Hypercars℠: Uncompromised Vehicles, Disruptive Technologies, and the Rapid Transition to Hydrogen

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Redefining the Global Automotive Industry: Technologies and Fuels for the Future

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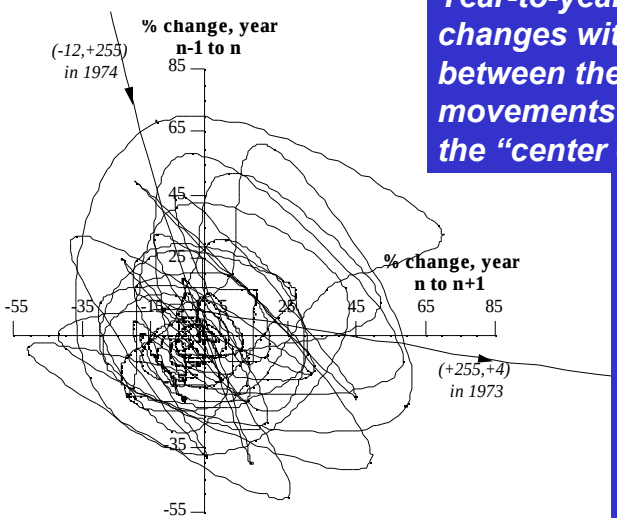
Business Won't Be As Usual

- *Official projections assume smoothly evolving technologies and markets*
- *But many "disruptive technologies" are now entering the market, often from unfamiliar sectors and sources*
- *Very large fuel savings can cost* less *than small ones (www.natcap.org)*
- *Traditional economic/political perspectives and oil-/car-industry developments offer little warning of big discontinuities*
- *Disruptive technologies interbreed*
- *Fasten your seat belts!*

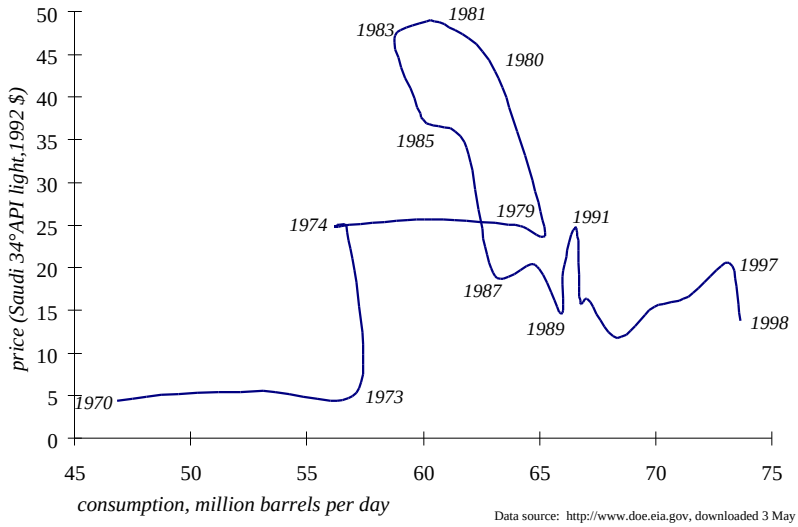
The Brownian Random Walk of World Real Oil Price, 1881–1993



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 1973 is that volatility tripled; changes stayed perfectly random, just as for any other commodity.

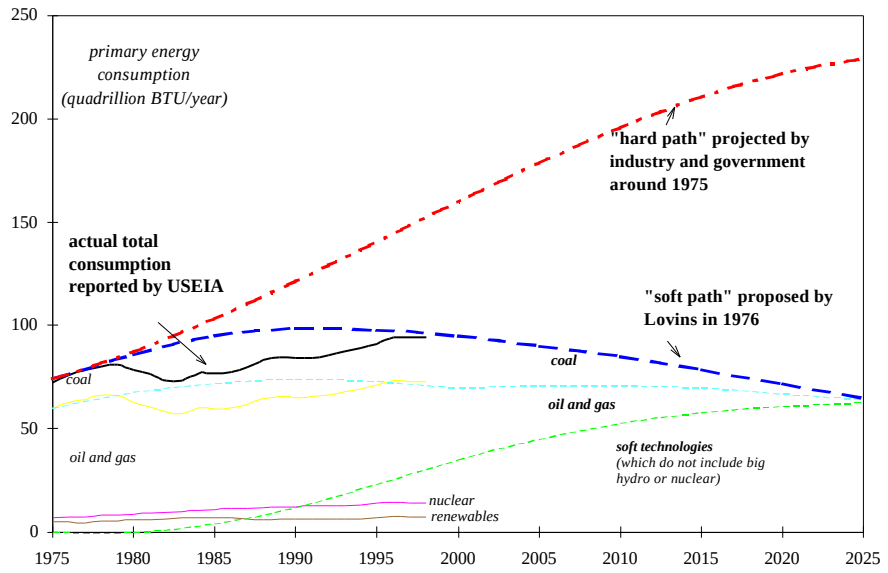
Graph devised by H.R. Holt, USDOE

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



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

US Primary Energy Consumption Is 2% Below the 1976 "Soft Energy Path"



Driving Forces May Be Nontraditional

- Not fuel price: other factors matter more
  - In 1990–96, Seattle, despite electricity prices half Chicago's, saved electric load 12_ and electric energy 3640_ as fast as Chicago
  - In 1996–99, the US neared an all-time record for 3-year primary E/GDP decrease (3_%/y), despite record low and falling energy prices
- Not emissions regulation: breakthrough vehicles can make it irrelevant
- Not alternative fuels: won't be needed
- CDs replaced vinyl phonograph records… but not because polycarbonate became cheaper than polyvinyl chloride

Hypercars℠: A Comprehensive Surprise

- *The biggest industry-changer since chips*
- *A nega-OPEC: 9+ Mbbl/d in N. America,...*
- *Soon a major distributed power generator with a unique value proposition*
- *Key to fast, profitable hydrogen transition*
- *New market entrants, low entry barriers*
- *Greatly improved risk/reward profile*
- *Driven by customer & maker advantages*
- *Success is market-driven,* independent *of both fuel price and government policy*

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!

US 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!

Rocky Mountain Institute Moves Ideas to Market

- 18 years of market-based design and technical 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 2200 m

- Earns half its revenue
- Four successful for-profit spinoffs
- Sold #3 in 1999 to Financial Times group for $18M

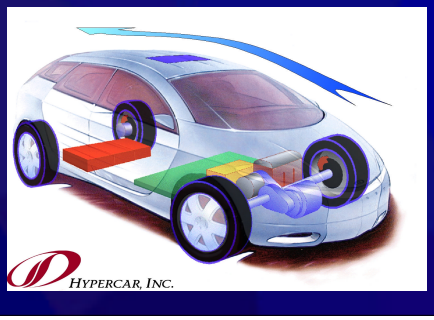
The Foundation: RMI's Hypercar Center℠

- 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

Hypercar℠: The Next Car Industry

- 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
- Key competitive advantages: up to ~10_ reduction in capital investment, product cycle time, assembly effort and space, body parts count,…

What's Now Possible

- Sport-utility, hauls _ ton up a 30% hill (but weighs less)
- 6+ adults, >5 m^3 cargo
- Mercedes safety & comfort
- BMW acceleration, handling
- Truck traction, ruggedness
- ~2 L/100 km* as direct H_2
- 1000 km (~180 km/kg H_2)
- Zero-emission (hot water)
- Ultra-reliable, flexible,wireless, software-dominated
- Competitive cost expected
- Decisive mfg. advantages

*a family sedan could get ~1 L/100 km

RMI's Unusual Commercialization Strategy

1991–93: Validated concept

1993: Rejected patent-and-auction route; put concept and much supporting analysis into the public domain so it's unpatentable but attractive (free-software model)

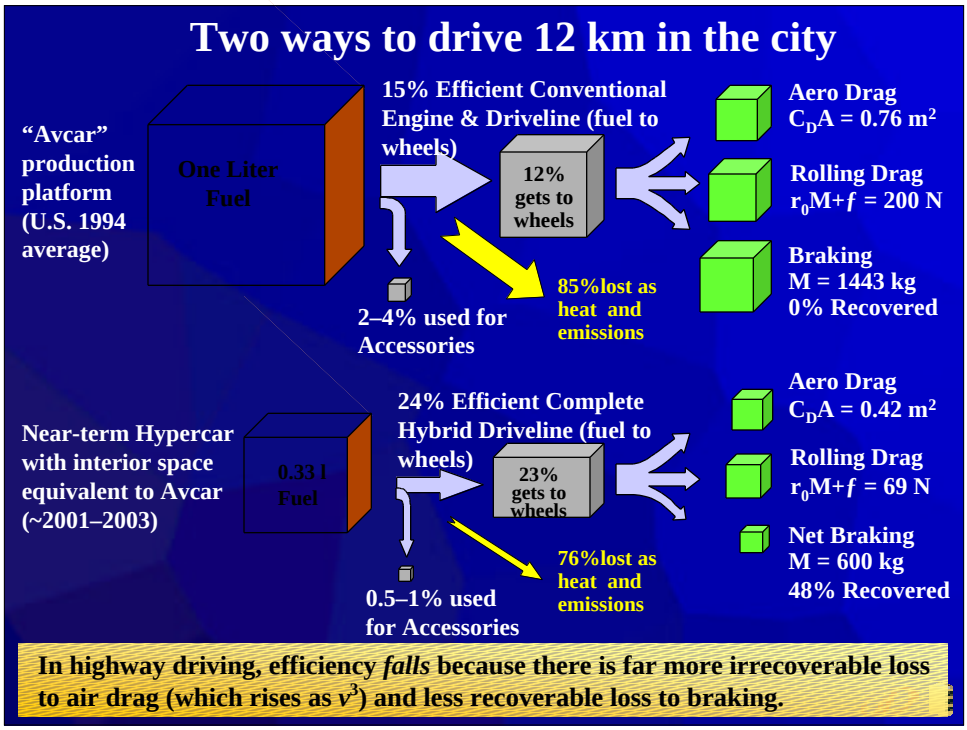
1993–99: Maximized competition in exploiting the idea

1993– : Rapid movement to market—www.hypercarcenter.org

by 2000: >30 firms committed ~$10b, doubling every ~1_ y

Automakers' cultural barriers left competitive gaps for agile & uninhibited to exploit, so RMI spun out Hypercar, Inc. in 1999

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.

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 hybrid-electric drive—preferably direct-H_2 fuel cell (the fuel tanks are now small enough to package)

Integrated advanced control systems, data management, and wireless communications

Advanced Polymer Composites: Lighter, Stronger, Safer,...Cheaper?

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 product cycles, flexible scale, low breakeven volumes, diversified model portfolio,…, hence lower financial risk

Challenges

- competitive cost : computer-modeled but not yet empirically proven
- manufacturability: steps each demonstrated 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 steel early, ~7/8 ultimately*
- *spell the end as we know them of the car, oil, steel, aluminum, coal, nuclear, and electricity industries…and the start of more profitable and benign successors*

WHEN? Within your planning horizon!

- *Hypercars will be widely available in ~5 years, dominant in ~10 y*
- *The old car industry will be toast in 20 y*

This needs no price or political changes!

Hypercars Can Greatly Accelerate the Hydrogen Transition

- *Make cars ready for direct hydrogen*
  - *Packageable ~350-bar compressed-H_2 tanks*
  - *No liquid-fuel reformer needed*
  - *3_ lower tractive load needs 3_ fewer kW*
  - *Tolerates 3_ higher $/kW, reached earlier*
- *Integrate stationary and mobile uses to leverage both (both markets very big)*
- *Make the H_2 transition* profitable at each step, starting now*, by a sequence RMI has published*, already being adopted by major energy and car companies*

**"A Strategy for the Hydrogen Transition," Natl. Hydrog. Assoc., 4/99, www.rmi.org*

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 being built 1999–2000*
  - *Equipment/system distribution by big, 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 FC retrofits now*
- *Buildings use two-thirds of all US 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 during 2003–05—an increasing number of them 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*
  - *US 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 and supplementing revenues
- Distributed H_2 appliances can be freestanding too
  - Modular, scalable electrolyzers & reformers mass-produced for buildings would become affordable (DTI/Ford)
  - 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 US 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 fuel-cell cars can produce 3–4_ as much traction as 1 J of gasoline in Otto-engine cars*
- At the wheels *of the car, US$1.25/gal ($0.33/L) gasoline has the same tractive value as H_2 efficiently electrolyzed with ~$0.09–0.14/kWh electricity—*vs. *today's ~$0.016/kWh PNW bulk el. market price*
- *This margin typically exceeds the cost of producing and delivering the hydrogen, so dam's profits rise*
- *Cheap local H_2 storage can convert intermittent renewables (wind, photovoltaics,…) into firm dispatchable resources that are far more valuable*

…and a Long Natural-Gas "Bridge"

- *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 US 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, heading for 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

Strategic Implications for Oil

- Oil isn't a great business anyway
  - Upstream and downstream rents nearly squeezed out; much political interference
  - Capital-intensive, long lead times
  - Price-taker in volatile markets
- So best to liquidate reserves early
  - Before the market discounts them further for this latest negative factor
  - Could invest proceeds in Hypercar industry as a hedge ("negabarrel straddle")
    - If cars do well, make less money on oil but more on cars; some are already doing this

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 (CEO, 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*
- *GDP and CO_2 are rapidly decoupling*
  - *World: 1998 GDP +2.5%, CO_2 –0.5%; '99 better*
  - *US: economy growing 6__ as fast as CO_2*
  - *All without new tech, tunneling, or price rises!*
- *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.hypercarcenter.org** (public information about Hypercars)*
- ***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): see* **Natural Capitalism** *(Little Brown, NY, & Earthscan, London)*

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, the Happold Medal, 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, including the oil industry since 1973. *The Wall Street Journal*'s Centennial Issue named him among 39 people in the world most likely to change the course of business in the 1990s, and *Car* magazine, the 22nd most powerful person in the global automotive industry. His work focuses on whole-system engineering; on transforming the car, energy, chemical, semiconductor, real-estate, and other sectors toward advanced resource productivity, and on the emerging "natural capitalism."

About Rocky Mountain Institute: This independent, nonpartisan, market-oriented, technophil-ic, 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 ~US$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.