Negawatts: Twelve Transitions, Eight Improvements, and One Distraction

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Twelve fundamental transitions are underway in the efficient use of electricity.[1] Six are well along, while the other six remain as a central challenge for the next decade and beyond. Once they are accomplished, the resulting economically efficient use of electricity will reduce by at least severalfold the quantity of electricity needed to provide present services with unchanged or improved quality.[2] This major substitution will be caused by economic fundamentals[3]; the negawatt debate is simply a subtext about whether they are to be recognized or suppressed.

The first six transitions are familiar to practitioners:

1. *From economic theorists' paradise to the real world.* It is now widely, though far from universally, recognized that market failures in buying electrical productivity are real and important. Indeed, some analyses[4] suggest that in certain key arenas, market failure can be more important than market function: the perverse incentives seen by all ~25 parties in the real-estate process so systematically reward inefficiency and penalize efficiency that the United States has already misallocated, at marginal cost, a sum approaching $1 trillion just to air-conditioning equipment and power supplies to run it.[5]

One of many striking empirical examples of market failure was revealed by Dow/Louisiana Division's implementation of nearly a thousand energy-saving and waste-reducing projects during 1981–93, with audit-confirmed returns on investment *averaging over 200% per year*—falling to double digits, 97%, only in a single year—and with the savings tending in recent years to become *bigger and more profitable* even as real energy prices tended to decline, because the practitioners' learning curve outran the depletion of the "negawatt" resource. Market theory would suggest that such enormously profitable savings should have been automatically achieved much earlier by a sophisticated firm in a cost-conscious industry: there shouldn't have been thousand-dollar bills lying all over the factory floor. But Dow's Ken Nelson found that not only was the floor figuratively carpeted in them, but as soon as he picked one up, he found two more underneath. Or to use another metaphor: not only did he find profuse low-hanging fruit, but the more he picked, the heavier with new fruit the boughs became. This is now a common experience for advanced practitioners in almost any electricity-using facility. Theoretical economists should get used to it. (PS: Nelson retired in 1993; his coordinating group was

[1] "Efficiency" in this article is used in the engineering sense—physical services (such as light, torque, or heat) delivered per unit of electricity consumed. In contrast, economists often construe "energy efficiency" to mean "economically efficient use of primary energy to produce aggregate economic output." This profoundly different semantic universe has created much of the divergence between *e.g.* the World Bank and its critics.

[2] A.P. Fickett, C.W. Gellings, & A.B. Lovins, "Efficient Use of Electricity," *Sci. Amer.* **263**(3):64–74 (Sept. 1990); A.B. & L.H. Lovins, "Least-Cost Climatic Stabilization," *Ann. Rev. En. Envt.* **16**:433–531 (1991); E SOURCE (Boulder CO 80302-5114), *Technology Atlas* series and bimonthly supplements, 1992– ; A.B. Lovins & W.D. Browning, "Negawatts for Buildings," *Urban Land* **51**(7):26–29 (July 1992); A.B. Lovins, "The Negawatt Revolution," *Across the Board* (The Conference Board, NY), September 1990, pp. 18–23; E.U. von Weizsäcker, A.B. & L.H. Lovins, *Faktor Vier: Doppelter Wohlstand—halbierter Naturverbrauch*, Droemer Knaur (München), 1995; and other publications, some detailed and technical, of Rocky Mountain Institute (Snowmass CO 81654-9199).

[3] Efficient use of electricity is far cheaper than making more of it[2], usually even at short-run marginal cost (*infra*), and the gap is widening. As customers figure this out, they will naturally want to buy less electricity and more efficiency. The only question is who will sell them the efficiency. Most utilities have figured out (although lately some have temporarily forgotten, as discussed below) that it is a sound business strategy to sell customers what they want before someone else does. Utilities' choice is hence between participation in the negawatt market and obsolescence.

[4] A.B. Lovins, *Energy-Efficient Buildings: Institutional Barriers and Opportunities*, E SOURCE (Boulder CO), SIP-2, November 1992; U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, May 1992; M.D. McMahon, E. Hirst, J.G. Koomey, J.E. McMahon, & A.H. Sanstad, *Energy Efficiency, Market Failure and Government Policy*, LBL-35376 (Lawrence Berkeley Laboratory) and ORNL/CON-383 (Oak Ridge National Laboratory), 1994.

[5] *I.e.*, that much capital (two-thirds of it for 200 GW_p of supply) would have been saved if the buildings had instead been optimally designed to deliver the same or better comfort in the cheapest way: D. Houghton *et al.*, *The State of the Art: Space Cooling and Air Handling*, E SOURCE (Boulder CO), 1st ed., 1992, at pp. xviii, 7–8, 36–40.

disbanded; data-tracking ceased, so management's claims that the program still lives cannot be validated. Apparently not even Dow's adjacent Texas Division went very far in adopting similar practices, because it had no corresponding internal "champion.")

2. *From supply extrapolation to end-use/least-cost.* Modern utilities no longer project aggregated demand and build to meet it. Rather, they appreciate that future demand for electrons is not fate but choice, and should represent market clearing (or its emulation by other means) between marginal supply of more electrons and marginal improvement in the productivity of converting electrons into end-use services. Modern utilities therefore ask how much of which specific end-use services customers may want, such as hot showers and cold beer, then seek to enable customers to meet those needs in the cheapest way through a least-cost mix of energy productivity and energy supply, optimizing the scale and quality of supply to the task's requirements. This is the essence of the Integrated Resource Planning required by the U.S. National Energy Policy Act 1992, §111, and of the principles unanimously adopted in 1989 by the National Association of Regulatory Utility Commissioners, although it can certainly be done in a decentralized and market-oriented fashion rather than by planners.

3. *From residential to all sectors.* Almost all utilities have found that although large and attractive residential opportunities remain, the biggest and cheapest savings are largely in the commercial and industrial sectors. These tend to dominate programs driven by economic rather than political criteria.

4. *From load management to efficiency.* Load management saves only generating and grid capacity. End-use efficiency saves capacity, usually more than it saves energy, but it *also* saves energy (hence fuel) and pollution. It's better to have all three benefits than just one. Load management is thus best seen, in general, as a useful adjunct to prior comprehensive efficiency efforts, not as the dominant or only form of demand-side investment.[6] Real-time pricing does not vitiate and may well strengthen this conclusion.

5. *From claimed to measured savings.* Many if not most utility efficiency programs now use the highly developed evaluation methods that can check cost-effectiveness and improve design. Any system without feedback is stupid, by definition, and any program without some sort of evaluation is probably suboptimized.[7]

6. *From sticks (exhort but punish efficiency) to carrots (reward efficiency).* Modern utilities and utility regulators understand that "sticks painted orange"[8] are no substitute for juicy carrots. So long as electricity prices are formed in a way that ties utilities' profits to how much energy they sell and that gives utility investors no share of the savings the utilities achieve, utilities will be understandably averse to investing in efficient end-use even when it's cheaper than just *running* existing thermal power plants. Such societally silly incentives prevail virtually worldwide except for about a half-dozen of the United States, which in various ways decouple utilities' profits from their sales volumes and let them share in the savings they create for their customers. Absent such fundamental reform of incentives, enormous misallocations of utilities' capital are both encouraged and guaranteed, even with such minor regulatory palliatives as lost-revenue adjustments or rate-of-return kickers.

This is not to say that all controversy over these matters has vanished. On the contrary, a few critics continue to infer from some specific and apparently costly programs that electric efficiency programs *in general* do or must have poor cost-effectiveness.[9] An enormous and often sophisticated literature on program evaluation, *e.g.* in the annual Chicago proceedings, shows the contrary, as do many helpful compilations comprising large numbers of programs.[10] For example:

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[6] This article avoids the catch-all term "DSM" (demand-side management). It was invented by Clark Gellings at EPRI, which serves many diverse masters, to embrace *any* action that affects demand, whether by increasing or decreasing it or by changing its temporal pattern. A term so broad is hardly unambiguous enough to be helpful.

[7] That said, the voluminous evaluations provided by large industry that has sprung up to jump through regulatory hoops—evaluations sometimes costing more than the programs being evaluated—often seek greater precision than is necessary, desirable, or valid, and may rest on shaky theoretical grounds: "free riders," for example, deserve far *less* attention than they have received (A.B. Lovins, "Apples, Oranges, and Horned Toads," *El. J.* **7**(4):29–49 [May 1994], at p. 37 and its nn. 5–6, and E. Hirst & J. Reed, *Handbook of Evaluation of Utility DSM Programs,* ORNL/CON-336, Oak Ridge National Laboratory [Oak Ridge TN], 1991).

[8] This phrase is Steve Wiel's when he was a Nevada Public Service Commissioner.

[9] Serious problems in perhaps the most prominent such contention are surveyed by Lovins, "Apples, Oranges, and Horned Toads," *op. cit. supra*—which also agrees that most programs cost much more than optimized ones would.

[10] *E.g.*, S. Nadel, *Lessons Learned*, N.Y. State Energy Res. & Devel. Authority 90-8 (American Council for an Energy-Efficient Economy, Washington DC, 1990), or the very thorough 1994 evaluation of California programs at the behest of that State's Public Utilities Commission (see CPUC Decision 93-09-078, 17 September 1993).

- a survey of careful evaluations performed on 158 California DSM programs or program segments found measured savings equal to 93–112% of predicted savings[11];
- the CPUC's Division of Ratepayer Advocate found that during 1991–94, the entire DSM portfolio of all three major California investor-owned utilities saved electricity at an average program cost that fell from about 2.8 to 1.9 current ¢/kWh (Southern California Edison Company was the cheapest, falling from 2.6 to 1.2¢/kWh and averaging 1.7¢/kWh)[12]; and
- the CPUC itself found $1.9 billion in *net* benefits from those programs during 1990–93 (equivalent on the same basis to $2.2 billion through 1994, corresponding to $1.5 billion separately found for New York State).[13]

However, even the most rigorous and independent evaluation is useless if critics reject it, often without even reading it, as obviously "biased" by the evaluators' desire to continue to be hired to do evaluations. (On this tendentious basis, no financial accounts of public companies should be accepted either.) Few critics of efficiency programs have taken the responsibility to acquaint themselves with the evaluation literature; if they had, they would hardly argue simultaneously that evaluation must be done, has not been done, has been done, and cannot be trusted.

These simmering disputes about cost-effectiveness, though they continue to obscure policy discussions, are by now largely confined to the uninformed and the ideologically motivated. Whether at the highest levels of aggregation, like EPRI and EIA compilations of total investment and savings each year, or at the most program-specific level, nearly all utility investments in electric efficiency beat long-run marginal supply cost by manyfold, and most—the main exceptions being some residential shell improvements—also beat short-run marginal supply cost. However, the critics do have a point: most utility efficiency programs, even if cost-effective, could be far *more* cost-effective if both their technical content and their mode of delivery were improved. That critique, which I have been advancing for the past couple of decades, is today more true than ever, even for the best-regarded utility efforts, and lies at the heart of the six new transitions that now challenge practitioners:

7. *From fragmented measures to integrated packages.* Most designers design, most clients buy, most vendors sell and install, most utilities reward, and most regulators analyze and require efficiency improvements *component by component*, requiring each part separately to meet a marginal cost-effectiveness test based on energy savings alone. This slice-and-dice approach is now known to yield electrical savings *severalfold smaller and costlier* than they would be if obtained as an integrated package of measures credited with a wider set of tangible, carefully measured benefits. This is because successive measures applied to a given technical system are *not* independent of each other, but often strongly interactive, and because the interactions often yield important new benefits, especially by making costly equipment smaller, simpler, cheaper, and even unnecessary. For example:

    - In Pacific Gas and Electric Company's "ACT^2" experiment (the Advanced Customer Technology Test for Maximum Energy Efficiency), a new house was built in Davis, California, with no heating or cooling equipment, yet with superior comfort despite ambient temperatures up to 40°C design and 45°C peak. Neglecting occupant-supplied plug loads, all the major uses—space and water heating, space cooling, refrigeration, and lighting—were designed to use ~20% of the energy allowed by the strictest energy code in North America. Yet in a mature market, rather than a one-off experiment, the marginal construction cost of this design was calculated to be ~$1,800 *less* than normal, and the present-valued maintenance cost ~$1,600 *less* than normal. The last seven measures needed to eliminate the last one-third of the air-conditioning capacity had been previously screened out as not "cost-effective," meaning that they didn't save enough *energy* to pay for themselves; yet when also credited with their saved *capital* cost from eliminating the last ~$1,500 worth of air-conditioner and ductwork, they *were* cost-effective.
    - Over a decade earlier, Rocky Mountain Institute had similarly shown reduced construction cost from eliminating the heating system in a climate going to –44°C: the marginal cost of superinsulation, superwindows, and ventilation heat recovery was less than the avoided capital cost of the furnace and ductwork.
    - Both these cases illustrate how single expenditures can yield multiple benefits: energy savings, capital savings, and in some cases other values (*e.g.*, spectrally selective glazings improve radiant comfort,

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[11] M. Brown & P. Mihlmester, "Summary of California DSM Impact Evaluation Studies," 11 August 1994 report to California DSM Measurement Advisory Committee. The results are from 1990–92.

[12] June 1995 compilation by Peter Miller, Natural Resources Defense Council (San Francisco). Costs include program outlays and administration, shareholder incentives, measurement and evaluation, and free riders, but not free drivers or customers' share of the investment; on nationwide average utilities typically pay ~50% of total cost.

[13] CPUC 93-09-078, *loc. cit.*, including CPUC correction for lower avoided costs; New York evaluation summary by Jim Gallagher, in press, August 1995.

permitting a re-setting of the thermostats and thus saving still more energy). Even more kinds of quantifiable engineering-economic benefits are available: superwindows have ten main kinds, premium-efficiency motors 12, dimmable electronic ballasts 18. Yet standard engineering methodology wrongly counts *only one* (direct energy savings). When other benefits are also counted, such as avoiding capital costs by downsizing or eliminating mechanical equipment, it is quite common to find that *big energy savings can be cheaper than small energy savings.*[14] Because multiple benefits from single expenditures are quite common with good engineering, such a downward-dipping supply curve of the efficiency resource, "tunneling through the cost barrier," has now been observed[15] in big and small buildings, hot and cold climates, new and even retrofit buildings, motor and lighting systems, hot-water systems, computer design, and even car design.[16]

- Another way to make big savings cheaper than small ones is to do a retrofit when some other major improvement must be done anyhow, such as renewing a building's exterior skin or renovating its mechanical equipment or glazings because of aging or other needs such as displacing chlorofluorocarbons. The energy-saving retrofit can then be advantageously coordinated with the improvements that are needed anyhow.
- An example combining these two concepts—multiple benefits and optimal timing—is the recently described design of a retrofit for a large, 20-year-old curtainwall office building with failing glazings in a severe (Chicago) climate.[17] Replacement superwindows could insulate four times as well, admit six times as much daylight but 10% less unwanted solar heat, and at least double sound attenuation, yet cost scarcely more. Combined with deep daylighting and with efficient lighting systems and plug loads, the reglazing would reduce cooling loads by nearly fourfold. But the mechanical systems, being also 20 years old, needed renovation. Retrofitting them instead to nearly four times the original system efficiency would cost 2_ times more *per ton* but one-third less *in total* because of the almost fourfold decrease in tonnage. Re-spending that saved renovation cost on the superwindows and the lighting retrofit would then yield a 75% predicted saving, with a simple payback ranging from –5 to +9 *months*.

8. *From equipment to applications and* then *equipment.* Most designers think of a lighting retrofit as modifying the existing lighting equipment: in the case of a tubular-fluorescent ceiling troffer, perhaps installing imaging specular reflectors, dimming electronic ballasts, T-8 tristimulus-phosphor lamps, and dimming and occupancy controls. This sensible package saves ~70–90% of lighting energy, yields unchanged illuminance with greatly improved quality and aesthetics, and has a technical cost that pays for itself (against 5¢/kWh electricity) in about 1_ years with, or up to 4 years without, credit for its saved maintenance and air-conditioning costs.[18] But it is *not* the right thing to do first; rather, it is only the sixth of seven steps (the seventh being improved training, maintenance, and management of the lighting system). The first five steps, often omitted, are:

   - Improve the quality of the visual task.
   - Improve the geometry (*e.g.*, source/task/eye relationship) and the cavity reflectance of the space.
   - Reduce veiling and discomfort glare so as to improve lighting quality and contrast.
   - Provide the right amount of the light on task for the task and viewer, with proper luminance ratios.
   - Harvest passive (natural) lighting where feasible and cost-effective.

   Similarly, many mechanical engineers called upon to improve the efficiency of cooling a large building will propose a more efficient and variable-speed chiller, variable-air-volume distribution with variable-frequency inverter drives for the supply fans, and the like. But while often valid, these improvements should be only the fifth step of seven in a logical cooling sequence. The previous four are:

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[14] The standard theoretical assumption that the supply curve of the efficiency resource is monotonic upwards is often empirically untrue even at a *component* level. Data collected by Evan Mills for Swedish refrigerators, by RMI for TVs, by the University of Lund for industrial pumps, and by E SOURCE for 5.1–20-ton rooftop chillers and for 1-, 10-, and 100-hp NEMA Type B 1800-rpm asynchronous motors shows *no* correlation between efficiency and price.

[15] A.B. Lovins, "If You Think Education Is Expensive, Try Ignorance," address to E SOURCE Corporate Energy Managers' Consortium, 6 June 1994 (RMI), and experimental results of PG&E's ACT^2 experiment.

[16] Technical publications of The Hypercar Center, Rocky Mountain Institute ('hypercar@rmi.org').

[17] A.B. Lovins, "The Super-Efficient Passive Building Frontier," *ASHRAE J.* **37**(6):79–81 (June 1995).

[18] A.B. Lovins & R. Sardinsky, *The State of the Art: Lighting*, RMI/COMPETITEK, 1988, illustrated in Fickett *et al.*, *loc. cit. supra*, and broadly consistent with other analyses, *e.g.* M.A. Piette, F. Krause, & R. Verderber, *Technology Assessment, Energy-Efficient Commercial Lighting*, LBL-27032, Lawrence Berkeley Laboratory (Berkeley CA), 1989, and with field experience. Most retrofitters omit important elements of the package, fail to take proper credit for some of the measured savings mechanisms, and hence save less but at a higher unit cost than they should.

- Expand the range of conditions in which people feel comfortable, by exploiting such variables as radiant comfort, turbulent air movement, and use of ventilative rather than insulating chairs.
- Reduce cooling loads by severalfold through better glazings, lights, plug loads, building-shell albedo, vegetative shading, surrounding microclimate, etc. In new buildings, architects can also exploit such important variables as siting, built form, orientation, massing, and shading.
- Exploit passive cooling—ventilative, radiative, and ground-coupling.[19]
- If needed, harness alternative cooling—evaporative, absorption, desiccant, and combinations of these.

Only after these first four steps should the designer make the refrigerative system more efficient (if it's still there), followed by improved controls and last perhaps by coolth storage if there's anything left to store. Yet most designers pursue these steps in reverse order and miss all the potential capital-cost savings.

Or yet again, if an engineer is trying to make a motor/pump system more efficient, the best place to start is by asking how much flow is required, and when, for an optimal process optimally controlled; then with how little friction that flow can be delivered through required pipes and valves (laying out the pipes first, then the equipment); then by seeking the optimal size and performance of the pump, then the drivetrain, then the motor, then the inverter, then the electricals. Energy saved at each step will avoid the compounding losses of delivering energy *to* that step in the pumping process, multiplying any energy savings achieved at the downstream (flow) end. It is therefore not unusual for a unit of saved flow to save *nine* units of fuel at the power station. Even more importantly, avoiding compounding losses often makes the expensive upstream components (pump through electricals) severalfold *smaller* and cheaper. Skilled downstream-to-upstream redesign of pumping systems in big buildings can cut pumping energy by ~90%, reduce equipment sizing severalfold, reduce whole-system capital cost, and improve reliability, controllability, and performance.[20] But capturing these energy and capital cost savings requires whole-system engineering with meticulous attention to detail, and as noted below, that is not what most clients today expect, request, reward, or receive.

9. *From engineered delivery to market-making.* Utilities in the 1970s tended to decide what efficiency improvements their customers should have, then deliver them directly ("We will wrap your water heater"). Utilities in the 1980s tended to let customers choose and buy the equipment, but still wanted to decide themselves what choices would be rewarded ("We will rebate each electronic ballast"). The best utilities in the 1990s build on the considerable achievements and flexibility of classical implementation programs: targeted and general information, rebates throughout the value chain (designer, manufacturer, wholesaler, retailer, installer) and for scrappage, rewards for beating minimum standards, concessionary loans, gifts, "golden carrot" contests to bring innovations to market sooner, equipment leasing, and third-party investments such as performance contracts. However, although these techniques can maximize participation and savings per participant, they cannot also maximize competition in who saves and how, so as to keep driving costs down and quality up. To achieve this requires not simply marketing negawatts but also making markets *in* negawatts: making saved electricity into a fungible commodity subject to competitive bidding, arbitrage, secondary markets, derivative instruments, and the other mechanisms that work for other commodities. To this end, utilities have developed bidding processes ranging from industrial modernization grants (to those customers who offer to save the most electricity per dollar of grant) to all-source bidding; ways to resell and wheel savings between customers, utilities, and even nations; ways to repurchase from customers both reduced demand and reduced uncertainty in demand—both resources that merit markets in which to express their value; ways for electric or gas utilities to sell electric efficiency in each others' territories; and performance-linked hookup fees or "feebates" (when you connect to the grid, you pay a fee or get a rebate; which and how big depends on how efficient your usage is; and the fees pay for the rebates—a system that is attractively revenue-neutral, yet unlike building standards, elicits continuous improvement).[21] Spot, futures, and options markets in both watts and negawatts cannot be far behind, with all the arbitrage opportunities they imply. The most attractive directions for utilities' efficiency programs clearly lie in these market-transformation directions...bringing us to the next opportunity.

10. *From promoting hardware to correcting market failures.* Making buildings far more efficient requires seeking "trimtabs" to correct perverse incentives: *e.g.*, rewarding architects and engineers for what they *save*, not for what they spend.[22] But it also means fundamental reforms in the dis-integrated design process[23], and replacing

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[19] These are surprisingly effective in most climates: one can maintain ASHRAE comfort in summer in Miami with nothing more than a roof pond and a ceiling fan. J. Cook, *Passive Cooling*, MIT Press (Cambridge MA), 1989.

[20] Lee Eng Lock, Technical Director, Supersymmetry Services, Singapore, personal communications, 1989–95.

[21] A.B. Lovins & M. Shepard, "Financing Electric End-Use Efficiency" and "Customer Behavior and Information Programs," RMI/COMPETITEK, 1989.

[22] *Energy-Efficient Buildings: Institutional Barriers and Opportunities*, *op. cit. supra.*

obsolete, fragmented rules-of-thumb with true whole-system optimization.[24] For example, pipes are normally sized using rules-of-thumb that count avoided pumping energy but not avoided *sizing* and hence capital cost of the pump-system components (pump, drivetrain, motor, inverter, electricals); yet those are by far the costliest parts. Similarly, most large U.S. buildings lose ~4–8% of their metered electricity before it reaches the load terminals—because wire size is specified by the low-bid electrician who is told to meet code, and the National Electrical Code's wire-size table is meant to prevent fires, not to save money; it's implicitly optimized at an order of magnitude below typical electricity prices. The economic optimum is to make the wire at least twice as fat, therefore with one-fourth the losses of the size normally installed.[25] Such egregious design errors are not unusual in the rules-of-thumb now used to size not only wires and pipes but also pumps, fans, motors, insulation, heat exchangers, and almost every other technical element that now wastes electricity.

11. *From engineering/economic models to the often different insights of energy anthropology.* Compelling evidence from this new discipline shows that both the engineering and the economic models of human behavior used to design efficiency programs and apparatus are often not only incomplete but also seriously misleading. For example[26], most people in hot apartments, if given free air conditioners and free electricity, will *not*, as economic theory predicts, turn on the air conditioner when they feel hot and set its thermostat at a temperature at which they feel comfortable. Only about 25–35% of American subjects behave in that way. Most, if they run the air conditioner at all, will instead do so in a way only very peripherally related to comfort, but rather depending mainly on household schedules, folk theories about how air conditioners work, general strategies for dealing with machines, complex belief systems about health and physiology, noise aversion, and (conversely) wanting white noise to mask outside sounds that might wake the baby. To be sure, both the engineering and the economic models of energy-using behavior are useful. But as any marketer knows, not giving at least equal weight to the complexities of human behavior wastes opportunities and risks unpleasant surprises.

12. *From marginal economics to qualitative superiority.* For decades if not centuries, engineering economics has balanced the cost of an efficiency improvement against the present value of the *energy* it will save. The resulting mindset of diminishing returns is not only incorrect in engineering terms (please see #7 above); it also misses an even more important point, namely that energy savings may be not the main economic motive for saving energy, but a rather minor byproduct of achieving a far more valuable result: not environmental or other social externalities in the usual sense, but some extremely valuable *joint outputs* of the energy-saving action, such as improved quality and productivity. For example, a typical American office pays about 100 times as much for people as for energy. A 1% increase in labor productivity would therefore have the same bottom-line value as eliminating the entire energy bill. Yet eight compelling case-studies from offices, shops, and factories have recently shown labor-productivity gains of *6–16%* from well-designed energy-saving improvements that also happen to improve visual, thermal, or acoustic comfort.[27] Such data had not previously been collected because of the pervasive mythology of the Hawthorne effect, which supposedly showed that only management methods, not working conditions, affect productivity. (In fact, the Hawthorne experiment never showed that, and it wasn't statistically valid anyhow, but its mythology lingers.) There is now, in short, good reason to believe that many important kinds of electricity savings are about an order of magnitude more valuable than would have been concluded from their energy value alone. This in itself should propel a revolution in how negawatts are marketed. Saved energy costs may be the *least* important benefit.

Collectively, these transitions imply a broad and important slate of new opportunities to make negawatts even cheaper, more numerous, and more valuable than their strongest advocates might have supposed a year or two ago. For completeness, the resulting agenda is summarized next. It omits such obvious, helpful, and insufficient solutions as proper pricing.[28]

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[23] *Id.; cf.* W.D. Browning, "NMB Bank Headquarters," *Urban Land*, pp. 23–25 (June 1992); D.L. Barnett & W.D. Browning, *A Primer on Sustainable Building*, RMI, 1995.

[24] "If You Think Education Is Expensive, Try Ignorance," *op. cit. supra*.

[25] Ned Brush has calculated a socially optimized wire-size table for the Copper Development Association (NY).

[26] A.B. Lovins, *Air Conditioning Comfort: Cultural and Behavioral Aspects*, E SOURCE (Boulder CO), SIP-1, 1992, citing chiefly research led by Willett Kempton and Loren Lutzenhiser.

[27] J.J. Romm & W.D. Browning, *Greening the Building and the Bottom Line*, RMI, 1994, Publication #D94-27.

[28] R. Cavanagh, "Energy-Efficiency Solutions: What Commodity Prices Can't Deliver," *Ann. Rev. En. Envt.* **20**:519–525 (1995), in press.

Eight Ways To Make Negawatts Work Better and Cost Less

A. More bang per buck: better technological content. This means more modern and better selected technologies, bundled into integrated packages and counting all relevant benefits (see #7 and #12 above), and done in the right sequence—application before equipment (#8 above).

B. More bang per buck: better program designs. Some rebates should be restructured to go further upstream so as to capture the leverage of manufacturer/wholesaler/retailer markups. Inefficient old equipment should be scrapped so it doesn't reënter secondary markets and have to be retrofitted out again. Free drivers should be maximized via effective outreach so more people follow paid participants' good example without payment (and evaluation methods should be modified so this valuable spinoff is rewarded, not penalized). Free riders may also be worth maximizing to transform markets, as B.C. Hydro did to switch its big-motor market from standard- to premium-efficiency models.[29] Program design should maximize competition and innovation (#9 above) and should slash transaction costs. Important, very inexpensive new opportunities beckon in often-neglected human-capital and organizational-process areas: operation and maintenance, commissioning, training, and education. Today's soft commercial leasing markets and the need to displace CFCs offer exceptional new marketing opportunities for well optimized efficiency packages—especially if such attributes as productivity, waste minimization, quality, amenity, productivity, and pollution prevention are marketed at the same time.

C. Bootstrap from savings elsewhere in the utility. A package of ~35 improvements to typical industrial motor systems can save ~50% of their metered energy (per unit of input torque to the driven machine) with a simple payback under ~16 months at a 5¢/kWh tariff.[30] The saving is so cheap because purchasing seven kinds of improvements typically yields a further ~28 as free byproducts. Savings further downstream, in and beyond the driven machine (such as a pump or fan), are often even larger and cheaper, and should be done first so as to capture the compounding savings in equipment sizing and cost upstream (#8 above). But such opportunities are not confined to *customers*: they should be demonstrated first by *utilities* in their own facilities, from HVAC to power-plant auxiliary drives. EPRI case-study retrofits, for example, showed many years ago the dramatic energy and cost savings available from variable-speed drive of induced draft fans and condenser feedwater pumps. Yet astonishingly few utilities have followed that example and improved their thermal power stations' heat rate, load-following ability, and availability. Money so saved could bootstrap even more savings for both utilities' own operations and their customers'.

Similarly, "precision-guided programs" that target customer efficiency in the specific areas and end-uses that can best defer or avoid costly expansions of grid (especially distribution) capacity can save extraordinary capital sums that can again be reinvested in customer efficiency without increasing pressure on electricity prices. At Ontario Hydro, the first three case-studies of this approach cut capital intensity by up to 90% and saved ~US$0.5 billion net.[31]

Further opportunities include retrofits of utilities' office and other non-power facilities, thus reducing General and Administrative costs and perhaps improving labor productivity (#12 above). In some cases, too, savings by utilities *or* their customers may enable utilities to free up and monetize emission rights under emission trading systems.

D. Get participating customers to pay more. This furrow has been thoroughly if not excessively plowed. Salient examples include Central Maine Power's industrial modernization grants; shared-savings programs such as PacifiCorp's FinAnswer, hybrids such as Southern California Edison's ENvest, the Land and Water Fund's bonus concept, and Wisconsin Electric Power Company's end-use pricing; rebate/loan choices (Burlington Electric, Wisconsin Power & Light); and leasing (Alberta Power). In general, performance has fallen short of expectations, but the concept merits further exploration and improvement, so long as it does not unduly shrink participation rates by creaming off only those few customers with the lowest implicit discount rates—the business opportunity, after all, is arbitrage on the spread between the utility's and the customer's discount rate—or imposing entry fees that suppress participation to an extent that sacrifices important system benefits.

E. Get third parties to pay more. Energy service companies are familiar, and even dominate a few sectors such as the provision of commercial buildings' heating in France. "Virtual ESCos" could also wheel saved power between

[29] T. Flanigan & A. Fleming, "BC Hydro Flips a Market," *Publ. Utils. Fortn.*, pp. 20–22 & 34 (1 August 1993).

[30] A.B. Lovins *et al.*, *The State of the Art: Drivepower*, RMI/COMPETITEK 1989. EPRI reached a similar conclusion by a somewhat different route a year later (Fickett *et al.*, *op. cit. supra*).

[31] John Fox (General Manager of Hydro's downstream half), personal communications, 1994–95; N. Lenssen is also preparing a 1995 E SOURCE Strategic Issues Paper on this experience. When Mr. Fox previously ran PG&E's efficiency programs, its first effort at precision-guided programs, the Delta Project, largely failed for site-specific reasons. But at Hydro, Mr. Fox later proved the concept sound and successful.

customers and utilities. Revenue-neutral feebates (#9 above) pay for savings from charges on those whose inefficient choices increase system cost. Multi-resource consortia can pay for electric savings from collateral benefits such as saving—in the case of, say, a superefficient washing machine—most of its water and sewage flows, chemical discharges, and landfill space (if it's more durable, remanufacturable, or recyclable), while providing local manufacturing jobs and capturing their multiplier. Marketing partners may be willing to pay for access to a utility's customers for their own purposes, or to provide to those customers other valuable concessions that help to market the efficiency program.[32] And advanced energy retrofits' potential to turn around distressed commercial properties may be a welcome lifeline to financial institutions saddled with nonperforming assets.

F. Pay for efficiency from new profit centers which it creates. For example, part of an intelligent response to real-time pricing[33] could be the installation of highly capable near-real-time meters, perhaps like the Metricom/Landis & Gyr type that uses packet-switching radio. Such a network is amply cost-justified by its internal benefits to the utility, but also happens to come with extra bandwidth that can be sold or leased to telecommunications firms. Moreover, some of the benefits of such metering may be quite surprising. Of course the utility expects to pay for the meters and radios through savings on meter-reading, remote connect/disconnect, emergency response, load management, and instant resolution of customer complaints about meter accuracy. But who would have guessed that SCE's 3,000-meter NetComm experiment would find that one-fifth of the test homes were miswired, with no functional ground or with ground and neutral interchanged—or that just having retail-meter-level real-time voltage information systemwide could improve substation-level voltage control enough to save 1 TW-h/y of generation?

G. Incentivize utility staff. Just as utilities should be rewarded for cutting customers' bills, not for selling more energy, so should their staff members who are responsible for helping customers to use electricity more productively. Incentives work. At one utility that started paying a $1 bounty for every kilowatt saved, the volume of savings achieved (verified by *ex post* audit) went up and their cost went down—both by an order of magnitude.

H. Rethink the conceptual foundations of saving electricity. Harnessing the new social-science insights emerging from energy anthropology (#11 above) is an important new tool. Potentially even more powerful is the detailed process analysis of how market failures happen (*e.g.*, the buildings example mentioned in #1,10 above). More than one alert utility, on studying that analysis of perverse incentives, has decided to redesign its commercial-sector efficiency efforts from scratch: paying several years' worth of energy savings to the design team, they felt, could displace far larger rebates for using efficient equipment. After all, the efficient equipment usually cost less[34], but either the designers didn't know how to specify and obtain it or, if they did, they knew that their fees (based on the *cost* of equipment specified) would fall while their effort went up, yielding a negative profit on the engagement. If that perverse incentive in design professionals' compensation is corrected, then it should no longer be necessary, in general, to rebate the equipment they specify.

Collectively, these eight classes of approaches provide an extremely powerful menu of ways to get far bigger and cheaper savings than any utility now does, and to do so at lower cost and hence with less potential for upward short-term pressure on electricity prices.[35] The resulting better, cheaper, and faster gains in the productivity of using electricity will benefit everyone, under *any* evolution of the utility system. In fact, this point is so fundamental that it bears emphasis in concluding remarks about the wider context of this issue of *Energy Policy.*

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[32] *E.g.*, when Janet Benjamin was a marketing consultant to B.C. Hydro's PowerSmart program, she found that a major bank, seeking new mortgage relationships, was willing to reduce its construction- and mortgage-loan interest rates for PowerSmart customers, while a major lighting-equipment manufacturer would equip for free one house for every ten equipped with its PowerSmart-compliant products.

[33] J. Newcomb & W. Byrne, *Real-Time Pricing and Electric Utility Industry Restructuring: Is the Future "Out of Control?"*, E SOURCE (Boulder CO), SIP-5, April 1995.

[34] Mainly because it was smaller and simpler after the load reductions, although its *unit* cost, *e.g.*, per ton of cooling capacity, might be higher.

[35] Acknowledging this concern does not, however, constitute acceptance of the Rate Impact Measure test for efficiency investments—a test whose misuse to screen out measures or programs *guarantees* societal misallocations. Some utilities' pleas for the RIM test to ensure equity between participants and nonparticipants might be more convincing if (a) those same utilities had cared about equity when building needless power plants and grid assets that forced electricity prices to the levels that now create political pressures (costly capacity and overcapacity created rate pressure that dwarf those of efficiency programs, and every supply-side investment flunks the "no-losers" test that RIM advocates wish to apply asymmetrically to demand-side investments only); (b) the equity effects cited rose above the clearly immaterial (E. Hirst & S. Hadley, "Rate Impacts of Electric Utility DSM Programs," ORNL/CON-402, 1994), and A.B. Lovins, "Saving Electricity Doesn't Have to Mean Raising Rates," RMI Publication #U88-16, 1988); and (c) *all* customers didn't get vastly larger system benefits from the least-cost investment.

Retail Wheeling: Big Noise on Stairs, Nobody Come Down

It has lately become fashionable to premise discussions of the future role of electric efficiency on the notion that a century of utility structure and regulation, especially in the United States, is being rapidly swept away by a surging torrent of retail wheeling (the ability of any customer to buy electricity from any supplier), usually considered synonymous with "deregulation."[36] While, as will be seen, I agree that the utility industry is in for even more wrenching change than advocates of retail wheeling propose, I think the premise that this change will be manifested as retail wheeling, let alone that retail wheeling is synonymous with deregulation[37], is false to a degree that its advocates will soon find embarrassing—an artifact of loose language and sloppy thinking.

The trade, professional, and public press have all reported, even in the most respected newspapers of record, that California has ordered retail wheeling and that others of the United States are rapidly following suit. That is rubbish. California's five-member PUC did unexpectedly publish in April 1994 a staff proposal for rapid adoption of retail wheeling, but in a proposed order on 24 May 1995, on riper consideration, the CPUC *rejected* that concept by a 3–1 vote. Rather, the three majority Commissioners proposed to adopt a largely sensible framework I had dubbed "virtual retail wheeling"[38] because it yields all the putative economic-efficiency benefits of retail wheeling with none of its difficulties. In essence, it is William Hogan's proposal for "Efficient Direct Access," nicely refined through the efforts of advisors and stakeholders convened mainly by San Diego Gas & Electric Company, and now accepted by all three California investor-owned utilities. It has three main elements:

- a new, independently operated regional market-maker in wholesale electricity ("Poolco") would clear that market half-hourly, take no positions on its own account, process settlements, and discover real-time spot prices for electricity;
- retail customers would buy electricity exclusively from their normal local utility at prices whose fixed component came from traditional ratemaking and whose variable component equalled (or added a fixed amount to) that spot price; and
- utilities would no longer be responsible for assembling, aggregating, and maintaining a portfolio of resources, but rather would simply buy and provide spot-priced electricity (giving no specially favorable access to their own generation) bundled with whatever other services or attributes their customers desired.

Under this system, any longer-term portfolio attributes desired would be assembled *by customers* through their unregulated, unreported private acquisition of Contracts for Differences or other hedges, options, insurance, etc., motivated solely by deep forward markets with long-term prices (unless augmented by regulators' or legislator' mandates, which could be expressed as *e.g.* diversification quotas or explicit subsidies but implemented by competitive bidding). There would be no actual financial transaction or notional physical transaction between retail customers and any electricity suppliers other than their local utility, so the paralyzing jurisdictional disputes, legal rewriting, and institutional transformations required by retail wheeling would not be necessary. Most importantly, utilities would continue to be rewarded by appropriate regulatory incentives for acquiring the cheapest resources, whether supply- or demand-side, and for flowing those resources' benefits through to customers. Appropriate fixed costs such as farsighted R&D, grid costs, and recovery of the utility's sunk generating costs would occur through the fixed-cost component of the tariff just as now. So could the costs of cost-effective demand-side investments. (Alternatively, any or all of these costs could be charged per kWh, not per customer.) The CPUC explicitly stated its desire to retain its decoupling of utility profits from sales volumes, albeit with modifications not yet stated, and for the time

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[36] This is especially odd because it is widely perceived to have been triggered by Britain's, Norway's, and New Zealand's privatization and "deregulation," followed by others such as Chile's. Those situations are profoundly different from that of the U.S., and all, though interesting, are problematical in different ways. For example, Britain, far from deregulating, established a Regulator for the first time, and the need for his intervention has steadily grown ever since. However, the enabling statute was fundamentally flawed, so the wholesale marginal price is effectively set not competitively but by a duopoly, and the regional distribution companies are explicitly rewarded for selling more electrons, not for cutting customers' bills. No halfway reform can mend these key flaws.

[37] Let alone "retail competition," which we have had for a long time: any customer has always been free to fuel-switch, buy end-use efficiency, or do onsite generation, all without the utility's knowledge or consent. Thus utilities' electrons have *always* had to compete at the retail level with other ways of providing the service.

[38] A.B. Lovins, invited comments of 17 August 1994 to CPUC President Fessler (see also comments of 22 May 1994, reprinted in *El. J.* **7**(6):67–80 [July-August 1994]), RMI Publication #U94-18.

being to retain current efficiency and load-management programs and their traditional cost recovery. The bedrock principle of performance-based regulation that rewards lower retail *bills*, not ¢/kWh, appears to be intact.[39]

What of other states? Before California rejected its own retail-wheeling proposal, quite a few states had already rejected similar or worse ones, often deterred by the prospect of putting their prize customers "in play" to be picked off by neighboring states' utilities without reciprocal access to theirs.[40] (As a New Mexico legislator remarked, "If you're the only kid on the block who says, 'Come play with my toys,' everyone will come play with your toys.") Contemplating this risk and even more daunting legal ones, only two states did anything[41]: Nevada offered retail wheeling to a particular steel rolling mill if it were built there (but so far it hasn't materialized); and Michigan authorized a limited-term, new-capacity-only, ~1%-scale experiment that was promptly taken to court by both Detroit Edison and the state Attorney-General.

Those lawsuits, wending their leisurely way toward the Supreme Court, soon became largely moot with two 29 March 1995 proposed orders by the Federal Energy Regulatory Commission. This "Mega-NOPR," which I interpret as quite discouraging to retail wheeling, states in detail how FERC intends to create the vibrant wholesale market required by the National Energy Policy Act 1992; warns that customers leaving the grid to shop around will *not* thereby escape paying for the assets they strand, but will be liable to pay for them anyway via wires charges (as the California PUC had also proposed in its original retail-wheeling Blue Book); and says that any state authorizing retail wheeling will thereby simply be transferring its authority to FERC, which will then interpret the transaction as a wholesale one and assert full jurisdiction all the way to retail distribution. Some "deregulation."

Of these FERC conclusions, the most devastating to retail wheeling is the most basic—the elaboration of how to carry out the 1992 Congressional mandate for full wholesale competition—because *wholesale competition will capture essentially all of the same benefit that was claimed to justify or require retail wheeling*[42], and it can only be captured once. Capturing that benefit—buying electrons in bulk at competitively reduced prices—by keeping the competition where it's needed, at the wholesale level, is entirely consistent with *also* capturing the severalfold larger benefit of efficient end-use by retail customers; whereas retail wheeling, using any conceptual structure proposed so far, would gravely inhibit if not destroy that larger benefit. Obviously it is better to seek, reward, and obtain *both* benefits than to trade off one for the other. Wholesale competition *plus* state regulation that rewards utilities for cutting customers' bills will indeed capture both benefits. It will do everything the advocates of retail wheeling want—except shift their costs to other customers. Indeed, San Diego Gas & Electric has persuasively argued that it will even make bilateral contracts unnecessary: SDG&E's version of the Poolco proposal provides "virtual bilaterals" with no actual bilateral relationships, all the same benefits, and none of the complications.

While many details, some of them quite important, remain to be worked out in both the California and the FERC proposals, the only three real proposals yet acted upon—a revolution offered and then rejected by California, a single-plant bribe offered (so far in vain) by Nevada, and a minor experiment authorized by Michigan but vanished into the litigative vortex[43]—hardly constitute the tidal wave of retail wheeling announced in the press. Where is that

[39] The majority also expressed its willingness to consider retail wheeling in four years if all its key problems could be solved, but displayed little optimism they could be nor belief they would need to be. The main conceptual problem remaining in the proposed order is the distortion it would introduce by not fully exposing nuclear generation to the discipline of pool dispatch. There seems no economic rationale for this exception.

[40] An astute 1994 California Energy Commission legal opinion showed, and the weight of authority concurs, that requiring such reciprocity would founder on the U.S. Constitution's Commerce Clause.

[41] At this writing, industrialist/environmentalist consensus proposals are pending in Massachusetts and Rhode Island but are a long way both from regulatory approval and from bearing much resemblance to what is normally described as retail wheeling. Emphasizing end-use efficiency and load management, rewards for cutting customers' bills, renewable energy, and other standard fare of environmentalist reforms, they would simply allow major industrial customers to try to beat the utility in the spot market, but not to escape stranded-asset costs.

[42] In theory, some modest marginal benefit of retail wheeling might remain if utilities failed to offer to customers as full a menu of unbundled and rebundled service options as independent providers wished to offer and customers wished to buy. In practice, however, it is hard to see how this potential Pareto improvement lost by using the utility as a second-best and perhaps not fully transparent service provider could be very substantial, especially since the utility would remain the sole provider only of *electrons*: any providers of unbundled financial, efficiency, or other services who felt inadequately served by the utility as intermediary could still sell services directly to customers.

[43] However, mid-1995 rulings by the Michigan PUC, clearly driven by political direction rather than by the record, essentially dismantled Michigan utilities' strongly demanded and highly cost-effective efficiency programs. (In 1994, for example, Consumers Power's programs were oversubscribed by 7:1 and save at an average cost of ~1.5¢/kWh.) Michigan industries' and utilities' resultant handicaps in the marketplace will follow in due course.

much-ballyhooed deregulatory tsunami? Only in the fertile imaginations of its advocates. And who are they? Largely a curious coalition of large industries[44] eager to grab the cheapest power at everyone else's expense, free-market ideologues with limited knowedge of utility reality and history, anti-environmentalists who think retail wheeling is a neat way of avoiding environmental accountability or expenditures and of killing demand-side programs they find ideologically distasteful, and consultants who see chaos as a profit opportunity and are not averse to helping create more. Though this unholy alliance has been surprisingly effective for a time in wrapping its notions in the superficially attractive language of "choice" and "competition," I think common sense, helped by Professor Hogan's and other independent analysts' incisive reasoning, is starting to reassert itself among regulators.

But meanwhile, many utility managers, not content to see Wall Street chop off their legs as analysts foresaw eventual confiscation of shareholder assets on a massive scale and hence wiped scores of billions of dollars off utility equity values, have started to chop off their own arms too—by preëmptively slashing their demand-side programs as a "customer-service frill" that will have no place in the cold, harsh world of competition. This panicky reaction, which has already destroyed or degraded many important efficiency capabilities (and done the same or worse to nationally vital R&D strengths[45]), is unsound for two main reasons: it misreads the lessons of competition in other industries, and it gets exactly backwards the role of efficiency services in a competitive environment.

My colleague Jim Newcomb has compellingly presented elsewhere[46] an insightful view of the restructuring of other industries undergoing competitive restructuring and deregulation. In every case—airlines, oil, gas, telecommunications, trucking, etc.—market actors who expected the business to turn into a purely price-driven commodity play did poorly. The firms that survived and prospered were those that appreciated early that any retail business is quintessentially a *service* business. Retail customers generally want not only affordable commodities but also a bundle of other services and attributes. Gas customers, for example, want not only cheap methane molecules but also inventory management, storage, price hedging, etc. Telephone customers want a variety of services now proliferating in immense variety, not just low cents-per-minute. Airline passengers tend to want services too: courtesy, reserved seats, baggage interlining, food, etc., not just low cents-per-seat-mile.[47] Thus utilities that try to carry the cheap-electrons-only mentality from wholesale to retail levels will do so at their peril.

Indeed, those frozen-in-the-headlights utility executives' assumptions about the inevitability of retail wheeling would suggest precisely the *opposite* of their conclusions about their efficiency programs. In a competitive world in which all retail distribution entities are buying bulk electrons at competitively leveled prices, it will be very difficult to distinguish one's service from others' except by offering the one really big advantage available: bundling electrons with their far more productive end-use, so as to deliver dramatically lower bills and better end-use services. For this reason, if retail wheeling *were* likely, a strong portfolio of efficiency services would become *more* rather than less important as a core element of utilities' competitive strategy: an unbeatable way to differentiate service, boost value, build customer loyalty and success (hence competitiveness, size, and demand growth), retain wavering customers, enhance public image, reduce present and future system costs and risks, cut rates *and* bills, and provide profitable service benefits to both customers and utilities. Jettisoning this capability in a competitive environment is an irrational act of unilateral disarmament.

It remains to be seen how rapidly utility managers come to understand the new world of wholesale competition, continuing regulatory turbulence, and ever more dramatic technical progress in and market demand for the attributes that advanced electric end-use efficiency alone can provide. Powerful market forces are at work, some largely unseen: Rocky Mountain Institute's real-estate practice, for example, is finding such superior financial performance from highly efficient buildings that utilities which fail to offer an attractive efficiency partnership may find themselves increasingly irrelevant to some of their biggest customers.

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[44] Chiefly ELCON, whose members use 4% of U.S. electricity. However, discussions with many of those firms leaves me convinced—as are they when we discuss the technical details—that they all have vast untapped opportunities to increase their electric productivity at far below short-run marginal supply costs. While it is natural for a profit-seeking organization to seek to shift its costs to others with less market or political power, those firms' lack of zeal in pursuing their own demand-side opportunities casts doubt on their seriousness about cutting costs.

[45] TECC Group (Littleton CO 80162-1992), *U.S. Electric IOU Research, Development, and Demonstration Expense Trends, 1990–94* (August 1995), found a $67.6 million or 9.9% drop between 1993 and 1994, compared with average increases of 4.5%/y during 1990–93. Worse yet, the best people, tired of budget fights, often left first.

[46] *The Future of Energy Efficiency Services in a Competitive Environment*, E SOURCE, SIP-4, 1994.

[47] It now appears from *Wall Street Journal* analyses that Southwest Airlines' initial advantage arose far less from its spartan flights than from its hubless structure, which enabled it to utilize its capital assets far more efficiently. Moreover, U.S. airlines' baroquely complex and daily changing fare structures so adroitly make customers (as an Ohio PUC member remarked) "an offer they can't understand" that their elegant price signals are quite opaque.

Why, then, did I say at the start of this concluding section that I thought the most radical changes in the utility industry were yet to come? Because the generals are, as usual, fighting the previous war. About the time we get really good at wholesale competition, we probably won't need it, because cheap proton-exchange-membrane (PEM) fuel cells, photovoltaics, and other decentralized generators, augmented by efficient end-use and by decentralized electric storage, will have put virtually all of today's central thermal stations out of business. There are three main reasons I now think this is plausible over the next couple of decades:

1. "Distributed benefits" omitted from traditional comparisons between centralized sources collectively raise distributed resources' economic value by about half to one order of magnitude—enough to make even such relatively costly options as photovoltaics cost-effective *now* in many applications.[48] The Hoganesque restructuring described above will increasingly give these benefits a voice in the market. For example, resources near the load center—or *at* it, by definition, in the case of demand-side resources—will start to get due credit, via an appropriate locational and temporal rent, for their "grid Dristan" (decongestant) effects.[49] Peak-coincident resources, like photovoltaics (and often windpower) in summer-peaking areas, will get due rewards. Even more importantly, renewable sources will gain value as constant-*price* resources, and may even be properly evaluated at *risk-adjusted* discount rates reflecting their lack of future fuel-price or carbon risk.

2. Cost-effective onsite storage devices using carbon-fiber superflywheels[50] are widely expected to enter the market around late 1995 for power conditioning and uninterruptible power supplies, and about a year later for vehicular use. While their specific energy is expected to be comparable to that of good batteries (~35–100 W-h/kg), their specific *power* can easily be two orders of magnitude higher. Their demonstrated in-out cycle efficiency is at least 96%, their lifetime should be many decades, their coastdown time is months, and their cost is potentially quite modest. Such devices, probably soon supplemented by even higher-specific-power ultracapacitors, not only augment load management and end-use efficiency as potent responses to real-time pricing, which will therefore become far less important as the peaks disappear, but will also greatly facilitate the transition to intermittent renewable sources, making them "firm," dispatchable, and hence far more valuable.

3. Technological progress with local generation is not only extraordinarily rapid and encouraging of late, yielding net electricity costs well below 2¢/kWh[51]; it has also gained a new driving force, namely superefficient cars and other hybrid-electric vehicles[52] that obtain the benefits of electric propulsion without the disadvantages of onboard batteries. Ultralight, ultra-slippery "hypercars" require ~3–5-fold less peak power than conventional cars, and obtain only a modest fraction of that peak power from the onboard fuel-to-electricity conversion device, such as a small engine, gas turbine, or fuel cell. They can therefore adopt PEM fuel cells for that role far earlier in their development cycle than conventional cars could, because the ~5–10-fold smaller fuel cell will be correspondingly less sensitive to its cost, mass, or volume per kW. Moreover, since the hypercar burns only ~10% the usual amount of fuel, it can use a tenfold costlier fuel—probably more than, say, solar hydrogen compressed into cylinders would cost—without raising its fuel cost per km driven. Thus not only compressed natural gas with a small onboard reformer but also ~200-bar hydrogen gas[53] seem plausible as surprisingly early automotive fuels. Even hydrogen electrolyzed and compressed using offpeak retail electricity can beat taxed retail gasoline at U.S. prices—cheaper than bottled water—because of the remarkable fuel-to-electricity conversion efficiency of proven PEM technology: ~65% with hydrogen, or the upper 50s of percent with methane or ~55% with methanol, all about four times the ~15% average efficiency of a typical gasoline-powered automotive driveline. Mid-1995 evaluations of PEM fuel cells show[54] that established technology can

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[48] A.B. Lovins & D. Yoon, "Renewables in Integrated Energy Systems," PictureTel address to ANZSES (Perth, W.A.), 3 December 1993, RMI Publication #E94-12, to be expanded in A.B. Lovins & A. Lehmann's forthcoming 1995 RMI technical publication.

[49] A.B. Lovins, comments of 17 August 1994 to CPUC, at pp. 3–6; to FERC, 24 July 1994 (urging symmetrical treatment for demand-side resources); and in EPRI, *DR Connection*, pp. 2–3, November 1994.

[50] W. Howe, "Protecting Facilities from Power Outages: Flywheel Technology Enters the Competition in an Emerging Market," E SOURCE (Boulder CO), TU-95-2, April 1995.

[51] T. Casten, remarks to Energy Committee of the Aspen Institute for Humanistic Studies, 12 June 1994, Trigen (White Plains NY), reporting net system efficiencies >90% and net electricity costs (after credit for industrial use of the waste heat) around 0.5–2¢/kWh from "trigeneration" with off-the-shelf MW-range gas turbines equipped with refiring and a waste-heat boiler. Many large industries have thermal loads of the required several-MW size.

[52] RMI Hypercar Center publications, *op. cit. supra*; these span the full range of technical content and depth.

[53] In a filament-wound carbon-fiber tank lined with a metallized polyester film; metal tanks are too heavy but do not appear necessary for excellent safety characteristics.

[54] *E.g.*, by Jeff Bentley of Arthur D. Little, Inc., Cambridge MA 02140-2390.

almost certainly be mass-produced at costs below \$250/kW, while the best experimental technology can probably beat \$50/kW. Even with a reformer added (now as low as another ~\$50/kW), such prices and efficiencies, plus the opportunity of onsite use of the waste heat, will clearly beat grid electricity almost anywhere natural gas is available, generating at ~1–2¢/kWh—less a broadly comparable credit for the ~80°C waste heat.

The fuel-cell production volumes necessary to displace central power stations may well come first from cars, but it could happen the other way around. Which happens first is almost irrelevant: the key point is that of these two potentially enormous markets, both are likely to happen surprisingly soon, and once either of them does happen, the other will not be far behind. Much the same is true of the way fixed-site power-conditioning and -storage markets for superflywheels and ultracapacitors will bring down costs for parallel development in electrically propelled vehicles, and vice versa. Naturally, all these devices will have smart controls responsive to the real-time price signals that will permeate the grid. Thus the beer-keg-sized household storage superflywheel will act as a house-scale power broker, buying and selling appropriately to maximize financial return.

PEM-fuel-cell cars could even make possible an option not practical with today's cars because internal-combustion engines are insufficiently durable: plugging the car, which is parked ~96% of the time, into the gas and electric grids as a dispersed *generator*—like a battery-electric car inside-out—with zero marginal capital cost and ~20 kW_e of highly reliable capacity. This is considerably more than the peak load of even an inefficient house. If even a modest fraction of car-owners did this, it could transform the utility business, because a full U.S. hypercar fleet, not counting heavier hypervehicles, could represent ~3 TW of generating capacity, or four times the total capacity of all grid-connected generators today, and the fuel cells are extremely long-lived. Thus utilities expecting to sell electricity to battery cars might find themselves buying it instead.[55]

In short, the prospect is now strong that some variety of new technologies, reinforced by the greater flexibility and diversity of the market actors becoming engaged in power markets at all levels, will realize Carl Weinberg's vision[56] of the "distributed utility" far earlier than anyone might have thought as recently as, say, 1994. The better the technology gets and the more rigorously competition hones our engineering economics, the faster the power plants (and new local storage devices with surprising capabilities) will shift to our roofs, basements, backyards, and driveways. The more distributed generation and storage resources disintermediate the distribution utility—which now moves across the meter and even *eliminates* the meter—the more irrelevant will become the otherwise historically observed tendency[46] for dis-integrated utility functions (genco, transco, disco) to seek vertical re-integration.

What is a "utility" that engineers, procures, leases, installs, and operates onsite resources which need no grid connection, or which optionally use it merely as a convenient local means of profitable temporal exchange? It is not a generator or distributor in the usual sense; it is purely an energy service company that provides light, comfort, and other end-use services, or the means to achieve them, right at your premises. Logically, its engineering and financing will intimately integrate end-use efficiency with the onsite supply, because that will yield the best buy. The elaborate arena just constructed for bidding bulk power sources will get bypassed by resources already *at* the users' premises and requiring no generation, aggregation, bidding, or distribution. Soon that shiny new arena could stand abandoned and empty, populated only by the ghosts of economic theorists long dead—blindsided, not for the first time, by the autonomous onrush of technologies they scarcely understood. This will not happen overnight, and the transition provides an impermanent "window" probably just long enough to pay off existing generating and grid investments before both they and the means of charging for them (as today's customers are steadily paying) become irreversibly bypassed. Happily, the transition seems likely to be long enough to be graceful—not so much because the dispersed generating technologies will be so slow to deploy as because persistent needs for temporal balancing of onsite thermal and electrical loads with supplies will justify retaining grid service for quite a while.

This market-driven "withering away of the state" will then make utilities write off remaining central thermal power plants[57]—magnificent engineering achievements which, like open-hearth furnaces and Bessemer converters, are no

[55] It is not immediately obvious how all these innovations in both mobile and fixed-site uses of natural gas, generally with extremely high system efficiencies, would affect the total demand for this key transitional resource, which is now known to be exceedingly abundant.

[56] Dr. Weinberg, former manager of R&D for PG&E, is at Weinberg Associates, 42 Green Oaks Court, Walnut Creek CA 94596.

[57] This would be a major hit on top of enormous writeoffs of project-financed Asian power plants, most of which will disappoint: they represent the same dumb money, chasing transactional rewards without favorable economic fundamentals, that inflated the 1980s U.S. real-estate bubble. It's not clear which of the two central risks is worse—that the sovereign host won't raise electricity prices to the levels needed to pay for the plants, or that it *will*, deflating demand far below expectations.

longer competitive even to run, let alone to build. (I'm already experiencing a twinge of pre-nostalgia just thinking about it.) And so Thomas Edison's original vision of a largely decentralized power system, perhaps even his vision of selling energy *services*—light and torque, not kWh—will at last be fulfilled: just a century late.

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