Oringinally posted as a comment to "Opportunties and challenges for a sustainable energy future" by Steven Chu and Arun Majumdar, *Nature,* **488**, 294–303 (16 August 2012) http://www.nature.com/nature/journal/v488/n7411/full/nature11475.html

My friends Steven Chu and Arun Majumdar ably review above the achievements, prospects, and challenges of the U.S. Department of Energy's R&D portfolio and related efforts. Missing, however, is the bigger story of how artfully *integrating* such technological solutions with innovative design, strategy, and public policy could profitably solve most of the problems they describe.

For example, two-thirds of the energy needed to move a typical U.S. automobile is caused by its mass, and each unit of energy saved at the wheels by reducing mass or drag will save about seven units at the fuel tank by avoiding the six units now lost in delivering one unit to the wheels. Ultralighting is thus the top priority (with equal or better safety). Though Chu and Majumdar's 12-year-old reference 10 says 20–40% mass reduction is feasible in the next 10–20 years, and a National Petroleum Council report[i] just submitted to Secretary Chu caps its analysis at 30% mass reduction by 2050, by 2010 the global auto industry had already achieved ≥30% mass savings in at least five production, four prototype, and ten concept autos, the lightest of which (Toyota's *1/X*) saved 69% in 2007.[ii] Proven manufacturing techniques can scale to mass-produce advanced-composite automotive structures for today's cost (and crashworthiness) per vehicle, because simpler automaking and smaller powertrain pay for the costly carbon fibre.[iii]

Moreover, propelling the auto with two-thirds less energy saves two-thirds of its costly batteries or fuel cells, making electrification affordable and potentially conferring striking competitive advantage on early adopters.[iv] That is, before making batteries cheaper, we can make them fewer. Electrified carbon-fiber automotive models are to enter volume production in Germany in 2013 from VW, BMW, and reportedly Audi.[v] (BMW says its *i3*'s carbon fibre is paid for by needing fewer batteries.) Ultralighting also shrinks bulky hydrogen fuel cell autos' compressed-hydrogen tanks by two-thirds for the same range, making 700-bar tanks unnecessary and packaging straightforward with commonplace 350-bar tanks.[vi] The same logic makes tripled-efficiency heavy trucks[vii] practical with compressed rather than liquefied natural gas. Applying "vehicle fitness" and productive use to all U.S. mobility systems could reduce their need for oil to zero and their need for advanced biofuels to ~3.1 Mbbl/d—two-thirds makeable from wastes, requiring no cropland, and no harming soil or climate; indeed, greatly expanded but oil-free U.S. mobility in 2050 could save $4 trillion net present value in private internal cost.[viii]

Similarly overlooked opportunities arise with electricity, both in specific technologies and in new ways to combine them, and without needing to encounter the constraints mentioned in the article. For example, rare earths needn't be an issue: *e.g.*, existing switched-reluctance machines don't need magnets and can match or beat permanent-magnet machines' cost and performance.[ix] The "intermittency…of renewable energy" is misphrased too: renewables except photovoltaics and wind are generally dispatchable, and intermittency, *i.e.* unforecastable outage, is a worse problem for big thermal plants than for photovoltaics (PVs) and wind. The authors' ref. 45 shows that 80–90%-renewable U.S. electricity need not require much bulk storage. An independent study using the same model but adding distributed renewables found even less need if wind and PVs are properly diversified by type and location, forecasted, and integrated with demand response, flexible renewable supply, and distributed storage (smart charging and discharging of electrified vehicles plus ice-storage air-conditioning); indeed, these options can provide 100% renewable electric supply in, say, the isolated Texas power pool (ERCOT) without bulk storage.[x] Some additional transmission will be needed, but probably much less than often supposed, since the Federal Energy Regulatory Commission intends to make new transmission compete fairly against efficiency, demand response, and distributed generation—and such competition will also free up much existing transmission capacity.

The power of an integrated view is illustrated by an independent, comprehensive integration[xi] of all four energy-using sectors—transportation, buildings, industry, and electricity—and of all four forms of innovation—technology, policy, design, and strategy. It found that a 2.6-fold bigger U.S. economy in 2050 could require no oil, coal, or nuclear energy, one-third natural gas, a $5-trillion lower net-present-value cost (counting all externalities at zero), 82–86% lower fossil carbon emissions, no new inventions, and no Act of Congress (because the needed policy innovations could be adopted by federal administrative processes and by the states)—the transition led by business for profit.

In short, attractive and profitable energy solutions emerge not simply from developing specific technological solutions, but even more from following the remark attributed to General Dwight Eisenhower: "If a problem cannot be solved, enlarge it"—until its boundaries include the options, synergies, and degrees of freedom that its solution requires.

When such integrative thinking guides Federal energy R&D, better results will be achievable with less effort, and what now seem daunting challenges will turn out to be easier than they look when viewed piecemeal.

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[i] National Petroleum Council, *Advancing Technology for America's Transportation Future*, 1 August 2012, http://npc.org/FTF. This analysis rightly contemplated 50–70% mass reduction, but its conclusions flowed from modeling that analyzed only up to 30%.
[ii] A.B. Lovins, "Mass-market Adoption of Ultralightweight Automobiles," Working Document of the NPC Future Transportation Fuels Study, 1 August 2012, http://npc.org/FTF_Topic_papers/22Ultra_lightweight_Vehicles.pdf.
[iii] A.B. Lovins and Rocky Mountain institute, *Reinventing Fire: Bold Business Solutions for the New Energy Era*, Chelsea Green, September 2011, www.reinventingfire.com; summarized by a TED talk at www.ted.com/talks/amory_lovins_a_50_year_plan_for_energy.html and by A.B. Lovins, "A Farewell to Fossil Fuels," *For. Aff* **91**(2):134–146 (March/April 2012), www.rmi.org/Knowledge-Center/Library/2012-01_FarewellToFossilFuels, and supported by extensive data at www.reinventingfire.com.
[iv] *Reinventing Fire*, ref. 3, Ch. 2.
[v] *Id.*
[vi] A.B. Lovins & D.R. Cramer, "Hypercars®, hydrogen, and the automotive transition," *Int. J. Vehicle Design* **35**(1/2):50–95 (2004), www.rmi.org/Knowledge-Center/Library/T04-01_HypercarsHydrogenAutomotiveTransition.
[vii] M. Ogburn, L. Ramroth, and A.B. Lovins, "Transformational Trucks: Determining the Energy Efficiency Limits of a Class 8 Tractor Trailer," Rocky Mountain Institute, 2008, www.rmi.org/Knowledge-Center/Library/T08-08_TransformationalTrucksEnergyEfficiency.
[viii] Ref. 4.
[ix] See more broadly A.B. Lovins, "Moving Heaven and (Rare) Earth," 4 November 2010, http://ndupress.blogspot.com/2010/11/moving-heaven-and-rare-earth.html.
[x] *Reinventing Fire*, ref. 3, Ch. 5.
[xi] *Reinventing Fire*, ref. 3.