Hypercars℠, Hydrogen, and Distributed Utilities: Disruptive Technologies and Gas-Industry Strategy

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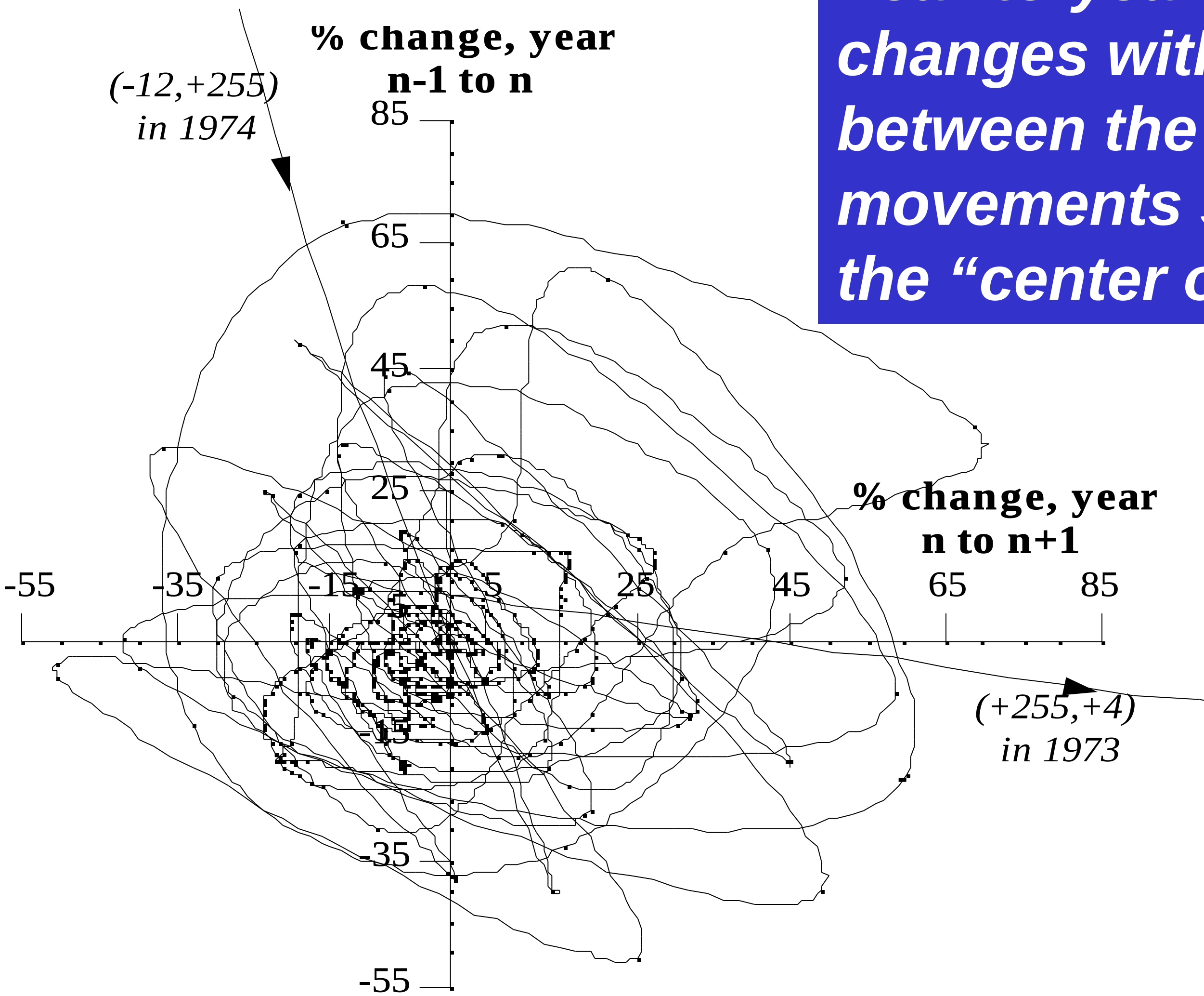
Three Major Linked Surprises

- Hypercars
  - A nega-OPEC of oil savings
  - The biggest industry-changer since chips
  - A major distributed power generator
  - Key to a rapid hydrogen transition
- Distributed utilities
  - Microturbines, renewables, now fuel cells
  - “Distributed benefits”
  - Twelve driving forces
- Major fuel shifts, mainly favoring gas

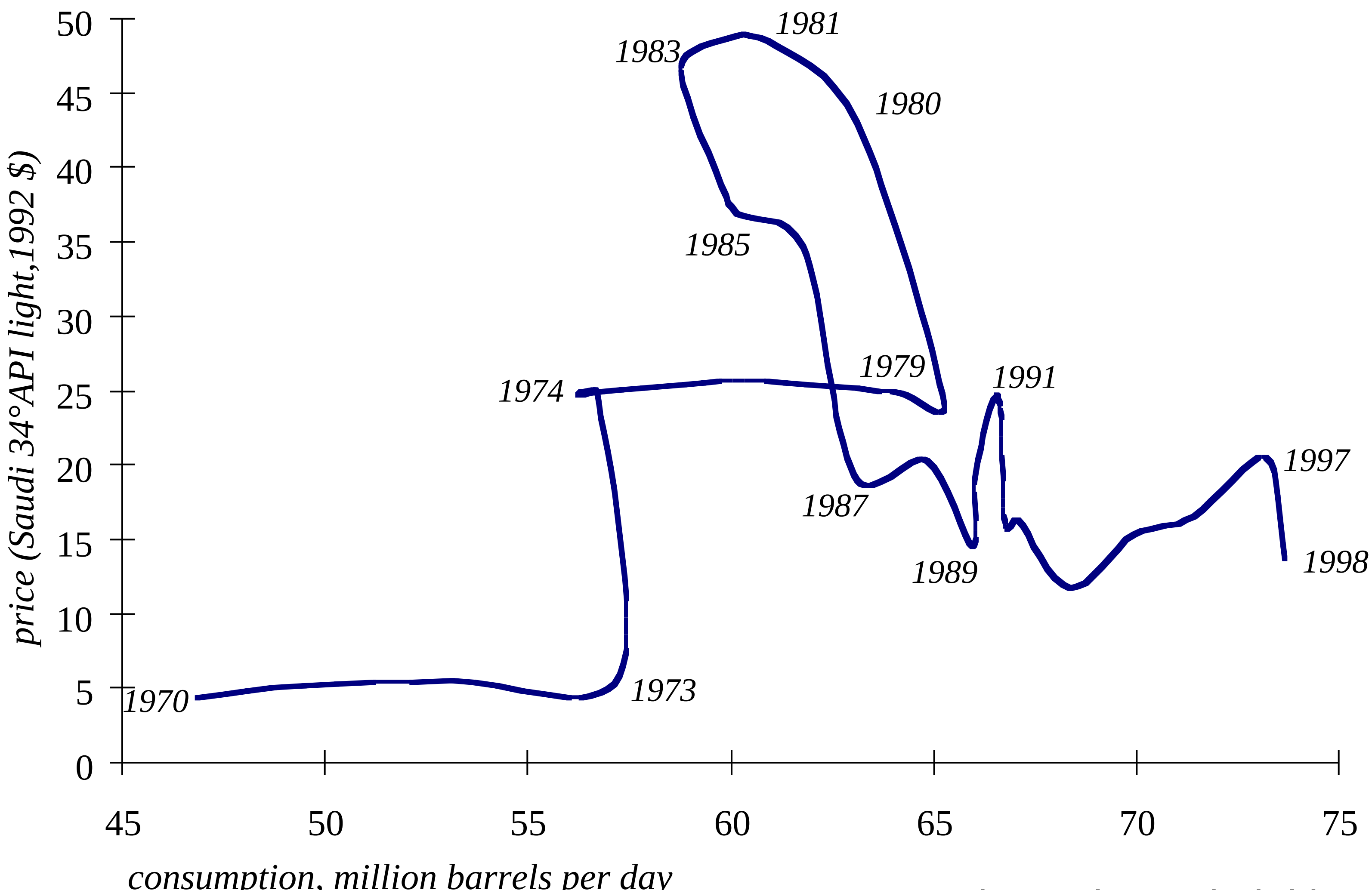
The Brownian Random Walk of World Real Oil Price, 1881–1993

Year-to-year percentage price changes with a one-year lag between the axes. If the price movements showed a trend, the "center of gravity" would favor a particular quadrant. All that happened after '73 is that volatility tripled; changes remained perfectly random, as for any commodity.



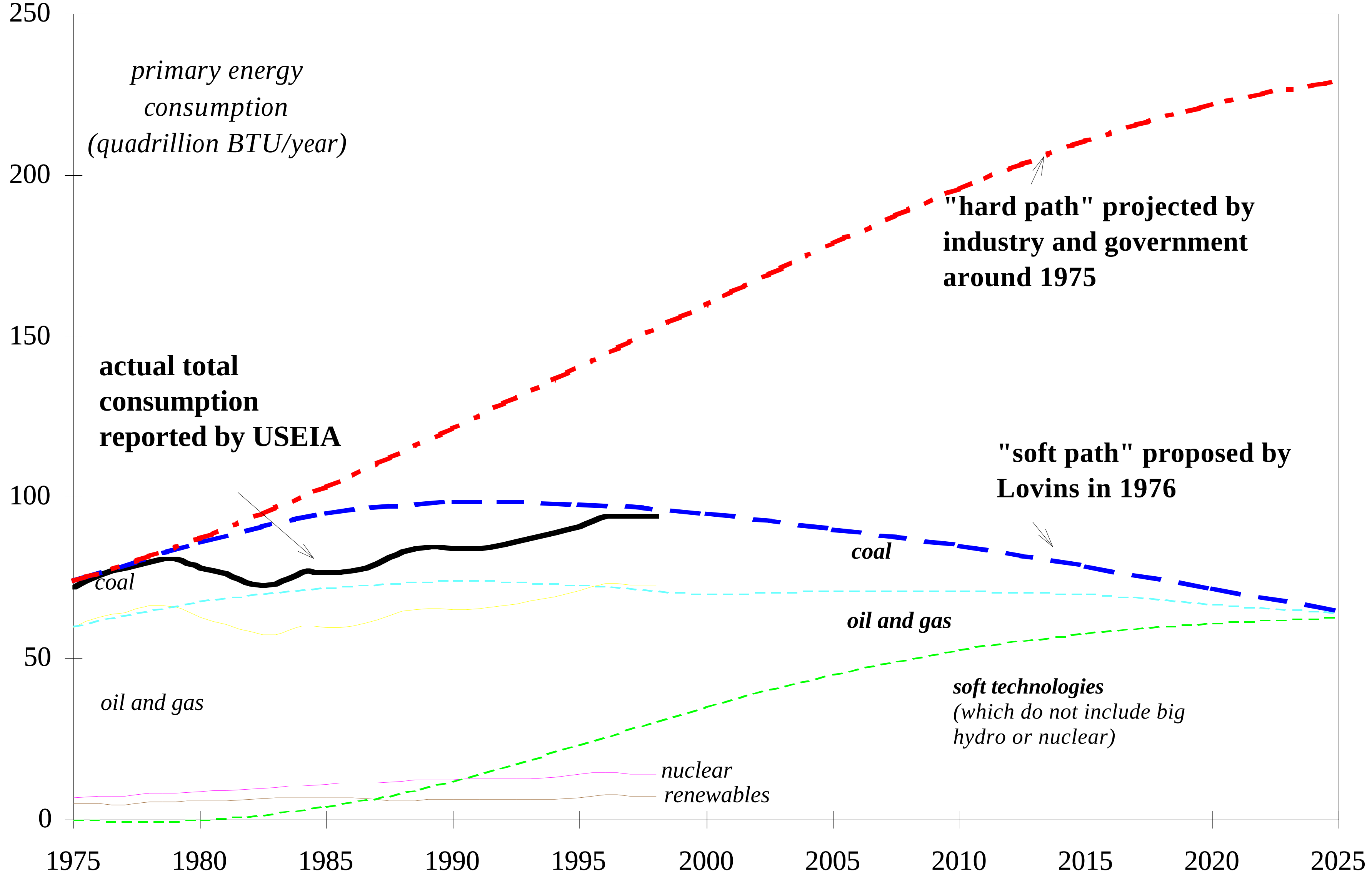
Graph devised by H.R. Holt, USDOE

Energy Surprises: World Oil Price vs. Consumption, 1970–98...



Data source: http://www.doe.eia.gov, downloaded 3 May 2000

…Yet US Primary Energy Consumption Is 2% Below the 1976 “Soft Energy Path”



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Rocky Mountain Institute Moves Ideas to Market

- *18 years of market-based solutions for resource productivity*

- *Laid foundations of the multi-billion-dollar electric-efficiency industry, "green real-estate development," many others*

RMI's HQ—a 99%-passive-solar banana farm at 7100'

- *Earns half its revenue*

- *Four successful for-profit spinoffs*

- *Sold #3 in 1999 to* Financial Times *group for $18M*

The Foundation: RMI's Hypercar Center℠

- ***Proposed the Hypercar™ concept in 1991 (won the 1993 ISATA Nissan Prize)***
- ***Synthesized cutting-edge technologies, designs, and mfg. concepts into a strategy for better cars***

- ***Published extensively (SAE, IBEC, SAMPE, IEEE,…), incl.*** **Hypercars: Materials, Mfg., & Policy Implications**
- ***Global consulting for OEMs, suppliers, new entrants, technology developers, & policy-makers***

Today's Cars: The Highest Expression of the Iron Age...

- Convergent products
- Fighting for ever-smaller niches
- In saturated core markets
- At cutthroat commodity prices
- With stagnant basic innovation
- And growing global overcapacity
- Forcing increasing consolidation
- Profits don't thrill recruits/investors
- A great industry but a bad business

It's time for something completely different!

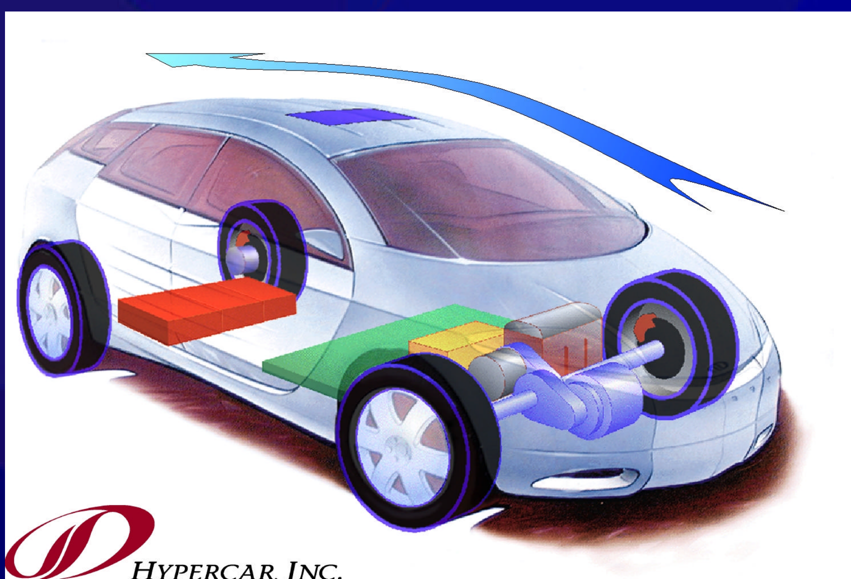
Policy Is as Gridlocked as the Cars

- ***Oil industry calls for stiffer eff. standards***
- ***Car industry calls for higher fuel taxes***
- ***Many environmentalists want both***
- ***Most politicians want neither***
- ***Auto-industry lobbyists are often the last to know their firms' strategic goals***
- ***Meanwhile, oil prices vary randomly***
- ***So, seemingly, do government policies***
- ***Why depend on random variables?***

Do an end-run around the whole mess!

Hypercar SM: Fundamentally Different

- *Synergistic fusion of ultralight, ultra-low-drag, hybrid-electric platform; highly integrated design, radically simplified, software-dominated*
- *Any body style, size, segment*—can be big



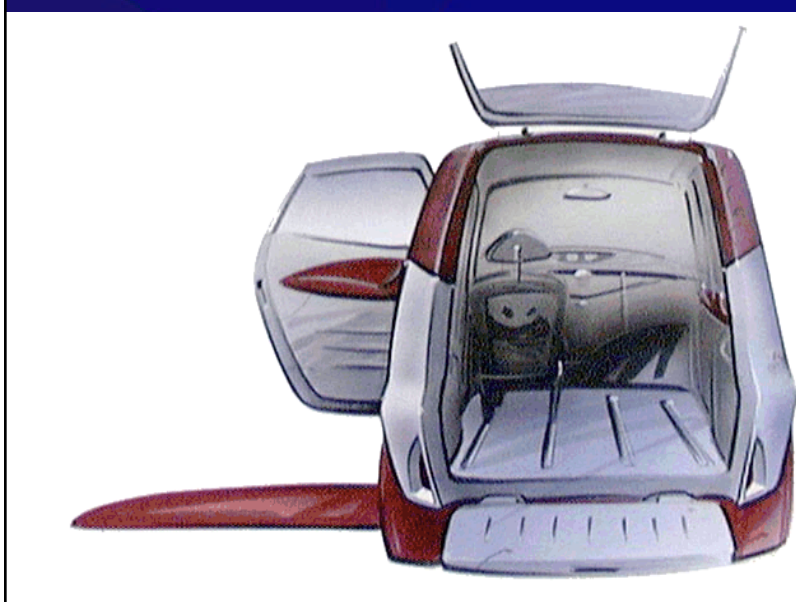
- *~3_–6_, even 8_. efficiency; ZEV; yet cost and all customer attributes are* the same or better
- *Will sell because it's superior and uncompromised (CDs)*
- *Key competitive advantages: up to ~10_ reduction in capital investment, product cycle time, assembly effort and space, body parts count,…*

What's Now Possible

- _-ton capacity (but weighs less), >175 ft^3 cargo, SUV
- Better safety, handling, beauty; hauls up 30% grade
- Sports-car acceleration
- Fine-sedan comfort & NVH
- SUV traction & ruggedness
- 110+ mpg (~2 L/100 km) equivalent as direct H_2
- 600-mi range (~50 mi/lb H_2)
- Zero-Emission (hot water)
- Ultrareliable, flexible,wire-less, software-dominated
- Competitive cost expected
- Decisive mfg. advantages

Unusual Commercialization Strategy

1993: RMI put Hypercar concept/ analysis in the public domain (free-software model); maxi-mized competition in exploiting its market and competitive ad-vantages, via compartmental-ized, nonexclusive support for OEMs and new market entrants



- ***>30 firms committed ~$10b 1993–2000, doubling ea. 1_ y***
- ***Very rapid movement to mar-ket: www.hypercarcenter.org***
- ***But OEMs' cultural barriers left key competitive gaps to exploit, so RMI formed Hypercar, Inc. in 1998 and spun it out in 8/99***

Elements of Hypercars℠ Are Emerging

- *12/91: GM shows the halved-weight-and-drag, doubled-efficiency carbon-fiber Ultralite concept car (but doesn't know someone else did it two years earlier).*
- *11/96 (Reuters): GM says it's developing "radically" more efficient cars with halved weight and drag and hybrid-electric drive, rightly calling them "hypercars."* Nihon Keizai Shimbun *reports Toyota will sell in Japan, in late 1997, tens of thousands/y of a 66-mpg hybrid sedan.*
- *3/97:* The Wall Street Journal *confirms that this Toyota "Prius" saves 50% of fuel and 90% of emissions; and, separately, that by 10/97, Ford will test-drive "P2000" all-aluminum midsize sedans with 40% less mass, 60–70 mpg, ultra-low emissions, and two kinds of hybrids.*

- *4/97: Ballard and Daimler-Benz invest US$350M to put fuel cells in cars, pledging 100,000 cars/y by 2005. Ford says it’ll test a fuel-cell P2000 by 2000.*
- *9/97: Chrysler unveils a modest $6k molded-composite 4-seat compact “China car”: 1,200 lb (half the weight of a Neon, but roomier), 15% cheaper, meeting all profitability requirements, needing 5_ less investment and 7_ less factory space, and 60 mpg without hybrid drive (or, one can estimate, ~100+ with it). Honda announces it’s developed a ~70-mpg hybrid car lighter than the Prius.*
- *10/97: Toyota announces 12/97 Japan launch of its Prius hybrid, and predicts hybrids will gain* a 1/3 world market share by 2005. *Toyota’s President says he’ll beat the Daimler-Benz/Ballard 100k/y-by-2005 fuel-cell-car goal.*

- ***10–11/97: Audi announces the light A2 and VW the Lupo, both ~80 mpg, for 1998 production. Volvo, Nissan, and others announce they're developing commercial hybrids.***
- ***12/97: Toyota's Prius hybrid dominates the Tokyo Motor Show, wins two coveted Car of the Year Awards, enters the Japanese market at ¥2.15M ($16.3k), presells 3k units, and heads for U.S. launch ~2000. GM retorts that it will be "second to none." Ford adds >$420M to the Daimler/Ballard fuel-cell project. Honda and Subaru show ~70-mpg ultracapacitor-buffered concept hybrids. Mazda says its fuel-cell hybrid will use H_2 gas, not reformed liquids. Mercedes announces limited production of methanol-fuel-cell cars in 2002. Nissan and Toyota show concept versions of such cars; Nissan shows the first public Li-battery car.***

- ***1/98: GM unveils gas-turbine, diesel, and fuel-cell 4-seat hybrid versions of its low-drag EV-1—relatively heavy, but 60–80 mpg, 0–60 mph in 6–8 s, and ranges >350 to >550 miles—and promises production-ready hybrids by 2001 and fuel-cell versions by 2004 "if not sooner." Front-page*** **Wall Street Journal** ***and*** **New York Times** ***stories confirm Detroit's revolutionary shift and stress GM's "deadly serious" intent.*** **Automotive News** ***says the Ford P2000 "could be in dealerships by 2000." Chrysler shows the Pronto Spyder composite concept sports-car (whose U.S.-crashworthy 6-piece body could cut factory investment 3_ and car cost 2_), saying it could enter production "as soon as 2003," and the 70-mpg hybrid-assisted light-weight composite ESX concept car.***
- ***2/98: VW says it'll make ~78, ~118-, then ~235-mpg cars.***

- *3/98: Ford's head of advanced materials and manufacturing, asked if he isn't concerned that someone else might make Hypercars first, replies, "Yes, we're absolutely* terrified*—that's why we're working so hard on it!"*
- *5/98: At least five automakers plan to start selling ~80-mpg cars before 2000. Toyota nears breakeven two years early on strong Prius sales (temporarily suspended while production caught up)—and says it hopes to market fuel-cell cars "well before 2002" (now officially 2003).*
- *6/98: Chrysler accelerates Spyder production to 2001.*
- *7/98: Toyota confirms 2000 U.S./Eur. Prius release. Zevco announces 1999 fuel-cell London taxi demo—H_2 by Shell.*
- *8/98: Shell agrees to provide its liquids-to-H_2 reformer technology to the Daimler/Ford/Ballard fuel-cell group.*

- *8/98 (cont'd.): Fifty-year-old Huatong Motors (Sichuan) differentiates itself in the crowded Asian market by announcing ~1999 production of 5,000 (30,000/y by 2002) 60-mpg molded-plastic-and-composite-monocoque hybrid "Paradigm" cars designed by a small Texas firm. Singapore's Asha/Taisun plans '99 China polymer taxis.*
- *10/98: VW announces early-2000s production of a ~118-mpg, 1,300-pound carbon-fiber subcompact. GM shows a fuel-cell concept minivan, market-ready in 2004, and says fuel-cells-plus-electric-driveintegration has "more potential than any other known propulsion system."*
- *12/98: Honda will sell a 2-seat ~66-mpg U.S. hybrid-assist coupé in 12/99 for $19,500. The 47%-lighter aluminum/ plastic "Insight" has air drag one-third below normal.*
- *1/99: Ford says it's designed an aluminum MeOH-fuel-cell sport-utility and built a Taurus-performance fuel-cell P2000 sedan. Ford also cites studies showing that small,*

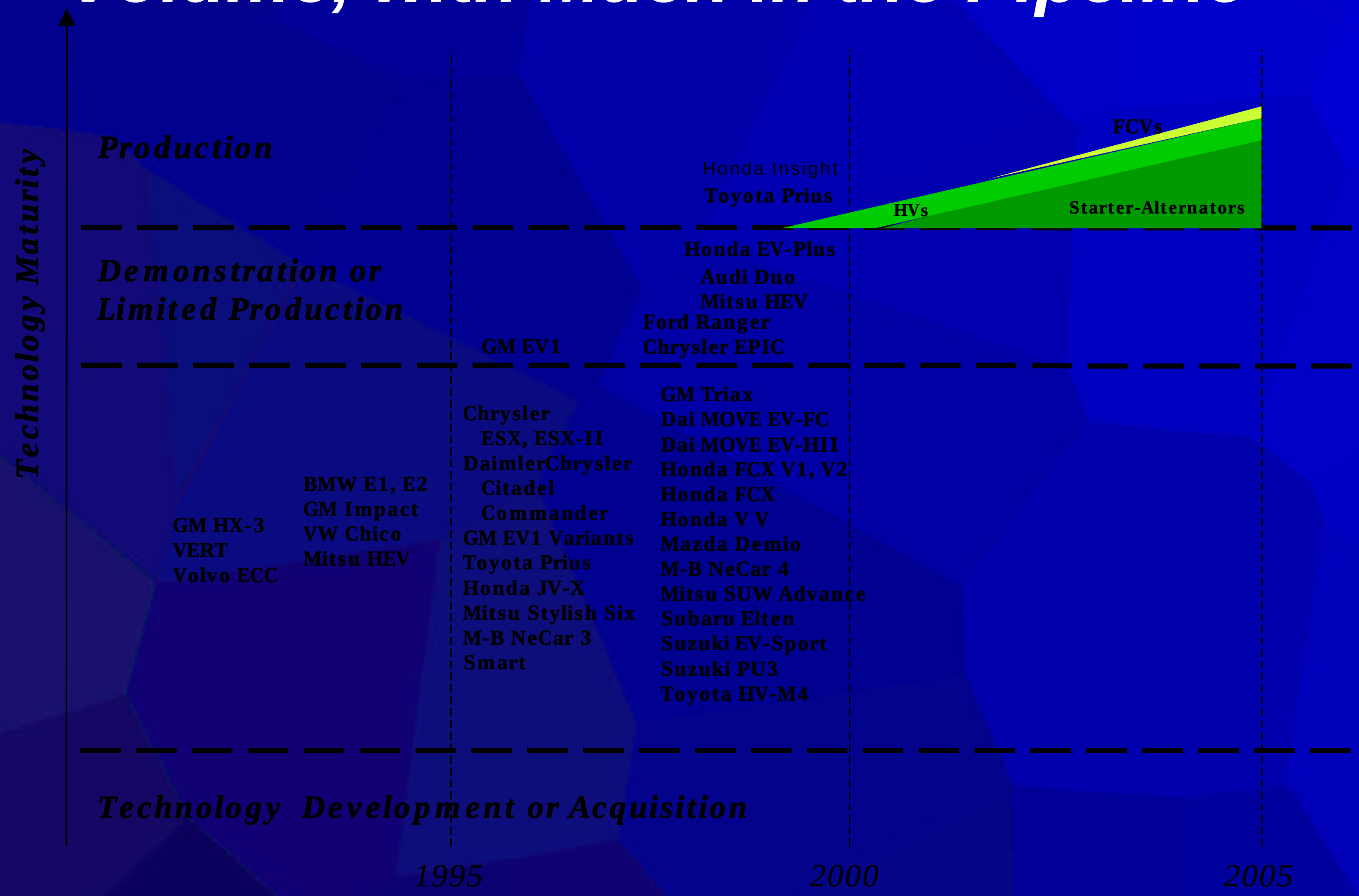
…factory-built electrolytic or steam-reformer hydrogen generators can make H_2 competitive with gasoline. Daimler-Chrysler shows the big, high-performance, gasoline-hybrid "Citadel" crossover vehicle; Jeep, the reformer-fuel-cell-hybrid "Commander," a large, active-suspension sport-utility with 40% mass reduction via a carbon-fiber body and composite/aluminum frame. DOE announces a PNGV project to cut inverter cost by at least 95% in the next three years.

- *3/99: Mitsubishi announces a hybrid to sell in late 2000 at half the $18,000 price of the Toyota Prius.*
- *4/99: Honda abandons battery cars to concentrate on hybrids. GM and Toyota launch a big 5-year collaboration on fuel cells, electric drive, and hybrids. Swatch explores US hybrid-car coproduction in 2002. BMW teams with Delphi on solid-oxide-fuel-cell cars.*

- ***5/99: Toyota announces a hybrid van and SUV; the Big 3 consider tripled-efficiency SUVs for PNGV. Lotus announces a light composite Boxster-competitor and a 2000 Opel-badged Elise. Formosa Plastics commits $2b to make 500k/y polymer electric cars, including a hybrid. Honda commits $0.4–0.5b to fuel-cell cars for production by 2003.***
- ***6/99: Toyota follows suit. Ford's Chairman says customers "can have any vehicle they want, as long as it is green."***
- ***7/99: Toyota projects 40k Eur./US sales of the Prius hybrid.***
- ***10/99: Three Japanese automakers show 87–92-mpg city cars. GM shows a halved-air-drag sedan (C_D 0.163), reveals its "G" program based on "dramatic weight savings,…aerodynamic shapes,...and smaller, lighter, more efficient drivelines," and a Hypercar-like Chevy Triax concept car. [Lots more news after 10/99…will update shortly.]***

If that's what they're announcing…imagine what they're up to behind the curtain! (They are. The global competition RMI is fomenting leaves them no choice.)

An Assessment for USDOE Shows Electric Drive Moving Rapidly to Volume, with Much in the Pipeline



Courtesy of Keith Hardy, CSMII Inc., and USDOE; examples largely complete to 12/99; retitled; Insight added.

Hypercars: Design Strategy

Dramatically reduced loading:

- *Aerodynamic & rolling resistance*
- *Heating, cooling, accessory loads*
- *Most important, vehicle mass ÷ 3*

Key: manufacturable advanced-composite autobody

Clean, efficient hy-brid-electric drive —preferably direct-H_2 fuel cell (the fuel tanks are now small enough to package)

Integrated advanced control systems, data management, and wire-less communications

Hypercars: Fundamental Change

Hypercars represent a fundamental change from:

- ***metals to composites***
- ***hard to soft tooling***
- ***hardware to software***
- ***liquid to gaseous fuel***
- ***fully mechanical to hybrid-electric drive***
- ***mechanicals/hydraul-ics to electronics***
- ***complexity to radical simplicity***

Advanced Polymer Composites: Lighter, Stronger, Safer, Better

Benefits

- *2/3 lighter than steel*
- *but stiffer and stronger*
- *highly tailorable properties*
- *safe: 110+ kJ/kg (5_ steel), square-wave crush response*
- *doesn't dent, rust, or fatigue*
- *many in-mold color options*
- *radar stealth, bullet-resistant*
- *reparability established*
- *recyclability demonstrated*
- *very low capital cost*
- *if soft tooling, very fast pro-duct cycles, flexible scale, low breakeven volumes, di-versified model portfolio,…, hence lower financial risk*

Challenges

- *competitive cost : computer-modeled but not yet empirically proven*
- *manufacturability: steps each demon-strated separately but not yet integrated*

Barriers that handicap OEMs

- *very sparse composite mfg. experience*
- *wrong cost metrics: cost/kg, part, or BIW, not per finished car, so can't see how costly material & cheap mfg. can match/beat cheap material & costly mfg.*
- *black-steel mentality, "metal mindset"*
- *little whole-system, lifecycle costing*
- *little true design for manufacturing*
- *unamortized assets, not sunk costs*
- *don't see they must kill their products*

Does the Frog Leap?

- *Incremental, component-level design, from engine toward wheels, emphasizing driveline gains*
- *Assume steel, gain mass*
- *Dis-integrated, specialist*
- *Huge design group (10^3)*
- *Relay race*
- *Lose most synergies*
- *Institutionalized timidity*
- *Baroque complexity*
- *Complex, hence difficult*

- *Whole-car, clean-sheet design, wheels-back, emph. platform physics*
- *Ultralight, maximize mass decompounding*
- *Integrative, holistic*
- *Tiny design group (10^1)*
- *Team play*
- *Capture all synergies*
- *Skunk Works™ boldness*
- *Radical simplicity**
- *Simple, hence difficult*

Einstein: "Everything should be made as simple as possible—but not simpler."

Hypercars Will Ultimately…

- *save as much oil as OPEC now sells*
- *displace 1/8 of the steel market early, ~7/8 eventually (as carbon fiber becomes cheap): out of the Iron Age*
- *spell the end as we know them of the car, oil, steel, aluminum, coal, nucle-ar, and electricity industries…and the start of successor industries that are more benign, profitable, and fun*

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Hypercars Can Greatly Accelerate the Hydrogen Transition

- ***Make cars ready for direct hydrogen***
  - ***So efficient that the tanks package well***
  - ***No liquid-fuel reformer needed***
  - ***3_ lower tractive load makes driveline smaller, lighter, simpler, cheaper***
  - ***tolerates 3_ higher $/kW, reached earlier***
- ***Integrate stationary/mobile uses***
- ***Make the H_2 transition* profitable at each step, starting now*, by a sequence RMI published at NHA 4/99, already being adopted by major energy/car companies***

Key to H_2: Transform Automobility

Redesign the car so it's ready for hydrogen, not the reverse!

Hypercars Are Half of the Solution

- *It's essential to integrate their deployment with stationary applications to leverage both*
- *Stationary and vehicular markets are each so big that* **whichever** *develops first will strongly encourage the other too, by building production volume and cutting fuel-cell and H_2-appliance cost*
- *But logically, most stationary applications will enter the market first, thus:*

[considering only Proton Exchange Membrane Fuel Cells]

Start with Stationary Cogen Applications

- PEMFCs for buildings enter mass market in 2001
  - At least 84 firms now active; some giants still quiet
  - Early mass-production factories now being built
  - Equipment/system distribution 2001+ by capable firms
- 70°C waste heat's bldg. services help pay for H_2
  - Reformer or electrolyzer appliance makes H_2 onsite
  - Thermal credit makes premium el. net-cost-effective
- Special benefits could justify even handmade-by-PhDs PEMFCs (3k$/kW) in many niche markets
  - El. distribution grid congestion can cost >1k$/kW to fix
  - Industrial niche markets can justify PAFC retrofits now
- Buildings use two-thirds of all U.S. electricity
- Volume + Design for Mfg. & Assembly = cheap

From Stationary to Mobile Applications

- ***At ~\$100/kW$_e$, put PEMFCs in Hypercars[SM]***
  - ***2–3_ conventional cars' \$/kW$_e$ limit, so years earlier***
    - ***At least 8 major automakers plan volume production of fuel-cell cars by 2004–05 (some may enter earlier)—some direct-H_2***
  - ***High efficiency permits H_2-gas tank, eliminates reformer***
    - ***Less weight, cost, bulk; further mass decompounding***
    - ***High driveline efficiency, lower Pt loading, instant response***
    - ***If you had a good reformer, better to take it out of the car!***
  - ***20–45-kW$_e$ power plant on wheels, parked ~96% of time***
  - ***Lease first to workers* in or near FC-powered buildings**
  - ***Park, plug into grid &* building H_2*, sell back power***
    - ***At real-time price, when and where power is worth the most***
    - ***Can often earn back one-third to one-half of car's lease fee***
  - ***U.S. Hypercar fleet will ultimately total ~3–6 TW$_e$—~5–10_ the total generating capacity of the national grid***

Orderly Buildup of H_2 Infrastructure

- *The H_2 appliances soon to be ubiquitous* in *buildings can serve nearby vehicles too, obviating special fueling stations & supplementing revenues*
- *Distributed H_2 appliances can be freestanding too*
  - *Modular, scalable electrolyzers & reformers mass-produced (for buildings) would become affordable: DTI*
  - *A corner "gas station" could use gas or el. or both*
    - *People now build gasoline stations to earn tiny margins and be dominated by refiner & distributor; H_2 is just the opposite; it's also not easy for governments to tax homebrew H_2*
    - *Use surplus offpeak capacity of natural-gas & electric grids already built & paid for; strong H_2 price competition*
  - *This can support a PEMFC price path to <$50/kW_e$—then the hydrogen provider gives you the fuel cell!*

Last *of All, Benign Upstream H_2 Production and Distribution*

- *Making H_2* now *uses ~5% of U.S. natural gas*
  - *Mature infrastructure available, more rapidly emerging*
- *Two known, climate-safe ways to make bulk H_2*
  - *Electrolyze water using renewable electricity*
  - *Reform natural gas at the wellhead and reinject CO_2*
  - *Other options may also prove practical & worthwhile*
    - *Biofuels and biosystems (algae,…) producing hydrogen*
    - *"Synthetic photosynthesis" molecules*
    - *Direct photolysis (sunlight plus catalyst)*
  - *Even if not, the two conventional methods are both practical and profitable, and their competition will drive further improvements in both*

A New Market for Renewable Electricity...

Hydro dams can earn far more profit as "Hydro-Gen" plants—just ship each electron with a proton attached

- ***1 J of direct H_2 in a fuel-cell car can produce 3–4_ as much traction as 1 J of gasoline in today's cars***
- **At the wheels *of the car, $1.25/gal thus has the same tractive value as H_2 efficiently electrolyzed using ~9–14¢/kWh electricity—vs. today's ~1.6¢/kWh Pacific Northwest bulk electricity market price***
- ***This margin typically exceeds the cost of producing and delivering the hydrogen, so dam's profits rise***
- ***Seasonal H_2 geological storage for NW salmon runs?***
- ***Cheap local H_2 storage converts intermittent renew-ables (wind, PV,…) into firm dispatchable resources that are far more valuable***

…and a Rich Long-Run Future for Gas

- ***Bob Williams (Princeton): reform CH_4*** **at gas wellhead, *reinject CO_2 into gasfield***
- ***Triple profit potential***
  - ***Ship hydrogen as premium product for fuel cells***
  - ***Enhance hydrocarbon recovery by repressurizing***
  - ***Sell carbon resequestration to a broker***
    - ***Can often fit in twice as much CO_2 as there was CH_4***
- ***This profit opportunity is already attracting major energy firms (Shell, BP, Norsk Hydro,…)***
- ***200+ years' CH_4 resource then becomes profitably usable without harming the climate***

Hydrogen for Fun and Profit

- *A robust future waiting to be unlocked*
  - *Could profitably ameliorate ~2/3 of U.S. CO_2*
  - *Strong retail price competition*
  - *Four main ways to make hydrogen*
    - *From electricity or natural gas, upstream or downstream*
    - *Not betting on the [random] price of one automotive fuel or the stability of its sources: highly diversified portfolio*
    - *Resource base ranges from huge to inexhaustible*
    - *Climate impacts modest short-term, soon reaching zero*
- *Expensive to delay*
  - *~$1 trillion in capital cost for the next global car fleet and its fueling infrastructure is at issue*
  - *Caution: “fuel neutral” is code for “status quo”*
- *Policy is barely starting to catch up*

Fuel Cells Capture "Distributed Benefits"

- **Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size *(RMI, late 2000; now in draft)***
- ***Codifies and quantifies ~75 "distributed benefits" that increase economic value of decentralized generation by typically ~10_***
- ***Four kinds: financial economics, electrical engineering, miscellaneous, externalities***
- ***"Fuel Cells Are Profitable" (RMI, fall 2000) will apply this work specifically to fuel cells***

Twelve Drivers of Distributed Utilities

- "Distributed benefits" sharply raise value
- Supply-side advances
  - Superefficient end-use → less/cheaper supply
  - Onsite cogen/trigen: microturbines, PAFC,…
  - PEMFCs in buildings, plug-in Hypercars,…
  - "Hydro-Gen," renewable H_2, wellhead-reformed natural gas, sustainable biofuels
  - Building-integrated/"vernacular" PVs, cheap windpower, other competitive renewables
  - 96+%-efficient electric storage, reversible FCs

Twelve Drivers (continued)

- **Grid and control advances**
  - Advanced switches/telecom let distribution grid automation shift grid topology from unidirectional tree to omnidirectional web
  - Pervasive real-time energy and stability pricing, customer communication; “out-of-control” distributed intelligence?
    - Control can disperse at least to substation level
    - Perhaps even to customer or device level

Twelve Drivers (continued)

- Market/institutional advances
  - Competition values many previously unmonetized distributed benefits
  - So does unbundling power quality & relia-bility, grid stability, cost control,…
  - New market entrants better understand needed disciplines (financial ecs.,…)
  - Local Integrated Resource Planning (being done by >100 North American electric utilities) prospects for distributed benefits

The Distributed Utility Revolution

- ***All twelve drivers reinforce each other, regardless of restructuring outcomes***
- ***The shift to distributed generation is rapidly accelerating***
  - ***US new units mainly at 1940s scale ($10^{6–7}$ W)***
  - ***Will soon be at 1920s scale ($10^{3–4}$ W)***
- ***Most restructuring ignores this reality***
- ***Important rules remain unresolved***
- ***But market demand will probably force simpler interconnects, net metering,...***

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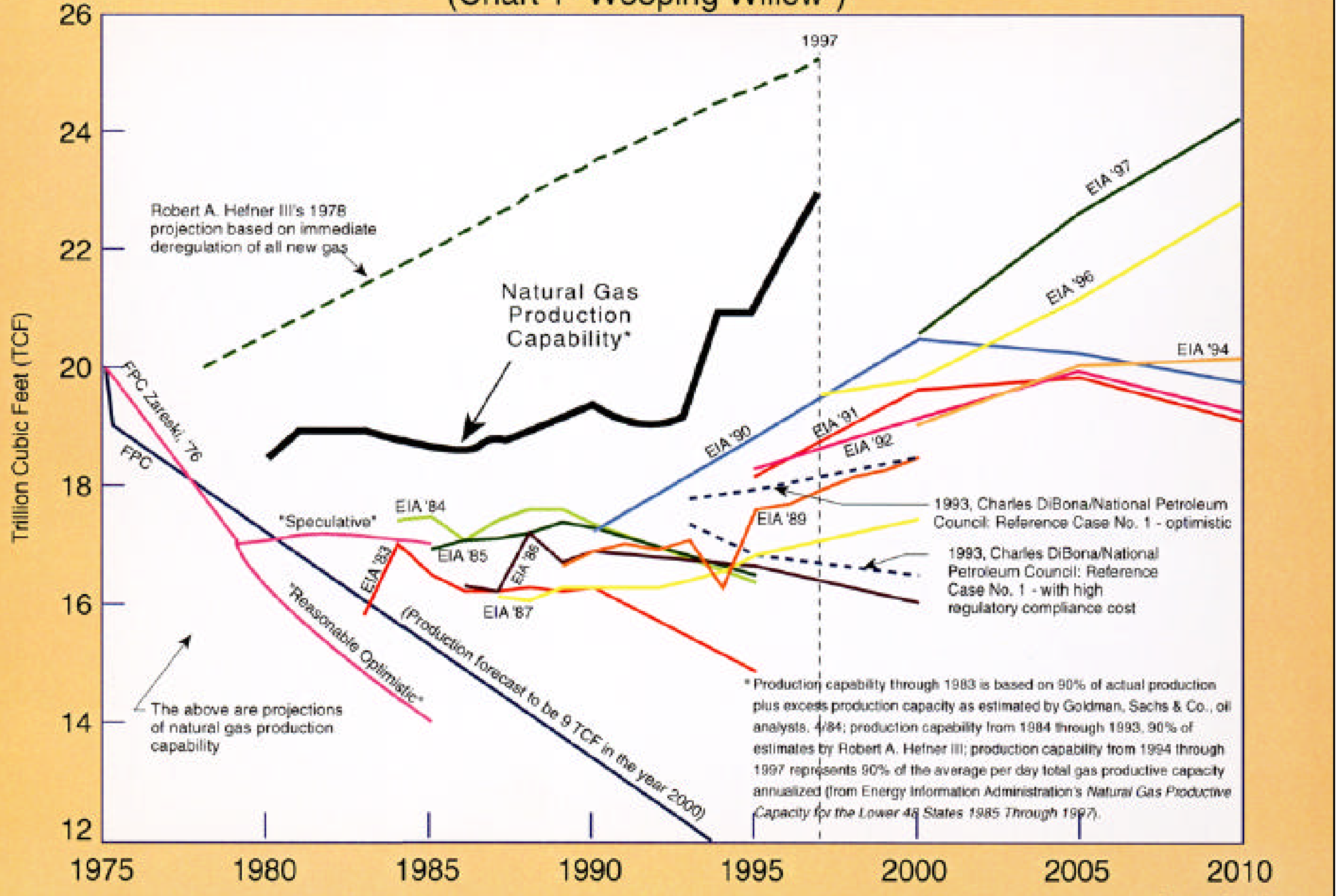
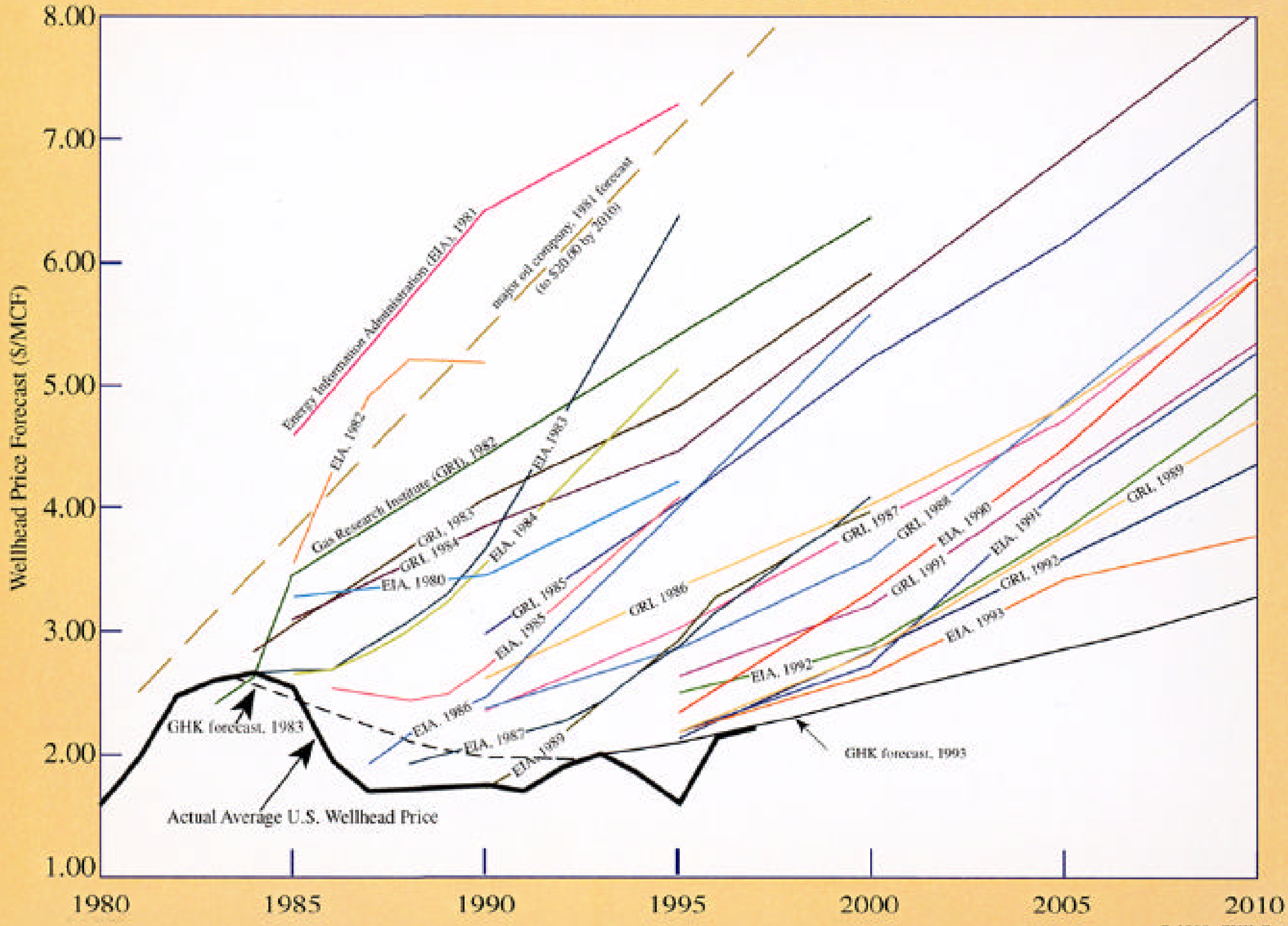
Strategic Implications for Gas

- ***Bad news: combined-cycle plants probably won't beat onsite co- and tri-generators***
- ***Good news: that's largely because of huge growth in fuel cells initially using $CH_4 \rightarrow H_2$ (and in the short run, CH_4 microturbines)***
- ***Both electric and gas heat will lose share***
- ***But CH_4 will become a major* car *H_2 source***
- ***Nobody knows* net *effect on gas demand***
  - ***Both quantity & daily/seasonal loadshapes***
  - ***Thermal and electric efficiency could become even more important in a fuel-cell world***

Various U.S. Natural Gas Production Forecasts vs. Actual Production Capability
(Chart 1 "Weeping Willow")



Forecasts of Future U.S. Natural Gas Wellhead Prices
Made from 1980 through 1993
(Chart 2 "Price Explosion")



Strategic Implications (continued)

- ***Wellhead reforming can fully use global gas resources, yet protect the climate***
- ***Gas must still beat efficiency & renew-ables; will their combination raise or avoid long-term gas availability issues?***
- ***As a H_2 source, gas will need to beat off-peak, not onpeak, electricity; but fuel-cell outputs will beat onpeak electricity better***
- ***Not clear whether more gas pipes are needed (may simply raise utilization), but new ones should be hydrogen-compati-ble, and conversions should be studied***

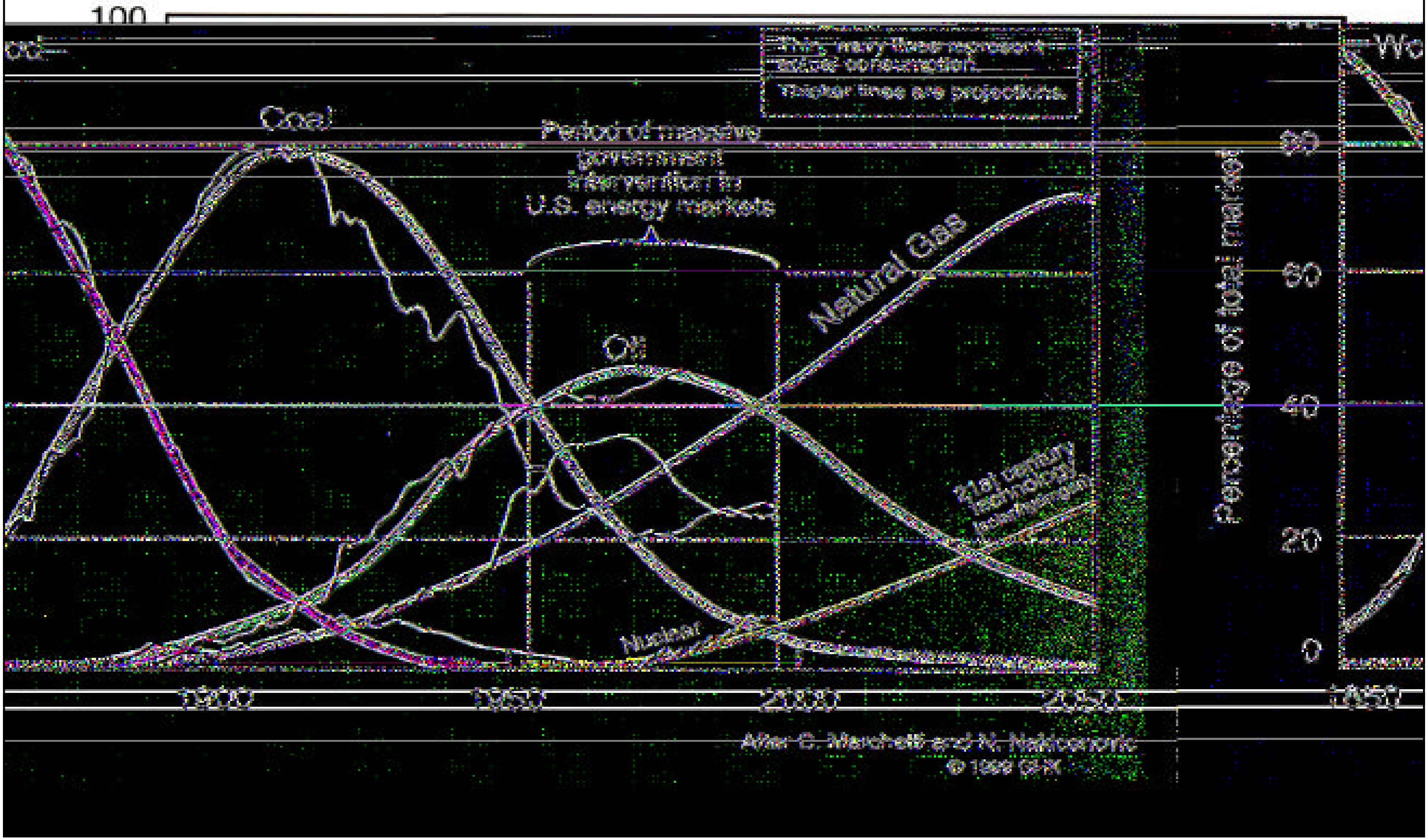
Illustrative Shifts: Pacific Northwest

- *Import oil for transportation*
- *Heat with BC gas and electricity*
- *Electricity from hydro and thermal (coal being phased out, gas combined-cycle phased in)*
- *Minor renewables*
- *Key energy carrier is* grid *electricity*

- *Import no oil*
- *Fuel-cell vehicles, buildings, most inds.*
- *Hydrogen main ener-gy carrier, from BC gas, “Hydro-Gen,” & wind/PV electricity*
- *Minor direct gas use for heat*
- *Minor central hydro-electric supply, most el. generated onsite*

Robert Hefner's Vision Is Looking Sounder All the Time...

U.S. Primary Energy Substitution (Chart 4)



And the Oil Endgame Is Starting

- ***Many oil majors wonder whether to say so; the chairs of four already did***
- ***In light of* all *demand- and supply-side alternatives, oil will probably become uncompetitive even at low prices before it becomes unavailable even at high prices***
- ***Don Huberts (head of Shell Hydrogen): "The Stone Age did not end because the world ran out of stones, and the Oil Age will not end because the world runs out of oil."***

The Oil Endgame (continued)

- *Like uranium already and coal increasingly, oil will become not worth extracting—good mainly for holding up the ground—because other ways to do the same tasks are better and cheaper*
- *Driven by E&P, efficiency, & substitution*
  - *Coal is already in absolute decline worldwide: China's burn in 2000 will be back to the 1986 level, with a very rapid shift to gas*
  - *Wind and PVs are the fastest-growing energy sources worldwide; renewables, the fastest-growing supplies in Europe*

The Oil Endgame (continued)

- *The half-renewables-in-2050 Shell global scenario now looks likely, even conservative*
- *The US has just set a new all-time record for speed of saving energy—~4%/y 1997–99—despite record-low and falling energy prices*
  - *Perhaps 1/3 from E-commerce structural change*
  - *Essentially all the rest from technical efficiency*
- *GDP and CO_2 are rapidly decoupling*
  - *World: 1998 GDP +2.5%, CO_2 –0.5%; '99 even better*
  - *US: economy growing ~5–10_ as fast as CO_2*

- ***But this cornucopia is the manual model—you must actually go turn the crank!***

Thank you! And please visit...

- ***www.rmi.org* (general information)**

- ***www.hypercar.com* (the new technology development company)**
- ***www.naturalcapitalism.org* or *www.natcap.org* for short (the wider context—making business far more profitable by behaving as if nature and people were properly valued)**

About the author: A consultant experimental physicist educated at Harvard and Oxford, Mr. Lovins has received an Oxford MA (by virtue of being a don), six honorary doctorates, a MacArthur Fellowship, the Heinz, Lindbergh, World Technology, and Heroes for the Planet Awards, and the Nissan, Mitchell, "Alternative Nobel," and Onassis Prizes; held visiting academic chairs; briefed 12 heads of state; published 27 books and several hundred papers; and consulted for scores of industries and governments worldwide. *The Wall Street Journal*'s Centennial Issue named him among 28 people in the world most likely to change the course of business in the 1990s, and *Car* magazine, the 22nd most powerful person in the global automotive industry. His work focuses on whole-system engineering; on transforming the car, energy, chemical, semiconductor, real-estate, and other sectors toward advanced resource productivity, and on integrating resource efficiency into the emerging "natural capitalism."

About Rocky Mountain Institute: This independent, nonpartisan, market-oriented, technophilic, entrepreneurial, nonprofit organization was cofounded in 1982 by its co-CEOs, Hunter and Amory Lovins. RMI fosters the efficient and restorative use of natural and human capital to help create a secure, prosperous, and life-sustaining world. The Institute's ~50 staff develop and apply innovative solutions in business practice, energy, transportation, climate, water, agriculture, community economic development, security, and environmentally responsive real-estate development. RMI's ~$5-million annual budget comes roughly half each from programmatic enterprise earnings (mainly private-sector consultancy) and from foundation grants and donations. Its work is most recently summarized in *Natural Capitalism* (with Paul Hawken; Little Brown, 9/99).

About Hypercar, Inc.: Rocky Mountain Institute transferred most of the technical activities of its Hypercar Center—whose public outreach function continues—to this partly-owned for-profit subsidiary, its fourth spinoff, in August 1999. Funded by private investors, Hypercar, Inc. pursues business opportunities related to the Hypercar concept developed at RMI since 1991.