Exchanges between Mark Mills and Amory Lovins about the electricity used by the Internet

14 September 1999

On 31 May 1999, *Forbes* published an article coauthored by its columnist Peter Huber and Mark Mills. Its text, posted at www.forbes.com/forbes/99/0531/6311070a.htm, read as follows:

Being digital was supposed to mean less demand for hard energy. It isn't turning out that way.

Dig more coal—the PCs are coming

BY PETER HUBER AND MARK P. MILLS

SOUTHERN CALIFORNIA EDISON, meet Amazon.com. Somewhere in America, a lump of coal is burned every time a book is ordered on-line.

The current fuel-economy rating: about 1 pound of coal to create, package, store and move 2 megabytes of data. The digital age, it turns out, is very energy-intensive. The Internet may someday save us bricks, mortar and catalog paper, but it is burning up an awful lot of fossil fuel in the process.

Under the PC's hood, demand for horsepower doubles every couple of years. Yes, today's microprocessors are much more efficient than their forerunners at turning electricity into computations. But total demand for digital power is rising far faster than bit efficiencies are. We are using more chips—and bigger ones—and crunching more numbers. The bottom line: Taken all together, chips are running hotter, fans are whirring faster, and the power consumption of our disk drives and screens is rising. For the old thermoelectrical power complex, widely thought to be in senescent decline, the implications are staggering.

About half of the trillion-dollar infrastructure of today's electric power grid exists to serve just two century-old technologies—the lightbulb and the electric motor. Not long ago, that meant little prospect for growth in the power industry. We have about as many motors and bulbs as we need. "The long-run supply curve for electricity is as flat as the Kansas horizon," declared green guru Amory Lovins in 1984.

While Lovins surveyed the prairies, however, IBM and others were just beginning to roll out serious numbers of PCs. Today, worldwide annual production stands at 50 billion integrated circuits and 200 billion microprocessors (many of those special-purpose controllers that run things like car engines and telephones). Every last one of these chips runs on electric power. On its surface, where bits are incarnated as electrons, a chip runs at enormously high power densities—up to one-tenth those at the surface of the sun. Lucent, Nortel, Cisco, 3Com, Intel, AMD, Compaq and Dell have become the new General Electrics behind a resurgent demand for power.

Your typical PC and its peripherals require about 1,000 watts of power. An IntelliQuest study reports that the average Internet user is on-line 12 hours a week. (Most data relate to home users; business usage is very hard to pin down, but almost certainly is higher.) That kind of usage implies about 1,000 kilowatt-hours of electrical consumption in a year.

For the thermoelectrical power complex, rising digital demand has staggering implications.

There are already over 50 million PCs in households, and 150 million more computers in businesses. Another 36 million are sold each year with 20 million going on the Internet.

And for every piece of wired hardware on your desk, two or three pieces of equipment lurk in the network beyond—office hubs and servers, routers, repeaters, amplifiers, remote servers and so forth. The heavy iron that powers a Schwab or Amazon typically requires a megawatt. There are already over 17,000 pure dot-com companies (Ebay, E-Trade, etc.). The larger ones each represent the electric load of a small village.

Getting the bits from dot-com to desktop requires still more electricity. Cisco's 7500 series router, for example, keeps the Web hot by routing an impressive 400 million bits per second, but to do that it needs 1.5 kilowatts of

power. The wireless Web draws even more power, because its signals are broadcast in all directions, rather than being tunneled down a wire or fiber. The digital PCS network—still in its infancy—will need a projected 70,000 radio base stations within a few years and twice that in a decade. Each of those stations burns at least a couple of kilowatts. The wireless handheld market (next-generation Palm Pilots and such) will reach 20 million units in annual sales within a few years.

Individually, many of these boxes only sip power; handhelds now run for weeks on a couple of AAA batteries. Cisco's newest gigabit router, the 12000 series, can handle 16 times the bandwidth of its predecessor, with the same electric power appetite. But total demand for computational power is outrunning any efficiency gains. According to the Semiconductor Industry Association, today's state-of-the-art integrated circuit can contain 21 million transistors and run at 400 megahertz, on 90 watts of power; it will give way, in a decade or so, to an 1,800-megahertz/1,400-million-transistor chip that draws 175 watts. And even if Hewlett-Packard's Toronado and Nokia's Internet cell phones end up running on body heat, they'll pump bits in and out of the Web, driving power demands upstream.

Traffic on the Web has indeed been doubling every three months. About 17 million homes already have two or more PCs. Communicating chips are now migrating off the desktop. Electrolux recently announced its "Internet refrigerator," an embedded PC replacing the scribbled note and door magnet. GE has an Internet microwave oven. EmWare, a software company, is working with Sybase, 3Com and Micron to bring vending machines on-line to make stocking and management more efficient.

Just fabricating all these digital boxes requires a tremendous amount of electricity. The billion-dollar fabrication plants are packed with furnaces, pumps, dryers and ion beams, all electrically driven. It takes 9 kilowatt-hours to etch circuits onto a square inch of silicon, and about as much power to manufacture an entire PC (1,000 kilowatt-hours) as it takes to run it for a year. (We're counting just the things that really go into the box—chips, boards and so forth—not the water cooler or the rest of the surrounding infrastructure.) A typical fab is already a 10- to 15-megawatt electric beast—about as big as a steel minimill, electrically speaking. And there are at least 300 of these factories in the U.S. Collectively, fabs and their suppliers currently consume nearly 1% of the nation's electric output.

A billion PCs on the Web means electric demand equal to total U.S. output today.

The infoelectric convergence is already having a visible impact on overall demand. At least 100 million nodes on the Internet, drawing from hundreds to thousands of kilowatt-hours per year, add up to 290 billion kWh of demand. That's about 8% of total U.S. demand. Add in the electric power used to build and operate stand-alone (unnetworked) chips and computers, and the total jumps to about 13%. It's now reasonable to project that half of the electric grid will be powering the digital-Internet economy within the next decade.

The global implications are enormous. Intel projects a billion people on-line worldwide. That's $1 trillion in computer sales—and another $1 trillion investment in a hard-power backbone to supply electricity. One billion PCs on the Web represent an electric demand equal to the total capacity of the U.S. today.

But won't all this new digital intelligence reduce energy demand in other ways? Telecommuting and e-mail, for example, reduce consumption in other sectors of the economy. Energy demand has indeed flattened somewhat in the transportation sector. Less warehousing, and the overall tuning of the economy, are cutting demand for gasoline, diesel and heating fuels. But not for electricity, which is generated mostly with coal (56%), nuclear (20%), hydro (10%) and gas (10%). Heating loads in winter are reduced by computers themselves, since the electricity that runs the chips ends up as heat dissipated out the back. But these gains are more than offset by the additional cooling loads computers impose in the summer.

Thus, despite years of dramatic improvement in lighting, cooling and heating efficiencies, there has been little if any reduction in total energy use per square foot in commercial office buildings. The typical home office gets set up in addition to the one downtown, not instead of. Canon's new digital X-ray machine, recently approved by the Food and Drug Administration, will replace millions of X-ray films and tens of thousands of machines—but it will also likely accelerate the deployment of X-ray machines in many more doctors' offices. These new units will be bandwidth hogs, too, as they pump high-resolution pictures across the Web in search of second opinions from distant experts. Overall, total electric consumption continues to grow about 3% a year—and more than half of that growth is attributable to the rise of the microprocessor.

Expect, as well, fundamental change in another aspect of the power grid: quality and reliability. The conventional grid tolerates power hiccups of a single cycle for 60-cycle power. With refrigerators, lightbulbs and ovens, a blip in the current is merely an inconvenience. With computers and routers, it can be a catastrophe.

That's why a company like American Power Conversion, of West Kingston, R.I., has seen revenues jump 70-fold in ten years by selling uninterruptible power supplies for everything from desktop machines to dot-com servers to routers and enterprise data centers. There's a parallel boom in the systems and electronics that keep power clean. Active Power of Austin, Tex. makes a flywheel-based electric storage system sized to isolate and protect entire office buildings and factories from "dirty" power. The 1.4 ton flywheels spin at 7700 rpm. American Superconductor of Westborough, Mass. uses a two megawatt superconducting magnet, weighing three-quarters of a ton, to do a similar job. It is inevitable that a lot more very heavy atoms will be deployed to keep our bits on their appointed rounds.

Futurists have been promising us an information highway, not unit trains loaded with coal. Fiber-optic cables, not 600-kilovolt power lines. We're going to get both.

Charts: Energizing the Internet Utilities sucked into the vortex of the Internet

Read more: By Peter Huber Technology From May 31, 1999 Issue

That article led to the following exchanges of E-mails, plus two letters meant for publication, all reproduced here by permission of their authors. The headers have been altered to protect the privacy of E-mail addresses. Peter Huber and Mark Mills are coauthors of the *Forbes* article; Drs. Alan Meier and Jonathan Koomey are staff scientists at Lawrence Berkeley National Laboratory; Dr. Joe Romm, former Deputy Assistant Secretary of Energy, now runs a nonprofit energy/climate policy group; Rob Bradley and Tim Vail are at Enron Corporation; Michael Totten is at the World Resources Institute; Payal Sampat is at Worldwatch Institute; Rick Heede and Amory Lovins are at Rocky Mountain Institute; and Fred Smith and Myron Ebell are at the Competitive Enterprise Institute. Side-correspondence with these and other parties is neither included here nor important to understanding this exchange, which is primarily between Mills and Lovins.

In the following compilation, commentary is in boldface Times New Roman like this; writings by Lovins are in Arial like this**; and writings by Mills are in** Courier New like this. **Writings by others are in** Times New Roman lightface like this. **All E-mail shown are reproduced in their textual entirety and by permission of their respective authors. Lovins's [bracketed] paraphrases of parts of three E-mails from Romm are also included with Romm's permisssion. Such permissions are of course required by normal Netiquette and by copyright law for publishing private E-mail correspondence, which in this exchange was originally meant only for a few specific recipients.**

From: Amory B. Lovins
To: Peter W. Huber, Mark P. Mills
Subject: your Forbes article "Dig more coal"
Date: Sun, 20 Jun 1999 17:29:00 -0600

I am familiar with this topic but am having difficulty reconstructing most of your numbers, and am naturally being asked to comment on them, so I'd like to do them justice. If the underlying report showing the calculational details and documenting your sources is available, could you please send it to me as soon as possible? If not, please let me know when and where it will become available. I'd greatly appreciate an interim E-mail while any mailed version is en route.

Thanks—Amory Lovins

[letter submitted to the Editor of *Forbes* 25 June 1999, later published in part]

To the Editor,

Your article "Dig more coal ? the PCs are coming" (May 31) certainly catches one's attention in a creative fashion. We thank Peter Huber and Mark Mills for raising popular awareness of this topic. Unfortunately, their article grossly overstated the actual electricity consumption involved and ignored industry and government efforts to moderate it. The topic has been researched for over ten years but the authors did not appear to have contacted anyone familiar with the area.

The article states that "your typical PC and its peripherals require about 1,000 Watts of power". In fact, a PC and monitor use about 150 Watts, and a printer and scanner increase the energy consumption only moderately. Furthermore, consumers often exploit built-in power management features or switch off the equipment, lowering the annual average power used for a PC, monitor, and printer in an office environment to the equivalent of a constant 60 Watts. Furthermore, the authors overstated the number of PCs in businesses by a factor of two. While data on office equipment energy has its weaknesses, we do know enough to be sure that the electricity use cited in the article is many times greater than what actually occurs.

The article also ignores the efforts to reduce computer energy consumption --underway for many years. The industry has developed technologies and protocols that allow digital devices to go into 'sleep' modes or turn themselves entirely off when not in use. The U.S. EPA's Energy Star program works with industry to promote efficient products in the marketplace to realize more of the savings potential and additional programs are planned. New technologies such as flat panel displays and more efficient power supplies also reduce the future energy consumption of digital devices.

The problem of electricity use of office equipment is an important one, worthy of attention by *Forbes* readers. However, the article unnecessarily misleads the public into thinking that the problem is much bigger than it really is, and implies that little is being done to ameliorate it.

Bruce Nordman and Alan Meier, [Lawrence] Berkeley [National] Lab[oratory]
David Isaacs, Electronic Industries Alliance
Andrew Fanara, U.S. Environmental Protection Agency

[letter submitted to the Editor of *Forbes* 27 June 1999, not published]

To the Editor,

Peter Huber and Mark Mills ("Dig more coal," May 31) claim my 1984 statement that "The long-run supply curve for electricity is as flat as the Kansas horizon" is rebutted by their expectation that "half of the electric grid will be powering the digital-Internet economy within the next decade." Yet these two ideas aren't contrary; they're unrelated. As any economist knows, a supply curve relates the quantity of supply to its marginal cost. As I foresaw, smarter technologies have made that cost flat or declining as generation has risen. This trend is now accelerating as ever cheaper decentralized options—co- and trigeneration, fuel cells, renewables—begin to turn central thermal stations into toast.

The authors thus seem to have confused a supply curve with a projection of demand over time. It's obvious that their demand projection is equally flawed, and anyone relying on it will be in for a shock. Of course, digital device populations and traffic are growing rapidly, but in order to save money and keep the chips from melting, virtually all the devices are also becoming far more energy-efficient to make and run. Ever since I coauthored the first book on efficient office equipment in 1990, experts on the race between usage and efficiency have been speculating which will win. Now, with powerful 15-watt servers, juice-sipping drives and LCD screens, inkjet printers, low-voltage chips, and radically more efficient fabs to make the chips, the odds are shifting even more to efficiency, not less. This trend would only strengthen if the devices gobbled over $100 billion a year worth of electricity, as Huber and Mills expect.

Their bizarre conclusion that a digital world will need far more giant coal plants—despite both their utter uncompetitiveness and modern electronics' burgeoning direct and indirect energy savings—is consistent with the coal-promoting mission of its sponsor, to which Mills is science advisor (www.fossilfuels.org). It's a propaganda arm of the Western Fuels Association, called the Greening Earth Society, which holds that releasing more carbon dioxide is not only inevitable but desirable. How ironic that Huber, an arch-foe of junk science, has now coauthored some of his own.

Amory B. Lovins, Co-CEO (Research), Rocky Mountain Institute

From: Amory B. Lovins
To: Mark P. Mills
Subject: Re: your Forbes article [replying to Lovins's 20 June E-mail to Mills, above]
Date: Mon, 28 Jun 1999 13:11:00 -0600 [replying to Mills's response of 27 June to Lovins, as shown]

At 08:26 27/06/99 PDT, you wrote:

One relevant report can be ordered (no charge) from the Greening Earth Society web site. GES is a sponsor of one aspect of our research on this topic. The GES report is now printed and does contain a detailed data table. It is my understanding that GES has only posted the Exec. Summary on-line at the moment; the full report is still only available in hard copy.

On the assumption this means that the full written report can be ordered in hard copy from the GES website, I'll gladly do so. Thanks. As to other work, presumably sponsored by someone other than GES, may I ask who sponsored it and whether/when/how it'll become available?

You may be interested to know that Rob Bradley and I have been engaged in a discussion on the substance and implications of this research for Enron and other companies.

Good. Most of your numbers are so different (by half to one order of magnitude, both bottom-up and top-down) from all the published data I know that I'll be very interested to see how you define and derive them. Obviously it's possible to drag a great deal of national energy use across the system boundary by saying that information-based businesses are generating and using data—in principle you could count most of the commercial and much of the industrial sector as digital energy use if you made your definition sufficiently inclusive—but I presume that's not what you had in mind.
—ABL

From: Mark P. Mills
To: Amory B. Lovins
Cc: Rob Bradley, Peter Huber
Subject: Re: your Forbes article
Date: Sun, 27 Jun 1999 17:25:30 PDT

Your assumption about the full report is correct. As to your observation about "system boundaries"—the data in my analysis include only kWh use from devices intended to create, feed and use the Internet. The assumptions are fairly clear. As a useful benchmark you are no doubt aware of the 1995 EIA survey of commercial building kWh consumption associated with computers, which found the equivalent of 4% of national supply consumed for that purpose (again in 1995). And, as you are no doubt aware, the total number of computers (importantly also, computer-type devices such as Routers) purchased, intalled and used (in particular for the Internet) exploded between 1995 and to date. For some obvious reasons, many of the 'boxes' that are kWh-consuming

PC-type devices are not included in many of the Information Industry's traditional data sets. There are, quite naturally, some approximations in the study/model I used. You will find that that model I used yields a result finding that about 6% total of all natiional kWh were associated with all computers in 1995 (i.e., more than the 4% for commercial building only data set from EIA). This data point compares favorably with the EIA results (hardly an order of magnitude different).

I'll be interested in your observations once you've had a chance to read the report.

From: Mark P. Mills
To: Amory B. Lovins
Cc: Rob Bradley, Tim Vail, Peter Huber, Jonathan Koomey, Joe Romm
Subject: Re: your Forbes article
Date: Tue, 29 Jun 1999 07:32:50 PDT

Rob Bradley tells me that you forwarded to him [on 27 June] a copy of a letter you have submitted to Forbes regarding Peter's and my article.

On the assumption that the letter is intended to address the substantive issues, and since Bradley et. al. are eager to further explore the underlying assumptions, as a courtesy please forward a copy so that I can provide additional perspective and/or corrections if necessary.

Mark P. Mills

From: Amory B. Lovins
To: Mark P. Mills
Cc: Bradley, Vail, Koomey, Romm, Huber)
Date: Wed, 30 June 1999 1624 MDT **[enclosing Lovins's *Forbes* letter (above), and shown here out of chronological order to connect it to the previous note it's replying to]**

Sure. You will not be surprised to hear that, as a longstanding student of this subject, I thought your numbers were very odd, although the letters column of *Forbes* is certain not to allow the space to explore the details. If I misunderstood you, any clarification would be welcome. My letter read as follows. As you suggested, I have also asked greeningearthsociety.org to send me a copy of your GES report. I trust that if there's a fuller explication of your calculations, you'll kindly send that too when available. I'm at RMI, 1739 Snowmass Ck Rd, Snowmass CO 81654-9199.

Incidentally, if you want my views on the economics of climate protection, they're at www.rmi.org/catalog/climate.htm. You may also be interested in two papers relevant to your thesis: http://redtail.stanford.edu/seminar/presentations/lovins1/ and /lovins3/. The former is "Putting Central Power Plants Out of Business"; the latter is "Negawatts for [Chip] Fabs." Many other relevant papers are posted at www.rmi.org, www.hypercar.com, and www.esource.com.

—ABL

On 30 June, Mills wrote Romm a commentary on Meier et al.'s letter to Forbes (above). This letter from Mills is shown below, interleaved with Lovins's reply of 3 July.

On 1 July, Mills wrote Lovins about Lovins's letter to *Forbes* (above). This letter from Mills is shown below, interleaved with Lovins's reply of 3 July.

On 2 July, Mills wrote Lovins responding to Lovins's 1 July reply to Mills's letter of 1 July. This letter from Mills is shown below, interleaved with Lovins's reply of 3 July.

From: Amory B. Lovins
To: Mark P. Mills
Cc: Romm, Koomey, Vail, Meier, Koomey, Smith,
Date: Saturday 3 July 1999, 0013 MDT
Subject: Mills 30vi99 comment on Meier et al.. Response to Forbes article

At 14:27 30/06/99 PDT, you wrote:

Thank you for forwarding the letter [to *Forbes*] from Meier et al. I have to say that I do not find that their letter shows a "remarkable consensus" since the authors do not provide any technical substance to their observations. To use an old advertisement phrase: "Where's the beef?"

As you well know, Mark, a magazine like Forbes leaves letter-writers like Meier et al. much less space to comment than it gave article-writers like you to state the material objected to. I think they did a good job in the space available, which was 1-3 orders of magnitude smaller than a technical rebuttal would require. To my mind, the affiliations of the writers do represent an impressive breadth of expert consensus that careful readers will note.

Here's the central question which Meier and colleagues do not address, nor have you or anyone else we've talked to come up with an answer (and I spoke with at least 50 knowledgeable people in the relevant Internet-related industries in undertaking the research): Just what is the total inventory of devices installed on the Internet, and how much electricity do they use?

Nobody knows. The point is that the few key figures presented in your article seem grossly at variance with the measurement-based literature available to the rest of us, leading us to be equally skeptical about your broader conclusions that apparently rest on those figures.

Peter and I still await an alternative estimate of the total kWh impact of the Internet. The Meier letter is, in essence, a refutation by vigorous asser-tion. I do not see how the Meier letter provides information sufficient to move you to "have little doubt" that we are "incorrect" (as if you had not already decided so in advance). Your conclusion is at best, premature since the Meier letter was clearly crafted without actually reading the report and the detailed tables.

Come on. The reason they hadn't read "the report and the detailed tables" was that your *Forbes* piece, which (in the nature of magazine letter response cycles) required immediate response, was published before you made your supporting analysis available—if indeed it is yet available (I'm waiting for it). What was premature was not their publication but yours. Stop blaming the victim.

Before addressing the specific claims made in the Meier letter, let's consider again the core issue.

Over the past five years, a total of over 100 million PC-type devices (note, not just home PCs) have been added to the U.S. inventory. Most, probably almost all, are connected to and driven by the Internet. Many of these devices are operated, in varying duty cycles, around the clock. They include such things as home, home office and business PCs, servers, "thin" servers, "super" servers, routers, amplifiers, digital switches, filters, and so on. Just how much electricity do all these boxes use?

Good question. I await your study with interest to see if you've usefully augmented others' attempts to answer it.

As you may recall in my response to your first communication to Rob Bradley and me, I directed you to the 1995 EIA study on PCs in commercial buildings. That report found 43 million PCs in commercial buildings and estimated that a total 98 billion kWh/year were consumed in 1995 by those devices (again, only in commercial buildings). It is clear from your letter that you and your colleagues find a 1999 total of about 300 billion kWh per year from ALL Internet PC-type devices incredible. But even accounting for efficiency gains, do you and your colleagues believe that a five-fold increase in the PC-type inventory (without accounting for the change in demand character) didn't at least double the 1995 commercial kWh estimate? A doubling would yield at least 200 billion kWh, a figure that would still be growing rapidly. I await an alternative estimate, any estimate. Meier et al.. do not provide one.

I find it hard to believe that 43 million PCs (if that's the right number), each presumably including both a CPU box and a monitor, would use 98 TWh/y. That's 2,279 kWh/PC-y. If they were on all the time (8766 h/y), that's 260 W/PC; if they're on for a typical office duty cycle of ~2500 h/y, it's 912 W/PC. The actual average duty could be somewhere in between, or might even be somewhat lower than 2500 h/y. It's unlikely, however, that the actual average usage is as high as 260 W/PC, especially in view of the recent gains in market and stock share by battery portables.

A word of caution about your source is in order. EIA studies of the type you cite are often done by econometrically minded statistical samplers who don't know the engineering literature, and hence tend to believe nameplate ratings that are usually (for PCs) about 3-5.5x higher than actual measured usage. It's also possible that they did spot measurements with a wattmeter that wasn't sophisticated enough to avoid spoofing by the third harmonics from the switching power supplies—a frequent source of error in this field that's well-known to computer-efficiency experts but not to econometricians. I have not had the time to inquire—perhaps one of my colleagues has—into the basis for the 1995 EIA number you cite. However, as a general matter, EIA, though normally pretty competent in keeping energy usage statistics, is perfectly capable of publishing absolute rubbish, as it recently did on climate/economic modeling, and its building end-use surveys are of variable quality. Without knowing a lot more about that 1995 estimate, therefore, I'd suggest not taking it at face value without careful cross-checks.

As a reality check, I just looked at Table 2.12 of the 1997 Annual Energy Review. It says the average U.S. commercial building surveyed in 1995 used 5.7kBTU/sf-y for "office equipment." Assuming, as appears to be the case, that this is site energy (3413 BTU/kWh), that's 1.67 kWh/sf-y, or 0.19 av We **[average Watts electric]** over 8766 h/y, or 0.67 av We over 2500 h/y. (The latter is consistent with the 0.6-0.7 W/sf measured in careful field studies, surveyed by E SOURCE a few years ago, for Class A offices.) However, the descriptions for the column headings make it appear plausible that "office equipment" probably includes task lights, photocopiers (a very big user), fax machines, coffeemakers, and other plug loads irrelevant to your thesis. If this is correct, then the Internet-related equipment usage is considerably lower. This illustrates why cautious interpretation is essential when one is dealing with EIA statistics. Specific measurements intended for your purpose are far more reliable. Also, please note that 0.7 W/sf for plug loads (which often include task lights and other irrelevancies) would be consistent with your 150 W/PC, assuming one PC/desk, only on an implausibly high 214 net sf/person. This too suggests that your 150 W/PC is probably too high.

It's also interesting that Table 2.11 shows that although per-square-foot electricity usage in the surveyed U.S. commercial buildings rose by nearly 2% during 1989-95, per-employee usage fell by 13%—a better indicator of plug-load intensity, since it evens out fluctuations in the real-estate market which affect occupancies and densities, and focuses on the number of users and desks.

Now, as to the specific observations and contentions from the letter from Meier et al. **[to *Forbes*]**, we identified nine specific points:

Claim #1
"Unfortunately, their article grossly overstated the actual electricity consumption involved..."

If we overstated it, what then is the actual electricity consumption?

Again, nobody knows. However, there's a large and careful literature on the specific consumption of such devices, and it's not at all clear that you consulted it. If you did, you have a lot of explaining to do about the sorts of inconsistencies with it mentioned below.

For the record, and it is clearly detailed in the full report, our analysis did NOT count all of the kWh-consuming devices that are on the Internet, devices such as the 3 million Web-TVs. Equally important, the analysis did NOT count fugitive electric demand from the Internet. An Internet Service Provider (or "dot-com") with 200 kW of electric load from a room full of servers also needs, on average, 200 kW of air conditioning—a net new load that would not have existed but for the Internet. Again, this ancillary form of demand was NOT included. (If you find this hard to believe, talk to an ISP; we did.)

This is interesting. Are you really saying that the ISP you talked to claimed an air-conditioning COP of unity (3.52 kW/ton)? If so, who was it? I'd like to go offer that firm a shared-savings HVAC retrofit deal. Or was your informant perhaps confusing thermal with electric kW?

Claim #2
"Unfortunately, their article ... ignored industry and government efforts to moderate it."

As for ignoring industry and government efforts to moderate the electric consumption of PCs, their monitors, etc., that is not the subject at hand. The issue is not how much one might reduce the growth rate in demand from the geometric rise in PC-type devices, but again, how much electricity those devices use.

I think the main point was that almost all PCs and most related devices and peripherals sold nowadays are Energy Star-compliant, at least in the U.S., and this has a considerable impact on their specific consumption.

It is self-evident, but irrelevant, to note that a future monitor may use less electricity than one today. The core issue is whether the increase in total number of devices (obviously not just monitors) will outstrip any efficiency gains in each device. History has shown this to be the case with new forms of demand of this kind.

This vague appeal to history (specifics? cites?) is no substitute for a careful analysis of competing trends. There's a big literature on this too. Since you're making a projection, it's important to look at current and emerging market trends. Some of us have. We reach different conclusions than you did.

Indeed there are some important countervailing trends. We note in both the article and the report that the trend for the central CPU in a computer is for rising, not declining, power needs as the number of transistors per CPU rises at least 50-fold within the decade. (From the National Technology Roadmap of the Semiconductor Industry Asociation.) Combining a trend of declining costs, driving increased purchase and use of equipment, along with rising power needs presents an intriguing challenge on the energy supply side.

It's not clear from this that you've examined the countervailing trends of more efficient device and circuit architectures, lower voltages, internal power management, and the other measures needed to avoid overheating as densities and clock speeds rise. If your trends occurred, the chips would simply burn out. To be sure, some power ratings are increasing, but in laptops, for example, an increase from ~10 to ~20 W/PC, such as we've seen over the past few years from much faster CPUs and bigger LCD screens, isn't so important.

Claim #3
"The topic has been researched for over ten years but the authors did not appear to have contacted anyone familiar with the area."

First, the writers of the letter did not contact us to find out whom we actually contacted. It appears we didn't contact anyone they know.

Since they are indeed among the world authorities on this subject, and those most active in the field do all tend to know each other, that's an important datum.

[snip **asking Meier et al. if they know of an analysis of Net-related electricity usage]**

Claim #4
"The article states that 'your typical PC and its peripherals require about >1,000 Watts of power'. In fact, a PC and monitor use about 150 Watts, and a printer and scanner increase the energy consumption only moderately."

We may disagree about the peak Watt demand of a PC (its horsepower, so to speak), but unbeknownst to the letter writers who didn't read the report or call to inquire about our assumptions, we actually agree fairly closely on the salient fact, a typical PC's kilowatt-hour, or fuel use.

Again, stop blaming people for not reading a report you hadn't (and perhaps still haven't) made available.
If you're close to 150 W/PC, how is that consistent with the 260-910 W/PC calculated above (for 2500–8766 h/y duty) from the 1995 EIA estimate on which you seem to rely?

The nomenclature of watts and watt-hours creates room for confusion (especially in short articles and letters). Peripherals such as printers and scanners actually increase the power need substantially (up to 250 and even 500 Watts depending on specifics), but as the letter correctly notes, increase energy consumption only modestly.

The 150 W peak figure is much too low. Good data on this is available from a company that actually makes a living selling products to protect PCs & peripherals from power outages, and therefore must know what the peak loads are. American Power Conversion's Web site is very helpful in this regard. A figure of 300 W to 500 W is more typical for fully configured 'desktops'—but this does not count the related devices behind the wall that are essential to a PC on a network.

It would be interesting to know eactly what APC measured and how. One can get a sub-ms-range spike of many kW when an older laser printer's tubular halogen lamp first turns on, due to the inrush current to the cold filament, but that's not a real peak load. APC also has a very strong incentive for customers to buy oversized UPSs, and to put it more charitably, probably assumes worst-cas[e] conditions (peak loads, hot rooms, every slot stuffed with the most energy-intensive card) in order not to be blamed by customers for recomme[n]ding too small a UPS. Anyhow, peak loads are hardly relevant here because they're so diversified.

All that aside, the relevant figure, as the letter writers know, is not peak Watts (the horsepower), but annual kilowatt-hours (kWh) used, or fuel used. If one uses a 150 W peak figure, and a common operational time for a PC

(say, left turned on about half the time), we arrive at a figure of600 kWh/year fuel use. In our model, we assumed instead a peak of 1,000 W (see below), but assumed that the PC and all its peripherals only operate 12 hours a week, or about 7% of the time—and the user (unrealistically) completely shuts everything down after every Web session. A 12 hour/wk "on time" with a 1,000 peak kW yields about 600 kWhr/year.

So you're effectively assuming ~150 W/PC (av, not peak) x ~4,000 h/y = ~600 kWh/PC-y. I hope your report will give the basis for these key assumptions.

The choice of a 1,000 W peak comes from the goal of incorporating the collective group of all the inter-related desktop devices including those "behind the wall" which are essential to Internet-linked PCs, but are not relevant to stand-alone desktop machines. In the interest of journalistic brevity the phrase "and its peripherals" encompasses details beyond the space limitations in a Forbes' article; the more detailed explanation is completely clear in the full report.

Good. I hope it will also explain why you were interested in "peak" demand and how you diversified the load. If you have actually constructed, as you imply, a full and detailed model of all the device types and their relationships, that could be useful if valid.

As for the bottom line regarding aggregate PC electric use Meier offers no specifics. In any case, there's more to the story than the desktop that Meier et al. focus on. In our calculations, the fuel appetite of the PCs accessing the Web comprises only 25% of the collective kWh consumed by the Internet.

That particularly puzzles me, since most of the rest (servers, routers, etc) are shared among very large numbers of PCs that connect to or via them. Your article's remark about (with emphasis added) using "about 1 pound of coal to create, package, store and move 2 megabytes of data" makes me wonder if "creating" the data is including indirect usage, such as running the building in which the officeworker sits while creating the data: that's about the only way I could imagine using a kWh to process 2 MB.

Claim #5
"Furthermore, consumers often exploit built-in power management features or switch off the equipment, lowering the annual average power used for a PC, monitor, and printer in an office environment to the equivalent of a constant 60 Watts."

A desktop [computer] that is left on all the time (which is increasingly typical) with the equivalent draw of 60 Watts, would consume 525 kWh per year—which is roughly the same as the 600 kWh/yr discussed in the above notes.

Basis for "increasingly typical"? And for your 600 kWh/PC-y to be valid, 8766 h/y operation would need to be universal, not merely increasing—clearly wrong.

[snip re Cisco routers, on which I'm checking data]

Meier's letter is pre-occupied with the energy-saving features of the end-user's desktop. But the devices that are the Internet are rarely "sleeping." Net banking, e-commerce and so on, all demand and serve 24-by-7 power requirements from routers, and servers and superservers, many of which are mainframes that individually can require from 250 kW to 1,000 kW of power. IBM (only one of many successful super-server vendors) shipped 1,000 of their new mainframe-based "servers" in 3 months last year. I'm not certain what the authors think these devices use for electricity, but I am certain that very few people have taken it into account, and I am certain that EPA's Energy Star PC monitors are not relevant to this aspect.

My impression is that modern mainframes and minis are getting considerably less power-hungry, but presume my colleagues will check this.

Claim #6

[snip re PC populations, which I gladly leave to my colleagues]

Claim #7
"While data on office equipment energy has its weaknesses, we do know enough to be sure that the electricity use cited in the article is many times greater than what actually occurs."

The office equipment data are worse than weak. We found that one of the main sources of data tracking the total inventory of computers, from the Information Technology Industry Council, does not include routers—because routers did not exist when the data series were started. Router sales are running one million a year into the U.S. alone.

But to the main assertion that our estimate is "many times greater" than actual office electric use. We are addressing the electric use of the entire Internet (not just PCs in office buildings), which I believe is clear in the article and the report. And, again, if office computers and equipment used 98 billion kWh in 1995 (according to EIA), given the growth in devices installed in the past 5 years, it is inconceivable that our rough estimate of 300 billion kWh today is off by a factor of "many times." We actually think the number is bigger. But whatever the actual number, Meier et al. provide no alternative insight.

I think subsequent analysis, especially once we get to see where your numbers came from, should illuminate this empirical question.

Claim #8
"The article also ignores the efforts to reduce computer energy consumption—underway for many years."

We intended to ignore such efforts because they are irrelevant to the calculation and the key issue. How much electricity the Internet consumes now has no relevance to past efforts to reduce growth rates, except to perhaps credit those efforts for keeping the current level from being even higher. Efficiency efforts are relevant to forecasts since efficiency will obviously moderate growth rates. But the emphasis is on "growth." The efficiency effect is addressed in the report, but it doesn't change the core question which Meier et al. do not address; what will be the future demand for electricity from the Internet, taking into account efficiency?

Efficiency not only will obviously moderate the Internet-related systems' electricity demand growth, but might reverse it. The relative strength of these competing trends is critical to your conclusion. That's why you should have analyzed it in detail. It's not at all clear that you did so.

Claim #9
[snip on whether the problem is big and is being ameliorated]

It is curious that Meier et al. see the Internet's use of electricity as a "problem." We see it is a reflection of enormous opportunities. As a practical matter, it is, as we briefly noted in the article, vastly more important to figure out how to meet the exploding growth in the need for 24-by-7 power for the Internet, than it is to label the Net's kWh appetite as a "problem."

If, as your projections imply, Net-related electricity usage grew within a decade to well over $100b/y, I believe very considerable effort would be devoted to saving most of that electricity. (A paper I prepared for IBM in the days when I was advising on a design of an efficient desktop machine found that the present value of the savings available to society from a single efficient such machine would range from roughly $1k to several k$.) Indeed, this is already occurring, albeit mainly for the technical reason of not overheating the chips. But strongly related evolutionary forces arise because a large and growing share of PCs is now portable, dependent on battery life and hence designed for efficiency, and because, to save cost, heat, and money, most desktop machines are tending to use similar chips, drives, and screens—just in a bigger box with more slots and a bigger power supply/fan.

—ABL

From: Amory B. Lovins
To: Mark P. Mills
Cc: Romm, Bradley, Vail, Meier, Koomey, Smith
Date: Saturday 3 July 1999, 0014 MDT
Subject: Your [i.e., Lovins's] letter to Forbes

At 07:28 01/07/99 PDT, you wrote:

My report produced for the Greening Earth Society (GES) contains details and should answer most if not all of your questions.

Good. I look forward to receiving it.

In addition, some of the issues you raised in your letter to Forbes are answered in my response to a letter from Meier et al. (you were e-copied).

Having read it, I don't think so.

I gather from your letter that you are attempting to re-cast the meaning of the specific forecast you made about flat electric load growth we cited in the Forbes' article. You present an irrelevant straw man observation in claiming that your 1984 "flat" forecast is not rebutted by our "expectation" for Internet electric use. Our contention is that history rebutted your 1984 forecast. U.S. electric use rose over 50% since you forecast "flat" electric demand growth. (We also believe that current trends, including explosive Internet growth, guarantee continued demand growth.)

It doesn't matter whether you're citing history or your forecast; my point was that neither rebuts "my 1984 forecast," because I made no such forecast. As you'll see in a moment, I'm not trying to recast a 1984 quotation; rather, you're representing it as saying something completely different than it actually said. What you quoted in your Forbes article said "supply curve," and taking your quotation as correct, my reply to Forbes simply reminded you what "supply curve" means. Its meaning in economics is specific and exact. A supply curve relates marginal supply quantity to marginal cost. It is not a demand forecast, is not a time-series, and has nothing to do with demand.

You, better than anyone, know of many other similar forecasts you made on the public record around the same time. To be sure, you were in good company in forecasting flat electric growth; it did become after all, something of an establishment view, even goal, a decade or two ago. I do not believe we took your forecast statement out of context or misquoted you. In the event you think we have, I've reproduced below more of the text from the 1984 *Business Week* interview. It seemed quite clear that you were talking specifically about your belief that efficiency would stop growth in overall electric demand.

I am extremely wary of forecasting energy demand, and don't recall making, in *Business Week* or elsewhere, a forecast of "flat electric load growth," i.e., a zero growth rate of electricity demand. I don't think I made such a forecast anywhere, in 1984 or at any other time. If you think I did, please specify. If you can't show that I made such a forecast, please stop rebutting it and criticizing me for making it.

The specific quotation you show below is from a pastiche in *Business Week* (i.e., they pasted together fragments of a roughly hour-long interview rather than quoting them verbatim and in context; that's why it reads so choppily). Nonetheless, it supports my interpretation, not yours. It is plainly about the relationship of supply quantity to price (or marginal cost), not of consumption to time. It reads, as you quote it **[the full text is shown below]**:

> The long-run supply curve for electricity is as flat as the Kansas horizon. We will never get, we suspect, to a high enough price to justify building centralized thermal power plants again. That era is over. The efficiency improvements are there to be bought. It is up to the utilities to choose participation rather than obsolescence.

Note that sentences 2–3, which I believe remain as true today as the first sentence does, confirm by their price topic that I was talking about supply cost vs. quantity, not demand vs. time. The first sentence contrasts my view, which includes the full range of competing technologies, with the then-prevalent utility view mentioned in my response to the interviewer's first question, where I state that "marginal supply of the kind you're used to buying [i.e., central thermal plants] is much more expensive than historic supply."

To be sure, *BW*'s paste-together then juxtaposed that idea—that newer, smarter technologies could expand supply without higher cost—with a separate thought about the overhang of unbought end-use efficiency. Perhaps this misled you into supposing that when I said "supply curve," I really meant to say "forecast of electric load growth over time." But I neither meant nor said that. Please stop pretending that I did.

By the way, in the hope it might shed some light on the context, I just searched for this 15-year-old *BW* article, but couldn't find it. If you have it, please fax me a copy…so I can check the quote and we can both peruse the rest of it too. As I recall, the interview you quote was just a sidebar to a longer article.

Meanwhile, if you look at that sidebar's beginning, as you quote it below, you'll find that the closest I got to a forecast of demand was to say that the rapid demand growth of 1–2Q84 (the reporter said by ~8%) was not surprising, though I expected "electricity demand ratcheting downward over the medium and long term." Actually, I'm confident that what I said was "demand growth," not "demand"; but even as reported, you can hardly translate that into a forecast that electricity demand wouldn't grow after 1984 or that "efficiency would stop growth in overall electric demand." I said no such thing.

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You assert that a trend is "now accelerating" in which "ever cheaper
decentralized [electric] options" have now begun "to turn central thermal
stations into toast."  There is zero evidence that decentralized generation
has made any significant impact on the electric supply system, unless by that
you include large merchant or industrial scale cogeneration.  Even there the
total supply is still under 5% of all generation, and virtually all of it is
fossil fuel.  There is simply no evidence of any relevant penetration in the
market for fuel cells, trigeneration or renewable electricity (excluding large
scale hydro of course, which I presume continues to be on your undesirable
list).
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You're mis-paraphrasing again. What I actually wrote to *Forbes* said: "As any economist knows, a supply curve relates the quantity of supply to its marginal cost. As I foresaw [in 1984], smarter technologies have made that cost [of generation] flat or declining as [the quantity of] generation

has risen. This trend is now accelerating as ever cheaper decentralized options—co- and trigeneration, fuel cells, renewables—begin to turn central thermal stations into toast." The antecedent of "this trend" is thus for smarter, decentralized technologies to make the marginal cost of generation constant or declining even as the quantity of generation rises.

That contention is not rebutted by your statements that those technologies still have a small market share—not surprisingly, since they are but newly introduced into a very large system. The clear competitive advantage of these new systems with the embedded capacity is of course on the long-run margin—on buying new capacity, not operating old capacity. I believe it is already clearly established by the collapse of U.S. orders for central thermal plants (now at Victorian ordering levels after a three-decade decline). It will become even clearer as customers discover that some decentralized options can beat even short-run marginal delivered costs while delivering many other, far more important, distributed benefits. This competition, of course, is only just beginning, as I said, so you can't yet expect it to be reflected in gross shares of the historic market. (Re short-run marginal cost competition, please see below.)

As for the current situation: Fig. 8.4 of the 1997 USEIA Annual Energy Review shows that 1997 U.S. nonutility generation was 13.0% as large as utility generation, or 11.5% of total generation, and that of the nonutility generation, 23% was renewable. I believe rapid growth in nonutility generation, including renewables, has continued since 1997. No data are available from EIA, nor (as far as I know) from any other official source, on unit scale or degree of co/trigeneration for nonutility generators.

As for your litany of radical improvements in the electric efficiency of the array of telecom and Internet devices, we probably agree that they're getting much better and very quickly. These issues are addressed briefly in the Forbes article and more extensively in the GES report. However, these efficiency gains have been, are, and will continue to be greatly overwhelmed by the exponential growth in the use of such devices. For example, it is true that chip fab plants will become more efficient. As you are doubtless aware, the Semiconductor Industry's "Roadmap" forecasts a 50% drop within the decade for the amount of electricity needed to produce a square inch of microprocessors. However, at the same time, all forecasts see total microprocessor production growing geometrically. Net effect; more not less electric demand from chip fabs.

That depends on whether the competitive success of a few firms more alert than the Roadmap's lowest common denominator—both in cutting their energy costs (~2% of chip manufacturing cost) and in achieving far more valuable operational benefits—causes their rivals to choose to follow suit with similarly aggressive old-fab retrofits and new-fab design improvements rather than lose market share. The last half-dozen fabs we've surveyed could be retrofitted, without disrupting operations, to save upwards of half their HVAC energy with average aftertax ROIs of ~100–200% (except for one where it was only 59%). Implementation is already underway. And that's just the low-hanging fruit that smacks you in the face as you walk in. There are at least five further layers of low-hanging fruit that got so rotten it dropped off and is mushing up underfoot—drivesystems, thermal integration, climatic adaptation, tool design, and fuel-cell retrofit. A nonproprietary summary of some of our salient findings is at http://redtail.stanford.edu/seminar/presentations/lovins3/index.htm. In summary, fab design is appallingly inefficient, and some major chipmakers are starting to see that as a major business opportunity. It's not at all clear that their pace of savings will be much smaller than their growth of output, especially once one such firm designs a next-gen fab that so far outperforms its rivals (including in such key parameters as capital cost, construction time, setup time, yield, and throughput) that its design creates irresistible new market pressures on the few design firms. We are currently working to make this happen. Similar trends are visible in back-end plants and in the boule-growing plants upstream, where Siemens has already figured out 3–5x efficiency gains, mainly retrofittable, with better performance.

We did not write that the world needs "far more giant coal plants."

I agree that you didn't write those exact words, and I didn't quote you as having done so. They're my paraphrase of such remarks as "For the thermoelectrical power complex, rising digital demand has staggering implications," "A billion PCs on the Web [a projection you seem to adopt] means [resulting] electric demand equal to total U.S. output today," "It's now reasonable to project that half of the electric grid will be powering the digital-Internet economy within the next decade," and "Futurists have been promising us an information highway, not unit trains loaded with coal. Fiber-optic cables, not 600-kilovolt power lines. We're going to get both." Particularly if you think so little of alternative supply options, the conclusion seems inevitable. Am I misinterpreting what seems to me the plain thrust of the article? Based on your own calculational methodology, as explained in your separate E-mail re the Meier et al. letter to *Forbes*, it seems to me that your projected peak load and energy consumption will remain roughly proportional, implying that such large growth in kW-h usage must mean considerable growth in capacity, not just longer running hours for the existing coal plants. If you'd like to clarify that you expect any capacity growth is far more likely to be met by gas than by coal, it would be useful for *Forbes* readers to be told that, although I doubt it's the impression your sponsors would like them to get.

However, the continuing, and Internet-accelerated, demand for electricity makes it impossible to abandon coal plants. I actually expect relatively little new coal construction in the near future as natural gas retakes its appropriate market share (recovering, in effect, from the foolish Fuel Use Act).

At least we agree about that last sentence.

However, just keeping the coal plants running means, to paraphrase the article's title, digging more coal. As you will see when you read the GES report, I expect the marginal demand for electricity to be significantly met by natural gas, and a reasonably large portion from distributed generation (but primarily gas and oil fired). Last year is likely a portent of the immediate future. The economy really perked, with GDP growth about 4% in 1998. Overall energy demand was basically flat. But, electric demand rose over 3.6%—a very significant growth and above expectations. Central fossil fuels were the primary power for that growth, natural gas and coal.

Not surprising. Such behavior can be expected in the short term. It neither proves your thesis nor disproves mine.

By the way, what rose over 3.6% in 1998—peak demand or kWh consumption? Are these figures weather-normalized?

[Romm noted in a 2 July E-mail to Lovins and Mills that the figures are *not* weather-normalized, and must be interpreted with caution due to 1997–98's warm winter and summer. He said that two days earlier, EIA had posted data showing the 1997–98 non-weather-corrected growth in electricity sales (possibly for utilities only) was ~3%, not >3.6%.]

[In an 8 July E-mail to Lovins and Mills, Romm noted that if Mills's conclusions about Internet electricity usage were correct, electricity sales to buildings during 1996–98 would have had to grow about twice as fast as EIA says they actually did grow. EIA reported growth of about 2% in 1996–97 and 3% (or 2% when weather-corrected) during 1997–98. In fact, the electricity growth Mills claims for the Internet exceeded the total observed growth in electricity sales to buildings. Yet growth in buildings' non-Internet uses was presumably robust because of nearly 4% annual GDP growth and 1998's record hot summer. Thus Mills's claimed Internet electricity growth cannot be reconciled with the officially reported data for 1996–98—a simple first-order test of their plausibility.]

It is bizarre for you to assert that today's coal plants are "utterly uncompetitive" when they dominate the wholesale electric market for the cheapest power; data that is regularly reported and easy to verify.

I do know those data. Perhaps, however, you're overlooking three points

( ) the implications of the dearth of new coal-plant orders, which you just conceded mirrors your own expectation, and which results from their being, as I said, uncompetitive on the long-run margin (I said "uncompetitive" in the specific context of more plants, i.e. new orders). You must know as well as I do that even at zero carbon-emission price, new coal plants on the Plains can't compete with new windfarms on the Plains, even though in short-run marginal cost, coal can beat wind in pure busbar-kWh commodity cost, as long as the carbon emission is free and no other attributes are counted.
( ) the considerable differences between busbar or wholesale electricity and delivered electricity, which is what distributed resources generally provide (the 1996 all-in cost of delivering the average U.S. kWh was ~2.4 cents); and
( ) the importance of ~75 distributed benefits that many buyers will increasingly count in addition to commodity kWh price. Our very detailed 8/97 draft analysis, being edited for publication later this year, shows that those distributed benefits can typically increase distributed resources' economic value by about an order of magnitude—swamping the small short-run-marginal-cost differences reported in the statistics you mention.

Your letter contains no information to rebut or address the core contention. The Internet is already a major consumer of electricity—probably about 300 billion kWh/yr and growing rapidly. If you have a better number, or know of a report that contains an inventory of the devices on the Internet and their aggregate kWh use, please foreword it. Questions as to where future power will come from (coal vs. renewables, central vs. distributed), or how efficient we might yet make PCs and screens, are ancillary to this central question. How much electricity do the 100 million-plus devices on the Internet now consume now—and how much electricity will one billion connected devices and people consume in the immediate future?

Please see my separately E-mailed comments on your response to my colleagues' separate *Forbes* letter. A *Forbes* letter is no place to provide a detailed rebuttal, any more than your article presented the data, calculations, and sources necessary to evaluate your thesis. As my letter said, the key issue is not that Internet traffic and hardware are growing, but the relative growth rates of those variables and end-use efficiency. Your article said very little about that. Although nobody knows exactly how much electricity Net-connected devices use, and others' estimates may be low, I very much doubt they're as far wrong as you state, because they rely on careful field measurements, not guesstimates.

More broadly, I think the costs associated with the very large demand you posit would turn out to be internally inconsistent with the implicit efficiency assumptions needed to yield that high a demand. (This would probably remain true even with the flat or downward-sloping electricity supply curve which I posit.) This is not a new issue; it's been true of all high forecasts of energy demand since at least the 1960s.

Finally, it is no secret that I serve as a Science Advisor to the pro-coal Greening Earth Society that sponsored one of my pieces of work on this subject. Like you, I have many clients and write in many venues.

You're welcome to have whatever clients and sponsors you like: diversification from nuclear into coal is certainly a logical career move. It would also have been normal practice to disclose the sponsor and its mission in your article, because that bears on your objectivity and its credibility.

The GES connection, which you appear to believe is a revelation of some kind, is featured on the report's cover.

No doubt, when I ultimately receive the report, I'll find its cover does say that. Your affiliation and the mission and origin of GES are also frankly stated on the GES and fossilfuels.org websites, and I'm glad you're not bashful about them. To help you achieve the same openness with the readers of

Forbes, to whom they weren't disclosed, I thought it appropriate to correct this oversight by mentioning them for you.

The fact that coal is nearly 60% of U.S. electric generation may be annoying to some, but it is still a fact. The fact that our society's is electric based, not to mention the Internet, creates a critical impediment for those who would suggest abandoning any major electric source. Whether you or one of my clients does or does not believe in catastrophic human-induced global warming (I don't, clearly you do) is irrelevant to the subject at hand. Again the issue is not coal, fuel cells or global warming, but the electric appetite of the Internet today and in the future.

As you could gather if you read my climate writings, such as "Climate: Making Sense *and* Making Money" (www.rmi.org/catalog/climate.htm, 9/97), I think how the climate science turns out won't matter. The most important fact, which I think is indisputable, is that saving fuel is generally cheaper than buying fuel, so buying less fuel (including power-plant coal) and more efficiency makes climate protection not costly but profitable, counting only private internal cost. Thus taking economics seriously—choosing the best buys first—is an attractive route to meeting society's needs for electrical services, including the Internet by which I send you this message, at least cost, both internal *and* external. – ABL

[The 1984 *Business Week* sidebar interview referred to follows, as provided by Mills:]

From: *Business Week*, July 23, 1984, Industrial/Technology Edition
HEADLINE: THE 'SOFT PATH' SOLUTION FOR HARD-PRESSED UTILITIES

Q. Electricity consumption is up something like 8% so far this year. Does that shake you at all?

A. (Amory) We would expect in the short term that a recovery would stimulate electricity demand to recover toward its previous levels. However, we see electricity demand ratcheting downward over the medium and long term. The long-term prospects for selling more electricity are dismal. Imagine being in a business where most of your costs are fixed and 80% of your product is uncompetitive, and yet marginal supply of the kind you're used to buying is much more expensive than historic supply. If demand is as sensitive to price as we now suspect, raising utility rates will probably reduce long-run revenue.

Q. How do you account for the utilities that are doing well financially?

A. (Amory) They've had a lot of rate relief. Many are [finishing] construction programs or have none. By stopping that cash hemorrhage, they can show a healthy cash flow. [But] that doesn't say anything about the long-term prospects of keeping their product competitive.

Q. At some point, though, won't utilities need to replace retiring base-load power plants?

A. (Amory) Only in the sense that the big hydro dams eventually silt up and have to be replaced. Far from there not being enough renewable sources to run an advanced industrial society, we will find there are too many. There won't be enough demand to support them all.

(Hunter) All the nifty solar technologies and everybody's favorite widget may compete with nuclear plants—but can they compete with those light bulbs?

(Amory) The long-run supply curve for electricity is as flat as the Kansas horizon. We will never get, we suspect, to a high enough price to justify building centralized thermal power plants again. That era is over. The efficiency improvements are there to be bought. It is up to the utilities to choose participation rather than obsolescence.

From: Amory B. Lovins
To: Mark P. Mills

Cc: Huber, Bradley, Vail, Koomey, Meier, Romm, Smith
Date: Sunday 4 July 1999, 2036 MDT
Subject: Response to my letter

At 13:19 02/07/99 PDT, you wrote:

Clearly you are at a disadvantage in not having read my GES report. And, since as you have stated you do not have an alternative number for the Internet's electric appetite, we will need to await further debate on this, the core subject. You and I have debated in the past on your favorite energy sources and efficiency claims. This debate could be useful to re-engage—but is not relevant at the moment.

Just to be clear about what happens next: You and Peter Huber have made important and controversial contentions about present and future demand for Net-related electricity. The burden of proof thereby falls on you, because hypothesis is not proof. It is not the case that if others don't put forward their own numbers, then yours must be accepted as correct. The plausibility and validity of your numbers can and will be scrutinized independently of whatever alternative numbers others might choose to propose. You in turn are welcome to scrutinize theirs.

I will not extensively revisit the reasons that I am confident that my general numbers are correct regarding the Internet, except to note that I have looked carefully at the excellent work from Koomey et al. Let me repeat at least this much. First, it is clear that while there may be dispute over some individual numbers and points in my analysis, the general kWh totals for equipment that I used in assembling an inventory are validated by the data in the LBL papers.

My colleagues who composed their separate letter to *Forbes* don't seem to think so, but they can speak for themselves. For now, we are all trying to understand what you calculated, how, and from what data and sources, so we can try to reconstruct and interpret your conclusions. We can't do this without the underlying details, which I look forward to receiving.

Secondly, you appear to have enormous difficulty at looking beyond the "desktop" and understanding the architecture, hardware and power needs of the network. Bits leaving a desktop don't travel free of energy needs into the Internet. Indeed, the pre-occupation with the PC, monitor and printer completely misses the magnitude and extent of the network. The LBL research papers provide no data or insight in those areas either. Perhaps there are some LBL papers and data that do, and if so I trust I will be directed to them.

It's incorrect to assume that I'm either ignorant of or inattentive to what's beyond the desktop. I commented on PCs just because that's one of the few numbers your article and E-mail provided; your discussion of Claims #4–6 dealt exclusively with the PC cluster. As to what you call the "behind-the-wall" gadgets, all I said about them is that I didn't understand the basis for your important assumption that they use three times as many kWh as the on-the-desk (or wherever) PCs and peripherals, since such devices as servers and routers typically serve large numbers of PCs.

It is a little ironic that the LBL paper by Koomey et al. ("Efficiency improvements in U.S. office equipment") from December 1995 completely misses anticipating the explosive growth in the Internet's appetite for equipment. One of their primary conclusions from the Executive Summary states:

> While total energy use for office equipment has grown rapidly in recent years, this growth is likely to slow in the next decade because the US commercial sector market is becoming saturated (especially for PC CPUs and monitors) and because mainframe and minicomputer energy use per unit is declining quickly.

Jonathan [Koomey] can respond to this himself if he wishes. I think all of us who follow this field were and are well aware of the relevant trends; the issue is whether you've correctly enumerated the Net-related equipment and its unit and total electricity consumption.

As I observed (and I trust your colleagues at LBL will undertake to verify), the inventory of PC and PC-related (e.g., servers, routers) equipment has probably increased by 100 million devices since 1995. To be sure, mainframes are more efficient today; but when you talk to folks with Enterprise Data Centers, you find the total load from an EDC frequently remains the same as they upgrade to new more powerful and more efficient equipment — they've just packed more stuff into the EDC. And on top of that, there are a whole lot more EDCs, to mention only one recent trend.

I'll leave this one likewise to LBNL and its network of topical experts.

I believe your tortured arguments about supply curves notwithstanding, your 1984 statements about forecasting load growth are unambiguous. Your claim that you did not make any forecasts in 1984 or any other time is certainly contradicted by history; perhaps at some point it would be useful to have a researcher pull together a large handful of similar forecasts you made in that time period? I suppose the cost of being so widely published is that one has to live with history. The truth is, for the subject at hand your forecasting failures in the past (like those of so many other people; there you are in good company) is really irrelevant to the debate about the Internet.

Let's get a few things straight:

- I made a correct remark in *BW* in 1984 (quoted in their pastiche sidebar) about a supply curve. *BW* and you both quoted it accurately.
- However, you completely misinterpreted it as a remark about a demand forecast, then claimed to rebut it.
- When I pointed out your error (in my letter to *Forbes*), you pretended I was misrepresenting what I'd said, when in fact you were.
- You now continue to claim that I was trying to distort what I said. Get over it. Both the plain meaning of the words and their context support only my interpretation, not yours. There is no "tortured argument" involved: just read your own quotation. I know what a supply curve is; don't you?
- In the same interview, I made some further and rather vague remarks, which your E-mail also reproduces, about my qualitative expectations for electricity demand. These too are contrary to your interpretation that I was forecasting zero demand growth.

The first rule of holes is that when you find you're in one, stop digging. If you persist in representing that it's I who am twisting my words, not you, you will cause thoughtful readers to think badly of your competence or integrity or both. If so, you'll deserve it, and I will not hesitate to describe your conduct as dishonest. That is not a type of discourse I want; you shouldn't either; so I suggest you stop inviting it.

Now you further claim that I said I "did not make any forecasts in 1984 or any other time." No; what I wrote (in my 3 July 1999 e-mail to you) was:

> I am extremely wary of forecasting energy demand, and don't recall making, in *Business Week* or elsewhere, a forecast of "flat electric load growth," i.e., a zero growth rate of electricity demand. I don't think I made such a forecast anywhere, in 1984 or at any other time. If you think I did, please specify. If you can't show that I made such a forecast, please stop rebutting it and criticizing me for making it.

Thus I did not deny making "any forecasts in 1984 or any other time"; I said I didn't recall making forecasts *of a zero growth rate of electricity demand.* If you believe this is "certainly contradicted by history," by all means go check the history and tell me, by specific quotations and citations, what you think it is. I have no problem taking responsibility for what I actually said and wrote, including any "forecasting failures" you can find. (I hardly ever forecast energy demand, but if you want to compare our respective track records, be my guest.) I do have a serious problem with having utterances falsely attributed to me.

The only cautionary note I would give you, since you seem bent on cautioning me, is to dig a little deeper into the Internet and telecom industry's network architecture before so quickly asserting that my base estimate is wrong. It's possible, after all, that I could be right and you wrong. As for forecasting the future electric demand of the Internet, that is clearly an activity that is more challenging, and about which much (unproductive) debate could be engaged. Understanding the current demand should be the first and primary focus.

I do know a bit about that architecture, and remain skeptical that your numbers will prove correct. I look forward to the prospect of shedding more light on this important empirical question.

I didn't assert that your "base estimate is wrong." I expressed skepticism about it, generally and specifically (including some 3 July queries that I hope you'll have time to answer). I used "wrong" only in the context of an imputed assumption that all PCs and their peripherals run 8766 h/y.

Understanding the current Net-related electricity demand will indeed be important. So will understanding the competing trends that contribute to *future* demand, which was, after, the main point of your article and provided its most dramatic conclusions.

I really fail to understand your preoccupation with my clients (who are far more extensive than you seem to know). The facts are the facts. Sure Forbes (which, as all magazines, do) chose a provocative title. But the facts in the article are as they are. Similarly, my GES report has a title that the sponsor likes—and again as you will read (and as that client knows) there are many observations in that report (such as the marginal value of natural gas) that you seem to think might be a surprise or annoying to my clients. Actually, that client (and indeed most of my clients) don't have a problem with my calling the facts as I see them.

Methinks you doth protest too much. I'm not in the least preoccupied with your clients. The issue I noted wasn't who they are, but rather your not disclosing the relevant sponsorship to *Forbes* readers, contrary to journalistic norms as I understand them.

I look forward to discussing specifics about the Internet's electric use once you have had the chance to read the report and engage in some of your own research.

Good.—ABL

From: Amory B. Lovins
To: Mark P. Mills
Cc: Bradley, Huber, Vail, Koomey, Meier, Romm, Smith, Bell
Date: Monday 12 July 1999, 2240 MDT
Re: your GES report

GES sent me your report on 30 June, it reached RMI 6 July, and I got it late 9 July on returning from a trip. Initial comments follow.

1. I think it highly unlikely that your estimates are conservative as p. 1 claims. Most of the underlying numerical assumptions about intensity (kWh/unit-y), and many of those I can loosely infer about h/y, look grossly unconservative. Prior E-mails gave examples; more below.

2. You also state on p 1 that your study is based on "the best data and insights available." In fact, it rather systematically ignores them. To my astonishment, your paper doesn't cite *any* of the large and rigorous professional literature in this field, much of it written or coauthored by such folks as Harris, Norford, and Meier. It relies heavily on an EIA survey (a genre whose main weaknesses are mentioned in my E-mail to you of 3 July, and which, as noted below, you seem to have misinterpreted). It uses a few aggregated market studies on equipment populations and sales, but seems to reflect no actual measurements of equipment intensities, either per-box or aggregated. It cites five personal communications (notes 10/45, 19, 22, 63, 68), mainly on populations, but cites none of the other "dozens and dozens" of unnamed experts you claim to have consulted. (Who were they?) Many of its citations are to secondary or tertiary sources—trade journals, popular journals, newspapers. Most importantly, its key assumptions about intensities and operating hours are almost entirely undocumented—apparently taken from thin air.

3. You seem to treat each class of device as homogeneous: PCs, routers, etc. In fact, a substantial fraction of each is of far less energy-intensive kinds than the extreme examples you assume. Recognizing this reality would probably change your results by half an order of magnitude—perhaps an entire order of magnitude (see #5 below).

4. Note 34's two alternative assumptions about intensity and duty for PCs and associated equipment (25% of your total estimated consumption) are not only undocumented but also undefined in system boundary. By assigning the unquantified non-PC part of your 1-kW intensity to a grab-bag of other unspecified equipment, much of it located elsewhere, you conveniently sidestep the need to identify, enumerate, and characterize that equipment in a way that transparently ensures it's not double-counted—once as "through-the-wall" from the PC and again as remote Net-related equipment such as routers and servers. The top of p 12 says it "almost doesn't matter" what intensity you assume, but certainly it matters—proportionately to the intensity. Could you please provide us all with an exact and itemized list of what equipment types, populations, duties, and intensities make up your average estimate of ~1 kW/office PC (when operating on the Net)?

5. The tables on pp. 17 and 28–31, which seem to represent the guts of your computation, do list many of your key assumptions about the non-PC-related equipment that collectively uses 65% of your total estimated Net-related electricity consumption:

- 2 million U.S. Internet routers plus a further 1 million WAN/LAN routers, each averaging 1 kW and operating continuously;
- 4 million U.S. small website servers, each averaging 1.5 kW and operating continuously;
- a telephone central office switch is identical with a telco central office (i.e., one switch per office), and 25k of them each use 500 kW (24/7);
- ~30k ".com" operations run on mainframes, each continuously using an average of 250 kW.

I expect my colleagues' check of these numbers to turn up significant data problems. For example, on 3 July I sent the 1.5-kW router assumption stated in your 30 June E-mail (re Claim #5) to a senior engineer at Cisco. I just received the following reply:

> Nothing that follows is proprietary. But the public stuff on the Cisco Web site would be hard to put in perspective without talking to someone who is somewhat knowledgeable about contemporary networking technology. (There is no evidence that [Mark] did anything of the sort.)
>
> 'A typical router is a 1.5 kW machine, not counting peripheral equipment, cooling, etc.' is really off the mark.
>
> There is no such thing as peripheral equipment associated with a router.

> Probably most HIGH-END routers are in 'externally cooled' rooms, because there's a lot of other stuff in there as well, but we can't find anything that says that cooling is required for any router operation per se. A lot of routers do have built-in fans, as do PC's, that obviously consume some of the router power requirement.
>
> Cisco's HIGHEST-END router, the 12000-series, draws 1.5–2 kW. These are used for Internet backbones—really serious stuff. Probably several thousand have been sold over the past year or two. They are very expensive. Cisco has about 88% of market share for this size router.
>
> The biggest-selling router has been, in the past, similar to [the 2500 series, nameplate-rated at 40 W, which]...is at the high end of 'typical' [intensity]. Over a million of them have been manufactured. The router of the more-immediate future, starting within the past year, is something like the 800-series baby. It's smaller and draws all of 20 W. Hundreds of thousands of them have been sold and there will be a lot more.
>
> ...There are probably at least a million routers out there but the vast majority of them are small.

This doesn't seem to bode well for your 1-kW average…router (p 30). I'm equally skeptical about your apparent assumption of universally used, top-of-the-line, fully loaded desktop PCs with big CRT monitors, each drawing (together with unspecified other equipment) an average of 1 kW, when in fact many PCs are battery portables using ~10–25 W complete with built-in screen. I'm writing this, for example, on a Pentium 166/MMX PC with 512k L2, 5-GB hard drive, 80 MB RAM, backlit color SVGA,..., and <15 W consumption.

It would be easier to understand what you did if you presented Section 7 in the usual device-line-item format of population times intensity times duty, documenting each box. If you have such a format, perhaps as a spreadsheet, I'm sure we'd all appreciate receiving it so we needn't build our own. I think we'll then find that most of your key numbers are untraceable to any empirical data.

6. Another problem arises on p 16 where you try to estimate the embodied energy content of a chip or a PC (10% of your computed total Net-related electricity usage). The SIA per-square-inch figure is useless for your purpose, for five reasons:

- it's outdated (the SIA roadmap showed 8.0 kWh/in2 in 1997 and declining: e.g., the world's #9 chipmaker, ST, averaged 5.0 in 1997, equal to your SIA target for 2012, and achieved 3.0 in its best fab, but plans ~1.2 in 2008 [Murray Duffin, VP, STMicroelectronics, 28 May 1998 talk at 16th Nikkei Microdevices Seminar, Tokyo]);
- it refers to a standardized 6" wafer with specific mask-layer and other characteristics, not to the characteristics of a PC CPU (but on p 26 you imply that you're using 9 kWh/in2 specifically to describe a 400-MHz, 21-million-transistor chip type, not the standard wafer type used in SIA benchmarking);
- it doesn't enable you to convert from square inches to chips—die sizes differ widely;
- differences between front-end and back-end plants (and ancillary processes such as boule and raw-wafer production) need handling; and
- most importantly, it doesn't tell you what fraction of the chip production goes into PCs or other Net-linked products rather than into, say, household appliances or cars. Your *Forbes* article correctly notes: "Today, worldwide annual production stands at 50 billion integrated circuits and 200 billion microprocessors (many of those special-purpose controllers that run things like car engines and telephones)." If 35M microcomputers are shipped annually, each has one CPU, and that's what you mean by a "microprocessor," then about 82% of the microprocessors don't go into PCs, and many among that 82%, as well as some of the PCs, have nothing to do with the Internet.

Of course, all these intensities are also moving targets: ST thinks it can build profitable and operationally superior new front-end fabs that are 92% less energy-intensive than its existing fleet average. Based on our field surveys of a half-dozen ST fabs, we at RMI think it can do even better, with significantly lower capital cost and construction time. That would get rivals' attention and beat by far the SIA roadmap.

You have a similar analytic problem with PC embodied energy, especially as chipsets have consolidated since 1993 and continue to do so rapidly. Literature values for kWh/PC are subject to many pitfalls and must be interpreted with great caution, as can be easily illustrated: you cite 2,300 and assume 1,500 kWh/PC. But 1,500 kWh/PC at $0.05/kWh costs $75/PC (much more at the electricity tariffs at many overseas fabs). If, as your previous arguments imply, chips are the most energy-intensive PC component per dollar, then you have a problem, because typical front-end fabs' total operating energy input represents only ~2% of their revenue, and a typical PC does not cost $75/0.02 = $3,750 to build.
[On 13 July, Romm E-mailed Lovins and Mills that Compaq reports its global average manufacturing energy for producing a PC to be 37–38 kWh, not including the energy embodied in its components. Thus the discrepancy cannot be resolved by appealing to the PC manufacturers' energy use in assembly plants.]

7. Your GES report and *Forbes* article assert two main things:

- Internet-related electric use is far larger than most experts think (8% of total U.S. electricity usage today, probably 50–67% of all growth in U.S. electricity demand 1988-98, and 0.5 kWh per MB moving on the Net), and
- that electricity consumption will grow so rapidly that it could readily account for half of U.S. electricity by 2008 (per *Forbes*; however, p. 4 of your GES report gives a far lower estimate, 30–50% "of the nation's electric supply", "certainly within two decades"; which is it?).

Of these, the second claim is by far the more important and controversial. Obviously you can't justify it by appealing only to increased device populations and traffic without also thoroughly analyzing competing trends, notably more efficient hardware, power-saving management of existing hardware, and displacement of other kinds of hardware or traffic (and part or all of their energy use) or of other electricity-using activities by the new ones you describe. Without that missing analysis, your conclusion about future consumption is not credible. At any university I know, an undergraduate paper drawing such sweeping conclusions with such a paucity of literature basis would risk a flunk.

8. I'm sorry to see that on p. 5, you again characterize my 23 July 1984 *BW* interview as placing me among "some enthusiastic forecasters [who] were certain that electric growth had finally ended." As noted in previous E-mails, I made no such claim, nor does your quotation support it. You quote two sentences from the *BW* sidebar constructed from an enormously longer interview. The first sentence is from the following colloquy at the beginning of that sidebar: "Q. Electricity consumption is up something like 8% so far this year. Does that shake you at all? A. (Amory) We would expect in the short term that a recovery would stimulate electricity demand to recover toward its previous levels. However, we see electricity demand [growth] ratcheting downward over the medium and long term." Well, it did ratchet down. Annual retail kWh utility sales reported by EIA (*Ann. En. Rev*. 1996, p. 237) grew 6.28% in the calendar year (1983–84) immediately preceding my *BW* interview—the period the interviewer had in mind—while real GDP grew at a sizzling 6.82%, for an el/GDP elasticity of 0.92. During 1984–96p, however, both these figures fell markedly: kWh/y growth averaged 2.53%/y while el/GDP elasticity averaged 0.76. That's despite the electric usage's not being weather-corrected and the period's being unusually hot: during 1983–96p inclusive, U.S. population-weighted cooling degree-days averaged 2.36% above the 1961–90 average. QED. By the way, EIA's 1999 *Energy Outlook* forecasts that for the next two decades, U.S. electricity consumption will grow at an average rate of only 1.4%/y, and EPRI's roadmap shows electricity and GDP decoupling markedly.

Your quotation continues: "...The long-run supply curve for electricity is as flat as the Kansas horizon." Not only have you misinterpreted "supply curve" to mean "forecast of growth in electricity

demand," as noted in previous E-mails, but you've also joined two utterly unrelated thoughts with a standard ellipsis, normally signifying one or a few missing words. Even in *BW*'s constructed "virtual interview," the two sentences of answer that you quote are separated by 11 others and by two diverse questions. To juxtapose them as if they represented a continuation of the same response, in an effort to reinforce your misinterpretation of "supply curve," is flagrant misrepresentation.

Contrary to p. 5, the rate of continuing recent load growth can be well explained without needing to invoke the emergence of very large but unrecognized Internet-related loads. My favorite nominees include hotter weather (Joe Romm's E-mail of 3 July); dramatically lower utility DSM expenditures and efforts since 1994; the contemporaneous rollback, in eight of the roughly nine states that practiced it, of regulatory practices that rewarded utilities for cutting customers' bills rather than for selling them more energy; the reemergence in some major states, such as New York, of declining-block tariffs meant to promote consumption; and renewed Congressional efforts to gut appliance efficiency standards, energy efficiency outreach programs, the Federal Energy Management Program, and similar initiatives.

9. What is the basis for your statement on p 10 that "the average integrated circuit" uses about 60 watts (presumably when turned on)? or for saying that this consumption by the average IC is rising (id., col. 2)? Are you equating "integrated circuit" with "high-end PC CPU"?

10. Does your definition of the Internet encompass the extensive dial-up data traffic—e.g., Verifone retail, gas-pump, and similar telephonic credit-card transactions—that don't go through the Internet, but instead are dialed directly into a non-Net server? If not, how do you distinguish them when estimating, for example, the Net-related fraction of telephone traffic (p 30)?

11. The URL for EIA's '95 commercial-buildings PC data, given as www.eia.doe.gov/emeu/consumptionbriefs/cbecs/pcsterminals.html/#1995, has been changed: drop the "#1995". Posted 7 June 1999, it contains, as I expected, this methodological summary for "How the Number of PCs and Computer Terminals [NB: not just PCs] Were Estimated":

> The estimates presented in this document are not derived from sales data. All data were collected by the Energy Information Administration's Commercial Buildings Energy Consumption Survey (CBECS).[2] The CBECS estimates are based on a national sample of approximately 6,000 commercial buildings. The CBECS web page contains more details on the survey, additional reports, and public use data files at the building level (ASCII and dBase format) that can be downloaded. The 1999 CBECS data collection will begin in late 1999. [If you visit ftp://ftp.eia.doe.gov/pub/consumption/commercial/cb95ques.pdf, you find the questionnaire EIA used in CBECS '95. Unfortunately my Acrobat reader couldn't open it.]
>
> Both the 1992 and 1995 CBECS questionnaires asked whether any PCs or computer terminals were in the sampled building and, if so, how many. The response was recorded in one of 11 categories, ranging from "1 to 4" to "5,000 or more." A weighted mean of the upper and lower category bounds was used to estimate the actual number of PCs and computer terminals. The weights were the number of buildings in the categories above and below the one being estimated. The use of these weights captured the shape of the distribution better than a simple average of the upper and lower bounds could.
>
> The estimates derived by this method are consistent with other estimates for the numbers of PCs in commercial buildings. Researchers at Lawrence Berkeley National Laboratory (LBNL 1995)[3. Koomey, Jonathan G., Michael Cramer, Mary Ann Piette, and Joseph H. Eto, "Efficiency Improvements in U.S. Office Equipment: Expected Policy Impacts and Uncertainties,"...LBL-37383, December 1995. This document is available at http://enduse.lbl.gov/Info/37383-abstract.html] estimated, using sales data, that there were 28.9 million PCs in commercial buildings in 1992, and 41.4 million in 1995 [EIA got 43.0 million PCs *and terminals*, many of them

> presumably dumb terminals, in 1995]. The LBNL numbers are lower than the CBECS estimates, as would be expected since the CBECS estimates include computer terminals. The LBNL researchers cited similar estimates from Dataquest, 29.1 million in 1992 and 40.9 million in 1995.

Then http://www.eia.doe.gov/emeu/cbecs/cbec-eu2.html points out that office equipment wasn't part of the FEDS (from CERL) methodology used to derive other end-uses; "other" uses, which included all office equipment, were a mere residual term. Moreover, the narrower office-equipment estimates were derived thus from statistically adjusted engineering analysis (SAE):

> The office equipment estimate was also made after the SAE by using REMP estimates and estimates from Arthur D. Little, Inc. (ADL). The REMP database contains estimates for subcomponents of "other" end-use consumption and was used to estimate the office equipment share of the '"other" end use energy consumption for 1989 and 1992 CBECS. Included in office equipment were large computer equipment (if the CBECS data indicated the presence of a computer area with a separate air-conditioning system), personal computer equipment, and general office equipment (typewriters, copiers, cash registers, etc.). For the 1995 CBECS, the REMP computer energy consumption estimates were replaced with the more recent ADL estimates [no link or data provided by EIA—LBNL, do you have them?] before calculating the office equipment share.

That's uncomfortably remote from sales data, and says nothing about intensity or duty—your two most critical and controversial numbers. But it does make clear that you've misinterpreted the EIA report, as I suspected. EIA's summary states: "The energy consumed by PCs and other types of office equipment has become a significant component of electricity consumption in commercial buildings—13 percent (98 billion kWh) of all electricity consumed [in those buildings] in 1995." Your GES report at p 17 ascribes this 98 TWh/y to "the 43 million PCs in commercial buildings" in 1995. No; the 43 million PCs and terminals were only part of the far larger *office equipment category* surveyed by EIA. EIA clearly states above that office equipment includes mainframes, minis, all PC peripherals such as printers, and all "general office equipment (typewriters, copiers, cash registers, etc.)." A substantial part of that demand thus wasn't related to PCs, let alone the Net. No wonder, in my E-mail of 3 July, I couldn't get that 98 TWh/y to go to 43 million PCs (i.e., 2,279 kWh/PC-y) without inferring a completely implausible duty or intensity. Your efforts to reconcile your 1 kW/PC and similar assumptions with the 98 TWh/y for what you erroneously believed to be a population of PCs are thus consistent with your PC intensities' (and/or duties') also being too high.

12. Some usage survey results for household PCs can be found at http://www.eia.doe.gov/emeu/recs/recs97/appusage.html and http://www.eia.doe.gov/emeu/recs/recs97_hc/tbl3_46a.html. This 1997 RECS survey found that 58% of the 35.6 million household PCs had a modem. (Only 44% of the households reporting "office equipment" had a PC; most of the office equipment was merely cordless phones or phone answering machines.) PC turnon times were reported thus: 9% of household PCs were left always on, 19% were run 16-40 hours a week, 49% 2-15 h/wk, and 23% <2 h/wk. As for actual usage, 72% reported <16 h/wk, 28% 16+. (Since virtually all machines sold in the past few years contain Energy Star power management features, many or most of which are activated, usage rather than turnon hours should dominate kWh usage.) Of those 16+h/wk heavy users, 48% reported personal use only, 21% business use only, and 31% a mixture. A reported 35% of home PCs used a laser printer (no usage hours stated). These survey results are subject to all the usual difficulties with EIA building surveys. Nonetheless, it's interesting to compare them with your 1998 assumptions that home PCs average 12 h/wk (28 million boxes), home PC power users 24 h/wk (5 million units), and PC home offices 20 h/wk (8 million units):

	EIA 1997	*Mills 1998*
households with PCs	35.6M, of which 29.6M million had 1 PC, 5.9M had 2+ PCs	55M total, of which 7.8-17M had multiple PCs
PCs in households	?	55M
households w/PCs + modems	20.7M	?; 33M "regularly" using Net
home offices w/PCs	5.2M using 16+ h/wk, + ? of 25.6M using <16 h/wk	34M PCs, ? home offices)
home "power users"	4.8M households with 16+ h/wk personal usage	5M averaging 24 h/wk online
PCs used in home offices	5.2M households w/16+ h/wk bus. or mixed usage, + ? out of 25.6M households w/<16 h/wk	8M, averaging 20 h/wk online
av. turnon h/wk of PCs in homes	~5.2 (averaging boundaries of ranges in accordance w/normal EIA procedure)	15.0 for Net-connected users (60% of total users)
av. usage h/wk of PCs in homes (ditto)	must be less than the 5.2 h turnon hours	same as turnon time bec. no allowance for pwr-management features

There are clearly significant differences during this one-year interval, including a dubious ~3x rise in turnon time.

13. On p 13, you say you assume "that the PC and its peripherals are only on when the Internet is being accessed" and that "the average time on-line for home users is 12.1 hours per week." This would seem to imply that for home users, you should therefore be assuming an average duty of 12 h/wk. Yet on p 29, you give usages of 12, 20, and 24 h/wk, with a weighted average of 15 h/wk, for home users. Please clarify—is this difference due to multiple PCs in home offices? If so, why do you write "Assume one PC online avg. 20 hrs/wk"?

14. On p 13, you estimate "sometime on the order of 1,000 kWh per year per home PC accessing the Internet." Isn't your figure (from p 29) actually 756 kWh/y per such unit?

15. Many computers shipped in the past are not yet retired but are nonetheless dormant. For example, my personal office includes two older computers that are available in principle but are run only a few hours a year, plus 4–5 even older ones that are not used at all. I actually use a battery-portable machine (~10–15 W) for almost everything, plus a desktop machine that runs probably <300 h/y. How do you count such things? Particularly given rapid technological obsolescence, shouldn't the table on p 20 show retired and dormant columns?

16. Of course digital equipment, unless battery-powered (as lots now is), requires especially clean and reliable power. However, since most power-quality and reliability problems originate in the grid, the cheapest and most effective way to provide it is typically distributed resources, especially isolated renewables—not central coal-fired stations. This line of argument is thus not very helpful to your sponsors.

17. Are you really assuming (p 26) that a typical PC CPU in 2012 will use 170 W? If so, how will it avoid melting? How are you taking account of concomitant, countervailing shifts—in architecture (e.g., bipolar CMOS), clock-speed and other power management, basic chip technology, and bus voltage? As feature dimensions and voltage scale down by S, switching time falls as S, packing density rises as S^2, power falls as S^2, and energy per switching operation falls as S^3 (Meindl, *SciAmer* 10/87 at p 81).

18. You conclude on p 27 that "While natural gas is the dominant fuel source for new power plant orders, there is no prospect of meeting future economically-driven and Internet-accelerated electric demand without retaining and expanding the coal component." Since your paper provides no analysis of gas-fired, renewable, or fuel-cell generation, nor of end-use efficiency, what analysis supports this conclusion, even it applies only to the load duration of existing coal plants rather than to building new ones? Is it merely your intuition?

19. Could you please clarify note 39, which seems to have some sort of typographic error (at least with regard to windpower)? The US now has upwards of 2 GW of wind capacity (1.7 GW end '97, 2.65 projected end '00), so 1,000–10,000% growth (not growth rate) would yield >20-200 GW. That would be 1% of 2000–20,000 GW of total capacity. Even doing it in energy terms (divide by perhaps 3 for decent but not great sites—3.7 TWh in '97, ~5+ TWh in '99), that doesn't sound plausible.

20. I'm intrigued by note 24, sentence 1. Source? Implications for your thesis?

Probably the most important priorities at this stage in our discussion are to clarify your intensity and duty assumptions, and the bases for them, for all main categories of hardware. We all look forward to your reply to these queries, as well as to my E-mail of 3 July. – ABL

From: Amory B. Lovins
To: Mark P. Mills
Cc: Romm, Koomey, Meier,
Date: Thursday 22 July 1999, 2000 MDT
Subject: your GES report

Dear Mark,

I sent you some fairly extensive comments and questions about your GES study on 3 and 12 July. I wanted to ensure you had received both these E-mails, and to ask when you expect to be able to respond—at least initially to those queries to which you know the answer, reserving those requiring further study. Please bear in mind that without basic responses, the sort of peer evaluation and refinement that you have requested from us will be difficult if not impossible.

-- Amory

From: Amory B. Lovins
To: Mark P. Mills
Cc: Koomey, Meier, Romm, Totten, Sampat
Date: Friday 23 July 1999, 2353 MDT
Subject: GES press release of 13 July incorporating some of our E-mail exchange

A friend in Washington faxed me today a copy of a 21 July mailing from your client, the Greening Earth Society (GES), an offshoot of the Western Fuels Association. The mailing comprises a 13 July press release entitled "Bad month for environmental policy: National publications undermine common assumptions, popular agendas." The release refers to the *USA Today* feature on the alleged safety hazards of CAFE standards and to the 9 July *New York Times* power-failure stories, one of which refers to power demand's being "driven by a booming economy and the proliferation of computers, fax machines, air conditioners and the other amenities of an affluent, wired society." The release then refers to your GES analysis of Internet-related electricity consumption, summarized in *Forbes*, and states in relevant part that your tentative conclusions "have elicited a furious reaction from noted anti-electricity advocate, Amory Lovins." The release concludes:

> With Mills' permission, Greening Earth Society today makes available a copy of their e-mail exchange, part of which was submitted for publication by *Forbes* and all of which has been copied to several other recipients. Their exchange of e-mail centers on the Internet's impact on electricity consumption and production. According to Greening Earth Society Fred Palmer: 'It is revealing in that it details environmentalists' antipathy toward increased electricity utilization for any reason. It also demonstrates the hollow intellectual core of Lovins' espousal of what he calls 'negawatts.' If as a society we adopt Lovins' views, we will—both literally and figuratively—be traveling down the dark side of humanity's future path.

Attached to the GES press release are copies of:

- my unpublished letter to *Forbes*, 27 June, as I E-mailed it to you 30 June
- your E-mail to me, 2 July, attaching the 1984 *Business Week* interview sidebar to which it refers
- my reply of 3 July to your E-mail of 2 July, with the two interleaved and my responses slightly reformatted in five places
- your reply of 3 July to that E-mail

It is unusual, impolite, and (most would say) unethical for you or your client to publish our private and collegial E-mail correspondence without asking me, or even having the courtesy to tell me. Nonetheless, though I'm critical of how this occurred, I'm glad it did occur. I hope it will continue on the most substantial scale GES finds feasible, because it will give a wider readership the opportunity to judge the merits of your views and of Mr. Palmer's interpretation. If others wish to see these materials, I too shall now feel at liberty to distribute them even more widely.

To assist this process of public assessment that you and your client have begun, I presume you would have no objection (insofar as anything you wrote might be included) to my reciprocally releasing the remainder of our relevant E-mail correspondence, which inexplicably failed to appear among the Greening Earth Society's attachments:

- my E-mail to you, 3 July, sent just before the 3 July one you did publish, and responding to your 30 June critique of the Meier et al. letter of 3 July (Alan, is that OK with you too? [Alan Meier said it was OK.—ABL] For clarity, I should probably also include the Mills-to-Romm reply of 30 June to the Meier et al. critique, which it includes)
- my 4 July E-mail response to your 3 July E-mail to me, which you distributed without that response
- my 12 July extended commentary on your GES report

as well as my 22 July query about when you would respond to these E-mails (that's the only E-mail you couldn't have provided to your client in time for inclusion with its 13 July press release). If you have any objection to my releasing these materials, along with this E-mail, please let me know the relevant details by 2000 EDT on Wednesday 28 July. Thank you. [No such objection was received.]

I haven't copied this E-mail to your Enron and CEI colleagues because it's procedural rather than a substantive part of our exchange of technical views, but if you wish to share it with them, please feel free.

Your now-published E-mail of 3 July ends, "I look forward to discussing specifics about the Internet's electric use once you have had the chance to read the [GES] report and engage in some of your own research." So do I, which is why I went to the trouble of this correspondence; but it takes two to discuss. Rejection of your own invitation may give rise to adverse inferences. – ABL

On 27 July, Mills wrote Lovins a response, which is interleaved here with Lovins's 27 July reply:

From: Amory B. Lovins
To: Mark P. Mills
Cc: Bradley, Koomey, Meier, Romm, Huber, Totten, Sampat, Smith, Bell, Vail
Date: Tuesday 27 July 1999, 2238 MDT
Subject: GES press release of 13 July incorporating some of our E-mail exchange

At 09:33 27/07/99 PDT, you wrote:

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ABL:
I have been travelling.
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Regarding the public domain aspect of our various e-mail correspondences:

I am pleased to learn that you are glad that our e-mail discussions are appropriately in the public domain.

As I noted 23 July, however, your manner of putting them there was utterly inappropriate. For the reasons stated below, your explanation of why you think this is OK does not expiate your offense but rather exacerbates it. (I'm copying this to the marked recipients of your note.)

As to how they've become public domain, and your observation that it was "unusual or impolite" and perhaps "unethical" for me to reveal our discussions, I should note that the public aspect of our correspondence was initiated by virtue of your sending a letter to Forbes magazine with technical (and personal) criticisms. One assumes that you anticipated the letter being published and thus in the public domain. Further, it is clear that you sent copies of that letter, regardless of it being published by Forbes, to a distribution list as I heard third hand about it.

I did indeed intend for the letter to *Forbes* to enter the public domain. I don't have a "distribution list," but I did share that letter with five people—Messrs. Meier, Koomey, Romm, Bradley, and Heede—who had expressed specific interest in the subject matter. However, you sent to GES not only the *Forbes* letter but also, without asking or telling me, my long E-mail of 3 July, which GES then released to the general public, also without asking or telling me. This is what's abnormal and objectionable. It's a breach of trust, and destructive of collegiality, to forward a personal E-mail without authorization to someone to whom the author didn't originally choose to send it, let alone to publish it to the world at large. I believe it's also legally a breach of copyright, whose principle is that the author controls the choice of recipients and the manner of any publication. An author's choice to send a writing to some specific people does not constitute a license for any of them to re-send it to anyone else, nor for it to be generally published. Your apparent belief that it does is a pretty good way to ensure that scholars will not consider you a peer nor care to deal with you.

(I do appreciate your sending a copy to me once I learned of the letter and so requested.)

You're welcome. I hadn't copied it to you when I sent it to *Forbes* because of your discourtesy in attacking me in your article without sending me a copy or, better still, checking your facts first. (That normal step would have saved you the subsequent embarrassment of appearing, to put the most charitable interpretation on it, not to know what "supply curve" means.) Your subsequent behavior suggests inability to take the hint.

In my experience, it is both unusual and impolite to stray beyond substantive technical issues into personal or ad hominums when engaged in a very public technical debate. But, as you have no doubt noted, I have chosen to ignore such lapses.

As a review of the *Forbes* letter will confirm, I didn't indulge in *ad hominem*. In our subsequent E-mail correspondence, as in this letter, I have on occasion criticized your personal misconduct in appropriate form and language. I regret that you don't accept that you have misbehaved nor accept responsibility for having done so. Your consistent effort to shift blame to the victims of your attacks is offensive and, if continued, will make untenable the rational discussion you claim to seek.

And finally, the extensive "cc" list on our e-mail correspondence made it clear that the information was not only intended for others, but quite obviously there was no explicit or implicit control of re-distribution by any of those parties on the "cc" list. Indeed, absent the standard "privileged and confidential" notification that is the standard when so intended, any party would rightly assume the discussion was public domain.

That's the difference between following the norms practiced and expected in discourse between scholars and gentlemen (and generally accepted as a key element of Netiquette), and being apparently unaware that such norms even exist. I'm sorry you don't acknowledge or appreciate the important difference between copying a letter to a half-dozen specific people as a courtesy—people who have expressed a specific scholarly interest in the discussion or asked to be copied on it—and being presumed thereby to have authorized unlimited public distribution by a third party (GES) to fourth parties unknown, accompanied by a scurrilous press release to boot, and with no notice or consent. Your extrapolation from the former to the latter—your assumption that anything copied to any third party, and not marked "privileged and confidential," can be assumed to be intended for release to the public—is outrageous. It has no basis in either common (or statute) law or common courtesy. You should be ashamed of yourself.

Incidentally, "privileged" is a legal term specific to certain relationships legally protected from disclosure. Ours is not among them. "Confidential" can in some circumstances create a legal duty not to disclose. Since you seem to acknowledge recognition of such a duty, I'd suggest to all your correspondents that they attach it to anything they don't want you to publish.

This letter is not confidential from my perspective, and, consistent with your practice, I'll presume (unless you otherwise notify me by 2000 EDT 30 July 1999) that you don't consider it confidential either. **[No such notification was received.]**

FYI: I will request of GES that they post the balance of our correspondence thus far so that you do not feel that there is any intent to keep your observations and criticisms hidden in any way.

Since your selective release may leave an unfortunate impression that you intended to conceal my E-mails of 3 (re Meier et al.), 4, and 12 July, I would indeed be obliged if GES could send those, as well as my E-mails to you of 12 and 27 July and this E-mail, to everyone who received the earlier press release, and to anyone to whom it is subsequently sent. Naturally, GES must take responsibility for any further commentary which it might attach to this additional information.

Let me also clarify that any intention of "concealment" in this instance would be properly ascribed to you and/or GES, not to me. You refer above to your "reveal[ing]" our discussions, as if it were I who were trying to conceal them. They were not meant to be secret; rather, they were meant to be treated as any honorable person treats personal communications. There are two main reasons for this. One is the moral and legal right of authors to control who receives their writings and in what way. The other is that if authors expect their work to be published, they may wish to present it in a different form, or after editing to a higher standard, than if they believe, as I did, that it is merely an informal and private discussion among technical colleagues.

As for how GES or any other organization characterizes your current or historic work, quite clearly you should take that up with them directly as I have no control (or desire to control) their musings.

May I take that as a personal assurance that Mr. Palmer's intemperate statements in the press release are entirely his own invention, in whose formulation you rendered no advice or assistance?

I have recently been exceptionally busy (in addition to the travel), however I will shortly have some observations about your technical questions and comments.

I too have been and remain very busy, but look forward to your replies to the many technical issues framed in my E-mails of 3, 4, and 12 July (as well as to the question just posed). Please be so kind as to copy your replies at least to Messrs. Meier, Koomey, Romm, and Bradley (and to anyone else you wish), since any substantive replies would greatly assist the independent analysis and dialogue you have solicited. Since your conclusions are being cited on Capitol Hill **[e.g., in invited USHR**

testimony 15 July by GES President Fred Palmer, featuring Mills's GES paper: www.westernfuels.org/news/071599%20 testimony.htm], it would be timely and useful to start resolving these technical issues.—ABL

MPM

From: Amory B. Lovins
To: Mark P. Mills
Cc: Bradley, Romm, Huber, Vail, Koomey, Meier, Smith, Bell
Date: Thursday 29 July 1999, 1228 MDT
Subject: [refers to an unpublished E-mail exchange in which another participant in this discussion, whom I'll call X, severely criticized Mills for breach of faith in publishing via GES E-mails that X had been assured were part of a private collegial exchange]

Your 28 July E-mail to Rob reinforces my impression that you have very different standards of behavior than the rest of us, and a very different understanding of "public." If [X] wanted to make a communication public, he would post it where anyone on the Web could see it, rather than sending it as a private communication to a small number of specific people whom he wanted to receive it. The two are not identical. [X] is right.

This is all explained further in my E-mail to you of 27 July. Having tediously explained it there, evidently to no avail, I must now assume you simply don't understand or won't accept points that seem obvious and incontrovertible.

If you want people to stop griping about your misbehavior, stop misbehaving. Otherwise you will soon have few people to discuss with. —ABL

From: Amory B . Lovins
To: Mark P. Mills
Cc: Koomey, Meier, Romm
Date: 1650 10 August 1999

>>Date: Thu, 22 Jul 1999 20:00:45 -0600
>>To: mark_p_mills@hotmail.com
>>From: "Amory B. Lovins" <ablovins@rmi.org>
>>Subject: your GES report
>>
>>Dear Mark,
>>
>>I sent you some fairly extensive comments and questions about your GES study on 3 and 12 July. I wanted to ensure you had received both these E-mails, and to ask when you expect to be able to respond— at least initially to those queries to which you know the answer, reserving those requiring further study. Please bear in mind that without basic responses, the sort of peer evaluation and refinement that you have requested from us will be difficult if not impossible.
>>-- Amory

PS added 10 August: If I continue to receive no reply, I am likely to start telling folks that you have been sent extensive questions about and rebuttals to your thesis but have not responded. This may invite adverse inferences. – ABL

On 18 August, Mills wrote Lovins an E-mail which is interleaved next with Lovins's 19 August reply:

At 07:21 AM 8/18/99 PDT, you wrote:
>ABL:
>Normally, I welcome technical feedback. However, I confess to being been
>quite strongly put off by the episodic venom (e.g."…I will not hesitate to
>describe your conduct as dishonest"), the condescension (e.g. my report
>"would risk a flunk … At any university I know") and the threats, (e.g. "I
>am likely to start telling folks … This may invite adverse inferences.") in
>many of your e-mails of this past month.

I regret that you feel offended, but having re-read those E-mails of 4 and 12 July and 10 August, I feel no need to apologize for what I wrote you. My language was appropriate to the circumstances, as can be verified by reviewing the E-mails, including the important context that all your quotations omit.

You are solely responsible both for your inappropriate interpretations of my remarks and for your own misbehavior which elicited them. That included, among other things, misleadingly attacking me in your article and GES report, misleadingly quoting me in a fabricated context (outrageously so in the GES report), insisting it was I rather than you who was misconstruing the quotation, claiming a thorough and documented analysis that doesn't even begin to deliver on that promise (but which you faulted people for not having read before you'd published it), and improperly publishing private E-mails. Your refusal to take responsibility for your misconduct, and your tendency to blame its victims, will disincline both scholars and gentlemen to deal with you.

On 10 August, I wrote that if you didn't acknowledge the extensive technical comments and queries I'd sent you on 3 and 12 July and inquired about on 22 July, I was "likely to start telling folks that you have been sent extensive questions about and rebuttals to your thesis but have not responded. This may invite adverse inferences." That wasn't a threat; it simply described the likely consequences if you solicit critical technical comments on your publications, you get them, and you ignore them. I'm sorry that your latest E-mail of 18 August is so nonresponsive and evasive that it seems to make this unhappy outcome inevitable. The remainder of that message reads:

"A constructive discussion on this issue can progress only if both sides have clearly put on the table alternative propositions. In this case both parties, you and/or your colleagues and I, must have put forth numbers about aggregate national Internet power consumption, complete ones, not partial ones. Mine are on the table. You have offered up a grab-bag of miscellany, some arguably valid but easily refuted, some irrelevant, some plainly wrong - but no bottom line. Perhaps, via a different route and methodology, your own analysis will find a number similar to mine. Either way, I await an independent calculation. If then we have different bottom lines, we may have something to discuss.

"For the record, I did not ask for 'peer evaluation' that you assert I requested. This series of e-mails started with a request you made of me to 'please send it [my report] … as soon as possible' since you stated that you were being 'asked to comment on [the Forbes numbers].' In my first response I confess to writing that 'I'll be interested in your observations once you've had a chance to read the report.' Some of your observations were interesting.

"MPM"

Sorry, but you just moved the goalposts and scored an own-goal. After you began this whole exchange with a gratuitous and misleading personal attack in *Forbes*, you specifically solicited technical critiques and commentary, and not only in the 27 June remark you admit to. For example:

- On 30 June, you objected to Meier et al.'s letter to *Forbes* because "...the authors do not provide any technical substance to their observations. To use an old advertisement phrase: 'Where's the beef?'"
- On 1 July, you wrote to one of our colleagues: "I look forward to hearing from your expert colleagues and others. / As I said in brief and at length—there is nothing in the responses so far that provides any substance to rebut the order-of-magnitude numbers we presented in Forbes."
- On 2 July, you wrote me: "I look forward to discussing specifics about the Internet's electric use once you have had the chance to read the report and engage in some of your own research."
- On 8 July, you wrote to Rob Bradley: "The preliminary assessment we've attempted is documented and I'll look forward to seeing alternative approaches and data. Our 'proof' is in the public domain. The burden is now on others to rebut and importantly, provide better information."

Not only do you say that you "Normally...welcome technical feedback," but you repeatedly asked Meier, Koomey, Romm, and me, if we disagreed with your analysis, to examine its details and say exactly what we disagreed with. Well, we did. The extensive technical commentaries and queries we sent to you showed in detail that, among other things, you misinterpreted your primary reference, committed order-of-magnitude errors in some of the most important numbers (such as the electricity used by typical PCs and routers), and used many odd or dubious assumptions and methods. A simpler but more devastating criticism came from another correspondent, who noted that your analysis could be reconciled with actual 1996-98 U.S. electricity consumption only by assuming that all non-Internet usage had meanwhile declined significantly in absolute terms. In short, by any scholarly standard, your analysis got shredded. It's now dead unless you resurrect it by responding convincingly, specifically, point by point, with sound data and documentation, to each of the questions and criticisms raised.

Yet on the contrary, rather than answering any of our questions or responding to any of our serious criticisms of your study, you're now asserting that you're excused from this normal obligation of scholarly discourse, for three reasons:

1. you feel offended by my criticisms of certain of your actual actions or warnings about your proposed actions—i.e., you claim that a commentator who frankly objects to or warns about your misconduct thereby becomes undeserving of a response;
2. you claim you didn't ask for "peer evaluation" anyway—i.e., you can first reject criticisms because they're not detailed and specific enough, then reject them because they're too detailed and specific; and
3. you've invented the novel proposition that there's nothing to discuss unless, perhaps, someone else duplicates your entire study with different assumptions and reaches a different conclusion: until then, you need not acknowledge or respond to any criticisms of your own study.

Science doesn't work that way. To invalidate your results, critics needn't rewrite your paper for you; they need merely show that its foundations are unsound. They needn't provide better or more complete assumptions (which indeed might not be available); they need only show that yours are wrong. They have no obligation to redo your work properly; their scientific duty ends when they've shown your findings to be false. We did. More precisely, we *both* showed that you had relied on grossly incorrect key data (bottom-up refutation) *and* showed that your overall demand analysis was seriously inconsistent with observed aggregate demand (top-down refutation). The only logical explanation consistent with the observed aggregate demand-growth data and unit-equipment-level data is that the Internet uses far, far less electricity than you claim.

In other words, as I wrote you on 4 July:

"Just to be clear about what happens next: You and Peter Huber have made important and controversial contentions about present and future demand for Net-related electricity. The burden of proof thereby falls on you, because hypothesis is not proof. It is not the case that if others don't put forward their own numbers, then yours must be accepted as correct. The plausibility and validity of your numbers can and will be scrutinized independently of whatever alternative numbers others might choose to propose. You in turn are welcome to scrutinize theirs."

Thus, if you publish startling assertions that rely on a supporting analysis, you're inviting the world to pick it apart. You even explicitly invited me and other analysts experienced in this field to do so. We did. You're now claiming a sort of sovereign immunity. Nobody wishing to be considered a scholar would do that. It's discourteous to the commentators, an affront to the scholarly process, and indicative of a lack of scientific integrity.

I think the most appropriate response would be to state publicly that you have refused to engage in the scholarly discourse you invited, and that the criticisms supplied to you, casting severe doubt on your findings in the GES report and *Forbes* article, now gain presumptive force by your refusal to acknowledge or respond to them. Your analysis must therefore be considered junk science. That's what I now intend to say. People wishing to assess the credibility of your work can then read our published exchange and draw their own conclusions. You and your clients may not enjoy the inevitable result, but you will all deserve it.

Unless otherwise notified by 1800 EDT on 28 August 1999 **[no reply was received]**, I'll presume that you consent to the publication of your E-mail of 18 August. I consent reciprocally to the complete publication of this one. I will also take the liberty of sending it to our previous correspondents on this topic, on the assumption that they will share my disappointment that our exchange has come to this sad end. I believe those who prefer dispassionate scholarship to partisan advocacy will conclude that any confidence they might have reposed in your analysis appears to have been misplaced, and that if they wish to save themselves further embarrassment, they will no longer rely on it.

—ABL