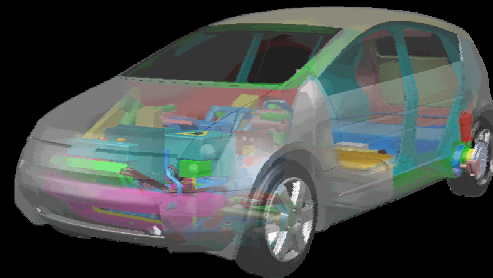




Energy Efficiency: The Main Road (Milano, Italia, 11.IX.2008)

Radical Energy Efficiency for Profitable Climate Protection



Amory B. Lovins, For. Memb. Royal Swed. Acad. Eng. Sciences, Hon. AIA
Chairman and Chief Scientist
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Energy policy: a multiple-choice test

Would you rather die of:

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

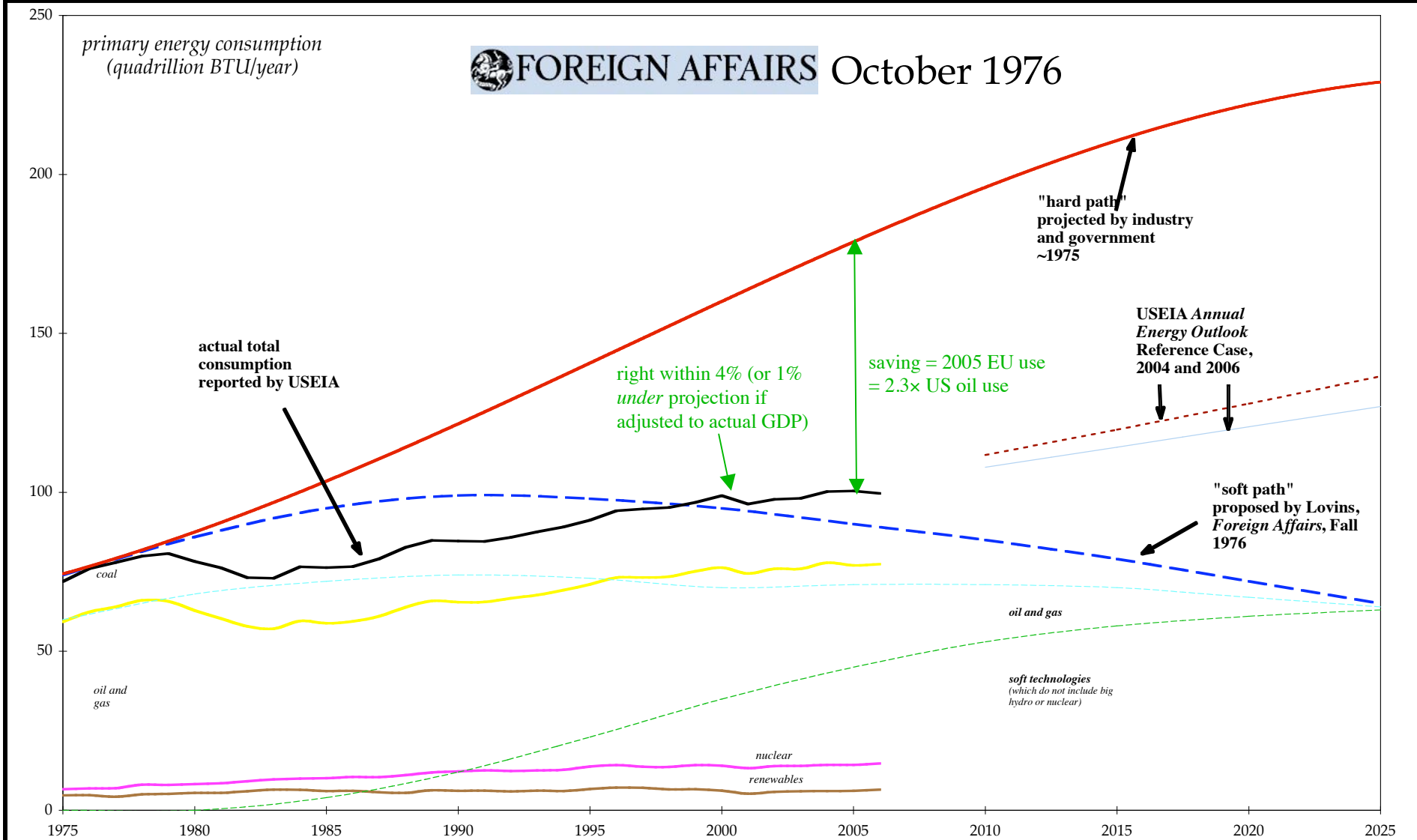
The right answer, often left out, is:

4. none of the above

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



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



but that just scratches the surface, especially for electricity



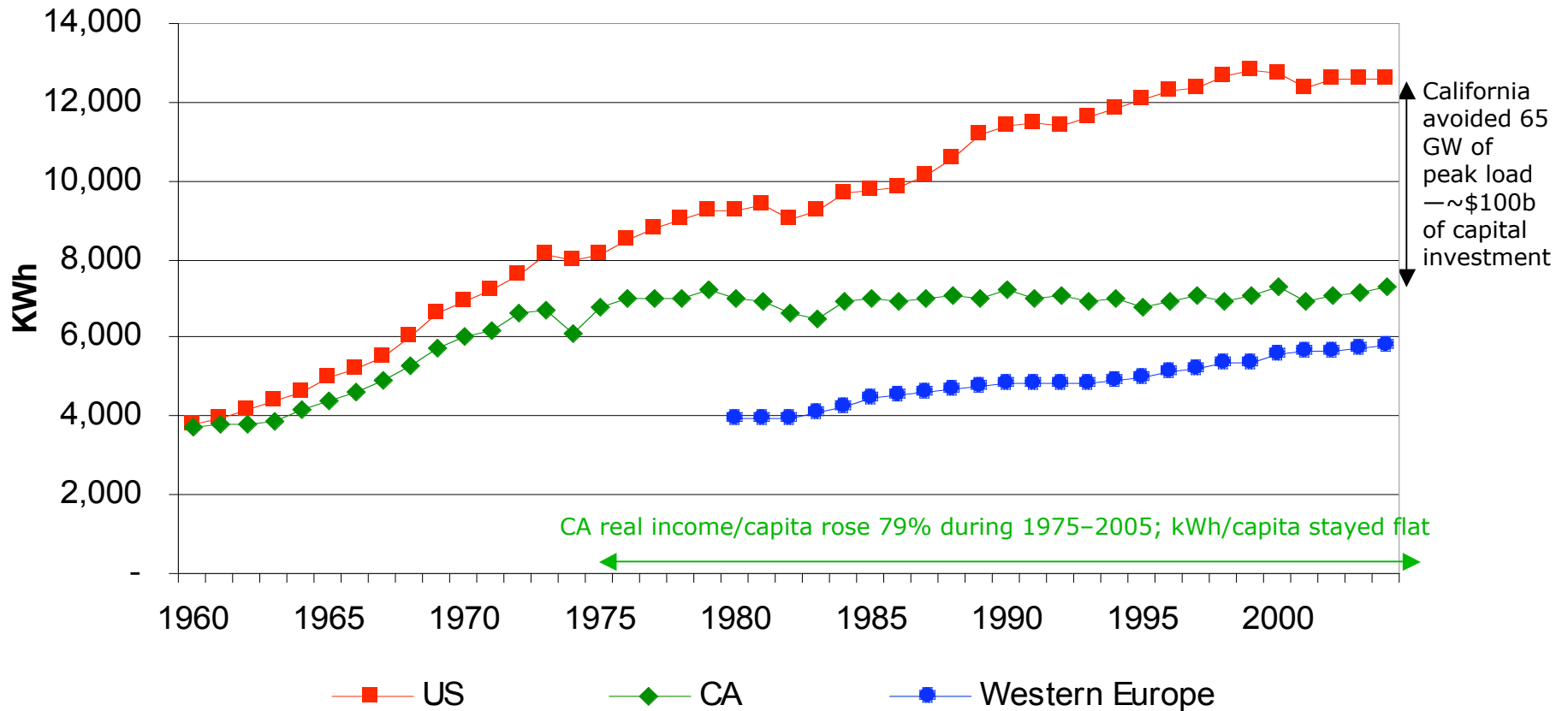
What has reduced energy intensity already done? What more can it do?

- ◇ During 1975–2006, the U.S. made a dollar of real GDP with 48% less total energy, 54% less oil, 64% less directly used natural gas, 17% less electricity, and two-thirds less water
 - Despite stagnant light-vehicle efficiency for >20 years, and perverse incentives rewarding electricity sales in 48 states
 - Nobody noticed: we 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 three-fourths of the electricity, at a cost 1/8 the price of buying that energy
- ◇ The EU's efficiency potential is surprisingly similar, and is broadly distributed across all sectors and fuels
- ◇ Proper pricing matters less than "barrier-busting"



Saving energy works—where allowed to

Annual electricity use per capita



Source: California Energy Commission

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



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

**A. Both got spoilt by a sign error
(confusing "+" with "-")**

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



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

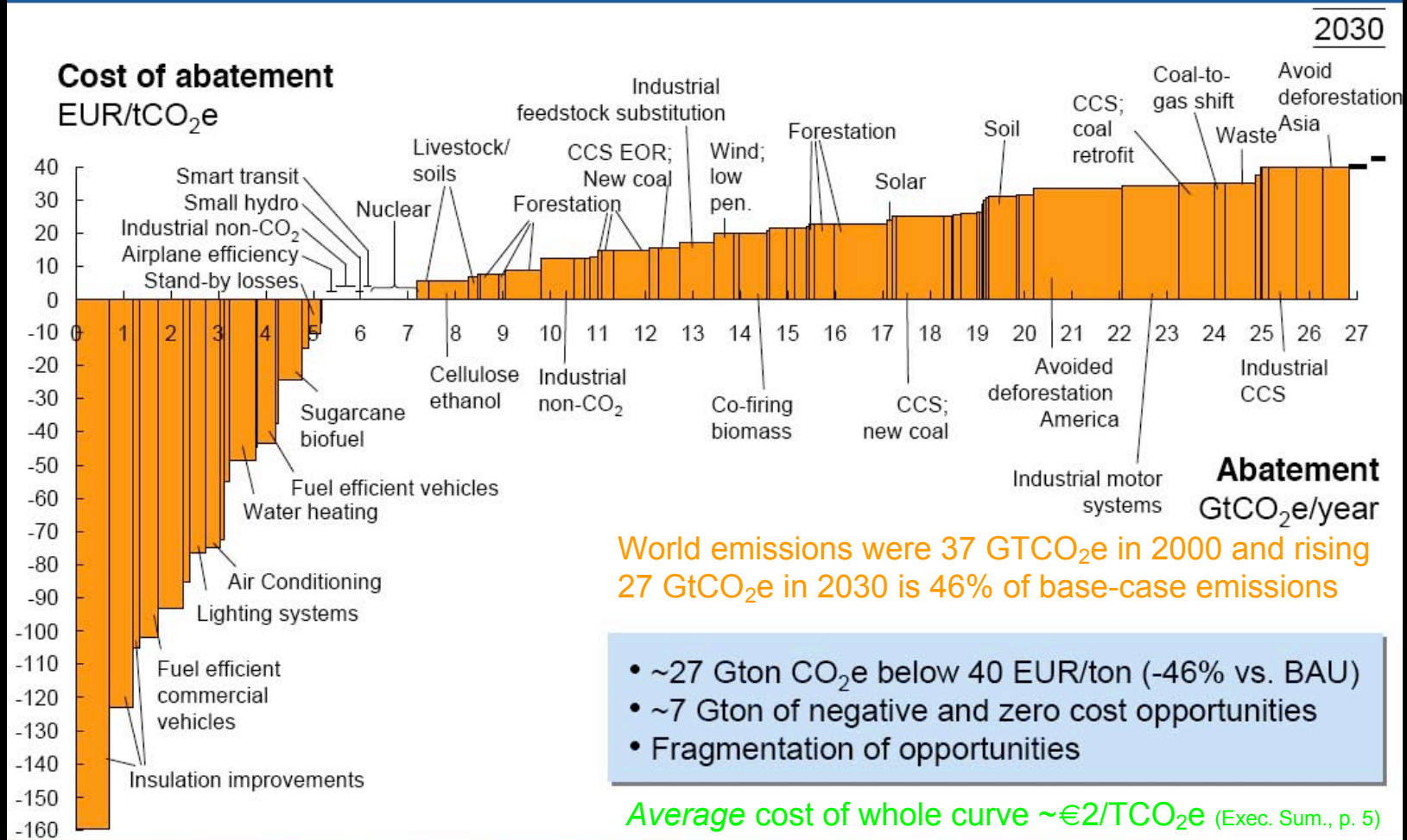
- ◇ IBM and STMicroelectronics
 - CO₂ emissions -6%/y, fast paybacks
- ◇ DuPont's 2000–2010 worldwide goals
 - Energy use/\$ -6%/y, GHG = 1990 level -65%
 - By 2006: actually cut GHG 80% below 1990, \$3b profit
- ◇ Dow: cut E/lb 22% 1994–2005, \$3.3b profit
- ◇ BP's 2010 CO₂ goal met 8 y early, \$2b 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





Profitable climate protection

- ◇ Global CO₂ emissions will triple by 2100 if we reduce E/GDP by 1%/y; level off if 2%/y; and drop—stabilizing Earth's climate—if $\sim 3-4\%/y$. Is that feasible?
- ◇ The U.S. has spontaneously saved $>2\%/y$ since 1997; $3.4\%/y$ 1981–86; $3.2\%/y$ '01 & '05; 4.0% '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 $\sim 6-15\%/y$
- ◇ U.S. wastes $>50\%$ of oil & gas, $>75\%$ of electricity
- ◇ Even Japan can profitably save $2/3$ of *its* energy
- ◇ Oil causes 42% of all CO₂ emissions, electricity 40%



**Independent, transparent,
peer-reviewed, uncontested,
USDoD-cosponsored, Sept 04**

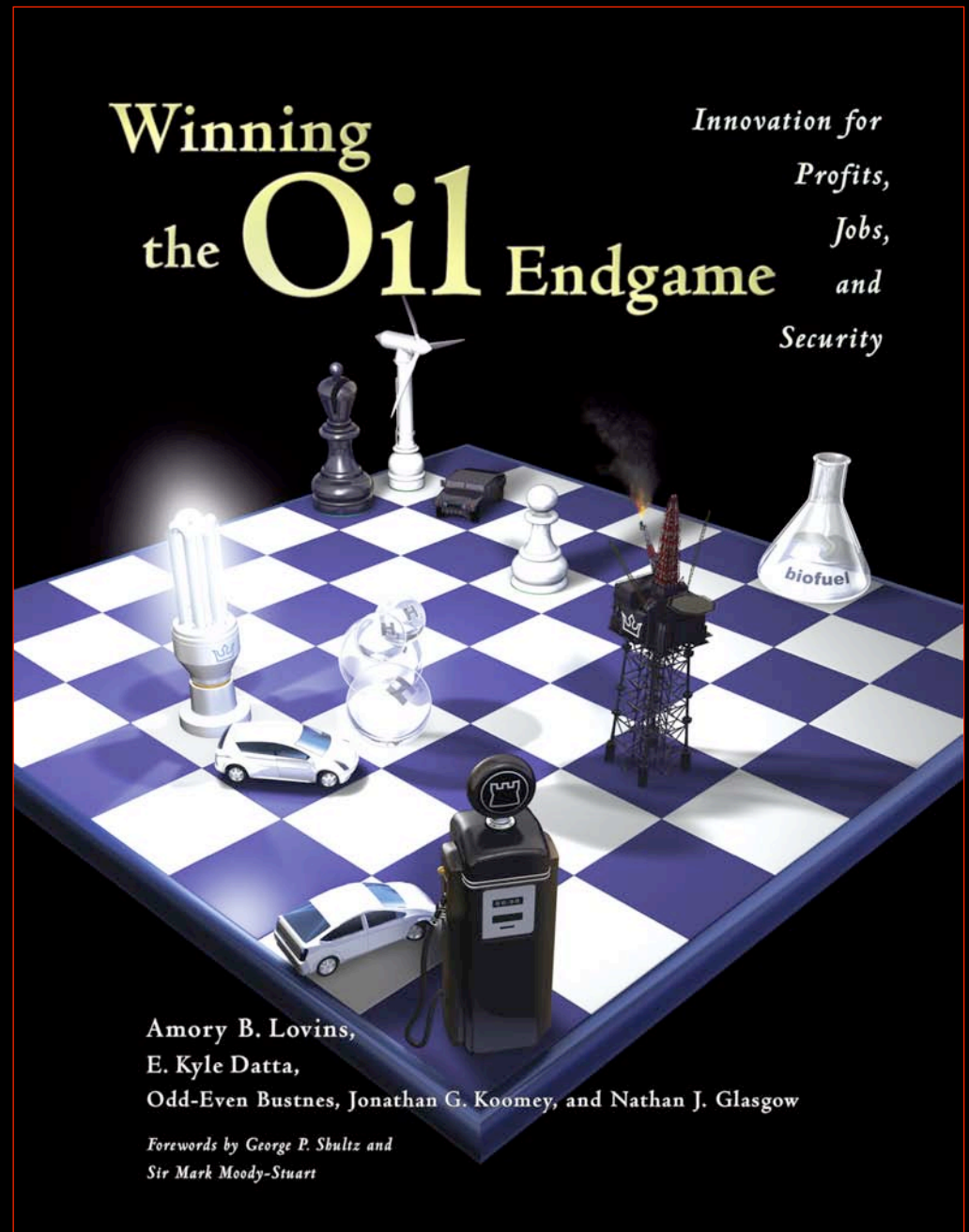
For business/mil. leaders

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

**Book and technical backup
are free at:**

www.oilendgame.com

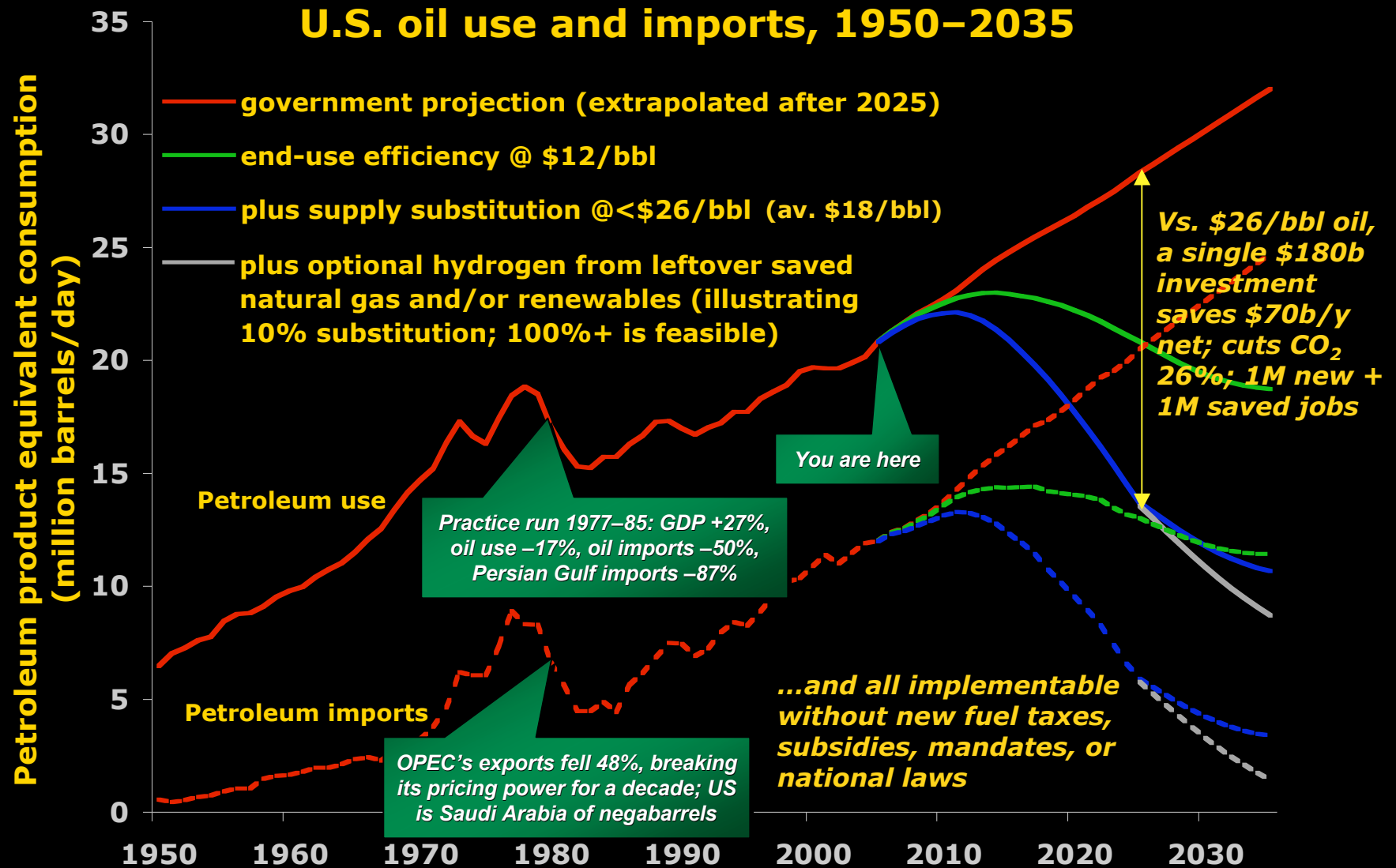
***Over the next few decades,
the U.S. can eliminate its use
of oil and revitalize its econo-
my, led by business for profit
(and so, probably, can Italy)***



This work was cosponsored by OSD and ONR. The views expressed are those of the authors alone, not of the sponsors.



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

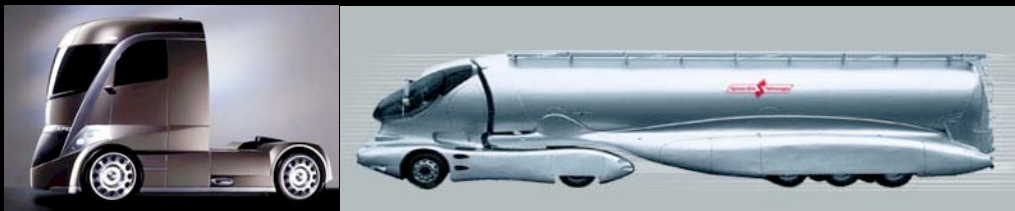
PLANES: save 20% free, 45→65% @ $\leq \$0.12/\text{L}$

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



250 km/h, 2.5 L/100 km

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

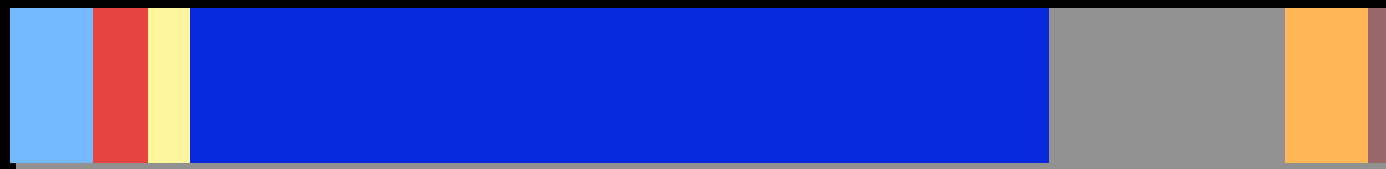


Each day, an average US car burns ~100× its weight in ancient plants. Where does that fuel energy go?

13% tractive load



87% of the fuel energy is wasted



0% 20% 40% 60% 80% 100%

Braking resistance	Rolling resistance	Aerodynamic drag
Engine loss	Idling loss	Drivetrain loss
Accessory loss		

- 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 fuel 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, manufactur-
able with a \$2,511 higher retail price (as hybrid)



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

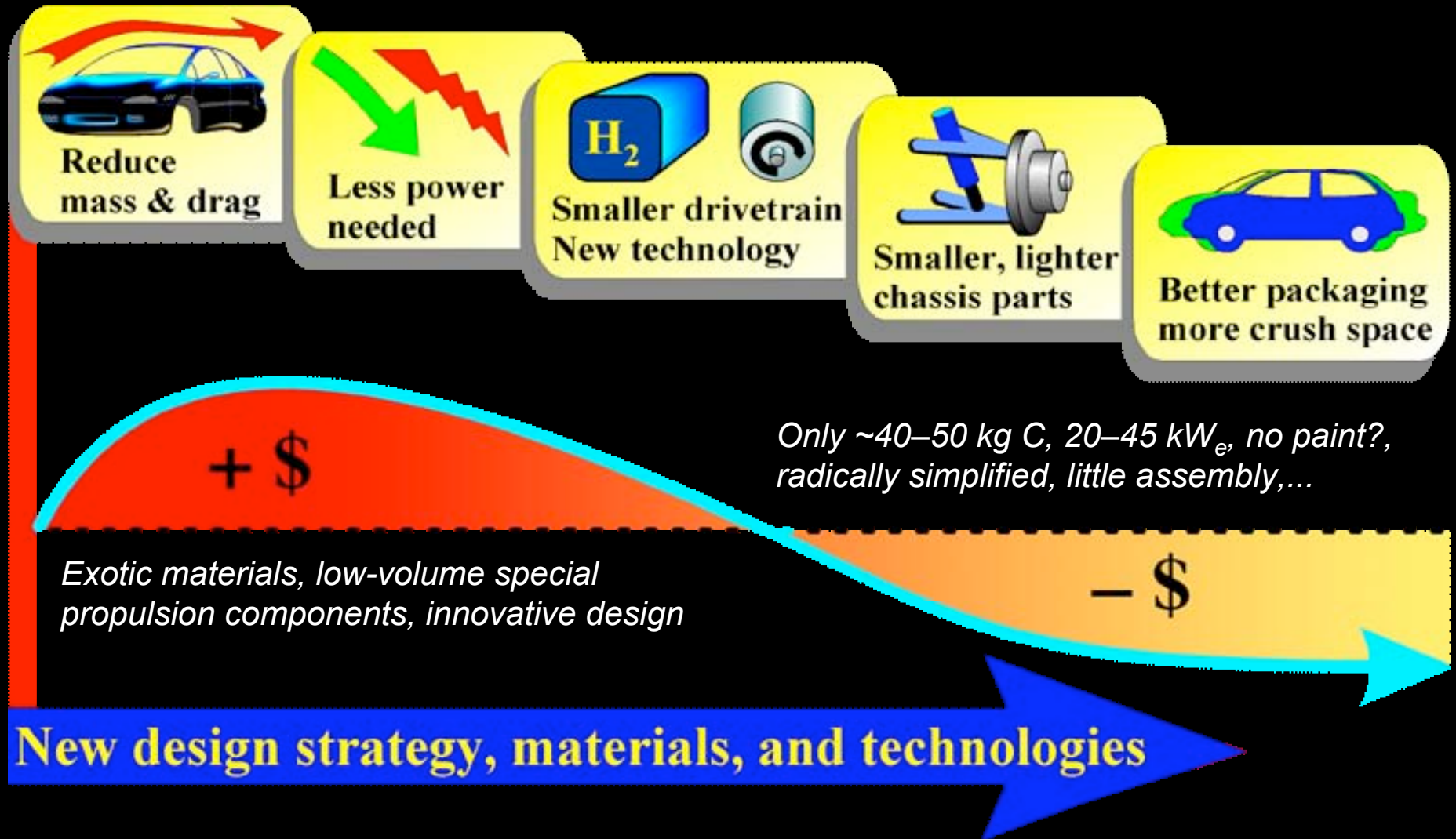


- ◇ 1/2 *Prius* fuel use, similar interior vol. (4 seats)
- ◇ 1/3 the weight (420 kg)
- ◇ carbon-fiber structure
- ◇ 0.5-L flex-fuel engine under rear seat, RWD
- ◇ plug-in hybrid-electric (if plain hybrid, 400 kg)

- 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 2010



Decompounding mass and complexity also decompounds cost

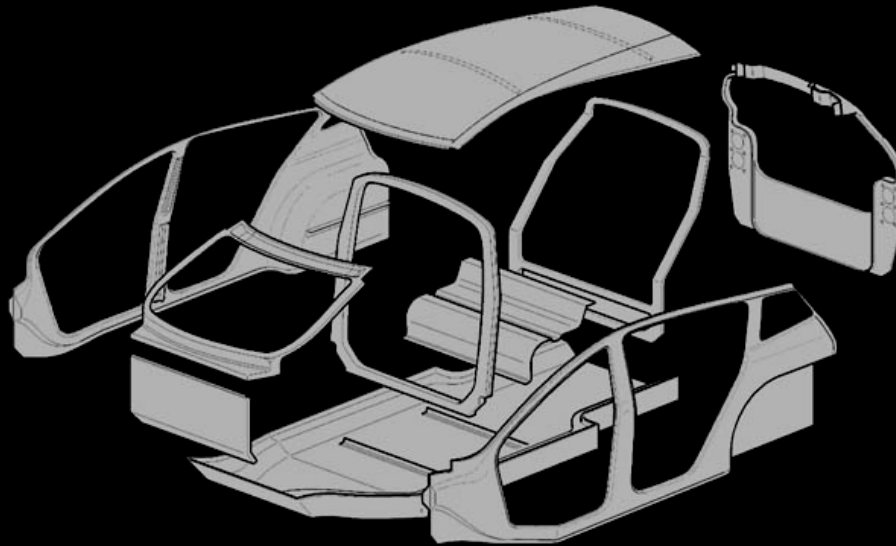




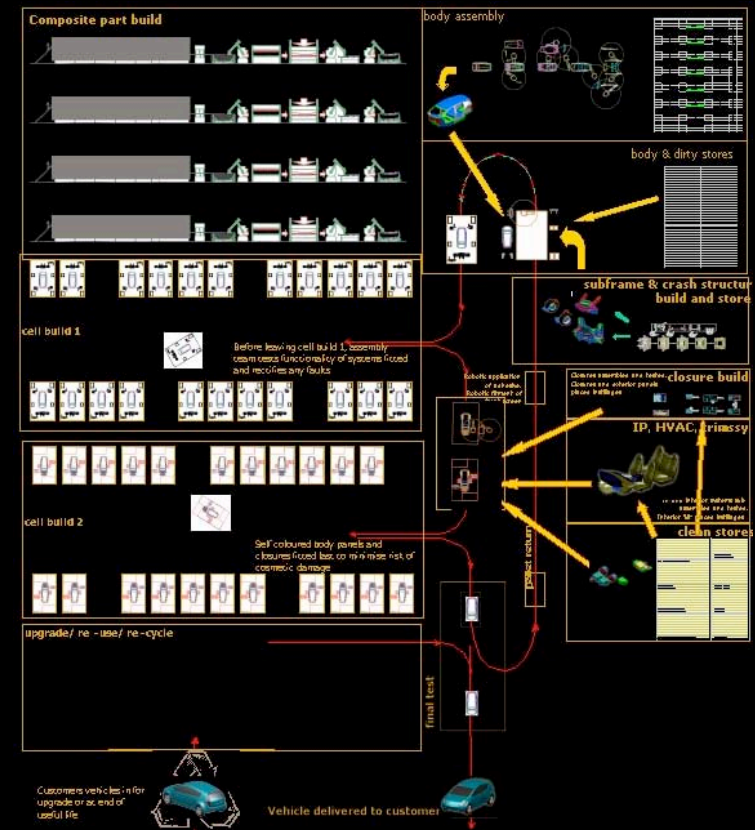
Radically simplified manufacturing

◇ 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 $\sim 10^3$)
- Self-fixturing, detoleranced in 2 dim.
- No body shop, optional paint shop
- 2/5 less capital than leanest, 2/3 smaller





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



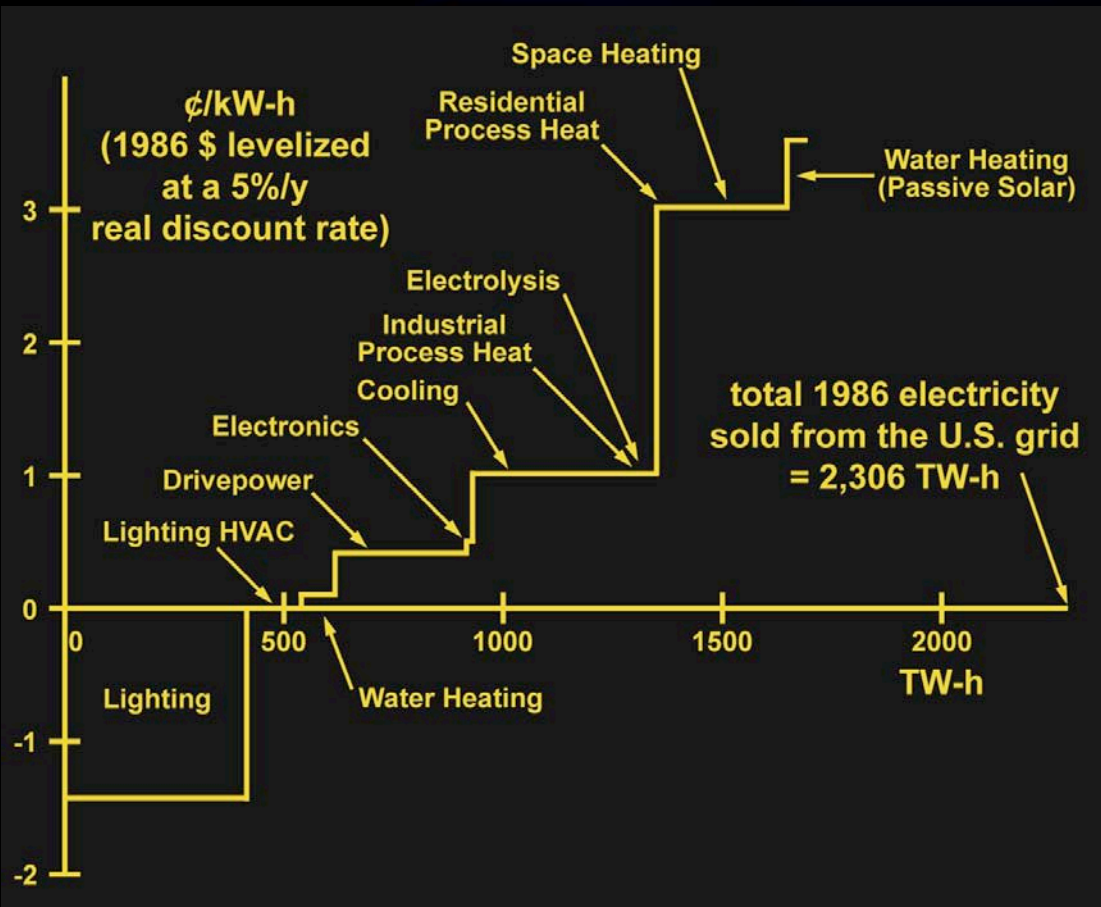


The oil endgame is being implemented via "institutional acupuncture"

- ◇ RMI's 3-year, \$4-million effort is leading & consolidating shifts
- ◇ Need to shift US strategy & investment in six sectors
 - Aviation: Boeing did it (*787 Dreamliner*)...and beat Airbus
 - Heavy trucks: Wal-Mart led it; other buyers & innovations being added
 - Military: emerging as the federal leader in getting US 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
 - UAW and dealers not blocking but eager for fundamental innovation
 - Schumpeterian "creative destruction" opens to unthinkable change
 - Emerging prospects of leapfrogs by China, India, ?new market entrants
 - New policy instrument ("feebates") can make efficiency very profitable
 - Accelerating competition, at a fundamental level and pace last seen in the 1920s, will change automakers' managers or their minds, whichever comes first...accelerated by RMI's transformational projects



1989 supply curve for saveable U.S. electricity (vs. 1986 frozen efficiency)



Best 1989 technology,
thoroughly retrofitted;
no integrative design

Similar S, DK, D, UK...

EPRI found 40–60%
saving 2000 potential

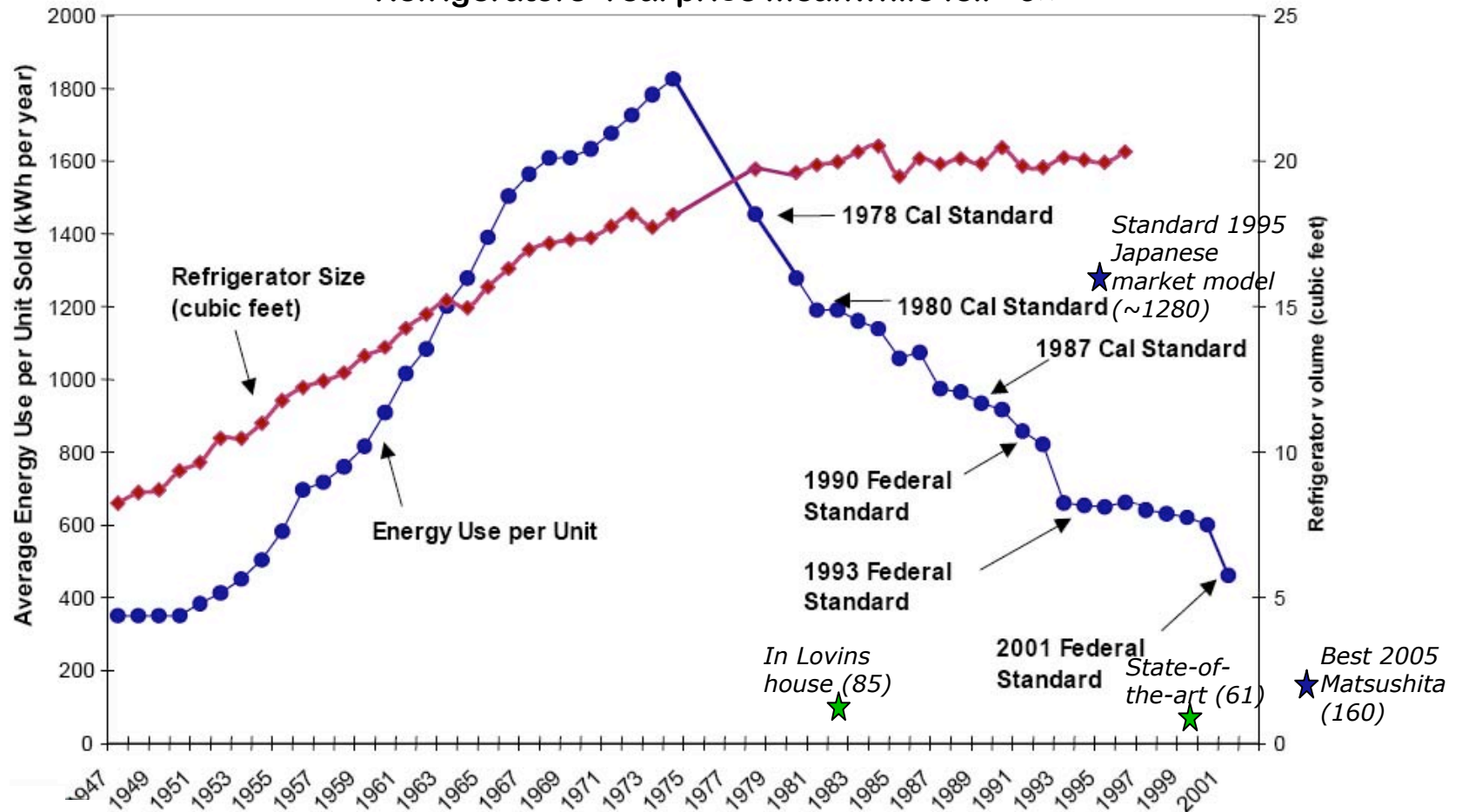
Now conservative:
savings keep getting
bigger and cheaper
faster than they're
being depleted

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



Efficiency is a rapidly moving target

United States Refrigerator Use v. Time
Annual drop from 1974 to 2001 = 5% per year
Refrigerators' real price meanwhile fell ~3×



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 makes very big energy savings cost *less* than small or no savings

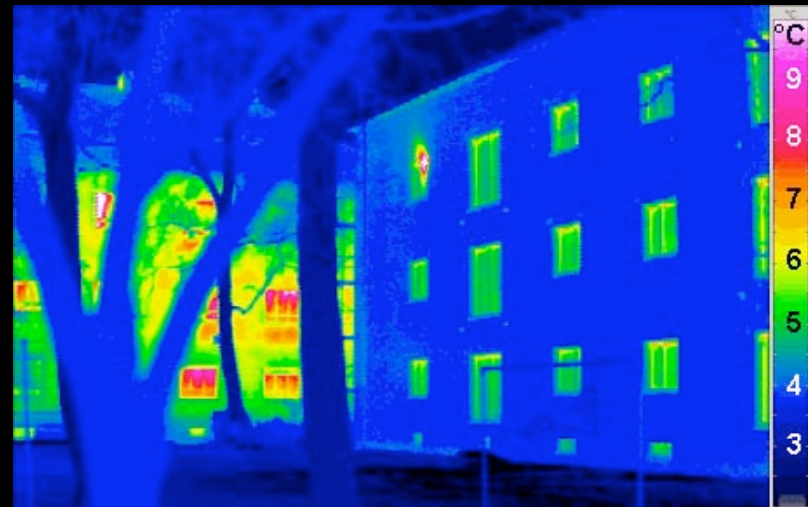
- ◇ Lovins house / RMI HQ, Snowmass, Colorado, '84
 - Saves 99% of space & water heating energy, 90% of home el. (372 m² use ~\$5/month worth @ 7¢/kWh, all made with solar)
 - 10-month payback in 1983
- ◇ PG&E ACT², Davis CA, '94
 - Mature-market cost -\$1,800
 - Present-valued maint. -\$1,600
 - Design 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 $\leq 120 \text{ kWh/m}^2\text{-y}$
- ◇ $\leq 15 \text{ kWh/m}^2\text{-y}$ & $< 10 \text{ W/m}^2$ heating energy—5–25% of U.S. allowables
- ◇ $k=0.10\text{--}0.15$ ($k=0.066$ roof in Sweden), airtight, high comfort, loses $< 0.5 \text{ }^\circ\text{C/d}$ w/ 0 el.
- ◇ $> 10\text{k}$ built in 5 EU nations; Vorarlberg (ÖS) standard
- ◇ *Zero marginal capital cost* (at least at $< 60^\circ \text{N}$ lat)

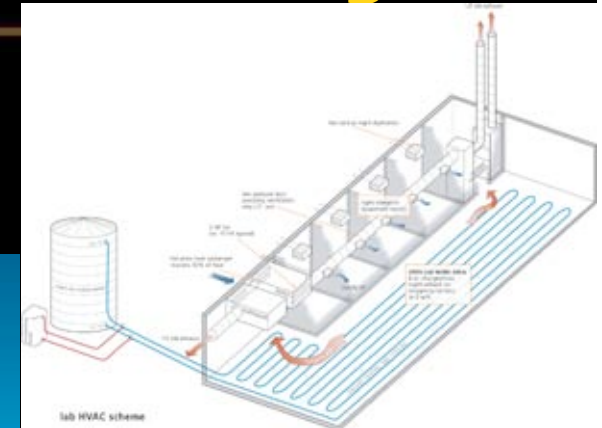
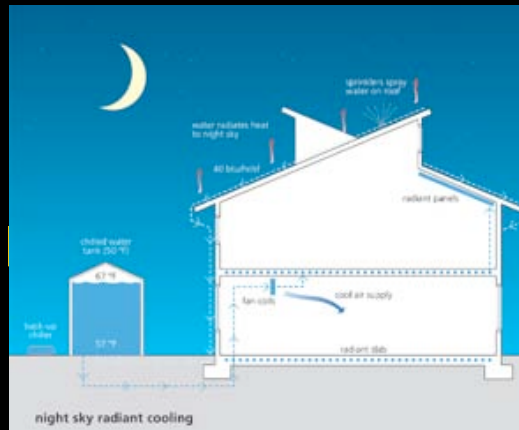


Infrared images of ordinary German apartment (L) and Passivhaus (R)



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, high occupant satisfaction
- ◆ Normal capital cost
- ◆ $\sim 1/5$ normal energy use, despite peculiar safety rules requiring high-rate ventilation 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>



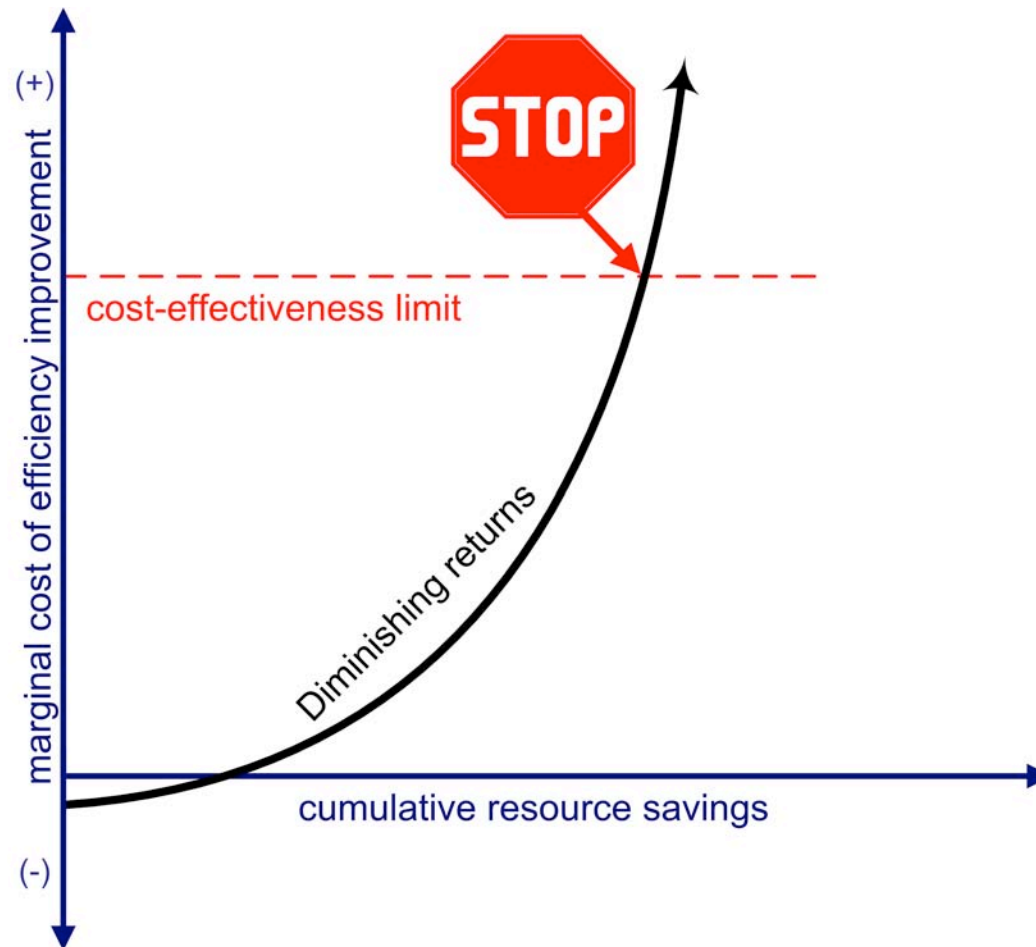


Rocky Mountain bananas with no furnace?





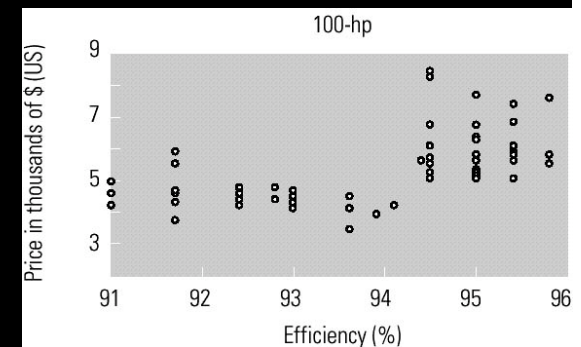
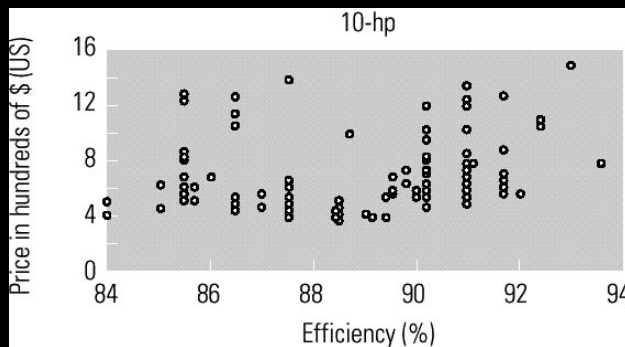
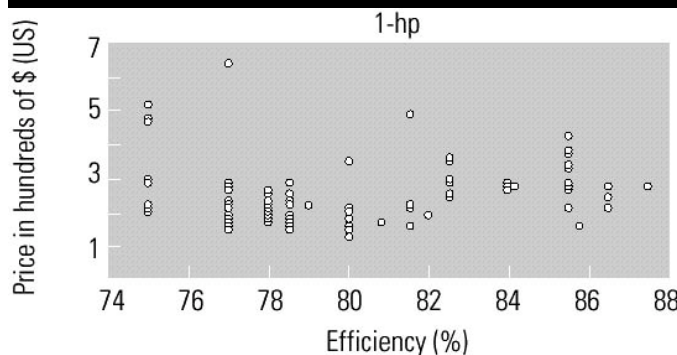
Old design mentality: always diminishing returns...





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 260 kW



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



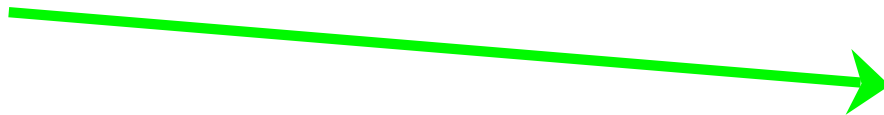
New design mentality: expanding returns, “tunneling through the cost barrier”





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

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



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



Two ways to tunnel through the cost barrier

1. Multiple benefits from single expenditures

- ◇ Save energy *and* capital costs...10 benefits from superwindows, 18 from efficient motors & lighting ballasts,...
- ◇ Throughout the design: *e.g.*, RMI HQ building's central arch has 12 functions but only one cost
- ◇ A Lotus *Elise* car has a front-end part with seven functions but only one cost



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
<u>HVAC</u>	<u>-\$160,000</u>
Total	<u>-\$36,300</u>

Energy savings: \$75,000/year





Two ways to tunnel through the cost barrier

1. Multiple benefits from single expenditures

- ◇ Save energy *and* capital costs...10 benefits from superwindows, 18 from efficient motors & lighting ballasts,...
- ◇ Throughout the design: *e.g.*, RMI HQ's arch has 12 functions, one cost

2. Piggyback on retrofits

- ◇ A 19,000-m² Chicago office could save 3/4 of energy at same cost as normal 20-y renovation — and greatly improve human performance—*if retrofit is coordinated with façade renewal*



Cost can be negative even for retrofits of big buildings



- ◇ 19,000-m², 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 more per m² of glass
 - Add deep daylighting, plus very efficient lights (3 W/m²) and office equipment (2 W/m²)
- ◇ 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



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, $\geq 40\%$ energy savings; ~60%? new, cost less
- ◇ Redesign \$5b gas-to-liquids plant, $-\$1\text{b}$ 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 pedagogy/practice reforms; see www.10xE.org



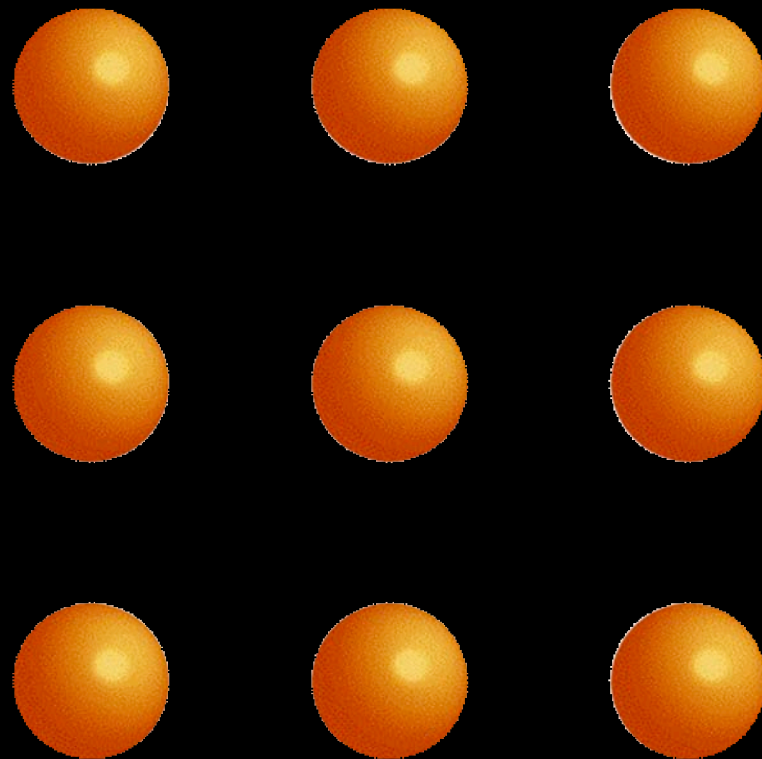
Edwin Land

"People who seem to have had a new idea have often just stopped having an old idea"



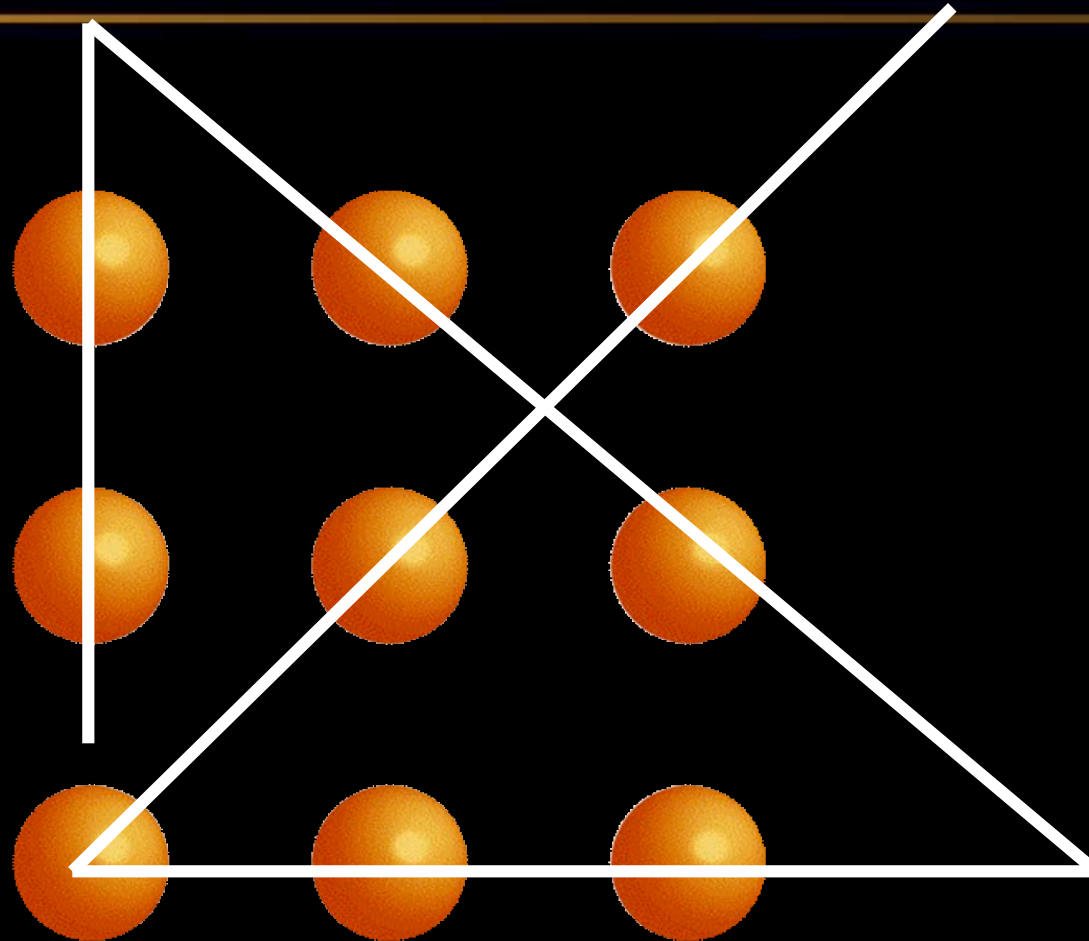


The Nine Dots Problem



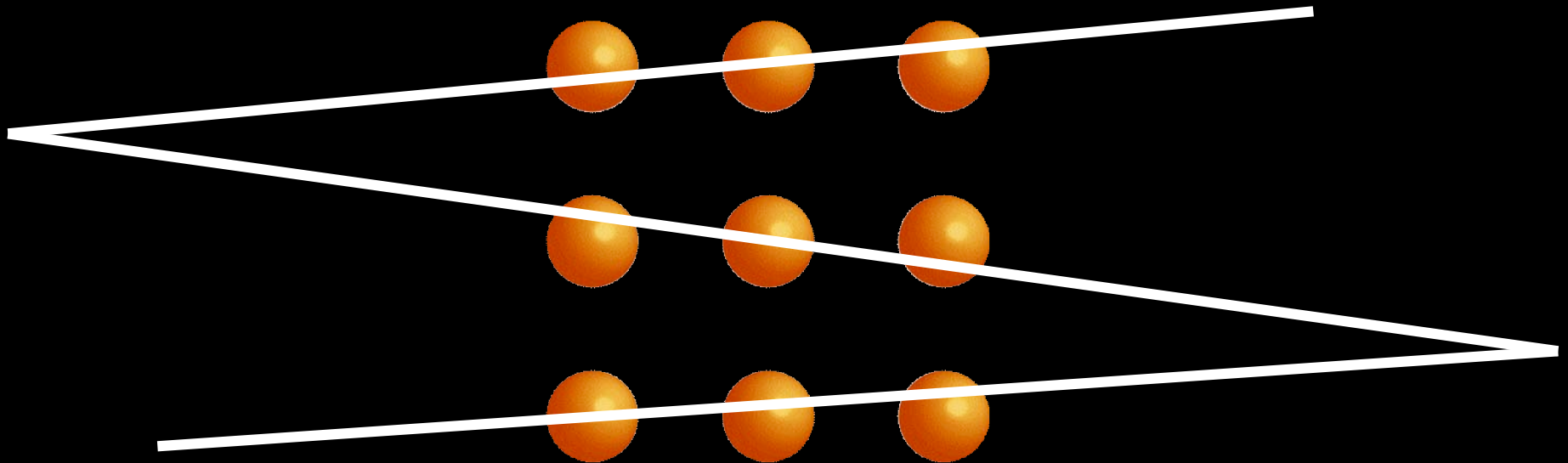


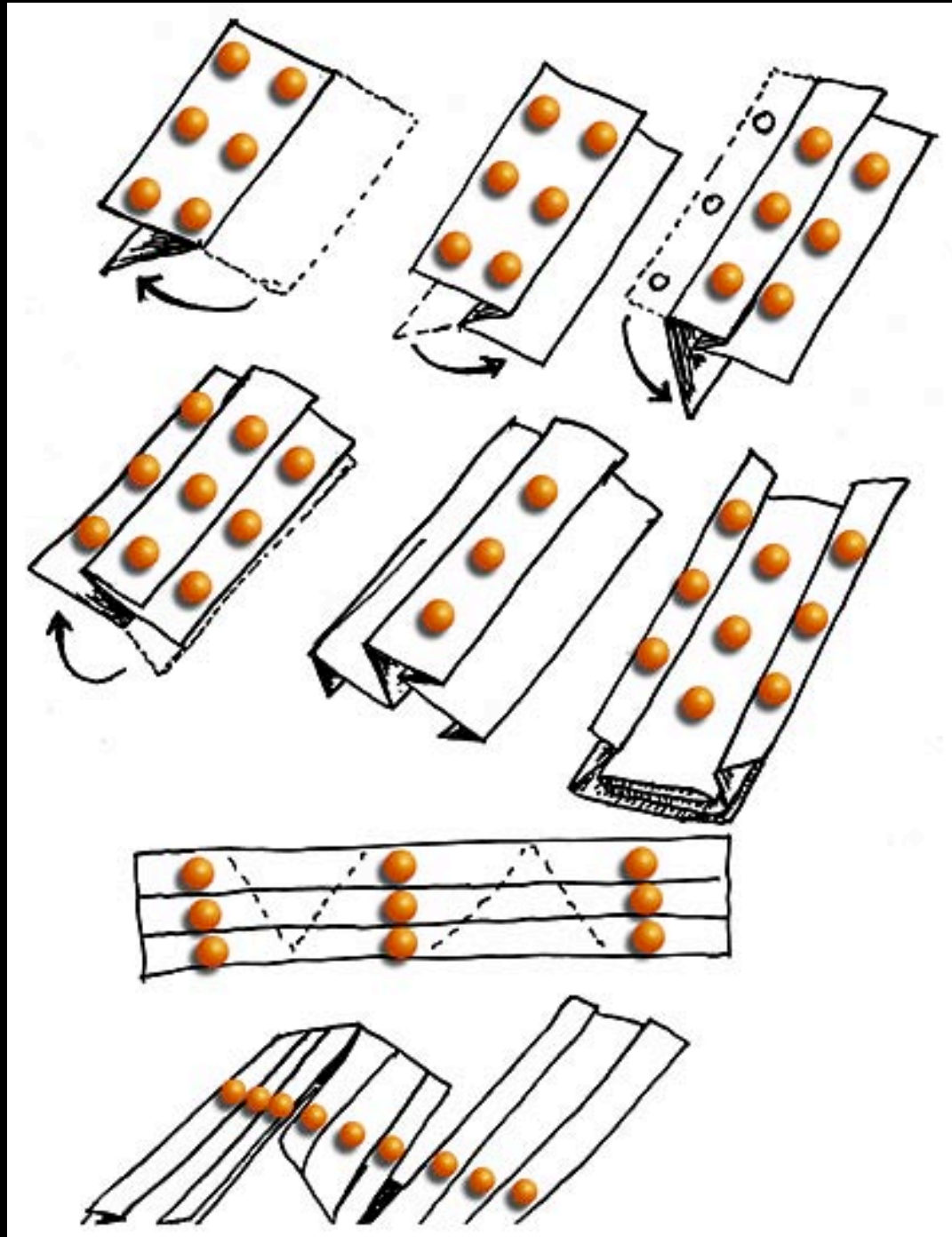
The Nine Dots Problem





The Nine Dots Problem

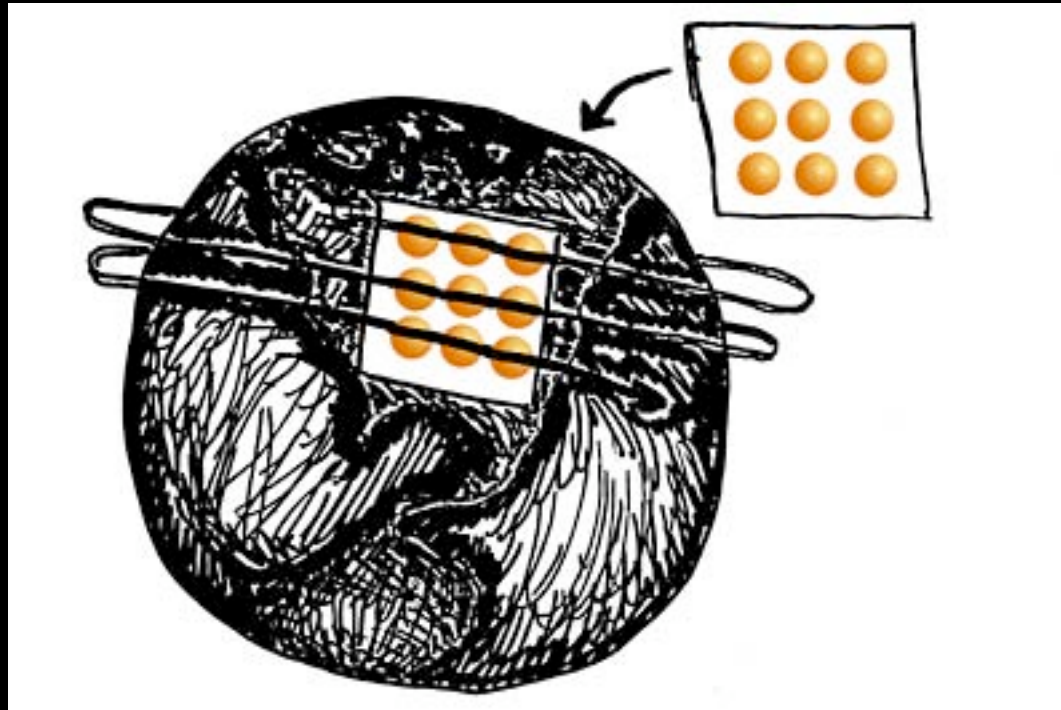




**origami
solution**



geographer's solution



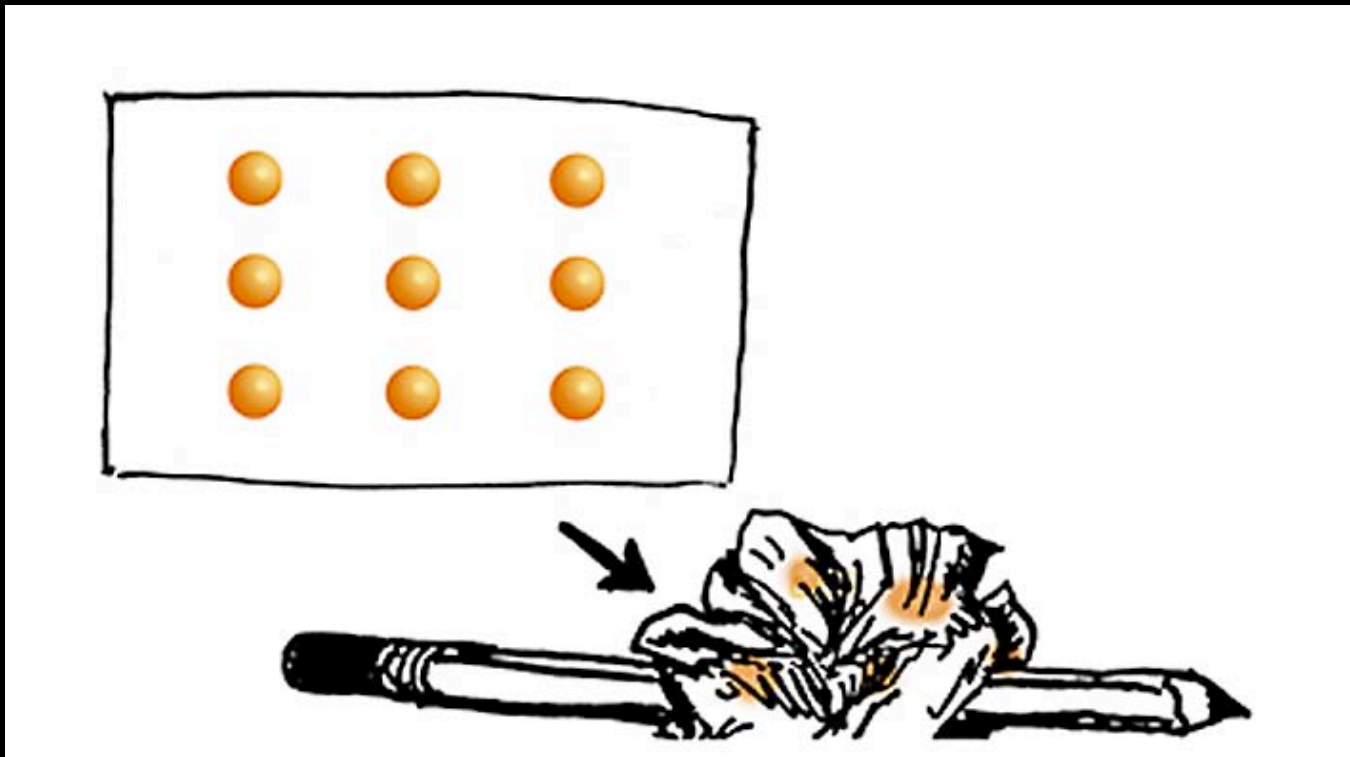


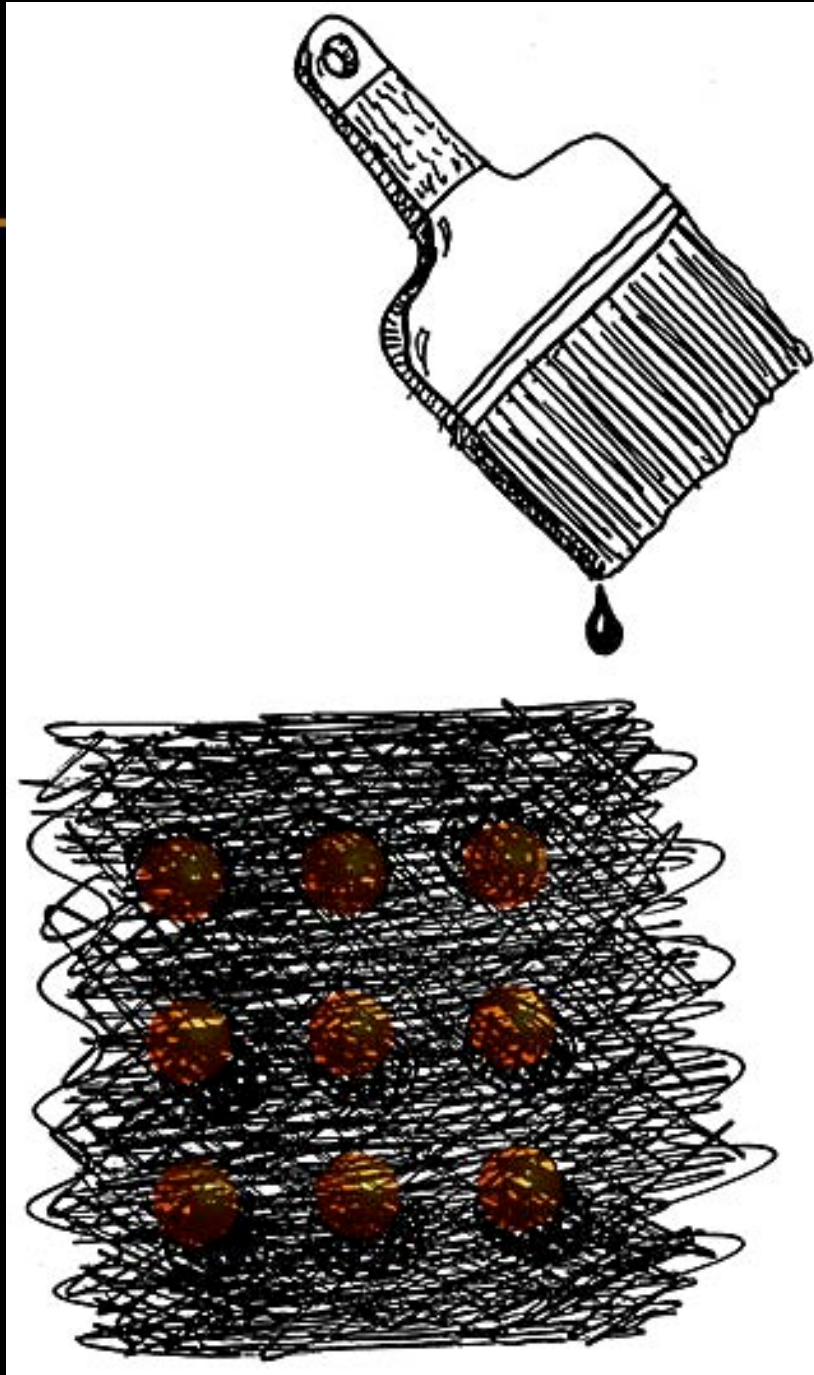
mechanical engineer's solution





statistician's solution





**wide line
solution**



New design mentality



- Redesigning a standard (supposedly optimized) industrial pumping loop cut power from 70.8 to 5.7 kW (–92%), cost less to build, and worked better
- Just two changes in design mentality...



New design mentality, an example



1. Big pipes, small pumps (not the opposite)



No new technologies, just two design changes



2. Lay out the pipes first, then the equipment (not the reverse)



No new technologies, just two design changes

- ◇ Fat, short, straight pipes — not thin, long, crooked pipes!
- ◇ Benefits counted
 - 12x less pumping energy
 - Lower capital cost
- ◇ “Bonus” benefit also captured
 - 70 kW lower heat loss from pipes
- ◇ Additional benefits not counted
 - Less space, weight, and noise
 - Clean layout for easy maintenance access
 - Needs little maintenance, yet better uptime
 - Longer equipment life
- ◇ Count these and save...~98%?



Why *systems*?



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



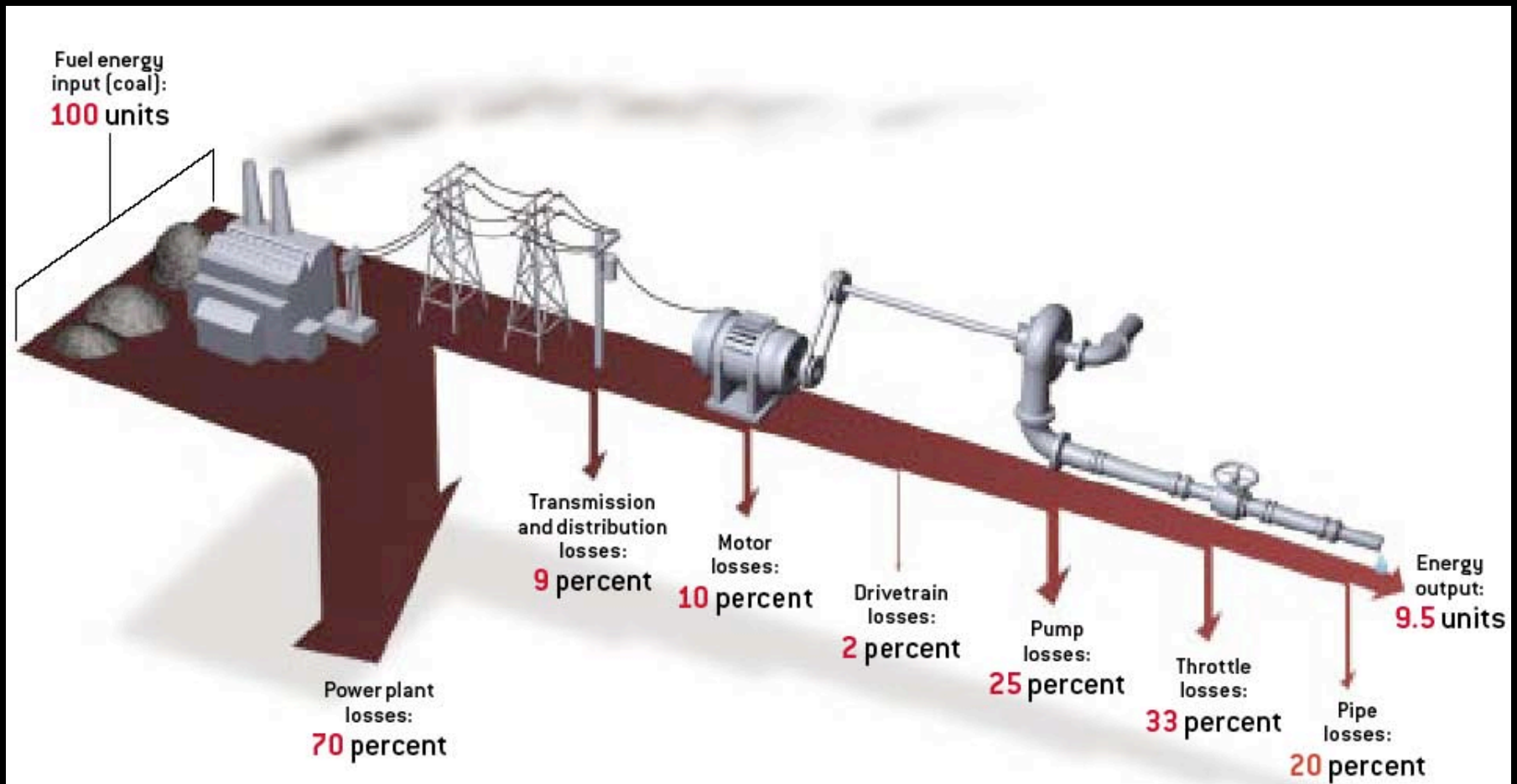


Why pumping systems?

- ◇ Pumping is the world's biggest use of motors, fans (same physics) #2; both total ~50%
- ◇ Motors use 3/5 of all electricity, so emit 20% of all fossil-fuel CO₂
- ◇ A big motor running constantly uses its capital cost in electricity every few *weeks*
- ◇ RMI (1989) and EPRI (1990) found ~1/2 of typical industrial motor-system energy could be saved by retrofits paying back in ~16 months at a \$0.05/kWh tariff (cheaper today)
- ◇ But downstream savings are often bigger and cheaper—so *minimize flow and friction first*



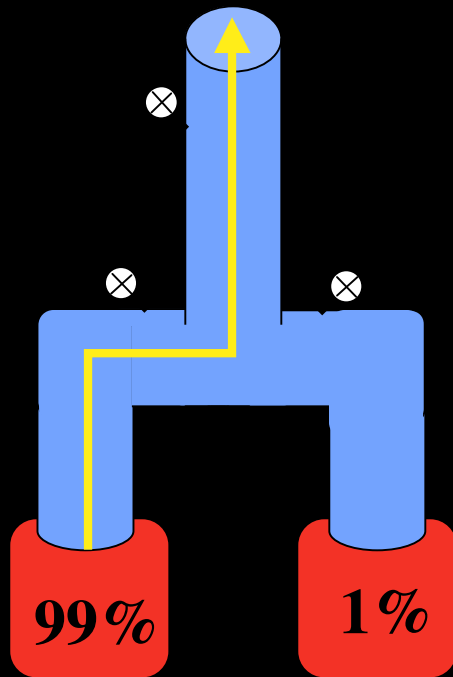
Compounding losses...or savings...so start saving at the *downstream* end to save ten times as much energy at the power plant



Also makes upstream equipment smaller, simpler, cheaper

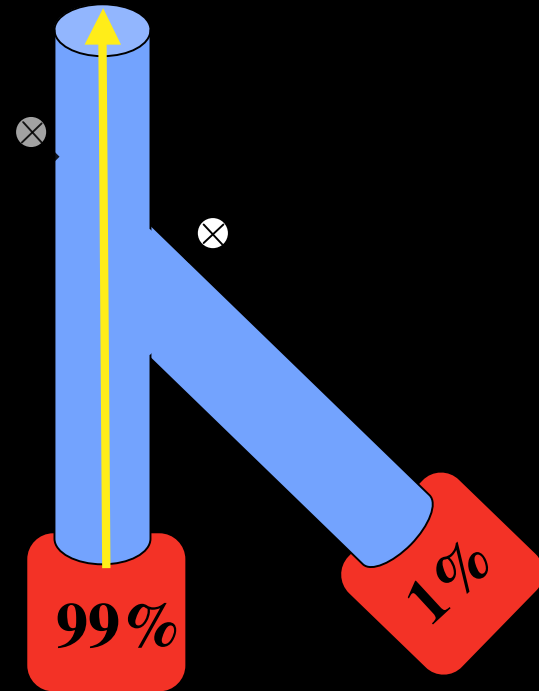


It's often remarkably simple



Boolean pipe
layout

VS.



hydraulic pipe
layout



High-efficiency pumping / piping retrofit (Rumsey Engineers, Oakland Museum)



15 "negapumps"

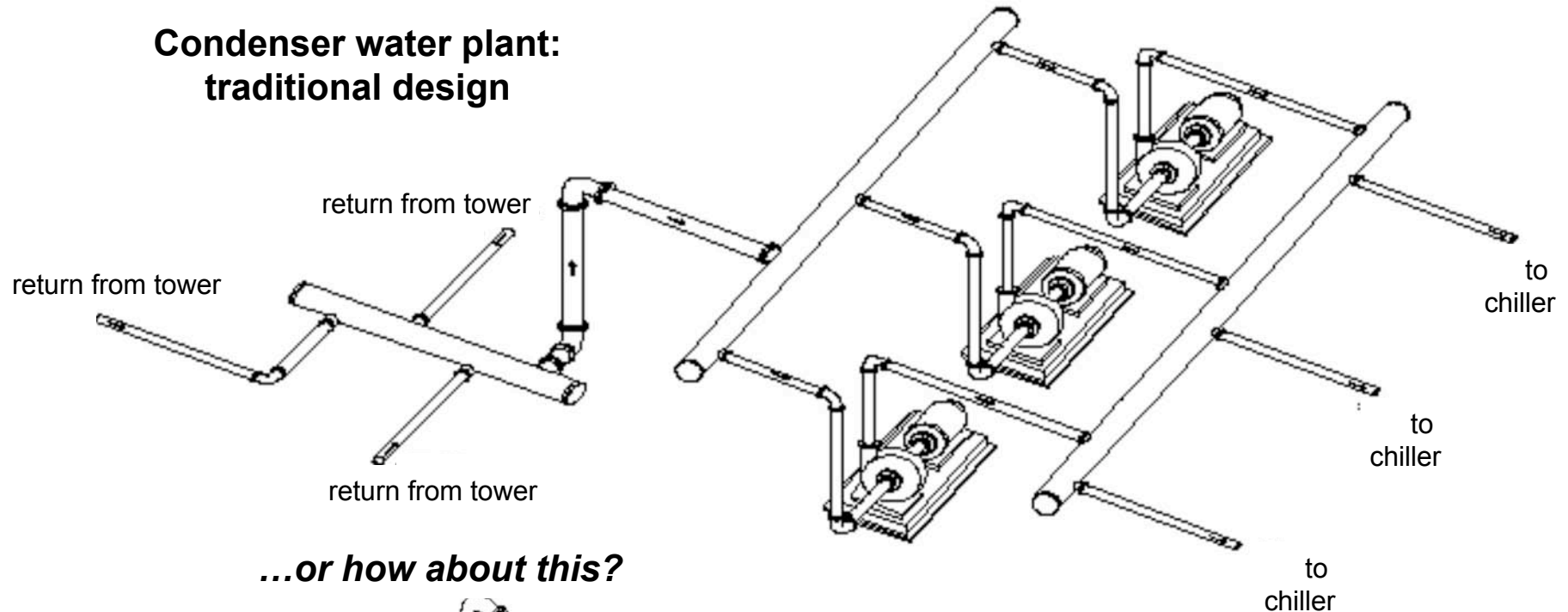


Notice smooth piping design
– 45°s and Ys

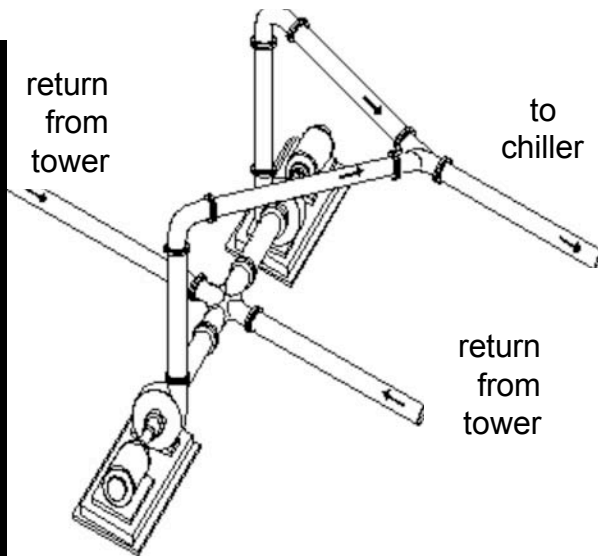
Downsized condenser-water pumps, ~75% energy saving

Which of these layouts has less capex & energy use?

Condenser water plant:
traditional design



...or how about this?



- Less space, weight, friction, energy
- Fewer parts, smaller pumps and motors, less installation labor
- Less O&M, higher uptime





Unexpectedly fundamental advances continue, e.g.:

- Biomimetic rotor from Pax Scientific, San Rafael, Calif. (www.paxscientific.com)
- Fibonacci spiral shape matches the laminar vortex flow found in nature, e.g. blood (160 km blood vessels)
- In fans, pumps, turbines, turboexpanders, etc., can raise efficiency ~20–30 percentage points and cut noise
- Computer muffin fans get +30% flow/W or –10 dBa
- Commercialization starting



Images courtesy of Pax Scientific



The right steps in the right order: lighting

1. Improve visual quality of task
2. Improve geometry of space, cavity reflectance
3. Improve lighting quality (cut veiling reflections and discomfort glare)
4. Optimize lighting quantity
5. Harvest/distribute natural light
6. Optimize luminaires
7. Controls, maintenance, training



The right steps in the right order: space cooling

0. Cool the people, not the building
1. Expand comfort envelope (check assumptions!)
2. Minimize unwanted heat gains
3. Passive cooling
 - Ventilative, radiative, ground-/H₂O-coupling, icepond
4. Active nonrefrigerative cooling
 - Evap, desiccant (CDQ), absorp., hybrids: COP > 100
 - Direct/indirect evap + VFD recip in CA: COP 25
- ~~5. Superefficient refrigerative cooling: COP 6.8 (0.52 kW/t) (Singapore water-cld. centrif. system @ design)~~
6. Coolth storage and controls
7. Cumulative energy saving: ~90–100%, better comfort, lower capital cost, better uptime

A worthy goal: eliminate refrigerative air conditioning, including big commercial (responsible for ~1/2 of China's growth in peak el. demand)



Superefficient big refrigerative HVAC too

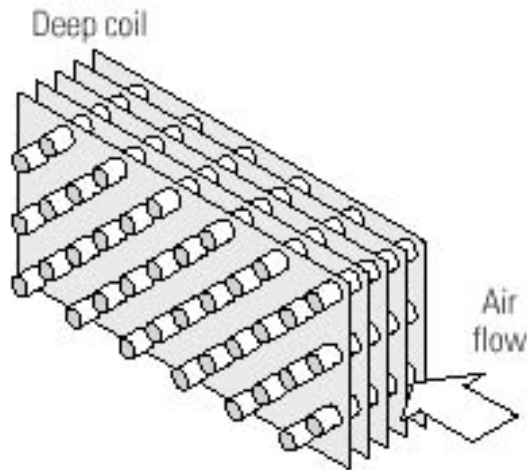
(10^5+ m² water-cooled centrifugal, Singapore, turbulent induction air delivery — but underfloor displacement could save even more energy)

Element	Std kW/t (COP)	Best kW/t (COP)	How to do it
Supply fan	0.60	0.061	Best vaneaxial, ~0.2–0.7 kPa TSH (less w/UFDV), VAV
ChWP	0.16	0.018	120–150 kPa head, efficient pump/motor, no pri/sec
Chiller	0.75	0.481	0.6–1 C° approaches, optimal impeller speed
CWP	0.14	0.018	90 kPa head, efficient pump/motor
CT 	0.10	0.010	Big fill area, big slow fan at variable speed
<i>TOTAL</i>	<i>1.75 (COP 2.01)</i>	<i>0.588 COP 5.98, 3× better)</i>	<i>Better comfort, lower capital cost</i>

Best Singapore practice w/dual ChW temp.: **0.52 total kW/t** including 0.41 chiller, **COP 6.8**

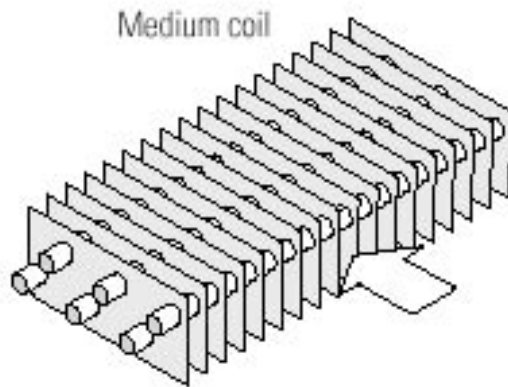
$$\text{Velocity} = 2V$$

$$\text{Face area} = \frac{A}{2}$$



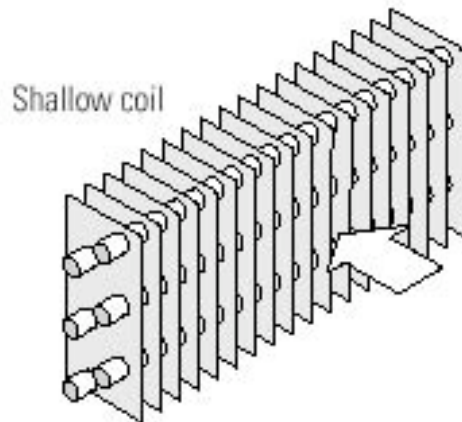
$$\text{Velocity} = V$$

$$\text{Face area} = A$$



$$\text{Velocity} = \frac{V}{2}$$

$$\text{Face area} = 2A$$

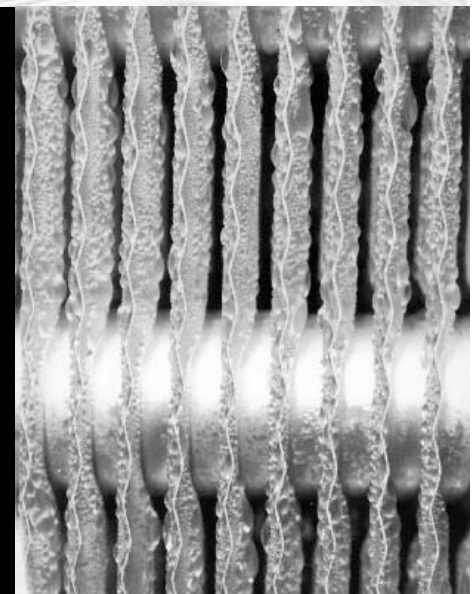
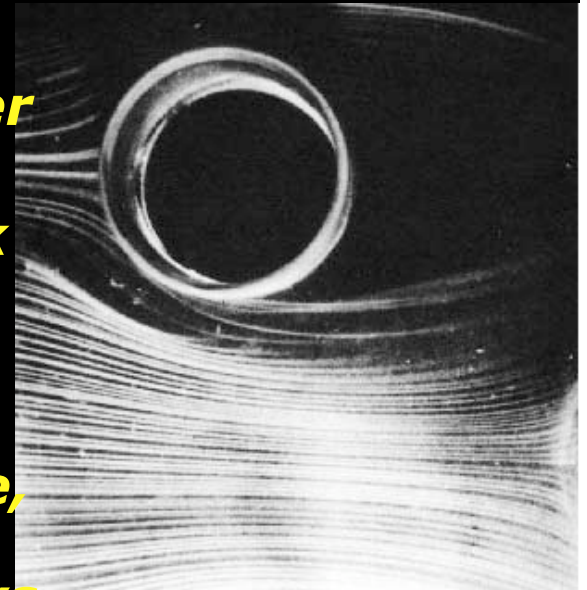


Source: Luxton and Shaw [25]

Low-face-velocity, high-coolant-velocity coils...

Just correct a 1921 W. Carrier error about how coils work

Flow is laminar and condensation is dropwise, so turn the coil around sideways, run at <1 m/s; 29% better dehumidification, ΔP -95%, ASHRAE comfort over the entire load range, smaller chiller/fan, smaller parasitics





Benchmarking a new office

(~10,000+ m², semitropical climate)

	standard US	better	best practice
site MJ/m ² -y	1,100	450–680	100–230
el. kWh/m ² -y	270	160	20–40
lighting W/m ²	16–24	10	1–3
plug W/m ²	50–90	10–20	2
glazing _{COG} W/m ² K	2.9	1.4	0.29–0.5
glazing T _{vis} /SC	1.0	1.2	>2.0
perimeter heating	extensive	medium	none
roof α , ε	0.8, 0.2	0.4, 0.4	0.08, 0.97
m ² /kW _{th} cooling	7–9	13–16	26–32+
cooling syst. COP	1.85	2.3	6–100+
relative capital cost	1.0	1.03	0.95–0.97
relative space effic.	1.0	1.01	1.05–1.06



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 m² use ~ 120 W_{av}, costing $\sim \$5/\text{month}$ @ $\$0.07/\text{kWh}$
 - So ~ 3 m² of solar cells can run the building (or ~ 1 m² with 2007 not 1983 efficiency technology!)
 - That costs less than just *connecting* 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



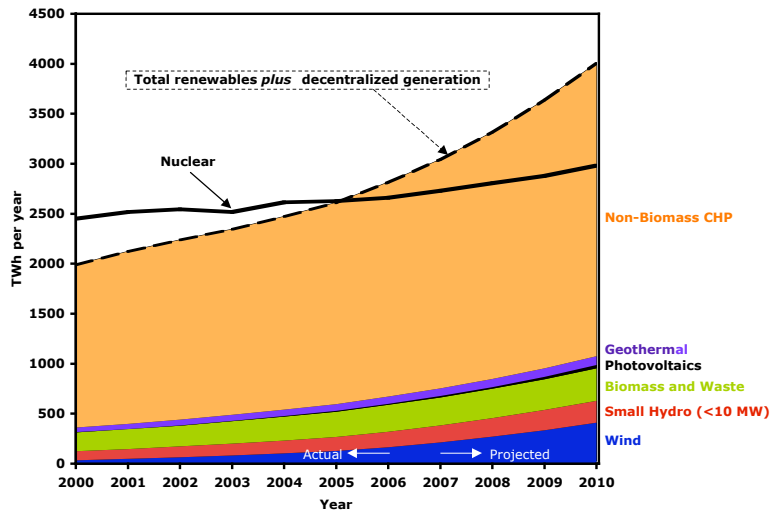
- ◇ Santa Rita Jail, Alameda County, California
- ◇ PowerLight 1.18 MW_p project, 1.46 GWh/y, ~1.25 ha of PVs
- ◇ Integrated with Cool Roof and ESCO efficiency retrofit (lighting, HVAC, controls, 1 GWh/y)
- ◇ Energy management optimizes use of PV output
- ◇ Dramatic (~0.7 MW_p) load cut
- ◇ Gross project 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.



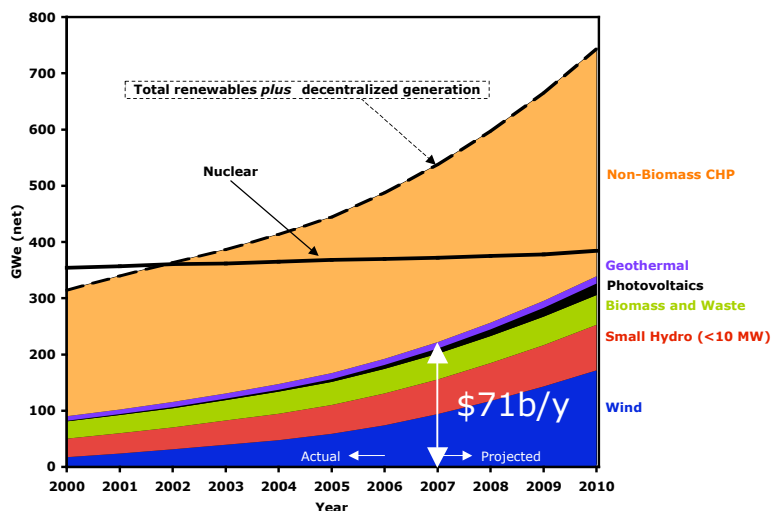
Electric shock: low-/no-carbon decentralized sources are eclipsing central stations

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, $\geq 50\%$ less CO_2

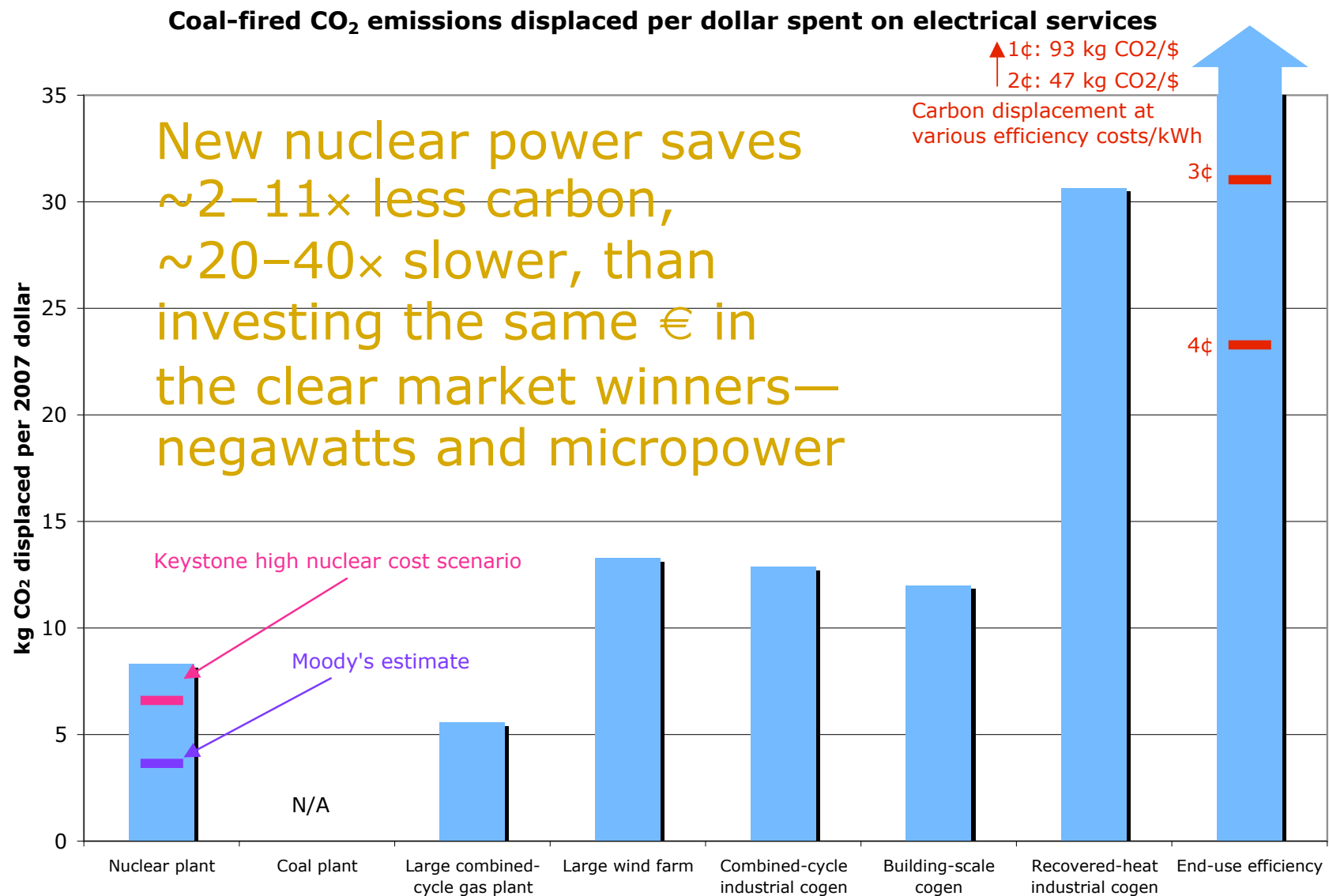
*Gas turbines ≤ 120 MWe, engines ≤ 30 MWe, steam turbines only in China

- One-third renewable (hydro ≤ 10 MWe)
- In 2006, micropower added 41 $\times$ (excl peaking & standby units, 30 $\times$) 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



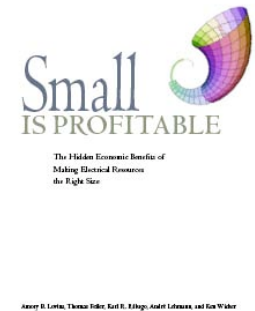
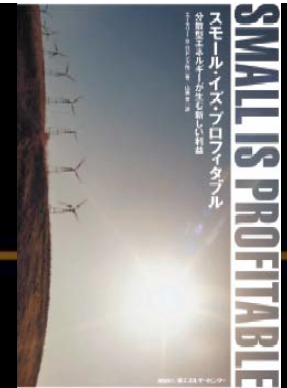
Nuclear power worsens climate change

www.rmi.org/images/PDFs/Energy/E08-01_AmbioNucIllusion.pdf, summarized at www.rmi.org/sitepages/pid467.php





"Distributed benefits" change the game



- ◇ Size matters!
- ◇ *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (Rocky Mountain Institute, 2002; Japan Energy Conservation Center, 2005)
 - 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 $\sim 10\times$ (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 (\$3,000–5,000/kW_e)
- ◇ As markets start to recognize distributed benefits, the distributed-electricity revolution will accelerate



Practical design keys to a broad and profitable efficiency revolution

$$\text{No } 1-\eta = \text{No } \text{無駄} + \text{No } \text{Rules} + \text{No } 1-\Delta + \text{No } \epsilon$$

- ◇ Optimize whole systems for multiple benefits
- ◇ Bust barriers, and reward what we want
- ◇ Faith, hope, clarity, and relentless patience
- ◇ This unprecedented cornucopia is the manual model: we must all actually go turn the crank!
- ◇ "Preach the gospel at all times. If necessary, use words."

—St. Francis of Assisi



Five implementation myths

- ◆ “It isn’t happening—why not?” ignores the data
 - Total U.S. oil, coal, and energy use *fell* in 2005–06. Nobody noticed. Far more *could* happen if we paid attention and fixed the 60+ well-known market failures in buying en. efficiency
- ◆ Solutions must await global agreement (why?)
- ◆ Pricing carbon will be valid and helpful—but not necessary, sufficient, or (probably) important
 - *Ability to respond* to price (“barrier-busting”) matters more: see RMI’s 1997 “Climate: Making Sense *and* Making Money”
 - Efficient carbon markets will ultimately clear at low prices, because climate protection is generally *profitable, not costly*
- ◆ 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 isn’t the only or the strongest key
 - Innovative competitive strategy, technology, and design, all from *business* coevolving with civil society, are more dynamic



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

—Marshall McLuhan

ur move...

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