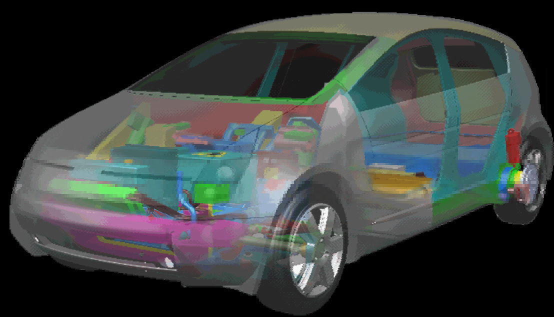
USHR Committee on Science, Energy Subcommittee

FreedomCar, Next Steps, 2318 Rayburn, Washington DC, 26 June 2002

FreedomCAR, Hypercar®, and Hydrogen



Amory B. Lovins, CEO, Rocky Mountain Institute

[also Chairman of the Board, Hypercar, Inc.]

www.rmi.org, www.hypercar.com

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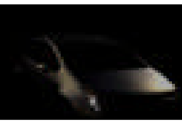
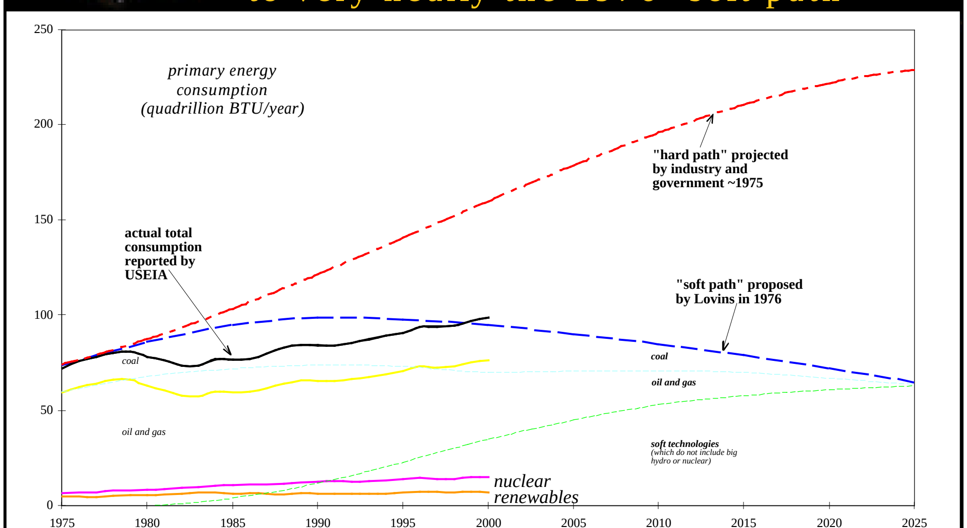
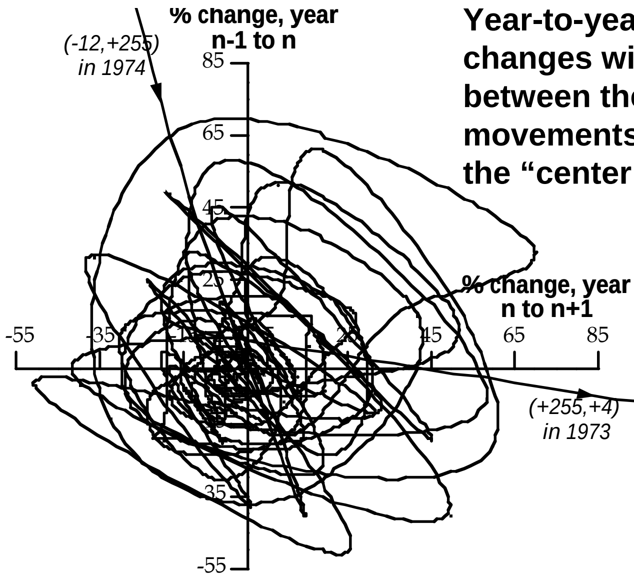


U.S. energy/GDP already cut 40%, to very nearly the 1976 "soft path"



...but that just scratches the surface, esp. for vehicles

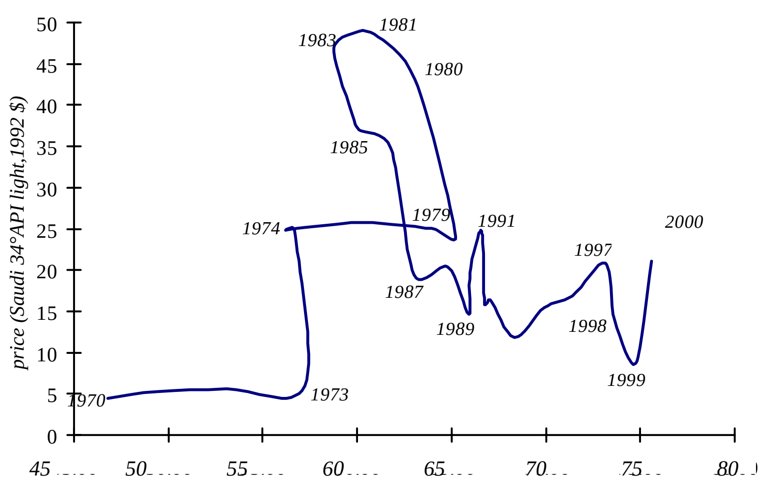
The Brownian Random Walk of World Real Oil Price, 1881–1993



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 trebled; changes stayed perfectly random, just as for any other commodity.

Graph devised by H.R. Holt, USDOE

Market surprise: world crude-oil real price *vs.* world oil consumption, 1970–2000

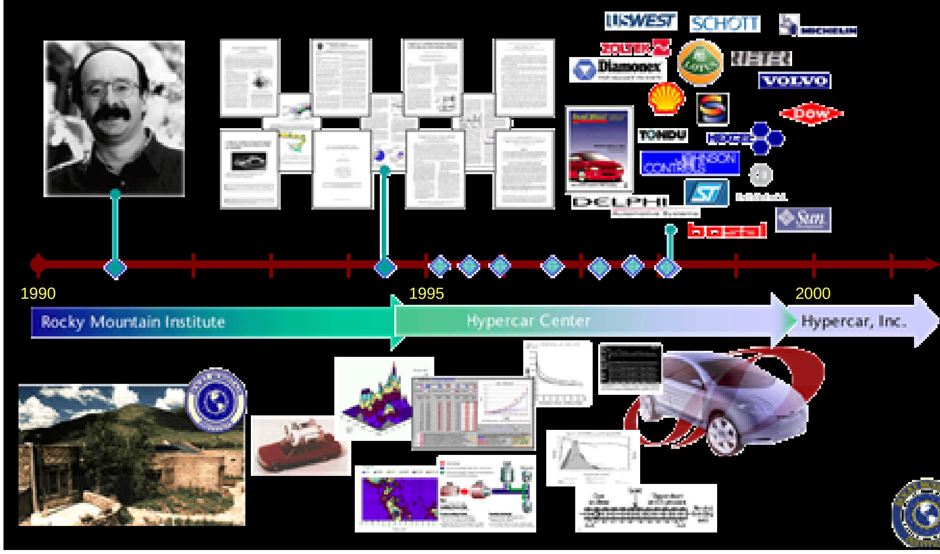


Data source: http://www.doe.eia.gov, downloaded 24 October 2000

Automotive development goals

- Uncompromised vehicles — same or better in all respects (size, performance, safety, reliability,…)
- Diverse, competitive price, new value proposition
- Radically improved fuel economy, off oil
- Secure US fuel with smooth, profitable transition
- Zero-emission, climate-safe, recyclable
- Decisive manufacturing advantages, better jobs
- Offered to all makers, maximizing competition
- Business model based on value to the customer and competitive advantage to the maker — not on government intervention, oil price,…

Hypercar, Inc.: 12 years of **vision**

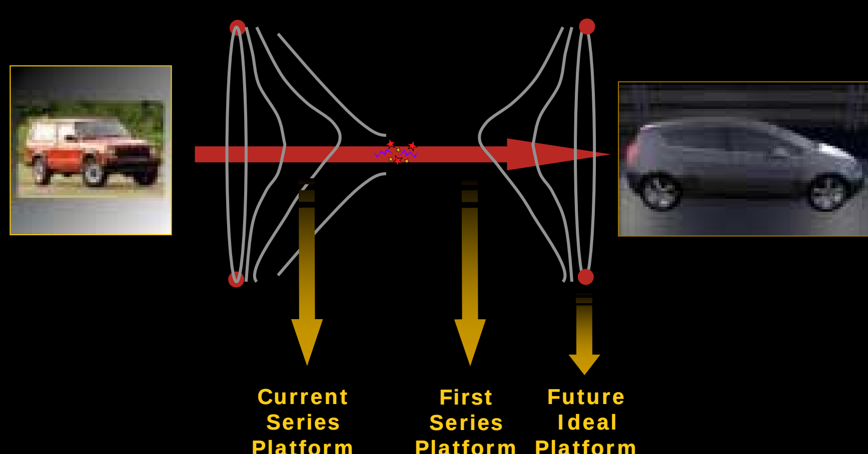


Hypercar® concept: brief history

- Invented 1990–91, previewed ’91 (NAS), explored w/GM,…, published ’93 (ECEEE, ISATA, Nissan Prize)
- Incubated at RMI’s Hypercar Center ($3M — 2/3 grants, 1/3 earned) 1991–99, many profl. publns.
- Published concept extensively ’93–99; ~$10b stimulated ’93–00 by nonexclusive consultancies
- Independent feasibility study by Lotus Engineering (UK) 1998 with 17 industrial partners
- Spun off Hypercar, Inc. 1999 to support the industry’s transition; raised $4.3M of private equity (now >$7M, seeking +$16M); IP-based business model
- Concept car designed 2000 with TWR Engineering (UK) and other US and European consultants
- Discussing joint development/licensing w/OEMs

design in the **future**

Present Paradigm | New Paradigm

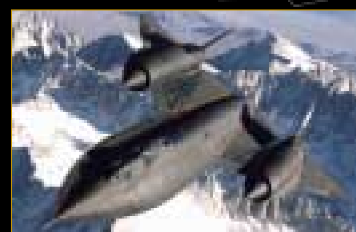


design in the future example: **U-2** and **SR-71** spy planes

It makes no sense to just take this one or two steps ahead, because we'd be buying only a couple of years before the Russians would be able to nail us again. No, I want us to come up with an airplane that can rule the skies for a decade or more.

Kelly Johnson, Lockheed Skunk Works

	U-2	SR-71
Speed	Mach 0.8	Mach 3.5
Elevation	70,000 ft	85,000+ ft



An encouraging example…

- At the Lockheed Martin Skunk Works®, engineer David Taggart led a team that designed an advanced tactical fighter plane…
  - 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 carbon, not from metal
- Now, as VP Product Development and CTO of Hypercar, Inc., he's doing much the same for cars — showing what happens when cars are designed less like tanks and more like aircraft

5×-more-efficient, no-oil, midsize SUV

an illustrative, costed, manufacturable, and uncompromised concept car (11/2000) developed with internal funding by a small firm, Hypercar, Inc. (www.hypercar.com), on time and on budget, with attributes never previously combined in one vehicle

- seats 5 comfortably, up to 69 ft^3 of cargo
- hauls 1/2 ton up a 44% grade
- 1,889 lb (47% mass of Lexus *RX300*)
- head-on wall crash @ 35 mph doesn't damage passenger compartment
- head-on collision with a car 2× its mass, each @ 30 mph, prevents serious injury
- 0–60 mph in 8.2 seconds
- 99 mpg-equivalent (5× *RX300*)
- 330 mi on 7.5 lb of 5-kpsi H_2 gas
- 55 mph on just normal a/c energy
- zero-emission (hot water)
- stiff, sporty, all-wheel fast digital traction
- ultra-reliable, software-rich, flexible
- wireless diagnostics/upgrades/tuneups
- 200k-mile warranty;no fatigue, rust, dent
- competitive manufacturing cost expected
- decisive mfg. advantages—manyfold less capital, space, assembly, parts count
- production feasible in ~2006

Ultimate public benefits of quin-tupled light-vehicle fuel efficiency

- Oil savings: U.S. potential = 8 Mbbl/day = 1 Saudi Arabia = 42 Arctic National Wildlife Refuges; world potential = 1 nega-OPEC
- Decouple driving from climate change and smog
  - Profitably deal with ~2/3 of the climate challenge
- Lead a fast transition to a hydrogen economy
  - Can be profitable at each step; adoption already starting
- Parked cars serving as plug-in "power stations on wheels" when parked (av. ~96% of the time)

"We'll take two." — *Automobile*, November 2001

efficiency **pays**

Vehicle	Fuel-cell power (kW)	Type	Relative output	Cost premium *	Range (mi)
Hypercar Revolution	35	hybrid	100%	**N.A.**	330
Toyota FCHV-4	90	hybrid	257%	**+ $ 5,500**	155
Ford Focus FCV	85	hybrid	243%	**+ $ 5,000**	200
GM HydroGen III	94	FC	269%	**+ $ 5,900**	250
Hyundai Santa Fe FCV	75	FC	214%	**+ $ 4,000**	250
Honda FCX-V4	78	FC	223%	**+ $ 4,300**	185
Jeep Commander 2	140	hybrid	400%	**+ $ 10,500**	93

* Department of Energy $100/kW target for 2004, *excluding* other fuel-system & traction components, mass decompounding,…

55 mph on same power as normal a/c, so well suited to direct-hydrogen fuel cells

Rapid, profitable H_2 **transition**

- Put fuel cells first in buildings for co-/trigen
  - Fuel with natural-gas reformers (or off-peak electrolyzers)
- Meanwhile introduce H_2-ready Hypercars
  - 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 PEMFC is modest
    - Earn back much/most of cost of car ownership
      - U.S. full-fleet potential ~5–10 TW, ~6–12× grid cap.

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
  - The capital intensity of a U.S. miniature-natural-gas-reformer fueling infrastructure is *less* than that of just sustaining the existing gasoline fueling infrastructure
  - As both hydrogen and direct-hydrogen fuel-cell vehicles become widespread, bulk production and central distribution of hydrogen may become justified

Rapid, profitable H_2 **transition (3)**

- ≥2 proven, climate-safe, cost-effective methods
  - Reform natural gas at the wellhead and reinject the CO_2
    - Reforming (~5% of US 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 economics of renewable electricity
      - Even US gasoline ($1.25/gal) 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
      - H_2 storage makes wind/PV power firm & dispatchable
- Probably more: coal (BP/Princeton), direct photolysis, novel biofuels, other renewables,...

Perspective on PNGV, FreedomCAR

- PNGV notably succeeded in tacit goals: changing game / culture, some tech. development, and (mainly) stimulating OEMs' black programs
  - Why do your best work in front of your competitors?
- Its key technical goals were met and exceeded
- FreedomCAR could be…
  - A bust if fuel cells are dropped into today's inefficient cars
  - A triumph if thoroughly integrated with the best PNGV and black-program results on low-tractive-load vehicles, and with modern integrated approaches to the hydrogen transition
  - If done right, extraordinarily important to national success
  - If not combined with policies to capture near-term conventional fuel economy gains, interpreted as stalling/diversion

FreedomCAR goals (based on www.cartech.doe.gov/freedomcar/technical-goals.html, 22.VI.02)

- Vision emphasizes vehicles, markets, H_2 transition, but goals omit most key elements except the powertrain
- Emphasis on reformer (unnecessary and unpromising)
- Wording unclear on role of direct-H_2 designs
- Somewhat odd inclusion of H_2-fueled IC engine
- Most technology goals look useful; H_2 storage done?
- Wording unclear on H_2 price (per GJ, or traction?)
- Seeks halved mass of "vehicle structure & subsystems" (not curb mass); omits aero/rolling resistance
- Vehicle "affordability" and "emissions stds." undefined
- No tech. or system goals for H_2 transition, nor integration with stationary fuel-cell applications
- Key vision, "freedoms," & vehicle performance goals *already met:* mass, range, affordable, recyclable,…

Suggested revision of goals

- Emphasize *vehicle*, not component, performance
- Highly integrated, radically simplified, software-rich design & manufacturing for ultralight, ultra-low-drag, direct-H_2-fuel-cell vehicles (*i.e.*, like fuel-cell versions of Hypercar vehicles)
- 2004 collaborative demonstration of well-driving ~100-mpg midsize SUV, then more models
  - (To declare an interest, I founded, chair, and hold minor equity options in a small company that has already designed—but can't afford to prototype—such a vehicle)
- Aim for initial production start around 2007–8, then rapid diversification of platforms & makers
- Aggressive, broad H_2 transition integrating mobile and stationary applications so each accelerates the other

Perspectives on automakers

- Institutions unique in the history of the world
- Major OEMs are *very* large, capable, and complex
- Some equally specific disadvantages & limitations
  - Superb skills in metals, far less in advanced composites
  - Focus on cost per part or per pound, not per car
  - Treat sunk costs as unamortized assets—acctg., not economics
  - Deep design integration improving but needs to be even better
  - OEMs' lobbyists often lobby *against* corporate strategy
- Many excellent engineers awaiting mobilization
- It is very hard for OEMs to make leapfrogs
- It is very risky for OEMS not to make leapfrogs
  - Other OEMs, major suppliers, and new entrants could compete
- The real barriers to leapfrogs are mainly cultural
- Vaulting those barriers will determine OEMs' fate

Critical national opportunities

- Creative Federal action, such as accelerated-scrappage feebates, could greatly shift OEMs' risk/reward perceptions of radical innovation
  - Likely soon anyhow at a State level; commands consensus
  - Technology-neutral, technology-forcing, integrative
- Well-managed big energy companies could agree
- Small business could make vital contributions, including whole-vehicle engineering — not the exclusive domain of the OEMs DOE mainly helps
- Many elements of civil society would help too
- Important military applications and spinoffs
- A bold, visionary, unifying, intensely practical and can-do national project, vital to security
- But foreign competition is rapidly emerging
- May be make-or-break for US automaking

RMI and Hypercar, Inc. have…

- Held expanding discussions with OEMs and Tier Ones, often at a very senior level, since 1991
- Addressed many key auto-industry conferences
- Extensively briefed energy industry leaders '93–
- Briefed President and Vice President 1993–2000 and military leadership 1995–2002
- Briefed DOE's Transportation Director, Asst. Sec. Garman, his predecessor, & USCAR 1993–
- Tried unsuccessfully to inform two NAS studies, neither of which considered ultralights or FCs
- Briefed NRC PNGV evaluation committee, which didn't know our work and seemed uninterested

"People and nations behave wisely —
once they have exhausted all other alternatives."
— Churchill

"Sometimes one must do what is necessary."
— Churchill

"We are the people we have been waiting for."
— Hopi Elders

www.rmi.org

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), seven honorary doctorates, a MacArthur Fellowship, the Heinz, Lindbergh, World Technology, and Heroes for the Planet Awards, the Happold Medal of the UK Construction Industries Council, and the Nissan, Mitchell, "Alternative Nobel," Shingo, and Onassis Prizes; held visiting academic chairs; briefed 16 heads of state; published 28 books and several hundred papers; and consulted for scores of industries and governments worldwide, including the oil industry since 1973, DOE, and DoD. *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 integrating resource efficiency into the emerging "natural capitalism."

About Rocky Mountain Institute (www.rmi.org): This independent, nonpartisan, market-oriented, technophilic, entrepreneurial, nonprofit organization was cofounded in 1982 by Hunter Lovins and CEO Amory Lovins. RMI fosters the efficient and restorative use of natural and human capital to 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 ~$6-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* (w/Paul Hawken; 9/99, www.natcap.org).

About Hypercar, Inc. (www.hypercar.com): In August 1999, Rocky Mountain Institute transferred its internally incubated technical activities on Hypercar vehicles to this partly-owned second-stage for-profit technology development firm, its fourth spinoff. Funded by private investors, Hypercar, Inc. pursues business opportunities related to the Hypercar concept developed at RMI since 1991. Mr. Lovins chairs Hypercar's Board and holds minor equity options in the firm.