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Advanced Design Integration for Radically Efficient Expeditionary Mobility

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Please see the Defense Science Board's 08 *More Fight—Less Fuel* at www.acq.osd.mil/dsb/reports/ADA477619.pdf, and my article "DOD's Energy Challenge as Strategic Opportunity," in editing for *Joint Force Quarterly 57* (2Q10, due online Feb–Mar 10). My views here are personal, not official.

Introduction to Mobility Panel
USMC Expeditionary Power & Energy Symposium
"Lightening the Load: Reducing the Footprint in the Expeditionary Environment"
National Defense Industrial Association Meeting #0820
New Orleans, Louisiana, 26 Jan 2010

Energy: DoD’s soft underbelly...revealing a source of strategic advantage

- The Department’s mission is at risk, and huge costs are being paid in blood, treasure, and lost combat effectiveness, due to:
    - Pervasive waste of energy in the battlespace
    - Fixed facilities’ 99+% dependence on the highly vulnerable electricity grid
- Solutions are available to turn these handicaps into revolutionary *gains* in capability, at comparable or lower capital cost and at far lower operating cost, without tradeoff or compromise, and with special advantage to expeditionary forces
- Adopting those means to achieve two vital new capabilities —**Endurance** and **Resilience**—can benefit enormously from harnessing Marines’ unique speed, focus, and innovation —most of all in mobility, the biggest fuel-user

Is this trip necessary?




One inefficient 5-ton a/c uses ~1 gal/h of genset fuel. The truck's 68-barrel cargo can cool 120 uninsulated tents for 24 h. This 3-mile convoy invites attack. (Photos aren't all in the same place.)

• The ideal expeditionary force is bred to be like a Manx cat—no tail

• In the example above, efficient and passive or renewable techniques do the the task (comfort) with no oil. No gensets, no convoys, no problem. Turn tail into trigger-pullers. Multiply force. Grow stronger by eating our own tail.

• Current example: the \$146M, 17-Mft^2 sprayfoaming in Iraq, saving over half the air-conditioning energy, pays back in 67–74 days at \$13.80/gal FBCF. Next steps: load-balancing, superefficient gensets & a/c; cooling without electricity?

• We didn't buy **Endurance** in the past: when designing everything that used energy in the battlespace, we assumed fuel logistics was free and invulnerable; fuel would automagically appear, both in theater and in wargames

• Now we know better, so we'll value fuel 1–2 orders of magnitude higher

The hidden costs of fuel logistics: the tail is eating the tooth

- Logistics uses 1/2 of DoD's personnel and 1/3 of DoD's budget
- ≥50% of tonnage moved when the Army deploys is fuel
- Fuel/warfighter rose 2.6%/y for past 40 y, proj'd 1.5%/y to 2017
- Of ~$1M/warfighter-y cost in Afghanistan, ~$0.20–0.36M/y is fuel
- Fully Burdened Cost of Fuel (*not yet electricity too!*) and associated energy KPPs are mandatory (NDAA 09) and helpful reminders, *but FBCF omits the two biggest losses: lives and missions*
  - In FY07, attacks on fuel convoys cost the US Army 132 casualties in Iraq (0.026/convoy) and 38 in Afghanistan (0.034/convoy), totaling ~12% and 35% of *total* US Army casualties in those theaters (including contractors but not other Services or Coalition forces); one of the Commandant's top casualty risks
  - Turning trigger-pullers into fuel-guards diverts combat effort
  - Fuel-chain vulnerabilities can even hazard mission success

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Fully Burdened Cost of Fuel—though often 1–2 *orders of magnitude* higher than *un*burdened cost—is not only incomplete but understated

Initial OSD guidance, though improving, still appears to omit:

- full support pyramids
- multipliers from in-theater to full rotational force strength
- actual (not book) depreciation lives
- full headcounts including borrowed and ?contractors
- full Air Force and Navy lift costs to/from theater
- possibly recursions on FBCF of the fuel that delivers fuel

Some treat garrison costs as dilutive, not additive, to FBCF

Some analysts average peacetime with wartime costs, or even assume a peacetime OPTEMPO

DSB 08: "FBCF is a wartime capability planning factor, not a peacetime cost estimate."

Aim: fully count all assets and activities that won't be needed, or can be realigned, if a given gallon need no longer be delivered

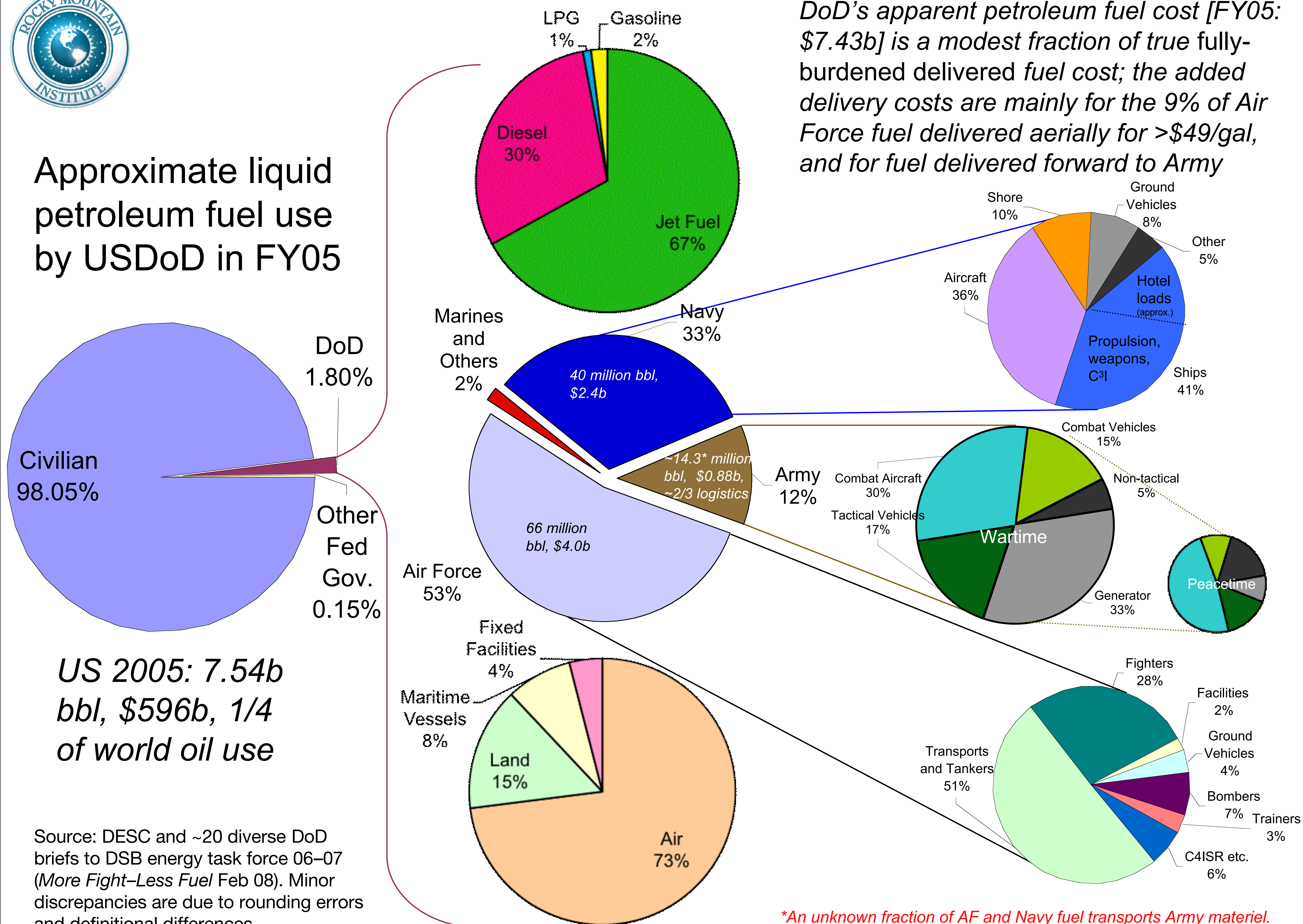
Military energy efficiency brings five big benefits at once

- **Force protector**, with far fewer vulnerable fuel convoys
- **Force multiplier**, freeing up convoy guards for combat tasks
- **Force enabler**, equipping warfighters with the greatly enhanced reach, dwell, agility, and flexibility that can affordably dominate in both dispersed (especially persistent and remote) and focused combat, while avoiding fuel vulnerabilities that risk mission failure
- **Key to transformational realignment** from tail to tooth—shifts ultimately totaling multi-divisional size and worth many tens of billions of dollars per year
- **Catalyst for leap-ahead fuel savings in the civilian sector**, which uses >50 times as much fuel as DoD: a nation that needs no oil needn't fight over oil—think no pipeline-guarding in Faroffistan, negamissions in the Gulf, Mission Unnecessary

Bottom line: fewer casualties, more effective forces, safer world

Approximate liquid petroleum fuel use by USDoD in FY05

DoD's apparent petroleum fuel cost [FY05: $7.43b] is a modest fraction of true fully-burdened delivered *fuel cost; the added delivery costs are mainly for the 9% of Air Force fuel delivered aerially for >$49/gal, and for fuel delivered forward to Army*



US 2005: 7.54b bbl, $596b, 1/4 of world oil use

Source: DESC and ~20 diverse DoD briefs to DSB energy task force 06–07 (*More Fight–Less Fuel* Feb 08). Minor discrepancies are due to rounding errors and definitional differences.

**An unknown fraction of AF and Navy fuel transports Army materiel. Oil used by contractors to which DoD has outsourced work is unknown.*

Prospecting for energy-saving winners: where to look

- The most *total fuel* can be saved in aircraft: they use 73% of DoD's oil, so a 35% saving in aircraft would equal total fuel used by *all* land and maritime vehicles plus facilities
    - 35% is conservative because 60% of Heavy Fixed Wing inventory (which uses 61% of AF aviation fuel) uses 50–60-year-old designs, and nearly all the Vertical Lift fleet is 30–50-year-old configurations and derivatives; respective saving potential is ≥50% and ~80–87%
- Savings in aerially refueled aircraft and forward-deployed ground forces save the most *delivery cost and thus realignable support assets*
- The greatest gains in *combat effectiveness* will come from fuel-efficient ground forces (land and vertical-lift platforms, land warriors, FOBs)
- Savings *downstream*, near the speartip, save more fuel, because delivering 1 liter to Army speartip consumes ~1.4 *extra* liters in logistics; in expeditionary Afghanistan, that number may be ~7 (British Army est.)
- So these are all worthy objectives—for different reasons—and they're not mutually exclusive

Prospecting for energy-saving winners: design principles

The biggest energy savings in any platform (anything that directly or indirectly uses energy in the battlespace) will:

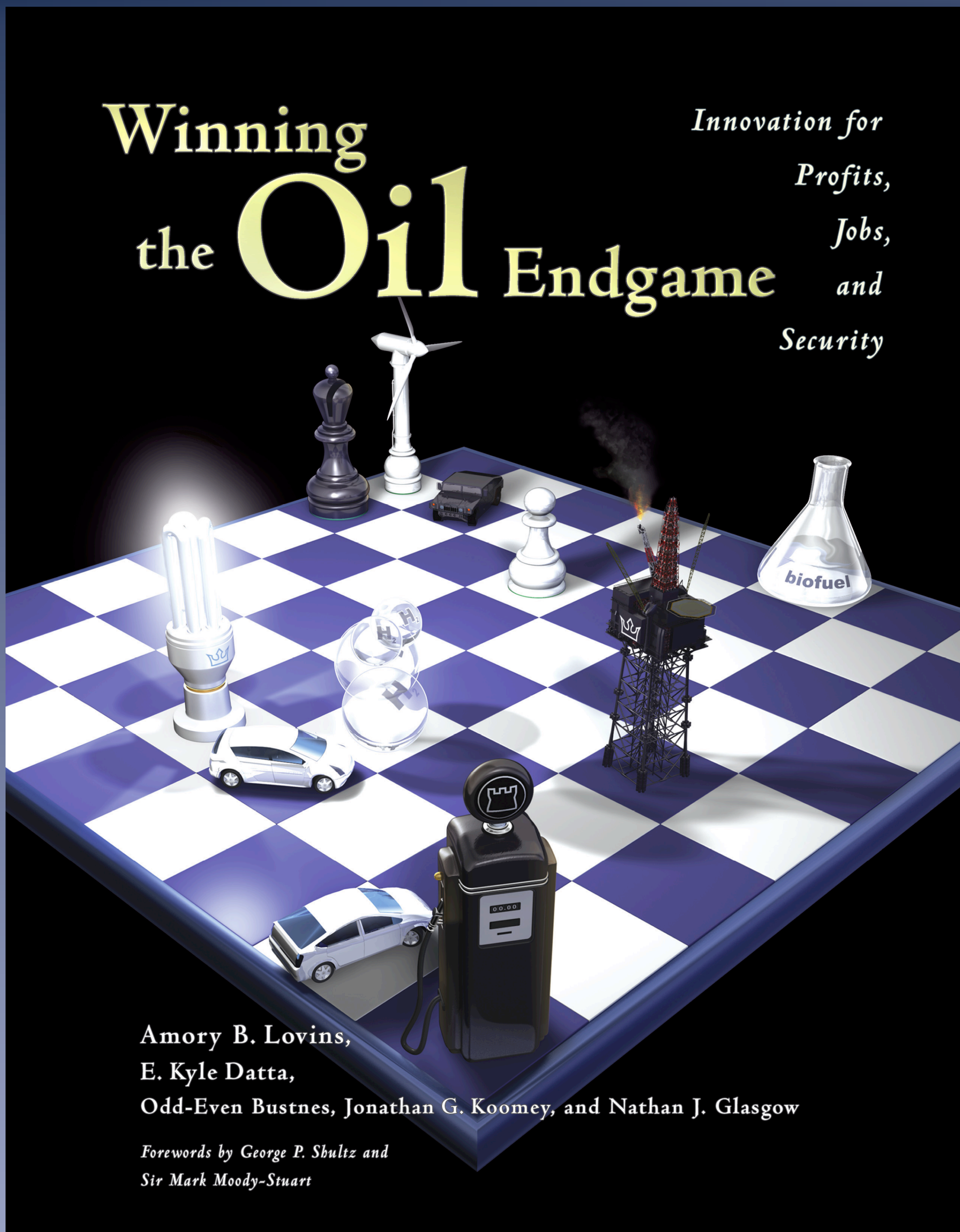
- Come from radical, clean-sheet redesign—not incrementalism
- Optimize whole systems for multiple benefits, not isolated components for single benefits, to make big savings cheaper than small savings, turning diminishing returns into expanding returns
- Strongly emphasize major reductions in *weight*, then drag, then onboard energy burden—*before* improving energy supply or propulsion
- Use downsizing and simplification of energy supply systems to pay for (or more) the savings in weight and drag, *reducing* direct capital cost
- *Not assume diminishing returns or tradeoffs; they are generally signals of poor design integration or a misstated design problem*

Not one of the 143 briefs to the DSB 08 study disclosed a tradeoff between energy efficiency and combat effectiveness or force protection

Let's look at some civilian examples, then their military implications

Details: www.rmi.org/stanford, www.oilendgame.com, and www.10xE.org

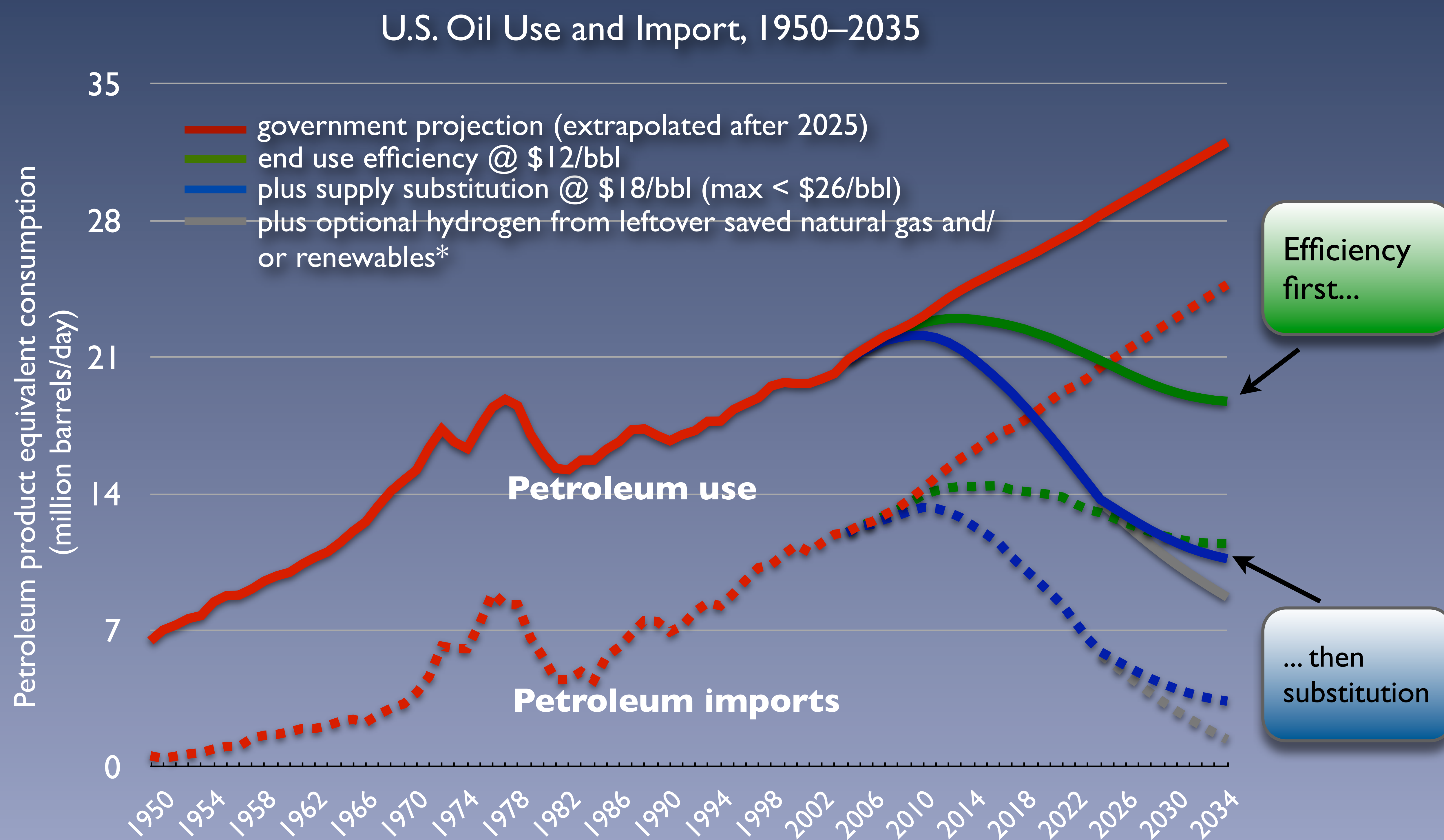
A 2004 roadmap for *eliminating* U.S. oil use by the 2040s



- **Business-led oil *solution***
- **Driven by profit, not policy**
- **Independent, detailed, transparent, peer-reviewed, uncontroverted**
- **Cosponsored by OSD and ONR**
- **Written for business and military leaders, built on competitive-strategy business cases**
- **Summarizes potential to boost DoD fuel efficiency ~3–4× over the next few decades**
- **Book and technical backup are free at move.rmi.org/oilendgame**

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

A realistic oil solution at an average cost of $15/bbl (2000 $)



Source: Lovins, Amory B. et al. *Winning the Oil Endgame*. 2005 Rocky Mountain Institute. www.oilendgame.com.
Technical Annex 23. * Illustrating 10% substitution; 100%+ is feasible

Vehicles use 70% of US oil, but integrating low mass and drag with advanced propulsion saves ~2/3 very cheaply

BUILDINGS and INDUSTRY: big, cheap savings;

PLANES: save 20% free, 45–65% @ ≤46¢/gal

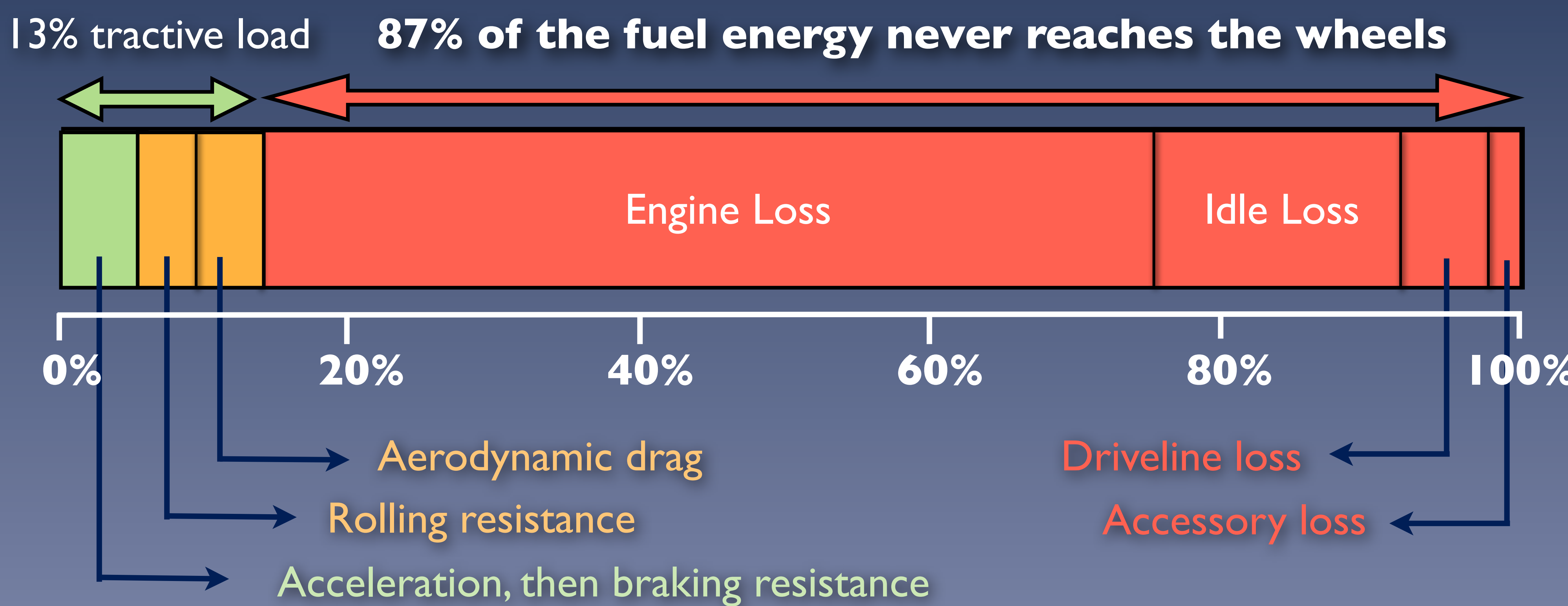
CARS: save 69% @ 57¢/gal

TRUCKS: save 25% free, 65% @ 24¢/gal

155 mph, 94 mpg

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

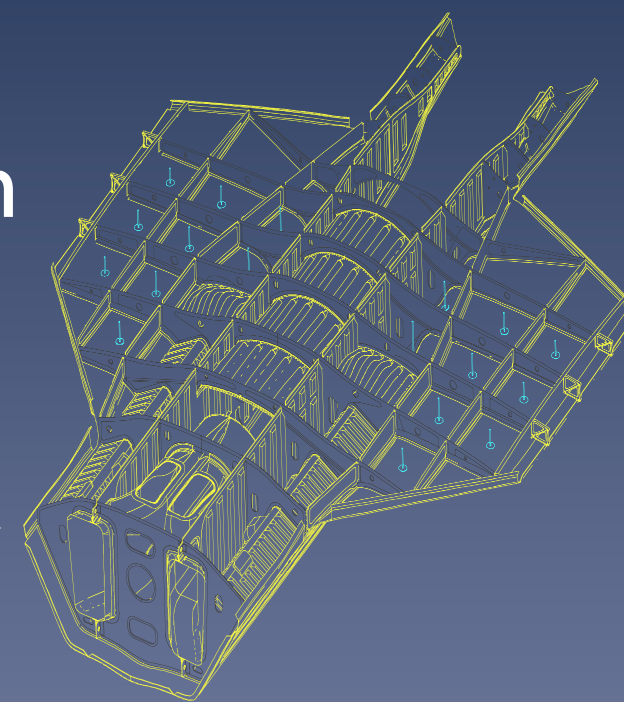
Each day, your car uses ~100× its weight in ancient plants. Where does that fuel energy go?



- 6% accelerates the car, ~0.3% moves the driver
- At least two-thirds 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!

Migrating innovation from military/aerospace to high-volume automaking



- 1994–96: DARPA/IATA* Skunk Works® team designed an advanced tactical fighter airplane
  - made 95% of carbon-fiber composites
    - 1/3 lighter than its 72%-metal predecessor
  - *but 2/3 cheaper (at 100th unit)...*
- because designed to made from carbon, not metal

**Integrated Technology for Affordability*

Finding no military customer for something so radical, the team leader left. I hired him to lead the 2000 design of a halved-weight, carbon-fiber SUV with two Tier Ones, *Intl. J. Veh. Design* **35**(1/2):50–85 (2004), paying back in about one year the the US fuel price...

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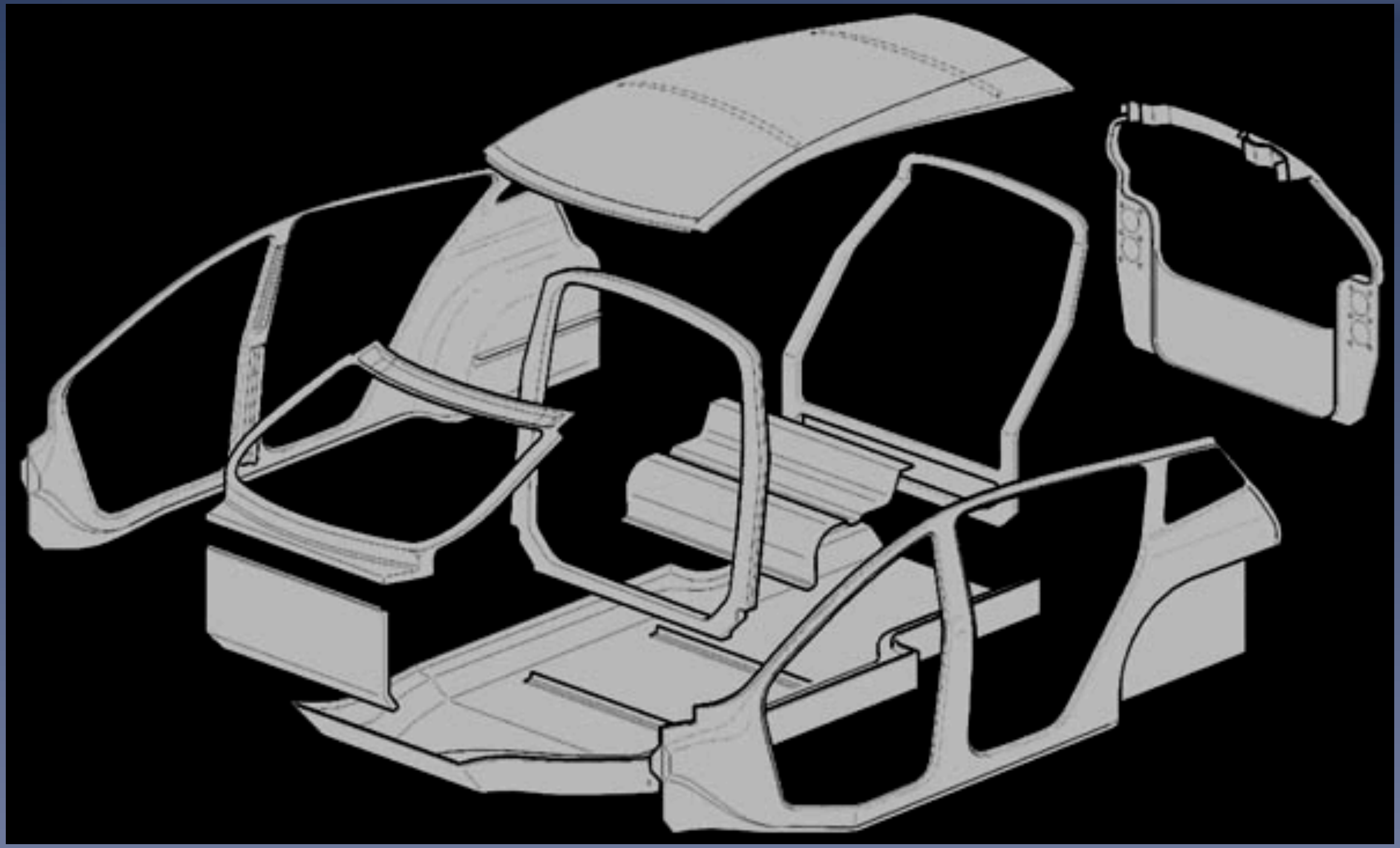
“We’ll take two.” — *Automobile* magazine

World Technology Award, 2003

67-mpg gasoline-hybrid SUV, 2000 show car & complete virtual design, production-costed, manufacturable at a $2,511 higher retail price

Radically simplified manufacturing



Mass customization

- *Revolution* designed for 50k/year production volume
- Integration, modular design, and low-cost assembly
- ~99% less tooling cost, no body shop, optional paint shop
- At least two-fifths less investment than today's leanest plant
- Uncompromised attributes, superior safety, 2/3 smaller powertrain

Confirmed by racecar crash experience (thermoplastics are even tougher)

Katherine Legge's 180-mph walk-away ChampCar (similar to Formula One) wall crash on 29 Sep 06

Toyota's 2007 *1/X* Showcases Lightweight Potential: *Prius* Volume @ 420 kg (mass/3), 120+ mpg (fuel/2)

The day before *1/X* was announced, Toray announced a ¥30b plant to *mass-produce carbon-fiber car parts* for Toyota and others; Toray announced a similar venture with Honda and Nissan on 24 July 2008; signals strategic intent

Bright Automotive's 2009 *IDEA*

Disclosure: My nonprofit employer, Rocky Mountain Institute, spun off this firm and still owns a few percent of its equity

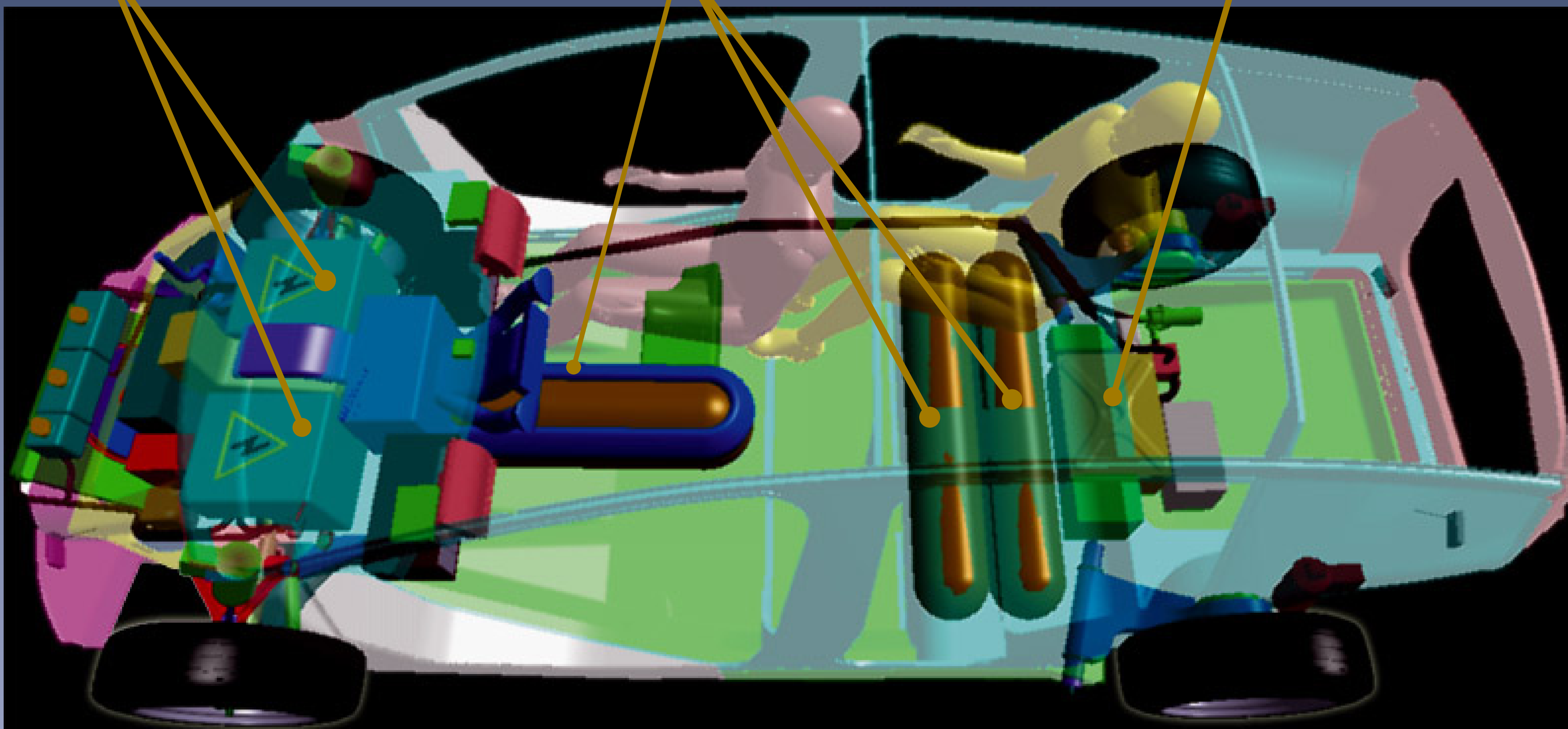
- Commercial 1-ton van with in-cab office, 5 m^3 cargo, quiet and comfortable
- **100** mpg equivalent on 50-mi/day urban route (>**140** if LA92 cycle), **50** on >150 mi/day, 119 on CAFE; US norm **12–14**
- m_c 3,200 lb, target C_d 0.30
- PHEV (30-mi electric range, 430-mi total range)
- Needs no subsidy: low tractive load makes the batteries small enough to yield a compelling business case for fleets
- Driving prototype shown in DC Apr 09 and at EVS-24 May 09

3.6x-more-efficient SUV can cruise at 55 mph with the same power to the wheels that a normal SUV uses on a hot afternoon to run the air conditioner

35-kW load-leveling batteries

137-liter 345-bar H_2 storage (small enough to package): 3.4 kg for 330-mi range

35-kW fuel cell (small enough to afford early: ~32x less cumulative production needed to reach needed price)



Platform fitness makes advanced powertrains practical and affordable

Decompounding mass and complexity also decompounds cost

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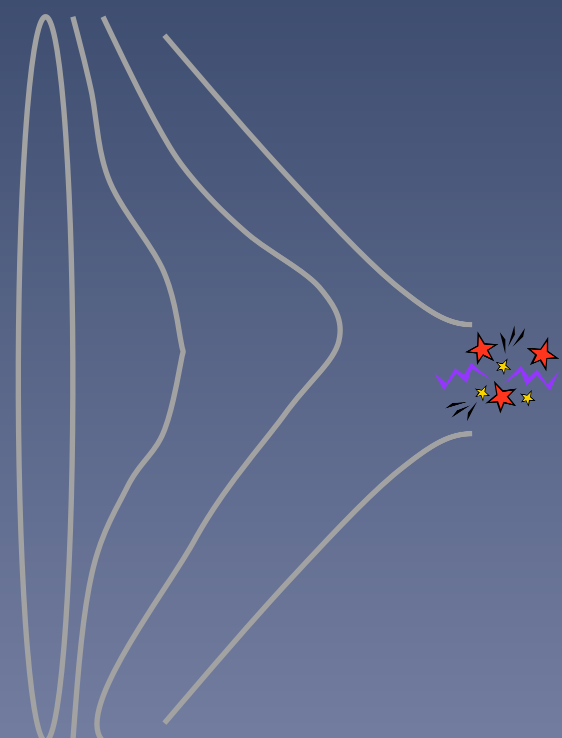
Design to win the future, not perpetuate the past

Present design space



New design space

Define the end point

Development targets

Risk management

Market introduction

Economic insight

Customer relationships

Technology introduction

Integration payoff areas

First production variant

Foundation Platform

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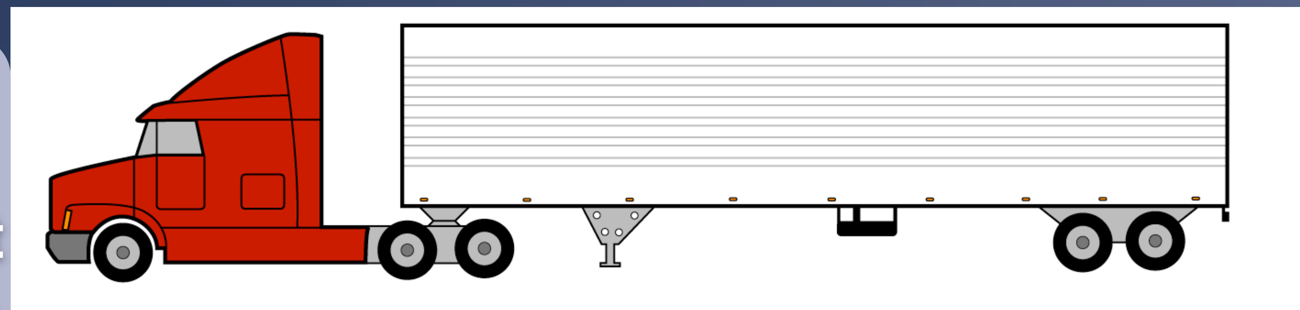
RMI's 2008 Transformational Truck study found 2.3–2.7× potential improvement using proven and available technologies

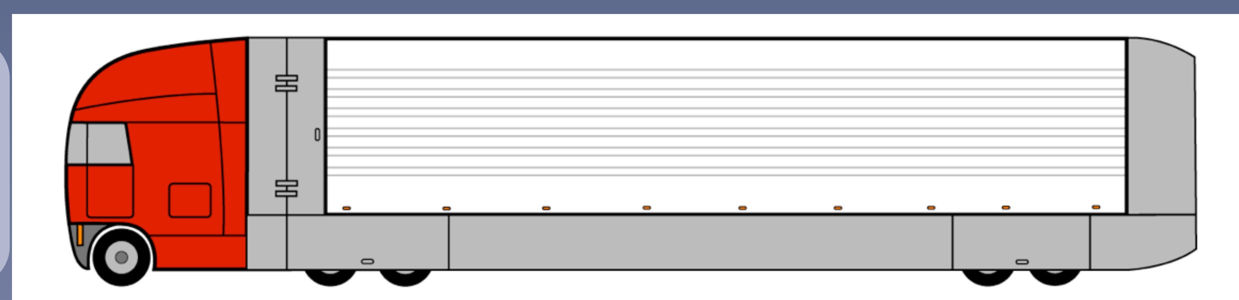
6.5 mpg
130 ton-mile/gal
(weighed-out, but typical is ~60–65)



Reduce energy consumption of the vehicle

1. Cargo: Volume 5%, Weight 7%
2. Aerodynamic Drag: 50%
3. Rolling Resistance: 30%
4. Engine Thermal Efficiency: 6

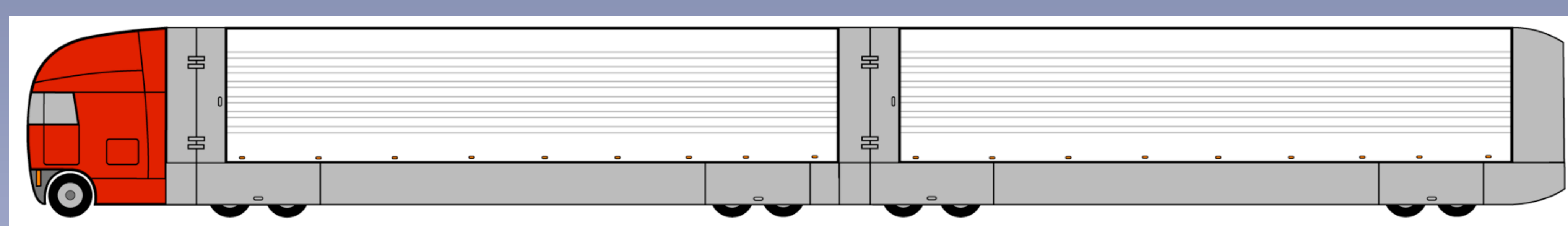
12.5 mpg
275 ton-mile/gal



Maximum delivered cargo per vehicle and trip

- Permit "turnpike doubles" on highways (63% of U.S. ton-miles)
- Increase weight from 80,000 lb on 5 axles, to 120,000 lb, 9 axles
- Better safety than today's doubles: C-dollies + Active Safety

8.7 mpg
335 ton-mile/gal

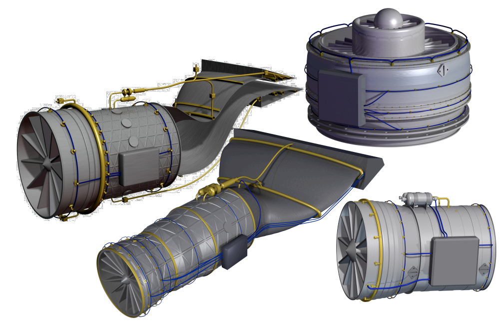


“Amory’s petting zoo” from DSB 08: dramatic gains in combat effectiveness *and* energy efficiency are widely available, *e.g.*:

(scaled-down wind-tunnel model)

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

SensorCraft (C[4]ISR): 50-h loiter, sorties ÷ 18, fuel ÷ >30, cost ÷ 2



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

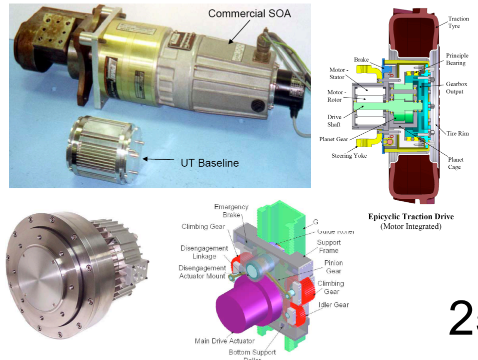
Optimum Speed Tilt Rotor (OSTR): range × 5–6, speed × 3, quiet, fuel ÷ 5–6

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

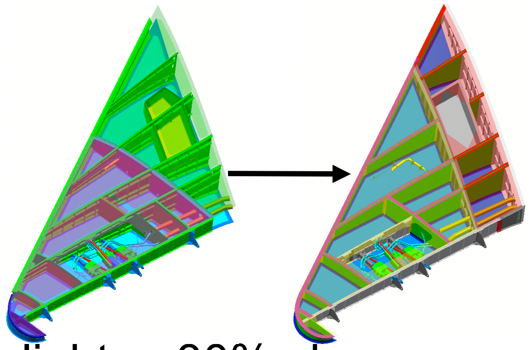
More lethal, highly IED-resistant, stable *HMMVV* replacement, weight ÷ 3, fuel ÷ >3 (up-armored *HMMVV* ~4 mpg)

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

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

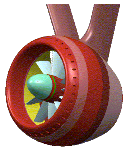


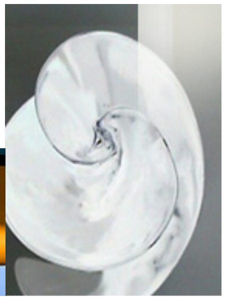
Actuators: per-formance × 10, fault tolerance × 4, size & mass ÷ 3–10



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

Advanced propulsors can save much noise and fuel

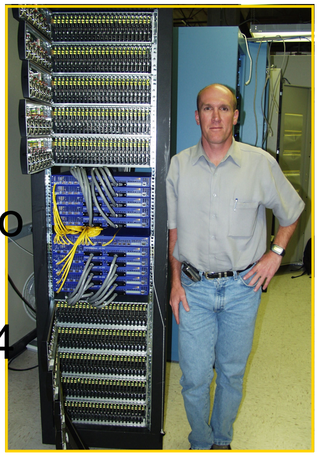




Rugged, 2.5-W PC, $150, solar + back-up crank

A zero-net-energy building (it’s been done in – 44˚ to 46˚C at lower cost)

240-Gflops supercomputer, ultrareliable with no cooling at 31˚C, lifecycle cost ÷ 3–4



A key expeditionary example of integrative design: *MRAP*-class protection and lethality without its weight (23–29 t), instability, and fuel

- Decoupling small crew compartment's survivability-driven mass from power, propulsion, & cargo req'ts *halves* weight
- Ultralight unconventional armor for superior ballistic protection
- "Flow through" design, oblique anti-blast geometries, and special materials
- Damped, slightly elastic, tailored-thickness, *molded* body should reduce TBI
- Very low CG (stable, easy *KC-130* fit) via unique articulated linkage and all-wheel active steering (10-m turn dia.)
- Acceleration, agility, and stability comparable to top-of-the-line pickup truck
- Fuel economy, weight, and cost better than a 5–6-ton up-armored *HMMVV*
- Ready for rapid prototyping *now*
- Could even be timely for Reset

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

—Marshall McLuhan

Your move…

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