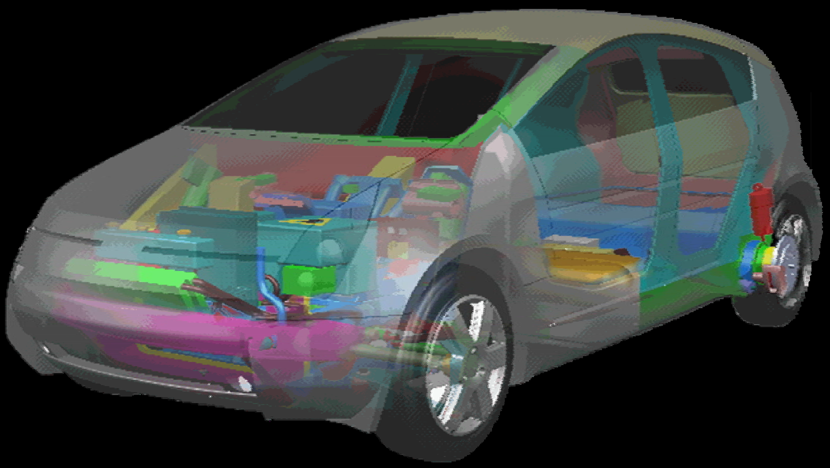
CNO’s Naval-Industry R&D Partnership Conference 2003
Ronald Reagan Building, Washington, DC, 5 August 2003

More Fight, Less Energy, at Lower Cost!



Amory B. Lovins

Chief Executive Officer
Rocky Mountain Institute
www.rmi.org

Chairman of the Board
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www.hypercar.com

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Transformational objectives

- Radically reduce the energy consumption of land, sea, and air platforms
- Increase their combat effectiveness, agility, deployability, and sustainability
- Reduce their capital and operating costs
- No compromise, no tradeoff

"If we are to achieve results never before accom-plished, we must employ methods never before attempted."
— Sir Francis Bacon

How can breakthrough design make big energy savings cost *less* than small or no savings?

Let's start with some building designs…

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^2K roof, -0.14 walls, -0.47 to -0.7 [COG] glazings, air-to-air heat exchangers
- ◊ Thermally passive, 95% daylit
- ◊ Superefficient lts/eqt

Savings (1983 tech.):

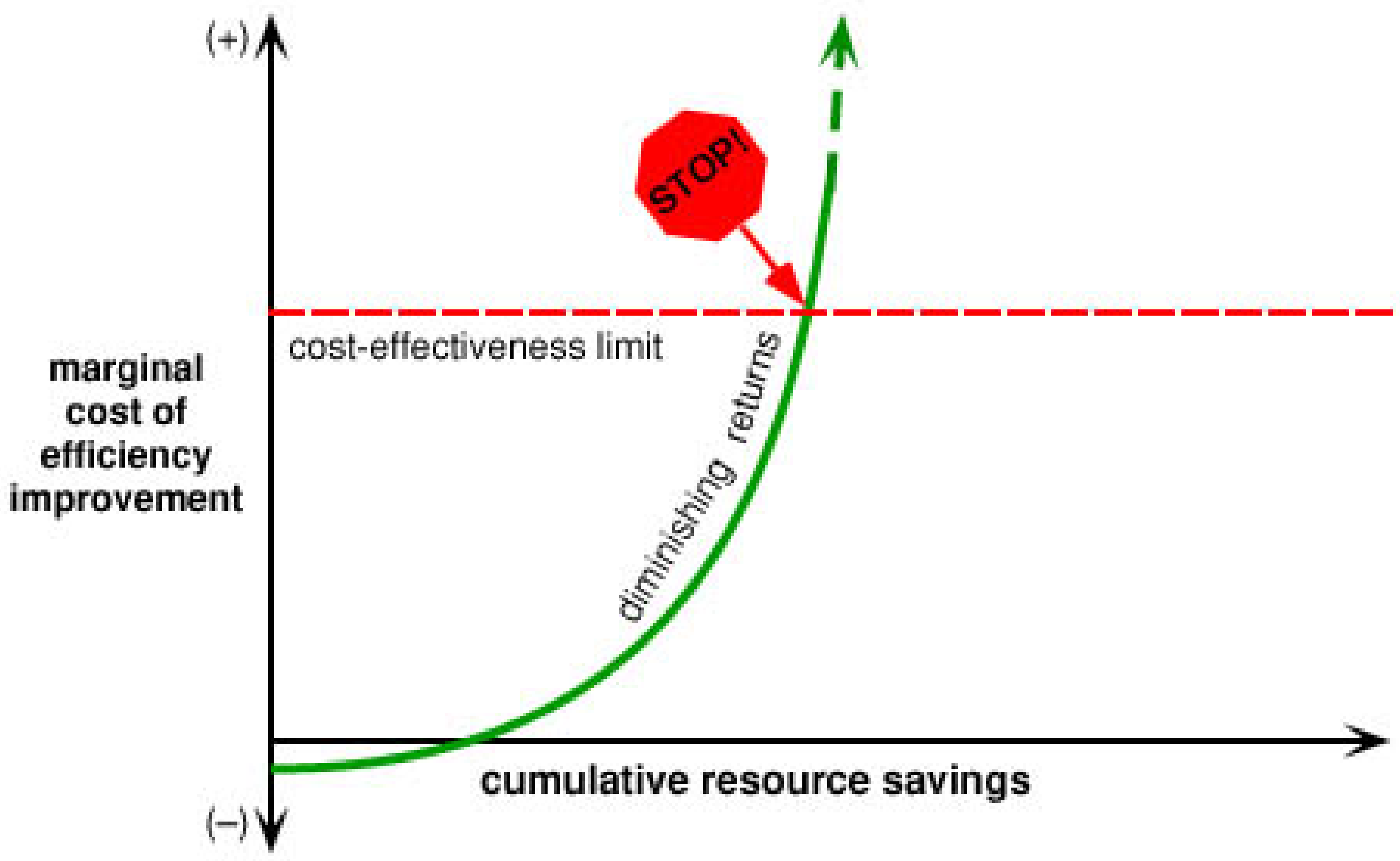
- ◊ 90% in home el. (~120 W_{av}/372 m^2)
- ◊ 99% in space & water heating
- ◊ 10-month payback, would be $\leq$0 now

PG&E ACT^2 House

Davis, California

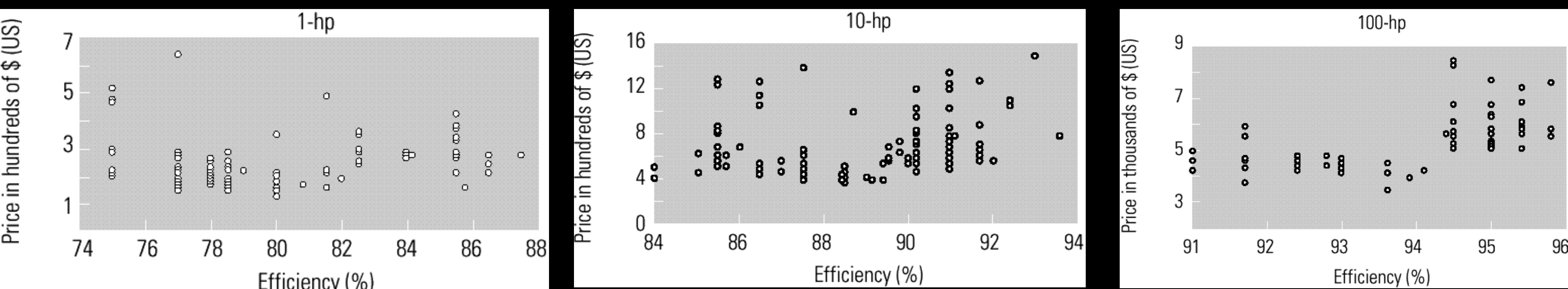
- ◇ Comfort without air conditioning at +45°C, even in 3-day heat storm
- ◇ Mature-market building cost $1,800 lower
- ◇ Present-valued mainten-ance cost $1,600 lower
- ◇ Original design’s energy use ~82% below California Title 24 standard (1992)
- ◇ Last 7 improvements jus-tified by savings of energy *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 too

New design mentality: turn diminishing returns…



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

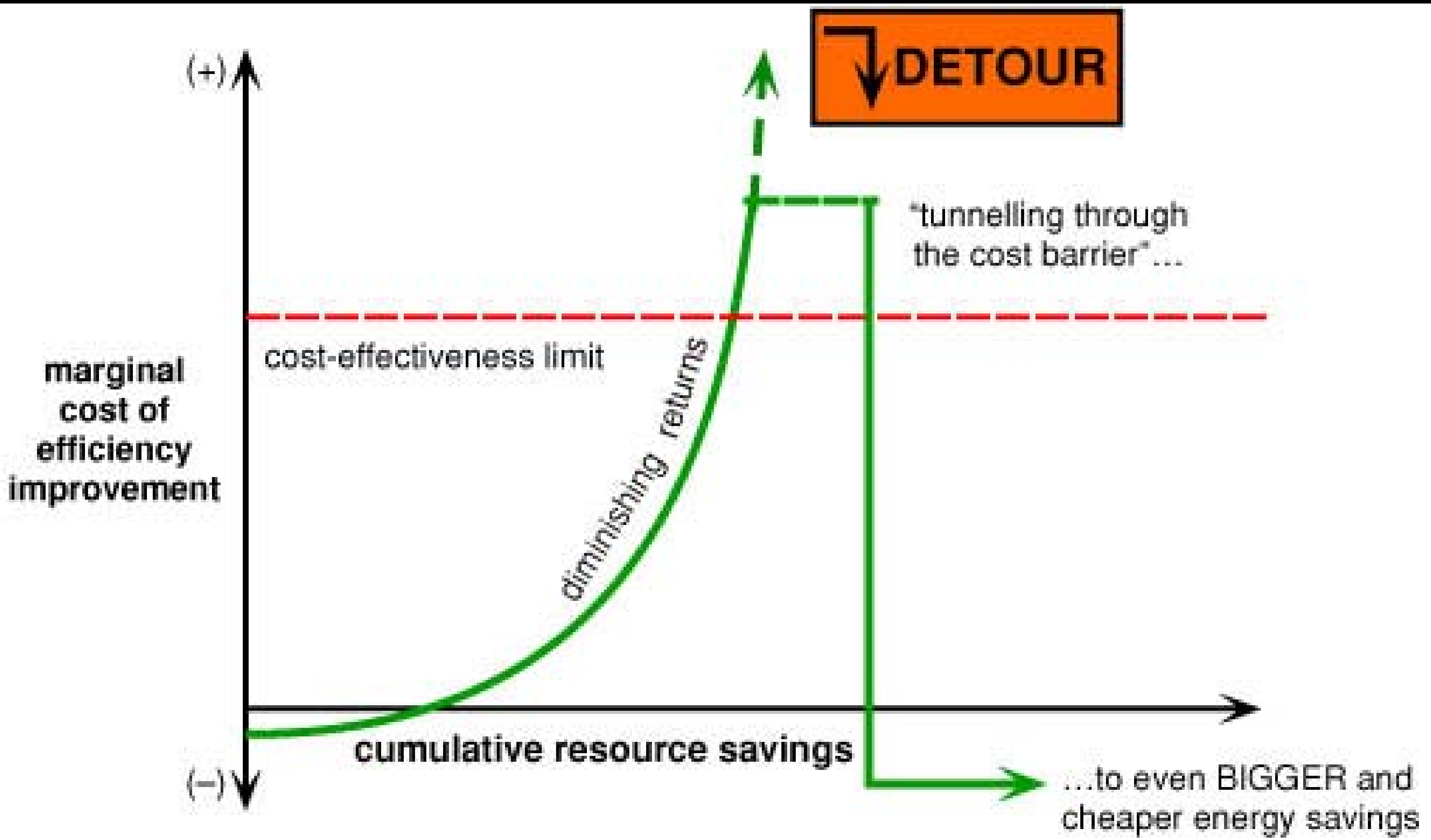
- Motor Master database shows no correlation between efficiency and trade price for North American motors (1,800-rpm TEFC Design B) up to at least 220 kW



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

...into expanding returns: "tunneling through the cost barrier"



Examples of industrial opportunities

- Save half of motor-system electricity with retrofit aftertax ROI ~100–200%/y — buy 7 improvements, get 28 more as free byproducts
- Similar ROI saving >50% of chip-fab HVAC
- Top-efficiency refinery retrofit: save 42%, 3-y payb.
- North Sea oil platform: save half el., recover the rest
- Major LNG plant: enormous savings evident
- New supermarket: save ~70–90%, cost ?less
- New chemical plant: save 3/4 el. and 10% capex without any process changes such as microfluidics
- New data center: save 89%, cost less, higher uptime

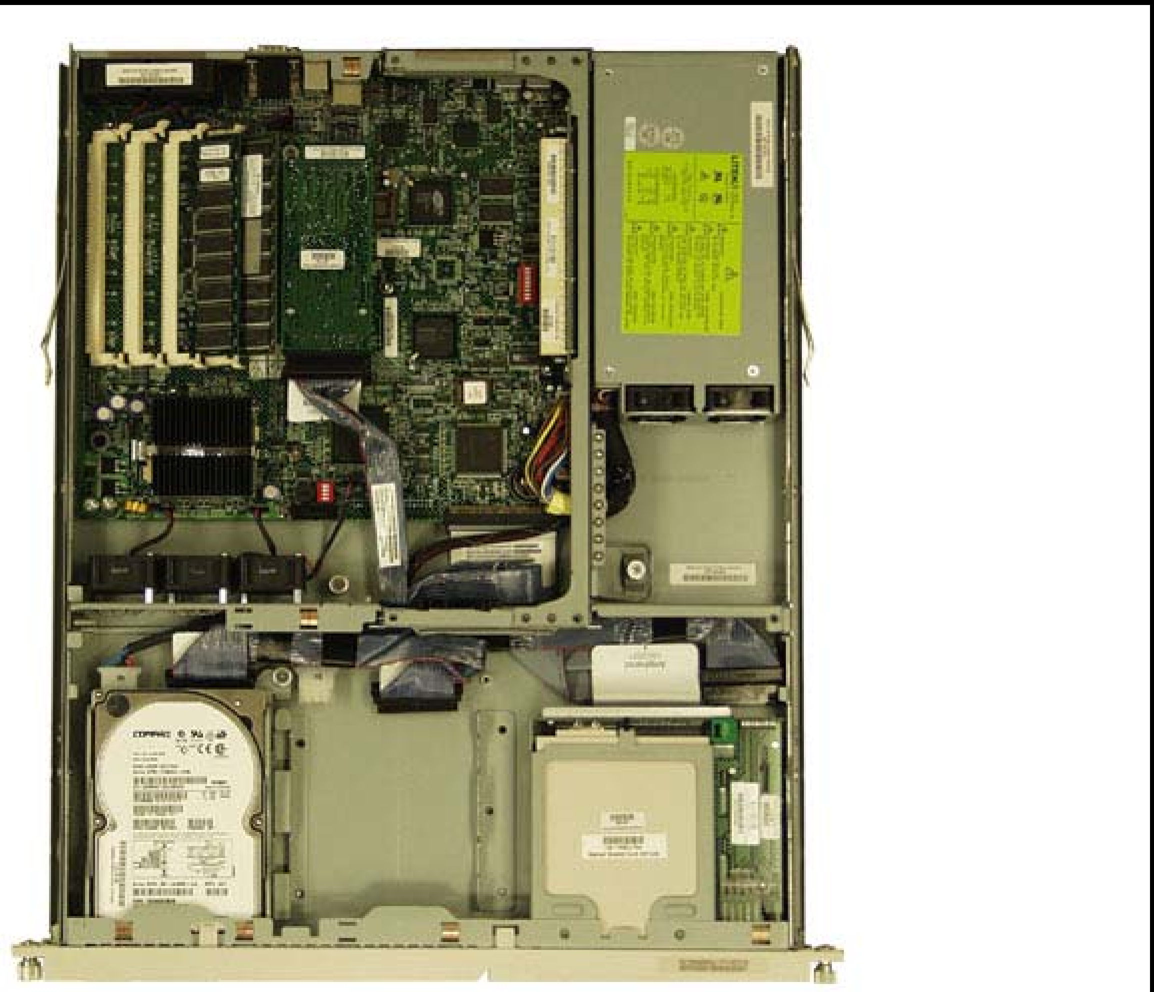
Frying an egg on an Athlon XP1500+ in 11 minutes

From Trubador, www.handyscripts.co.uk/egg.asp

Simple RMI server substitution

- RMI replaced three (could have replaced four) WinNT servers with one small NetWinder Linux box (now model 3100)
- Nominal power 14 W, no fan
- Faster and more capable than NTs
- Hardware plus software cost less than NT license fee on replaced NT boxes
- 98–99% energy saving
- Big space saving
- Now imagine this aboard a Naval vessel — avoiding extra power and cooling capacity…

1U Wintel rack-mounted server



- 800 MHz Intel processor
- 19"×30"
- Disk drives, I/O ports, memory
- Floppy drive
- CD ROM
- Video capabilities
- Serial / parallel ports
- PCI expansion slots
- 160 Watt power supply; often runs at lower power, with disproportionately lower power-supply efficiency
- 9 fans using ~20–25% of total server power
- $2000+

This and following slide courtesy of Chris Hipp, ex-RLX

RLX ServerBlade™, ~15.7 W

CMS 1 MB

- **Public NIC**
- **33 MHz PCI**

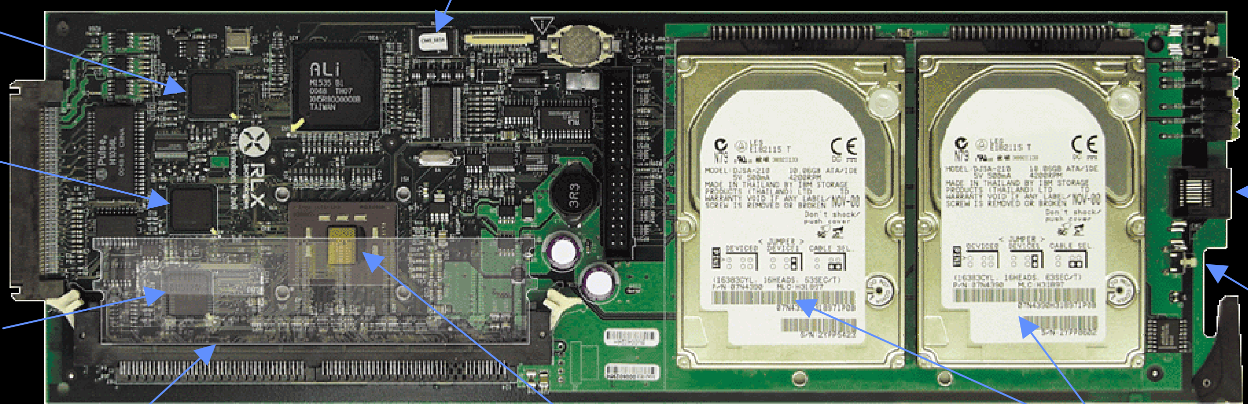
Private NIC
33 MHz PCI

Management NIC
33 MHz PCI

Status LEDs

Serial RJ-45
debug port

Reset Switch



128MB, 256MB, 512MB
DIMM SDRAM
PC-133

512KB
Flash ROM

Transmeta™
TM5600 633 MHz

Crusoe™

128KB L1 cache, 512KB L2 cache
LongRun, Southbridge, X86 compatible

ATA 66
0, 1 or 2 - 2.5” HDD
10 or 30 GB each

72 blade servers in 9U

Wu-chun Feng's Green Destiny supercomputer, LANL

- ◇ RLX passively-cooled blade servers using 0.13μm TransMeta Crusoe CPU: 8× denser, 5–8× less power-intensive than Wintel
- ◇ Reliable in an uncooled, hot warehouse
- ◇ ~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

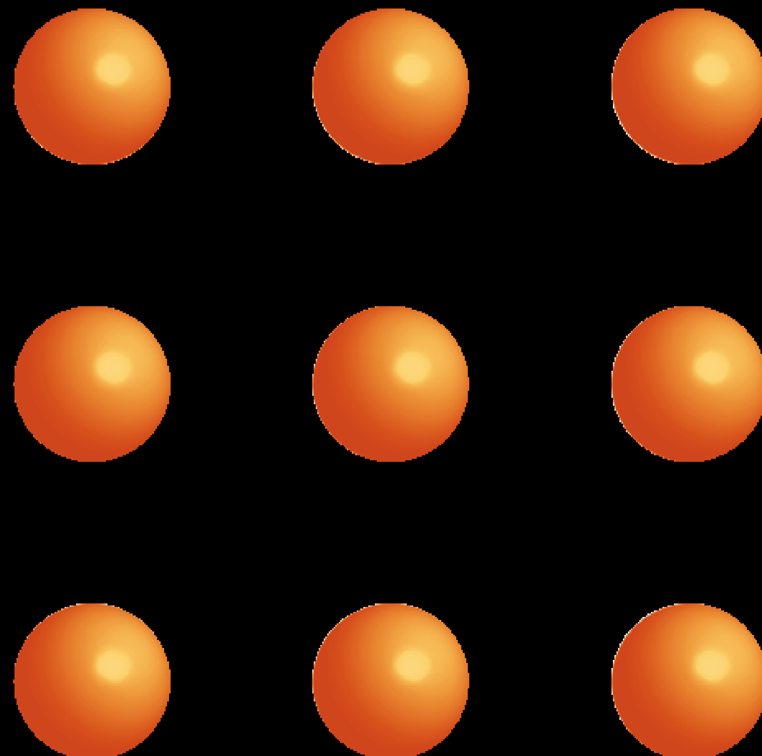
RMI’s Energy-efficient Data Center Charrette, San Jose, 2–5 Feb 2003

- >90 industry experts found ways to save 89% of the energy used by a typical data center (server farm), probably with lower total capital cost and better throughput and uptime
- Ultra-low power consumption at the architecture, software, compiling, and device levels
- Superefficient onsite power-and-cooling system; integrated design d*ecompounds loads*; very efficient, multi-purpose accessories and systems
- Real-estate model also very important
- Listserv: RMI_DataCenterDialog-on@rmi.org

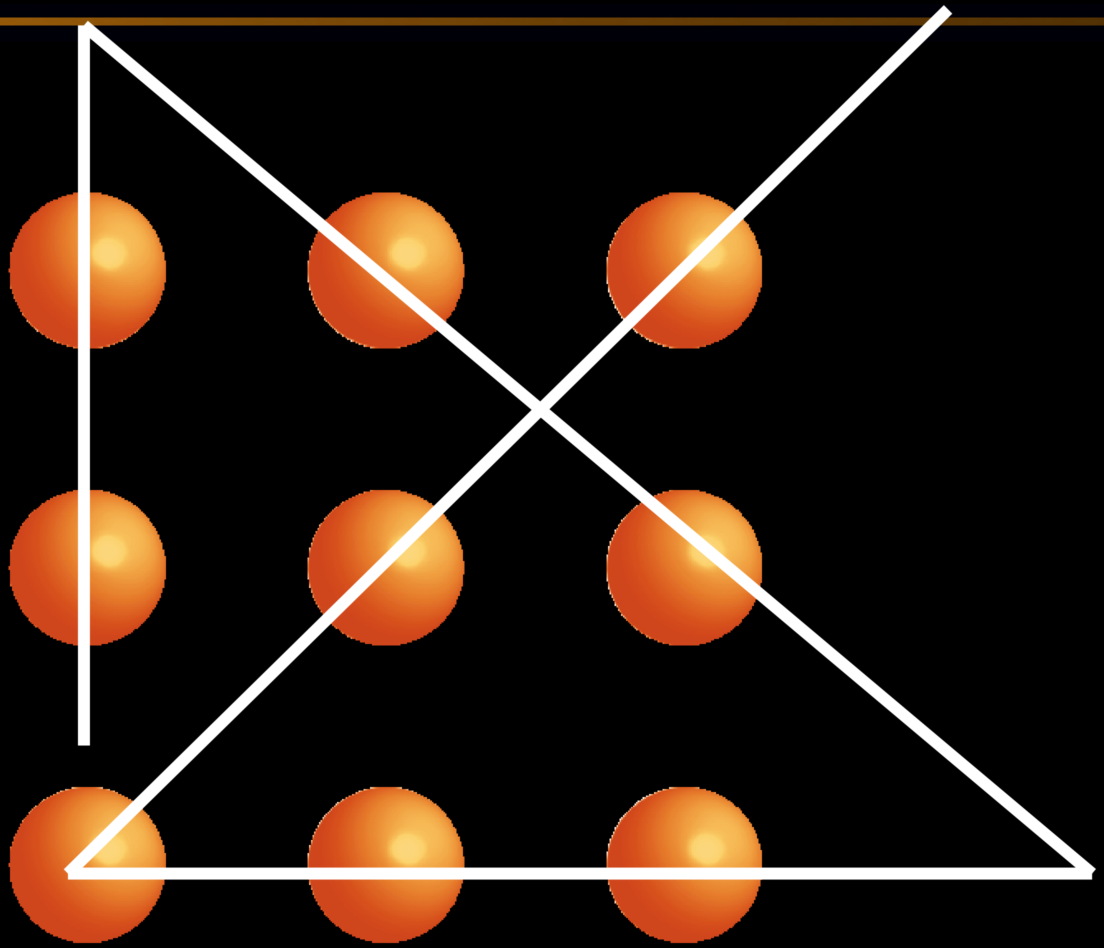
Edwin Land

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

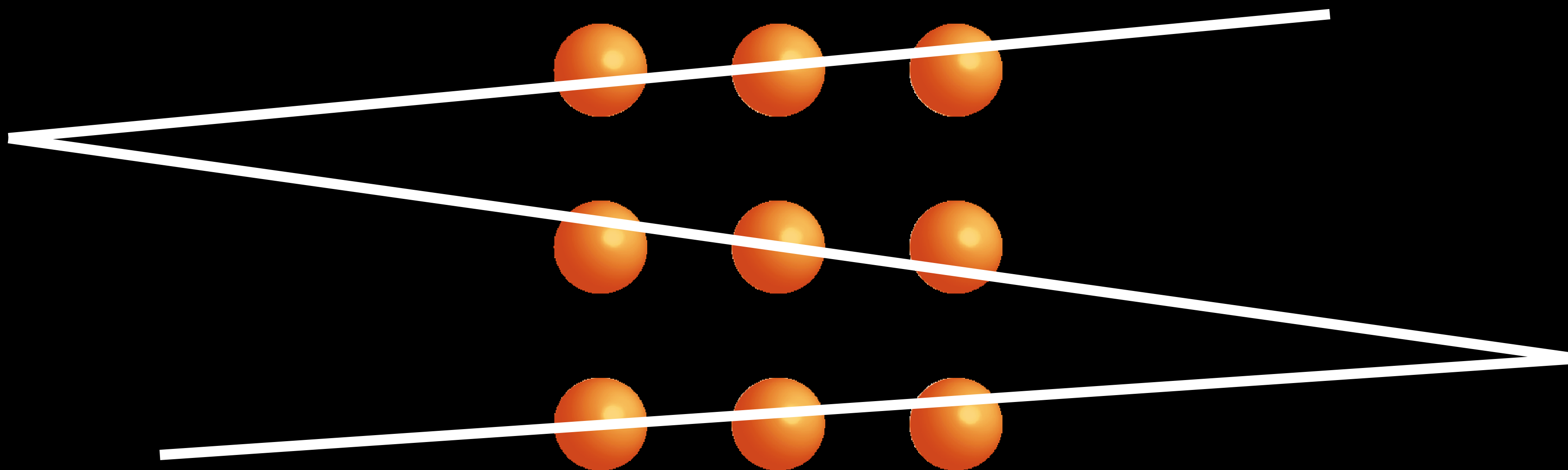
The Nine Dots Problem

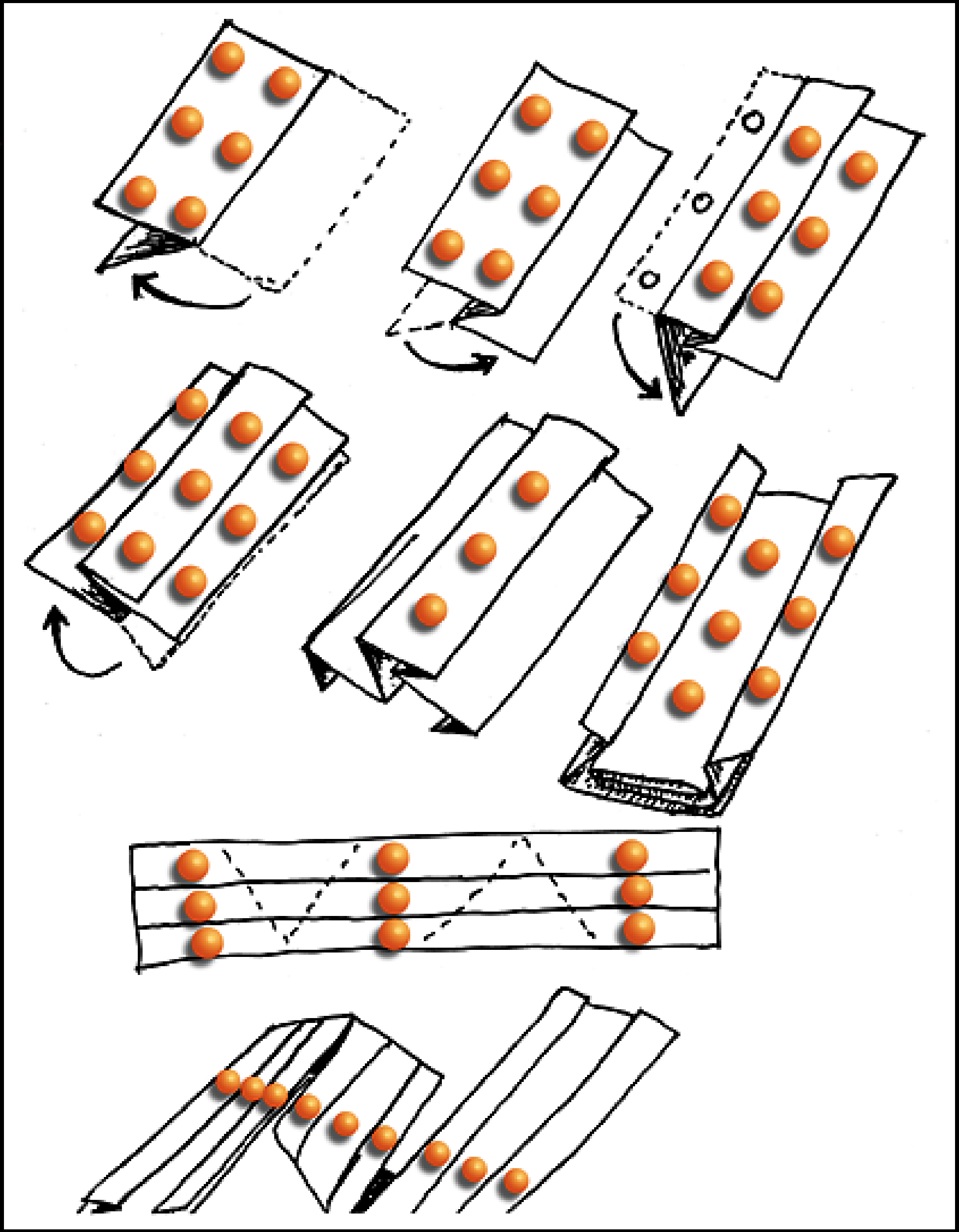


The Nine Dots Problem



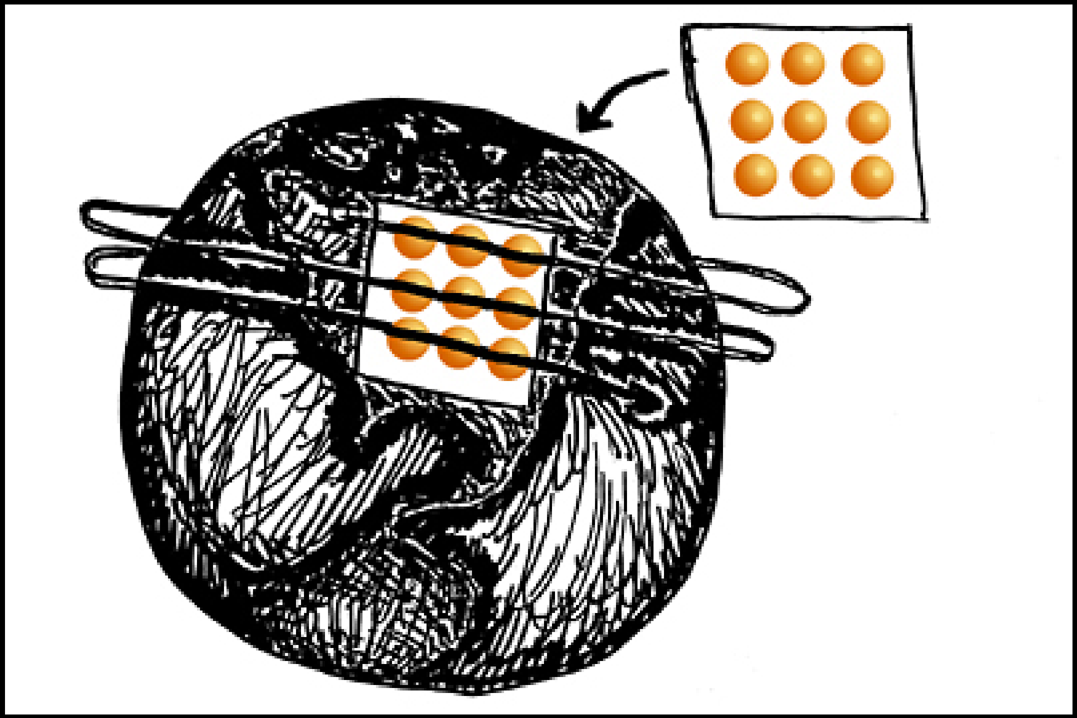
The Nine Dots Problem





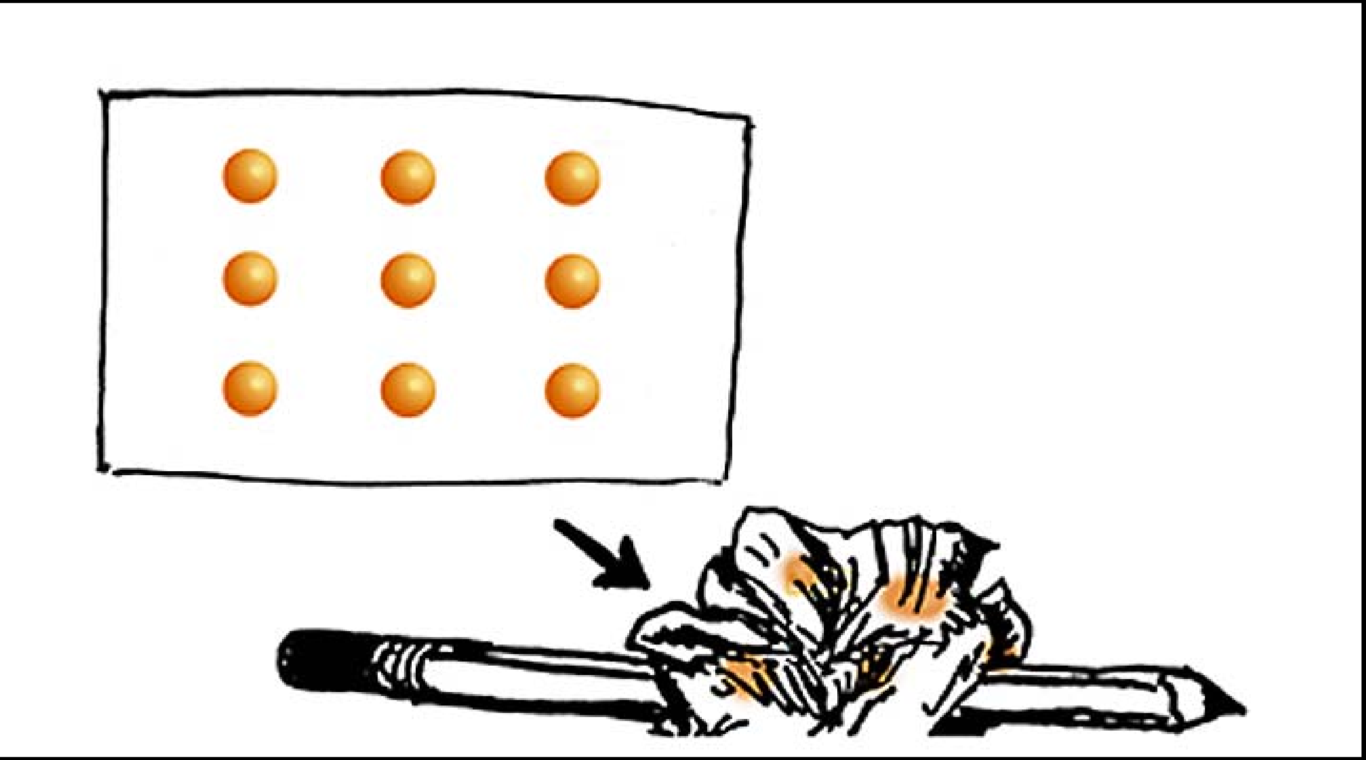
origami solution

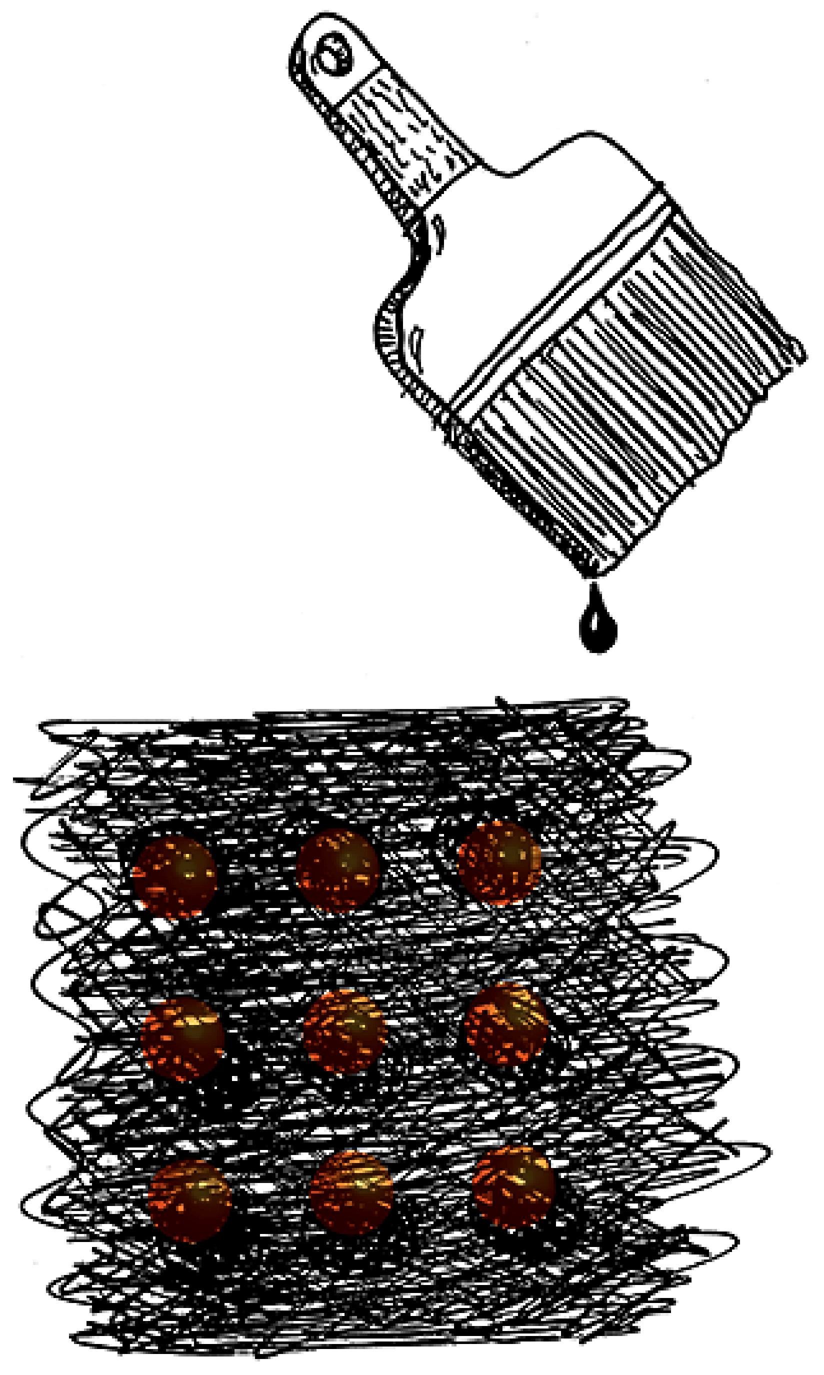
geographer's
solution



mechanical engineer's solution

statistician's solution





wide line
solution

Edwin Land

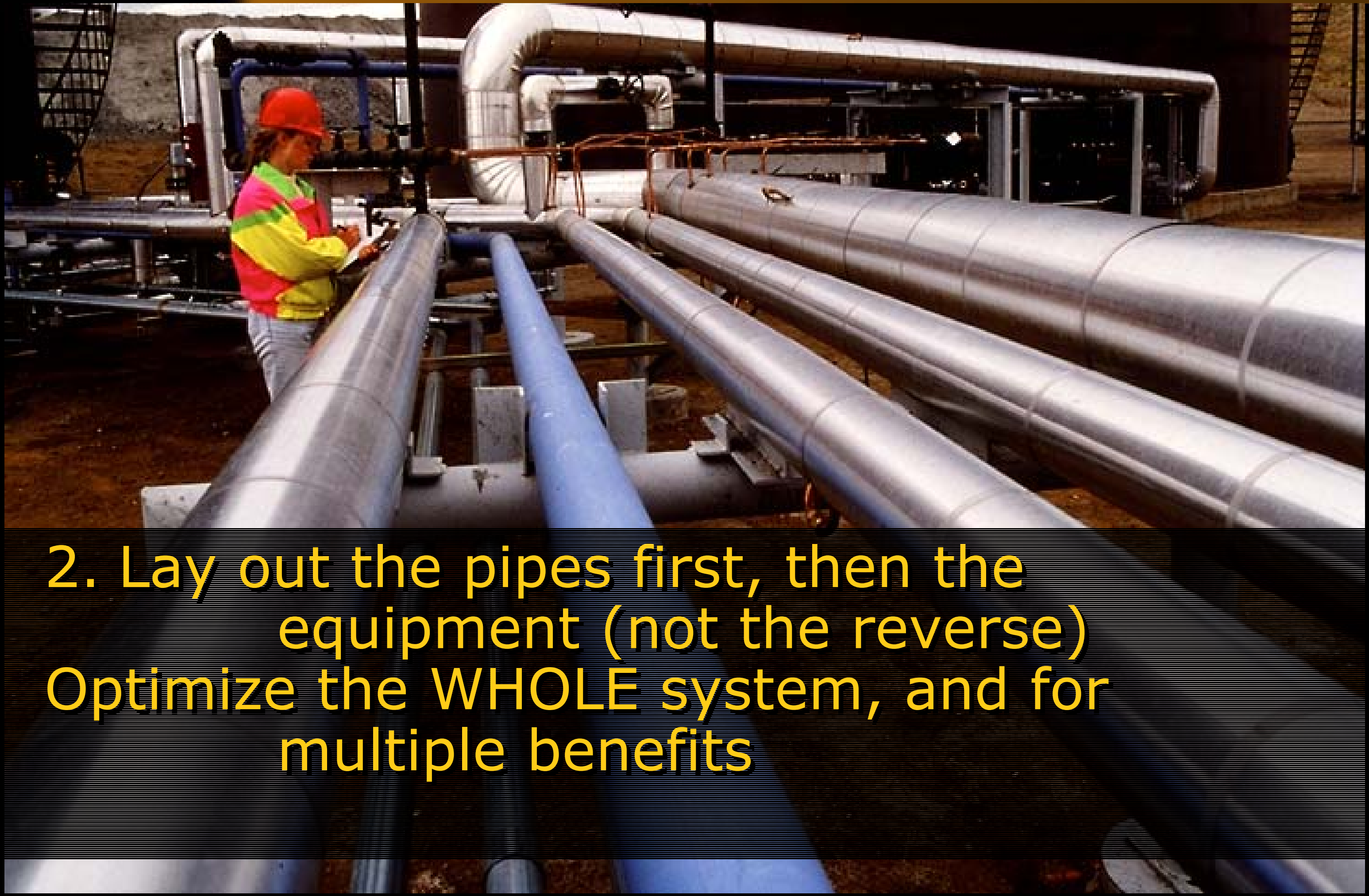
Invention is "… a sudden cessation of stupidity"

New design mentality

- Redesigning a standard (supposedly optimized) industrial pumping loop cut power from 70.8 to 5.3 kW (–92%), cost less to build, and worked better
  - Just two changes in design mentality

New design mentality, an example

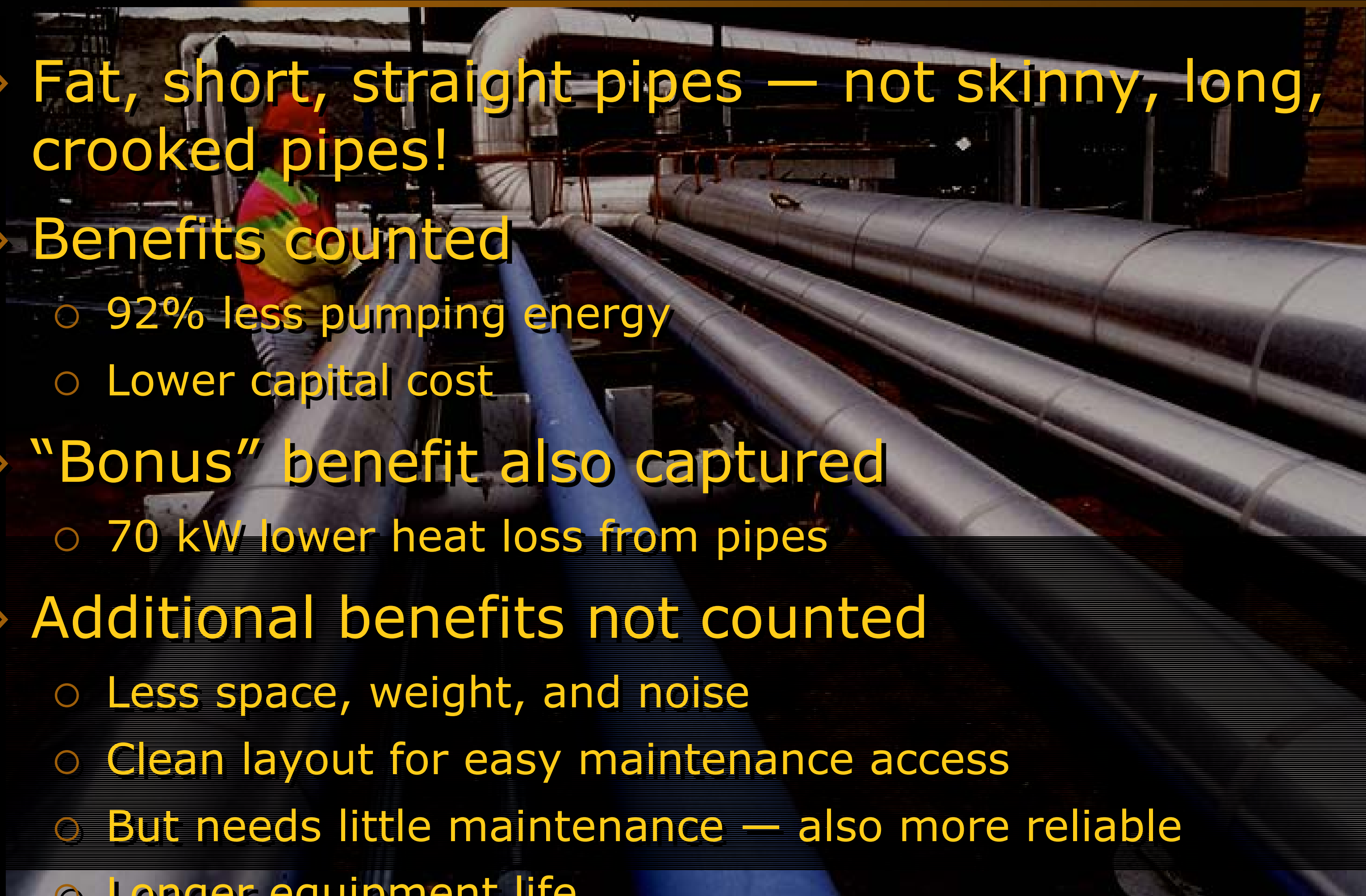
No new technologies, just two design changes



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



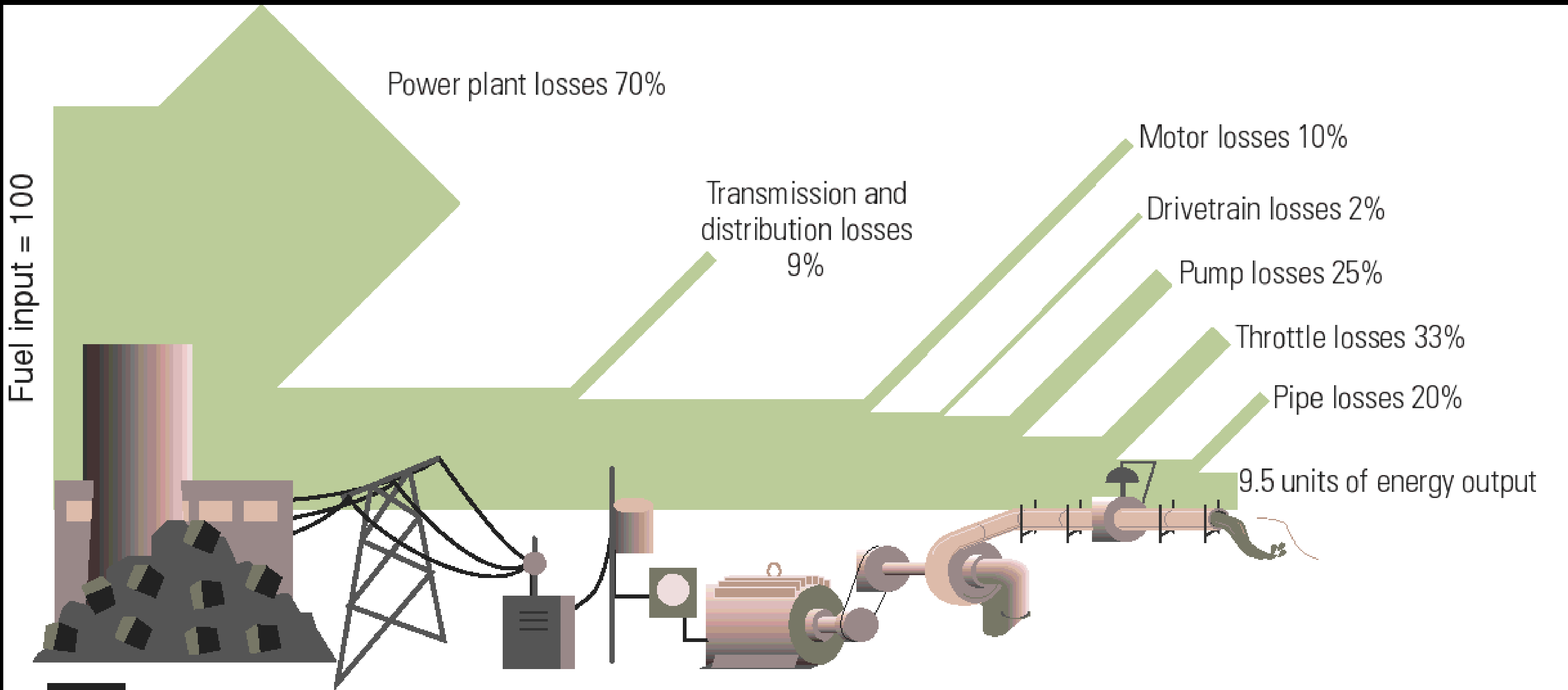
- Fat, short, straight pipes — not skinny, long, crooked pipes!
- Benefits counted
  - 92% less pumping energy
  - Lower capital cost
- "Bonus" benefit also captured
  - 70 kW lower heat loss from pipes
- Additional benefits not counted
  - Less space, weight, and noise
  - Clean layout for easy maintenance access
  - But needs little maintenance — also more reliable
  - Longer equipment life
- If counted, we'd have saved more…maybe ~98%

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 power plant
- This is archetypical: applying whole-system design principles to almost *every* technical system yields ~3–10x energy/resource savings, and usually costs less to build, yet improves performance
- We need a pedagogic toolkit of diverse examples…for the nonviolent overthrow of bad engineering (RMI’s DIG project)

The leverage of downstream savings: pipes and pumping

- Compounding losses require ~10 units of fuel at the power plant to produce 1 unit of flow in the pipe — ~20 with GTGs!



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

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!

The right steps in the right order: space cooling

1. Expand comfort envelope
2. Minimize unwanted heat gains
3. Passive cooling
   - Ventilative, radiative, ground-/groundwater-/seawater-coupled
4. Active nonrefrigerative cooling
   - Evaporative, desiccant, absorption, hybrids: COP ≥100
   - Direct/indirect evaporative + VFD recip in CA: COP 25
5. Superefficient refrigerative cooling: COP 6
6. Coolth storage and controls
7. Cumulative energy saving: ~90–100%, better comfort, lower capital cost, better uptime

The secret of great design integration:

No Compromise!

Design is *not* the art of compromise and tradeoff—how not to get what you want

J. Baldwin: “Nature doesn’t compromise; nature optimizes. A pelican is not a compromise between a seagull and a crow.” It is the best possible pelican (so far) — and after 90 million years, that’s a pretty good one

The need for compromise is generally a symptom of misstated design intent

More Capable Warfighting Through Reduced Fuel Burden

- Defense Science Board Task Force report 1/01, released 5/01; chaired by VADM Richard Truly (Ret.)
- DoD spends 1/3 of its budget and 1/2 of its personnel on logistics, mostly moving fuel (~70% of the Army's tons deployed in Desert Storm)
- Most of that fuel could be saved, but isn't; why?
- Platform designers assume logistics is free!
- E.g., tank designers assume the Defense Energy Support Ctr. fuel price ($1.34/gal in FY02)—but quick delivery 600 km into theater (via 3-stage helicopter relay —not an unusual improvisation) adds ~$400–600/gal.
- Cost and warfighting both need efficient platforms
- The prize: ~$2–3b/y in avoidable direct fuel cost, + several times that in avoidable fuel logistics costs, redeployed assets, far more effective warfighting

DESC *vs.* true *delivered* DoD fuel cost per year

Service	DESC fuel cost FY99 @ $0.87/gal	Delivered fuel cost	Ratio	Omitted costs
Army	~$0.2b (1997; excl. energy used for deployment by Navy & Air Force)	$3.4b incl. 20k active POL @$100k/y + 30k res POL @ $30k/y	16	POL equip-ment/facilities + combat fuel delivery
Navy	$1.6b (1997; excl. midair refuel-ing by Air Force)	$2.5b	1.6	purchase of new oilers
Air Force	$1.8b	$4.4b	2.4	proposed new tank-ers (>$9b)
Total	$3.6b ($5⁺b FY02)	$10.3b (conservative!)	2.9	those plus pyramids of support costs

Source: Defense Science Board, *More Capable Warfighting Through Reduced Fuel Burden*, May 2001 (USD/AQT), at:

p. 39; omits indirect use by Navy and Air Force to deploy Army assets; omits ownership cost of equipment; ratio for delivery far beyond FEBA can be many hundreds

pp. 4, 20; delivery 70% by oiler @ $0.64/gal, 30% pierside @ $0.05/gal (Dr. Alan Roberts, pers. comm. 3 April 2001)

p. 17; includes total ownership cost of tanker fleet except purchase of >55 new tankers

Delivered fuel cost would scale to ~$12–14b/y at FY02 DESC fuel price ($1.37/gal)—much more if all the omitted costs are counted

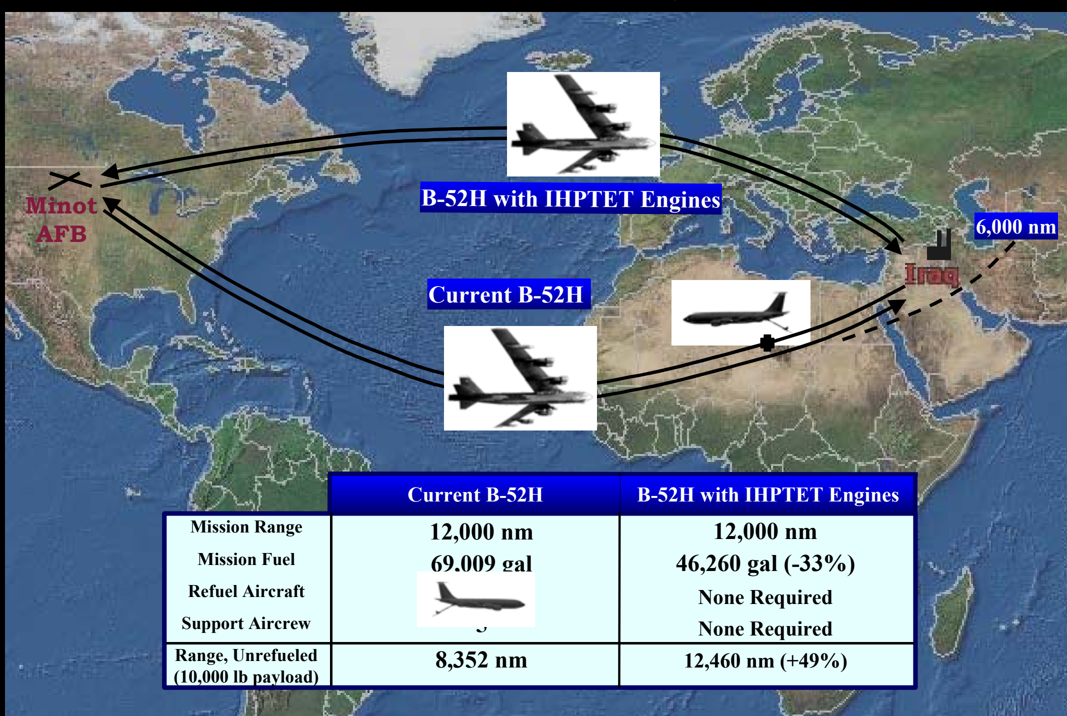
Reality check: DoD spends roughly a third of its budget on logistics, for which ≥60% of tonnage is fuel, so hypothetically saving half the fuel and then downsizing would be worth ~10% of DoD's budget, or ≥$30b/y, if logistics cost were proportional to tons and budget included only hauling (both assumptions probably false)

ROCKY MOUNTAIN INSTITUTE

Typical misallocation of funds: Air Force

- B52H bomber: @ $1/gal, 1960s engines were felt not worth retrofitting (fuel –33%, range +28% to +49%); but retrofit looks great, counting just 10% midair refueling, @ $17.5/gal—and then midair re-fueling is seldom necessary (Minot↔Iraq on one fill)!

Benefits of B-52H Efficiency Improvements



	Current B-52H	B-52H with IHPTET Engines
Mission Range	12,000 nm	12,000 nm
Mission Fuel	69,009 gal	46,260 gal (-33%)
Refuel Aircraft	[illegible]	None Required
Support Aircrew	[illegible]	None Required
Range, Unrefueled (10,000 lb payload)	8,352 nm	12,460 nm (+49%)

A prompt engine upgrade (vendor-financed?) might save tanker cost in current budget, pay for PGM upgrade; DSB panel unan'y. recommended 4/03, est'd $6–9b sav.

Typical misallocation of funds: Army

- M1A2 tank: late-1960s gas turbine, 1500 hp to sprint 68 tons around the battlefield at 30 mph, idles ~60–80+% of the time at <1% efficiency to run a 5-kW hotel load: no APU, for two reasons
  - Designers calculated 46-y payback @ ~$1/gal; but it's 3.5 y at *delivered* peacetime fuel cost ($13/gal), ~1 month in wartime (up to $400–600/gal delivered)
  - No room under armor…so just strap it on the back! If it gets shot away, you're just back to current situation.

Today's Top 10 Battlefield Fuel Users

SWA scenario using current Equipment Usage Profile data

Of the top 10 Army battlefield fuel users, only #5 and #10 are combat platforms

1. **Truck Tractor: Line Haul C/S 50000 GVWR 6X4 M915**
2. **Helicopter Utility: UH-60L**
3. **Truck Tractor: MTV W/E**
4. **Truck Tractor: Heavy Equipment Transporter (HET)**
5. ***Tank Combat Full Tracked: 120MM Gun M1A2***
6. **Helicopter Cargo Transport: CH-47D**
7. **Decontaminating Apparatus: PWR DRVN LT WT**
8. **Truck Utility: Cargo/Troop Carrier 1-1/4 Ton 4X4 W/E (HMMWV)**
9. **Water Heater: Mounted Ration**
10. ***Helicopter: Attack AH-64D***

Italics indicates combat systems.
Source: CASCOM study for DSB using FASTALS for SWA.
The end-state force list for SWA (based on the FASTALS Deployment Report) was used as the force structure.

Of the top ten Army battlefield fuel users, #5 is the tank, #10 is the Apache helicopters; the other 8 are noncombatants, several of which...haul fuel!

Army After Next fuel efficiency simulation*

- Based on M1 Series AAN fuel saving of 89%
- AAN saves 3,942 POL personnel, 1,155 maintenance, 4,179 other ($\Sigma = 9,276$); 228 cargo trucks, 219 line haul trucks, 30 util trucks, 68 MHE, 89 gensets; 106,477 tons fuel in division base area + 128,334 tons in brigade area; not counting upstream logistics to deliver fuel & associated assets into theater
- Total saving: up to 20,000 POL personnel and their equipment, plus more upstream
- Total fuel use = AOE – 60%; ≥75% “easily” w/improved tactics & info-dominance gains

*Based on CASCOM FASTALS w/TAA 05 MTW West (NEA) Baseline; no Army XXI or AAN Op Tactics, Techniques, or Procedures included; constant mission, same battle outcome; per LTC Ronald Salyer, USARL, 757/864-7617, 17 Aug 1999 brief to Defense Science Board panel, c/o panel member A B Lovins, CEO, RMI, & Chairman, Hypercar, Inc.

Typical misallocation of funds: Navy

- As of 2001, stern flaps, paying back in ~1–2 years, were retrofitted on 12 hulls (saving ~$2M/y), with 48 more planned (+ $8M/y), but should have been on 58 more (+ $10M/y); costs/benefits show up on different budgets, splitting the incentive
- Navy is the only Service that assessed delivered fuel cost (until 1994—then NAVSEA stopped)
- Comptroller let(s?) PACFLT (only?) skippers keep part of operational fuel savings, correcting the split incentive
- FY99 savings ($23M) is <1/2 of NAVSEA's min. potent'l.
  - *E.g.*, optimal power setting cuts fuel by ~10–20%, up to ~65%
- Design practice and pedagogy can be much improved in ships, just as NAVFAC did in facilities starting in 1995

An encouraging example of breakthrough design

- At the Lockheed Martin Skunk Works®, engineer David Taggart led a team that designed an advanced tactical fighter-plane airframe…
  - made 95% of carbon-fiber composites
  - 1/3 lighter than its 72%-metal predecessor
  - *but 2/3 cheaper*…
  - because it was designed for optimal manufacturing from carbon, not from metal
- As VP Product Development and CTO of Hypercar, Inc., he then did much the same for cars — showing what happens when cars are designed around a breakthrough composites manufacturing technology (Automotive Volume Advanced Composite System™ = AVACS™)

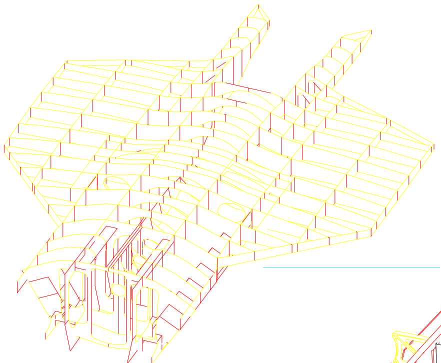
Integrated Technology for Affordability (IATA)

INTEGRATED AIRFRAME TECHNOLOGY FOR AFFORDABILITY
ARPA • AIRFORCE • SKUNK WORKS

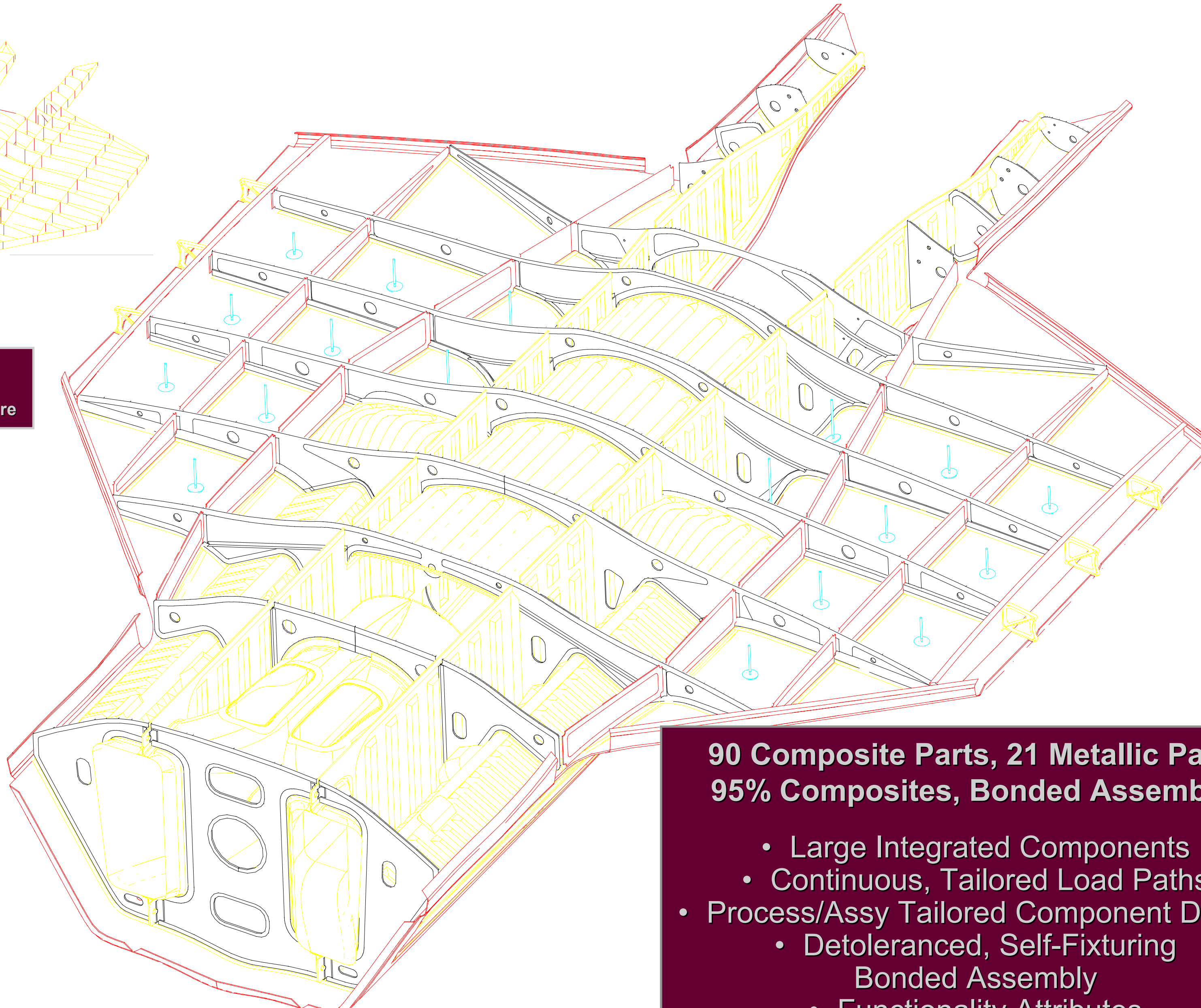
- DARPA funded effort (1994–96)
- The challenge: Airframes must provide performance **affordably**
- What was needed: A ***Breakthrough*** cost reduction compared to airframe technology
- Proposed solution: Design—create a new paradigm
- Lockheed Martin Skunk Works, Alliant Techsystems, Dow-UTC, AECL
- Focus: JSF

This and next 6 slides from D.F. Taggart brief to DSB, 20 Sept 2000

IATA Preferred System Concept



JAST / ASTOVL
Config. 140:
Conventional Structure

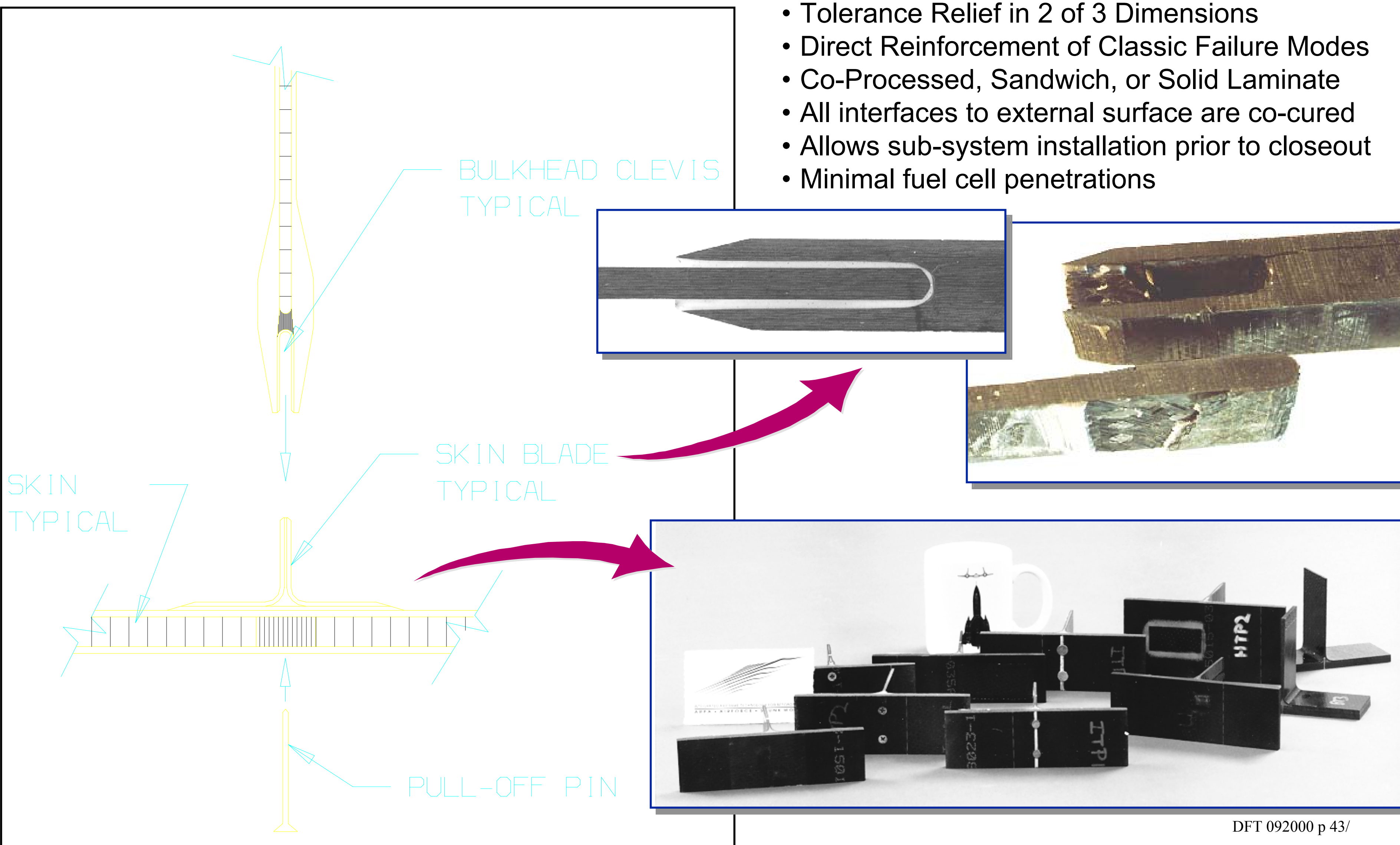


90 Composite Parts, 21 Metallic Parts
95% Composites, Bonded Assembly

- Large Integrated Components
- Continuous, Tailored Load Paths
- Process/Assy Tailored Component Design
- Detoleranced, Self-Fixturing Bonded Assembly
- Functionality Attributes

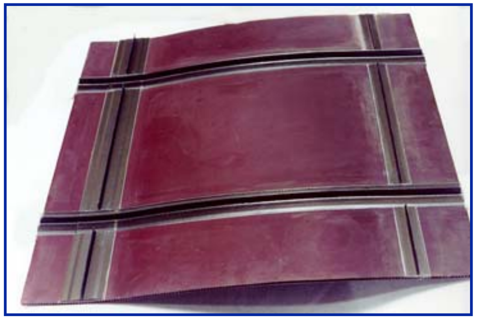
Low Tolerance Bonded Assembly

- Fastenerless Assembly of Multiple Components
- Tolerance Relief in 2 of 3 Dimensions
- Direct Reinforcement of Classic Failure Modes
- Co-Processed, Sandwich, or Solid Laminate
- All interfaces to external surface are co-cured
- Allows sub-system installation prior to closeout
- Minimal fuel cell penetrations



Process Demonstration Assembly

- *Full Scale: 5 ft x 5 ft x ft section*
- *Envisioned Production Processes*
- *Most complex, highly loaded section*



Fiber Placed Upper/Lower Skins
- E-beam Cured: Cationic Resin
- Co-Cured Large Cell Core
- Alliant TechSystems

Bonded Assembly
- Detoleranced
- Self-Fixturing

RTM Spar/Bulkheads
- Tailored Load Paths
- PR500 Epoxy
- DOW-UT

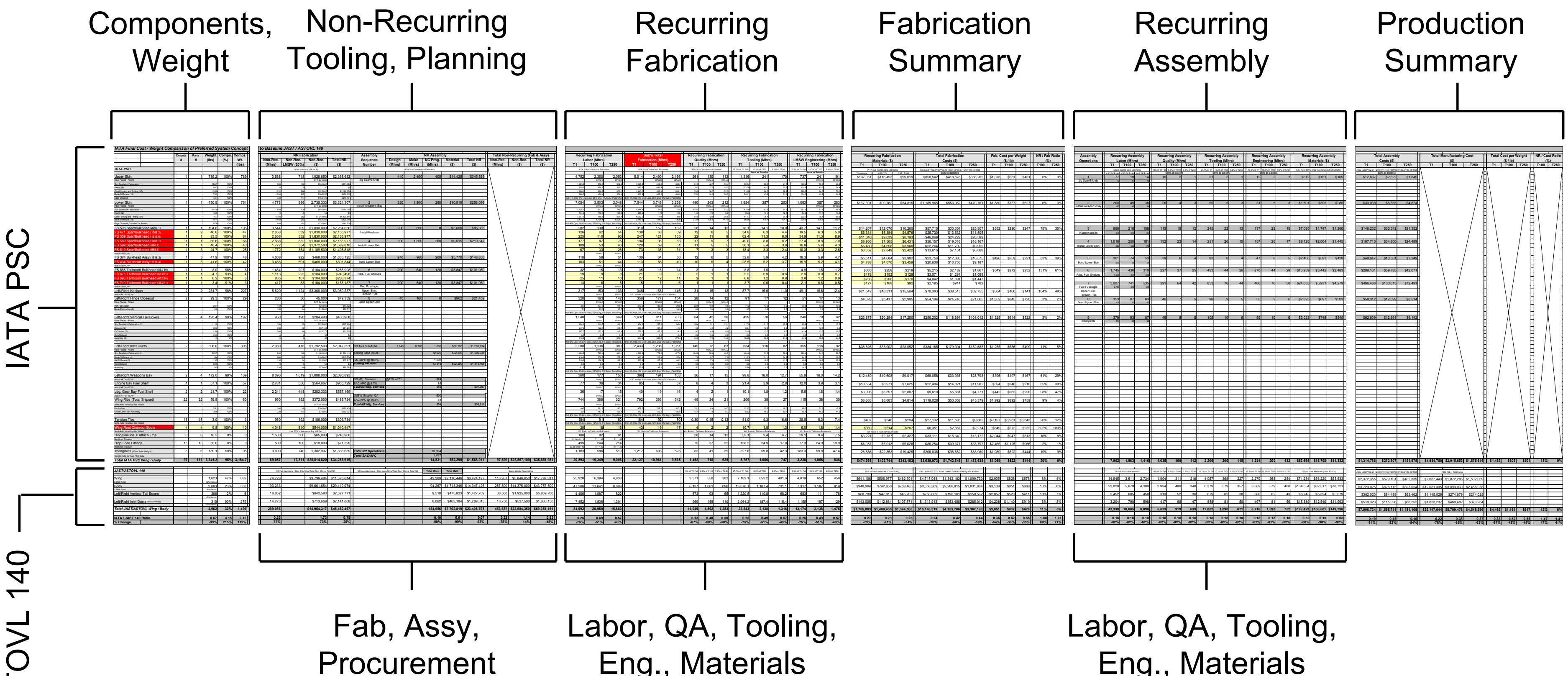
VARTM Keelson
- E-beam Cured: Cationic B/C
- Skunk Works / AECL

Hand Lay-up Ribs
- Thermoset Materials
- Alliant TechSystems

Critical Technology Areas

- Fastenerless Assembly
- Skin Stabilization Approaches
- Integral Hard Points
- Battle Damage Survivability
- High Temperature Structure
- Integral, Fully Bonded Fuel Cells (and Structure)
- R, M, & S Culture / Issues
- E-Beam Technology

Benchmark Comparison to Baseline



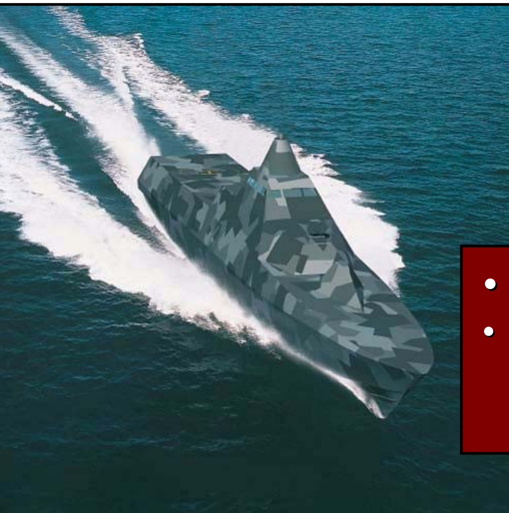
- IATA Production Costs: Bottoms-Up NR, Recurring QA, Matls, Fab, Assy, and Weight
- Baseline Production Costs: Parametric Historical Database Based on Weight
- Assumptions:
  - 4 AC/month, 100-1000 Total AC over 10 years
  - Assume Development Program Completed, Facilities Exist
  - Same Rates Applied to IATA and 140 Manhours
  - IATA Subs Estimated Fab, Skunk Works Estimated Assy

Benchmark Comparison to Baseline

IATA Final Cost / Weight Comparison of Preferred System Concept to Baseline 140							
	Weight (lbs)	Total Recurring Production Cost ($)			Total Cost per Weight ($ / lb)		
		T1	T100	T250	T1	T100	T250
Total IATA PSC Wing / Body	3,341.3	$5,004,231	$2,023,334	$1,680,545	$1,498	$606	$503
Total JAST/ASTOVL Wing / Body	4,962	$22,147,044	$5,709,476	$4,548,296	$4,463	$1,151	$917
IATA / JAST 140 Ratio	0.67	0.23	0.35	0.37	0.34	0.53	0.55
% Change	-33%	-77%	-65%	-63%	-66%	-47%	-45%

- **90 Composite Components, 21 Metallic**
- **65% Reduction in T100 Rec. Production Costs** ($3.68M savings)
- **48% Reduction in Non-Recurring Production Costs** ($30.2M savings)
- **33% Reduction in Weight** (1621 lbs savings)
- **95% Composites** (vs 30% in Baseline)
- **Orders of magnitude part count reduction**
- **Conservative PSC Estimates:**
  - 6% "Intangible" Cost and Weight Added to PSC
  - Full Recurring Engineering Added to PSC
  - Full Extent of E-beam Cost Advantage Not Included
  - No Credit for Material Forms to Enhance Producibility
- **Commensurate Reductions in LCC Anticipated**

Applicability?



- Naval Vessels
- Embedded EMS
  - Fast Attack
    - OPV's

- Land Vehicles
  - Survivability
  - Endurance
  - Mobility

- Air vehicles
  - Prototypes
  - UAV's

5×-efficiency, no-oil, same-cost, mid-size SUV (see 1615 breakout session)

an illustrative, costed, manufacturable, and uncompromised concept car (11/2000) developed with internal funding by a small firm, Hypercar, Inc. (www.hypercar.com), on time and on budget, with attributes never previously combined in one vehicle

- ◇ seats 5 comfortably, up to 1.96 m^3 cargo
- ◇ hauls 1/2 ton up a 44% grade
- ◇ 857 kg (47% mass of Lexus RX300)
- ◇ head-on wall crash @ 56 km/h doesn't damage passenger compartment
- ◇ head-on collision with a 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 mpg-equiv,5× RX300)
- ◇ 530 km on 3.4 kg of 350-bar H_2 gas
- ◇ 89 km/h on just normal air-cond. energy
- ◇ zero-emission (hot water)
- ◇ stiff, sporty, all-wheel fast digital traction
- ◇ ultra-reliable, software-rich, flexible
- ◇ wireless diagnostics/upgrades/tuneups
- ◇ 320-Mm warranty;no fatigue, rust, dent
- ◇ competitive manufacturing cost expected
- ◇ decisive mfg. advantages—≤10× less capital, space, assembly, parts count
- ◇ production rampup feasible in ~2007

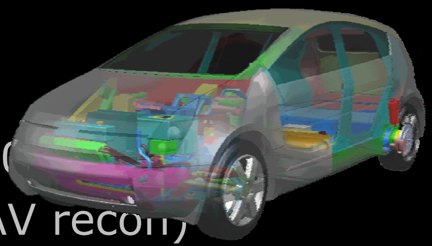
Ultimate public benefits of quin-tupled light-vehicle fuel efficiency

- Oil savings: U.S. potential = 8 Mbbl/day = 1 Saudi Arabia = 42 Arctic National Wildlife Refuges; world potential = 1 nega-OPEC; hence nega-missions 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 serving as plug-in "power stations on wheels" when parked, recovering much or most of their capital cost from electric revenues

"We'll take two." — *Automobile*, November 2001

Leapfrogging military transformation: an Army example

1. M1A2 tank: 68 T, ~0.56 mpg, peerless fighting machine but nearly undeployable, hard to sustain
2. AAN Army Research tank: ~7–10 T, ~4.3 mpg, claimed to offer similar protection and lethality
3. HyperVee ultralight tactical/scout vehicle, ~0.9 T
   - ~100 mpg, ultralow sustainment/signatures/profile
   - Uses very little fuel, makes 2.5 gal water/100 mi
   - Fast, agile, occupant-liftable, field-refuelable
   - 2 soldiers could load ~20 weaponized units into one C-130
   - Resists only small arms, so protected more by tactics (UAV recon)
   - Potentially formidable: in a 1982 desert experiment, Baja dune-buggies w/PGMs had a 9:1 exchange ratio against Abrams tanks, and dirtbikes w/PGMs reportedly did even better



4. Warrior in bouncy exoskeleton, ~0.09 T, 3 MRE/day
   - Might run all day @ 20–30 mph w/100-lb pack?

Naval opportunities include…

- Operational benefits to Naval Aviation: *e.g.*, from IHPTEP engines, for tactical fighter (combat air patrol) 36% lower TOGW or 44% lower fuel burn @ constant mission; ASW helos, +430% radius @ constant payload & loiter, or +80% payload @ constant radius & loiter
- Longer range/time on station? virtual ships? + lower signatures, more battle damage resistance, less maintenance and logistics burden
- Vast additional potential — subsystem to platform level
  - Just optimized fluid-handling & HVAC design is a gold-mine
  - Civilian aircraft have major scope for saving *electricity*, hence fuel
  - A recent Naval design would go faster/farther with 3 engines than 4
  - Potential Hyperships? (exploiting analogies with Hypercar® design)

Hyperships?

- Start the "design spiral" by knowing the full value of saving a ton, a m^3, and a kW in combat systems
  - *E.g.*, *direct* generating cost alone on CG-59 is worth ~$20PV/W, *excluding* all potential to decompound volume and mass
  - Mass compounding/decompounding alone is often ~5–10× in surface ships (how much depends on location and other factors)
  - Probably >>$20PV/W when m^3 and kW are decompounded too
  - We design the whole platform around the combat systems
  - But we're not optimizing those combat systems now, because nobody has determined the whole-system value of doing so
- Highly integrative design, optimizing the whole ship (and associated systems) for multiple benefits
- Ultralight, paintless, advanced-composite structures
- Advanced electric propulsion, fuel cells?, super-efficient lighting/HVAC/fluid-handling,…

An illustrative opportunity: Naval "hotel loads"

- Improve operations and equipment aboard ships, as explored in RMI's 6/01 ONR report for SECNAV
- Preliminary survey, still under NAVSEA and ONR review, of hotel loads on typical surface combatant
- Navy uses ~$2.5b/y fuel, $0.9b to deliver it aboard
- Hotel loads use nearly one-third of the Navy's non-aviation fuel
- RMI found nearly $1M/y potential hotel load savings on Aegis cruiser *Princeton* (CG-59) — in the top quartile of class e

- Electricity aboard directly costs ~$0.27/kWh to make, six times the typical industrial price ashore

Onboard "negawatts" are especially lucrative

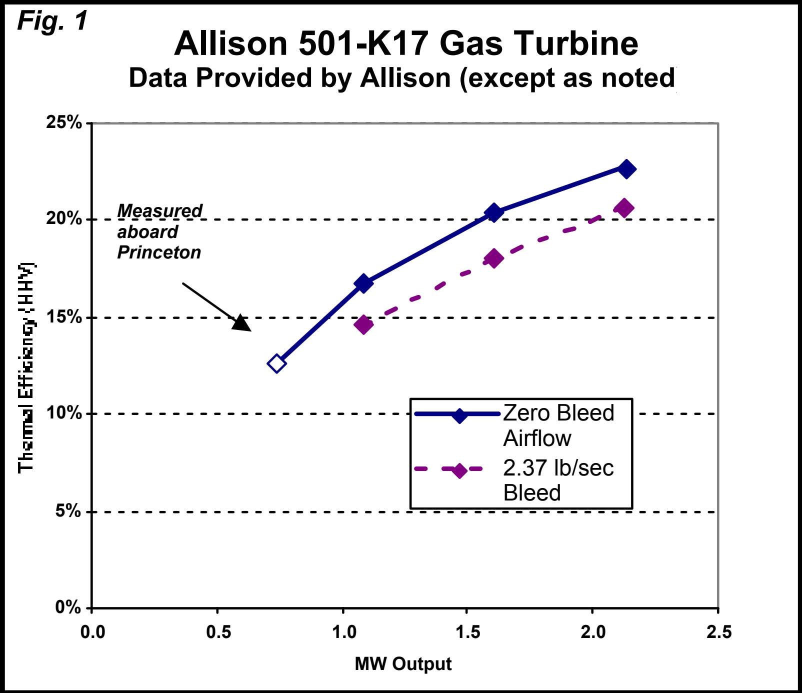
- 20-y present value of saving 1 W is nearly $20
- Making an always-on 100-hp motor one percentage point more efficient saves $1k/y
- Each chiller can save its own capital cost's worth of electricity ($120k) in eight months' operation
- Shifting two always-on fire pumps to off/pressurized/autostart mode can save $200k/y if prudent under noncritical, low-threat conditions
- $200k/y more could be saved by similar operational changes to other always-on systems
- Implies saving ~$10M present value/hull while *improving* warfighting (range, signatures,…)
- These savings could be significantly understated

CG-59's electricity costs ~$2–3M/y; ~$1M/y looks savable by retrofit

- Total CG-59 fuel use costs nearly $6M/y
- Main finding: ~20–50% of electricity could be saved by retrofitting motors, pumps, fans, chillers, lights, and potable water systems (but *none* of the radars, weapons systems, propulsion, etc.)
- NAVSEA estimated ~11% potential savings in these hotel-load systems, *plus* 8% more in propulsion, power, and combat/command
- RMI's el. savings equal up to ~10–25% of fuel
- That might reach 50–75% if combined with better electric generation and propulsion systems
- But 3/4 of el. savs. are lost unless GT ops. change

Gotcha…

Even large electrical savings will save little fuel unless GTG operational practice is also changed, because current practice runs GTGs at a low load, and still lower loads would even further worsen their efficiency; try virtual trailshafting?



Saving 1 unit of electricity from the GTG *should* save ~6–7 units of fuel, but won’t, because each 2.5-MW GTG is run at ~1 MW…so saving 20–50% of electricity will save only 5–12% of GTG fuel, losing ~3/4 of savings

Efficiency / Load Management Basics

- *First* reduce loads and energy use, *then* select optimal energy supply; integrate both
- Specify premium-efficiency equipment
  - Impossible to assess motor efficiency: no nameplates
- Use measured, not rated or guessed, efficiencies
- Turn off unnecessary equipment
- Minimize parasitic loads
- “Rightsize” equipment to match measured loads
- Optimize sizing, and dispatch of multiple units, over pattern of actual loads, not for a single point
- Question rationale of traditional operating modes

Low-cost / No-cost Improvements

- Decrease chiller lift
- Decrease chilled water flow rate
- Optimize seawater cooling system flow rate
- Reset chilled water temperature to 1 F° below highest zone temperature
- Turn off equipment that needn't be running under actual threat condition

Potential retrofit opportunities

- Improve motor, fan, and pump efficiencies comprehensively via whole-system design
- Use variable-speed drives on variable loads
- Improve duct/pipe pressure drops and entering/leaving conditions
  - Design/installation process needs overhaul
  - Confined space needn't create the constrained conditions observed
- Improving power factor (~0.8) and understanding of its value (*e.g.* 0.8→0.95 raises distribution capacity by 20%; GTG cap. too?)—often as a free byproduct of efficient motors, lighting ballasts, etc.

Potential retrofit opportunities (2)

- Improve GTG efficiency, integrated w/end-use
- Improve propulsion power efficiency (also hull and propulsor efficiency, not examined here)
- Turn off fire pumps, provide reliability by other appropriate means (as in refineries,…)
- Run one lead chiller to double efficiency; control backup chillers with autostart
- Cool Combat Information Center equipment directly, not the space it occupies
- Improve space conditioning controls
- Reuse waste heat, explore heat-driven chillers

Potential retrofit opportunities (3)

- Improve potable water production and heating efficiency: use waste heat without raising steam, and conserve 20–50% of the water to save energy
- Improve lighting efficiency and quality
  - More efficient lighting designs and technologies
  - Consider white and colored light-emitting diodes
- Improve air compressor efficiency
- Upgrade system monitoring, sensors, controls, and displays
- Use integrated lifecycle whole-system design
- Practice NAVSEA’s Encon program fleetwide

New-ship opportunities

- Design mentality implicit in CG-59 needs a tuneup — will we get it right in DD(X)?
  - Whole-system optimization for multiple benefits normally cuts capital as well as operating costs
  - Crucial in all-electric ships: value of a saved W?
  - Analogy of undervaluing saved amps in car design by counting only alternator sizing
  - Integrated design should work better, cost *less*
- Ultralight, ultra-low-drag analog to Hypercar?
- Innovative propulsion, power, control systems
- Low-friction design in fluid handling (10–50× savs.)
- Completely different HVAC and lighting design

RMI's 6/01 recommendations to ONR

- Rigorously scrutinize RMI's findings; if broadly correct, implement decisively fleetwide
- Accelerate NAVSEA Encon execution too
- Expand NAVSEA's physical measurements
- Resolve the longstanding single-GTG issue
- Test RMI's off+autostart, VSD, and other recommended modifications of ops practice
- Improve design philosophy, pedagogy, and practice
- Consider an intensive experiment on redesign of two vessels (1 retrofit, 1 new ["Hypership"?])
- Consider indoctrinating designers in whole-systems thinking (as RMI helped NAVFAC do w/buildings to save cap+op cost & improve quality of Service life)
- Please give RMI your feedback

Implications for all Services

- What would ultralight tactical vehicles mean for the Naval and Air Force assets needed to deploy and sustain them? Easier Sea Basing?
- How much tail-to-tooth redeployment could result from radical energy efficiency throughout land, sea, and air platforms…if DoD required it?
- How can we reward the results we want?
- How can stovepiped design culture and process be changed to optimize whole systems for multiple benefits, not components for single benefits?
- How can we purge tradeoffs, diminishing returns, and incrementalism from our design mentality?

Thank you

With gratitude to the Naval leaders who made this work possible, notably SECNAV Richard Danzig, ADM Joe Lopez (Ret.), VADM Dennis McGinn (Ret.), VADM Richard Truly (Ret.), and RADM Jay Cohen — fine teachers of the crucial difference between leadership and management.

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You are cordially invited to the 1615–1730 breakout session on Hypercar's unique *Revolution* concept vehicle and its H_2 fueling.

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