The Business of Energy Efficiency:
Australia's First National Energy Efficiency Conference

Videoconference keynote to Melbourne, 13 Nov 2003

Designing a Sustainable Energy Future

Integrating Negawatts with Diverse Supplies at Least Cost

Amory B. Lovins, CEO, Rocky Mountain Institute
(also Chairman of the Board, Hypercar, Inc.)
www.rmi.org, www.hypercar.com

By 2050, an affluent world could meet or beat a 3–4× C reduction goal

× 2 **× 3–4** **÷ 2–4**

$$C_{energy} = \frac{population \times affluence\ per\ capita \times carbon\ \text{intensity}}{\text{conversion eff.} \times \text{end-use eff.} \times \text{hedonic eff.}}$$

× 1.5 **× 4–6** **× 1–2?**

or ~1.5–12× lower CO_2 emissions despite assumed 6–8× growth in GWP. (A 1993 UN study* found 1.35× and 8× respectively, 1985–2050.) Great flexibility is thus available. The future is not fate but choice.

*Johansson, Kelly, Reddy, Williams, & Burnham, *Renewable Energy*, 1177 pp., Island Press, Washington DC. This analysis, though mostly excellent on the supply side, assumed relatively weak end-use efficiency opportunities.

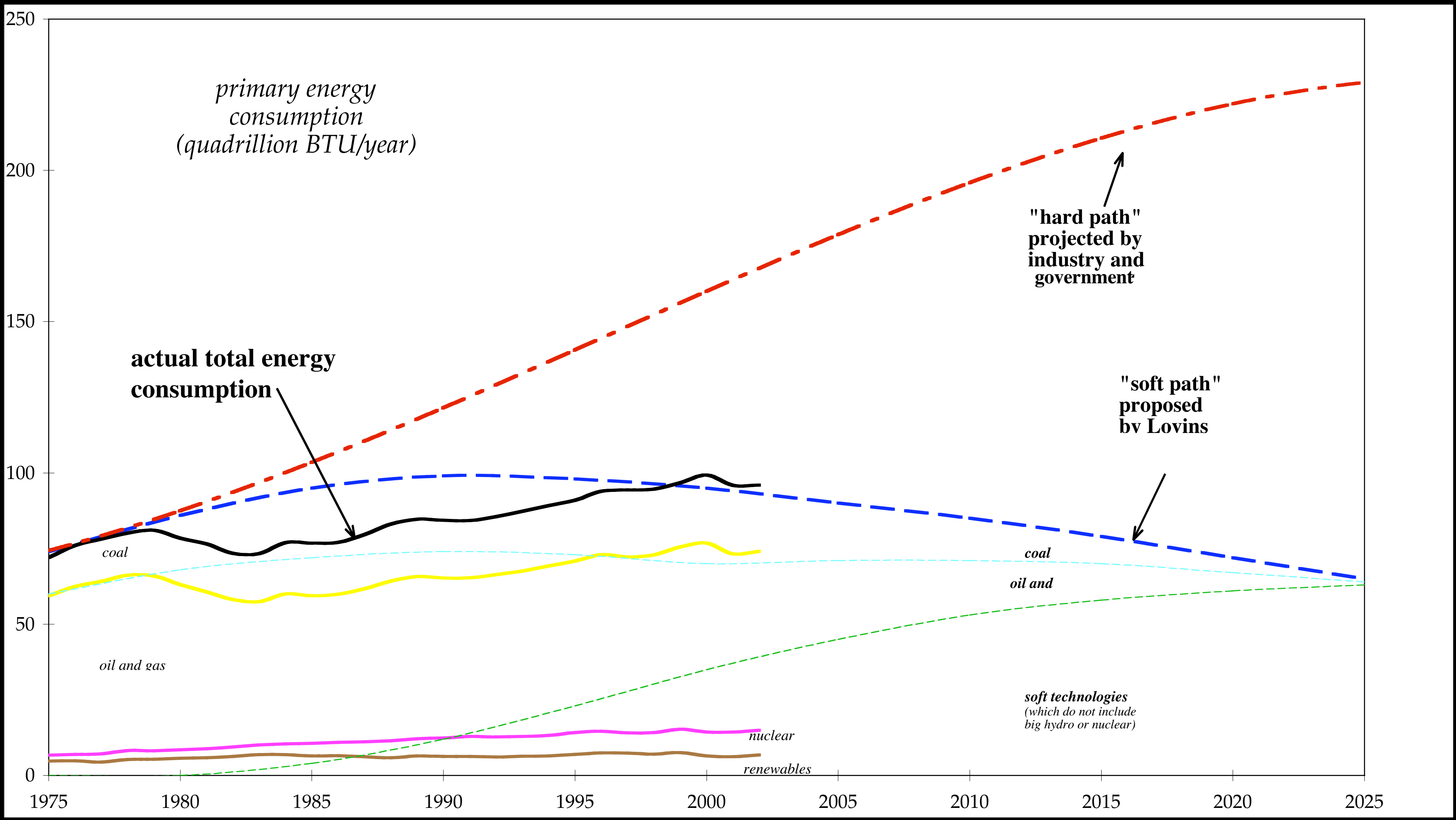
Global corporate leadership in profitable climate protection

- DuPont (worldwide), 2000–2010
  - Revenue +6%/y, energy use at worst constant
  - 1/10 of energy, 1/4 of feedstocks renewable
  - 2010 greenhouse gas = 1990 – 65%; saved US$1.5b so far
- STMicroelectronics (#3 in the world)
  - Zero net carbon emissions by 2010 despite 1990 chips ×40
  - CO_2/chip –92% profitable now, –98–99% soon
  - kWh/wafer –6%/y 1994–2002, +$50M, 2.5-y payback
  - Fabs build faster and cheaper, work better
- BP: met 2010 CO_2 goal (1990 – 10%) in 2002 at a net 'cost' of –US$0.65 billion
- All in the name of shareholder value
- Now renewable energy is starting to join too

The future of energy is in…

- Superefficient end-use — in ways that make big savings cost less than small or no savings
- Increasingly diverse, dispersed, renewable electricity sources that cost less and make large-scale failures impossible by design
- A shift of the key energy carrier from electricity to hydrogen — clean, storable, efficient, and the key to getting off oil
- Policy frameworks and market processes that find and integrate the least-cost mix of all options, encourage innovation, and build on consensus

U.S. energy/GDP already cut 42%,
to very nearly the 1976 "soft path"



but that just scratches the surface, esp. for oil & electricity…

The modern 'negawatt' (electric end-use efficiency) potential is…

- Not incremental: not 10–30% savings but ~60–80+%
- Not costly: returns are extremely high (many times the marginal cost of capital) for retrofits, and capex typically *decreases* for new construction
- Not diminishing returns: often expanding returns
- Not a tradeoff: service quality gets *better*
- Not already done: even if you've already 'done energy efficiency', you can start right over again
- Not dwindling: the 'efficiency resource' is getting bigger and cheaper faster than we're using it up, and faster than even the stunning progress in supply tech.

Negawatts cost less than megawatts:
some recent building examples

- Grow bananas with no furnace at –44°C, 90% household electric saving
- Comfort without air-conditioning at +46°C
- Both cost *less* to build; 90% a/c saving in a new Bangkok house cost nothing extra
- Big office buildings: 80–90% less energy, builds ~3–5% cheaper and 6 months faster, with better comfort and market performance
- 75% energy savings retrofittable in a big Chicago office tower, costs same as routine 20-year renovation
- 97% a/c saving design for retrofitting a California office

Rocky Mountain bananas with no furnace?

Rocky Mountain Institute

Grow bananas with no furnace at –44°C

- At 2200 m nr Aspen
- "Winter and July," frost any day, 39-d midwinter cloud
- Integrated design
- Superinsulated: k-0.05 W/m^{2}K roof, -0.14 walls, -0.47 to -0.7 [COG] glazings, air-to-air heat exchangers
- Thermally passive, 95% daylit
- Superfficient lts/eqpt

Savings (1983 tech.):

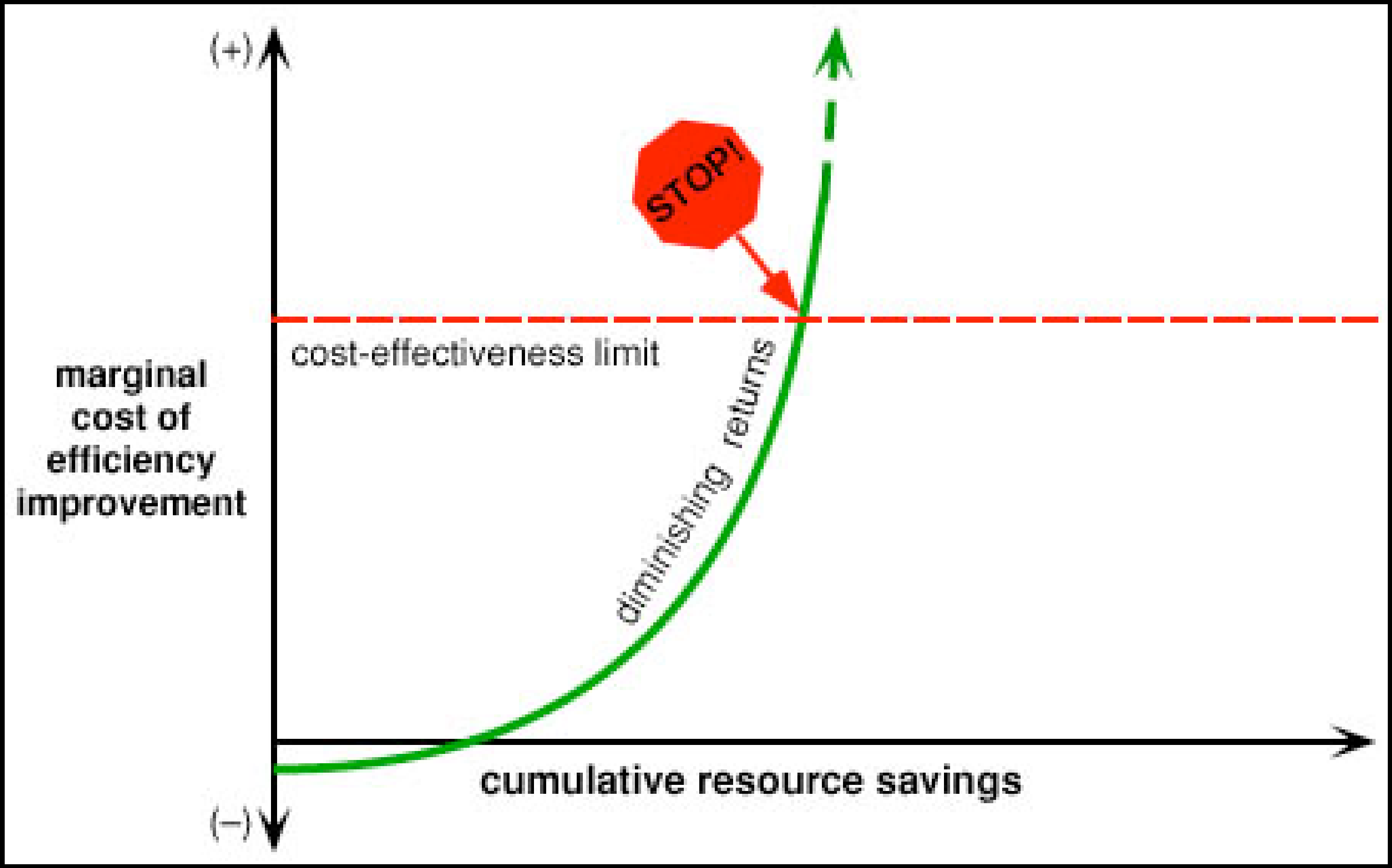
- 90% in home el. (~120 W_{av}/372 m^2)
- 99% in space & water heating
- 10-month payback, would be ≤0 now

PG&E ACT² House

Davis, California, 1994

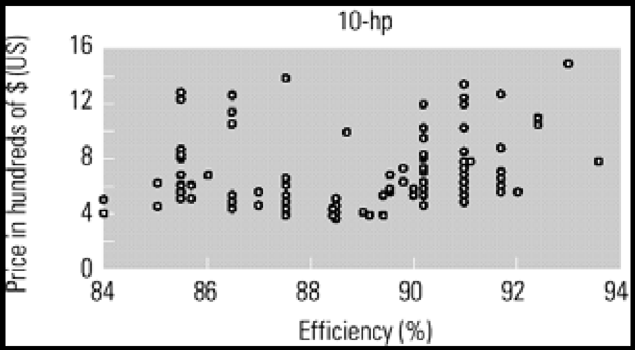
- Comfort without air conditioning at +45°C, even in a 3-day heat storm
- Mature-market building cost US$1800 lower
- Present-valued maintenance cost US$1600 less
- Design energy savings ~82% below California Title 24 (1992)
- Last 7 improvements justified only by savings of energy *plus* capital cost (last 1.5 t of a/c), not of energy alone
- Saved 3/4 of wall wood
- Later done at 46°C

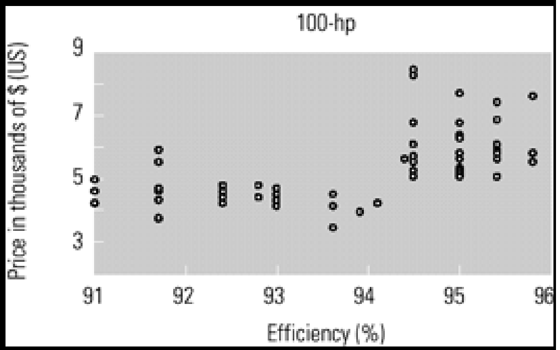
Old design mentality: always diminishing returns...



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

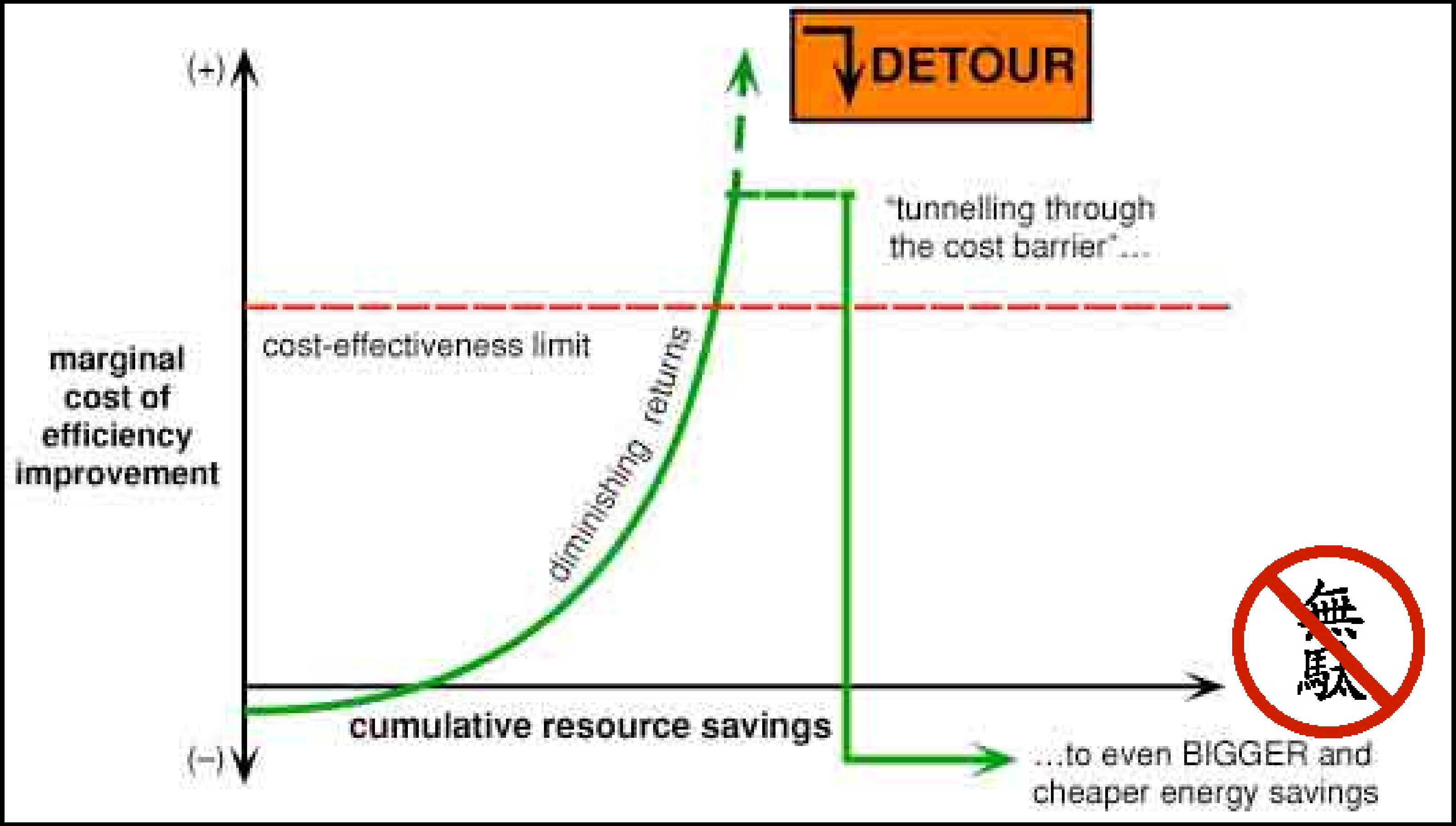




E SOURCE (www.esource.com) **Drivepower Technology Atlas**, *1999, p 143, by permission*

- 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"



Two ways to tunnel through the cost barrier

1. Multiple benefits from single expenditures

- Save energy *and* capital costs…10 benefits from superwindows, 18 benefits from efficient motors & lighting ballasts,…; so why count just one?
- The arch that holds up the middle of RMI's HQ has twelve functions but only one cost

2. Piggyback on retrofits

- A 19,000-m^2 Chicago office could save 3/4 of energy at same cost as normal 20-year renova-tion —greatly improving human performance

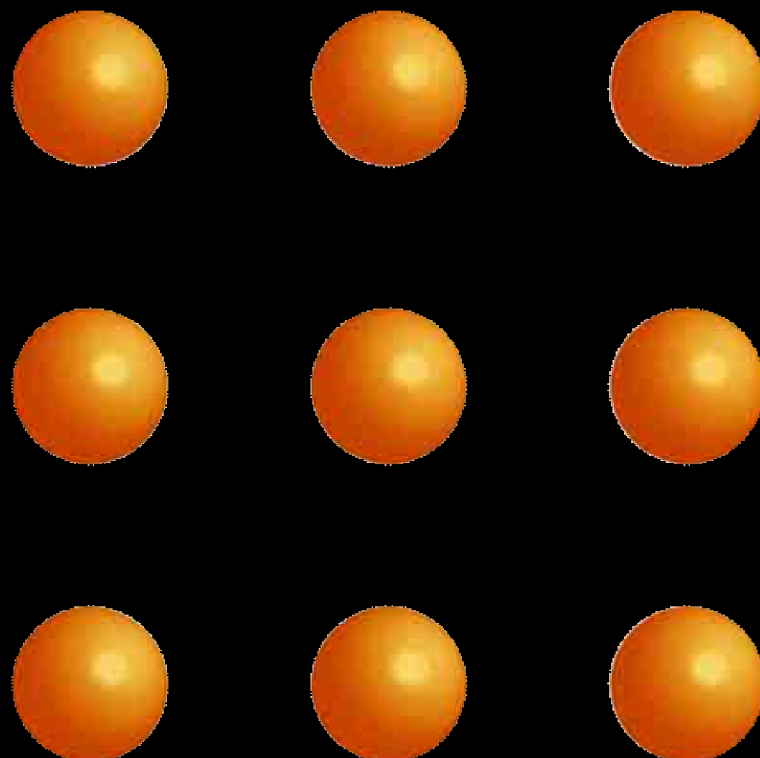
Renovating a 19k-m² office

- 20-y-old curtainwall, hot-and-cold climate
- Failing window seals require reglazing
- Superwindows: T_{vis} 0.51 (×5.7), *SC* 0.25 (× 0.9), *k*-0.8 W/m²K (÷3.35), noise ÷4, cost +US$8.4/m² glzg
- + deep daylighting, efficient lights (3 W/m²) & plug loads (2 W/m²), cut cooling at the design hour from 2.64 to 0.61 MW_{th} (–77%)
- 4× smaller HVAC with 3.8× better COP 1.85 → 7.04 (1.9 → 0.50 kW/t) costs US$200,000 less than renovating the big old system — paying for everything
- Design would save 75% of energy (US$285,000 → $80,000/y); peak load 1.25 → 0.30 Mw_e (–76%); much better comfort; –5 to +9 month payback (–/+ new curtainwall system)

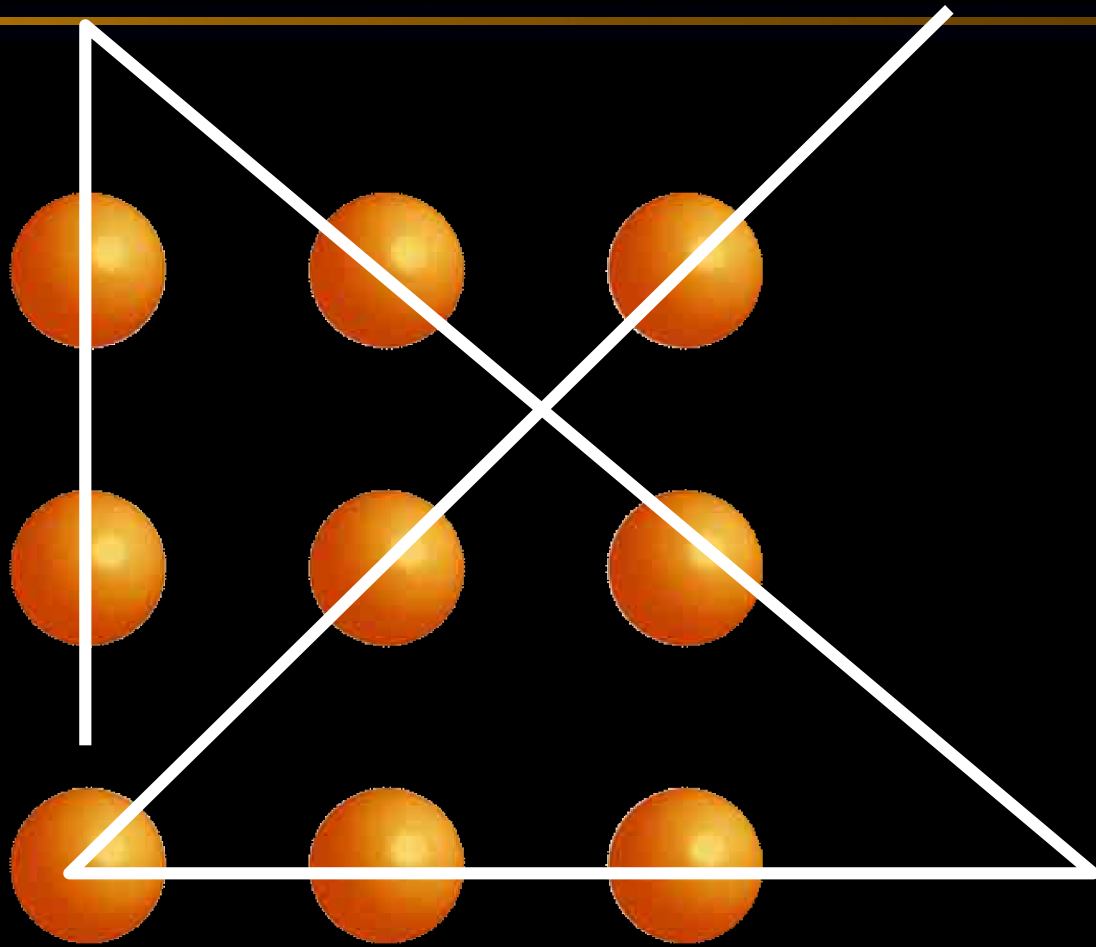
Edwin Land

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

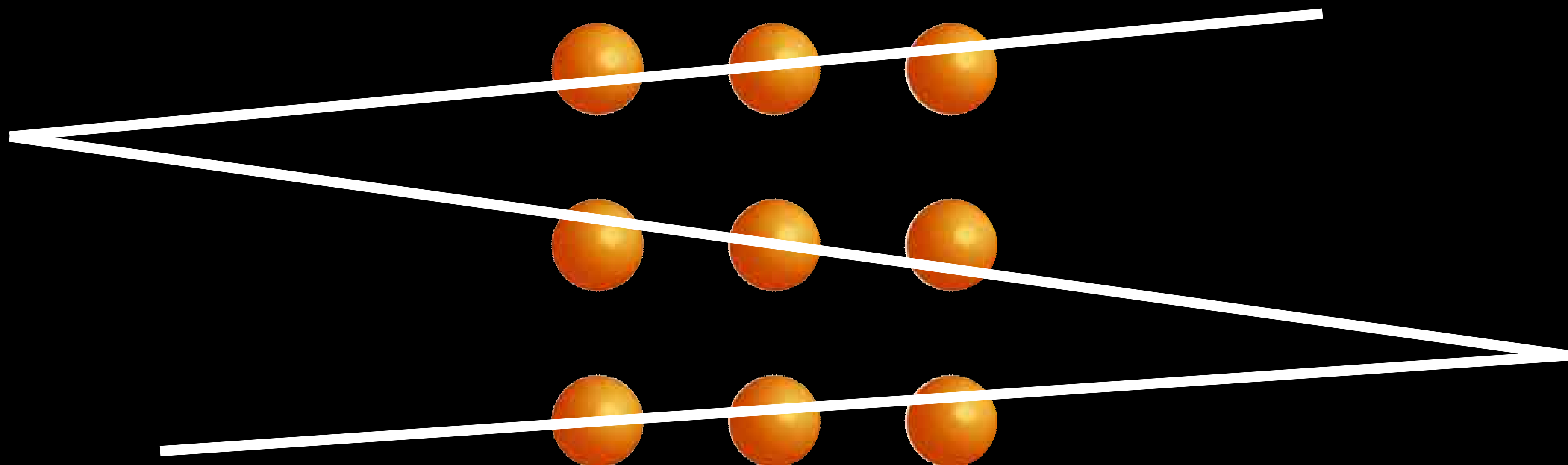
The nine dots problem



Standard nine dots solution

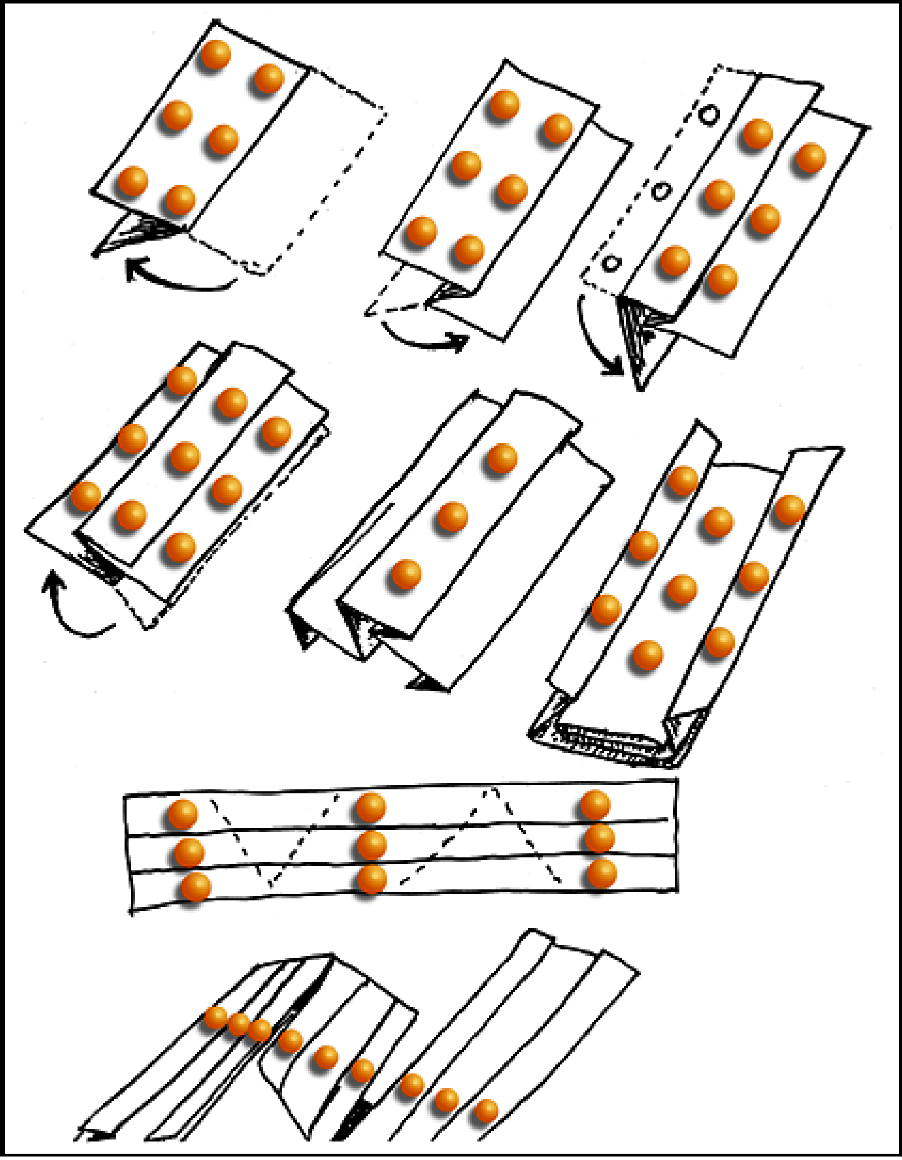


Better: use just *three* lines

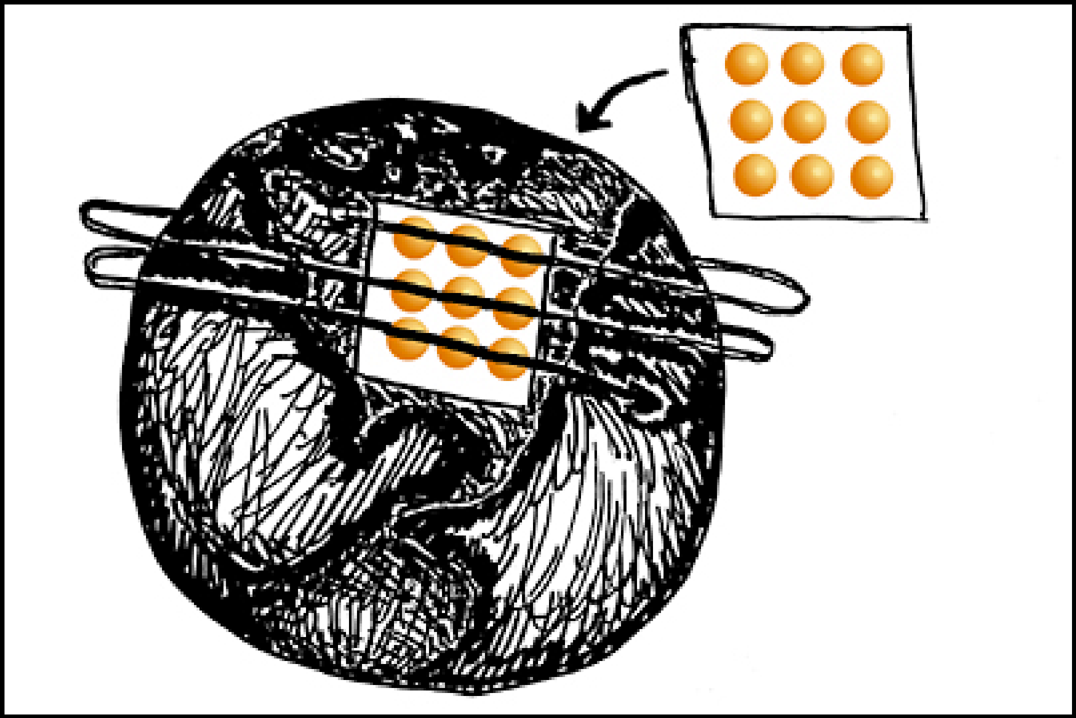


But…how about just *one* line?

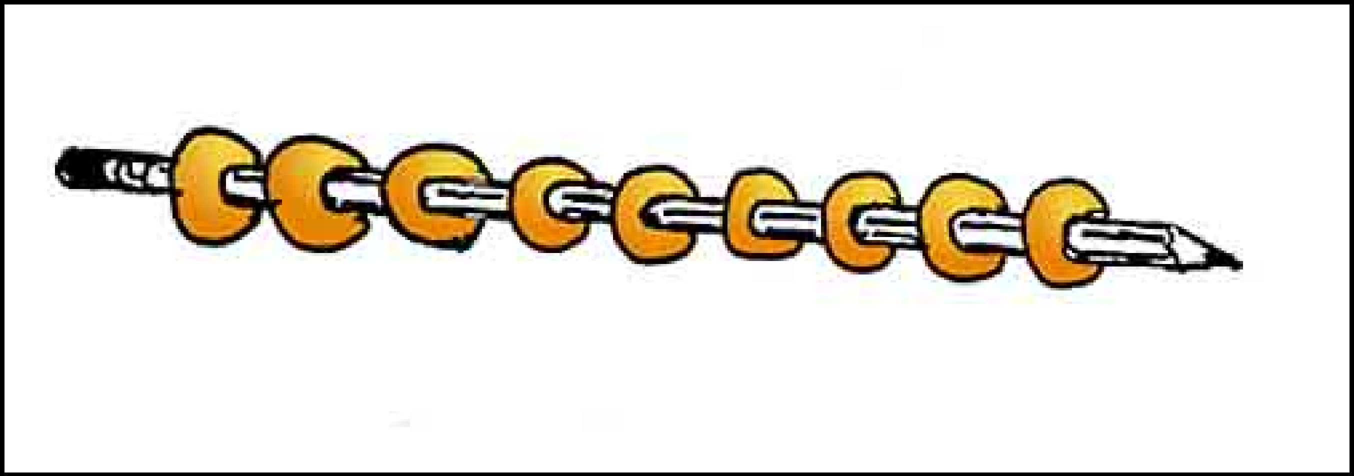
Examples: Paul MacCready; art: Chris Lotspeich



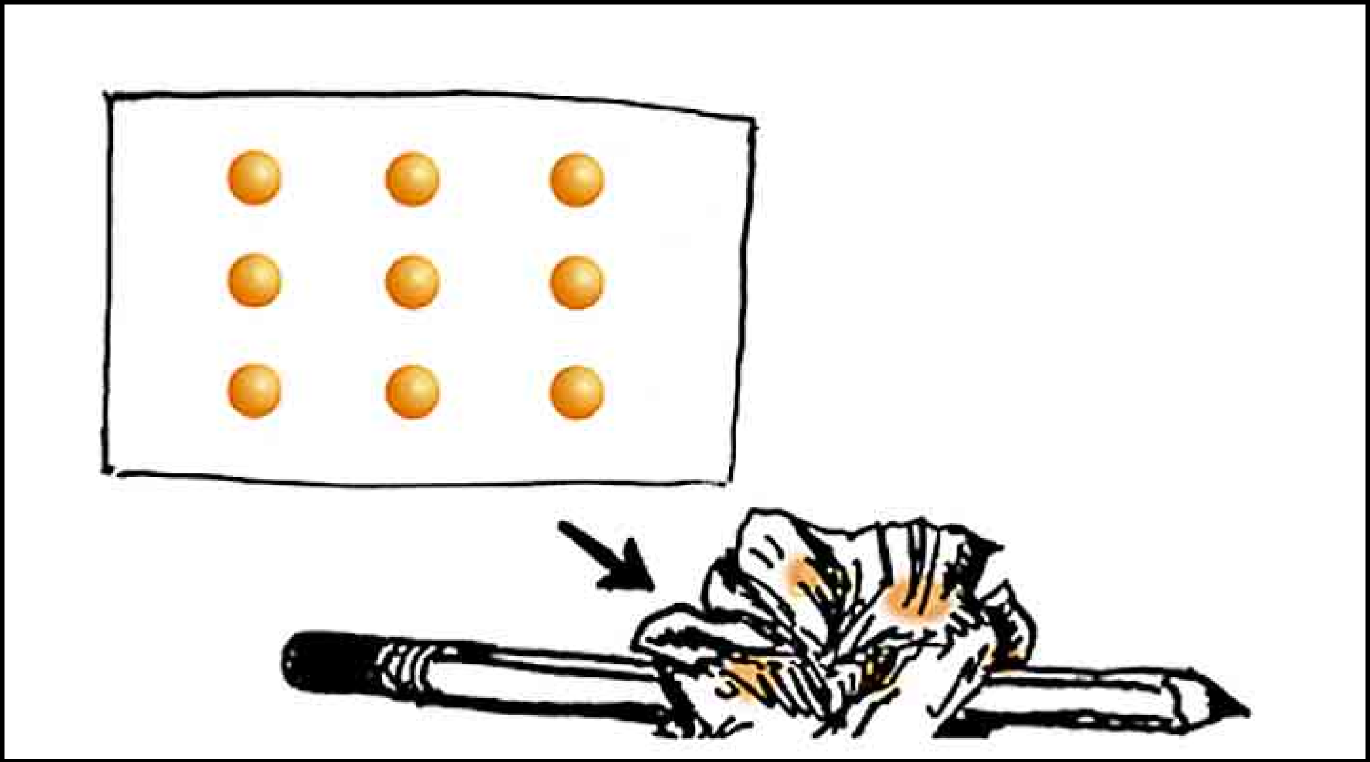
origami
solution



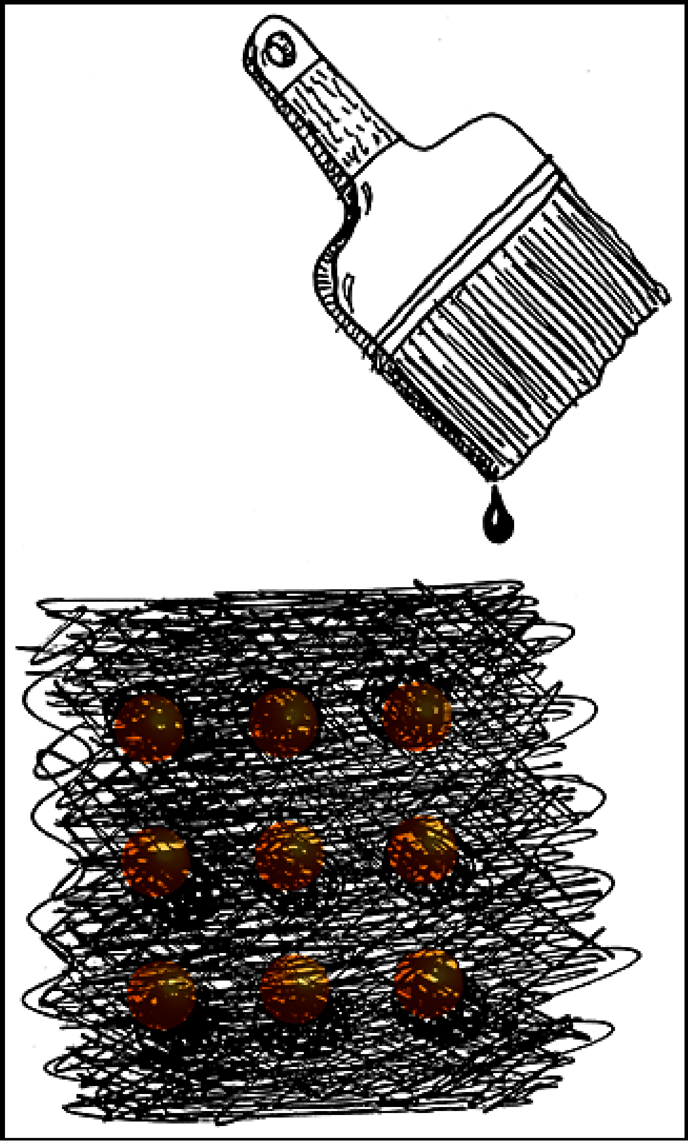
geographer's
solution



mechanical
engineer’s
solution



statistician's
solution



wide-line
solution

Edwin Land

Invention is "… a sudden cessation of stupidity"

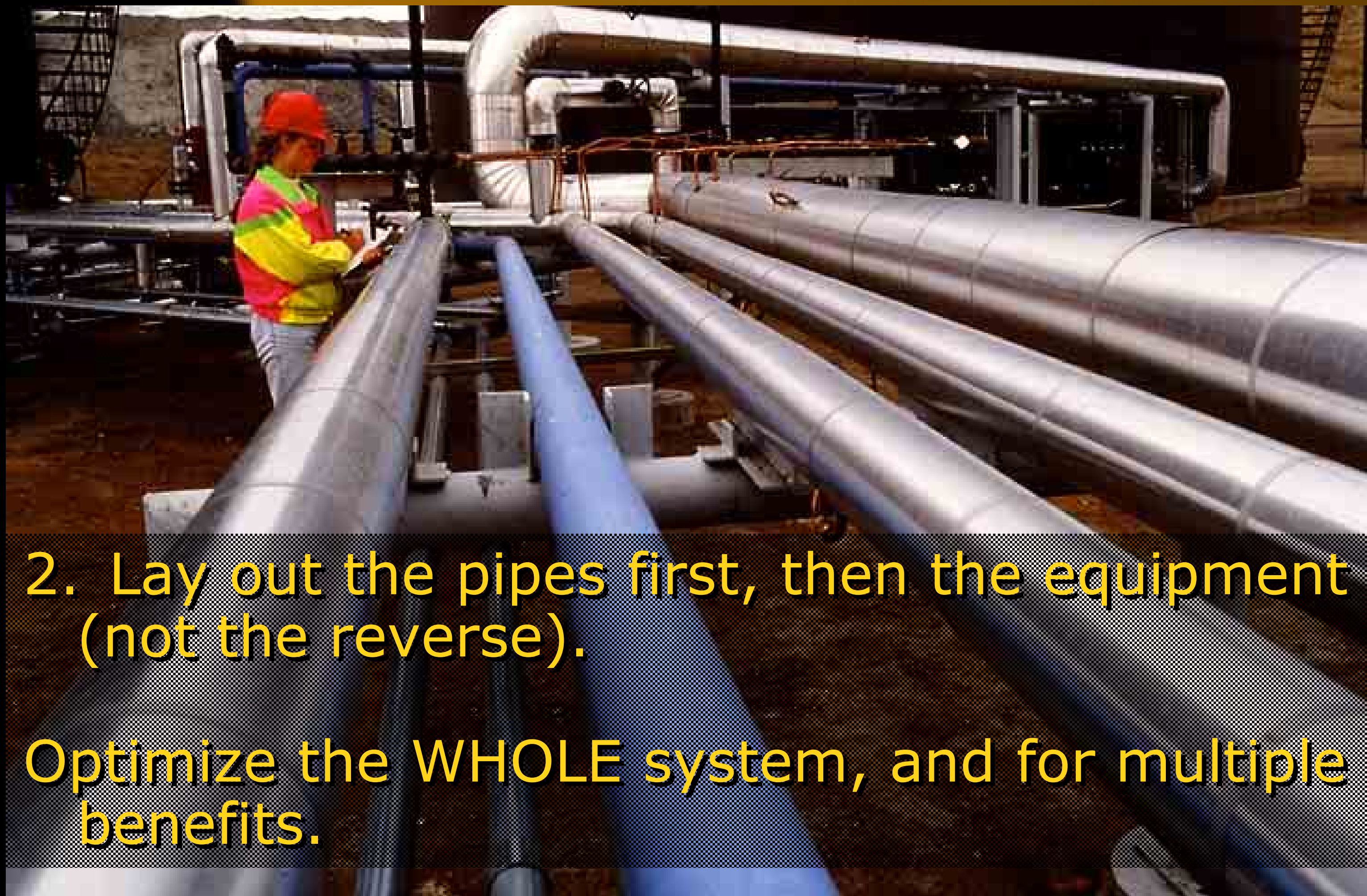
Optimized industrial design

- 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 in every way
- No new technologies — just two changes in the design mentality
- Many other examples are in *Natural Capitalism*, free at www.natcap.org

New design mentality, an example:

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

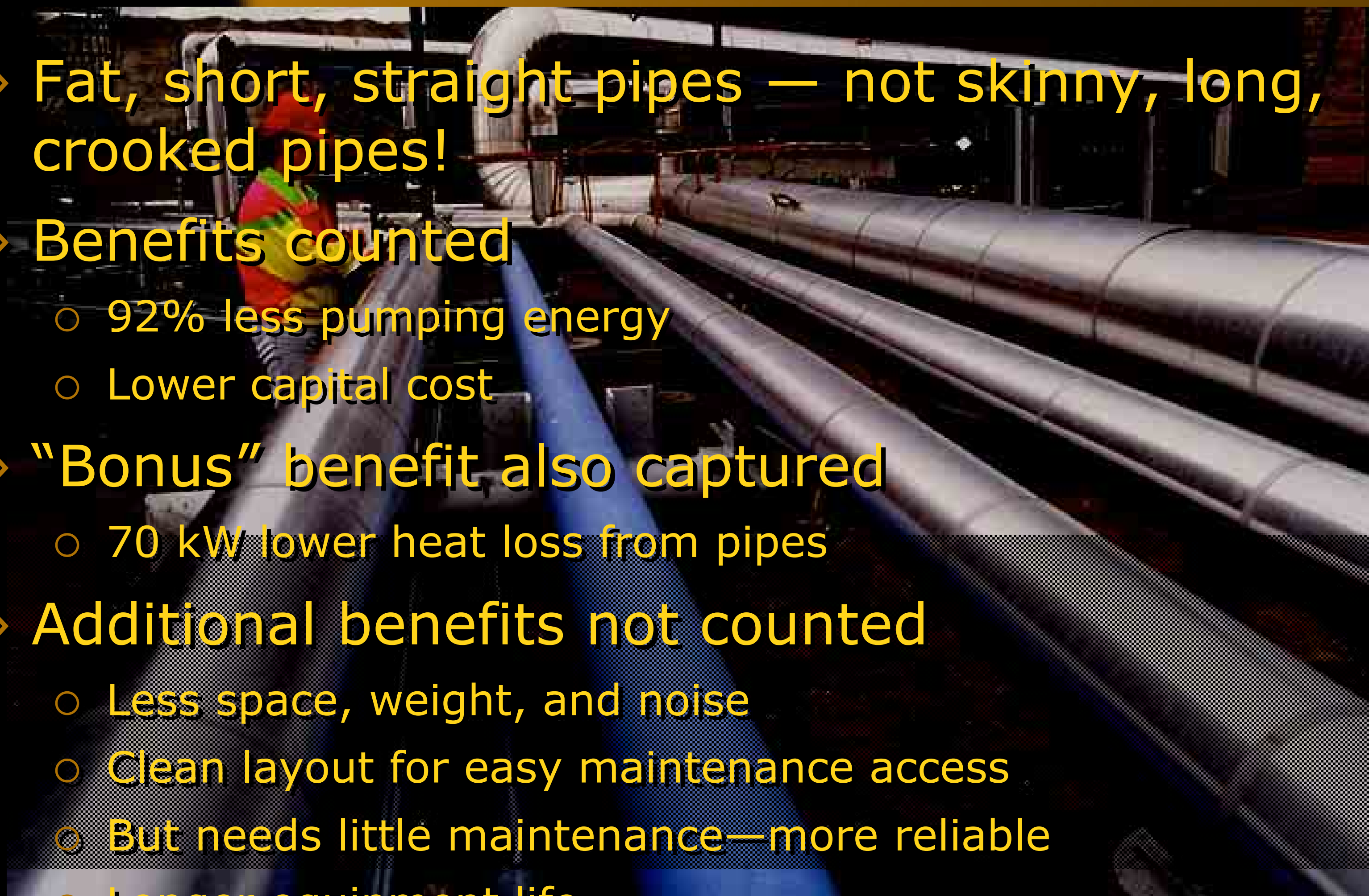
No new technologies, just two design changes



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

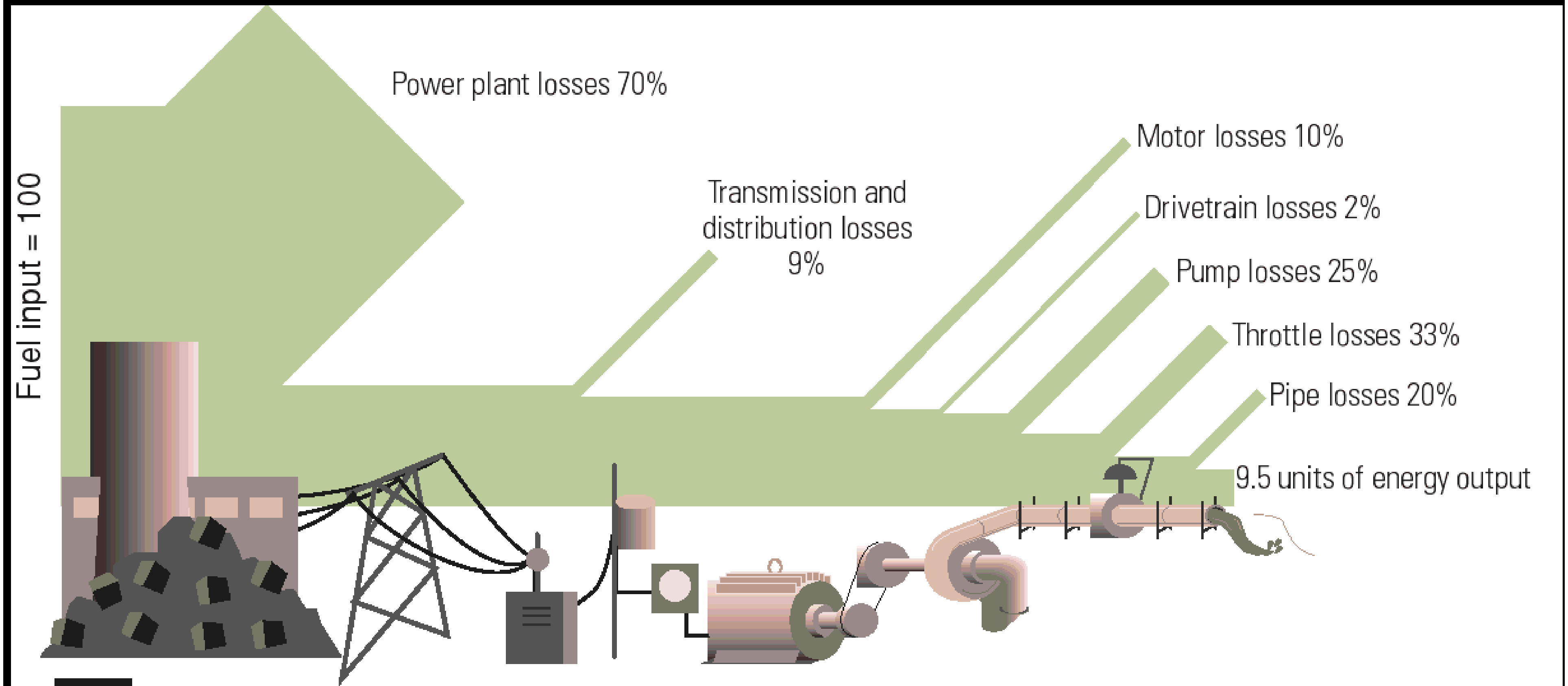
Optimize the WHOLE system, and for multiple benefits.

No new technologies, just two design changes



- Fat, short, straight pipes — not skinny, long, crooked pipes!
- Benefits counted
  - 92% 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
  - But needs little maintenance—more reliable
  - Longer equipment life
- If counted, we'd have saved more…maybe ~98%

Compounding Losses…or Savings — So Start Saving at the Downstream End



From the *Drivepower Technology Atlas.*
Courtesy of E SOURCE, www.esource.com.

New design mentality: why this example matters

- Pumping is the biggest use of motors
- Motors use 3/5 of all electricity
- Saving one unit of friction in the pipe saves 10 units of fuel at the thermal power plant
- Almost every energy-using system has been mis-designed in the same archetypical way
- Applying whole-system design principles to almost *every* technical system yields ~3–10× energy/resource savings, and usually costs less to build — now demonstrated in a wide range of tech systems
- RMI is assembling a *10XE: Factor Ten Engineering* casebook, mid-2004, to change practice/pedagogy

Industrial opportunities

- Save half of motor-system electricity (3/8 of all industrial electricity), retrofit aftertax ROI 100–200%/y
- Similar returns saving >50% of chip-fab HVAC power
- Retrofit refinery, save 42%, 3-y simple payback
- Redesign data centre, save 89%, costs less, up more
- Redesign supermarket, save 70–90%, costs less
- Redesign new chemical plant, save ~3/4 of el., cut construction time & cost by ≥10%
- Radical new process designs, like microfluidics
- Materials productivity (less mass, last longer, reuse more) lets less manufacturing deliver more service
- Higher labour productivity (~6–16%), industrial output/quality,…often worth more than saved energy

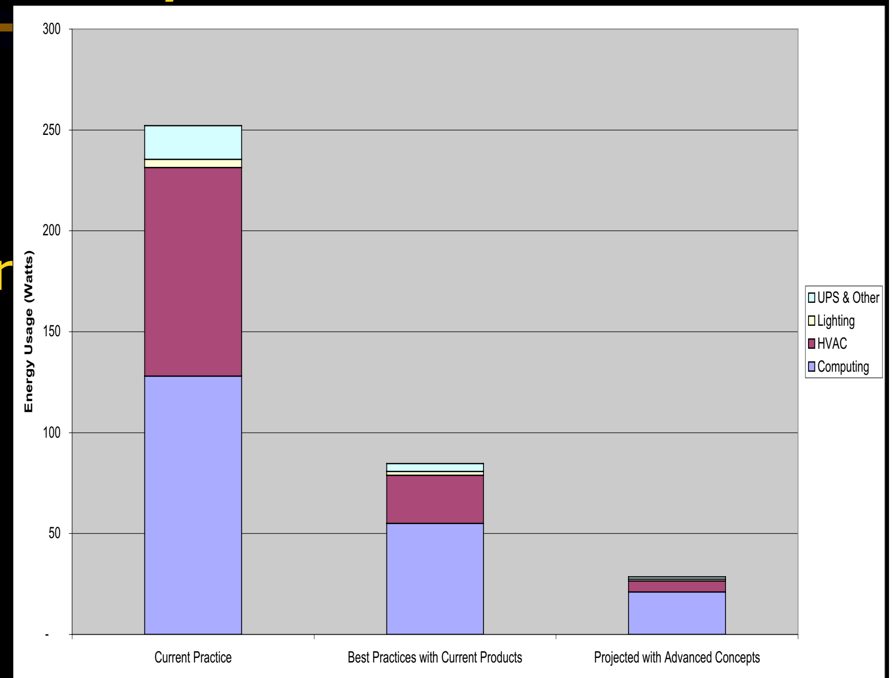
Two Chip-Fab Retrofit Examples

(both advised by Supersymmetry Services Pte Ltd)

- Big Asian back-end: 1997 retrofit, mainly HVAC
  - Cut energy use 56% (69% per chip) in 11 months with 14-month av. payback; further projects will save more
- STMicroelectronics's world-class Singapore fab
  - '94–7 retrofits saved US$2.2M/y w/0.95-y av. payback
  - '91–7 improvements saved $30M; kWh/6" std. wafer –60%, from ~226 to 91 (1998 target = 86 & falling)— providing 80% of energy capacity for a 3.5× expansion
  - all retrofits were performed during continuous opera-tion via cryogenic freeze-plugs and hot-taps (>20 ea.)
- This is mainly just harvesting the low-hanging fruit that already fell down and is mushing up around the ankles; HVAC, no improved tools

RMI's Energy-efficient Data Centre Charrette, San Jose, 2–5 Feb 2003

- >90 industry experts found ways to save ~89% of the energy used by a typical data center, probably with lower total capital cost, faster construction, and better uptime and throughput
- Ultra-low power consumption at the architecture, software, compiling, and device levels
- Superefficient onsite power-and-cooling system; integrated design *decompounds loads*; very efficient, multi-purpose accessories and systems; can probably go further
- Real-estate model also very important: charge by m² *and W*



www.rmi.org/store/p385pid2424.php (US$20)

Wu-chun Feng's Green Destiny bladed Beowulf cluster, LANL

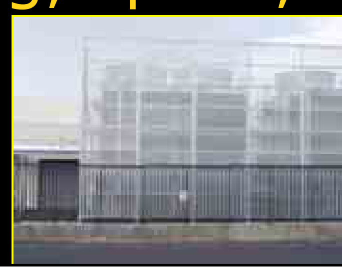
160 peak Gflops

◇ 240 RLX passively-cooled blade servers, 0.13μm TransMeta Crusoe CPU: 8× denser, 5–8× less power-intensive than Wintel

◇ 100% up ≥9mo in uncooled 31°C hallway

◇ ~7–8× better energy efficiency (in an iterative science application) with ~65–75% lower total cost of ownership

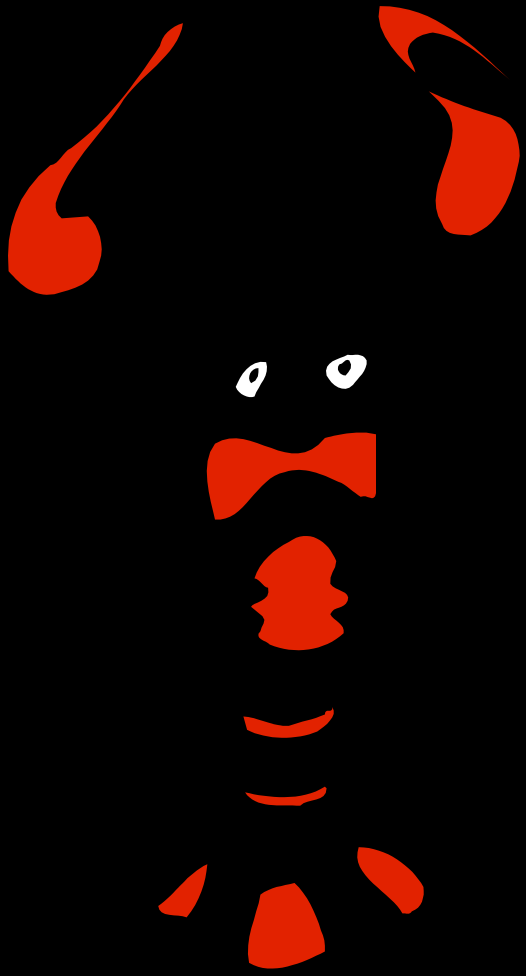
◇ Pay ~50–75% more for the bare hardware (at least at early blade prices) but ~90% less for power and cooling, space, downtime, and system administration



Compare LANL Q supercomputer's cooling towers

Eating the Atlantic lobster

- Big, obvious chunks of meat in the tail and the front claws
- A roughly equal quantity of tasty morsels hidden in crevices, requiring skill and persistence to recover
- Go for both
- Mmmmm!



"Like Chinese cooking…

Use everything. Eat the feet."

— LEE Eng Lock, Singapore efficiency engineer

Chinese food is world-famous for using every part and wasting nothing. Why not do everything else that way too?

The right steps in the right order: lighting

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

Remember to credit avoided lighting mainten-ance & HVAC capacity! (∴ <1A¢/saved kWh, not 4–6 as commonly supposed)

The right steps in the right order: space cooling

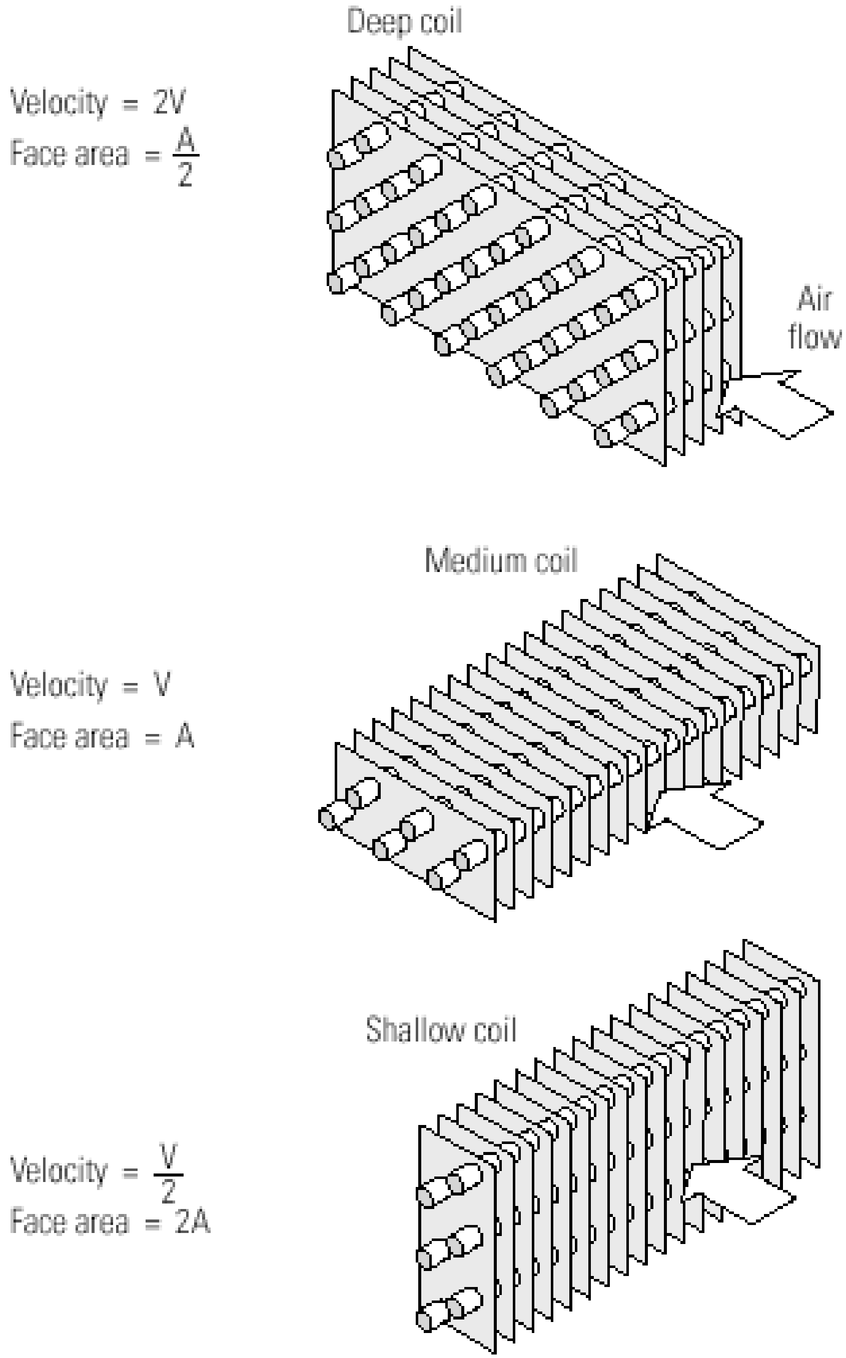
1. Expand comfort envelope
2. Minimize unwanted heat gains
3. Passive cooling
   - Ventilative, radiative, ground- / H_2O-coupling
4. Active nonrefrigerative cooling
   - Evap, desiccant, absorption, hybrids: COP >100
   - Direct/indirect evap + variable-speed recip in CA: COP 25
5. Superefficient refrigerative cooling: COP 8.6/Singapore
6. Coolth storage and controls
7. Cumulative energy saving: ~90–100%, better comfort, lower capital cost, better uptime

Superefficient big HVAC

(10^5+ m^2 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	7–14 kPa head, efficient pump/motor, no pri/sec
Chiller	0.75	0.500	0.6–1 C° approaches, optimizal impeller speed
CWP	0.14	0.018	7–10 kPa head, efficient pump/motor
CT	0.10	0.012	Big fill area, big slow fan at variable speed
TOTAL	*1.75* *(COP 2.01)*	*0.609* *(COP 5.78, 65% better)*	*Better comfort, lower capital cost*

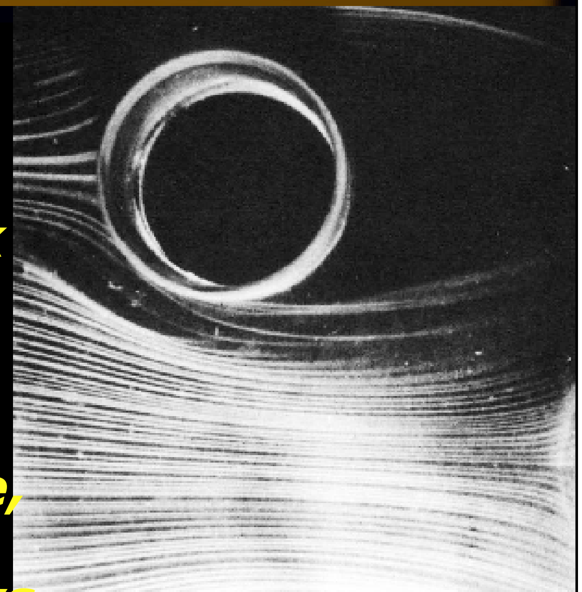
or 0.41 (–77%) with dual chilled-water temperature)



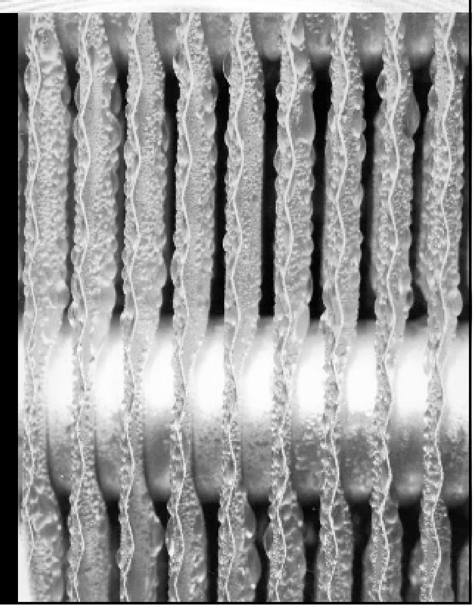
Source: Luxton and Shaw [25]

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

Just correct an 80-year-old mistake about how coils work



Flow is laminar and condensation is dropwise, so turn the coil around sideways, run at <200 fpm; 29% better dehumidification, ΔP −95%, ASHRAE comfort over the entire load range, smaller chiller/fan, smaller parasitics



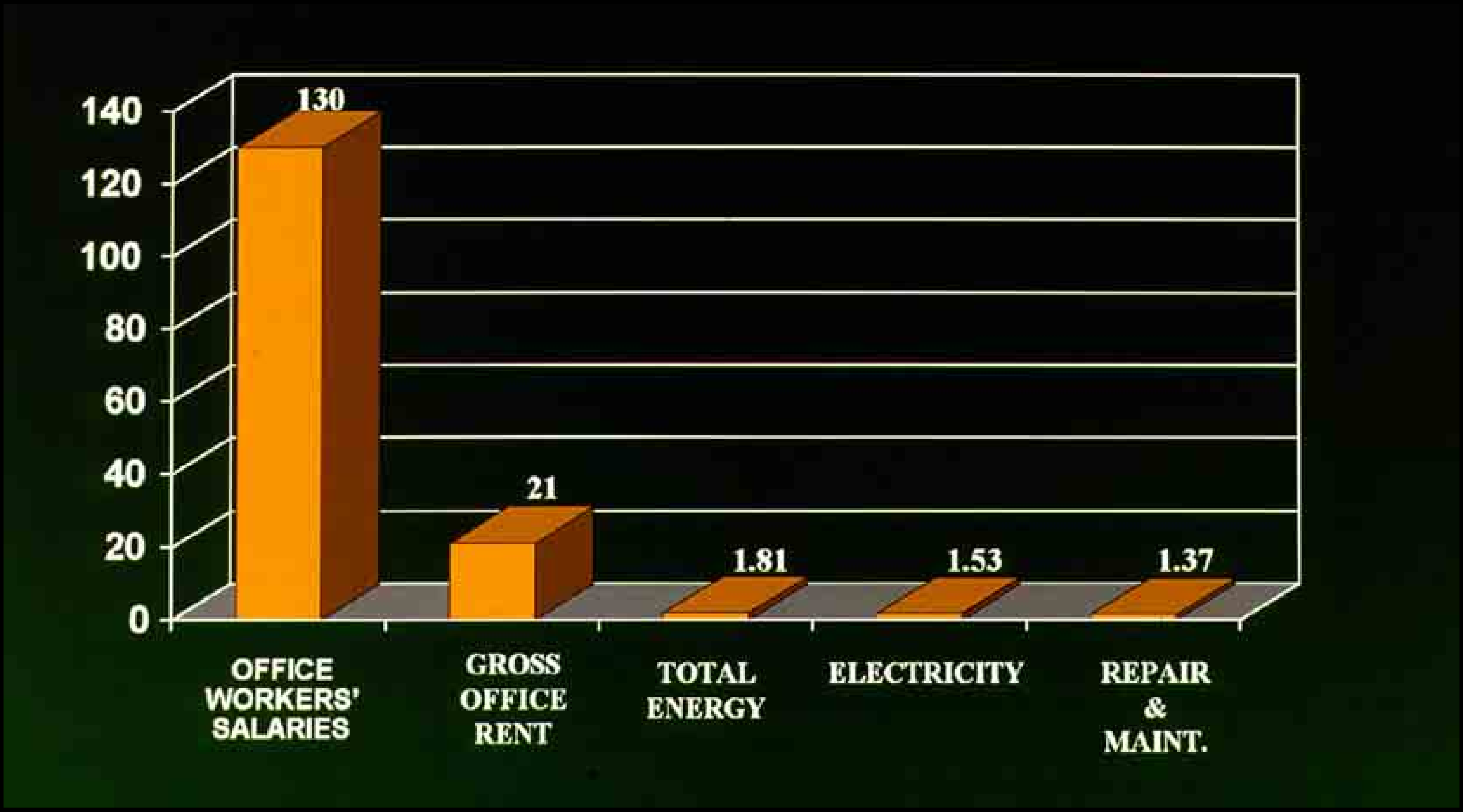
Benchmarking a new office

(~10,000+ m^2, European climate range)

	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 W/m^2K	2.9	1.4	<0.5
glazing T_{vis}/SC	1.0	1.2	>2.0
perimeter htg.	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+
cool'g syst COP	1.85	2.32	6.9–25+
rel. cap. cost	1.0	1.03	0.95–0.97
rel. space eff.	1.0	1.01	1.05–1.06

Comparative Costs (1990 $/ft²) in Large US Office Buildings

Data from Building Owners and Managers Association, Electric Power Research Institute, *Statistical Abstract of the United States 1991*



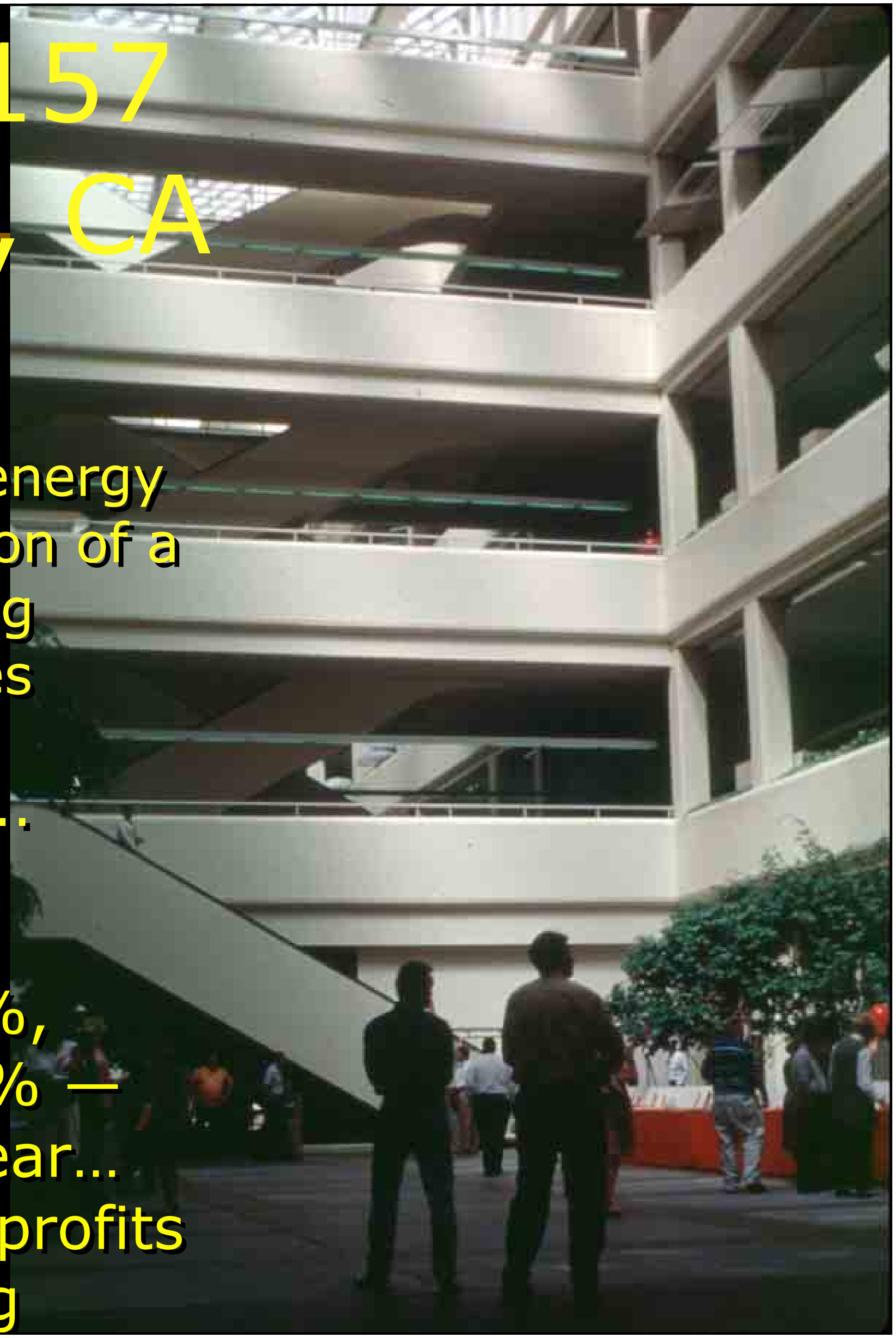
Lockheed 157
Sunnyvale, CA

- 55,760-m^2 office building for 2,700 engineers & support staff
- Textbook example of daylighting

Lockheed 157
Sunnyvale, CA

- 75% reduction in lighting energy
- Half the energy consumption of a comparable standard building
- Cost $2 million extra; saves $500k/year worth of energy (4-year payback), but also…

Absenteeism dropped 15%, productivity increased 15% — paid back 100% in first year… then won contract whose profits paid for the whole building

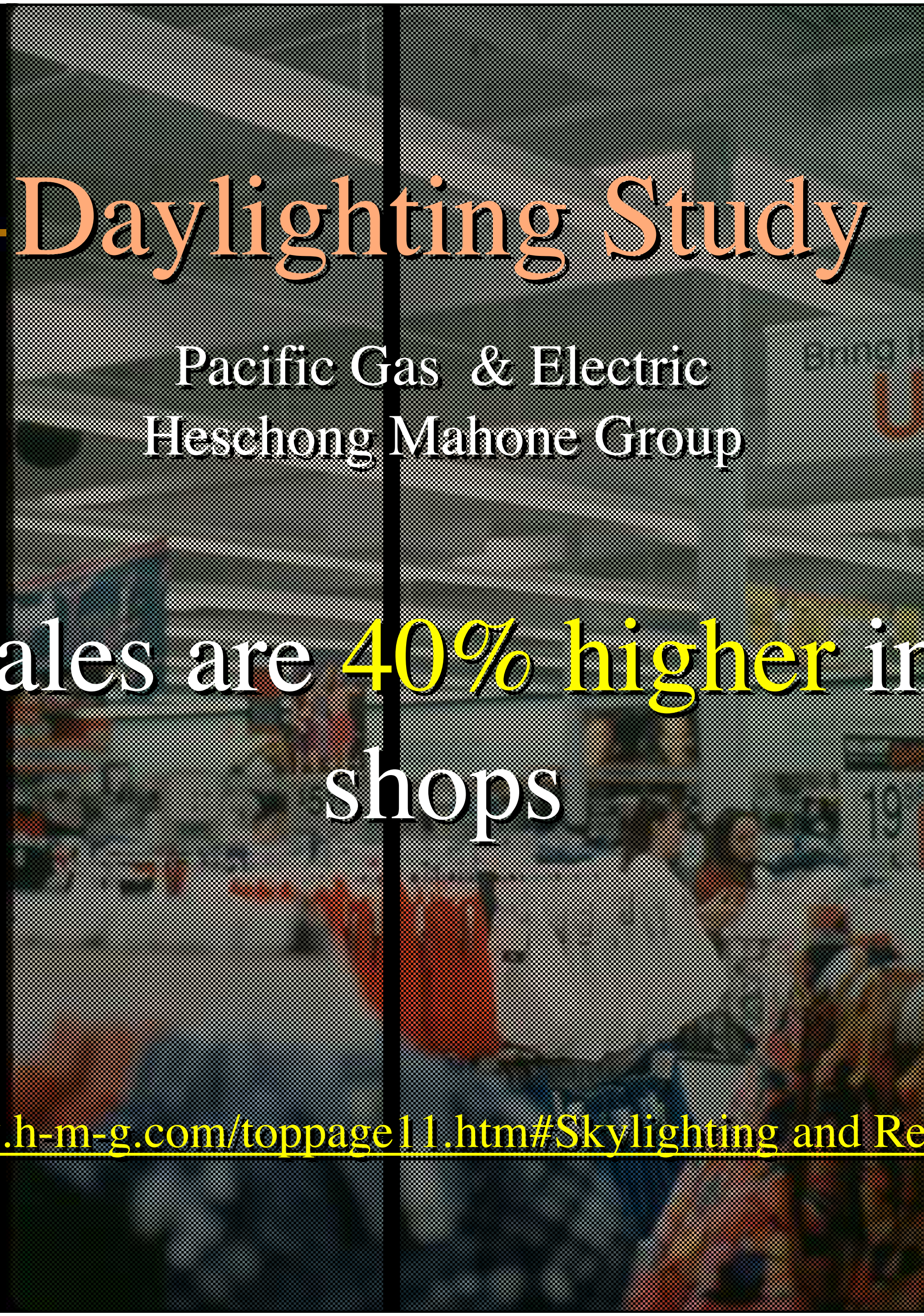


Boeing

- Lighting system retrofit in design and manufacturing areas
  - Cut lighting energy costs by up to 90% with <2-year payback; also...
  - Workers could see better
  - Valuable improvements in avoided rework, on-time delivery, customer satisfaction

Daylighting Study

Pacific Gas & Electric
Heschong Mahone Group



Retail sales are 40% higher in daylit shops

http://www.h-m-g.com/toppage11.htm#Skylighting and Retail Sales

Nature and Health: The Relation Between Health And Green Space in People's Living Environment

Vries *et al.* 2001

n = 11,296 (!)

"The results showed that the amount of green space in the living environment was indeed positively related to the experienced health condition."

Schools in Curitiba, Paraná, Brasil

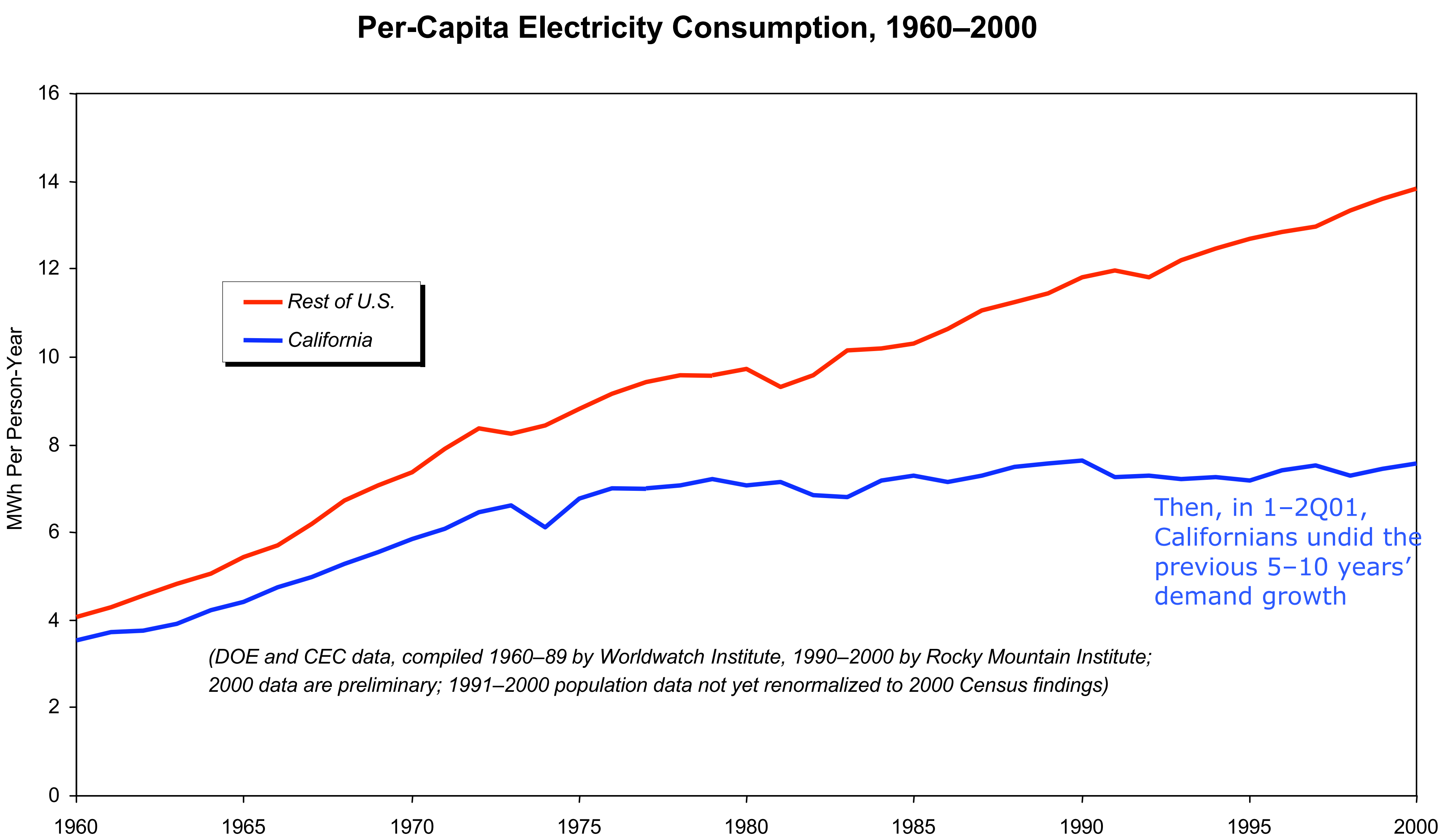
- Of the two classroom window units on the top right, the second has a light shelf inside and outside

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, ENSAR Group, Boulder, Colorado

California: policy works



When rewarded not penalized, efficiency can work quickly

- In 1983–85, 10 million people served by So. Cal. Edison Co. (then the #3 U.S. investor-owned utility) were cutting its 10-y-ahead peak load by $8\frac{1}{2}$% *per year*, at ~1% of marginal supply cost
- In 1990, New England Electric System got 90% of a small-business retrofit pilot program's market 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 January
- New marketing and delivery methods are even better
- Such major firms as DuPont, IBM, and STMicroelectronics (world #3 chipmaker) are cutting their energy intensity 6% *per year*
- During 1977–85, U.S. GDP grew 27%, oil use fell 17%, oil imports fell 50%, and Persian Gulf oil imports fell 87%
- During 1996–99, the U.S. cut its energy intensity 3.2%/y and its electric intensity 1.6%/y despite record-low and falling prices

Negawatts partner with megawatts

- The less electricity you need, because you use it more efficiently, the smaller, simpler, and cheaper the supply will be
  - Hot-water-saving house has very high solar-water-heat fraction with a small collector (*e.g.*, 99% in Rockies)
  - Electricity-saving house needs only a few m^2 of PVs
  - Passive-solar, daylit building needs little electricity, and can pay for even costly forms of onsite generation (PVs) via its reduction or elimination of mechanical systems
  - Similarly in other end-use applications and sectors
- Efficiency opens new horizons in distributed generation, saving vast infrastructure costs

Four Times Square, NYC (Condé Nast Building)

- 149,000 m²; 47 storeys
- non-toxic, low-energy materials
- 40% energy savings/m² despite doubled ventilation rates
- Gas absorption chillers
- Fuel cells
- Integral PV 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, ~3 acres of PVs
- Integrated with Cool Roof and ESCO efficiency retrofit (lighting, HVAC, controls, 1 GWh/y)
- Energy management optimizes use of PV output, raising profit — leverages demand response
- 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 anything cheaper

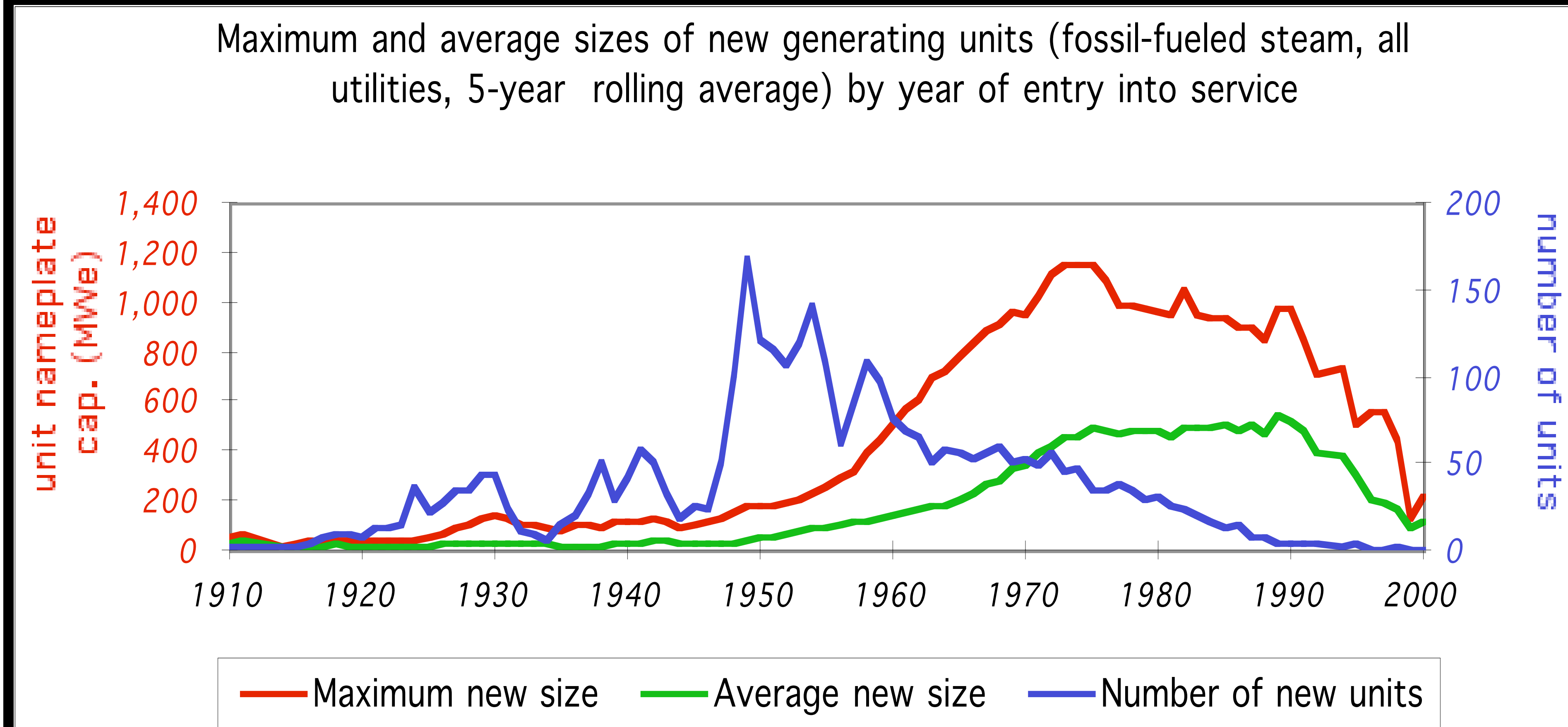
Impact of demand respon-siveness on U.S. gas demand

- R.S. Jewell of Dow Chemical Company stated on 18 March 2003 in his talk "Natural Gas: What Is Going On?!":
  - For the ~6 Tcf/y of gas used to make electricity, the variable cost is around US$45–60/MWh, higher than for other fuels, so gas is the first decrement
  - "A 5% drop in electric demand can drop gas demand into electricity by 25% or 1.5 Tcf/yr.
  - "A 5% drop in remaining electric demand can further decrease gas demand by 0.8 Tcf/yr.
  - "This reduction would bring the 23 Tcf natural gas market back into balance for 3–5 years with US$2–3 natural gas prices again."
- If such a steep dependence also applies to BC, as user or export-er, the benefits for cutting peak loads are correspondingly greater
- Could reduce power-sector vulnerability to insufficient gas storage or gas deliverability constraints, not just electric constraints
- Could also help insulate direct-gas consumers from spillover price volatility originating in the power sector
- Value of avoiding price spikes could be asymmetrical for BC gas, just as it appears to be for U.S. oil ("price-spike hysteresis")

Electricity supply: the surprises are coming

- ~1880–1980: power stations costlier & less reliable than the grid, so must be shared via the grid
- ~1980– : power stations cheaper & more reliable than the grid, so really cheap and reliable supply must be at or near customers, *i.e.*, 'distributed'
- Central thermal power plants stopped getting more efficient in the 1960s, bigger in the 1970s, cheaper in the 1980s, and bought in the 1990s
- New distributed technologies growing rapidly
- A dozen forces are driving distributed architecture
- Capital market prefers its far lower risk

A 5-year rolling average reveals that U.S. fossil-fueled steam unit orders have been fading since the 1970s; their ordering rate, all ≤1/5 the former size, is now back to Victorian levels



New technologies are entering rapidly

- Europe plans 22%-renewable electricity by 2010
- Wind (30%/y) & photovoltaics (~26–42%/y) are the world's fastest-growing energy supply technologies
- Global wind capacity 31 GW at end 2002, adding 7 GW/y (faster than nuclear grew in '90s); it's 20% of Denmark's power today, sometimes >100% locally
- 10^3s microturbines shipped; 200-kWe phosphoric-acid fuel cells costly (US$2–4/W) but worthwhile
- Next: cheap polymer fuel cells, cheap photovoltaics
- PVs, esp. bldg-integrated, starting very fast "liftoff," can be fully competitive on many new U.S. houses 2003–05; US$0.05/kWh very plausible long-term

Distributed generation can compete

- Industrial gas-turbine cogen/trigen delivers a few MW_e at ~US$0.005–0.02/kWh net ($\eta \sim 0.90$)
- ~26–29%-efficient 30–75-kW_e natural-gas microturbines shipping, often for cogen/trigen
- A recent microturbine retrofit design would give a 1-y payback against US$0.055/kWh utility power ($\eta \sim 0.92$) in a 160k-m^2 U.S. office/lab complex
- Windpower profitable in good sites (now edging below US$0.025/kWh + $0.017 subsidy; practical potential ~1.5–4× global el.; intermittence solved
- But commodity ¢/kWh omits many impt. benefits

‘Distributed benefits’ change the game

- *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (RMI, 8/02)
  - www.smallisprofitable.org
  - One of *The Economist*’s top three business/economics books of 2002
- Codifies and quantifies 207 ‘distributed benefits’ that collectively increase the economic value of decentral-ized generation by typically ~10× (but site-specific)
- Four kinds: financial economics, electrical engineering, miscellaneous, externalities
- ‘Cleaner Energy, Greener Profits’ (www.rmi.org, 2001) applies this approach specifically to fuel cells

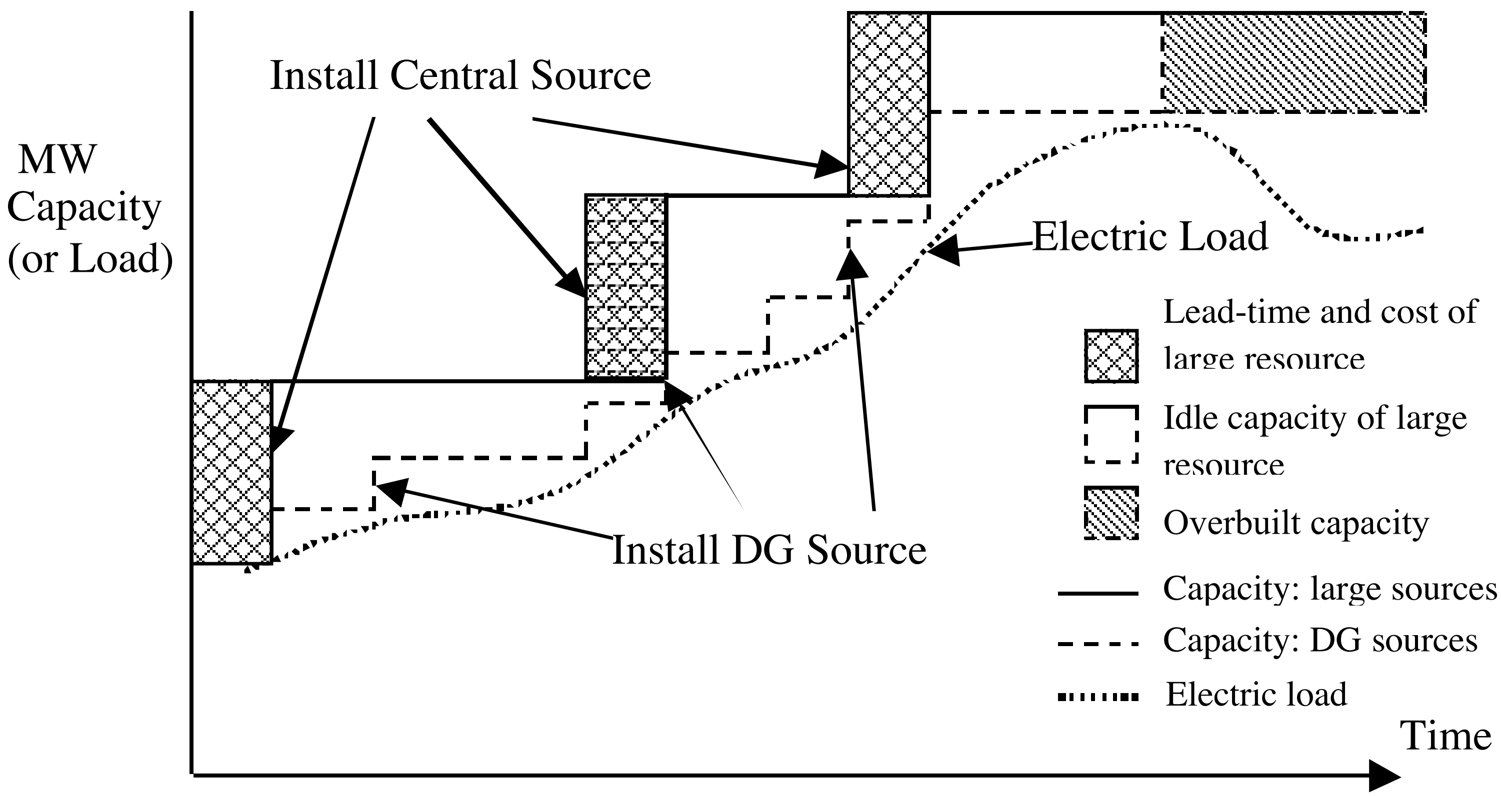
Whence the order-of-magnitude typical value increase?

- 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/quality is required
- Miscellaneous benefits: often around 2×, more with thermal integration
- Externalities: indeterminate but may be important; not quantified here

Option value of DG resources

Small scale and modularity provide an option value from:

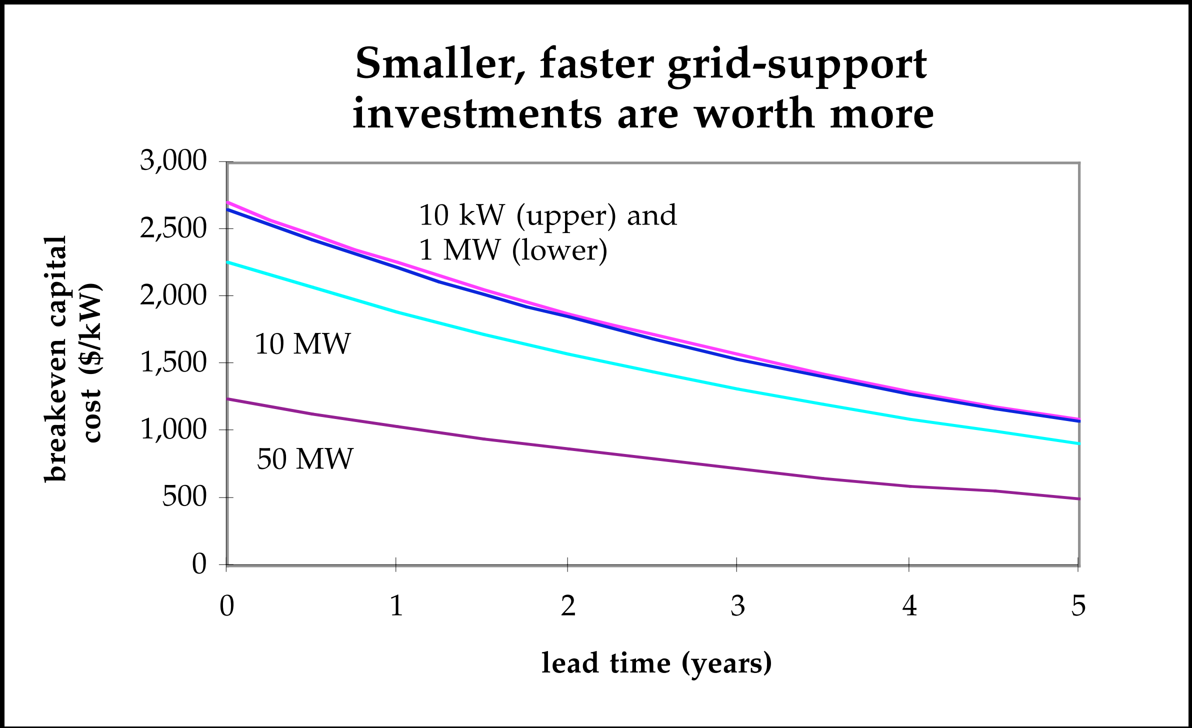
- Increased flexibility
- Shorter lead-time, and
- Decreased risk of overbuilding



207 Distributed Benefits: ~10× Value

(Actual Value Is Very Technology- & Site-Specific)

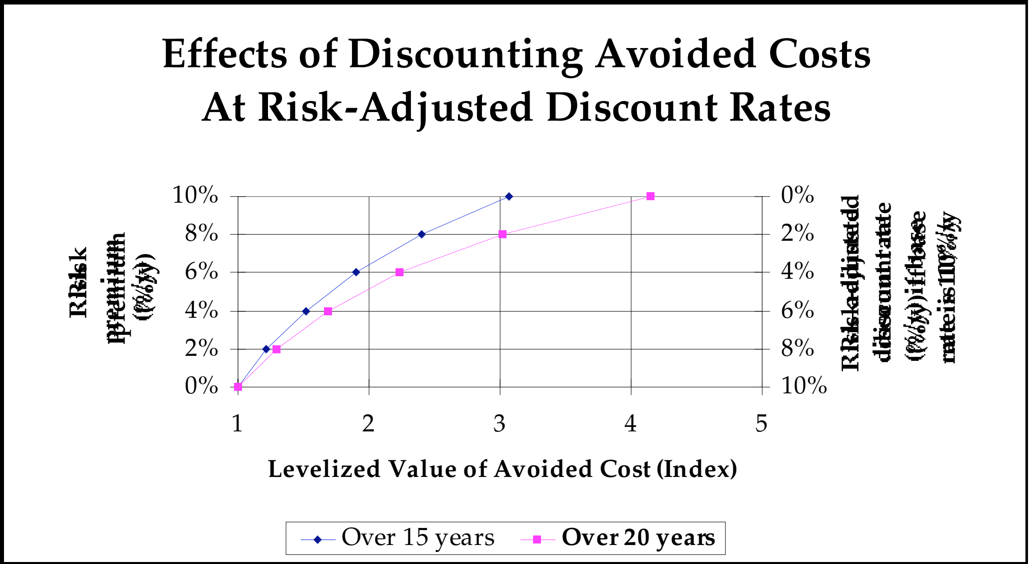
- ~10¹×: Minimizing regret (financial ecs.)
  - Short lead times and small modules cut risk
    - Financial, forecasting, obsolescence
    - Overshoot and 'lumpiness'



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

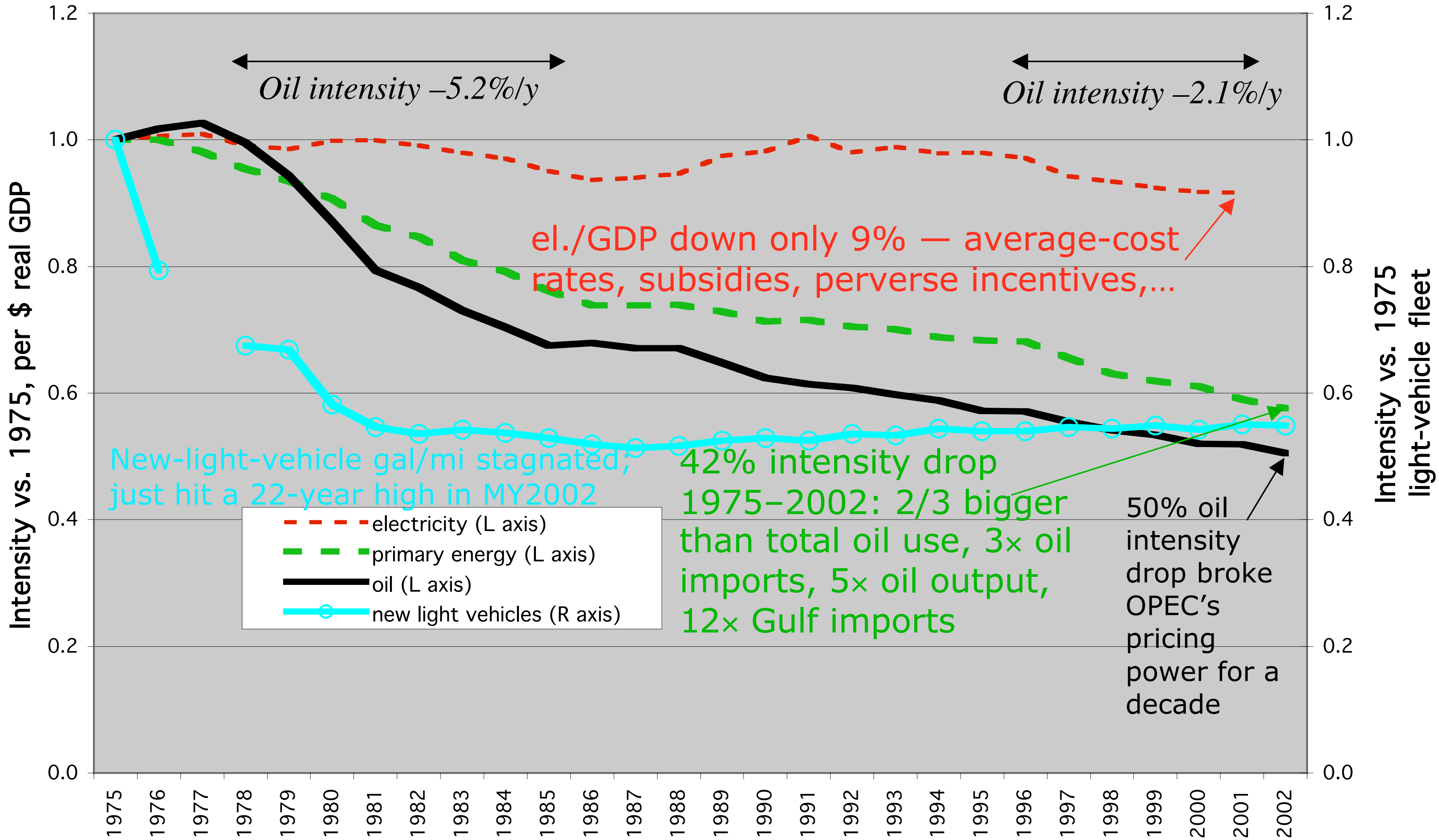
Financial-Economics Benefits (cont'd)

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



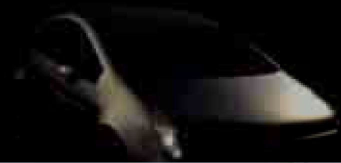
- Genuinely diversified supply portfolios
- 'Load-growth insurance' of cogeneration & efficiency

U.S. energy intensity since 1975



Data source: U.S. Energy Information Administration, *Annual Energy Review* , www.eia.doe.gov/emeu/aer/contents.html

Light-vehicle data from *id* . and TEDB 22 (ORNL-6967), 2002, www-cta.ornl.gov/cta/data/index.html



Well-to-Wheels Efficiency (Toyota)

	Fuel Efficiency (%)	Vehicle Efficiency (%)	Overall Efficiency (%)
Average 2003 Car	79	18	14%
1998 Prius	79	27	21%
2003 Prius	79	31	24%
2004 Prius with HSD	79	37	29%
Commercial FCHV	58 Natural gas-hydrogen	50	29%
FCHV Target	70	60	42%

Source: Toyota Motor Corporation, 2003; US EPA efficiency labels and US fuel systems

An uncompromised, same-cost, 5×-efficiency midsize SUV

an ***illustrative, production-costed, manufacturable concept car*** ***developed for a few million dollars in eight months in 2000 by Hypercar, Inc. (www.hypercar.com) — on time, on budget, with attributes never before combined in a single vehicle***

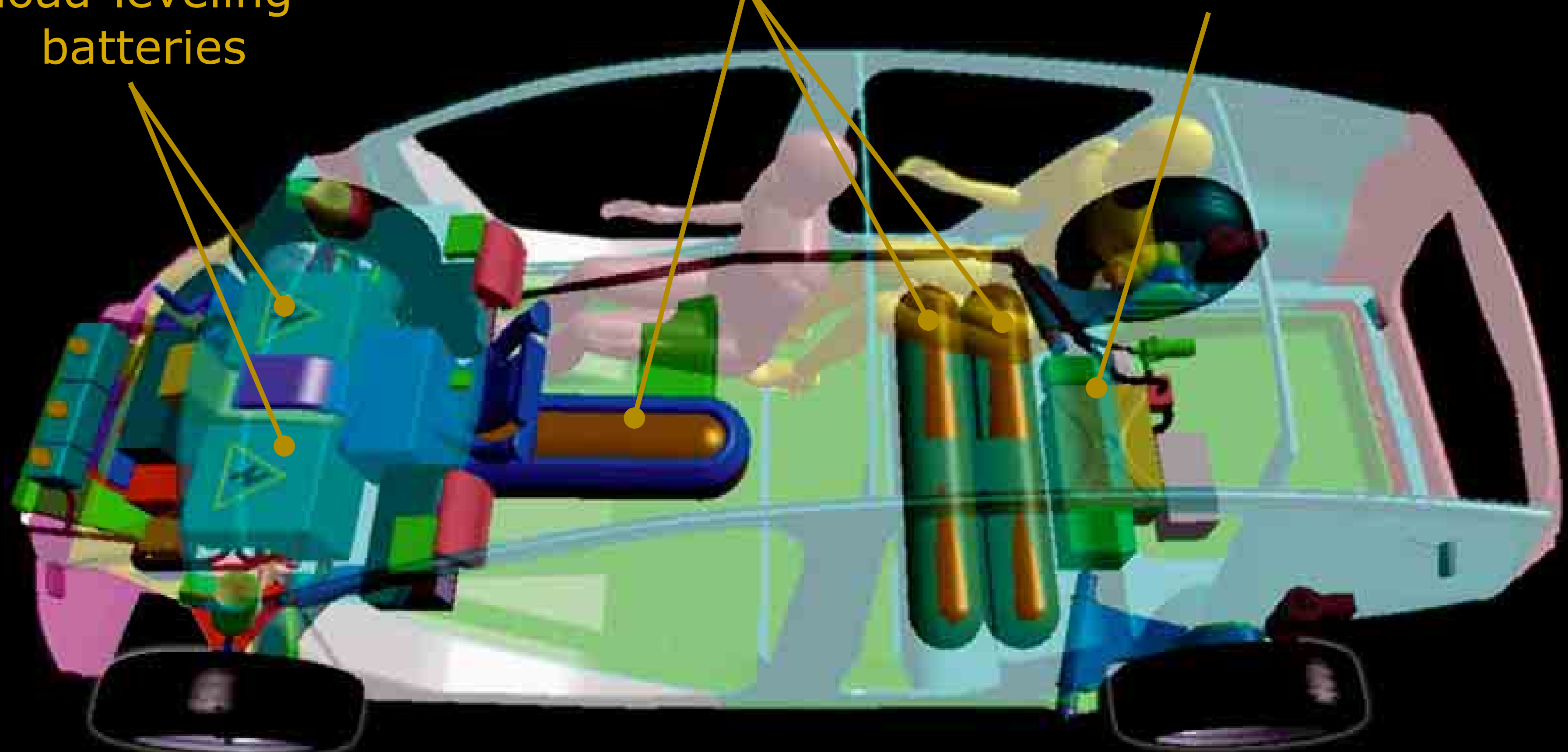
- 5 adults in comfort, up to 1.96 m^3 of cargo
- hauls 460 kg up a 44% grade
- 857 kg (47% mass of Lexus *RX300*)
- sim. head-on wall crash @ 56 km/h doesn't damage passenger compartment
- sim. head-on collision with car 2× its mass, each @ 48 km/h, prevents serious injury
- 0–100 km/h in 8.3 seconds
- 2.38 'L'/100 km (99 mi/'USgal', 5× *RX300*)
- 530 km on 3.4 kg safely stored 345-bar H_2
- 89 km/h on just normal a/c energy
- zero-emission (hot water)
- sporty, all-wheel digital traction
- ultra-reliable, software-rich, flexible
- wireless diagnostics/upgrades/tuneups
- 330-Mm warranty; no fatigue, rust, dent
- competitive manufacturing cost expected
- decisive mfg. advantages—≤90% less capital, space, assembly, parts count
- production ramp-up ≥2007–08 … in ANZ?

Ultimate public benefits of quintup-led light-vehicle fuel efficiency

- Oil savings: U.S. potential = 8 Mbbl/day = 1 Saudi Arabia = 42 Arctic National Wildlife Refuges (if any there!); world potential = 1 nega-OPEC (negamissions in the Gulf — Mission Unnecessary)
- Decouple driving from climate change and smog
  - Profitably deal with ~2/3 of the climate challenge
- Lead a fast transition to a hydrogen economy
  - Can be profitable at each step; adoption already starting
- Parked cars (~96% of the time) can valuably serve as plug-in ‘power stations on wheels’

‘We’ll take two.’* — Automobile *magazine

5×-efficient midsize SUV, 2.38 'L'/100 km: 89 km/h on same power as normal a/c, so ready for direct hydrogen fuel cells



Alternative vehicle/fuel strategies: many options

- Cars can run clean IC engines on petrol or NG (≡1η)
- Better ones using hydrogen in IC engines (~1.5 η)
- Still better ones using H_2 in IC-engine hybrids (~2.5η)
  - Ford 'Model U' concept car…but tanks >4× bigger (niche market)
- Better still with ultralight autobodies and low drag (3η)
- Power such platforms with IC-engine hybrids (4–4.5η)
  - Hypercar 5-seat carbon *Revolution* has the same m_c & C_D as 2-seat Al Honda *Insight…Insight* powertrain in *Revol'n.* ~3.5 L/100 km?
- Best putting fuel cells in superefficient bodies (5–6η)
- But the aim isn't just saving fuel and pollution
  - Also strategic goals in automaking, plug-in power-plants-on-wheels, off-oil, fuel flexibility, transition to renewables,…
- Hydrogen needs 5η vehicles far more than vice versa
- 5η vehicles make robust the business case for providing the H_2 fuel they require

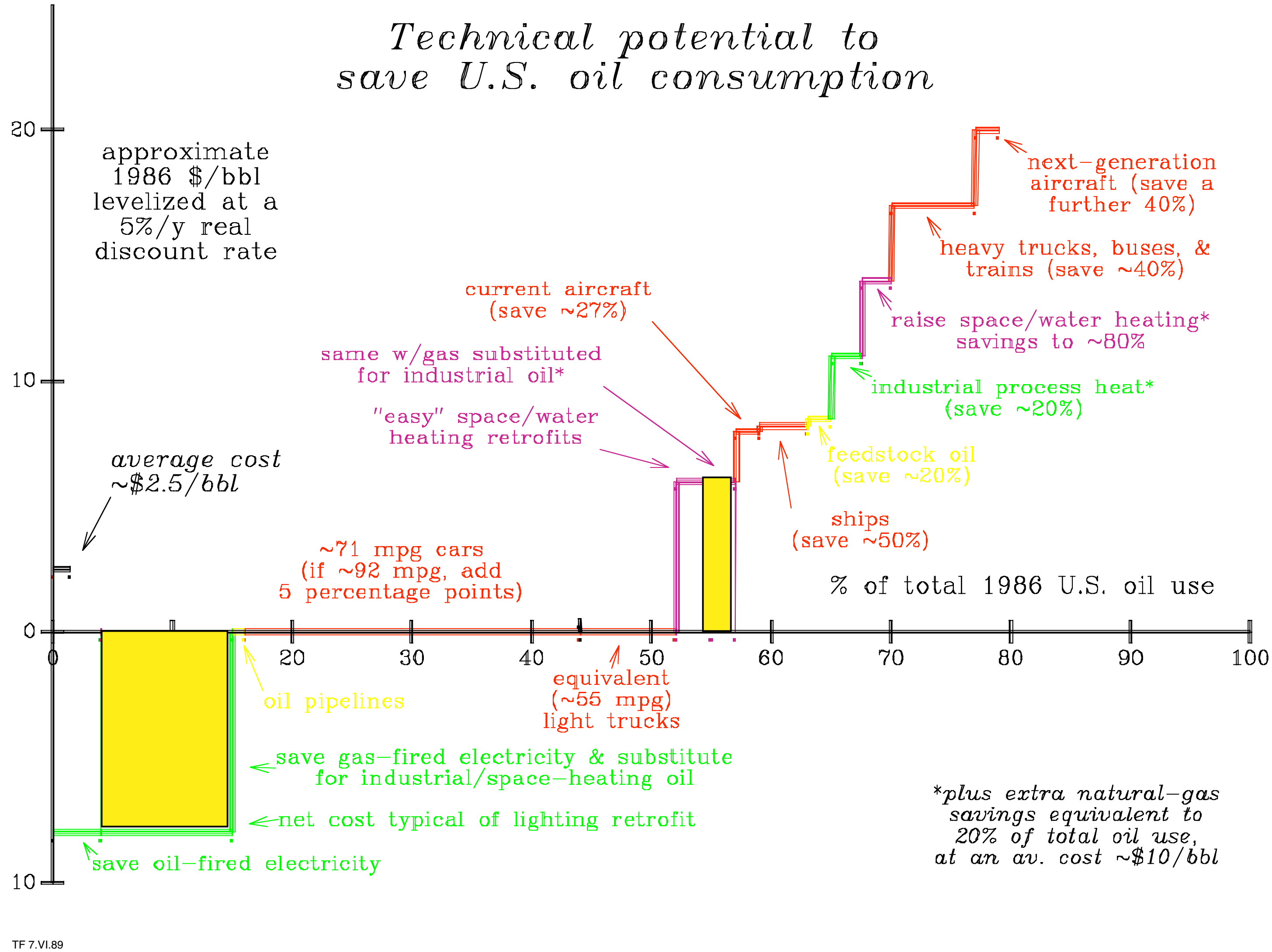
The hydrogen surprise

- A thoughtful hydrogen transition probably needs less capital, and may even need less natural gas, than business-as-usual
- It's more profitable for oil and gas companies: the hydrogen in their hydrocarbons is worth more without the carbon than with the carbon, even if carbon is priced at zero
- May also look good for coal, w/ C sequestration
- Much of the needed hydrogen is already being made…just used for making petrol & diesel fuel
- See 'Twenty Hydrogen Myths', www.rmi.org

Layer upon endless layer of efficiency in various forms…

- *Beyond Hypercars® (5–6×)*: transport demand mgt; mode-switching (Curitiba/Bogatá/Lima bus, Cyber-tran™, hybrid bikes…); vehicle-sharing (Stattauto, ZIPcar, Lynn MA); mobility- or access-based business models (mobility.ch…), land-use reforms
- *Beyond efficient aircraft (2–3×):* big operational gains at airport & system levels; point-to-point in smaller aircraft (hubless); Eclipse/Adam/… ‘air taxis’; mobility- or access-based business models; virtual mobility
- Total effect so far can reach or well exceed ~10×
- Plus possible changes in values or scorekeeping to meet nonmaterial needs by nonmaterial means; do we need better vehicles or better neighbourhoods?

A 1987–88 RMI Analysis for Shell Found a Retrofit Potential to Save ~80% of U.S. Oil at Average Levelized Cost ~US$2½/bbl…



…but now every step is known to be bigger and cheaper!

Out of the Oil Box: A Roadmap for U.S. Mobilization

- RMI synthesis is now synthesizing a full, rapid, attractive, *profitable* U.S. off-oil roadmap
- This exercise, co-funded by the Pentagon, will:
  - update, w/2 variants, RMI's 1987–88 Shell supply curve for oil end-use efficiency & saved natural gas; these could have saved 80% of 1986 oil use @ <$3/bbl — now more & cheaper
  - add an aggressive supply-side transition (biofuels, hydrogen)
  - analyze how much of the unbought overhang of oil savings can be elicited by traditional plus ~15–20 new policy instruments (those not using price, tax, or de/regulation)
  - emphasize market economics, sound business models, and 'barrier-busting' tweaks to public policy: *e.g.*, rewarding not penalizing energy distributors for cutting customers' bills
- Planned for ~April 2004 publication by RMI

How do political leaders choose?

- Most of the action is at State and Municipal level, but Canberra's policy sets context — can help or hurt
- Current Federal policy is at best seriously incomplete, and if current US Energy Bill passes (??), it won't do much, for much the same reasons as in Australia
- National Energy Policy Initiative, www.nepinitiative.org
  - Start with principles and objectives, focus on existing consensus
  - Organized by two nonpartisan nonprofits, 2001–02
  - Funded at arm's-length by seven foundations
  - Interviewed 75 diverse constituency leaders
  - Convened 22 bipartisan US energy policy experts
  - Reached broad consensus on vision, goals, and strategies; suggested innovative, win-win policy options in a highly integrative framework
- Encouraging for a fractured polity in Australia as in US

Policy wildcatters drill through thick strata of partisan polarization…and strike a gusher of consensus

- Endorsed by 32 bipartisan energy leaders
  - Half are or were senior energy-industry executives
  - Others' backgrounds include:
    - Two Presidential advisors, two Dep. Secs. of Energy
    - Five Subcabinet members (State, Com., En., DoD, EPA)
    - A CIA Director, a House energy leader & his deputy
    - Two senior economists of President's CEA
    - Chairs/members of 2 Fed. & 3 State en. reg. commns.
- Meeting national energy, economic, environmental, and security needs simultaneously and without compromise…by building on the consensus that already exists but remains largely unacknowledged

It's time — and we're here

'People and nations behave wisely —
once they have exhausted all other alternatives.'
— Churchill

'Sometimes one must do what is necessary.'
— Churchill

'We are the people we have been waiting for.'

www.hypercar.com

www.rmi.org

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Thank you! To dig deeper…

- Advanced energy efficiency, green buildings, etc.: www.natcap.org, www.rmi.org, and www.esource.com
- Hypercars: www.hypercar.com and www.rmi.org/sitepages/pid386.php
- Hydrogen transition: www.rmi.org/images/other/HC-StrategyHCTrans.pdf
- Barrier-busting to speed up efficiency: www.rmi.org/images/other/C-ClimateMSMM.pdf
- Energy security: www.rmi.org/sitepages/pid533.php
- The Alaskan threat to energy security: www.rmi.org/images/other/E-FoolsGoldAnnotated.pdf
- National Energy Policy Initiative: www.NEPInitiative.org

About the author: A consultant experimental physicist educated at Harvard and Oxford, Mr. Lovins has received an Oxford MA (by virtue of being a don), eight honorary doctorates, a MacArthur Fellowship, the Heinz, Lindbergh, World Technology, and Heroes for the Planet Awards, the Happold Medal of the UK Construction Industries Council, and the Nissan, Shingo, Mitchell, "Alternative Nobel," and Onassis Prizes; held visiting academic chairs; briefed 18 heads of state; published 28 books and several hundred papers; and consulted for scores of industries and governments worldwide, including oil majors since 1973, automakers since 1991, USDOE, and USDoD. He has advised Canada's Federal and Provincial governments and major energy firms for three decades. *The Wall Street Journal*'s Centennial Issue named him among 39 people in the world most likely to change the course of business in the 1990s, and *Car* magazine, the 22nd most powerful person in the global automotive industry. His work focuses on whole-system engineering; on transforming the car, energy, chemical, semiconductor, real-estate, and other sectors toward advanced resource productivity, and on the emerging "natural capitalism."

About Rocky Mountain Institute (www.rmi.org): This independent, nonpartisan, market-oriented, technophilic, entrepreneurial, nonprofit organization was cofounded in 1982 by Hunter Lovins and CEO Amory Lovins. RMI fosters the efficient and restorative use of natural and human capital to create a secure, prosperous, and life-sustaining world. The Institute's ~50 staff develop and apply innovative solutions in business practice, energy, transportation, climate, water, agriculture, community economic development, security, and green real-estate development. RMI's ~US$7-million annual budget comes roughly half each from programmatic enterprise earnings (mainly private-sector consultancy) and from foundation grants and donations. Its work is summarized in the best-selling 1999 business book *Natural Capitalism* (with Paul Hawken and L. Hunter Lovins, www.natcap.org).

About Hypercar, Inc. (www.hypercar.com): In 1999, Rocky Mountain Institute transferred its internally incubated technical activities on Hypercar vehicles to this partly-owned second-stage technology development firm, its fourth for-profit spinoff. Funded by more than US$9 million of private equity capital, Hypercar, Inc. supports the auto industry's transition toward the Hypercar concept developed at RMI since 1991, focusing chiefly on integrated ultralight designs and the Fiberforge™ manufacturing solution. Mr. Lovins chairs Hypercar's Board of Directors and holds minor equity options in the firm.