
ROCKY MOUNTAIN
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Sacramento CA

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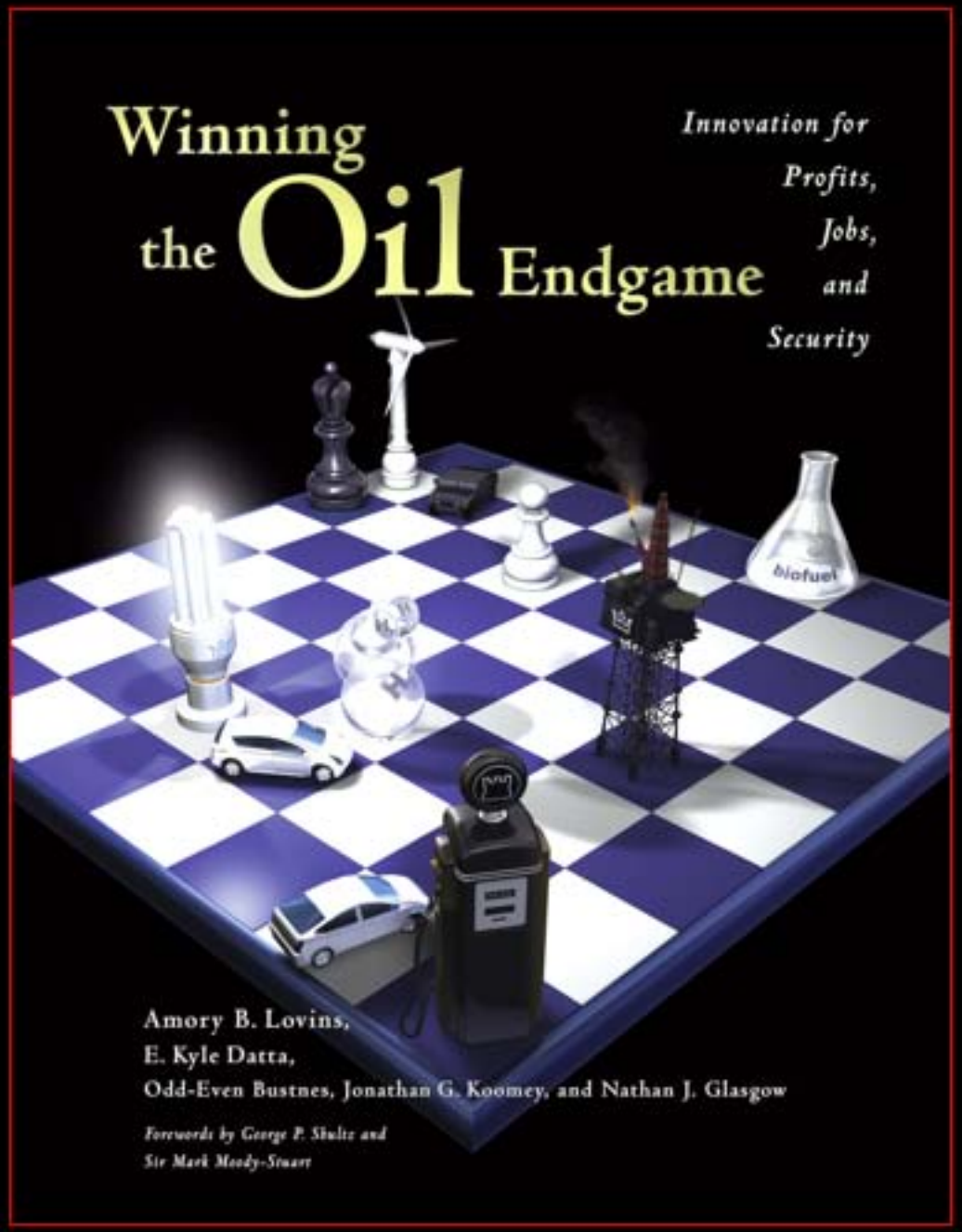
Book and technical backup are free at:

www.oilendgame.com



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Over the next few decades, the United States can get completely off oil *and* revitalize its economy—led by business for profit

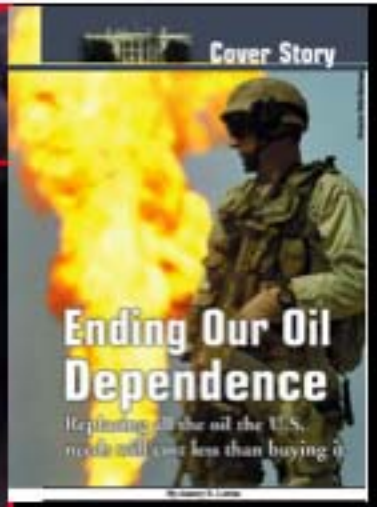
US 2025 CO_2 emissions would drop 26% as a free byproduct of the profitable oil savings

THE WALL STREET JOURNAL.

POLITICS & POLICY

Unlikely Allies Fight U.S. Oil Dependence

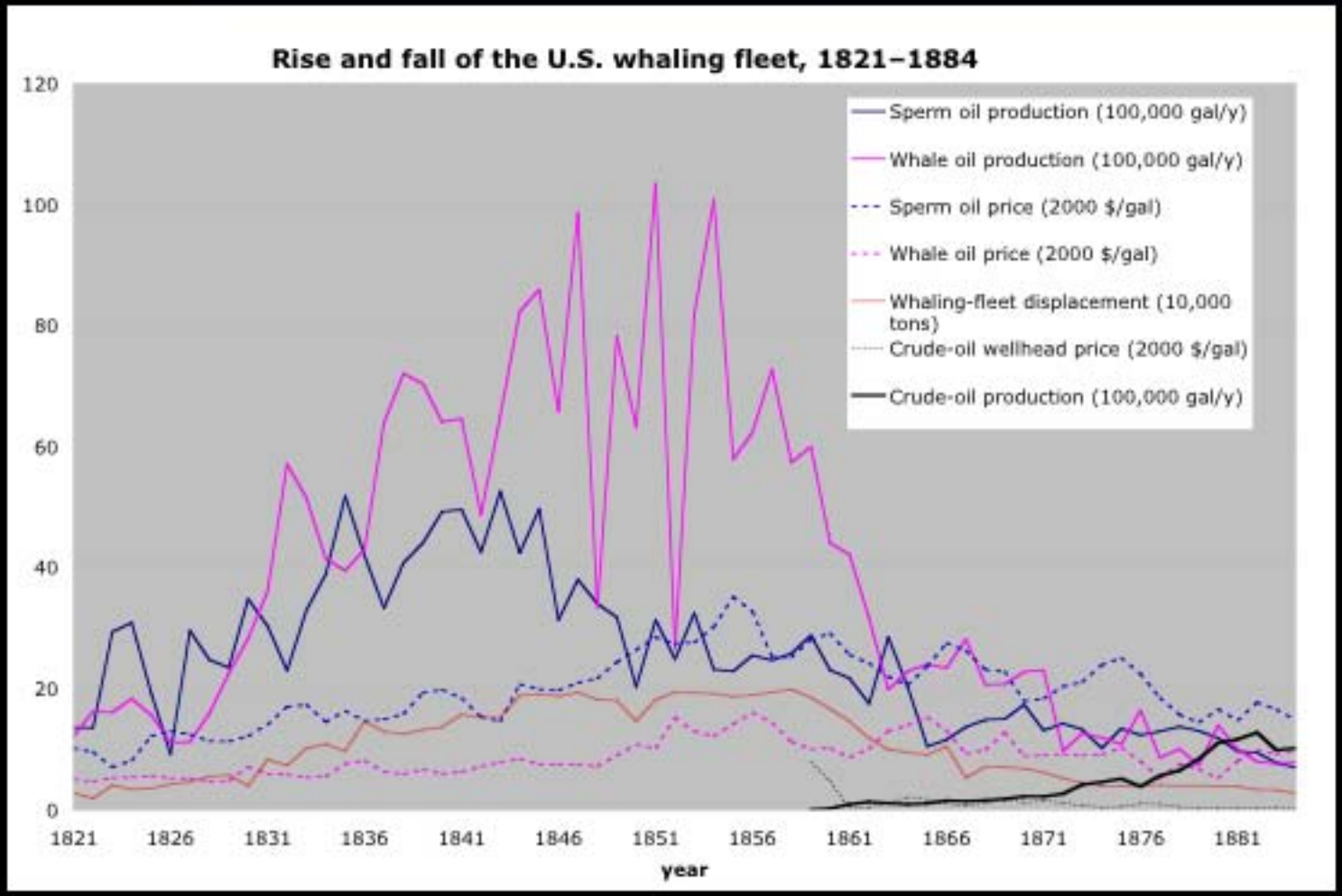
Bipartisan Network to Press for Reduced Consumption, Quicker Development of New Fuels



Wall St. J., 28 March 2005

FT, Asian edn., p. 1, 12/13 March 2005

Whalers ran out of customers before they ran out of whales...



...even *before* Drake struck oil in 1859!

Winning the Game: restoring competitiveness *and* eliminating oil dependence

- National security *and* national competitiveness at risk

Why should we care?

- Oil insecurity, geopolitical rivalry, price volatility, perhaps depletion, climatic stability,...
- Japan, EU, China will eat Detroit for lunch; Airbus has overtaken Boeing; core sectors are at risk; the U.S. choice

How do we win?

1. Efficient end-use can save half the oil @ $12/bbl (2000 $)
2. Biofuels can replace another fifth
3. Saved gas can displace the rest

} av. cost $18/bbl

Vs. EIA's forecast $26/bbl in 2025, save net $70 billion a year

How do we capture this prize?

- Invest $90 billion in transportation equipment industries, plus…
- $90 billion to build an advanced biofuels industry

→

- Creates 1 *million* good new American jobs (3/4 rural)
- Preserves 1 million jobs
- Returns >$150 billion/year

- Business should lead, but…
- …needs acceleration, while…
- …expanding customer choice and reducing business risks

→

- Support, not distort, business logic with new policies…
- Market-oriented without taxes
- Innovation-driven without mandates
- Reduce federal deficit
- Broad political appeal

- Federal government: lead, follow, or get out of the way

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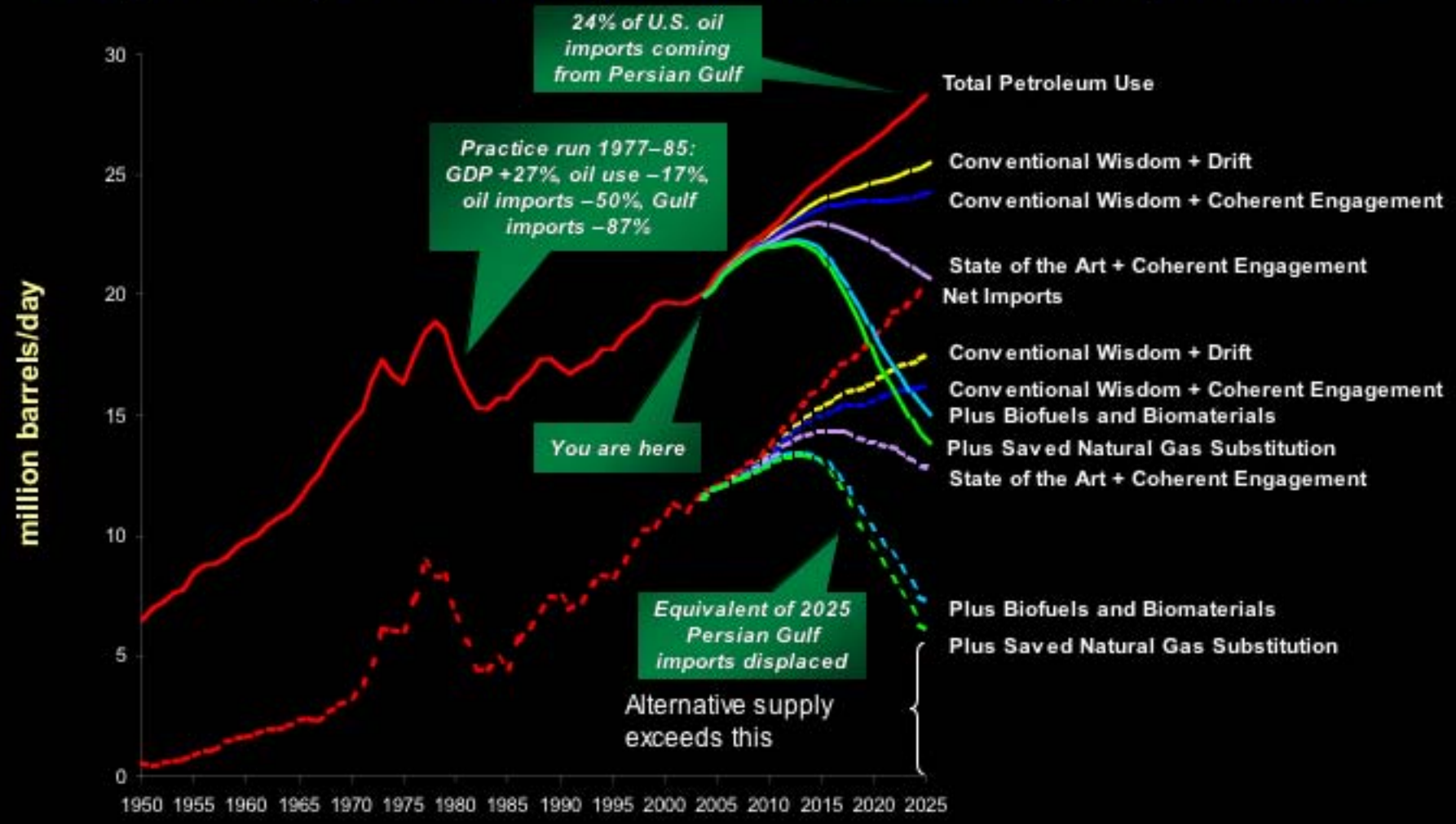
- Needs little or no Congressional action
- Can be administrative, or done by the states

The energy future is choice, not fate

U.S. petroleum product consumption and net petroleum imports, 1950–2025



Cars and light trucks: save 69% of EIA 2025 fuel at an av. cost of 57¢/gallon

Ultralight (e.g. carbon composites), low drag, hybrid

GM *Ultralite* 1991, 5 seats, 0–60mph/7.3s, 84 mpg, nonhybrid

Opel *Eco-Speedster* 2002, 2 seats, 155 mph, 94 mpg, diesel hybrid

*Surprise: 2x-mpg ultralighting is **free**, because the costlier materials are offset by cheaper automaking and smaller propulsion system*

Toyota *Allesandro Volta* 2004, 3 seats abreast, 408 hp, 0–60/<4 s, 32 mpg

Hypercar *Revolution* 2000 virtual design, 5 seats, midsize SUV, 66 mpg gasoline hybrid w/3-y payback, 0–60/7.1 s), 114 mpg w/H_2

Heavy trucks: save 25% free, 65% @ 25¢/gallon

Better aero & tires, better engines etc., less weight

PACCAR high-eff. concept truck

Colani/Spitzer tanker (Europe), reportedly 11.25 mpg

Two recent concept trucks

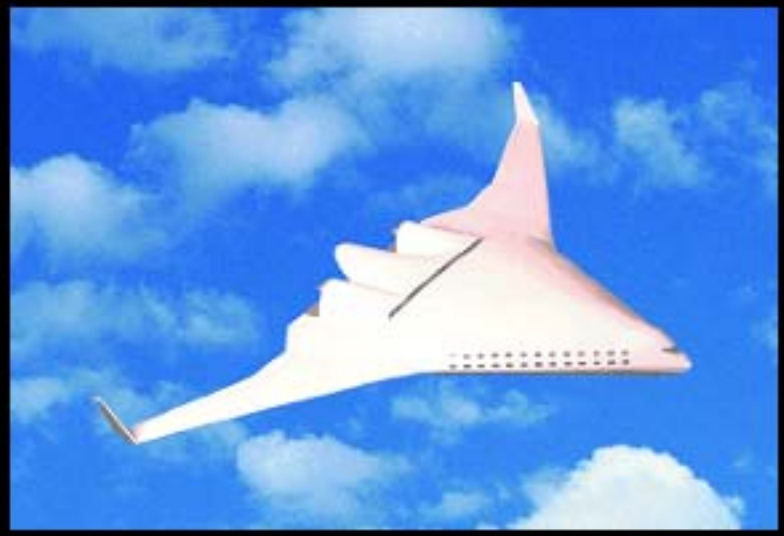
6.2 to 11.8 mpg with 60% IRR by improving aero drag, tires, engines, mass, driveline, acces. loads & APU; then ~16 mpg via operational improve-ments; being built 2005

Big haulers' margins double from 3% to 6–7%…so create demand pull — currently underway, led by major customers

Planes: cost-effectively double or triple efficiency

Save 20% ~ free (*787*, 2007)

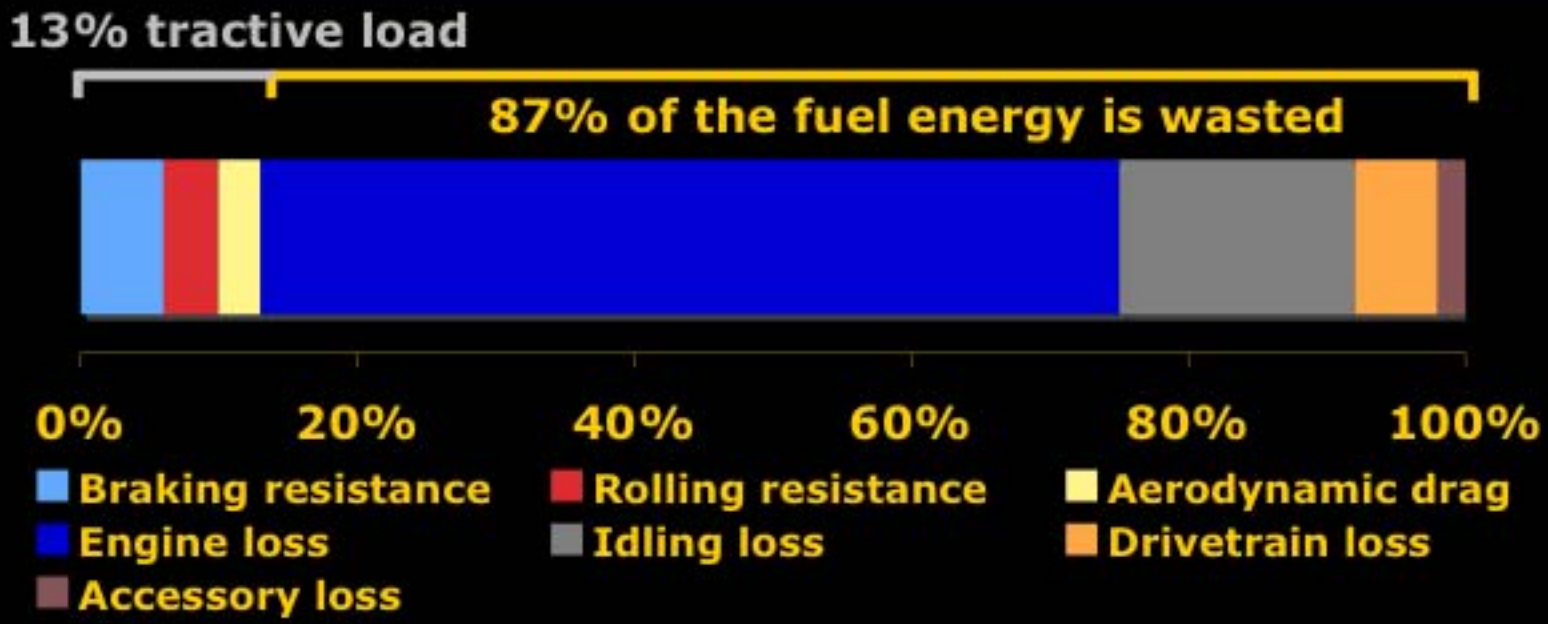
…then, ~2015–20, save 45% @ 46¢/gal; with blended-wing-body & internal engines, ~65% at comparable or lower cost, via lighter weight, better engines & aerodynamics



Light vehicles: challenging a basic Detroit and Washington assumption

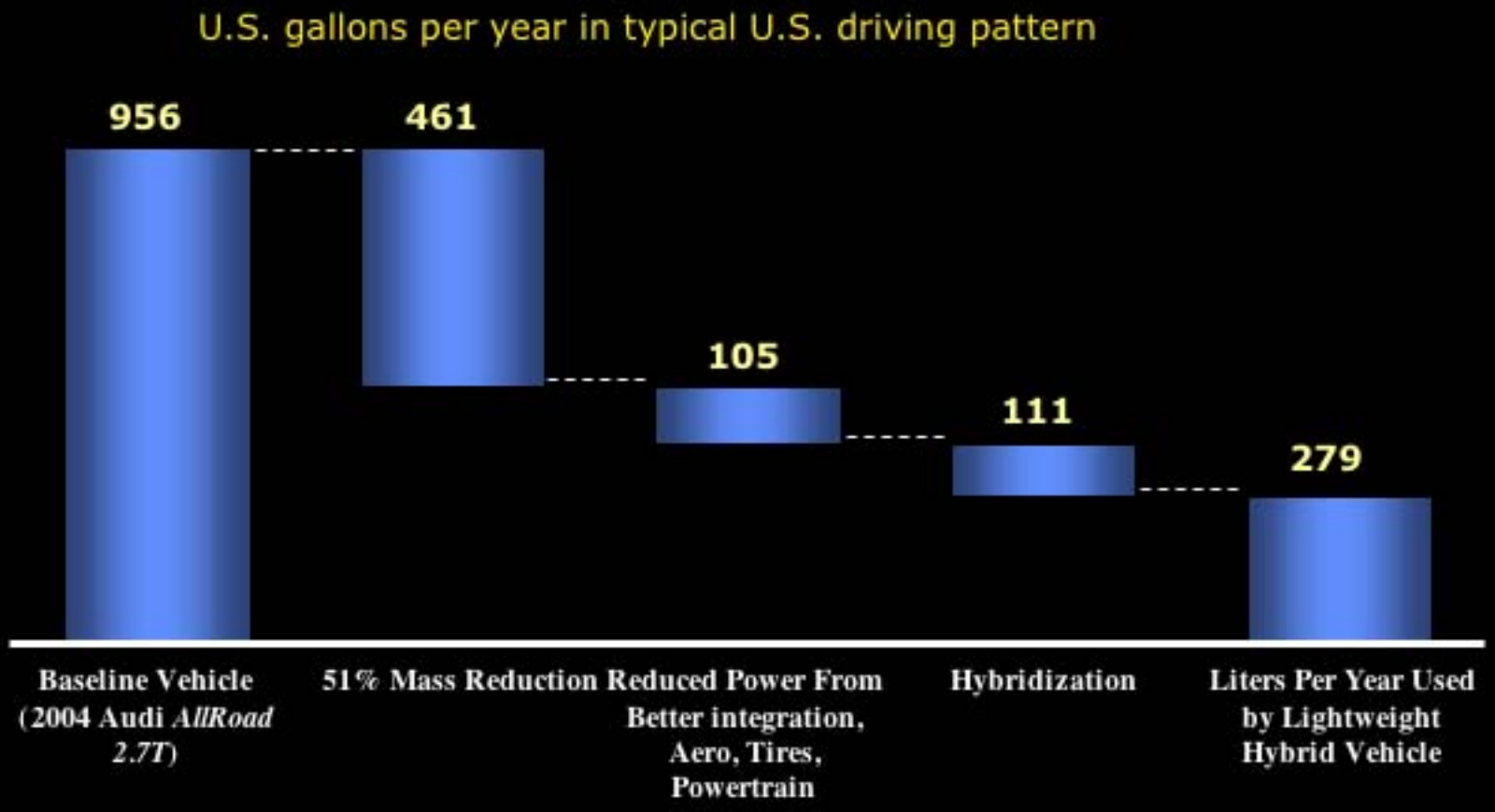
- Efficiency assumed to be a tradeoff against price, size, performance, safety,…
- Hence policy intervention needed to induce customers to buy the compromised vehicles; but Congress has gridlocked on that for >20 years
- But what if superefficiency were a byproduct of breakthrough engineering, so people would buy the cars because they're *better*—like buying digital media instead of vinyl phonograph records?
- An engineering end-run around tax/CAFE gridlock
- Robust business model based solely on value to customer and competitive advantage to maker

Where does a car's gasoline go?



- 6% accelerates the car, <1% moves the driver
- Three-fourths of the fuel use is weight-related
- Each unit of energy saved at the wheels saves ~7–8 units of gasoline in the tank (or ~3–4 with a hybrid)
- **So first make the car radically lighter!**

Critical insight: light weight *before* aerodynamics and powertrain creates 68% of SUV fuel savings (hybrid: 16%)



Means: light metals, composites, ultralight steels

Issues: crashworthiness and manufacturing cost

Three technology paths: aluminum, light steels, carbon composites (the strongest & lightest)

- Immaterial damage when T-boned by *Golf*
- 15 lb of carbon crush cones (0.4% of car's weight) can absorb all crash energy @ 66 mph

- **Carbon-composite crush structures can absorb 6–12× as much energy per pound as steel**
- **This can make cars lighter *but* bigger *and* safer… *and* simpler and potentially cheaper to manufacture**

Migrating innovation from military aerospace to civilian cars

- At the Lockheed Martin Skunk Works®, engineer David Taggart led a ’94–96 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 composites, not from metal

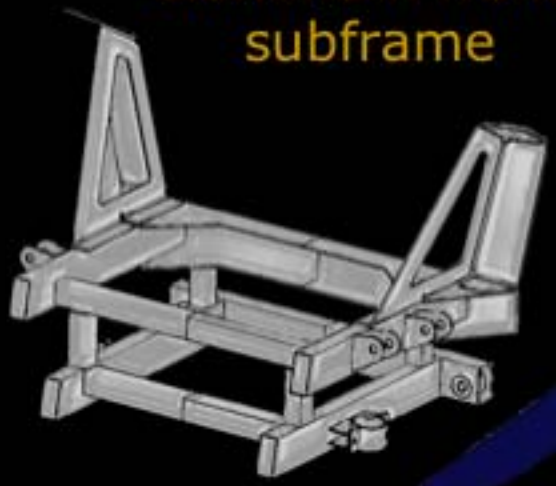
*Integrated Technology for Affordability (IATA)

- Finding no military customer for something so radical, he left. I soon hired him to lead the 2000 design of an halved-weight SUV with two Tier Ones, *Intl. J. Veh. Design* **35**(1/2):50–85 (2004), with a 2-y payback at today’s gasoline price

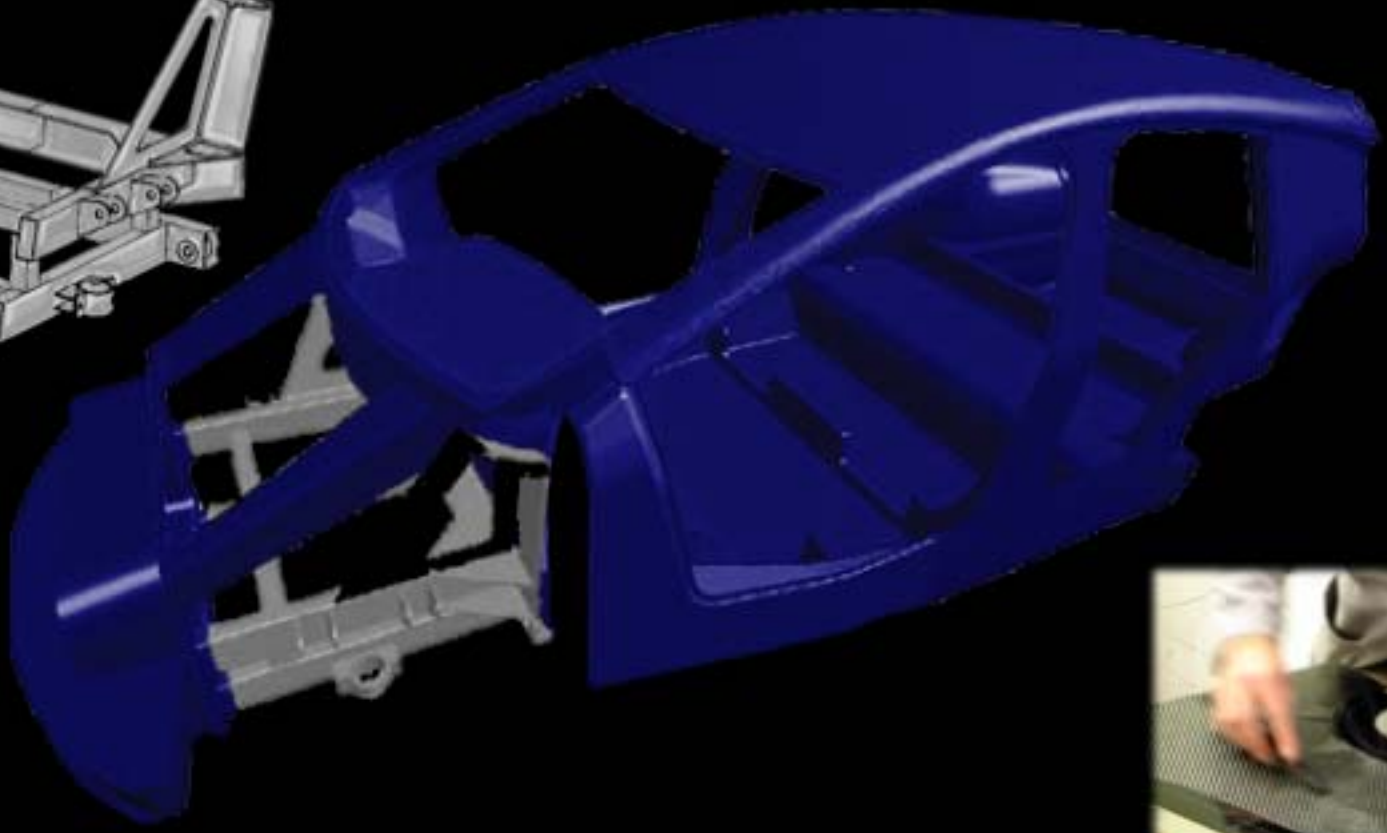

Midsize 5-seat **Revolution** *SUV (2000)*
Ultralight (1,889 lb) but ultrasafe
0–60 mph in 8.2 s (later 7.1)
66 mpg w/gasoline hybrid
114 mpg w/H_2 fuel cell
"We'll take two."
— *Automobile* magazine
World Technology Award, 2003
Show car and a complete virtual design (2000), uncompromised, production-costed, manufacturable at competitive cost

Ultralight autobody materials

aluminum front subframe

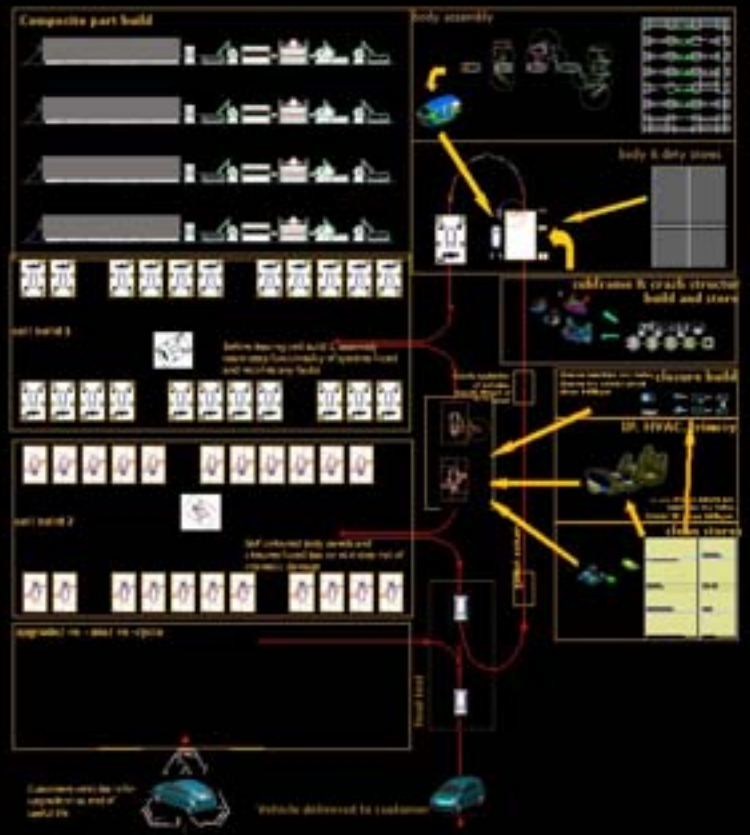


advanced-composite passenger safety cell



Radically simplified manufacturing

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



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

Rapid progress with midvolume cost-competitive advanced composites

- BMW: 60 specialists at Landshut, world's biggest RTM press, series production ASAP
  - Already making >1k/y carbon roofs, hoods,…
  - Website strongly praises carbon composites
- Honda and Toyota: carbon airplanes
- Fiberforge™: small Colorado private firm
  - Patented digital automated fiber placement process
  - Thermoform to net shape, cycle times probably 1–2 min.
  - 80% of hand-layup aerospace performance, 20% of cost
  - Should beat Al in $/part, and steel in $/body up to ~40k/y
  - Mature process should beat steel in $/*car* at any volume
  - JCI privately showed *Genus* chair at NAIAS Jan. 2005
  - Selling samples and small pilot runs to OEMs & suppliers

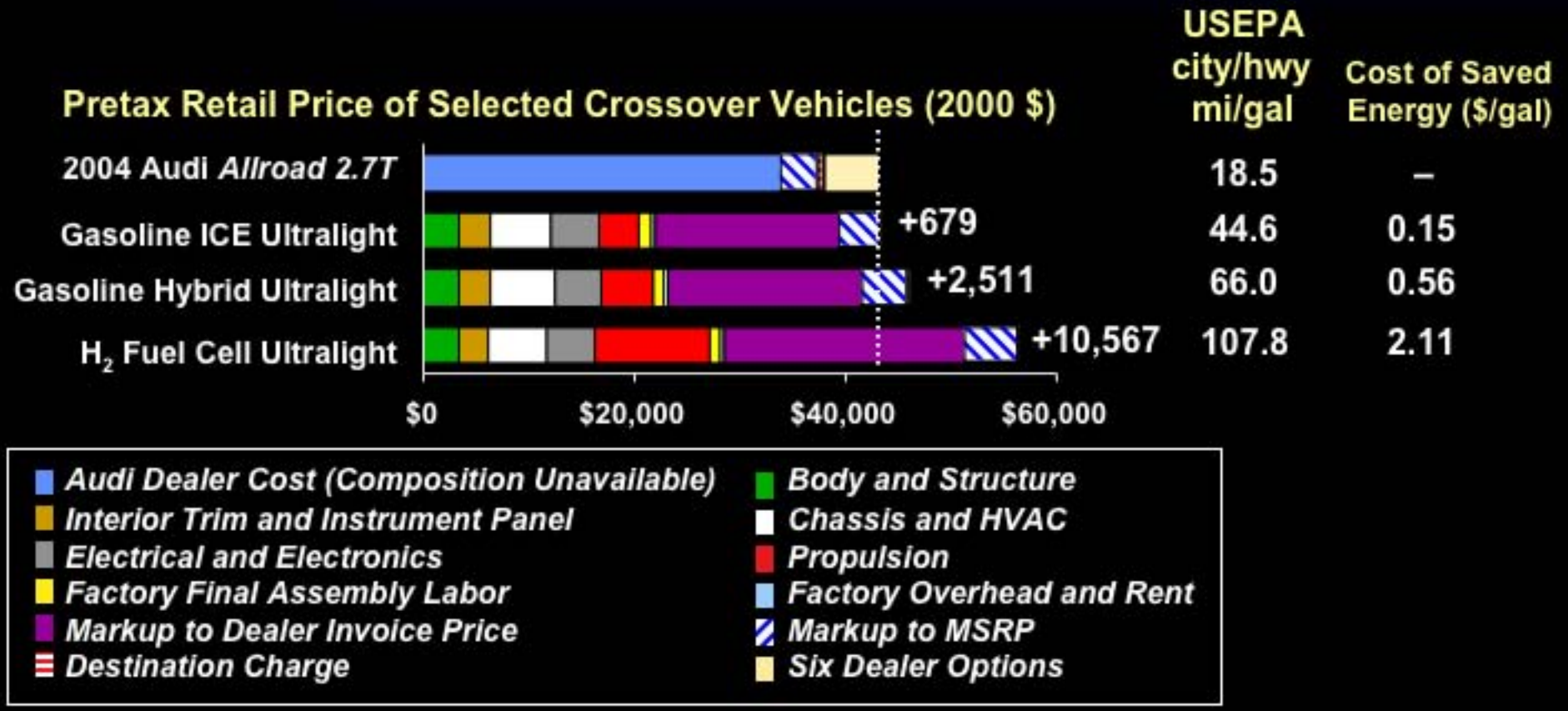
Examples of recent Fiberforge parts

JCI *Genus* 1.1-kg seat bucket and finished JCI concept seat, *Reinforced Plastics*, Feb. 2005, p. 40

Anisotropic prototype part for a demanding non-automotive application, courtesy of Fiberforge

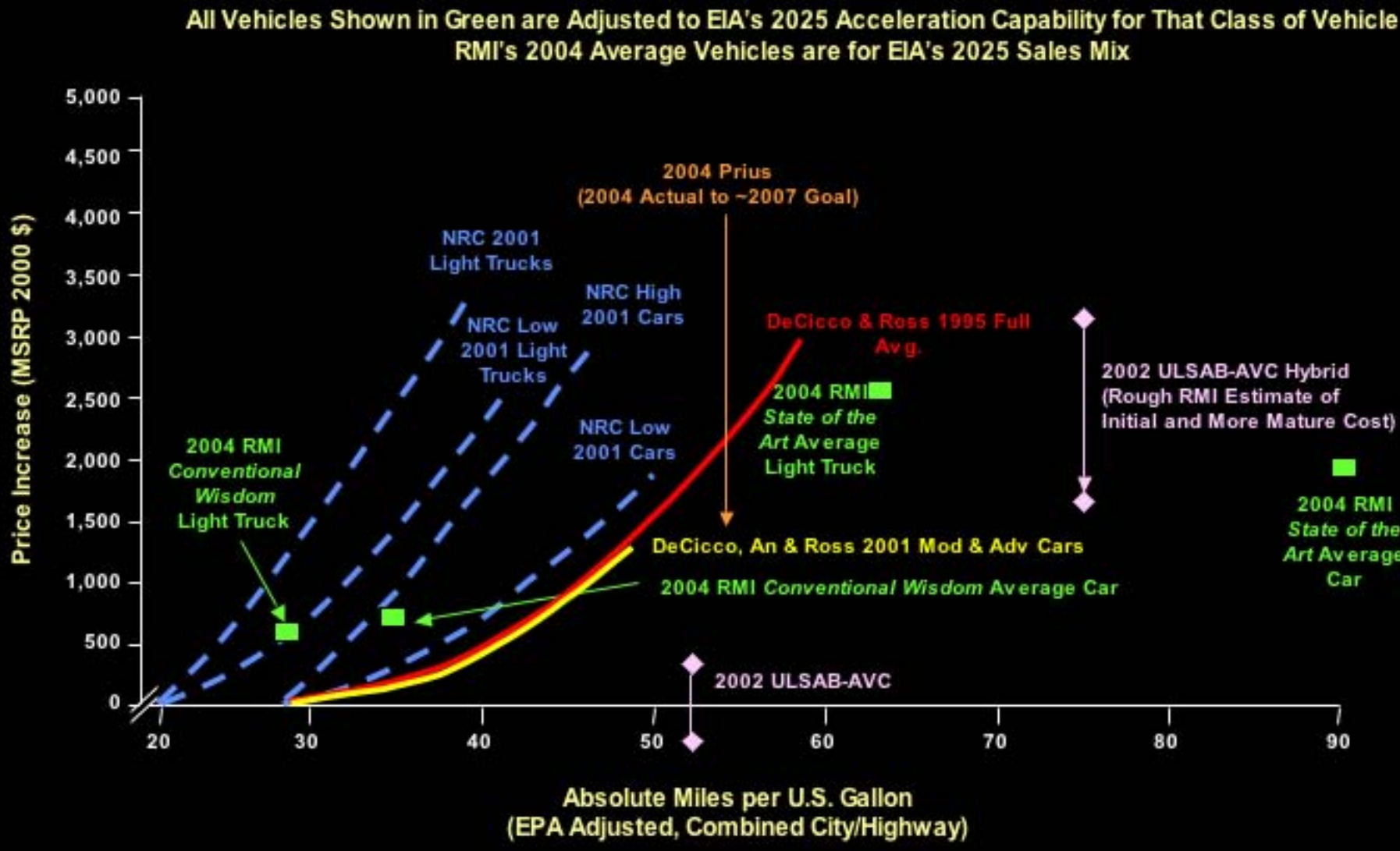
Main advantages: break-through cost at midvolume, very low scrap, automated layup from CAD drawing

This means that ultralight hybrid midsize SUVs fueled with gasoline could achieve 67 mpg for 57¢/gal

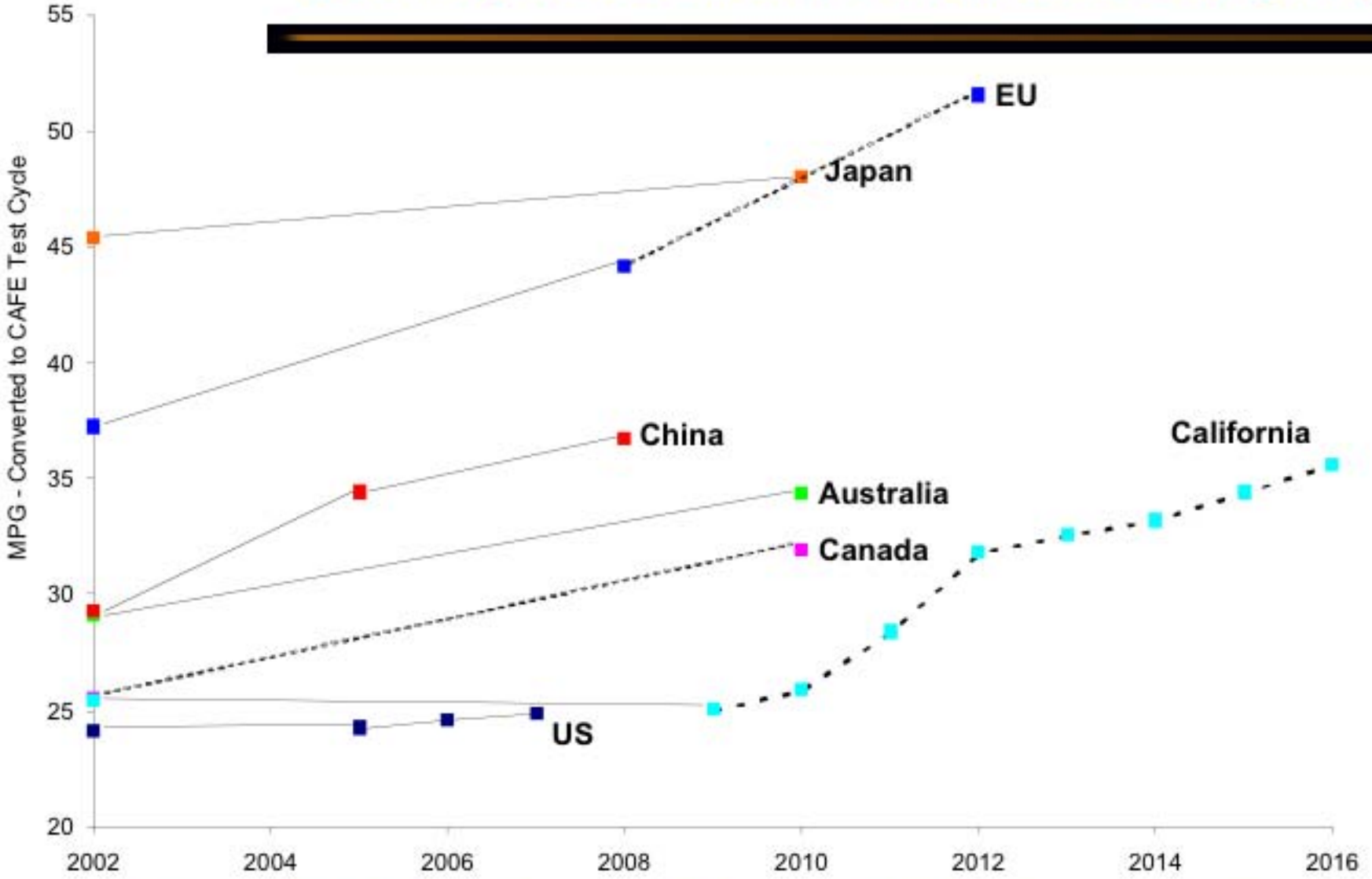


...based on a concept-SUV virtual design with two Tier Ones, production-costed mainly by bids (the rest by independent consultants and 9% by in-house models)

Ultralight-but-safe light vehicles open a new, vast, roughly free ultralight-hybrid design space

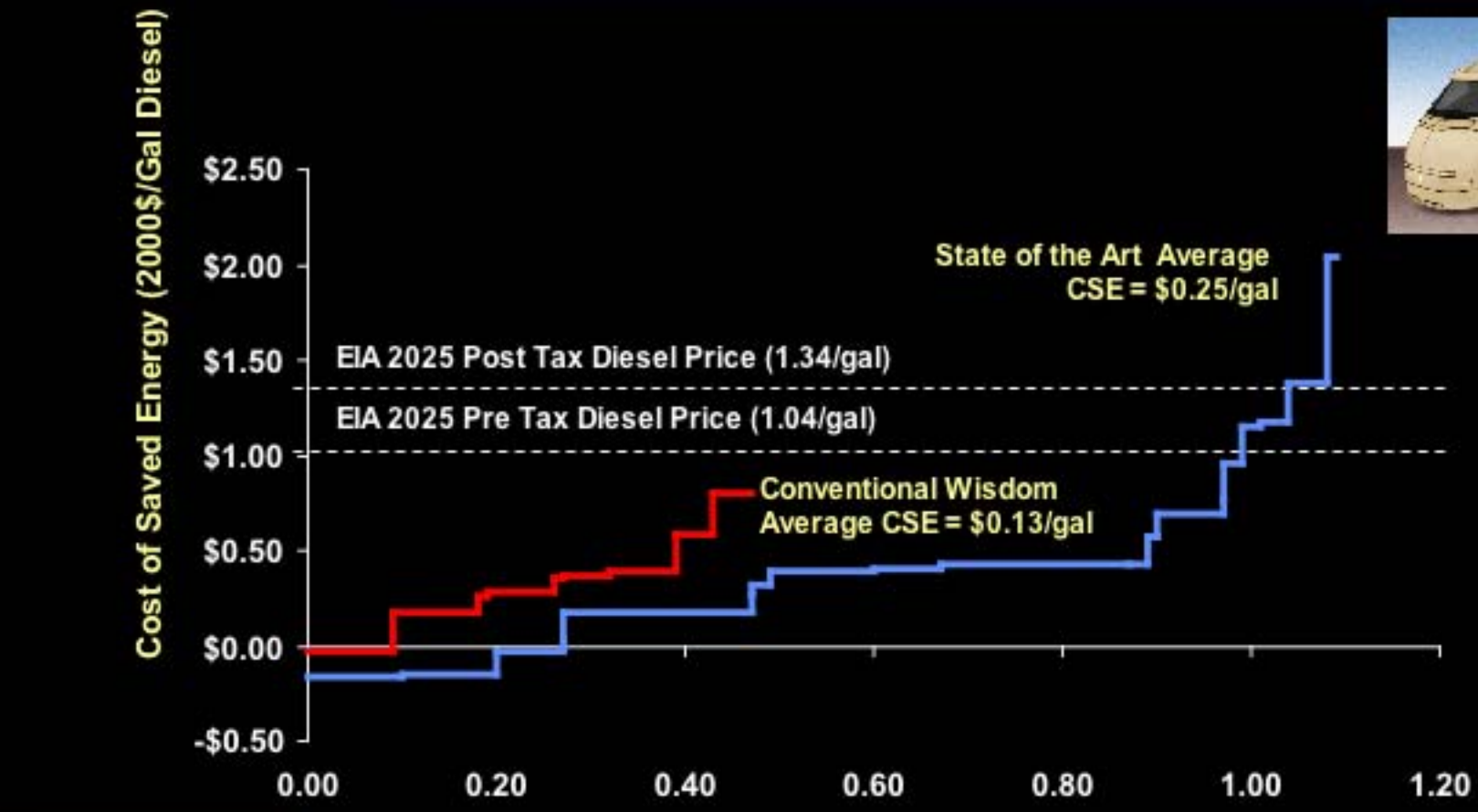


Current and projected new-car eff. stds. (in US CAFE miles-NEDC/gal.)



Source: F. An & A. Sauer, "Comparison of Passenger Vehicle Fuel Economy and GHG Emission Standards Around the World," Pew Center on Global Climate Change, Dec.

Heavy trucks use 12% of all U.S. oil in 2025; the same technologies could save 65% of that use at 25¢/gal diesel



End:
11.8 mpg, then ~16-equivalent w/further improve-ments

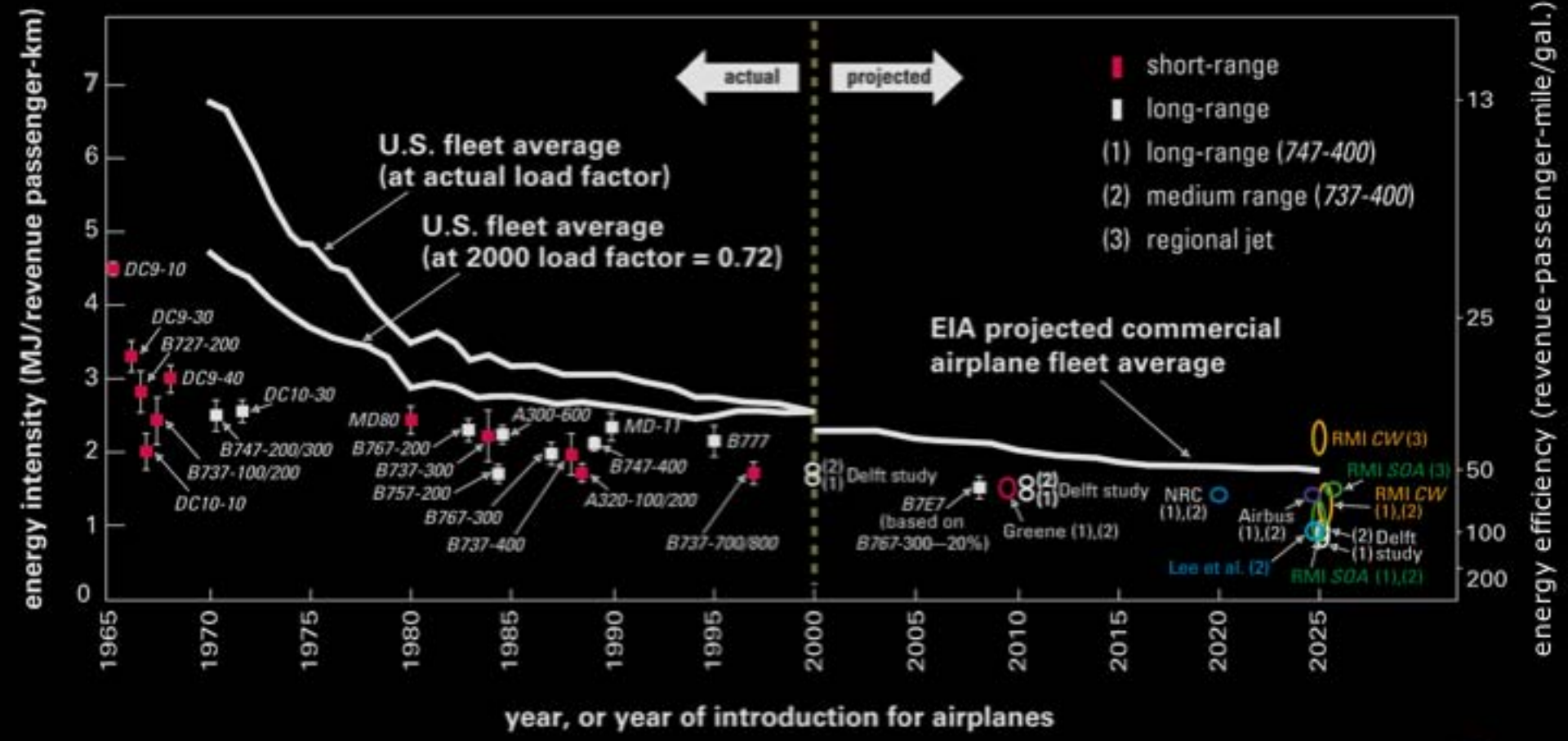
Start: 6.2 mpg

Main sources: MIT, ANL, industry tests

Boeing *787* interior

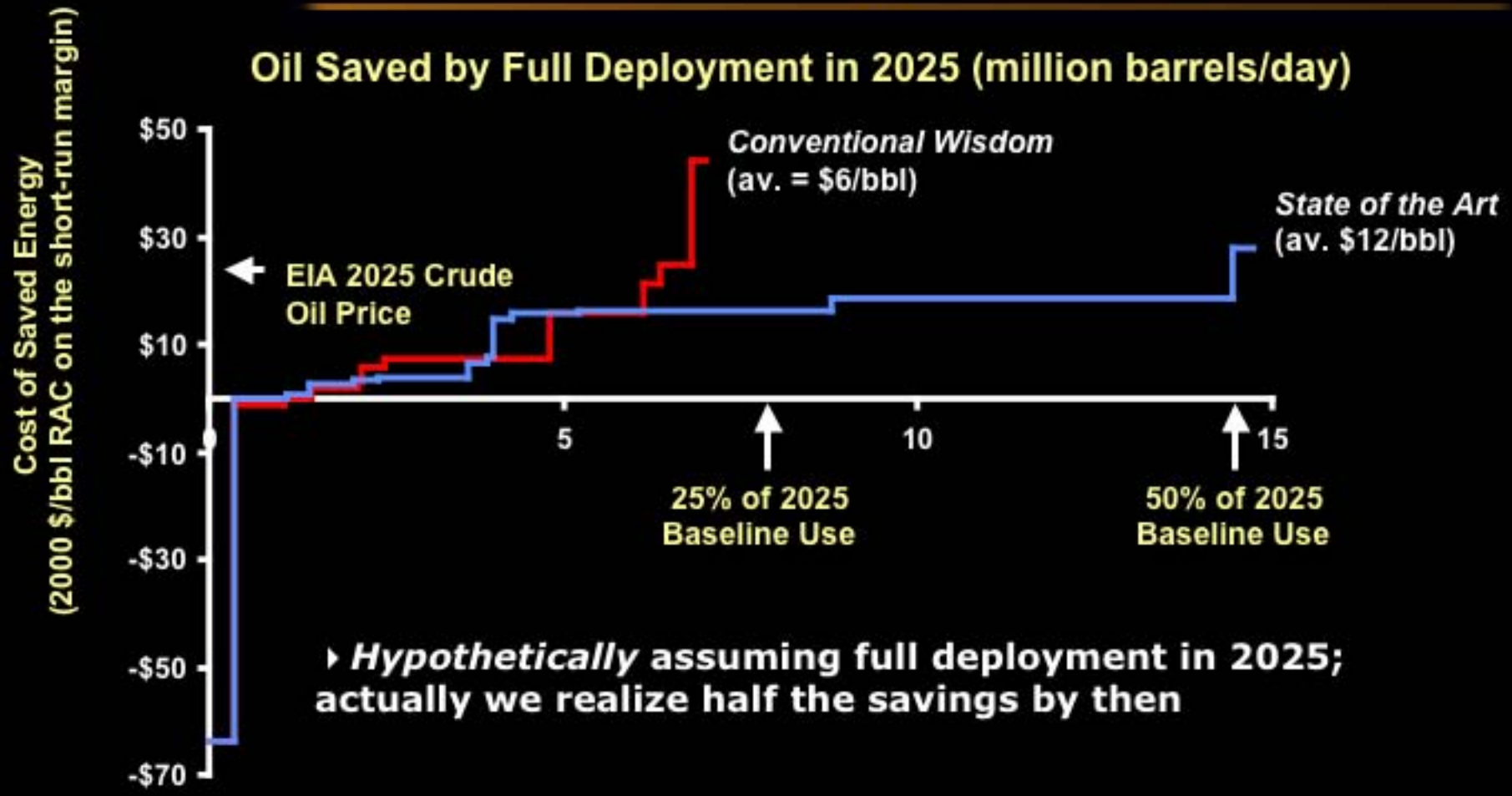
Airplanes: industry agrees fleet can get 2–3× more efficient

NASA image of Blended-Wing-Body



- Keys: advanced composites, new engines, aerodynamics
- Could save 45% of EIA 2025 fuel @ av. 46¢/gal Jet-A

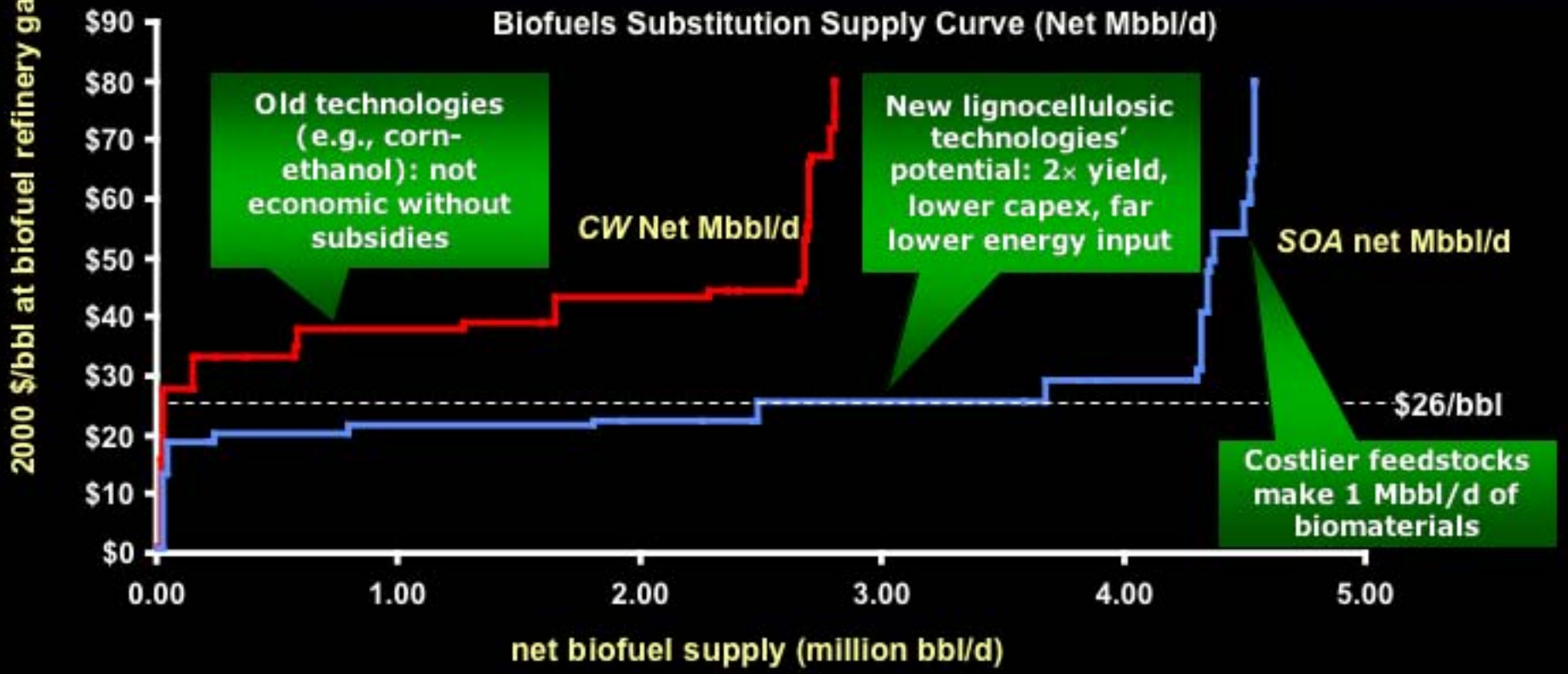
It pays to be bold: saving half the oil for $12/bbl is better than saving a fourth at $6/bbl — else alt. supplies cost too much



- *Hypothetically* assuming full deployment in 2025; actually we realize half the savings by then

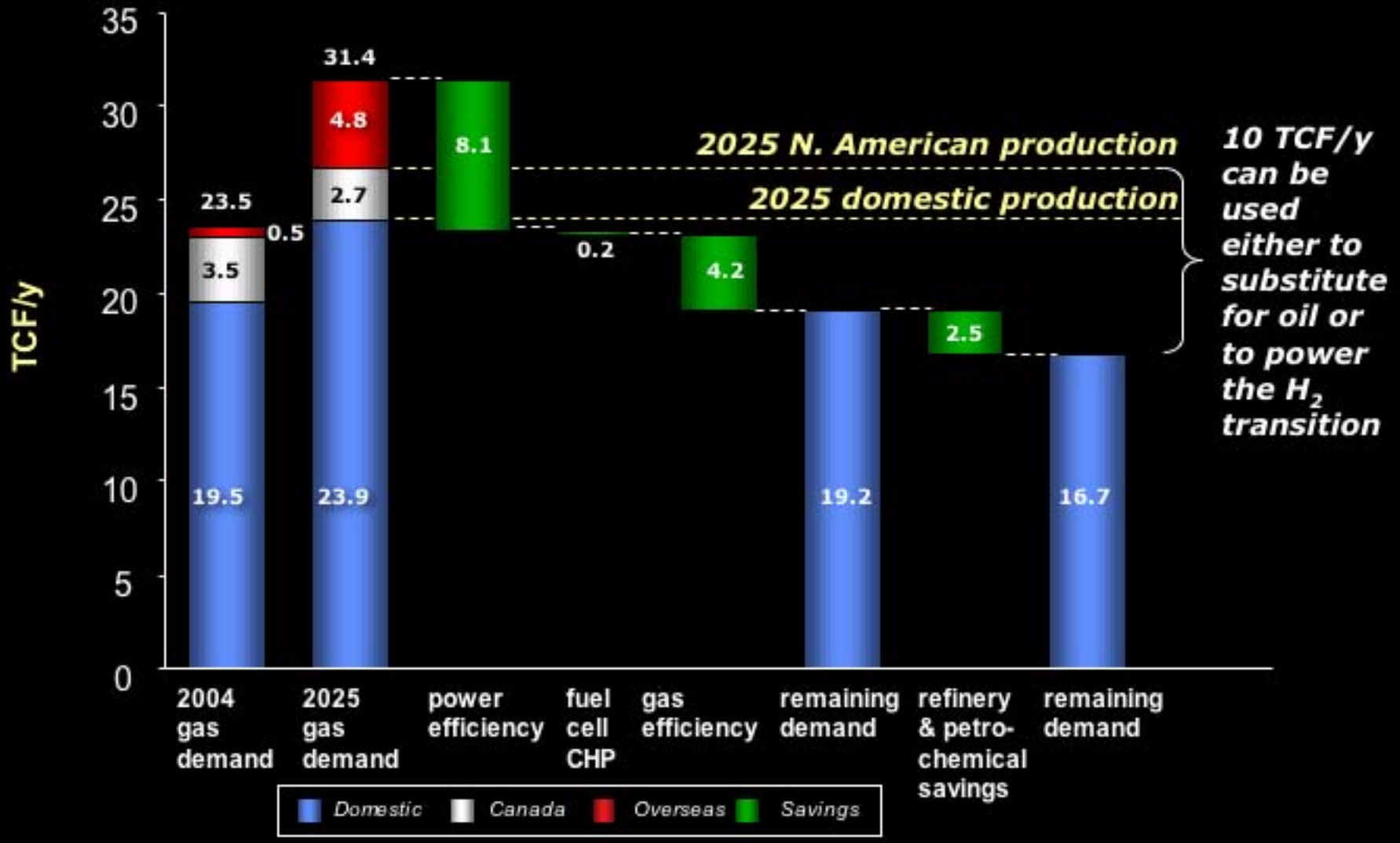
No further invention is assumed during 2005–2025

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

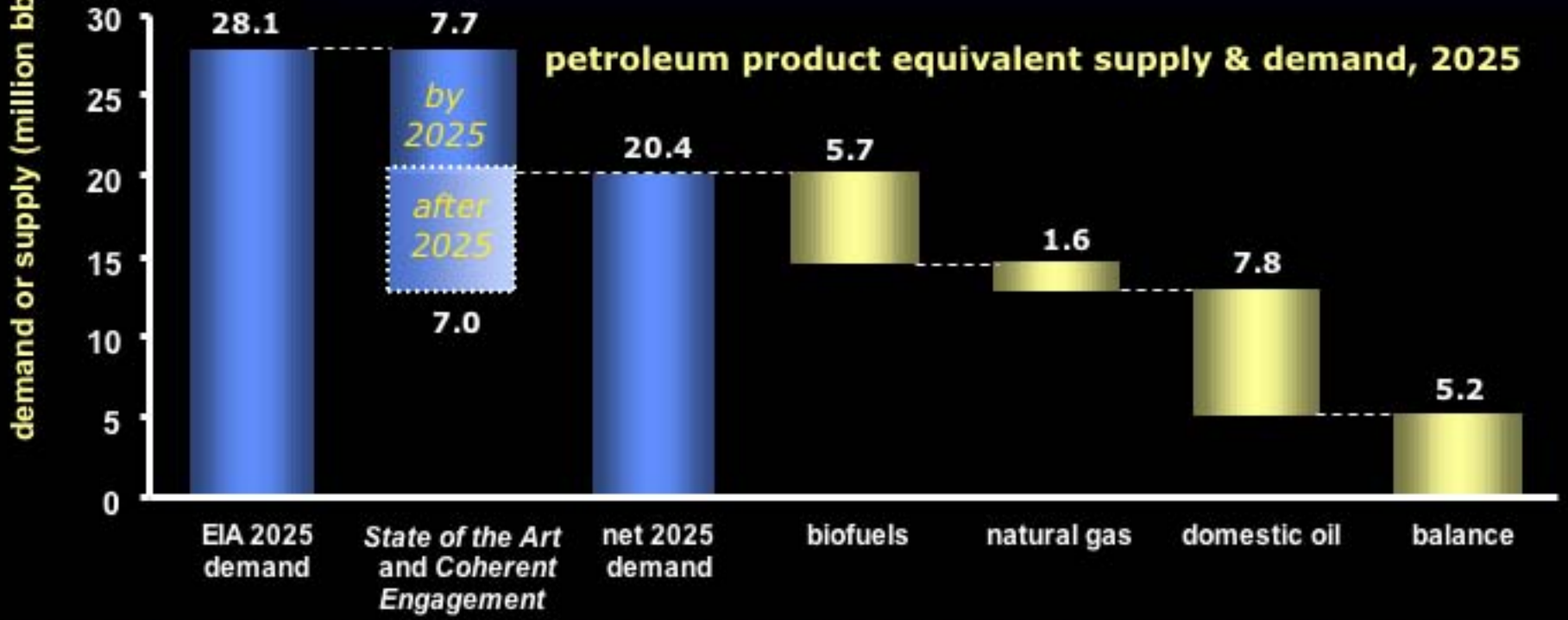


- Brazil has replaced 1/4 of its gasoline with sugar-cane ethanol, competitive without subsidy; oil savings so far are 50× the startup subsidy; exporting 2007–08 to Japan and China
- Europe in 2003 made 17× as much biodiesel as U.S.: oil companies distribute it; shifts farmers from subsidy to revenue

Over 12 TCF/y of natural gas could be saved by lucrative energy efficiency



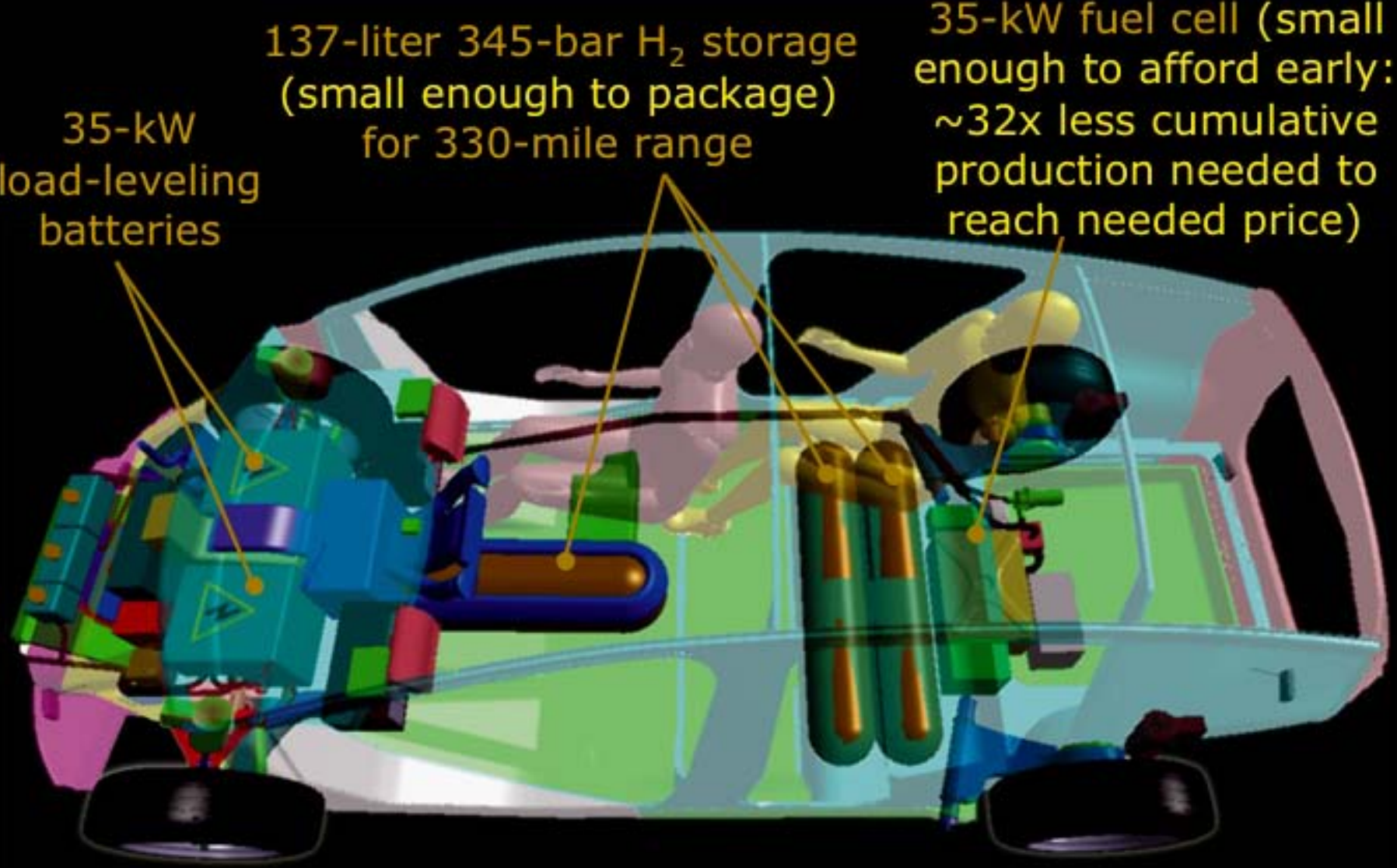
2025 demand-supply integration



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

- **Buy more efficiency (it's costing only half as much as the oil it replaces)**
- **Efficiency is only half captured by 2025—7 Mbbl/d still in process**
- **"Balance" can import crude oil/product (can be all N. Amer.) or biofuels**
- **Or saved U.S. natural gas @ $0.9/MBTU can fill the "balance"…or**
- **H_2 from saved U.S. natural gas can displace "balance" *plus* domestic oil**
- **Not counting other options, *e.g.*, Dakotas windpower—huge H_2 resource**

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



So the first automakers to go ultralight wins the fuel-cell race

Vehicle	Power (kW)	Type	Cost @ $100/kW	Range (km)
Hypercar *Revolution*	35	hybrid	**$3,500**	531
Jeep *Commander 2*	50	hybrid	**$ 5,000**	190
Hyundai *Santa Fe FCV*	75	fuel cell	**$ 7,500**	402
Honda *FCX-V4*	85	fuel cell	**$ 8,500**	298
Ford *Focus FCV*	85	hybrid	**$ 8,500**	322
Toyota *FCHV-4*	90	hybrid	**$ 9,000**	249
GM *HydroGen III*	94	fuel cell	**$ 9,400**	402
GM Hy-Wire	94	fuel cell	**$ 9,400**	129

The creative-destruction challenge for oil companies

- The Oil Endgame is starting: the chairs of 4 oil majors and 3 car majors have said so
- Oil will probably become uncompetitive even at low prices before it becomes unavailable even at high prices
- Biofuels can be the transitional product line, as oil companies are exploiting in Europe
- Compelling arguments for changing business model to provide mobility and access, not gallons
- In the future, H_2 in hydrocarbons will be worth more without C than with C (even if nobody pays to protect the climate), so it's better to take H_2 out of HCs (reform) than to put more in (refine); oil asset values may be sustained or increased

What if DoD investment in advanced light materials could transform the U.S. economy as profoundly as Internet, GPS, and chips ?

- Advanced materials & propulsion systems can find a Saudi Arabia (>9 Mbbl/d) of saved oil under Detroit & Seattle…
- …and help DoD transform its forces, strengthen warfighting capability, and cut fuel cost by billions of $/y and logistics cost by tens of billions of $/y
- The U.S. could cut oil use by 50% by 2025, imports by 75%
- The key DoD action needed is S&T investment in advanced materials, especially high-volume/low-cost manufacturing

The prize

- A nega-Gulf every 7 y
- Vastly less world dependence on oil and conflict over oil
- A competitive Big 3
- Cheaper oil; more balanced U.S. trade, global development, and diplomacy
- More capable and confident warfighting
- Less need for it
- A safer world

Four basic market failures

- Oil is priced below its societal cost
- Most customers are very short-sighted
- Most customers have poor information
- Most managers resist disruptive innovations

Policy portfolio must turn these obstacles into business opportunities and accelerate adoption of advanced-technology vehicles

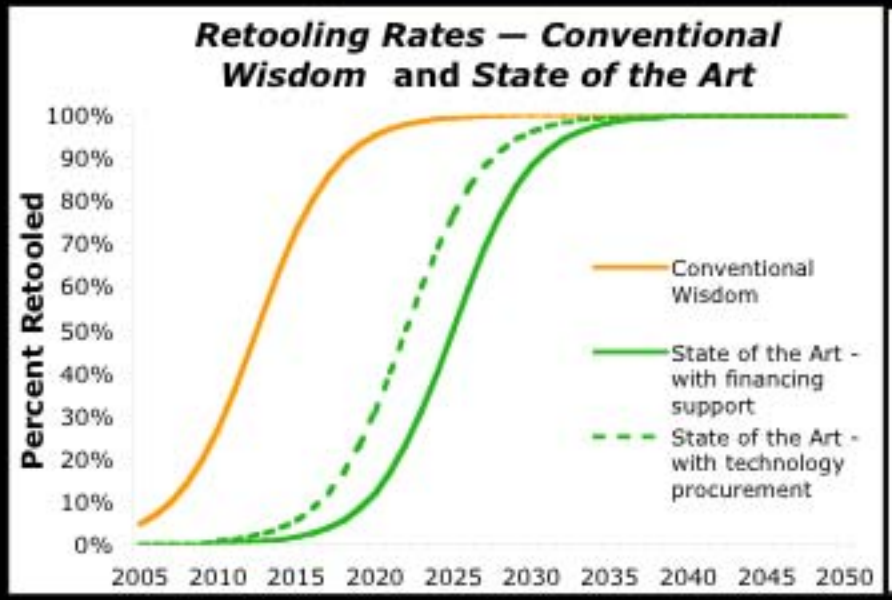
Five ways government can help

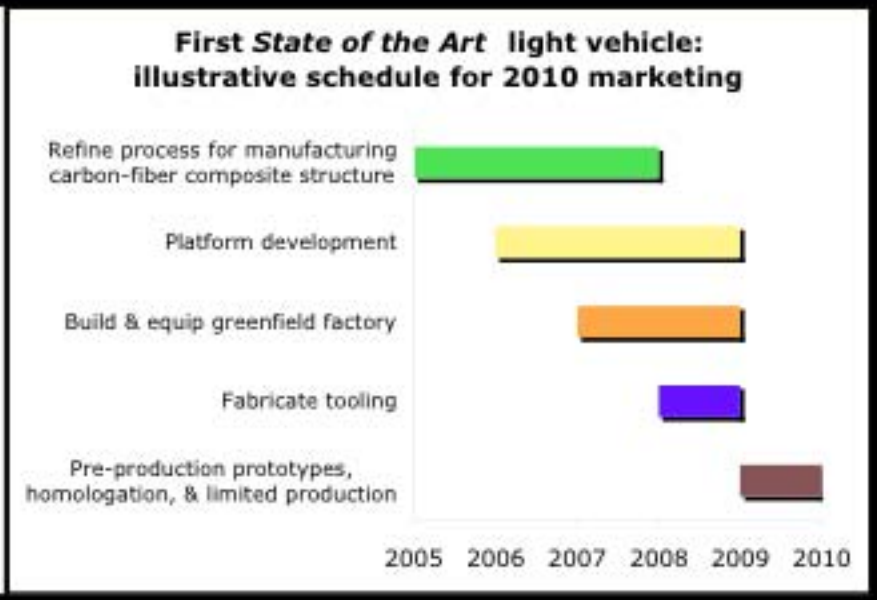
1) **Stimulate demand for very efficient vehicles**
   - Feebates—revenue- and size-neutral, more automaker profit
   - Create a new million-car-a-year market through leasing to low-income customers (and scrapping clunkers)
   - Smart military and government fleet procurement; "Golden Carrot" and "Platinum Carrot" to speed innovation
   - Heavy-truck-buyer info/leadership, airline loan guarantees
2) **Build vibrant 21st Century industries by sharing R&D risk and deploying faster than the private market**
   - Military S&T should finance advanced materials development
3) **Lower risk of investment for new manufacturing plants through loan guarantees to automakers**
4) **Support development of domestic energy supply infrastructure (hydrocarbons → carbohydrates)**
5) **Remove barriers to efficiency through coherent policies and purging perverse incentives**

State policy opportunities (once you've DONE utility decoupling!)

- Light vehicles
  - Revenue- and size-neutral feebates; shift registration/excise?
  - Smart procurement (aggregating state and local?)
  - Pay-at-the-pump insurance; shift tax from fuels to roads/driving
  - Fund initial dealer carrying charges/bonuses for superefficient cars
- Heavy trucks
  - Allow extra axle, 2-/3-trailer combos w/better brakes, 60 mph
  - Raise GVWR to EU norm (110klb), 14'H, 59'L
  - Require fuel-economy driver's ed
  - Encourage truckmakers to get first-mover advantage—*e.g.* Oregon Business Energy Tax Credit (up to 35% of $10M/project), loans,…
- Biofuels (good fit to ag & water needs & capabilities)
  - Procurement, labeling, detaxation?, ?bonds, totalflex vehicles

Bringing affordable, ultralight, advanced-composite vehicles to market starting 2010





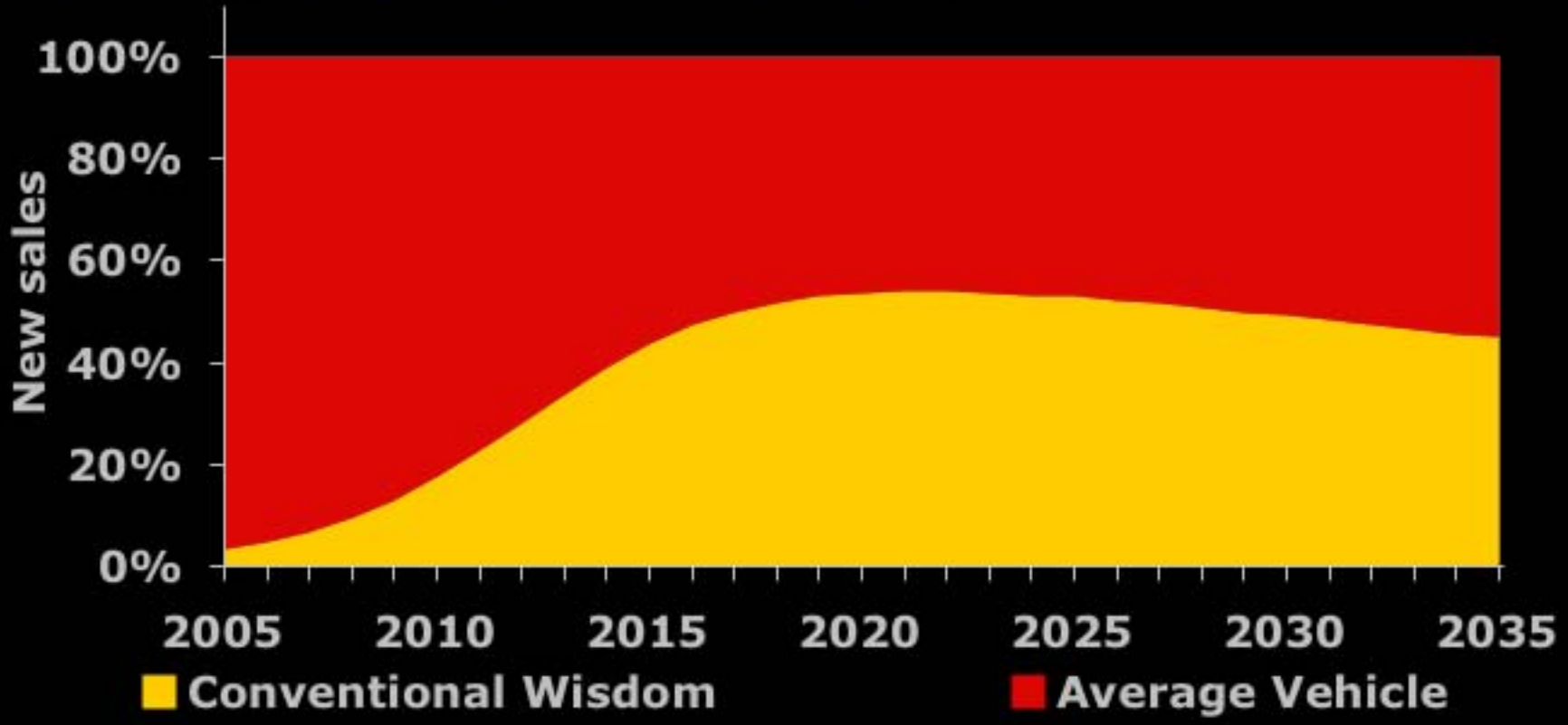
- Insider view of industry programs and state of mfg. process development supports this timeline
- Some OEMs may be faster: BMW 2005?; Honda & Toyota entering the carbon-fiber aircraft business

U.S. Energy Information Administration (EIA) scenario

Absent demand-driving policies and *Conventional Wisdom* and *State of the Art* technologies

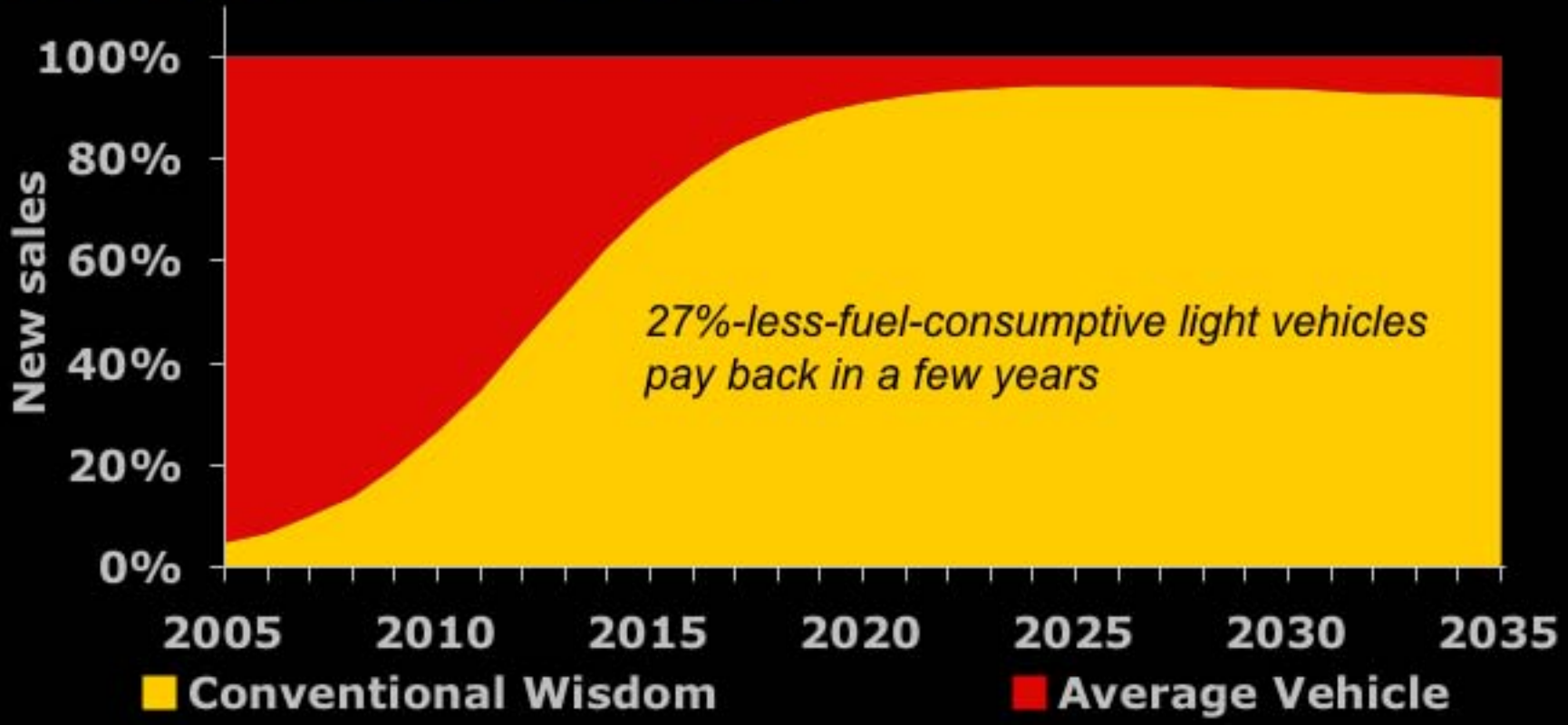
Drift scenario

Absent demand-driving policies, *Conventional Wisdom* vehicles capture half the market in 2020



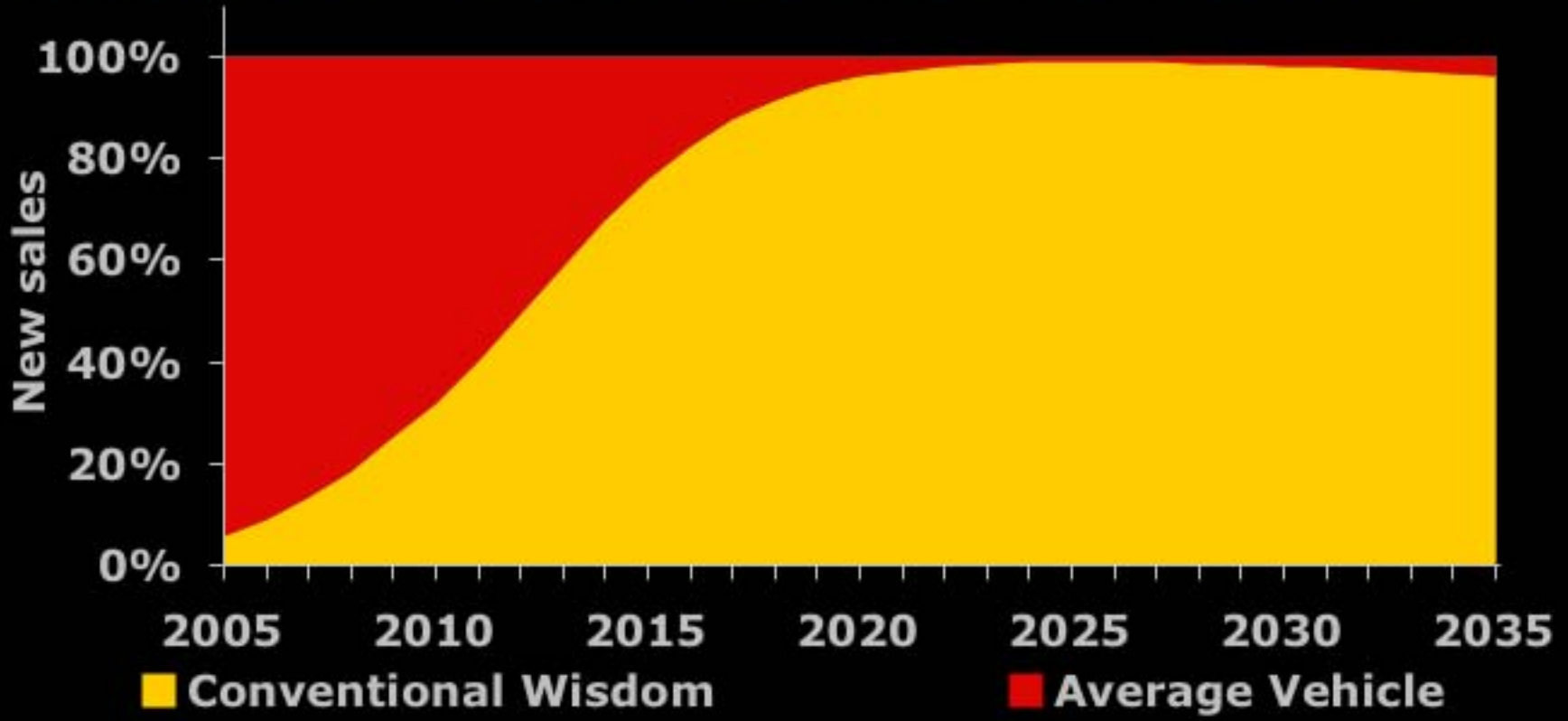
Let's Get Started scenario

Feebates at the $1,000/0.01 gpm rate allow buyers to see 14, not 3, years of fuel savings



Let's Get Started scenario

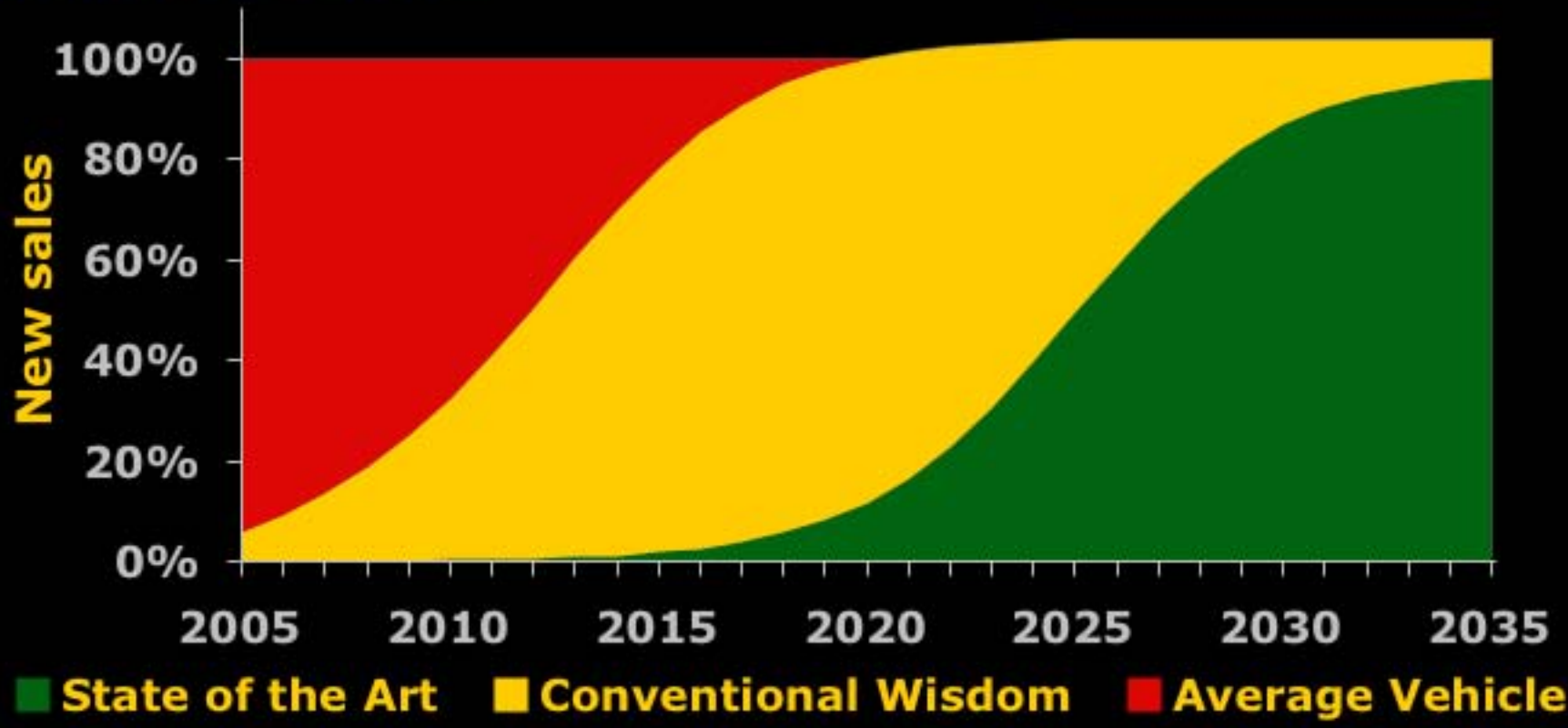
Low-income scrap-and-replace program is not a big oil saver, but it's vital for equitable social development



Reality check: a 2025 fleet as efficient as 2*004* hybrid cars & SUVs would save 1/6 of all 2025 oil use (2 Gulfs' worth), costing ~$45b/y

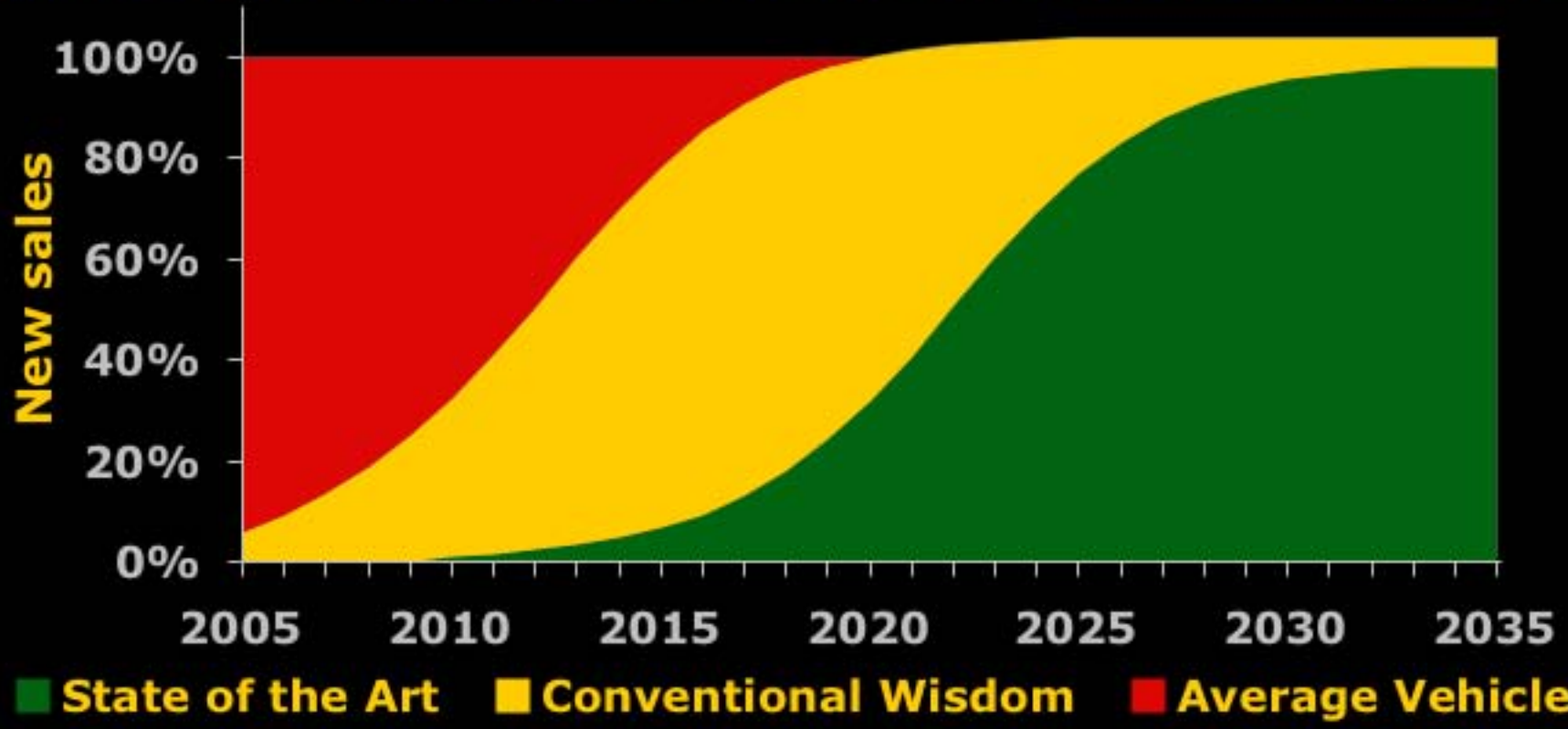
Mobilization: Accelerating Change

Increasing the feebate rate to $2,000/0.01 gpm starts to count public goods



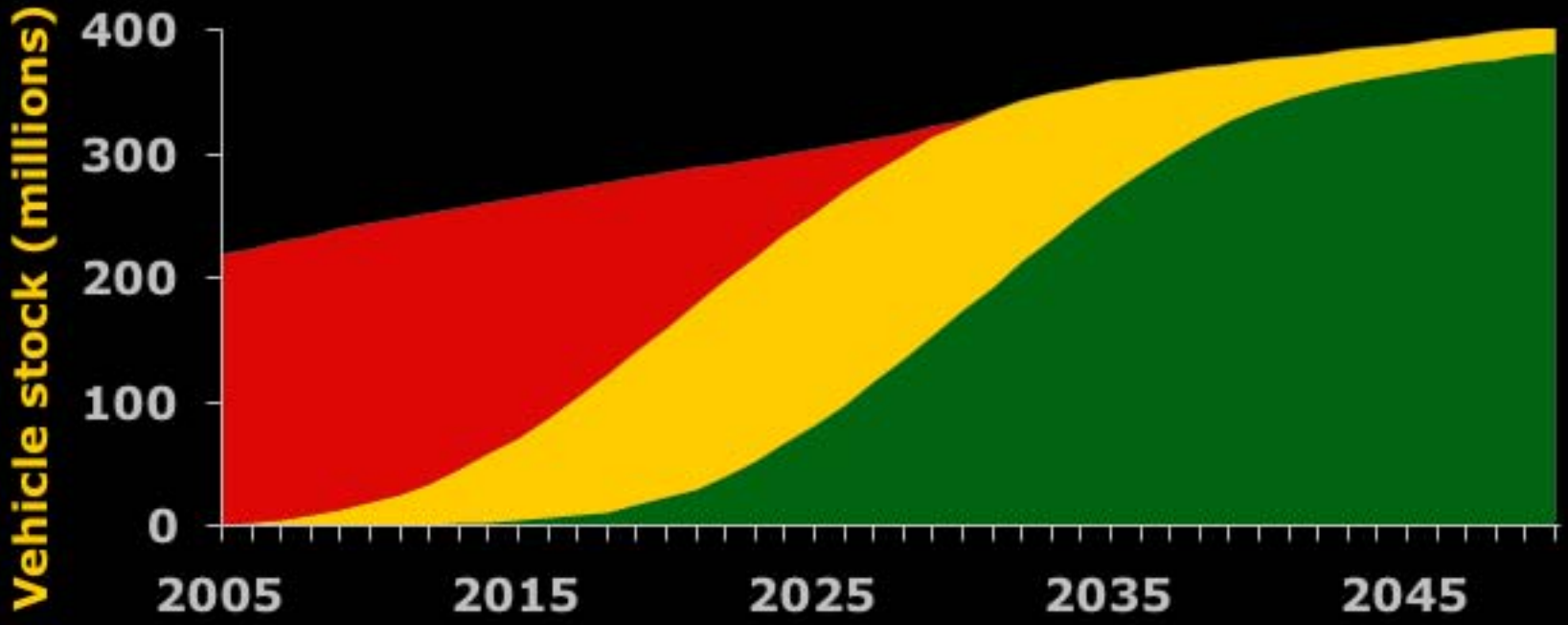
Mobilization: Accelerating Change

Adding smart government procurement and Golden and Platinum Carrot competitions increases market capture pulls *State of the Art* vehicles to an earlier starting date



Mobilization: Accelerating Change

4.5 Mbbl/d saved, $391 billion in retail fuel savings

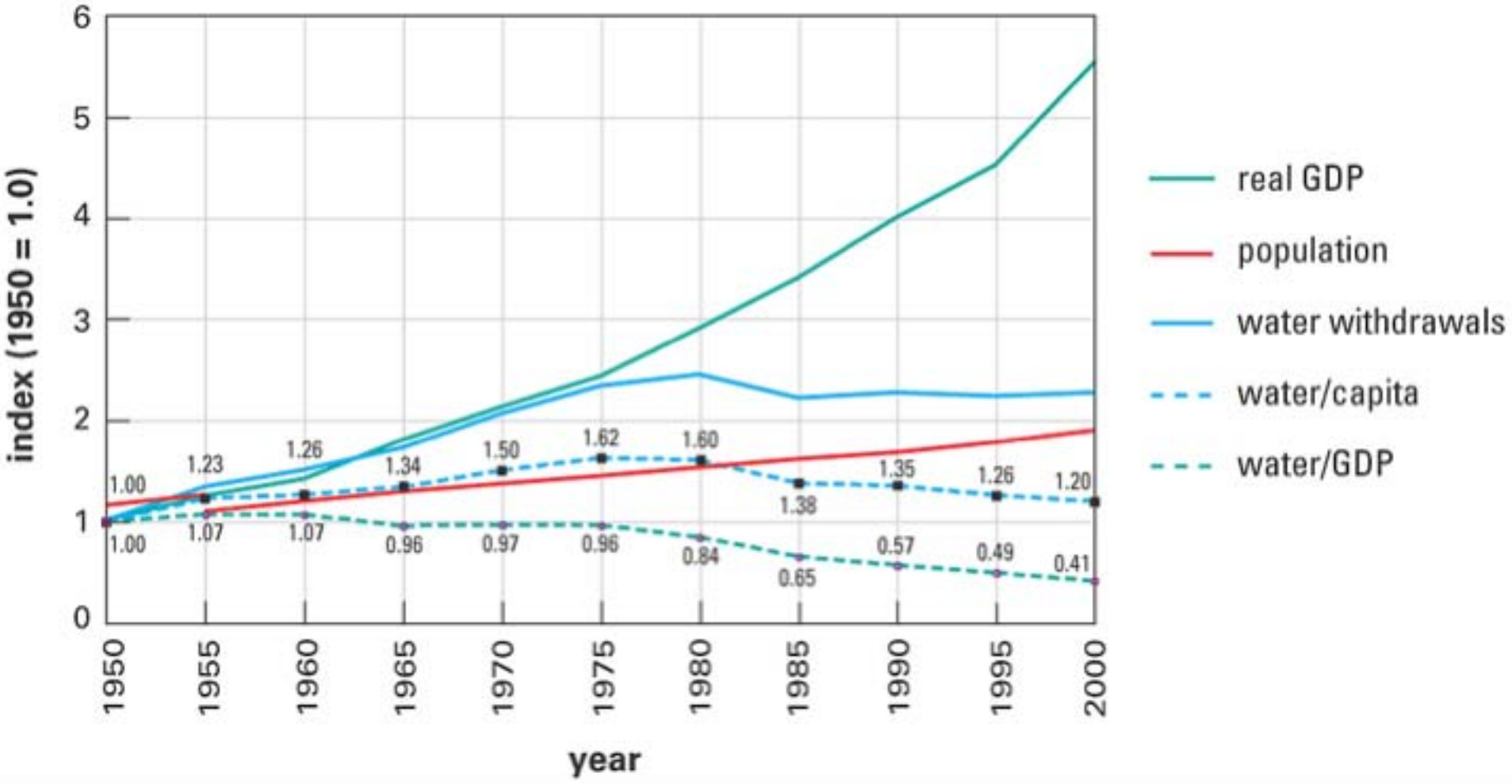


90–100% *State of the Art* vehicles by 2040

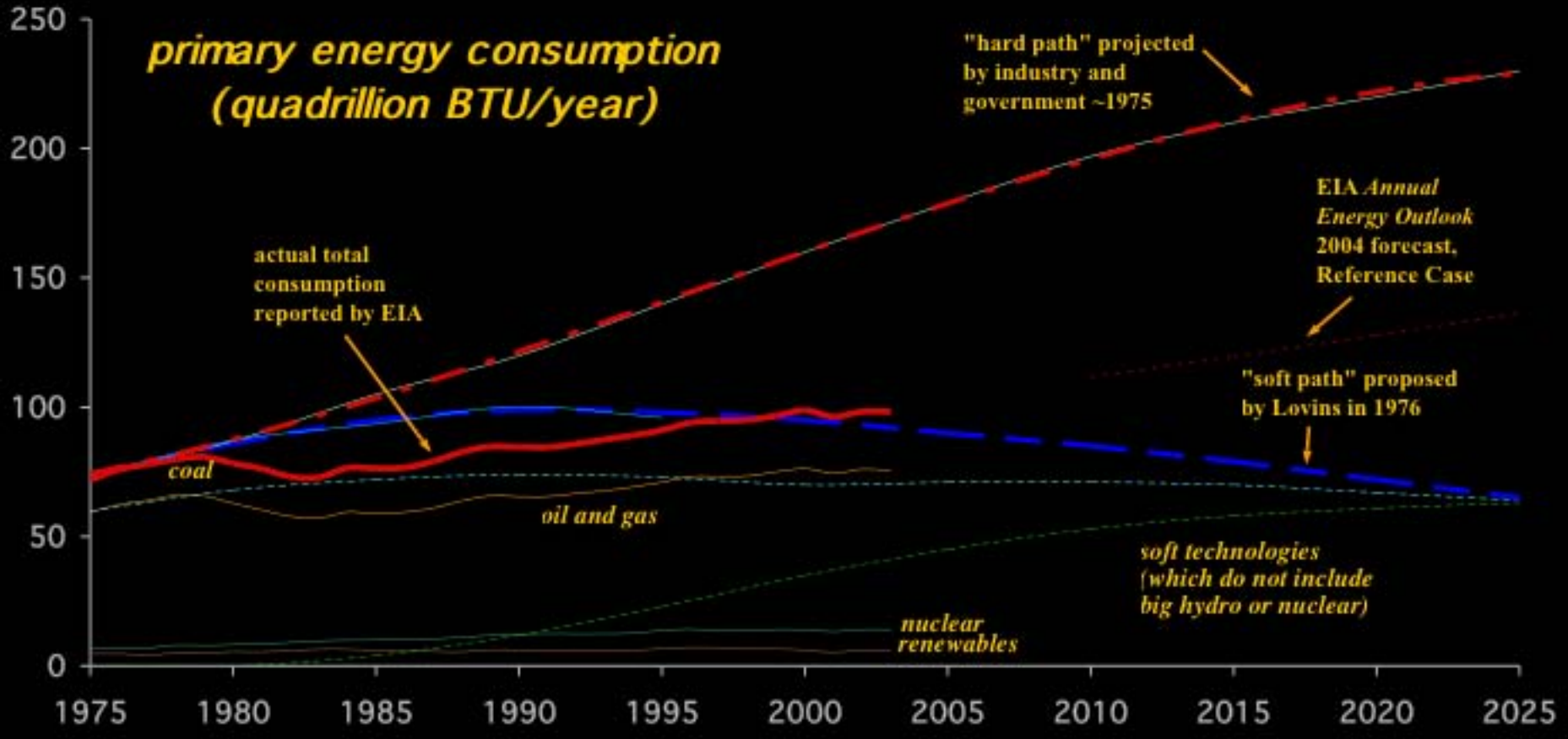
Big, fast changes have happened

- U.S. automakers switched in **SIX YEARS** from 85% open wood bodies to 70% closed steel bodies—and in **SIX MONTHS** from making four million light vehicles per year to making the tanks and planes that won World War II
- Major technological transformations take **12–15 years** to go from 10% to 90% adoption
- The key is to get to the first 10% much faster!
- In 1977–85, U.S. cut oil intensity 5.2%/y—equivalent, at a given GDP, to a Gulf every 2.5 years
- If every 2025 light vehicle were as efficient as the best 2004 cars & SUVs, they'd save 2 Gulfs' worth

Analogy: did anyone notice the U.S. water-efficiency revolution?

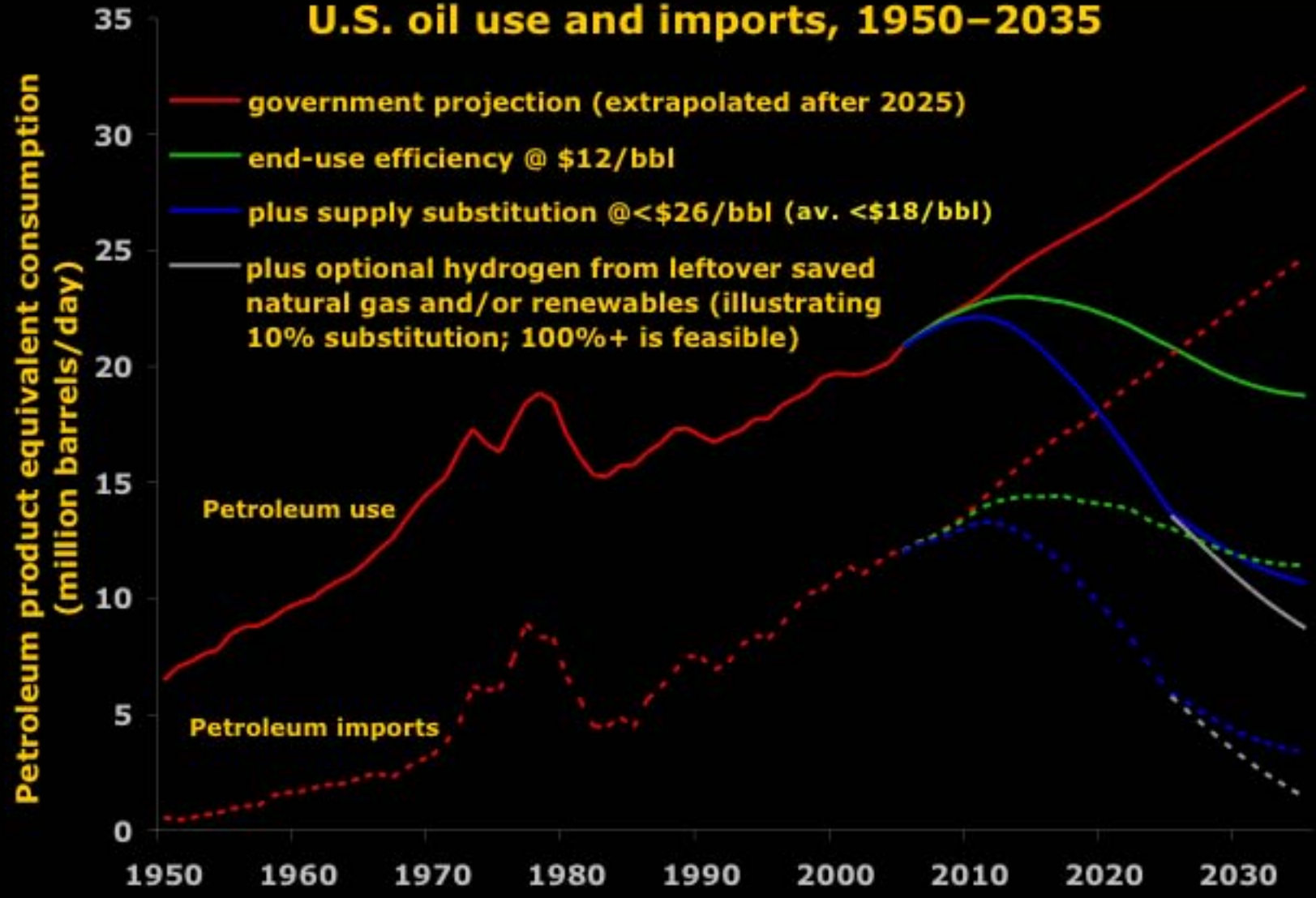


U.S. energy/GDP already cut 43%, to very nearly the 1976 "soft path"



...but that just scratches the surface, especially for oil

A profitable U.S. transition beyond oil



Why should you care enough to act?

What are we waiting for?
Let's play the Oil Endgame to win.

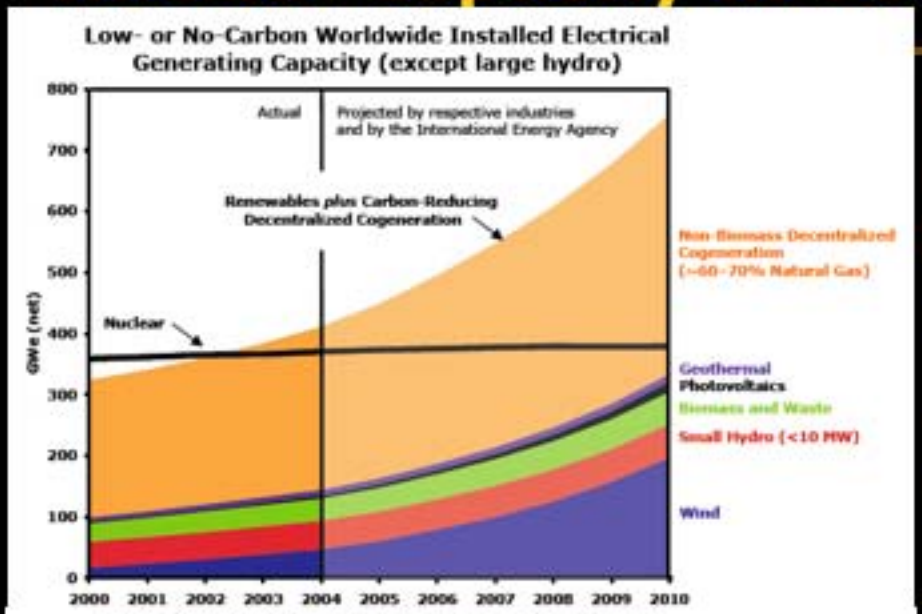
Free download from

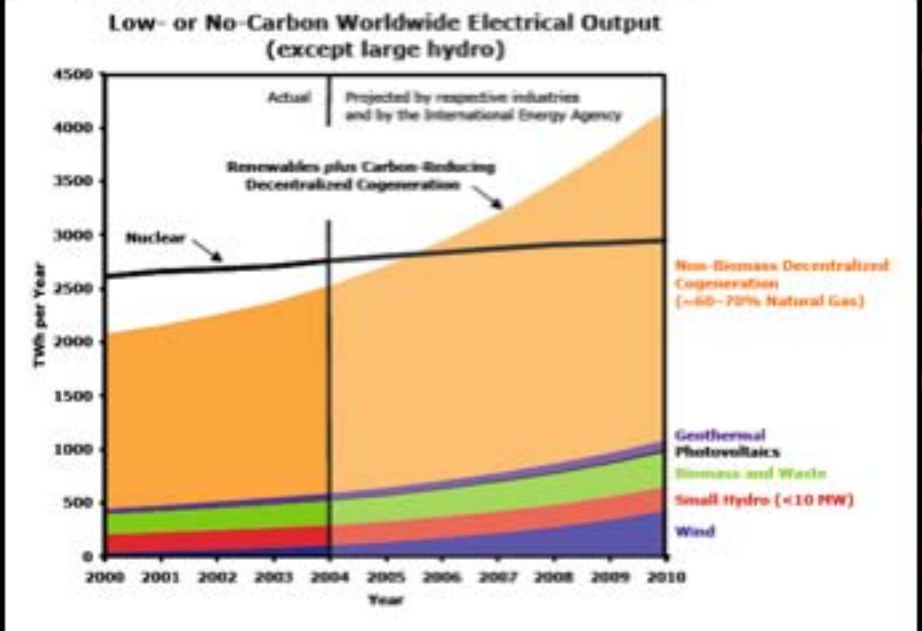
www.oilendgame.com

(What about nuclear power?)

- Unfinanceable in the private capital market; the few orders are all in centrally planned electricity systems
- That's because it's fundamentally uncompetitive
  - A new delivered nuclear kWh costs ~10–30x more than end-use efficiency, ~5–10x more than gas-fired cogen/trigen, & ~2–3x more than windpower: the IAEA, MIT, Harvard, & Chicago studies all ignored all these, and compared nuclear with the wrong competitors
  - Regulatory change, new reactor types, H_2, C tax won't save nuclear
  - The three fatal competitors are getting even cheaper…2 more soon
- Irrelevant to U.S. oil problem: <3% of el. is oil-fired (0.3% distillate), <2% of U.S. oil makes el., both ↓
- Red herring, died of an incurable attack of mkt forces
- That's good…it can belatedly help block proliferation
- Big opportunity cost: nuclear spending harms climate

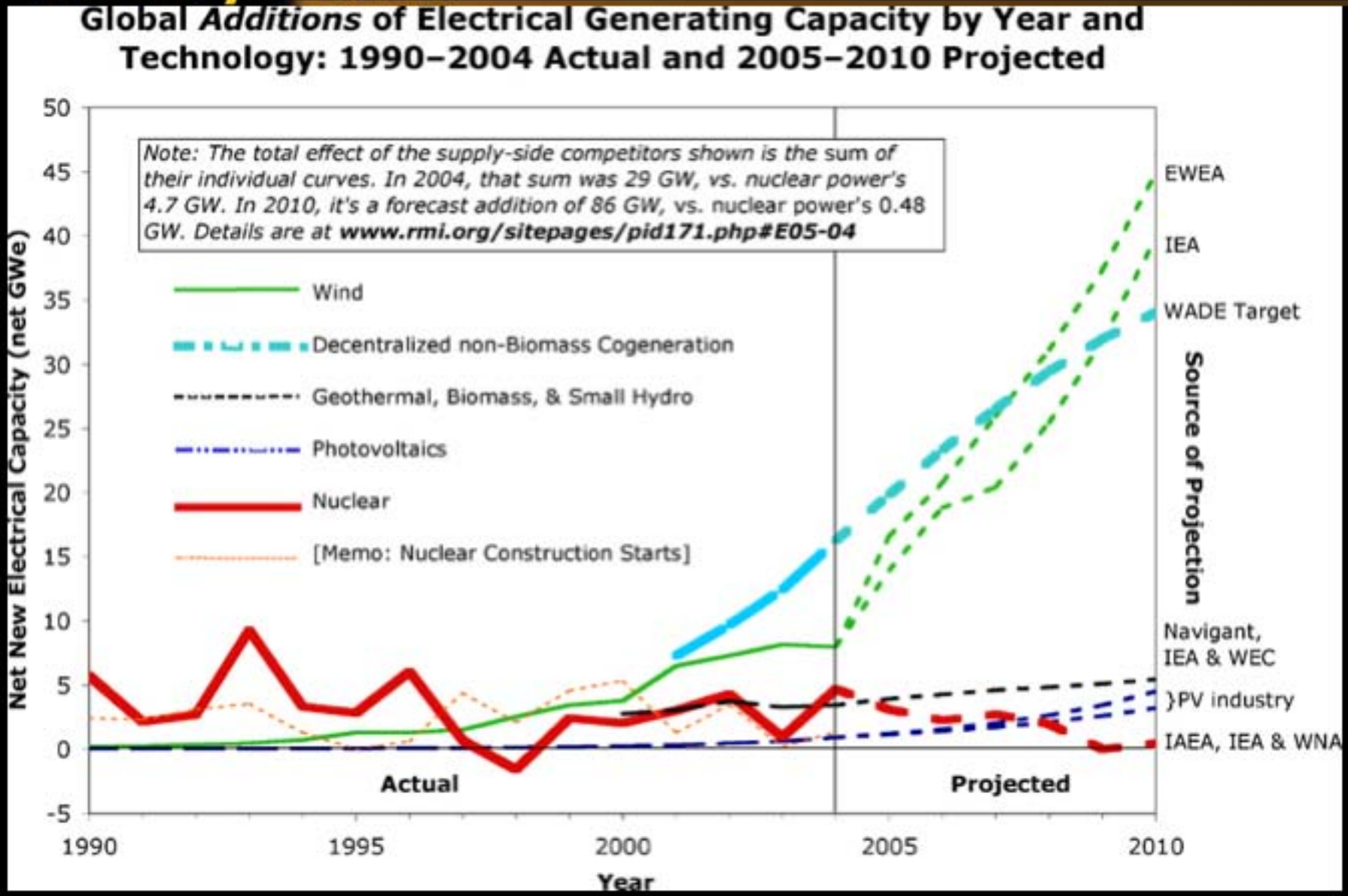
Decentralized generators surpassed world nuclear capacity in 2002, its output in 2005





- Two-thirds of decentralized new capacity is combined-heat-and-power, ~60–70% gas-fired
- The rest is renewable (hydro only if <10 MW_e)
- These low- or no-carbon options added in 2004 5.9× as much capacity & 2.9× as much output as nuclear
- Their projected 2010 cap-add is ~177× nuclear's
- Demand-side resources bigger…but no data kept!

Nuclear's decentralized supply competitors, supposedly small and slow, already beat it



Nuclear power's supposedly rosy prospects are bad and worsening

- The claim that decentralized competitors are small and slow is rebutted by actual market behavior
- The demand- and supply-side competitors are bigger, faster, and improving far faster
  - New reactor types (pebble-bed,…) won't help materially
- The market is also starting to value 207 "distributed benefits" that make micropower ~10× more valuable
- Featuring and favoring nuclear power in national energy policy has historically harmed its advance
- Competitive power markets and transparent political choices, both spreading, destroy nuclear's prospects
  - It's never been bid into a power auction, because it'd lose
- Building nuclear plants earns only a few b$/y of revenue and no profit—hardly a serious business—*vs* renewable power's $28b/y revenue and significant profit; education & infrastructure are dwindling

Nuclear "revival": the U.S. industry's proposed conditions

- Taxpayers pay first $1.8b + 20% of the rest of the capital cost + all licensing + R&D costs
- Taxpayers guarantee the loans and guarantee to buy all the power at above-market prices
- Current large operating subsidies + 1.8¢/kWh
- Liability capped forever; most lesser liability evadable by shell companies
- All waste taken for small fee, w/penalty if late
- All offsite security costs borne by taxpayers
- Substantive public participation eliminated, local objections overridden, big risks ignored (such as plausible and threatened terrorism)
- In short, taxpayers take all remaining costs and risks; promoters pocket any upside

Nuclear power: policy questions

- Why divert public resources from market winners to the big market loser?
- Why pay a premium to incur its problems?
- Why incur the opportunity cost of buying less climate solution per dollar (and slower)?
  - Why not use normal marginal cost/benefit comparison?
- If you think "we need everything" (no choices):
  - What's your analytic basis for that belief?
  - How do you propose to pay for buying everything?
  - Since different choices have different prices, how do you avoid the "Chinese restaurant menu problem"? (Pick one item from each section, spend half your money on shark's-fin soup, be unable to afford rice, go away hungry)

What happens with competitive bidding?

- California's 1982–85 fair bidding with roughly equal subsidies elicited, vs. 37-GW 1984 load:
  - 23 GW of contracted electric savings acquisitions over the next decade (62% of 1984 peak load)
  - 13 GW of contracted new generating capacity (35% of 1984 load), most of it renewable
  - 8 GW (22%) of additional new generating capacity on firm offer
  - 9 GW of new generating offers arriving *per year* (25%)
  - Result: glut forced bidding suspension in April 1985
- U.S. 1979–85: more new capacity ordered from small hydro and windpower than from coal and nuclear plants, excluding their cancellations (>100 GW)…yet nuclear got (in FY1984) 24x the subsidy/kWh that nonhydro renewables got, and doesn't face their obstacles to fair interconnection

The next electric revolution: efficient and distributed

- In late 1980s, full best retrofit could save ~3/4 of U.S. el. @ av. ~0.6¢/kWh ('86$)
- Key technologies & delivery methods now far cheaper
- Biggest revolution: whole-system design integration yields *expanding* returns to efficiency investment
  - See *Encyc. of Energy* 2004 article; www.natcap.org
- Distributed electricity is often competitive *now*—even PVs when integrated with demand-side management
- But commodity ¢/kWh omits key "distributed benefits"
  - *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (www.smallisprofitable.org, 2002), an *Economist* Book of the Year
  - 207 distributed benefits boost typical economic value *by ~10×*; the biggest benefits come from financial economics, then el. engineering
  - "Cleaner Energy, Greener Profits" (www.rmi.org, 2001) shows fuel cells can often be profitably applied even at $2,000–3,000/kW

The U.S. oil problem

- Americans use 26%, produce 9%, and own 2–3% of the world's oil, so we can't drill our way out
- Fungible in world market; issue is use, not imports
- The next barrel is cheaper abroad than at home
- Only three solutions in a market economy
  - Protectionism
  - Trade
  - Substitution
- Three basic approaches to oil strategy
  - Ostrich
  - Drill and kill
  - Innovate and revitalize—cheaper, safer, surer; our focus

The wider context: eight keys to energy security

- Remove climate change's risks and costs
- Make electric blackouts impossible by design
  - Efficiency & load response, distributed generation, renewables
  - More and bigger powerlines are part of the problem
- Continue the market's phaseout of nuclear power
  - Removing ambiguity unmasks proliferators
- Apply to natural gas what we've learned about el.
  - Efficiency & load response; avoid overshoot into costly LNG
- Evolve the whole energy system toward resilience
  - Efficient, dispersed, diverse, renewable (*Brittle Power* thesis)
- Get off oil—systematically, rapidly, and profitably
- Same for DoD, now the world's largest oil buyer
- Change the energy policy process so it works (NEPI)

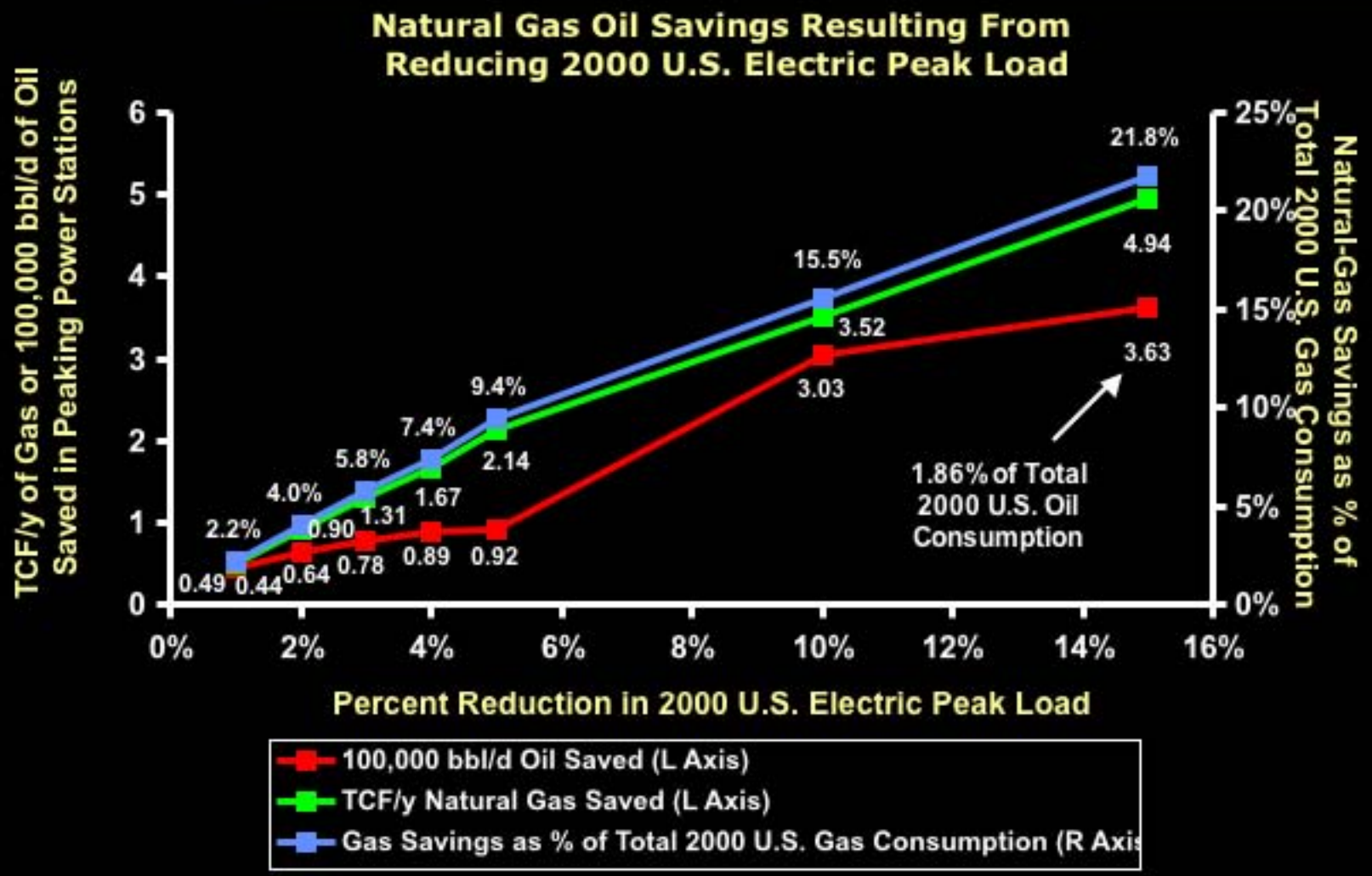
Our economic framework (2000 $)

- EIA 2025 Refiner's Acquisition Cost (RAC) is $26/bbl
- We compare all costs w/ RAC on the *short*-run margin
- We omit all externalities; many are important
  - The market values oil-price volatility at ~$3.5/bbl over next 5 y
  - Some upstream and downstream capex to 2025+ is avoidable
  - Military: U.S. pays ~2–3× as much for peacetime readiness costs of forces whose main mission is Gulf intervention as for Gulf oil; could cost ~$10/bbl (econometric) or several times that much; even so, the market currently attaches a ~$5-12/bbl security-risk premium
  - Nonmilitary federal budget net subsidies: ~$2–3/bbl and rising
  - Environmental and climatic: NAS/NRC ~$11/bbl but very uncertain
  - Major costs to foreign relations, peace, development,…
- We count rebound for light vehicle VMT, but net the effect of sustaining gasoline tax revenues & of IHS
- Transparent: all #s from hand calculator/spreadsheets
- All discounting is at 5%/y real (OMB uses 3.2%/y)

No general-equilibrium calc, but if savings drop RAC far below EIA's $26/bbl…

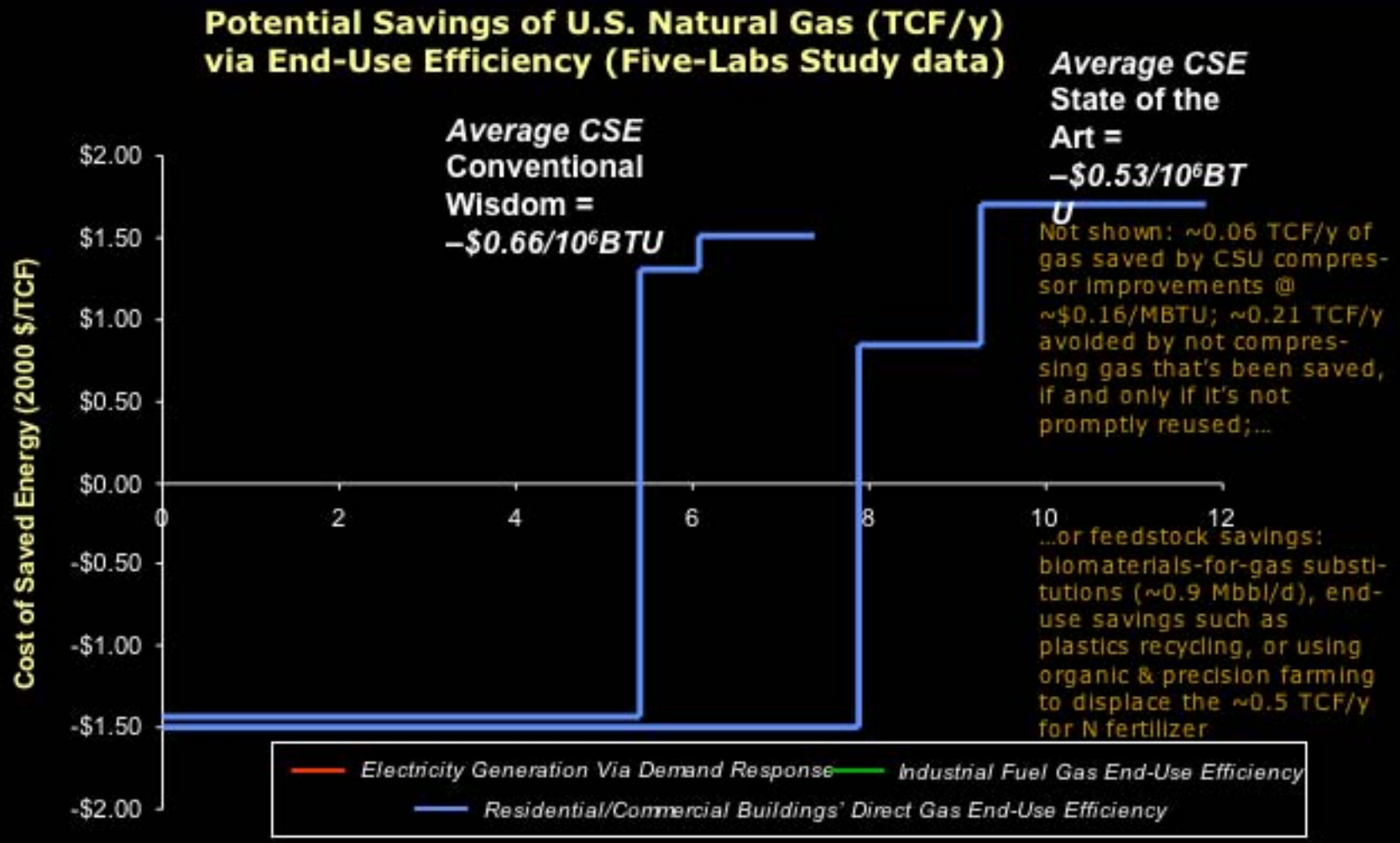
- Since we save half the oil, the value of that saving will drop by the same amount as the cost of the other half—a wash (assuming no change in energy taxation)
- Our savings might decrease at low oil prices, but there are important countervailing effects:
  - Half our *SOA* savings cost <$12/bbl on the short-run margin; the average of *all SOA* savings costs <76¢/gal *retail* gasoline
  - Our *SOA* savings are conservatively calculated, assume only technologies being commercialized now, and omit many options
  - Once installed, efficiency techniques don't get uninstalled—our savings are technological/permanent, not behavioral/temporary
  - If the U.S. fully adopts our recommendations, that's only 1/4 of the world market, diluting 4:1 the effect on world market price
  - While the U.S. & others save, low- & mid-cost reserves outside the Gulf are being depleted, increasing OPEC's market power
  - EIA may understate demand growth in China, India, etc.
- So we don't think lower oil prices (resulting from the wild success and fast, wide adoption of our recommendations) are likely to change our results significantly… though that'd be a nice problem for the world to have

How to return U.S. gas prices to ~$2–3 for ~3–5 y: ~*5% electric* load management/demand response



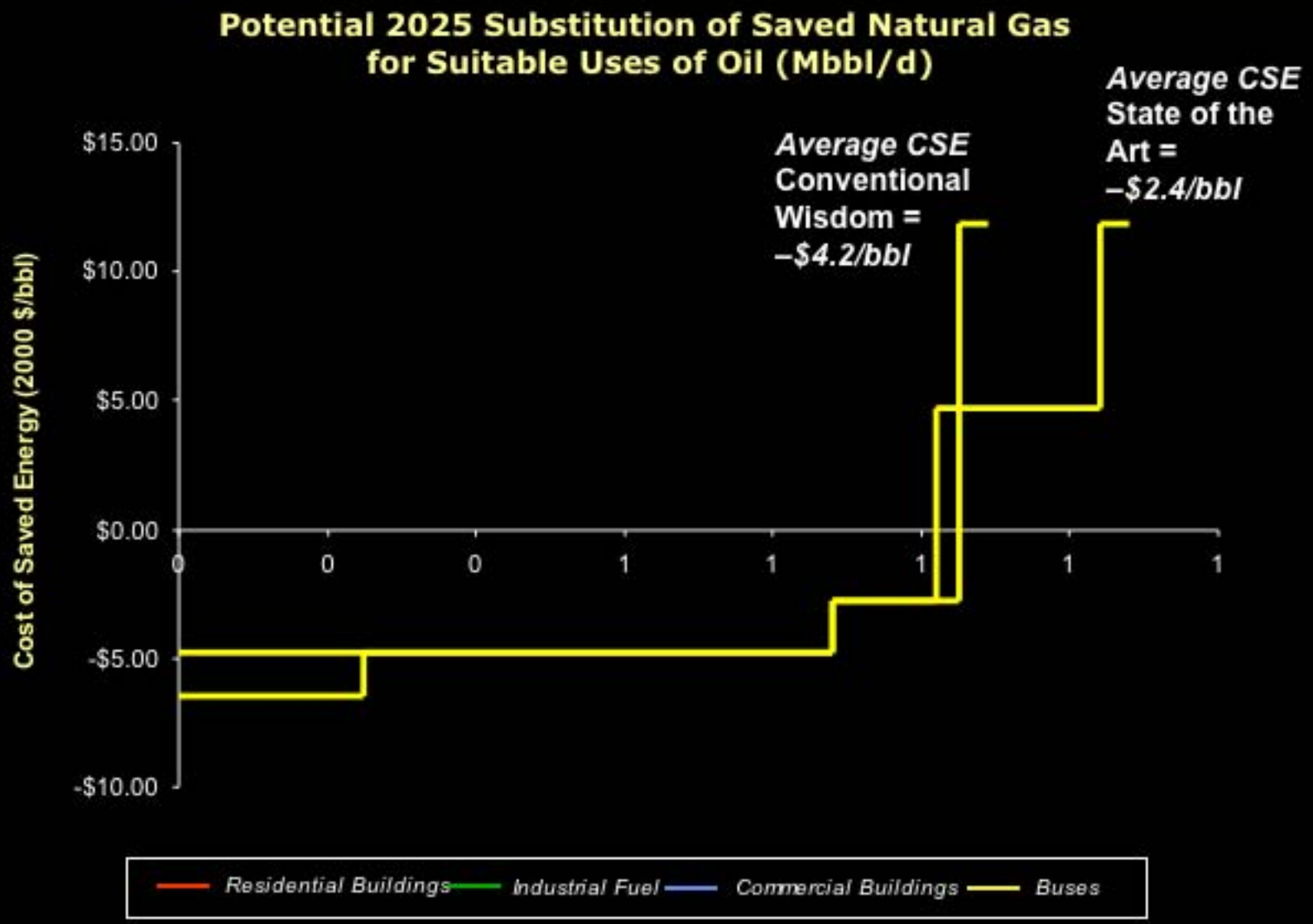
Note: This August 2003 analysis by Kyle Datta and his colleagues at Rocky Mountain Institute uses the entire published plant-by-plant inventory, and assumes economic dispatch. There are unresolved minor uncertainties associated with dual-fueled peaking plants, interregional power flows, and transmission constraints.

Saving U.S. natural gas



Five-Labs (CEF) Study's conservative costs of saving electricity, less avoided onpeak gen. cap. & deferred grid cap., saves electricity at –1.6¢/kWh. Converted at the appropriate heat rates, that can save 25% of total 2025 gas use at –$1.5/10⁶BTU.

Substituting saved gas for oil if relative burner-tip prices unknown



$180 billion total investment for >$150 billion *annual return*

- The **$180 billion investment over 10 years** is small compared to our other choices: **$18 billion a year vs.:**
  - Oil imports (largely wasted, money lost)—**$18 billion every 5–6 weeks**
  - **$40 billion a year** for Homeland Security, some oil-related
  - **$50+ billion a year** in peacetime military readiness for Gulf intervention (~2–3× what we pay to *buy* oil from the Gulf); increasing oil-protection burdens on all Commands
- **>$150 billion a year** in societal value by 2025
  - **$133 billion a year** in lower oil consumption (@ USEIA's $26 a barrel)
  - **$10–30+ billion a year** in military fuel logistics costs saved
  - **$0.5 billion a year** in unnecessary agricultural subsidies
  - **$11 billion a year** in carbon credit value

- **What's it worth to eliminate worries about oil's insecurity, volatility, and depletion? To regain the moral high ground? To have a safer world?**

Today's concept vehicles will go mainstream, integrating ultralight, ultra-low-drag, and advanced-propulsion

CARS: save 69% at 57¢/gal

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

155 mph, 94 mpg

PLANES: save 20% now (*787*), 45% @ 46¢/gal

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

TRUCKS: save 25% free, or 65% @ 25¢/gal

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

The future is already here: today's concept vehicle approaches will be tomorrow's mainstream …

CARS: save 69% at 57¢/gal

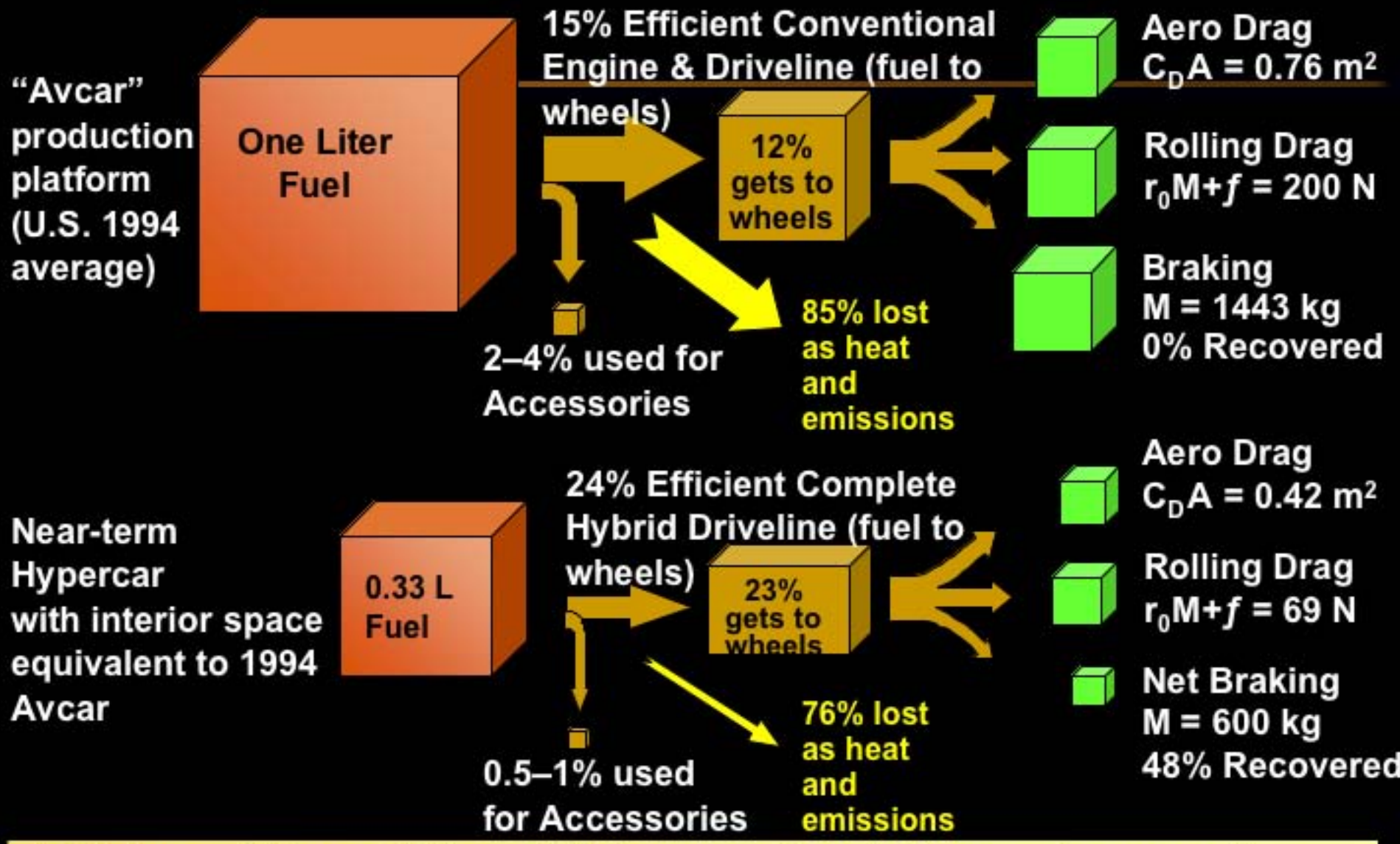
PLANES: save 20% free (*787*), 45% @ 46¢/gal

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

TRUCKS: save 65% @ 25¢/gal

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

Two ways to drive 12 km in the city



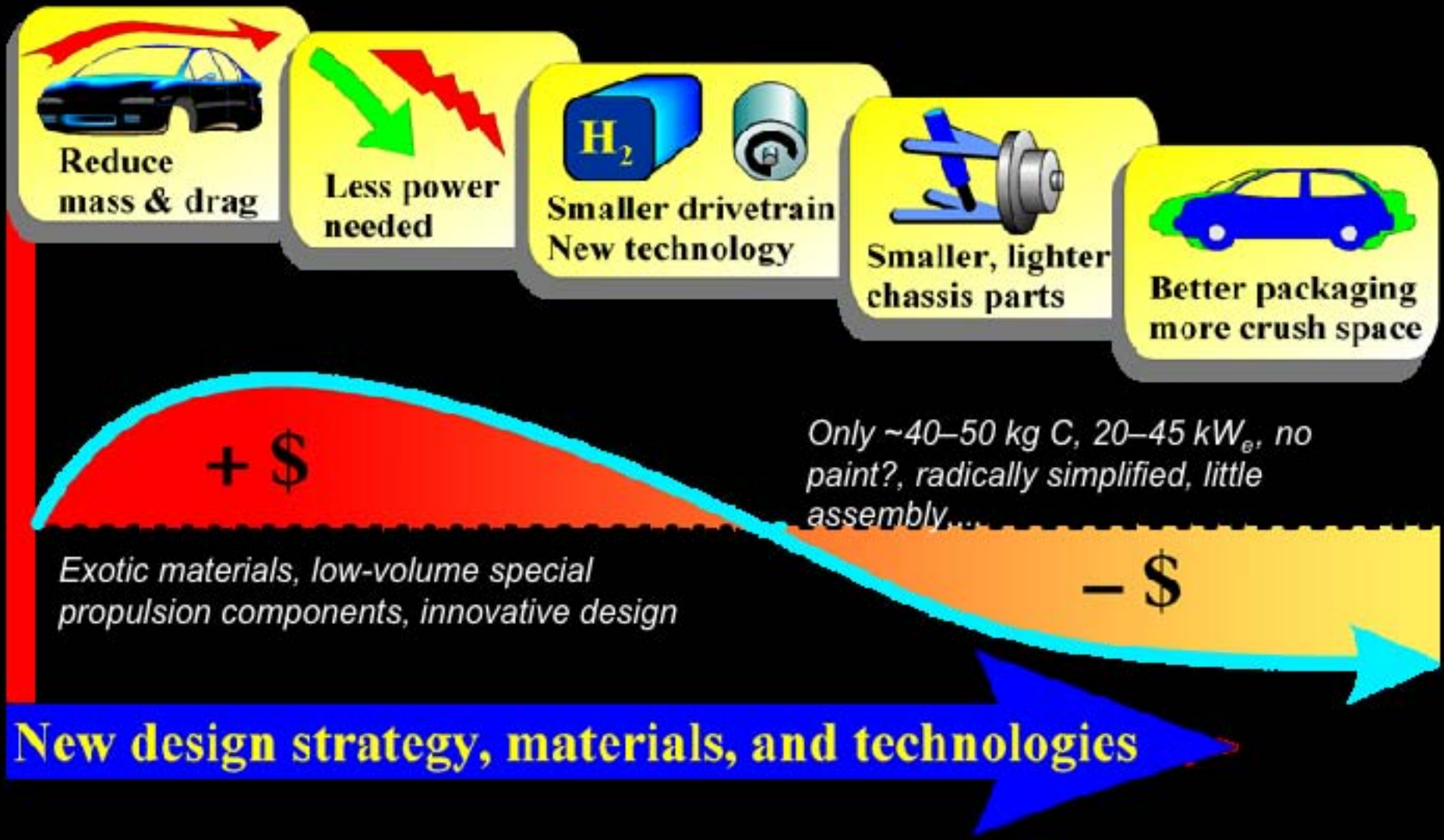
In highway driving, efficiency *falls* because there is far more irrecoverable loss to air drag (which rises as v^3) and less recoverable loss to braking.

Saving >80% of fuel...incidentally

- Conventional design: save fuel as specific goal
- Trade off and compromise other design goals (size, cost, performance, perhaps safety)
- Rely on government intervention—efficiency standards, gasoline taxes, subsidies, mandates—to induce people to buy those less attractive cars

- Hypercar design: make the car *superior*, yet comparably priced, so people will want to buy it (like buying digital media instead of vinyl phonograph records)
- This also happens to save even more fuel
- Ultralight, ultra-low-drag triggers a long series of "virtuous circles"; then hybrid drive can make the car lighter, simpler, cheaper
- Mass savings snowball... nonlinearly

Decompounding mass and com–plexity also decompounds cost



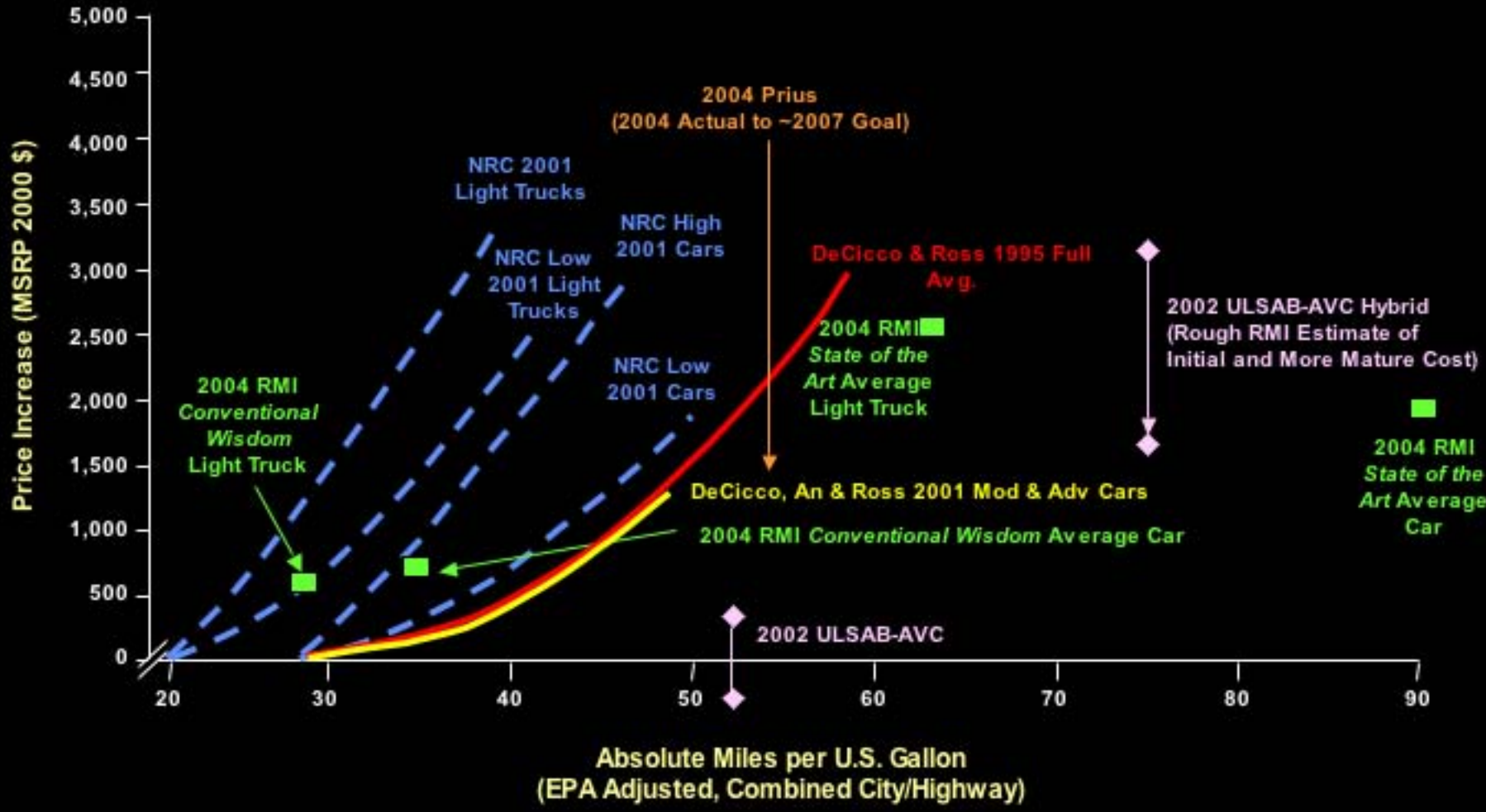
Affordable cars via costly materials

- Conventional design: stamped/welded steel
- Cheap material/kg, but costly to manufacture
- Two years to design & make ~1,000 steel dies
- High capital intensity, breakeven volume, and financial risk per model
- Long product cycle time increases risk
- Uninviting risk/reward profile

- Hypercar design: molded/ glued advanced composites
- Costly material/kg, but we all buy cars by the car, not by the kg; offset by mfg.
- <20 dies, can be soft tooling
- Self-fixturing assembly
- Many-fold less capital, assembly, parts, ?time
- Small propulsion system
- Very low breakeven volume and risk per model
- Not sumo but aikido

Ultralight-but-safe light vehicles open a new, vast, roughly free design space

All Vehicles Shown in Green are Adjusted to EIA's 2025 Acceleration Capability for That Class of Vehicle
RMI's 2004 Average Vehicles are for EIA's 2025 Sales Mix



Detroit must act to avoid the "Creative Destruction" fate

- U.S. share for light vehicles steadily declining; SUVs last profit bastion; Big 3 mkt. capitalization < Toyota
- Consumers want provide comfort and safety without guilt—but won't pay much more
- Breakthrough vehicles will be a disruptive product. Do we have the management vision this shift requires?...
- ...or will we fall short, and succumb to Schumpeter's "creative destruction"?
- The question is who will make them: the U.S. or Japan (or possibly Europe and China and India)?
- If we fail to act, our car companies, and the industrial cluster that depends on them, could fade away
- We can import efficient cars to replace foreign oil...or make the cars ourselves and import neither

Seattle/Chicago has already bet on efficiency: Boeing vs. Airbus

- The competitive battle for the next generation of commercial aircraft features the efficient *787* (~20% less fuel, ~same price) vs. *A380*
- Disruptive change is more than technology, it's also new business models
- Boeing is betting on a change in the airline business model to point-to-point (discounters) vs. fortress hubs (legacy airlines)
- Since the market cap of U.S. discount airlines is already 4× that of the 6 U.S. legacy airlines, Boeing may have made a good bet

Rapid, profitable **H_2 transition**
(RMI, NHA paper, April 1999, www.rmi.org)

- Put fuel cells first in buildings for co-/trigen + UPS
  - Fuel with natural-gas reformers (or off-peak electrolyzers)
  - Big market — buildings use 2/3 of US electricity
- Meanwhile introduce H_2-ready Hypercar® vehicles
  - Fleets (return nightly to the depot for refueling)
  - General market: start with customers who work in or near the buildings that by then have fuel cells
    - Use buildings' hydrogen appliances for refueling
      - Sized for peak building loads that seldom occur
    - Sell kWh and ancillary services to grid when parked
      - Marginal investment in H_2 compression/fueling, grid connection, & more durable fuel-cell stack is modest
    - First ~2M earn back much/most of cost of car ownership
      - U.S. full-fleet potential ~5–10 TW, ~6–12× grid capacity

Rapid, profitable H_2 transition (2)

- Meanwhile, hydrogen appliances get cheaper, so put them outside buildings too
  - At filling stations — a much better business than gasoline
    - Use two ubiquitous, competitive retail commodities — CH_4 and el. — and play them off against each other
    - Use just the offpeak distribution capacity for gas and electricity that is already built and paid for
    - Mainly reformers: electrolyzers favored only at high volume, small unit scale, and cheap offpeak kWh
    - ~10^3 reformers @ US$6/GJ gas beat $0.24/L in $/km
  - Scaleable, modular, big economies of mass-production; carbon sequestration may scale down to the forecourt
  - As both hydrogen and direct-hydrogen fuel-cell vehicles become widespread, bulk production and central distribution of hydrogen becomes practical and may be justified

Rapid, profitable H_2 transition (3)

- ≥2 proven, cost-effective, climate-safe methods
  - Reform natural gas at the wellhead and reinject the CO_2
    - Reforming (6–8% of U.S. gas now) & reinjection are mature
    - Potentially three profit streams: H_2, +CH_x, –C
    - Strong industry interest (BP, Shell, Statoil), 200-y resource
  - Electrolyze with climate-safe electricity
    - Greatly improves ecs. of renewable electricity, bec. H_2-to-wheels is ~2–3× more efficient than gasoline-to-wheels
      - Even U.S. gasoline ($0.33/L) is equivalent at the wheels to $0.09–0.14/kWh electricity with a proton attached to each electron — so run dams in "Hydro-Gen" mode, shipping compressed hydrogen instead of kWh (a value-added product instead of the electron commodity)
      - H_2 storage makes wind/PV power firm and dispatchable
- Probably more: coal, oil, various renewables,...

Demonstrating hydrogen *vs.* gasoline safety

Side-by-side worst-case test of deliberate leakage of hydrogen (left: 1.54 kg = entire tank volume in ~100 s, 185 MJ) compared with a rather small leak of gasoline (right: 1.6-mm hole, 2.37 L, 74 MJ). The hydrogen flame is visible because sodium in particulates naturally present in the air. This test assumed a leak at the tank's Pressure Relief Device (yielding the fastest possible loss) *and* failure of the standard H_2 sensor, pressure-drop, and flow-comparator shutoff devices. A hydrogen leak *under* a fuel-cell vehicle designed to standard protocols would require failure of those three safety devices and of the fuel line. M.R. Swain, "Fuel Leak Simulation," www.eren.doe.gov, 2002.

3 s: Ignition. H_2 @ 28 L/min, gasoline @ 0.68 L/min

60 s: H_2 flow subsiding; max 47˚C on rear window, 19.4˚C on tray behind rear seat. Zooming in on gasoline car…

90 s: H_2 plume nearly stopped.

140 s: Gasoline-car interior alight. Tires later burst.

Hydrogen-ready cars + integration with buildings = fast, profitable H_2 transition

(A.B. Lovins & B.D. Williams, NHA, 1999, www.rmi.org)

- No technological breakthroughs required (new storage tech or onboard reformers); as soon as durable and cheaper fuel cells arrive, fuel-cell cars can be marketed profitably, many years earlier than would be possible with inefficient vehicles
- Staged deployment based on building & gas-station reformers
- Meanwhile, engine or engine-hybrid Hypercar® vehicles can save most of the oil & CO_2 (3.5 L/100 km midsize SUV, vs 2.1 with H_2 FC)
- It doesn't matter whether stacks first become durable (favoring buildings) or cheap (favoring cars); whichever happens first will accelerate both markets
- No need for new liquid-fuel infrastructure (methanol, ultrapure gasoline,…), liquid H_2, or costly central H_2 production/distribution
  - See "Twenty Hydrogen Myths," 2003, www.rmi.org, *Intl J Hydr En* forthcoming
- Integrating mobile and stationary deployment makes the transition profitable at each step (>10%/y real return)

Six hydrogen surprises (see "20 Hydrogen Myths," www.rmi.org)

- >2/3 of fossil-fuel atoms burned today are H_2 — we only need to get rid of the last 1/3 (the carbon)
- Natural gas use won't go up much, may go down
- Hydrogen will need less capital than gasoline does
- Hydrogen would reduce drivers' fuel cost per km
- Hydrogen is more profitable for HC companies
- Hydrogen needs superefficient cars a lot more than they need hydrogen—but once you have them, the business case for producing the H_2 becomes robust
- Just Dakotas windpower could make enough H_2 (50 MT/y, = today's world H_2 production) to fuel all U.S. highway vehicles if they're profitably efficient

Platform physics is more important than powertrain—and is vital to its economics

- Cars can run clean IC engines on gasoline 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: ultralight autobodies, low drag, Otto (3η)
- Power those platforms with IC-engine hybrids (4η)
  - Hypercar 5-seat carbon *Revolution* has the same m_c & C_D as 2-seat aluminum Honda *Insight*…*Insight*-engine hybrid version 3.5L/100km
- Best: put fuel cells in such superefficient bodies (5–6η)
- **The aim isn't *just* saving fuel and pollution**
  - Also strategic goals in automaking, plug-in power-plants-on-wheels, off-oil, primary fuel flexibility, accelerated transition to renewables,…
- **H_2 needs 5η vehicles far more than vice versa**
- **5η vehicles make robust the business case for providing the H_2 that their fuel cells would need**

State/regional policy opportunities

- Electric and natural-gas distribution utilities
  - Efficient use, aligned incentives; distrib. bens. (www.smallisprofitable.org)
- Light vehicles
  - Revenue- and size-neutral feebates; shift registration/excise?
  - Smart procurement (aggregating state and local?)
  - Pay-at-the-pump insurance; shift tax from fuels to roads & driving
  - Fund initial dealer carrying charges/bonuses for superefficient cars
- Heavy trucks
  - Allow extra axle, 2-/3-trailer combos w/better brakes, 60 mph
  - Raise GVWR to EU norm (110klb), 14'H, 59'L
  - Require fuel-economy driver's ed
- Biofuels (integrate with general farm/ranch reform)
  - Procurement, labeling, detaxation?, ?bonds, totalflex vehicles