, save 42%, ~3-y payback
- Retrofit North Sea oil platform, save 50% el., get the rest from waste
- Retrofit big LNG plant, ≥40% energy savings; ~60%? new, cost less
- Redesign $5b gas-to-liquids plant, –$1b capex, save >50% energy
- Redesign giant platinum mine, 43% energy savings, 2–3-y paybacks
- Redesign new data center, save 80% el., 50% capex, no chillers
- Redesign new chip fab, save 20% el., 35% water, 30% ($230M) capex
- Redesign next new chip fab, save ~67% el., 50% capex, no chillers
- 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%
- "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

Negawatts can be fast, even with old implementation methods

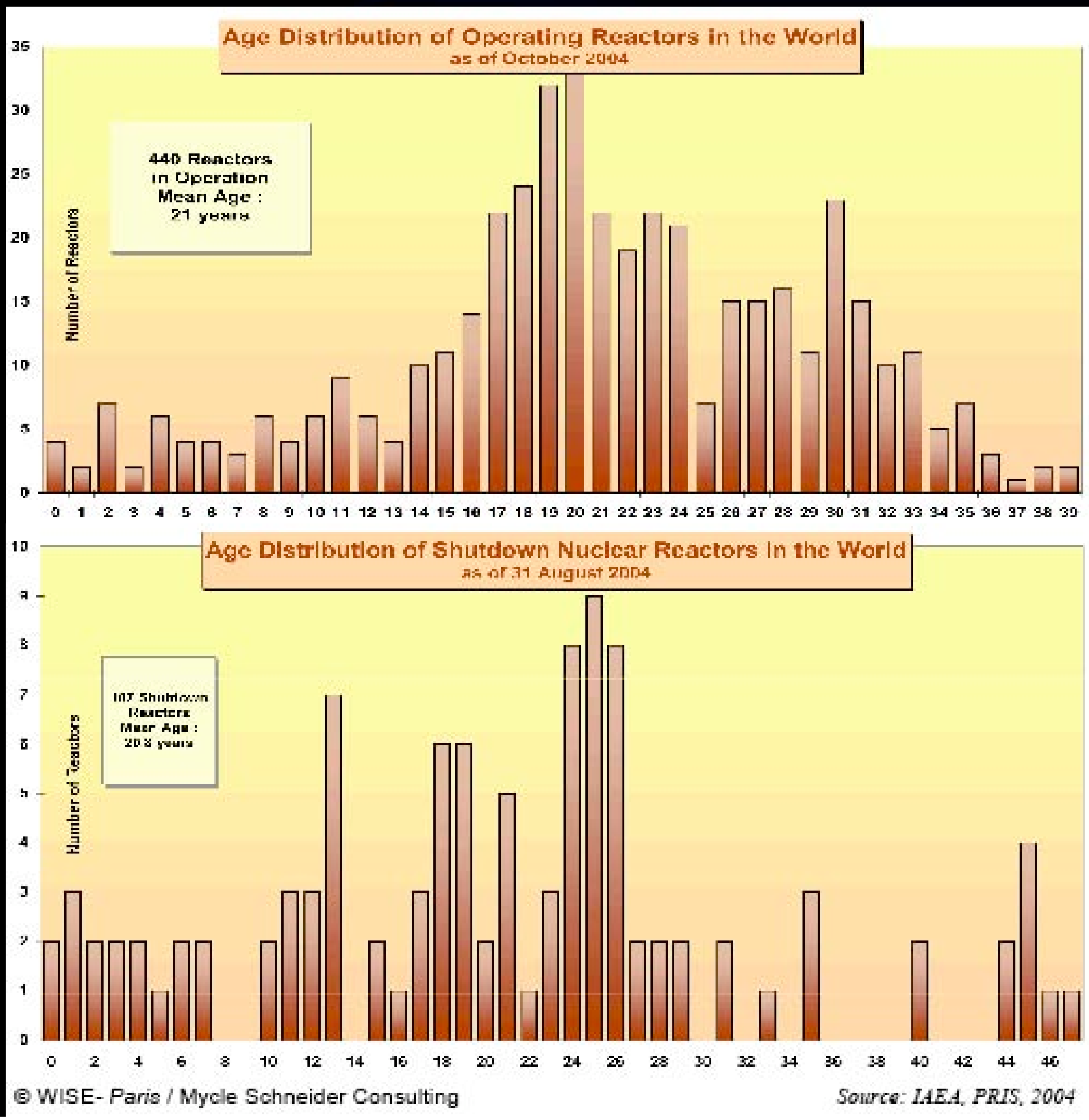
- In ~1975–85, most new U.S. end-use devices—cars, buildings, refrigerators, lighting systs., etc.—doubled in efficiency (~7%/y)
- In 1983–85, 10 million people served by Southern California Edison Company (then the #3 US investor-owned utility) were cutting its 10-years-ahead forecast peak load by 8½% *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

Global nuclear expansion is coasting to a halt



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

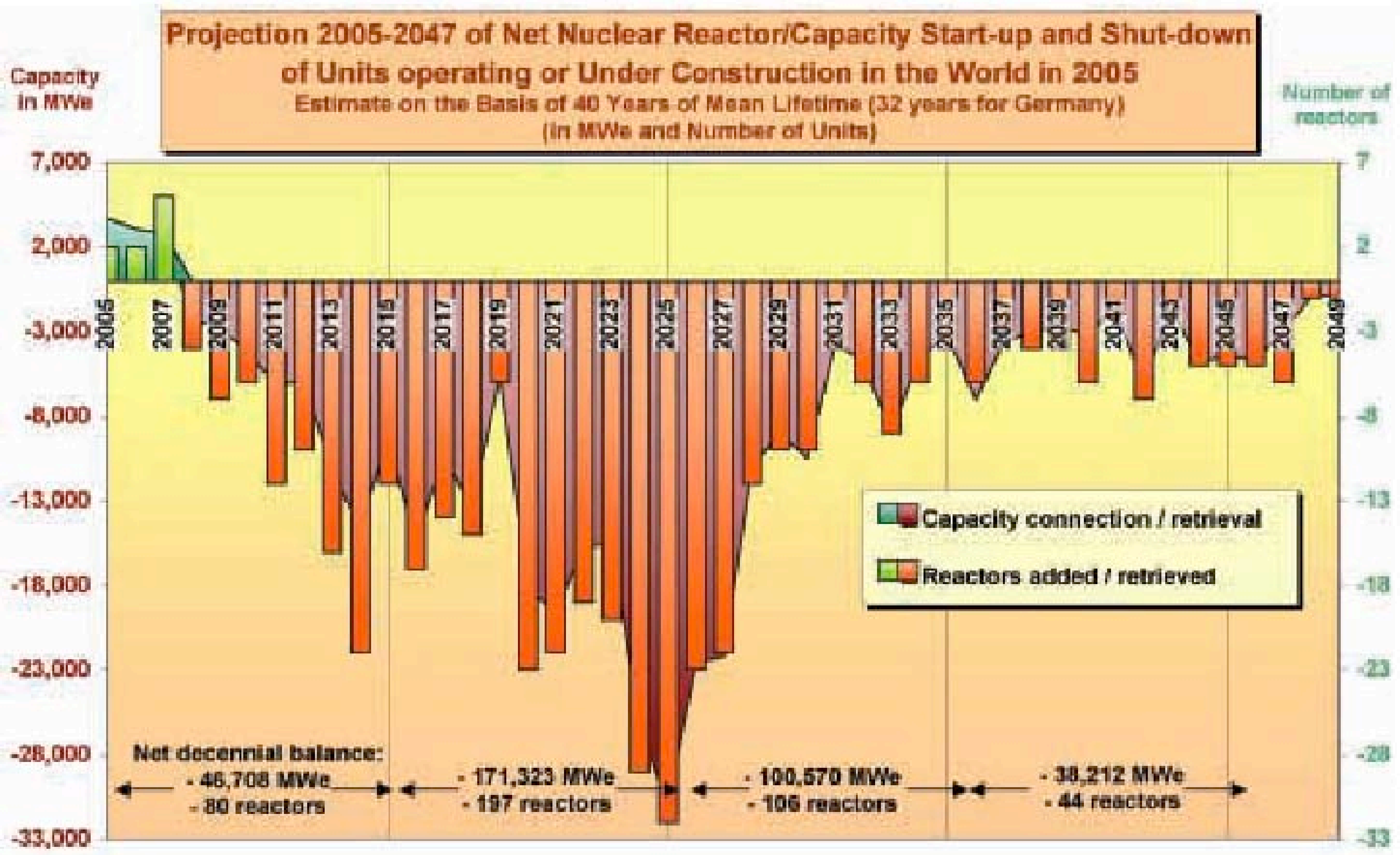
Average reactor in 2005 was 21 years old—as was av. unit permanently retired



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

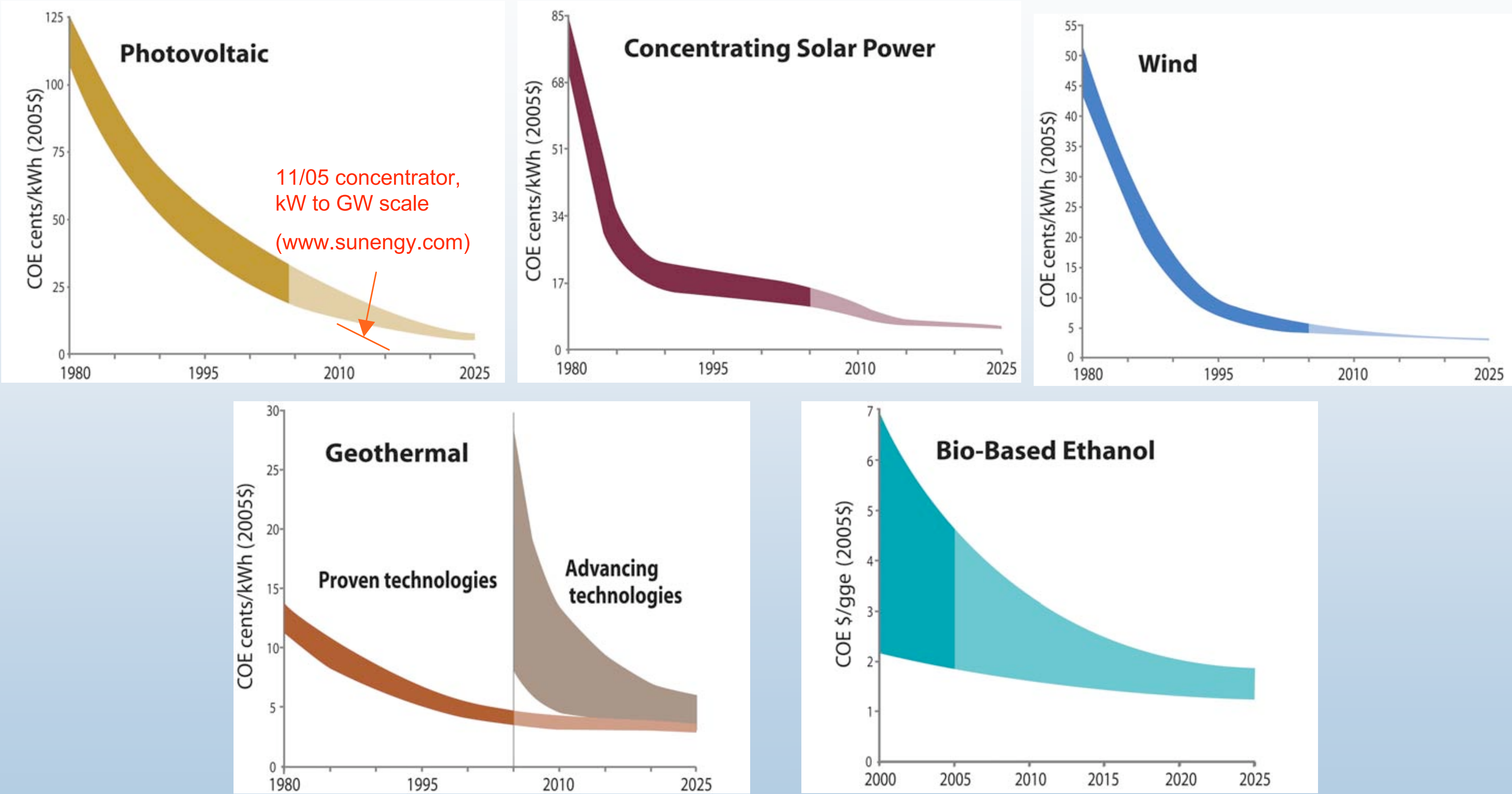
Global nuclear capacity is about to start a long, inevitable decline



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

Renewable Energy Cost Trends

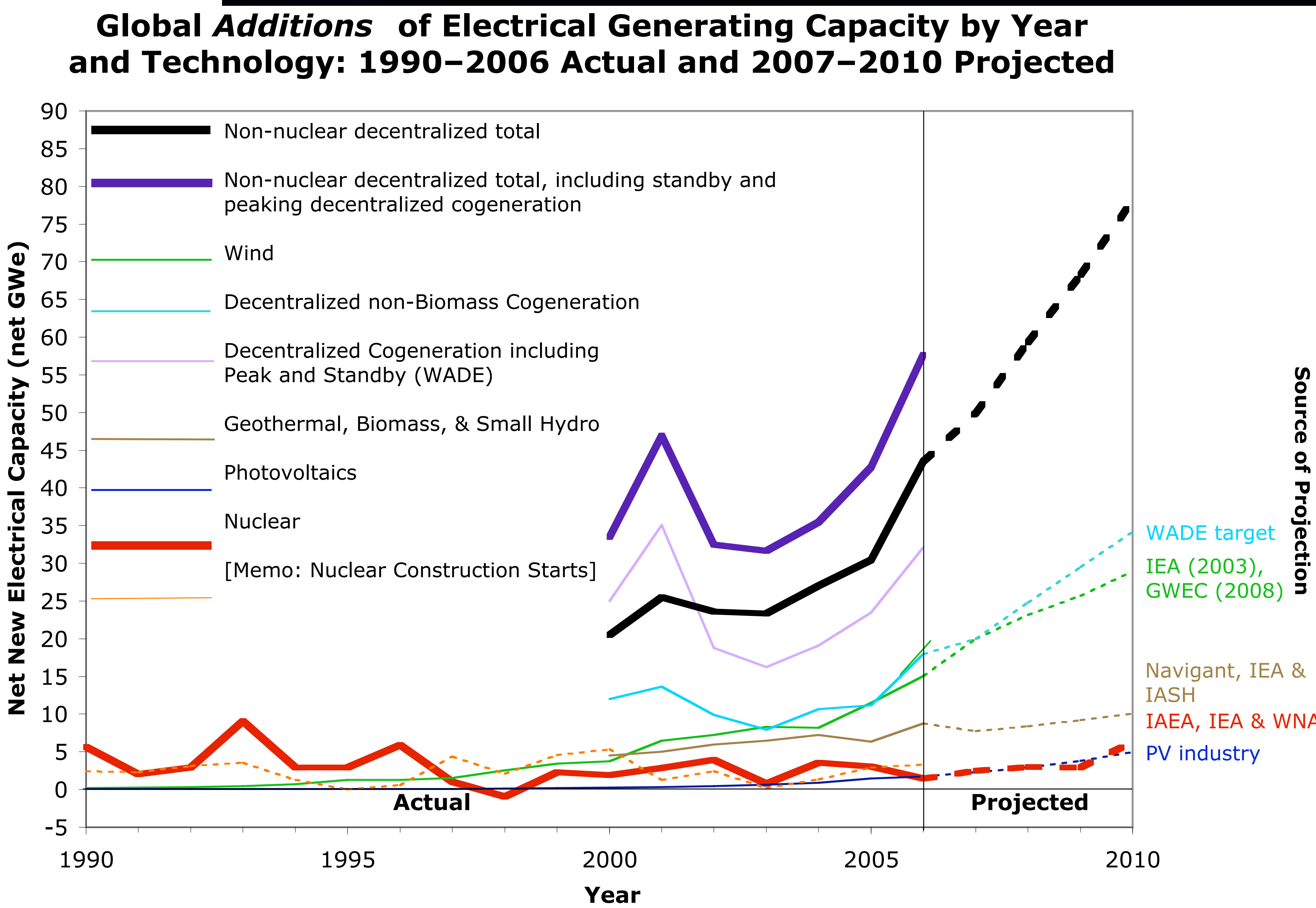
Levelised sent-out cost of energy in constant 2005 US$, excluding subsidies[1]



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

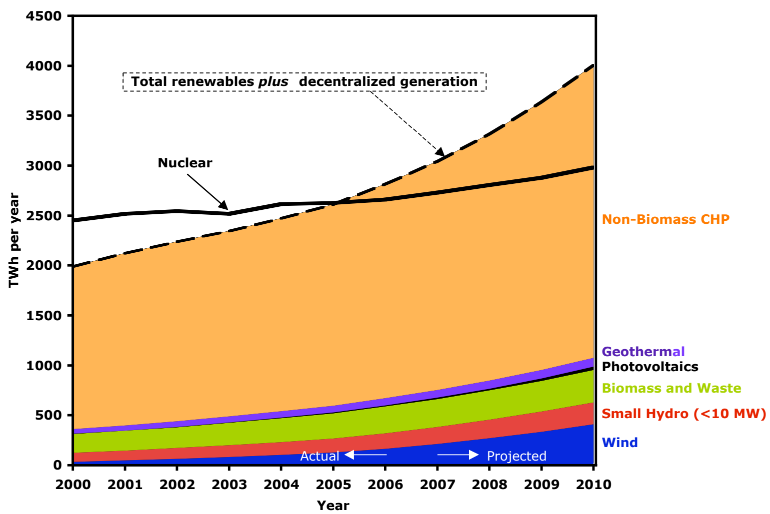
Micropower is the world's top source of new electricity



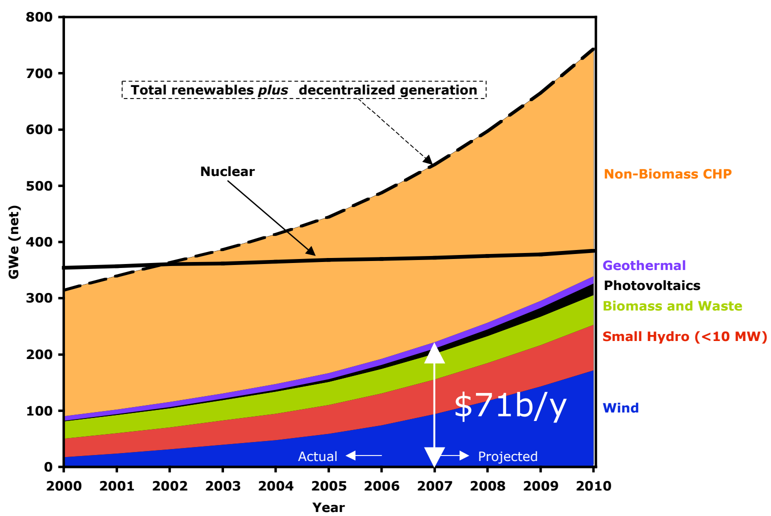
Electric shock: low-/no-carbon decentralized sources are eclipsing central stations

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

Low- or no-carbon worldwide electrical output (except large hydro)

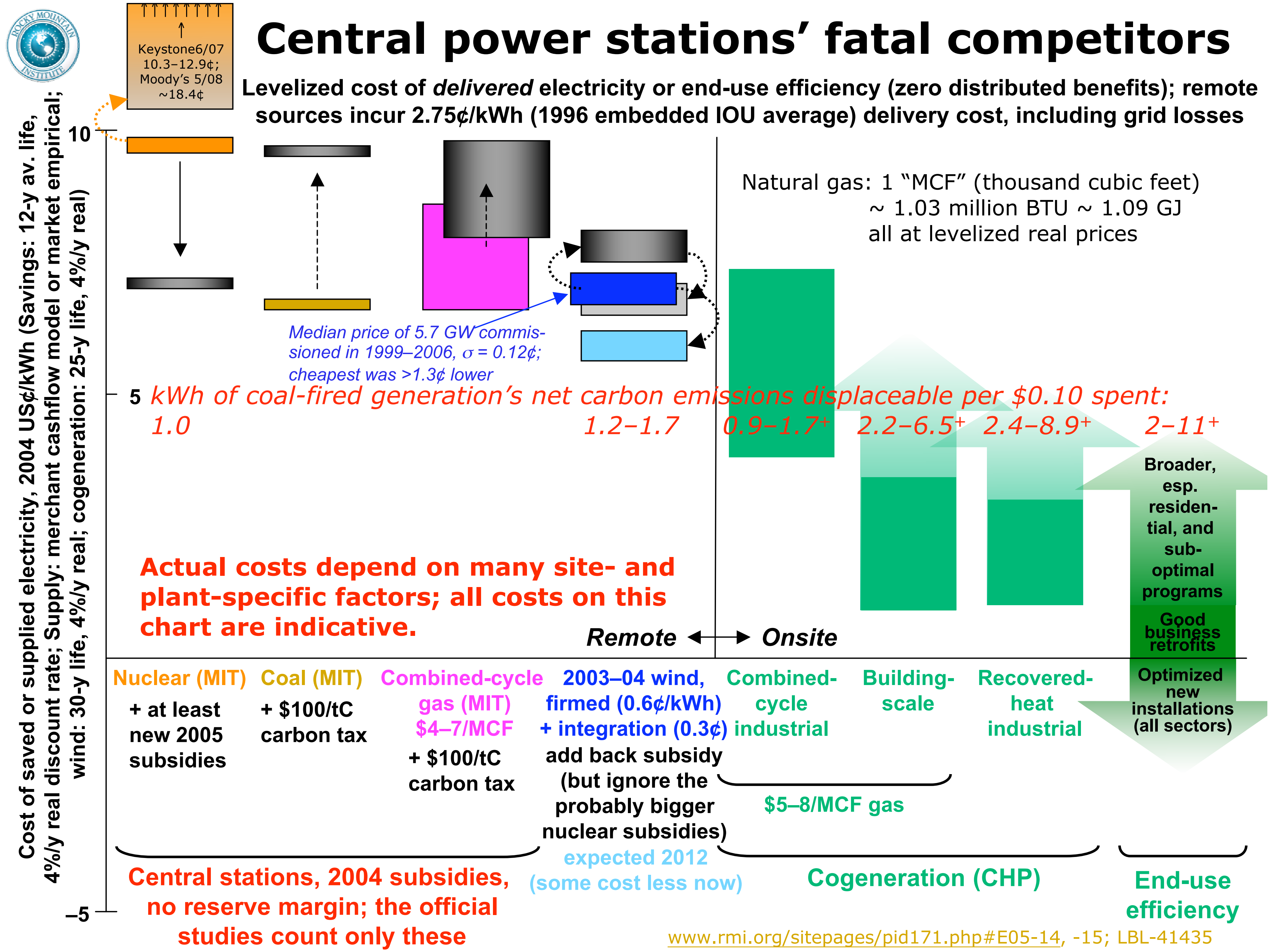


Low- or no-carbon worldwide installed electrical generating capacity (except large hydro)

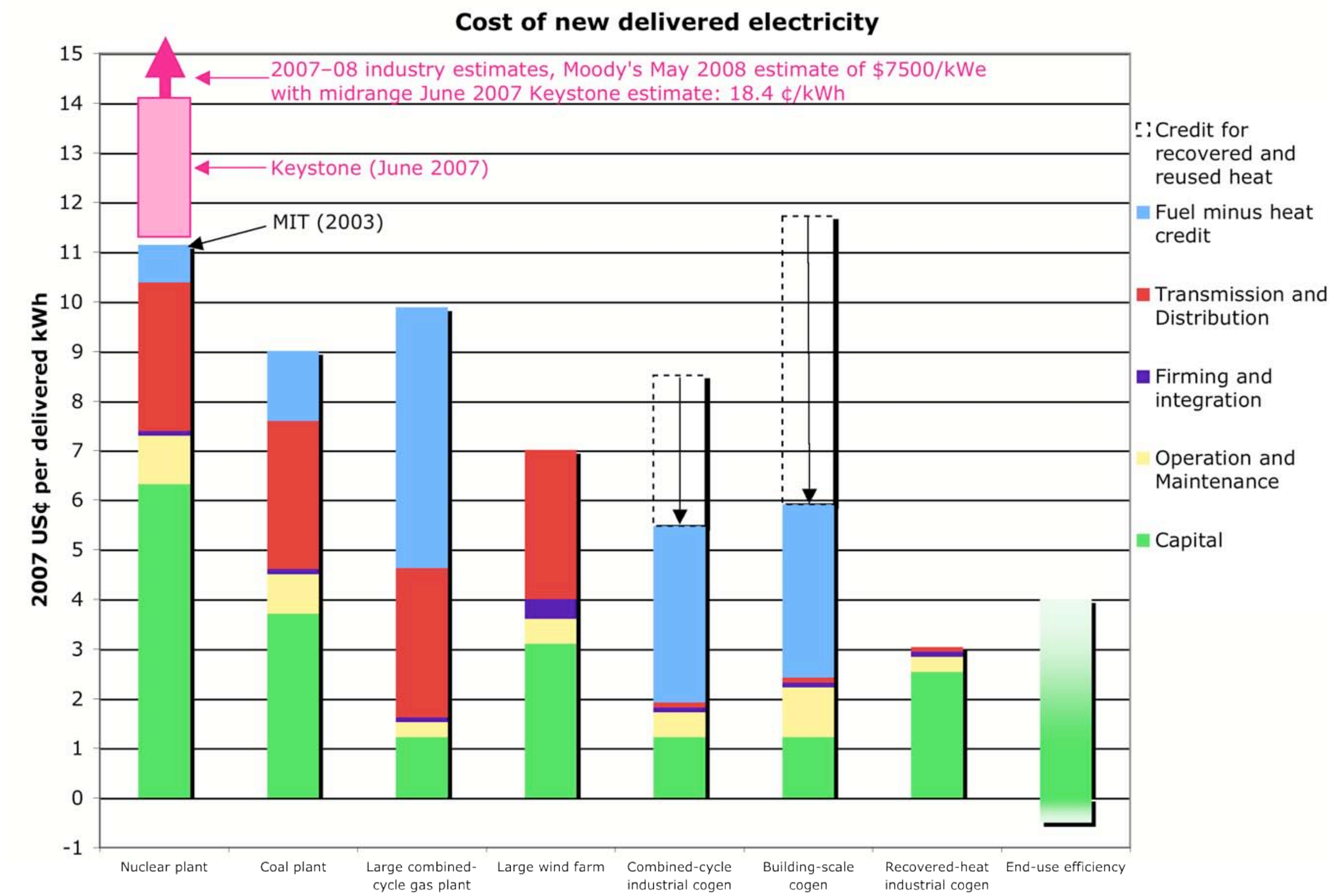


- 2/3 combined-heat-and-power*, mostly gas, ≥50% less CO_2

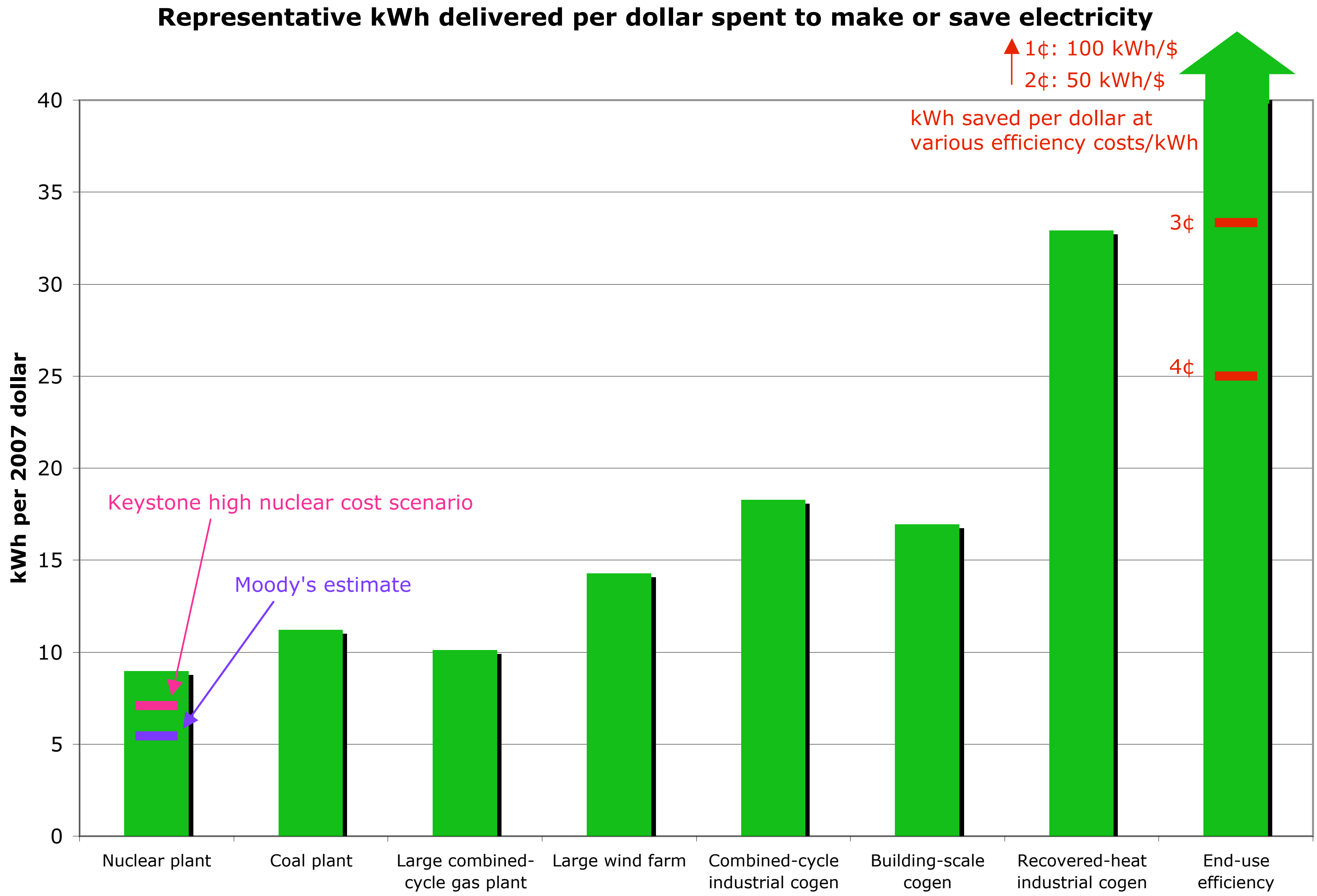
  *Gas turbines ≤120 MWe, engines ≤30 MWe, steam turbines only in China
- One-third renewable (hydro ≤10 MW_e)
- In 2006, micropower added 41× (excl peaking & standby units, 30×) as much capacity as nuclear added (which was less than PVs added, or 1/10th wind)
- *1/6 of el, 1/3 of new el, & rising*
- 1/6 to >1/2 of all electricity in 13 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
- In 2007, China, Spain, & US each added more windpower than the world added nuclear capacity; US added more windpower than 2003–07 coal capacity


Central power stations' fatal competitors
Levelized cost of delivered electricity or end-use efficiency (zero distributed benefits); remote sources incur 2.75¢/kWh (1996 embedded IOU average) delivery cost, including grid losses
Keystone6/07 10.3–12.9¢; Moody's 5/08 ~18.4¢
10
5
–5
Cost of saved or supplied electricity, 2004 US¢/kWh (Savings: 12-y av. life, 4%/y real discount rate; Supply: merchant cashflow model or market empirical; wind: 30-y life, 4%/y real; cogeneration: 25-y life, 4%/y real)
Natural gas: 1 "MCF" (thousand cubic feet) ~ 1.03 million BTU ~ 1.09 GJ all at levelized real prices
Median price of 5.7 GW commissioned in 1999–2006, σ = 0.12¢; cheapest was >1.3¢ lower
kWh of coal-fired generation's net carbon emissions displaceable per $0.10 spent:
1.0
1.2–1.7
0.9–1.7+
2.2–6.5+
2.4–8.9+
2–11+
Broader, esp. residential, and sub-optimal programs
Good business retrofits
Optimized new installations (all sectors)
Actual costs depend on many site- and plant-specific factors; all costs on this chart are indicative.
Remote
Onsite
Nuclear (MIT)
+ at least new 2005 subsidies
Coal (MIT)
+ $100/tC carbon tax
Combined-cycle gas (MIT) $4–7/MCF
+ $100/tC carbon tax
2003–04 wind, firmed (0.6¢/kWh) + integration (0.3¢) add back subsidy (but ignore the probably bigger nuclear subsidies)
expected 2012 (some cost less now)
Combined-cycle industrial
Building-scale
Recovered-heat industrial
$5–8/MCF gas
Central stations, 2004 subsidies, no reserve margin; the official studies count only these
Cogeneration (CHP)
End-use efficiency
www.rmi.org/sitepages/pid171.php#E05-14, -15; LBL-41435

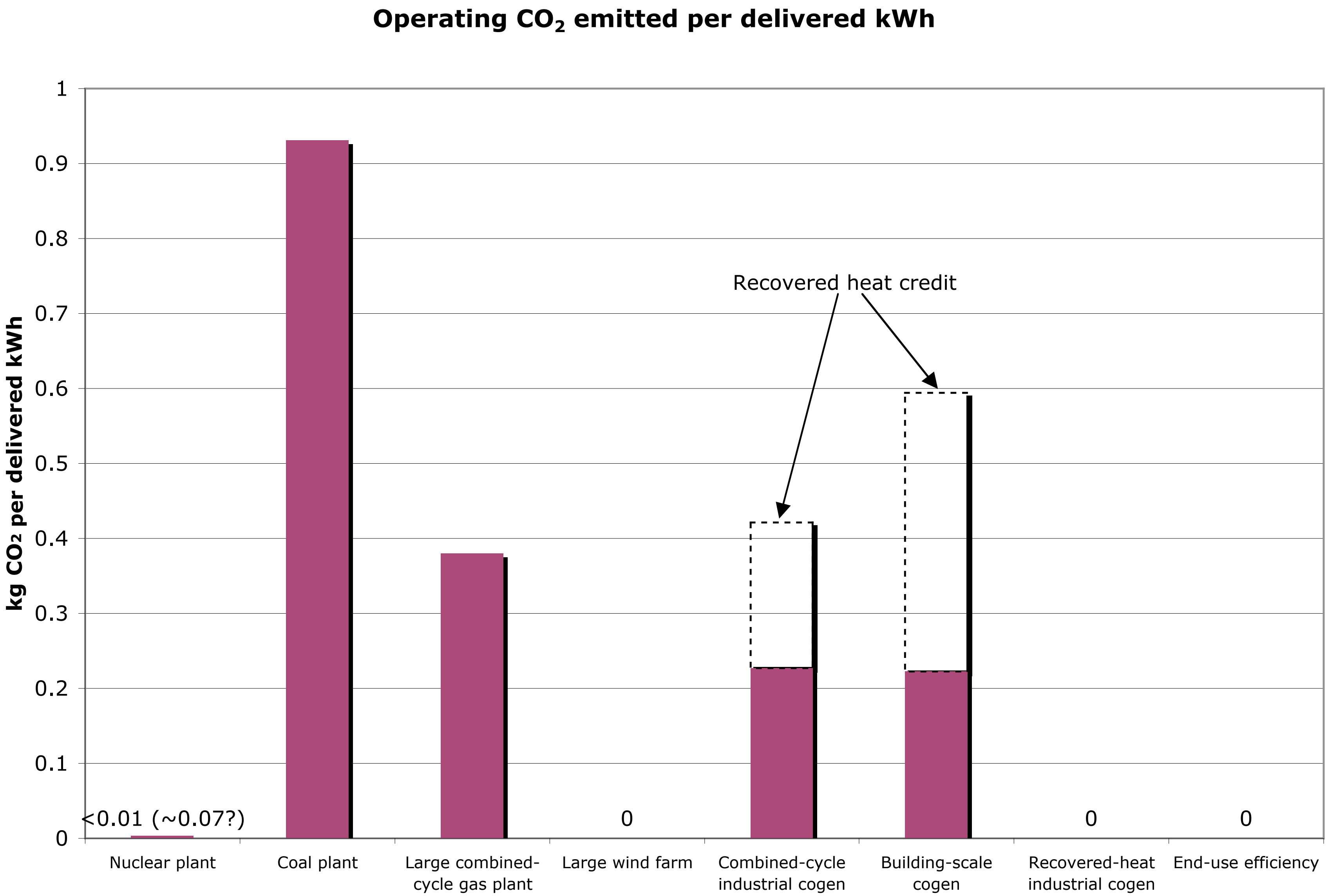
Nuclear is the costliest of the low- or no-carbon resources



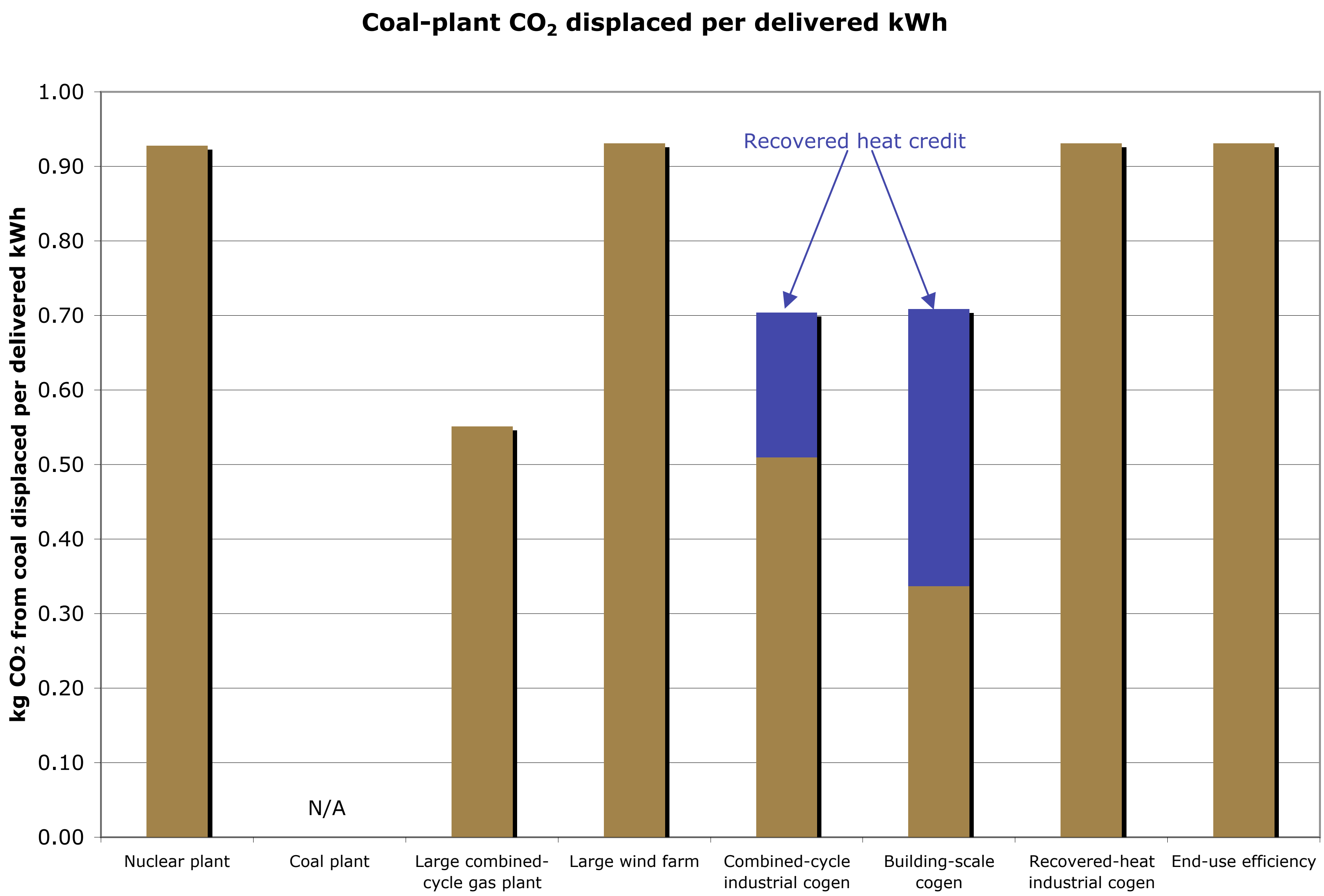
Cheaper options deliver more electrical services per dollar



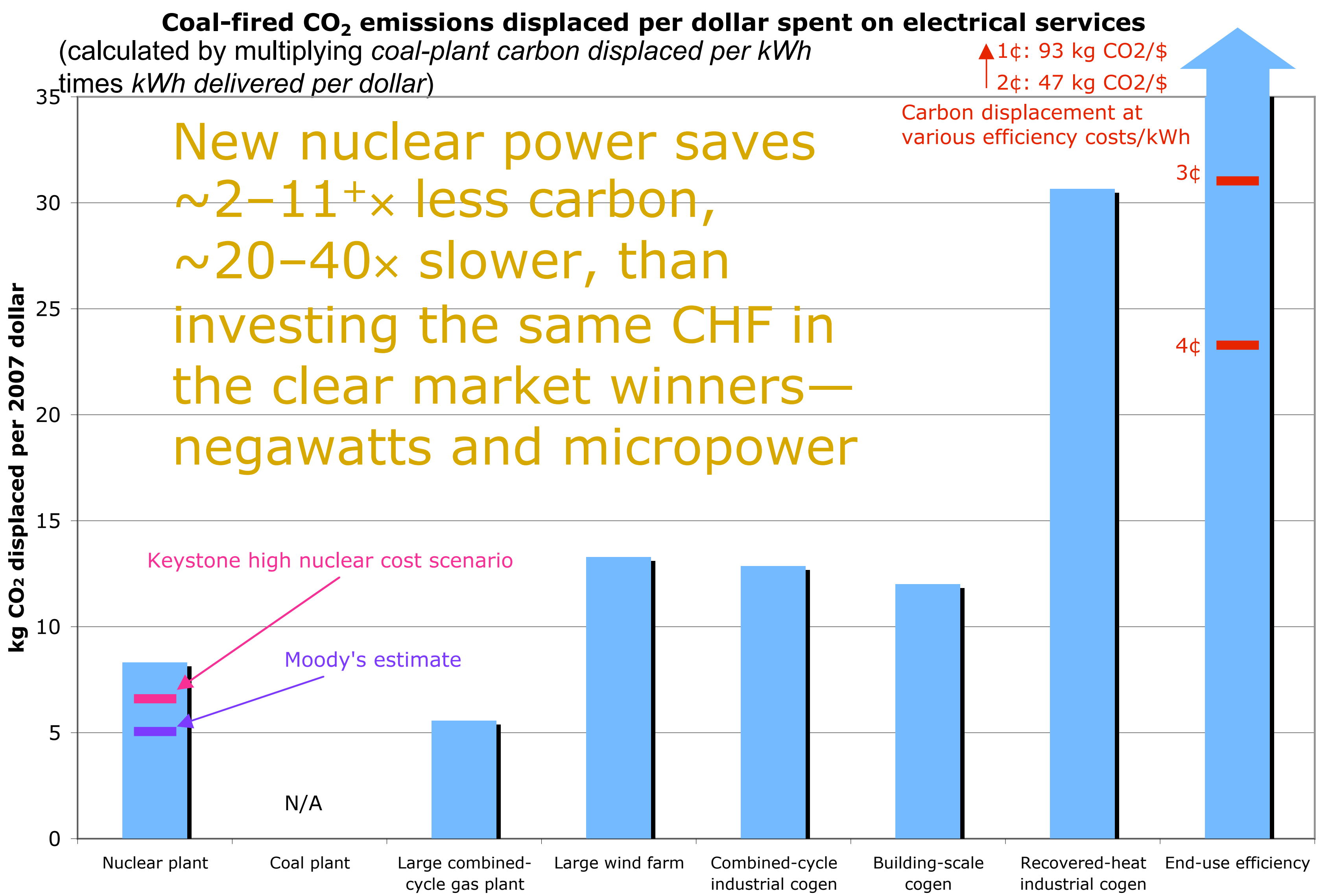
Various resources emit different amounts of carbon



Carbon/kWh determines carbon saved by switching from coal

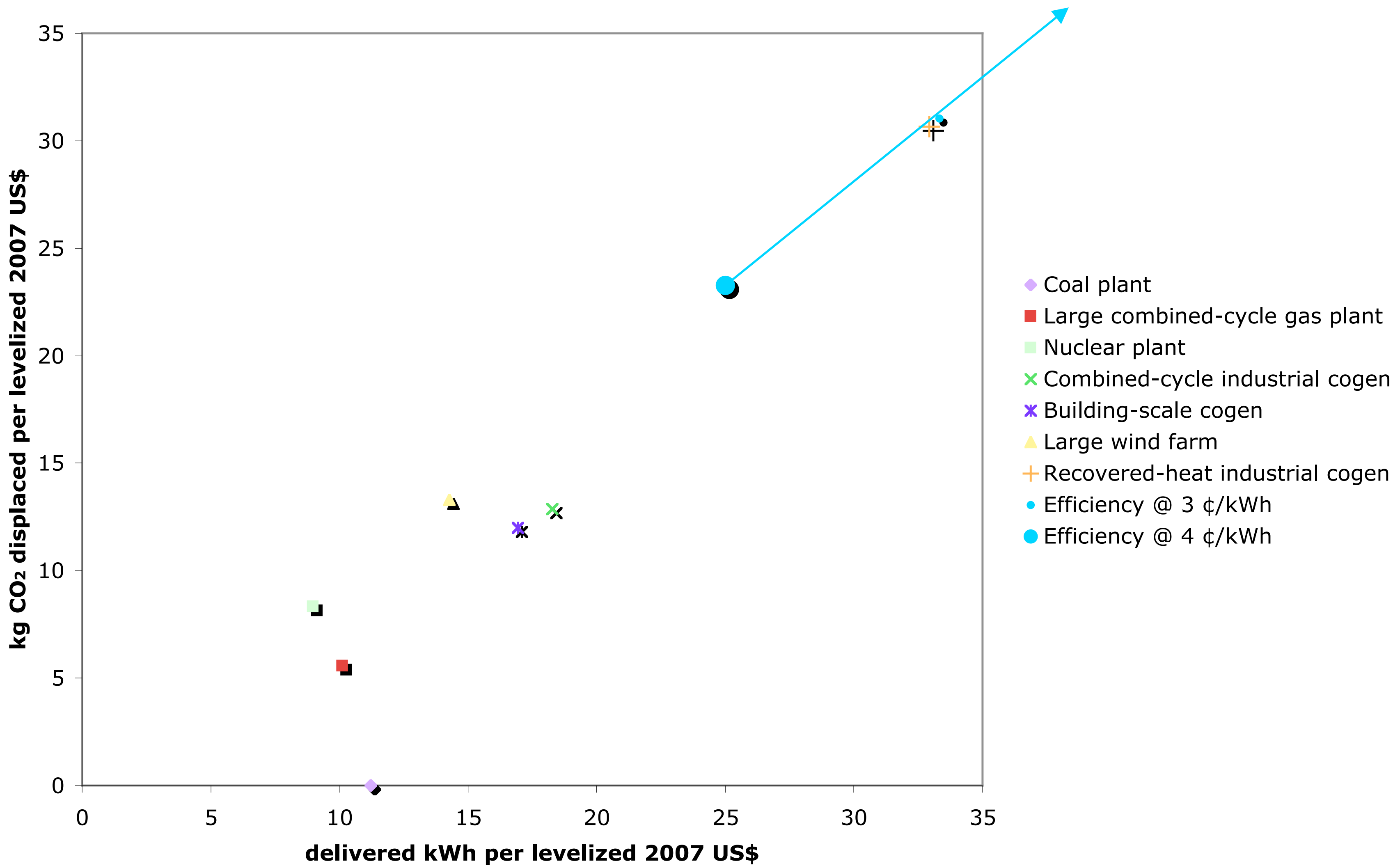


Cheapest *and* lowest-carbon sources save the most C per $



Buying the most climate solution and energy service per $

Carbon emissions saved vs. electrical service delivered, per dollar spent

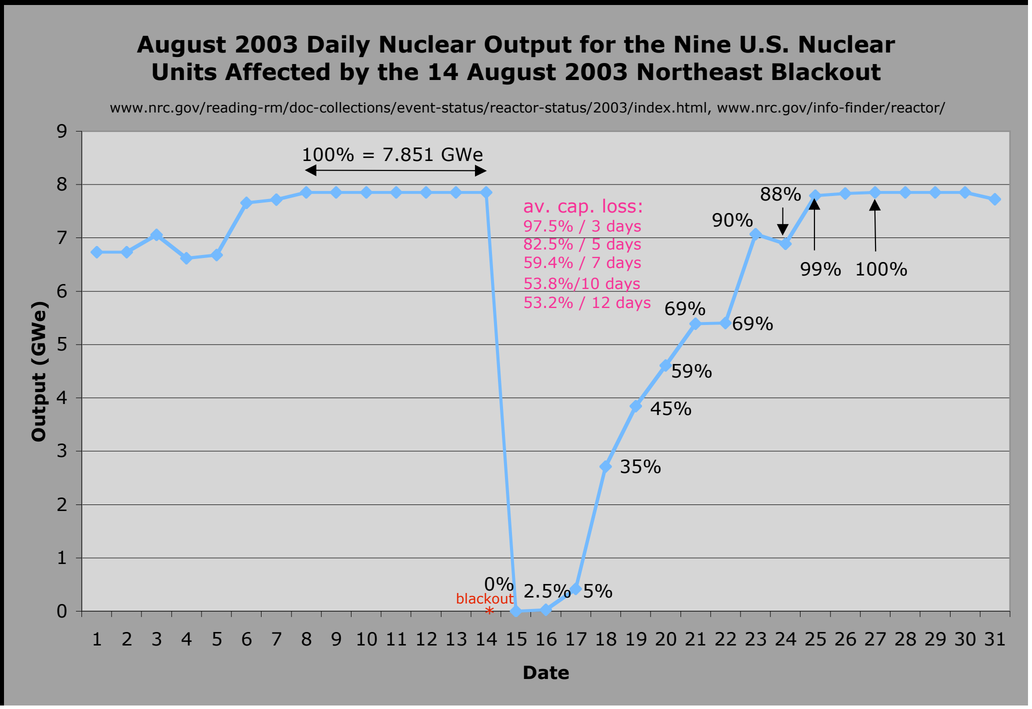


All options face implementation risks; what does market behavior reveal?

- California's 1982–85 fair bidding with roughly equal subsidies elicited, *vs.* 37-GW 1984 load:
  - 23 GW of contracted negawatt acquisitions over next ten years (62% of 1984 peak load)
  - 13 GW of contracted new generating capacity (35% of 1984 load), most of it renewable, + 8 GW (22%) more 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× nuclear's 20% US share at below its *short*-run marginal delivered cost
  - CHP: US industrial pot'l 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 are *not* significant problems or costs: variable renewables need *less* storage/backup than today!

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

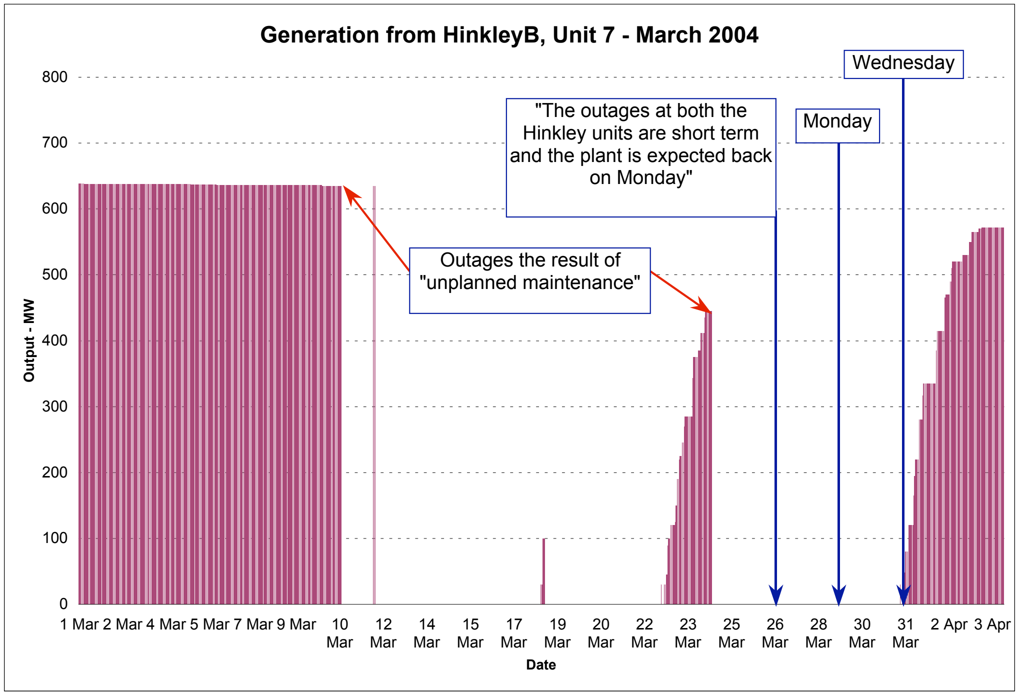
- ◇ Arithmetically, one 1-GWe unit or a thousand 1-MWe units or a million 1-kWe units are equivalent
- ◇ But in practice, many small units are *more* reliable than a few big ones even if all are equally reliable—and those near customers are more reliable than faraway units (98–99% of US outages originate 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…

- ◇ Wind & solar 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



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

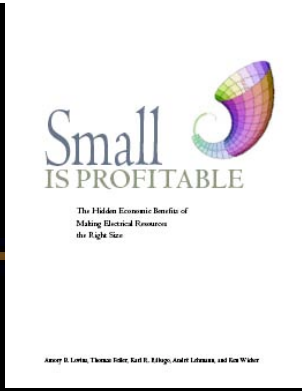
2200 m, frost any day, 39 days' continuous midwinter cloud…yet 28 banana crops with no furnace

- Lovins house / RMI HQ, Snowmass, Colorado, 2084
  - 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 wires on the house
- Ing. Kees Daey Ouwens, Utrecht, 1991
  - A similarly efficient small house used only ~50 W_{av} (like mine but with a gas-fired refrigerator/freezer rather than electric one)
  - 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!

Negawatts/renewables synergy: 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 $9 million
- State incentives $5 million
- Gross savings $15 million/25 y
- IRR >10%/y (Cty. hurdle rate)
- Works for PVs, so should work better for cheaper distrib. gen.

"Distributed benefits" change the game



- Size matters!
- *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (RMI, 8/02)
  - www.smallisprofitable.org; an *Economist* book of the year
- 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 ($3–5,000/kWe)
- As markets start to recognize distributed benefits, the decentral-ized-electricity revolution will accelerate
- Next: vehicle-to-grid revolution (can displace all central plants)

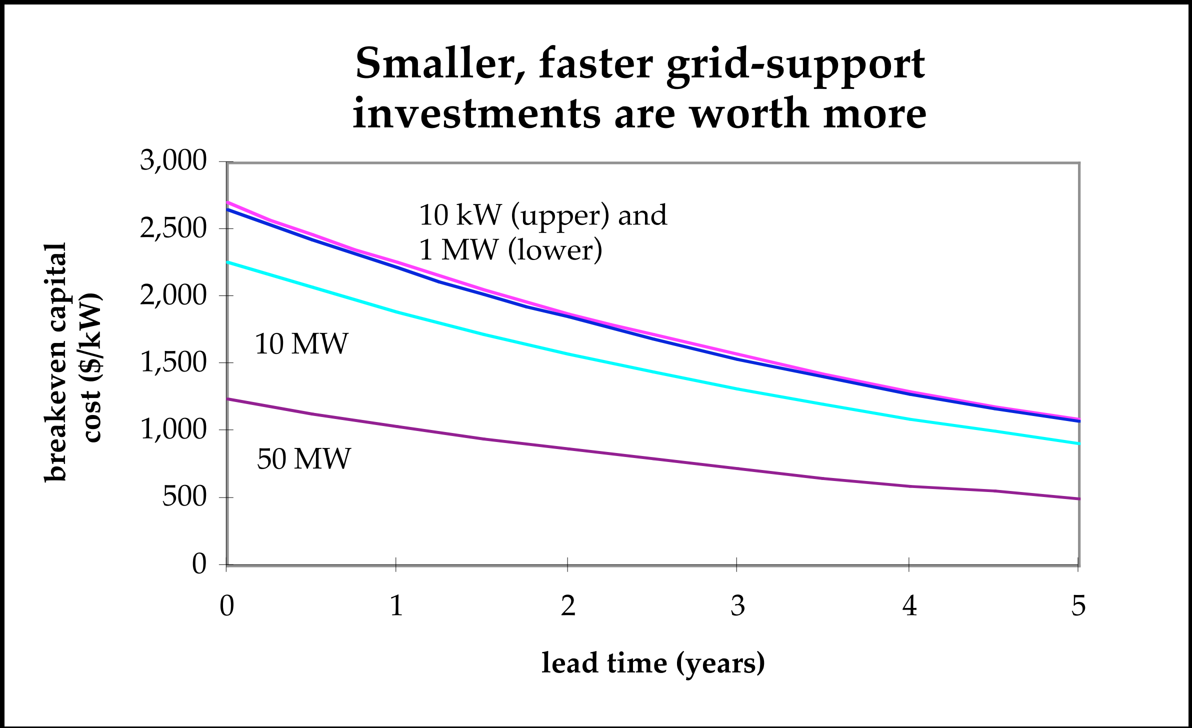
Whence the order-of-magnitude typical value increase?

- 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)

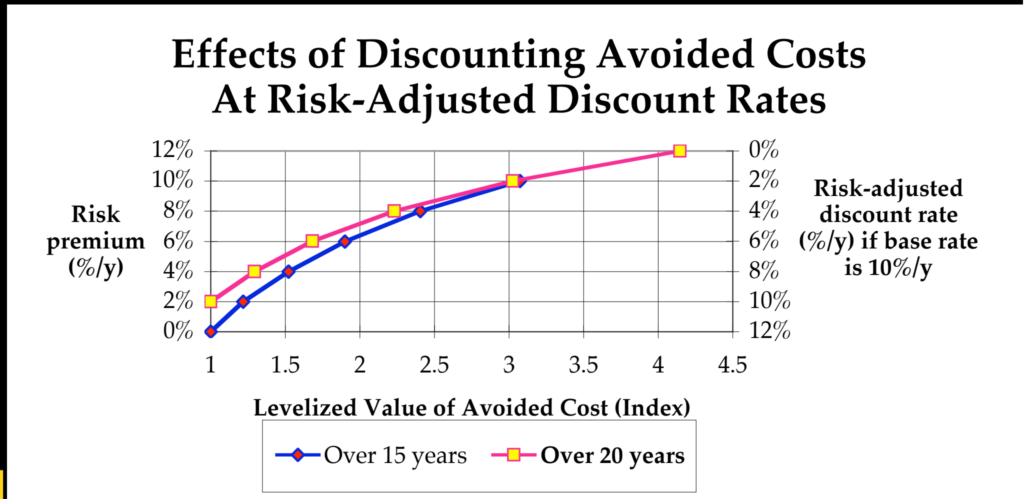
- ~10[1]×: Minimizing regret (financial economics)
  - Short lead times and small modules cut risk
    - Financial, forecasting, obsolescence
    - Overshoot and 'lumpiness'



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 ~5–6 percentage points in 2002 but is probably higher now.

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 US and CH examples are critical to the world

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
- Frees up money and attention for superior alternatives—~10^4× macroeconomic leverage to fund other needs (development/health/education/public safety)
- Inhibits 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
- Key to a richer, fairer, cooler, and safer world

Five implementation myths

- “It isn’t happening—why not?”
  - Total U.S. oil, coal, and energy use *fell* in 2006. True, far more *could* happen if we paid attention and busted barriers
- “Solutions must await global agreement”
  - China’s top emphasis on energy efficiency is self-interested
- “Pricing carbon is the essential first step”
  - Pricing carbon is correct, helpful, and desirable…but not essential, sufficient, nor probably a big price effect (because efficient carbon markets will ultimately clear at low prices)
  - *Ability to respond* to price (“barrier-busting”) matters more
- “Public policy = taxes, subsidies, and mandates”
  - Other instruments, such as car feebates and utility decoupling-and-shared-savings, are more effective and attractive
- “Public policy is the only, or the strongest, key”
  - Innovative competitive strategy, technology, and design, all from *business* coevolving with civil society, are more dynamic

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
(Publications),
www.natcap.org