Hypercars\textsuperscript{SM}: 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


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\textsuperscript{SM}: 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
- Earns half its revenue
- Four successful for-profit spinoffs
- Sold #3 in 1999 to Financial Times group for $18M

RMI’s HQ—a 99%-passive-solar banana farm at 2200 m
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 _1_ ton up a 30% hill (but weighs less)
- 6+ adults, >5 m³ cargo
- Mercedes safety & comfort
- BMW acceleration, handling
- Truck traction, ruggedness
- ~2 L/100 km* as direct H₂
- 1000 km (~180 km/kg H₂)
- 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**

"Avcar" production platform (U.S. 1994 average)

- **One Liter Fuel**
  - 15% Efficient Conventional Engine & Driveline (fuel to wheels)
  - 85% lost as heat and emissions
  - 2–4% used for Accessories


- **0.33 l Fuel**
  - 24% Efficient Complete Hybrid Driveline (fuel to wheels)
  - 23% gets to wheels
  - 76% lost as heat and emissions
  - 0.5–1% used for Accessories

- **Aerodynamic Drag**
  - $C_D = 0.76 \text{ m}^2$

- **Rolling Drag**
  - $r_0M_f = 200 \text{ N}$

- **Braking**
  - $M = 1443 \text{ kg}$
  - 0% Recovered

- **Aerodynamic Drag**
  - $C_D = 0.42 \text{ m}^2$

- **Rolling Drag**
  - $r_0M_f = 69 \text{ N}$

- **Net Braking**
  - $M = 600 \text{ kg}$
  - 48% Recovered

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.

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**Hypercars: Design Strategy**

*Dramatically reduced loading:*
- Aerodynamic & rolling resistance
- Heating, cooling, accessory loads
- *Most important, vehicle mass $\times 3$*

*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<sub>steel</sub>), 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 break-even 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<sup>3</sup>)
- 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<sup>1</sup>)
- 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

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 H₂**
  - Reformer or electrolyzer appliance makes H₂ 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/kWₑ, put PEMFCs in Hypercars℠**
  - 2–3 conventional cars’ $/kWₑ 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-H₂
  - **High efficiency permits H₂-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-kWₑ power plant on wheels, parked ~96% of time**
  - **Lease first to workers in or near FC-powered buildings**
  - **Park, plug into grid & building H₂, 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 TWₑ—~5–10 the total generating capacity of the national grid**
Orderly Buildup of H₂ Infrastructure

• The H₂ appliances soon to be ubiquitous in buildings can serve nearby vehicles too, obviating special fueling stations and supplementing revenues
• Distributed H₂ 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; H₂ is just the opposite; it's also not easy for governments to tax homebrew H₂
    • Use surplus offpeak capacity of natural-gas & electric grids already built & paid for; strong H₂ price competition
  – This can support a PEMFC price path to <$50/kWₑ— then the hydrogen provider gives you the fuel cell!

Last of All, Benign Upstream H₂ Production and Distribution

• Making H₂ now uses ~5% of US natural gas
  – Mature infrastructure available, more rapidly emerging
• Two known, climate-safe ways to make bulk H₂
  – Electrolyze water using renewable electricity
  – Reform natural gas at the wellhead and reinject CO₂
  – 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 resquestration 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 CO₂
  - 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 CO₂ are rapidly decoupling
  – World: 1998 GDP +2.5%, CO₂ –0.5%; ’99 better
  – US: economy growing 6__ as fast as CO₂
  – 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, 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 ~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.