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SORRY, WRONG NUMBER: The Use and Misuse of Numerical Facts in Analysis and Media Reporting of Energy Issues*

Jonathan G. Koomey,[1] Chris Calwell,[2] Skip Laitner,[3]
Jane Thornton,[4] Richard E. Brown,[1] Joseph H. Eto,[1]
Carrie Webber,[1] and Cathy Cullicott[2]
[1]Lawrence Berkeley National Laboratory, One Cyclotron Road, Building 90-4000, Berkeley, California 94720; e-mail: jgkoomey@lbl.gov, rebrown@lbl.gov, jheto@lbl.gov, cawebber@lbl.gov
[2]Ecos Consulting, 801 Florida Road, Suite 6, Durango, Colorado 81301; e-mail: calwell@ecosconsulting.com, cullicott@frontier.net
[3]U.S. Environmental Protection Agency, Office of Atmospheric Programs, MS 6201 J, 1200 Pennsylvania Avenue, NW, Washington, DC 20460; e-mail: laitner.skip@epa.gov
[4]International Business Machines, 425 Market Street, 20th floor, San Francisco, California 94105, e-mail: jcthorn@us.ibm.com

■ **Abstract** Students of public policy sometimes envision an idealized policy process where competent data collection and incisive analysis on both sides of a debate lead to reasoned judgments and sound decisions. Unfortunately, numbers that prove decisive in policy debates are not always carefully developed, credibly documented, or correct. This paper presents four widely cited examples of numbers in the energy field that are either misleading or wrong. It explores the origins of these numbers, how they missed the mark, and how they have been misused by both analysts and the media. In addition, it describes and uses a three-stage analytical process for evaluating such statistics that involves defining terms and boundaries, assessing underlying data, and critically analyzing arguments.

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Introduction

This paper presents four examples of numbers in the energy policy arena that have been widely cited but are either misleading or wrong. They include estimates of how much power is used by homes, how much unreliable power costs the U.S. economy, how much electricity is used by office equipment, and how much oil is likely to be found in the Arctic National Wildlife Refuge (ANWR). The paper explores the origins of these numbers, how they missed the mark, and how they were misused by both analysts and the media.

Getting the numbers right really matters because quantitative data inform virtually all major business and policy decisions. Some misstatements may seem innocuous enough (like the 1 megawatt = 1000 homes statistic described below), but no good can come of incorrect information becoming widely accepted. At some point that information will be used to make a decision, and annoyance, inconvenience, or disaster will ensue.

Each section below uses a three-step analytical process to structure the discussion. The first part of this process is to establish careful definitions and clear boundaries around the problem under scrutiny. The next step is to assess the underlying data by determining the credibility of the source, looking for any indications of bias, comparing the information to other independently derived data, and assessing its accuracy. The final step is to assess the validity of the inferences and arguments derived from the data by checking for logical consistency and relevance to the issue at hand. For more details on relevant skills and strategies (as well as more examples of widely accepted but misleading statistics), see References (1) and (2).

Is 1 Megawatt Equal to the Electricity Use of 1000 Homes?

THE ISSUE One of the often cited indicators of electricity use is the number of households that can be served by 1 megawatt (MW) of generating capacity. The rule of thumb typically used is 1000 households per MW of capacity, implying a load of 1 kilowatt (kW) per household. This rule of thumb dates back to the 1970s, although it became more prominent in the past few years.

The California Independent System Operator (CAISO), after discussions with California utilities, began using this equivalence for reporters during the California power crisis, and the California Energy Commission includes it on its official web site (2a). More recently, the CAISO started using 750 households per MW after the California utilities suggested that it was a more representative statistic [Information Officer Lori O'Donley (CAISO), personal communication, November 1, 2001]. Unfortunately, this simplification can lead to confusion. It is an acceptable approximation in many situations, but it conceals complexity in the underlying data and can sometimes be misleading.

DEFINITIONAL AND BOUNDARY ISSUES Inaccuracies from the use of this statistic are directly related to boundary and definitional issues. When assessing whether 1000 homes are really served by 1 MW, we also must determine what kind of homes and power plants are being compared and whether the comparison is in terms of energy or peak demand. For example, variability in home sizes, appliance ownership, microclimates, household income, and occupant behavior all affect how much electricity particular homes use.

In addition, the choice of where the MW is measured is important. A MW of demand at the meter is different than a MW at the busbar of a power plant because of transmission and distribution losses (typically 5% to 8%). Unfortunately, this distinction is rarely made. In this paper, we show the capacity at the busbar needed to meet the average and peak demand for one home, or the number of homes supported by 1 MW of generating capacity at the busbar. Transmission and distribution losses are therefore included in these estimates.

A MW can be calculated in two ways: It can be the instantaneous power at any time (usually the peak time), or it can be measured as the average power associated with a certain amount of energy use or generation over time. Both assumptions have been used at various times, and the choice of one or the other can affect the validity of the underlying comparison. Power plants that operate as baseload resources can supply many more kWh per MW than peaking plants or some nondispatchable resources, which can also affect the comparison.

ASSESSING THE UNDERLYING ASSUMPTIONS AND DATA After assessing boundary issues, the next step is to focus on underlying data. Using the California Energy Commission (CEC) data presented in Brown & Koomey (3), we examine the conventional assumption that 1 MW equals 1000 California homes. The picture is not a simple one. As indicated in Figure 1, 1 MW of dispatchable capacity can serve about 1200 California homes if measured in terms of the electricity produced by an average MW in kilowatt-hours (kWh), or about 600 homes if the MW is measured at peak times. The same data can be expressed in a different form, in terms of kW per household, measured on average or at peak times, as shown in Figure 2.

The values in Figures 1 and 2 are averages across all households that mask some important variations. Different housing types vary greatly in their electricity consumption and peak demand. A typical single-family home, for example, might draw three to five kW at peak times, whereas a typical apartment might use less than one kW at peak. Geography and climate also contribute to the large variation between utility service territories. The Sacramento Municipal Utility District (SMUD) is located in California's Central Valley, which is a hot part of the state. Because of the air-conditioning load, the peak demand per household is more than three kW, compared to the California average of about 1.6 kW. The other four

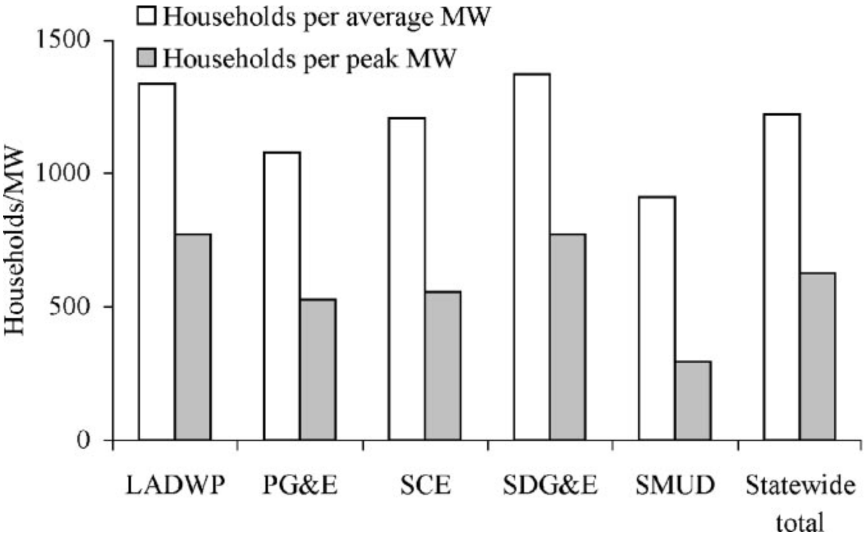

Figure 1 Number of households per peak and average MW of capacity for major California utilities in 1999. Acronyms used include: LADWP, Los Angeles Department of Water and Power; PG&E, Pacific Gas and Electric Company; SCE, Southern California Edison Company; SDG&E, San Diego Gas and Electric Company; SMUD, Sacramento Municipal Utility District. Source: Brown & Koomey (3).

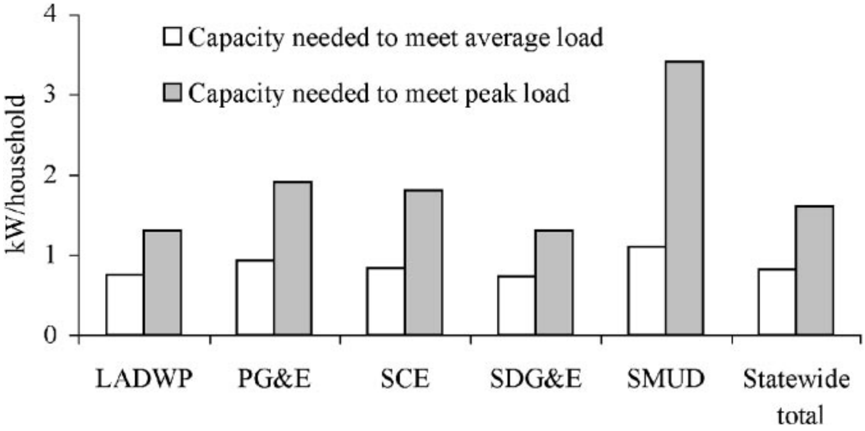

Figure 2 Number of kW of capacity per household to meet average load and peak load for major California utilities in 1999. Source: Brown & Koomey (3).

major California utilities have customer bases that are more concentrated in the coastal areas (where the climate is cooler and the need for air conditioning not so acute), so their peak demand per household is much lower than that for SMUD.

ANALYZING ARGUMENTS It is important to have simplifications that both analysts and the public can use in discussing and understanding issues such as the California power crisis. These simplifications are mainly used for illustrative purposes, but it is easy to imagine how someone might use such a widely cited statistic to make incorrect calculations of how much power would be required to meet the needs of a new subdivision or city. Basing an argument on such statistics is risky unless their complexities are fully understood.

MEDIA COVERAGE This statistic (of the number of homes served by a MW) is a round number that people often compared to the size of a new power plant (in MW) or to the shortfall in supply (also in MW) during the 2000/2001 California power crisis. Instances of this statistic are too numerous to count, but we present below some illustrations of how it has been used.

A typical appearance of this statistic is like the one that appeared in the *San Francisco Bay Guardian* in September 2001 (4): “Right now San Francisco uses a maximum of about 845 megawatts of power on the hottest summer day. (A megawatt is generally enough energy for 1,000 houses.)”

The New York Times, in February 2001 (4a), used essentially the same phrase to give context to their description of the total generating capacity for the Southern Company: “One spinoff, the Mirant Corporation, which is still 80 percent owned by Southern Company of Atlanta, plans to own or control 30,000 megawatts of generating capacity by 2004. (One megawatt is roughly enough to power 1,000 homes.)”

A slightly different but roughly equivalent statistic appeared in *The New York Times* in April 1999 (5): “A 1,000-megawatt plant produces roughly enough power for one million small homes.” In this article, the adjective “small” was applied to the homes, for reasons that are not clear.

In another article in August 2000 (6), *The New York Times* modified the statistic to reflect differences between types of homes: “A megawatt, or one million watts, is generally considered enough to supply power to about 250 single-family homes, or a larger number of apartments, at periods of peak demand.”

The 1000 or 750 homes per MW statistic is meant to reflect average houses at peak times, so the distinction being made in this last quotation is qualitatively accurate, though whether it is precisely correct depends upon the characteristics of houses in the New York region.

A common mistake in the media has been to apply this statistic to intermittent renewable power sources. For example, a *USA Today* article (7) in early 2002 stated, “The $570 million [wind] project will be capable of providing 520 megawatts of power—enough, officials say, to eventually supply 10% of [Ireland’s] electrical needs (one megawatt can power approximately 1000 homes).” An Associated Press article reproduced in *The New York Times* (8) stated, "Within a year, San Francisco could produce 10 to 20 megawatts of electricity by using solar panels. A megawatt is enough electricity to power roughly 750 homes."

Intermittent renewables generally produce far fewer kilowatt-hours per MW than conventional power plants. Of course, wind and photovoltaic (PV) electricity generation can be highly coincident with system loads, so the value of such resources to the system can be higher than their relatively low capacity factors might indicate (9). Nevertheless, this widely used equivalence between homes and MW should generally not be applied to intermittent renewables such as wind and PVs.

Some articles have been more careful in distinguishing between the typical statistics for homes/MW and those associated with intermittent power sources. Lavelle et al. (10) cite the 1000 homes per MW statistic, but they also state that grid operators use 350 homes/MW for wind power to account for its intermittent nature. However, this article is the exception.

SUMMARY The key lesson from this example is the importance of carefully defining boundaries and definitions when interpreting any number. While this particular statistic is a reasonable approximation, it masks substantial variation in household characteristics and geography. It is also susceptible to misunderstanding by people who confuse average and peak loads. Finally, it can be misleading when applied to nondispatchable sources of electricity generation that sometimes have relatively low capacity factors and can support fewer homes per MW than dispatchable power plants with high capacity factors.

What is the Cost of Unreliable Power to the U.S. Economy?

THE ISSUE A key energy policy issue in recent years has been the cost to the U.S. economy of problems with electric reliability and power quality (11). One set of aggregate estimates of the cost of power quality problems, in particular, has been quoted and misquoted over more than a 10-year period. This section explores how that statistic evolved from a rough estimate of the costs of power quality problems in manufacturing firms to an aggregate estimate of the costs of all power quality and reliability problems to society as a whole. The statistic then grew larger over time as different analysts cited it and modified it, and it became disembodied from the caveats and cautions attached to the initial rough calculation from which it originated.

This particular statistic is important because it lies at the center of a growing policy debate about how much public and private money should be devoted to improving the reliability of the electric power system (11, 12). The California electricity crisis and the continued debate over the goals of utility industry restructuring have propelled this discussion to the highest levels of government and industry. If the cost of unreliable power to the economy is large, that could justify substantial public and private investments. If it is small, then the issue may be of less pressing concern than some recent news stories might indicate.

The often misused estimate of the cost of power quality problems to the U.S. economy appears to have originated in an industry conference paper by Jane Clemmensen (Thornton). She was a research engineer at SRI International in the mid-1980s and a contractor for the Electric Power Research Institute (EPRI) in the area of power quality. As a result, her estimate of $12.8 billion per year to $25.6 billion per year for the aggregate cost of power quality problems is often attributed to EPRI.

The source of these numbers was a technical paper she presented in the opening session of a conference called Power Quality ’89. Her paper first established that the market for equipment to improve power quality, such as transient voltage surge suppressors, was about $1.2 billion ($10^9$) in 1989. She then noted that this market was an order of magnitude smaller than the size of the power quality problem the industry was experiencing. The difference in scale, she asserted, presented industry with an opportunity to close the gap. The calculation was simple and rough, as befits an illustrative estimate:

> As much as twenty-five cents of every sales dollar in the U.S. manufacturing industries is spent correcting for or accommodating quality control problems of all types, according to quality expert Phillip Crosby. Of this amount, let us estimate that 1-1/2 cents to 3 cents is attributable to power quality control. While a true economic study would disaggregate industries and figure the cost to each industry segment separately, taking into account specific data (sales data, energy consumption and demand data, price of electricity), let us simply work with the portion of the gross national product attributable to manufacturing industry sales. In 1987, sales by U.S. manufacturing industries amounted to $853.6 billion in current dollars. The cost of power quality in 1987 by this method is therefore $12.8 to 25.6 billion dollars (13).

Another formulation in Clemmensen’s paper used other independent industry sources to estimate the cost to commercial, service sector users at $13.3 billion in 1987, but the number that appeared in newspapers, magazines, vendor product literature, and company business plans was typically the $25 billion (rounded down), or $26 billion (rounded up). This estimate applies to power quality problems in U.S. manufacturing industries and excludes outages from unreliable power as well as the potential effects of both outages and power quality problems on all sectors other than manufacturing.

In 1993, Clemmensen herself summarized the original estimate in a sidebar to an IEEE Spectrum article (14), and other analysts have continued to rely on her initial calculation. Swaminathan & Sen (15) cited $25 billion as a measure of the aggregate cost of all reliability problems to the U.S. economy. In addition, EPRI used Clemmensen’s estimate as the basis for a $50 billion estimate of the cost of all reliability problems (16, p. 11), which takes into account the effects of inflation since the time of Clemmensen’s original work (R. James, EPRI, personal communication 2000). A more recent article by Clemmensen et al. (17) estimates the market for power quality equipment and services at $5.13 billion in 1999. This estimate was developed through a survey of equipment manufacturers and service providers.

DEFINITIONAL AND BOUNDARY ISSUES From a customer's perspective, electricity reliability problems come in many forms. Sustained interruptions (voltage drops to near zero), more commonly referred to as outages or interruptions, are the most visible problems and affect the widest range of electricity-consuming equipment. Less apparent are smaller voltage deviations, either above or below nominal voltage, which influence the operation of only some types of equipment depending on the magnitude and duration of the variations. These smaller deviations are aspects of power quality. Both outages and power quality problems can impose costs for utility customers, and both aspects should be considered when creating estimates of the total costs associated with these problems.

Power quality refers to the degree to which power characteristics align with the ideal: 120 V (in the United States), 60 Hz, sinusoidal voltage, and current waveform, with current and voltage in phase. Power quality therefore encompasses not only variations in voltage magnitude but also a host of other, more subtle deviations from the ideal, such as harmonics. Voltage events may be classified by magnitude and duration, as shown in Figure 3.

The significance of specific events depends on characteristics of the equipment experiencing them. All electrical equipment has tolerances for the duration of

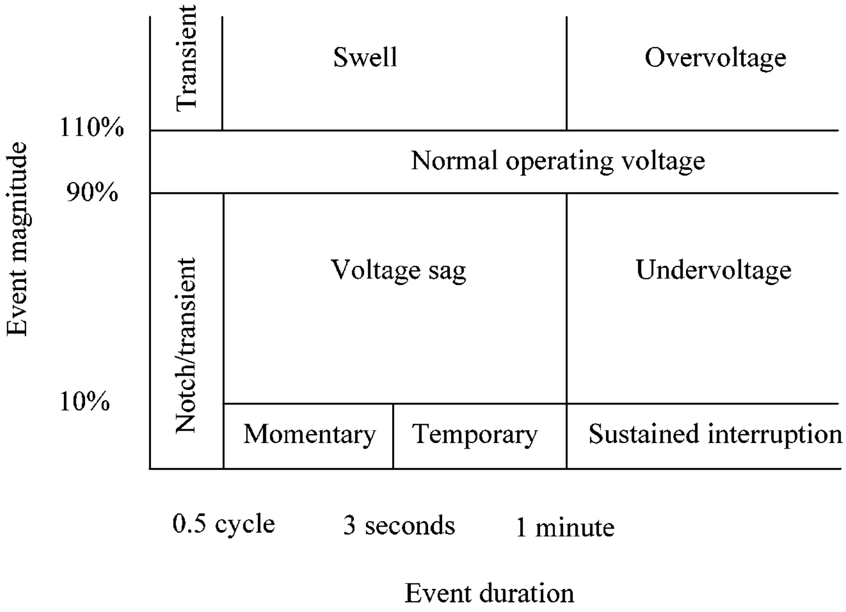

Figure 3 Definitions of voltage events in the IEEE standard 1159-1995. Source (119).

deviations under which it will continue to operate. Eto et al. (11) cite an example based on the voltage tolerance of a sample of U.S. computers. In this example, the computer most sensitive to voltage disturbances can tolerate zero voltage for less than one cycle, and requires a minimum of 80% of nominal voltage to operate. At the other end of the spectrum, a second computer could ride out an interruption of 15 cycles, and a third could continue to operate at only 30% of nominal voltage. The user of the first computer would perceive many more voltage events as interruptions than would users of the less sensitive computers.

It is also important to distinguish between the effects of reliability events on electricity-consuming equipment and the resulting cost of these effects to the customer. The effects of an electricity reliability event on a piece of equipment are easily quantified; either the equipment is operating normally or it is not. Whether abnormal operation of equipment creates additional costs for the customer depends on the role of affected equipment in meeting the customer's objectives. For example, an industrial customer may use a large number of electrical devices in its processes, some more critical than others and each with its own voltage tolerance. Depending on the processes and equipment involved, a momentary outage or voltage fluctuation could cause no interruption at all or could shut down production for hours. Even when companies have similar processes and equipment, interruption impacts can differ significantly. For example, a factory ahead of its production schedule might experience little financial impact from an outage compared to one struggling to maintain its schedule.

Traditionally, the costs to customers of electricity reliability problems have been examined based on the magnitude, duration, and frequency of the events, when they occur, and the degree of advance notice. The time of day, day of the week, and season when the event is experienced can also have an effect on costs. Weekday events during daytime are more likely to cause business interruptions for commercial and industrial customers. Evening and weekend outages are most likely to inconvenience residential customers. Winter outages are likely to be more costly for residential customers who depend on electricity for heating, especially if the outage is prolonged.

An additional boundary issue is that power quality problems and solutions may originate either on the customer or the utility side of the meter. The estimates cited above do not usually make this distinction, but it is germane when considering the potential damages from power quality problems and when tallying the costs of efforts to mitigate those problems.

ASSESSING THE UNDERLYING ASSUMPTIONS AND DATA Electricity reliability cost estimation methods fall into three broad categories: (*a*) proxy methods, (*b*) market-based methods, and (*c*) survey methods. Proxy methods use macroeconomic data or observable expenditures as a proxy for customers' willingness to pay for service reliability. These methods produce aggregate estimates of reliability costs.

Market-based methods infer reliability costs based on consumers' observed behavior. For example, where interruptible and curtailable electricity rates are available, customer subscription behavior can be used to derive a market value for service reliability. Similarly, investment in back-up generation (or other mitigation approaches, such as insurance premiums for utility service interruption) can be used to indicate a greater or lesser preference for reliability of electricity service.

Survey methods take the direct approach of asking customers about their reliability experiences and perceptions. Customers may be asked to identify their costs during an actual event or to estimate their costs for a series of hypothetical events. Surveys can use one of two approaches: direct costing (also referred to as enumeration or cost decomposition) or contingent valuation. In direct costing, customers are asked to estimate expenditures for a series of components, such as lost product, spoilage, and damage to equipment. Contingent valuation methods ask customers how much they would be willing to pay to avoid an event (willingness to pay) or how much they would be willing to accept in compensation for an event that has occurred (willingness to accept).

Clemmenson's estimates in both 1993 and 1999 were based on a proxy method, where the expenditures of the industry on power quality represented the size of the problem. Proxy methods can give useful information, but there are many pitfalls in their use. For example, some parts of industry may be spending $15 billion to solve a problem, but other parts may be ignoring the problem because they face more pressing competitive needs or technological concerns. In addition, there are often ancillary costs in addressing such problems that are difficult to track. These calculations should therefore be treated as rough estimates that are uncertain and should be used with care.

ANALYZING ARGUMENTS High costs of power quality and reliability problems to the U.S. economy are typically used to argue for large public and private investments that will solve the problem. Banc of America (BoA) Securities published one highly visible report that made such arguments in June 2000 (16, p. 11). That report stated:

> The Electricity Research and Policy Institute (sic) (EPRI) estimates that the U.S. economy lost $50 billion in productivity and replacement of damaged equipment and inventory in 1999 as a result of power quality breakdowns. At the same time, the total worldwide power quality market in 1999 was approximately $12 billion, including uninterruptible power supply systems (UPS), standby generation and DC power systems for the telecommunications industry. This means that in 1999 the amount lost as a result of power quality issues in the U.S. alone was roughly five times the amount that was spent on power quality worldwide. With an increasing percentage of U.S. commerce expected to be conducted over the web over the next five years, we believe EPRI's $50 billion loss estimate could potentially escalate to more than $100 billion.

Like many other summaries of this issue, this quotation lumps power quality and reliability together. It contains two major claims. First, it cites the EPRI cost estimate of $50 billion for the United States, and compares it to worldwide expenditures on just one set of technologies used to minimize the damages from interruptions in power use, implying that the expenditures on the problem were much less than the damages caused by the problem. Second, it claims that the $50 billion loss estimate could grow to $100 billion because of increases in the use of the web for commerce.

The purpose of the BoA analysts was to make investment recommendations, as becomes clear by reading further in the report: "It is extremely important that investors recognize that the primary demand for Power Quality equipment is likely to come directly from the technology and telecommunications industries, which in our opinion will accelerate the demand curve for power quality equipment" (16, p. 32).

The report then identifies which sectors are likely to cause this increased demand and which are likely to benefit from it. Its stock recommendations follow from these results.

Unfortunately, this line of reasoning does not withstand scrutiny. The large uncertainties in the estimate of total costs of unreliable power have already been noted above. It is also inappropriate to compare U.S. estimates of damages from unreliable power to worldwide estimates for expenditures on technologies that ameliorate this problem. Further, it is not clear that the list of technologies that resulted in the $12 billion estimate reflect a complete list of all such expenditures. Perhaps society is already spending $50 billion to fix this problem, or it may be that the problem really is only a $12 billion problem and the $50 billion is an overestimate. Nobody really knows for sure. The claim that the $50 billion in damages could grow to $100 billion is not justified or documented, so it must be considered unsubstantiated.

It is unfortunate that a widely read investment report contained such incorrect information and that investors were probably influenced to purchase stock by this and other reports touting the digital economy's effects on electric power use. These investors may learn an expensive lesson as to why critically assessing claims and data is essential for successful decision making.

MEDIA COVERAGE The Clemmensen estimate has been widely cited and is still in circulation today. In 1991, *Business Week* used the top end of the estimate ($26 billion) in an article (18). In 1992, *The Wall Street Journal* (19) used the bottom end of the range ($12 billion). Neither of these publications quoted the range of the estimate, how it was derived, that it was illustrative in nature, that it was done in 1989 using 1987 dollars, or that it applied only to the manufacturing sector.

In *Energy User News*, Brender (20) estimates the U.S. cost of lost productivity due to power quality problems as $15 to $30 billion but provides no sources or supporting data. Brender's numbers are roughly the same as Clemmensen's but without clear documentation it is impossible to tell if they were derived from that source.

Other estimates of the costs of unreliable power have also circulated in the popular press. For example, the *Washington Post* in June 2001 (21) cited an estimate for the damages from unreliable power from EPRI:

> Alban's Caterpillar flywheel power system guards well against short-term power outages, and that's vital to companies, said Bill Winnerling, technical manager for power quality for the Energy (sic) Power Research Institute (EPRI), a Palo Alto, Calif.-based industry research-and-development group that helped Active Power develop it. The institute estimates that U.S. businesses lose $15 billion to $30 billion a year from power interruptions.

In this quotation, the $15 to $30 billion per year of losses is attributed to "interruptions" not to power quality. This distinction is an important one, because Clemmensen's original estimate only applied to power quality, not to outages.

The *New York Times*, in a February 2002 article (22), quoted several different analysts on various estimates related to the size of power quality problems in the United States and in the world:

> The Electric Power Research Institute, a research consortium supported by utility companies, estimated last year that power failures cost the United States economy $104 billion a year and that power quality problems, like spikes and drops, cost an additional $15 billion. Manufacturing companies suffer greater losses than "new economy" companies, like those involved with data processing, the group said.
>
> "Worldwide expenditures to address these problems each year run $10 billion to $15 billion, including the cost of backup generators," said James P. LoGerfo, an analyst at Banc of America Securities.
>
> The research firm Frost & Sullivan estimates that the market for uninterruptible power supplies reached $5.8 billion last year and will grow to $7.9 billion in 2007. High-end industrial systems represent 45 percent of sales.

This last quotation from EPRI makes the distinction between power quality problems and interruptions, but most other citations of these numbers are not as explicit.

SUMMARY Clemmensen's simple calculation lends credence to widespread concern about the reliability and/or power quality delivered by the electric grid, but it has been misused to represent a broader class of power quality and reliability issues than the one to which it originally applied. Its magnitude has also been inflated by others to further dramatize its significance, with little recognition of the illustrative nature of the initial calculation. Those attempting to justify public or private investments based on these or related statistics should use caution. The originator of the calculation was quite clear about its boundaries and simplicity, but those caveats have been lost as the number has been repeated, adapted, and reused.

How Much Electricity is Used by Office Equipment?

THE ISSUE Some of the most widely cited statistics during California's energy crisis in 2000 and 2001 ostensibly indicated that the Internet used 8% of all U.S. electricity, that all office equipment used 13%, and that total office equipment electricity use would grow to half of all power use over the next 10 to 20 years. These numbers all originated in an article for *Forbes* by Peter Huber and Mark Mills in May 1999 (23), based on a report written by Mills (24). The Mills report estimated the electricity used by eight categories of energy-using equipment or processes associated with the Internet:

1. Major dot-com companies
2. Web sites
3. Telephone central offices
4. Personal computers (PCs) in offices
5. PCs at home
6. Routers on the Internet
7. Routers in local area networks and wide area networks
8. Energy to manufacture equipment

Mills calculated energy use for equipment in each category by multiplying estimates of the power used by the population and operating hours for each device.

The *Forbes* estimates appeared when the Internet boom was at its peak. At that time, the information technology industry had captured the imagination of U.S. society as a force that would revolutionize both consumer lifestyles and business practice. Many people therefore found it plausible that such an important part of the U.S. economy should also use significant amounts of electric power, which was one reason for the rapid proliferation of these statistics.

In subsequent research, Koomey et al. (25) demonstrated that the Huber and Mills estimate of Internet power use was at least a factor of eight too high, and Kawamoto et al. (26, 27) and Koomey (28) showed that the *Forbes* estimate of total office equipment electricity use was a factor of four too high. Recent analysis by Roth et al. (29) at Arthur D. Little (now Tiax) also corroborated these findings.

Creating credible estimates of electricity requirements for information technology is fraught with difficulty. The underlying data are not known with precision, the empirical data are limited, the most useful data are often proprietary, and the technology is changing so rapidly that even accurate data are quickly obsolete. Forecasts of future growth in power use are even less reliable. Nevertheless, much is already known about information technology electricity use, and we bring that information to bear in the sections below.

DEFINITIONAL AND BOUNDARY ISSUES The boundary issues in defining the categories in Mills' analysis are difficult to address. Is a home computer associated with the Internet? People might use it for writing, for doing calculations, for analyzing personal finances, for creating party invitations, or for accessing the net. Does this mean that all of its energy use can be attributed to the Internet or just a part? If just a portion, how much should be allocated to Internet use? Many of the reasons for owning a computer are independent of the Internet and taken together justify the purchase of a computer. The same conclusion holds even more strongly for PCs in offices, because there are many reasons for companies to invest in PCs beyond Internet access. This kind of arbitrary allocation makes for calculations that are at best limited in usefulness.

The electricity used to manufacture electronic equipment was only partly accounted for in the *Forbes* calculations (manufacturing energy for PCs, monitors, servers, and routers was counted, but manufacturing energy for peripheral equipment, mainframe computers, and telephone switching equipment was not). Boundary issues in this part of the analysis are complex—they involve completeness (i.e., whether all equipment types were treated similarly) and scope (which parts of the production process for the equipment will be counted? Will it include direct manufacturing energy only or also the electricity used in all the materials used in the equipment? How will exports and imports of equipment be treated?). It is possible to draw these boundaries in many different ways. The most important point is that they be drawn consistently across equipment types and production processes.

Mills also made the assumption that all direct electricity usage associated with the Internet is incremental. The evidence suggests instead that at least some of this usage is substituting for other energy-consuming functions that preceded the Internet. In other words, the Internet is expanding uses for the PC at the expense of other energy-using devices. Private computer networks and fax machines, for example, are increasingly being displaced by the Internet. Computer use is substituting for other forms of entertainment, like TV. Even some voice communications (formerly the exclusive province of the telephone network) are being carried over the net, and the phone system itself is evolving to make greater use of the Internet to transmit both voice communications and data. These displacement effects represent another difficult boundary issue.

An additional boundary issue affecting these calculations is that Mills chose to estimate the electricity used by the Internet and associated equipment, but he did not attempt to assess the effects of structural changes in the economy that are enabled by the existence of the Internet (30). These structural changes (like the accelerated growth of the service sectors of the economy and reorganization of business relationships, production processes, and transportation arrangements) will almost certainly affect electricity and energy use. Without assessing the effect of these changes, the net effect of the Internet cannot be calculated, yet that is the most relevant quantity from the policy perspective. Given the large productivity benefits induced by computer hardware when properly used, these changes will probably be large enough to matter.

The most credible studies of this issue analyze direct electricity used by all computer, office, and network equipment, and they do not focus just on what is Internet related because these boundary issues are so difficult to resolve. One study that explicitly addressed some of the boundary issues related to electricity used by the phone system is Blazek et al. (31), but there are precious few others.

ASSESSING THE UNDERLYING ASSUMPTIONS AND DATA We present analyses of two parts of the underlying data, the power use data that Mills used to calculate total electricity use for various equipment types, and the macro data on total power used by the United States that bear upon Mills' assertion that electricity demand growth accelerated in the Internet age.

The power use data The footnotes in the calculations in (24) give detailed assumptions for the Forbes calculations. The reviews of those assumptions in (25, 29) both concluded that Mills substantially overestimated the power used by computer equipment in almost every case. We explore two examples here.

The power used by most personal computers is assumed by Mills to equal 1 kW. This estimate is assumed to include all peripheral equipment associated with PCs, as well as some unspecified other equipment. Without a detailed accounting of assumptions about this equipment, it is difficult to determine how this figure was estimated. However, there is a large body of literature on actual power used by such equipment. Recent measurements of Pentium IV PCs show active power levels of 60–80 W (32). A typical 17″ cathode ray tube monitor uses about 90 W in active mode, but the new flat panel displays of comparable size use a half or a third of that amount. After accounting for other peripherals and "behind the wall" equipment, the analysis in (25) concludes that 200 W is a more reasonable estimate for the active power of PCs than is 1000 W, implying that the *Forbes* estimate is a factor of five too high.

Mills further assumes that all routers (network devices that channel information to and from networks) draw 1000 W as well. Roth et al. (29) present measured data from Kunz (33) that shows the vast majority of routers consume 40 W or less, with only the largest routers approaching 1000 W. In this case, the *Forbes* article overstated power used by this category of equipment by more than a factor of 20.

The macro data Another piece of empirical evidence that the assertions in the Forbes article might not be accurate showed up in some of the key indicators of electricity use and energy use over time. Joe Romm of the Center for Energy and Climate Solutions plotted Figure 4 from Energy Information Administration data, which shows annual growth rates for U.S. electricity use, primary energy use, gross domestic product (GDP), and carbon dioxide emissions for the 1992 to 1996 and 1996 to 2000 periods. While GDP grew faster in the second period, electricity, energy, and CO_2 emissions all grew more slowly in that period than in the preceding period. If the Forbes thesis were correct, we would expect electricity demand growth in the latter part of the 1990s (the heyday of Internet growth) to have gone up, but in fact the opposite occurred. These data appear to contradict the assertion that demand growth was stronger with the widespread use of the Internet.

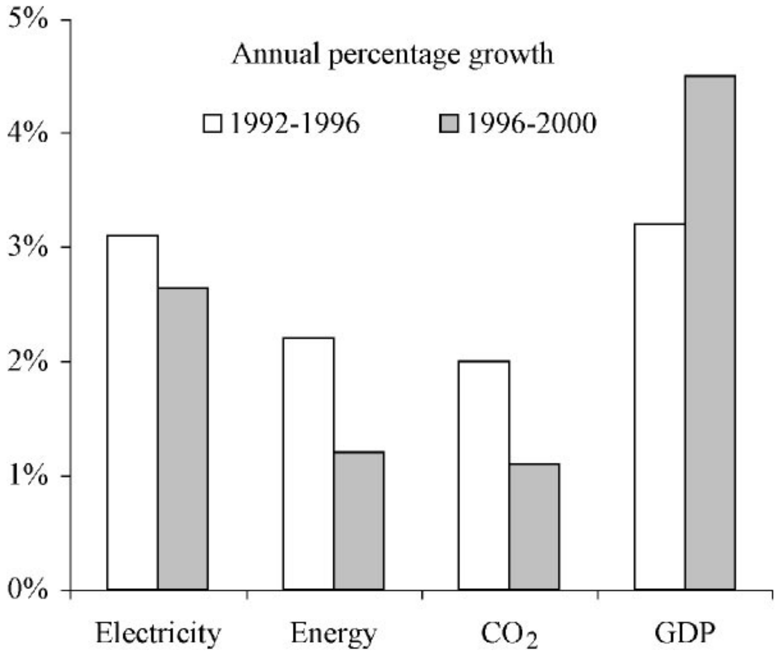

Figure 4 Comparison of annual growth rates in electricity use, energy use, carbon dioxide emissions, and GDP. Source: Joe Romm of the Center for Energy and Climate Solutions, based on EIA data.

ANALYZING ARGUMENTS In assessing the credibility of the *Forbes* article it is important to recognize the several different lines of argument reflected in the analysis. The bulk of the analytical work was focused on estimating the electricity used by the Internet in 1999 (24), which totaled 8% of U.S. electricity consumption. Mills then took this number and added 5% based on a misunderstanding of a 1996 article by Koomey et al. (34) to get his estimate of the electricity consumed by all information technology equipment in 1999 (13%). Then he forecast that electricity used by office equipment would grow from 13% of all electric power to account for more than half of all electric power in 10 or 20 years.

We focus here on that forecast because it has been so heavily cited but largely unanalyzed. Forecasts are inherently uncertain, and most analysts are wary of them, particularly when fast-changing technologies like office equipment are involved. This forecast was widely reported, and it influenced at least one generator manufacturer and researchers from five investment banks (16, 35–38) to conclude that rapid demand growth would once again return to the electric utility sector. We even located an ad in *The Wall Street Journal* (39) by a mutual fund company specializing in alternative energy stocks that cited it [based on an August 2000 report from Stephens, Inc. (37)]:

> From rolling blackouts to soaring fuel costs, the world is facing an energy crisis. It's gotten to a point where a well-placed turbine windmill can generate more income for a farmer than a whole crop of alfalfa. And demand is only going to go up. In fact, computer usage alone is expected to account for 50% of the total U.S. electric consumption by 2010.

This forecast took several forms in the work of Mills & Huber, but we focus here on a quotation from their 1999 *Forbes* article: "It's now reasonable to project that half of the electric grid will be powering the digital-Internet economy within the next decade." We analyze this assertion in two ways. First, we assume that the Annual Energy Outlook 2001 (AEO) forecast for total electricity from 1999 to 2010 is a reasonable projection and that the Mills & Huber percentages (13% in 1999 and 50% in 2010) apply to those totals. That result is shown in Figure 5, expressed as a fraction of total 1999 electricity use. In order to fit under the total growth constraint from AEO 2001 and also meet Mills' estimate of half of all electric power in 2010 coming from office equipment, total electricity use for nonoffice equipment end uses must decline by about one third, even as the number of households increases by 12% and the value of gross industrial output goes up 32%. Electricity used by office equipment must in this case increase by a factor of four and a half in 11 years, which corresponds to an annual growth rate of almost 15% per year.

The second case we consider is that of total projected electricity demand growth of 3%–4% per year, as cited in Mills' *American Spectator* article (40). Using 3.5% per year over 11 years yields growth in total electricity use of 46% over this period. We then apply the same percentages as before (13% in 1999 and 50% in 2010) to determine the information technology (IT) component. This calculation is shown as the third bar in Figure 5, which shows a decline in non-IT electricity use of more than 15%, and an increase of IT electricity use by a factor of more than five and a half. Annual growth in IT electricity use in this case is about 17% per year and corresponds to adding 180 TWh of additional IT load to the grid every year for 11 years.

It is clear that people accepting this forecast did not conduct even the minimal analysis described in the preceding two paragraphs. The required decline in electricity used by the other end uses would be a remarkable reduction in demand. It is possible to make the argument that IT would result in savings in the other end uses, but Mills did not do so. Moreover, the required savings are larger than most advocates for IT as an energy-saving technology would consider plausible.

The Mills & Huber projected growth rates of the IT energy requirements are large in both absolute and percentage terms. In order to conclude that these growth rates are plausible, a detailed end-use forecast would have to be conducted, listing the types of equipment expected to be purchased, their power use per unit, and their expected lifetimes. As far as can be determined from Mills' published reports and articles, no such analysis underlay this forecast. The logic was that forecasted spending on IT technology was growing at a furious pace, and as a result, the

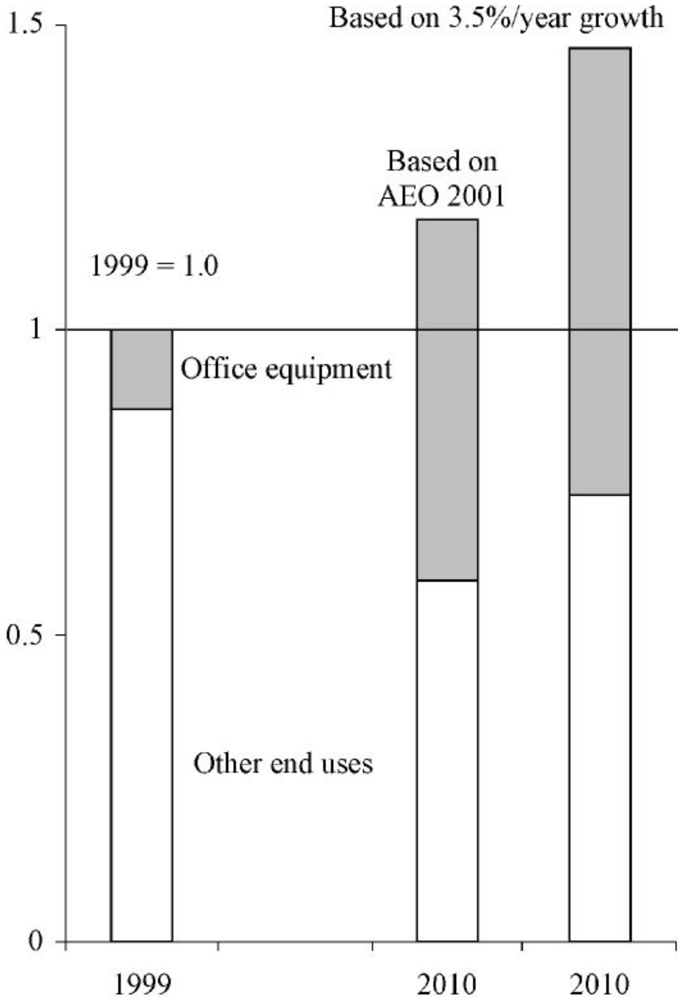

Figure 5 Electricity use associated with information technology (IT) and other end uses in 1999 and 2010, using two different forecasting methods (assuming IT is 50% of all U.S. electricity use in 2010).

electricity used for this equipment would also grow at a comparable pace. Here is one example of how Mills' makes this assertion:

> As bandwidth demand rises, power use rises, as does the market's use of the services. Yes efficiency will rise too. But for some time, as we build out the new infrastructure of the Digital Age, efficiency gains will be overwhelmed by sheer growth. Electricity is the fuel of the Digital Age, and the Internet at the heart of this revolution. (24)

The conclusion that "efficiency gains will be overwhelmed by sheer growth" was not substantiated by any analysis. New routers and switches have vastly higher data throughput than their predecessors yet use less power. Distributed and mobile applications of microprocessors require the use of low power chips because batteries have limited storage capacity. New mainframes use half or a third of the power of their decade-old counterparts but possess far more computing capacity. If new devices are much more efficient than their predecessors, electricity demand growth from these devices could be modest. Without a detailed analysis, it is impossible to be sure, and the forecast that IT electricity use will grow to half of all electricity use must be considered speculative at best.

The most recent forecast of office equipment electricity use that relied on such a detailed end-use approach is that by Roth et al. (29), who found that office and network equipment electricity use would range from 2% to 3.5% of total electricity demand in 2010, and it would in their highest growth rate scenario grow at no more than a 5% annual rate from now until 2010. This rate of growth is lower than that embodied in the Annual Energy Outlook 2001 forecast (41) and substantially lower than the growth rates implicit in the *Forbes* projections discussed above.

MEDIA COVERAGE We identified six news stories, three magazine editorials, and five reports from major investment banks that cited the erroneous *Forbes* numbers with little or no indication that there was even a debate about them. Table 1 summarizes those stories (the other sources cited below did mention that there was a debate about the numbers).

The reports from investment banks were particularly noteworthy because some investors and media were presumably influenced by their recommendations. Although an exact cause and effect link is often difficult to establish, in one case (that of the editorial in *Energy Markets*) there is a clear link between the findings in the *Forbes* article and the investment recommendations made by the author of the editorial. Koomey is aware of one major power generator manufacturer that considered altering its strategy in fall of 2000 based on the assumption of faster demand growth for electricity, although a brief explanation of the measured data soon made them more cautious.

We identified about twenty additional stories that alluded to the debate and reported on it in various ways (42–61). Some cited both sides of the debate, giving them equal weight, while others dismissed the *Forbes* numbers after citing them. The *New York Times Magazine* (43) used the latter approach to characterize the debate: "The West Virginia Coal Association's Web site claims . . . that computers and the Internet suck up 13 percent of the electricity in America. In fact, the best studies suggest that such activities consume only 3 percent of the nation's electricity." Most articles simply left the reader with the impression that there was controversy among experts about this topic.

Some reports cited ranges for the percentage of power use associated with computers in an attempt to show balance but were careless about how they created the ranges. For example, an Associated Press report in the *San Francisco Examiner*

TABLE 1 Stories that cited the *Forbes* information technology electricity use figures without describing the debate

Publication and date	Type of publication	Quotation
Electric Power Research Institute Winter 2000 (108)	Research institution news magazine	"Information technology itself now accounts for an estimated 13% of electricity consumption in the United States, and some industry observers believe the IT share may grow to as much as 50% by 2020."
Deutsche Bank May 2000 (35)	Investment research report	"Mark Mills estimates that by 1999, the growth in (sic) Internet and related IT equipment now consumes 13% of our electricity supplies."
San Francisco Chronicle June 10, 2000 (109)	News article	"Computers and computer peripherals now consume about 13 percent of the nation's available power, a figure that has soared from less than 1 percent since 1993 as the Internet becomes a preferred method of doing business and communicating."
USA Today June 10, 2000 (110)	News article	"Computers consume about 13% of the nation's power, according to EPRI Corp., a Palo Alto research and development group that studies the utility industry."
Banc of America Securities June 2000 (16)	Investment research report	"Internet-related demand for power represented 8% to 13% of electricity consumption in 1999 . . . . It is estimated that by 2010, one-half of U.S. electric consumption will be related to the Internet in some way."
USA Today August 2, 2000 (111)[a]	News article	"The growth is due, in part, to the proliferation of computer and high-tech peripherals . . . . Industry studies found that high-tech paraphernalia had a negligible effect on power usage as late as 1993. Today, it is estimated to account for 13% of all usage. By 2020 it is expected to reach 25%."
Business Week August 14, 2000 (112)	News article	"Fax machines, printers, PCs, and the like already account for up to 10% of commercial electricity use, according to estimates . . . "
Fortune Magazine August 14, 2000 (113)	News article	Mark Mills "estimates that new-economy sectors—computers, semiconductors, telecom, information storage, and Internet-oriented companies—account for 12% to 14% of the country's power consumption."

(*Continued*)

TABLE 1 (*Continued*)

Publication and date	Type of publication	Quotation
Energy Markets August 2000 (114)	Editorial	"Banc of America Securities just launched coverage of the energy industry technology sector. The firm attributes to Huber and Mills the comment, 'Internet-related demand for power represented 8% to 13% of electricity consumption in 1999.'"
Stephens, Inc. August 2000 (37)	Investment research report	"The percentage of electricity consumed directly by the Internet is currently estimated to be 10% in the U.S., up from roughly zero in 1993, and there are no signs of slowing growth in the pervasiveness of the web. Some estimates project that the Internet and the equipment to support its growth will consume 50% of domestic power within 10 years."
JP Morgan Sept 14, 2000 (36)	Investment research report	". . . information technology (IT) and telecom should account for an increasingly large piece of the total energy pie (up from about 16% today)."
Salomon Smith Barney Sept. 25, 2000 (38)	Investment research report	"In 1995, the U.S. Department of Energy estimated that personal computers consumed approximately 3% of U.S. electricity supplies. Mark Mills, a well-known technology consultant, estimates that in 1999 Internet and related IT equipment consumed 13% of our electricity supplies."
Mechanical Engineering Magazine April 2001 (115)	Editorial	"It has been estimated by the Energy Information Administration that the Internet alone now accounts for nearly 10% of the nation's electricity demand."
ZD Net News May 14, 2001 (116)	News article	"The total energy consumed by the Internet information technology sector . . . is an estimated 8% to 13% of the nation's electricity, according to data from the Energy Information Administration."
Newsweek May 6, 2002 (117)	Editorial	"Manufacturing and running computers consume 15 percent of U.S. electricity. Internet use alone accounts for half of the growth in demand for electricity."

[a] On October 5, 2000 *USA Today* published a correction to their story (118): "In a story August 2, 2000 on a growing shortage of electrical generation capacity, *USA Today*, citing industry figures, reported that computers and their accessories . . . account for 13% of the nation's power consumption. While there is much debate on the figure, a study by the Department of Energy's Lawrence Berkeley National Laboratory puts that number at about 3% of annual use of electricity."

(42) said, “the equipment needed to power the Internet consumes from 1 percent to as high as 13 percent of national demand.” The *San Jose Mercury News* (44) stated, “depending on who you believe, high technology consumes from 3 percent to 20 percent of the nation’s total power generation, and some expect that number to rise to as high as 40 percent by 2010.” In the first case, the range was created from incomparable statistics, and in the second, the two high ends of the range (20% and 40%) are of unknown origin.

SUMMARY The claim that information technology uses large amounts of electric power proliferated quickly, driven by a superficially plausible story line and a high-profile crisis in the California electricity sector. *Forbes* itself lent credibility to the argument simply by publishing it. The trade press and the popular media repeated the key claims in the *Forbes* article, often without citing a source, thus enshrining the erroneous statistics as common knowledge. Leaders in business, government, and academia were misled by this barrage of media attention and cited the statistics widely, thus ensuring their proliferation.

How Much Oil is Recoverable from the Arctic National Wildlife Refuge?

THE ISSUE One of the most contentious issues in U.S. energy policy in the last few years has been the discussion about drilling for oil in the Arctic National Wildlife Refuge (ANWR). This South Carolina–sized region in northeast Alaska contains a coastal plain, known as area 1002, which is both a key wildlife habitat and a potentially promising area for oil exploration. The 1002 area alone is the size of Delaware.

The area has been off-limits to drilling since its Refuge designation by President Eisenhower. Limited seismic testing in the 1002 area suggested some potential for substantial oil resources. Subsequent legislation signed by President Carter expanded protections for the area, stating that the 1002 area would require another act of Congress to open it for further oil exploration and drilling.

This topic attained a high profile in the media as well, after it became a key point of distinction between the two major presidential candidates in the fall of 2000 and a central feature of now-President George W. Bush’s proposed national energy policy.

The debate has centered largely on the quantity of oil likely to be found in the Refuge. Although it is not surprising that proponents of drilling believe large amounts of oil will be found there and that opponents believe the amount is smaller, what is surprising is the extent to which the media have misunderstood and poorly represented the underlying science. With few exceptions, the media have characterized the story of the Arctic Refuge as a brawl between impassioned pursuers of economic benefits and equally fervent defenders of wildlife, not bothering to dig into the science itself to understand how much oil is likely to be found. Yet that science is critical to sound decision making about the Refuge.

Of course, whether or not to drill in the 1002 area is about more than just economically recoverable reserves. Balancing wilderness preservation against resource development ultimately requires a value choice, and there are those for whom that choice is unequivocal—either drill or not. For the majority in the middle, however, the question of how much oil might actually be found could influence their decision. It is this group that participants on both sides of the debate most hope to sway, hence the prominence of the oil resource estimates in the public discourse.

Like other fields of science, the study of petroleum geology employs its own quantitative language. Though seemingly complex to a layperson, that language revolves around a handful of fundamental concepts of geography, geology, technology, economics, and probability. What follows is a brief background on those issues.

Most resource estimates to date consider only the amount of oil likely to be found in area 1002, although others also include resources in offshore areas controlled by the state and in adjacent native lands. The latter approach increases the total amount of oil likely to be found, but it is outside the scope of the present policy debate, which asks the simple question, Should Congress open area 1002 to drilling? As a result, the U.S. Geological Survey (USGS) has concentrated most of its research regarding the economics of developing the resource on the federally controlled 1002 area of the Refuge.

Petroleum geologists at the USGS began by examining area 1002 to determine the total amount of oil in place, assessing whether the type and age of the rocks in question are conducive to forming and trapping oil. It is akin to estimating the wetness of a vast, unseen, underground sponge. It includes no consideration of how much can be squeezed out of that sponge, by what means, and at what cost.

Next, the USGS looked in more detail at the physical characteristics of the underground formations where oil is likely to be trapped. Overlaying that resource assessment with an understanding of the current technologies and techniques for extracting oil, they produced estimates of the amount of technically recoverable oil. Such assessments include no consideration of economics—they simply estimate the amount of oil the industry knows how to recover by any means at any cost. The USGS published its most recent set of such findings in 1998, after a reexamination of all existing seismic testing data for the region (62).

Finally, the USGS analysts overlaid technically recoverable estimates with a variety of economic considerations. These include assessments of the likely quality and market value of the particular type of oil found, estimates of the cost of seismic testing and wildcat exploration, and considerations of the specific locations and depths of individual oil accumulations to determine drilling and infrastructure costs. In addition, they included transportation costs to market and the rate of financial return expected by oil companies from such projects at particular oil prices. In short, they constructed an estimate of economically recoverable oil using the same methods a private oil company would use to decide whether to invest its own capital to drill in the hopes of making a profitable oil discovery, assuming a 12% real rate of return.

The final issue to consider is the probability of cost-effective recovery. The USGS builds computer models to test a wide range of assumptions for the variables above and then runs thousands of simulations to determine the range of resulting resource forecasts. Plotting these results on a graph gives something resembling a bell curve: A small number of the estimates predict miniscule finds and a small number predict large finds, with most of the estimates clustering in between. This distribution allows the USGS to predict the mean, 50% (F50), 5% (F5), and 95% (F95) probabilities of finding a particular amount of oil.

Probability and the size of the resource move inversely with each other. So, for example, both the mean and 50% forecasts are considered middle-of-the-road, reasonable scenarios and are usually fairly close in magnitude. The 95% forecast is often a small amount of oil, yet it comes with the virtual certainty of being found. The 5% forecast will often point to an enormous amount of oil, yet the likelihood of finding that much is quite remote.

Probability comes into play in another way too. Economically recoverable resource estimates can be either conditional or fully risked. Conditional estimates are appropriate for thoroughly explored regions (such as the onshore oil fields of the lower 48 states) with well-understood geology. They assume a 100% probability of finding economically valuable quantities of oil and simply assess how much of it is there.

Fully risked estimates are more appropriate to remote areas like the Arctic Refuge, where much of the detail about underground structures is still unknown (K. Bird, lead Arctic Refuge geologist, USGS, personal communication, February 2001). They multiply the amount of oil that may be economic by the likelihood of finding it to yield a resource estimate that accurately reflects the potential risk and reward (63).

DEFINITIONAL AND BOUNDARY ISSUES Several definitional and boundary issues arise in discussions of the oil reserves in the Arctic Refuge. The first is geographical: statements about recoverable oil often do not distinguish between oil resources in the whole Arctic Refuge and those just in the 1002 area. In addition, economically recoverable reserves must be distinguished from oil in place and technically recoverable resources. Next, discussions about the possibilities for recovering oil from the refuge typically do not specify the oil price upon which those assessments are based. Finally, the distinction between conditional and fully risked estimates of recoverable oil is often ignored, but it is an important one that affects any assessment of the expected value of oil that can be extracted economically.

ASSESSING THE UNDERLYING ASSUMPTIONS AND DATA As shown in Figure 6 [adapted from (62)], the various studies that have assessed Arctic Refuge oil over the last few decades have predicted widely different amounts of oil (62, 64–71).

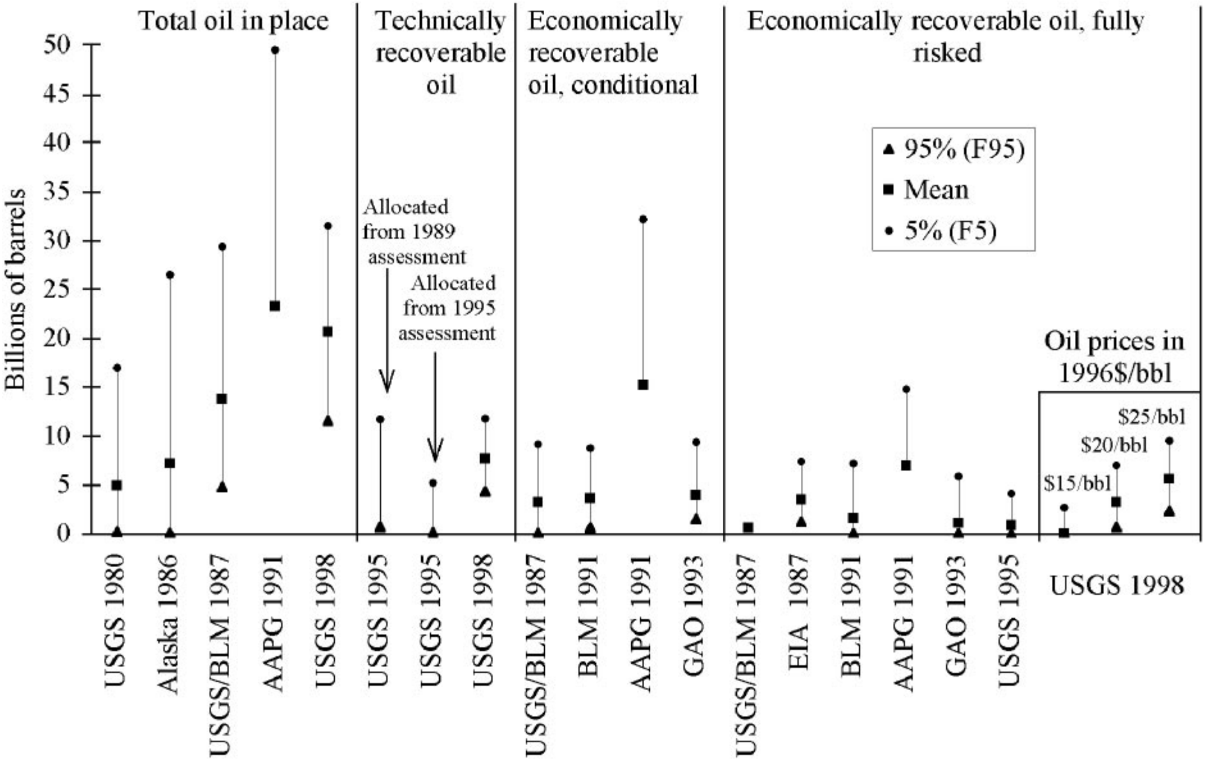

Figure 6 Different estimates of the oil reserves in the 1002 area of ANWR. Source: Adapted from a graph in USGS (62), which was based on the studies in References (64–71).

Even studies of the same basic type (i.e., oil in place) have varied substantially, particularly when conducted by some party other than the USGS.

As evidenced by the large variation in resource estimates in Figure 6, the data on oil resources in the Arctic Refuge remain uncertain. Exploratory drilling has occurred primarily around its perimeter, and seismic data for the region were collected decades ago. Drilling additional wells or conducting more thorough seismic studies would provide additional information but at the cost of disturbing the wilderness character of the region itself. In addition, such detailed studies are normally undertaken only as a prelude to auctioning the rights to drill a commercially viable oil field, and until the decision is made to auction those rights, the exploratory drilling will not occur. For the moment, policy decisions are being made on the basis of best currently available information.

In the 1998 USGS studies of the region (62), the agency reexamined all publicly available well data for the region and proprietary seismic data for area 1002 using the latest computer analysis techniques. The USGS added greater resolution to its economic assessments as well, with scenarios keyed to three market oil price forecasts: $15, $20, and $25 dollars/barrel (1996 dollars). Table 2 shows the resulting estimates, in billions of barrels.

The distinction between market price and world oil price is a significant one. Given the difference in quality between Alaskan North Slope crude oil and West Texas Intermediate crude, which serves as the benchmark for world oil prices, market price is actually a few dollars below world oil price in this case. Market price must also take into account the cost of transporting the oil from the Refuge to refineries and markets in the Lower 48.

Historical wellhead (first market purchase) prices of oil from the North Slope of Alaska are contained in Figure 7, taken from (72). For comparison, Figure 7 also contains an approximation to market prices that is consistent with the $15 to $25/barrel range from the USGS analysis. Since 1986, the market price of Alaskan oil has remained between $14 and $23/barrel, only rising above this range in 2000 when the price rose to $28/barrel, then fell back again in 2001.

The technically recoverable estimates are about 35% larger when the offshore state waters and adjacent native lands are included in the totals. They are 16

TABLE 2 USGS estimates of oil reserves in ANWR's 1002 area (billion barrels)

Probability	Oil in place	Technically recoverable	Economically recoverable		
			$25/bbl[a]	$20/bbl	$15/bbl
F5	31.5	11.8	9.5	7.0	2.7
Mean	20.7	7.7	5.6	3.2	0
F95	11.6	4.3	2.3	0.7	0

[a] Oil prices are in 1996 dollars. Source: USGS 1998 (62).

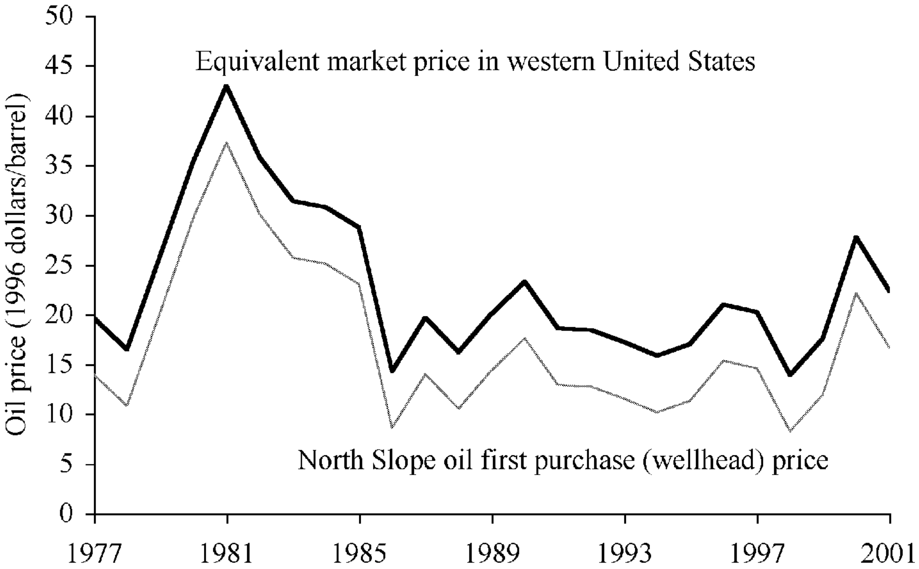

Figure 7 First purchase and equivalent market prices in the western United States for North Slope crude oil from 1977–2001. Notes: First purchase market price is the price of oil to the first purchaser of oil after it is extracted from the earth, also known as the wellhead price (which does not include transportation costs to the refinery). Equivalent market price is derived by adding transport costs (about $5.70/barrel in 1996 dollars) from USGS (62) to the North Slope first purchase prices. Source of North Slope prices—*Annual Energy Review 2000* (72), except for the 2001 numbers, which came from (120). Inflation 2000–2001 is estimated to be 2%, based on the latest GDP deflators.

billion barrels at F5, 10.4 billion barrels at the mean, and 5.7 billion barrels at F95 (62).

The economic studies yield a series of supply curves (one for each probability). All three share the same basic shape, as shown in Figure 8 [adapted from (62)]. Initially, small increases in price greatly expand the amount of oil likely to be economically recoverable. Eventually each curve reaches a “knee” and then becomes nearly horizontal, suggesting that additional price increases only minimally affect the resource total.

ANALYZING ARGUMENTS Virtually all stakeholders in the Arctic Refuge debate are arguing from an identical set of numbers from the same source—the 1998 USGS study. Few advocates have claimed that the research process or science conducted by the USGS is flawed and that some other study is more accurate. Instead, advocates have simply gravitated toward the particular set of numbers that most strongly support their views and then represented those numbers to the media as USGS findings.

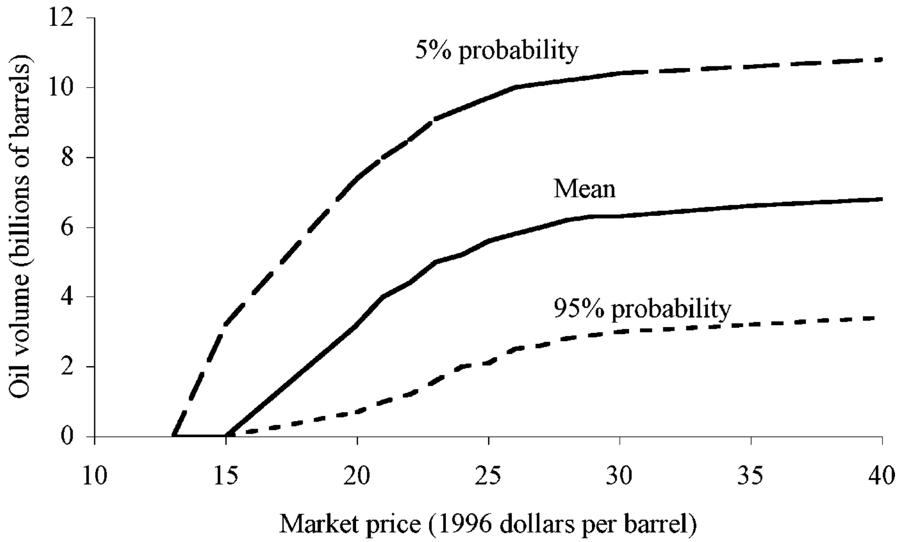

Figure 8 Economically recoverable oil potential in ANWR's 1002 area as a function of oil price. Source: USGS (62).

Proponents of drilling have a number of options for reporting a high estimate and attributing it to USGS. They can select the most favorable geography (whole region, not just area 1002), a favorable study type (technically recoverable instead of economically recoverable), and a favorable probability (5%) to conclude that 16 billion barrels are available for the taking. Or, they can look just at area 1002, but move all the way up to oil-in-place studies to state that 20 to 30 billion barrels are there (mean to 5% probability). Drilling advocates also commonly quote estimates in the 10 to 12 billion barrel range, which can be found in the mean technically recoverable estimate for the whole region or the 5% technically recoverable estimate for area 1002.

Opponents of drilling, likewise, could argue that no oil is likely to be found in the Refuge, based on the USGS conclusion that 0 barrels are economically recoverable from area 1002 at a world oil price of $15/barrel in the mean and 95% probability scenarios. Perhaps the most commonly quoted number by opponents of drilling, though, has been the mean estimate of economically recoverable resources at the middle price ($20/barrel) for the 1002 area—3.2 billion barrels.

MEDIA COVERAGE Rather than going back to the original USGS research and publications, the media have largely taken at face value advocates' assertions about what the USGS said. So most of the stories follow a formulaic pattern—quoting wildly different resource estimates from advocates on both sides and leaving the reader with the impression that the truth is somewhere in between. This is muddled science at best and, on the whole, a great disservice to policymaking.

Using online searching tools, we located 35 different news stories printed or aired between December 2000 and September 2001 regarding the amount of oil likely to be found in the Arctic National Wildlife Refuge (73–107). All were written by mainstream journalists; editorials and opinion pieces were specifically excluded from consideration, as were articles appearing in advocacy or trade association publications. Five of the stories included specific references to multiple types of studies, so those are plotted separately, giving a total of 40 specific sets of resource estimates. If only one estimate was provided, it was treated as both the high and the low for that particular story. As shown in Figure 9, those estimates are—literally—all over the map.

Only one story noted the possibility of 0 barrels being recovered, and only one indicated that 20 billion barrels might be found. The most frequently cited estimate was 16 billion barrels, which appeared in 24 of the stories. Other commonly cited numbers were approximately 3 to 3.5 billion barrels, approximately 6 billion, and roughly 10 billion. The average high estimate cited was 13 billion barrels and the average low estimate was 7.6 billion barrels, leaving readers to conclude that a number somewhere in the middle—about 10 billion barrels—would be roughly right. Comparing the average 10 billion barrel figure from the media reports to the mean curve in Figure 8 at ($20/barrel) indicates that the media reports (on average) implicitly overstated the economically recoverable reserves in the 1002 area by about a factor of three.

One interesting feature of these articles is the absence of clear descriptions for the types of studies being cited. Only 10 of the 43 estimates mention anything about economics in determining how much oil can be recovered, and only 4 of those specifically mention an oil price (one of which misquoted the USGS data by concluding that there is a 95% chance of finding 3.2 billion barrels at a price of $20/barrel). None of the stories noted that the price estimates used by USGS were computed in 1996 dollars, meaning that current and future oil prices would need to be discounted by growing percentages for parity with them.

Only 5 of the stories mentioned that the amounts quoted were recoverable or technically recoverable or recoverable with current technology to distinguish them from oil-in-place or economically recoverable estimates. One story noted that it was referring to the total amount of oil in place. Overall, 56% of the estimates given included no information about the type of study being cited.

Only 2 of the 43 estimates specifically noted which geographic area they were referring to (Refuge + coastal waters and adjacent native lands), leaving unstated the geographic distinction between the 1002 area and the broader region. Similarly, only 3 of the stories made any distinctions of probability between 5%, mean, and 95% estimates.

Though 21 stories specifically referred to the USGS as the ultimate source of the numbers, and another 2 referenced the government or government geologists, few if any of the stories actually quoted someone from the USGS itself. A handful of other stories were content to source estimates to prodrilling lawmakers, oil lobbyists, experts, and skeptics.

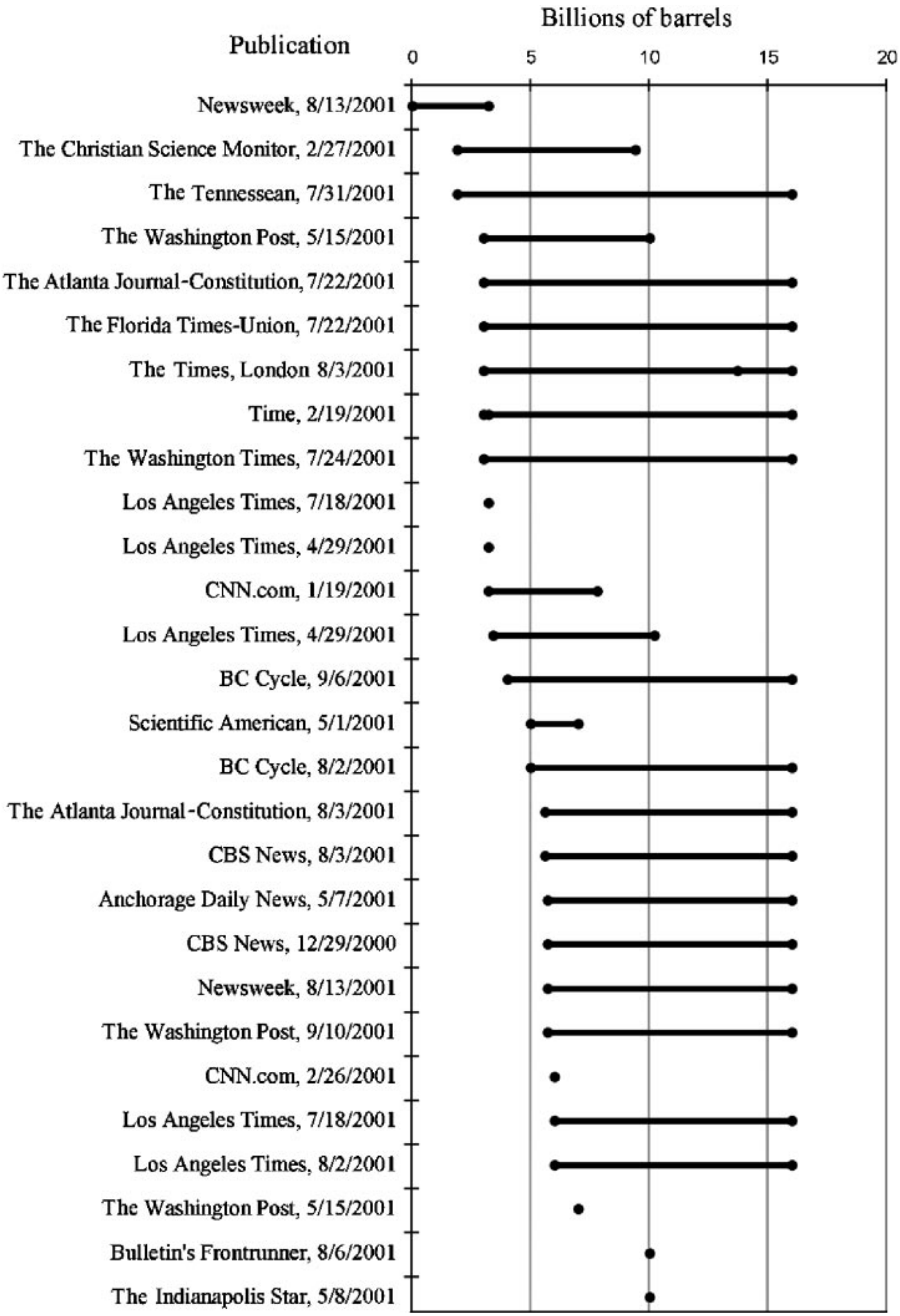

Figure 9 The amount of oil in the Arctic Refuge, as characterized in recent news stories

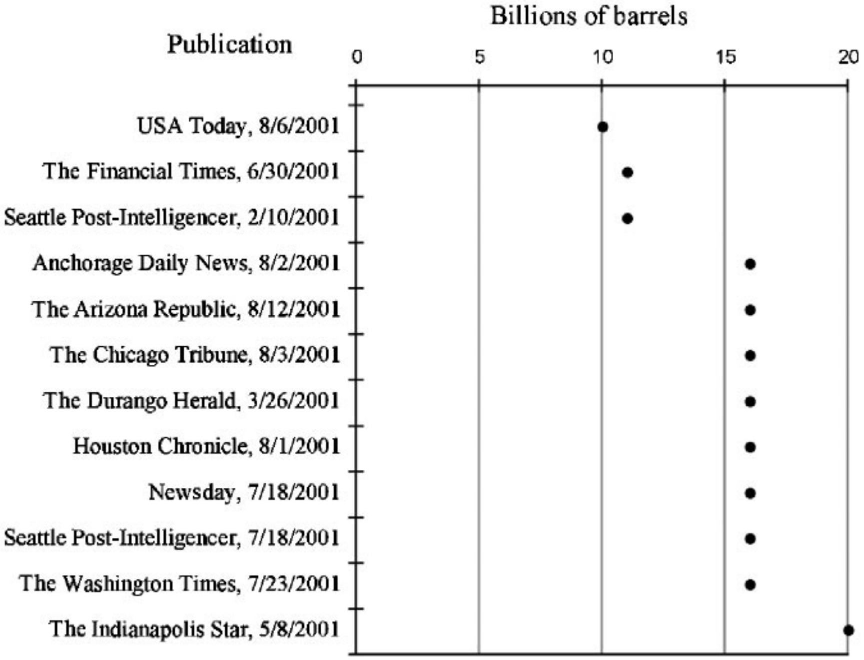

Figure 9 (*Continued*)

SUMMARY The nation must weigh carefully the costs and benefits of drilling in the Arctic Refuge against pursuing other energy policies. The Refuge contains highly uncertain geology, world oil prices fluctuate wildly, exploration and extraction would take 40 to 50 years to complete, and private oil companies will demand a fair rate of return for investing their capital to explore and drill there. For these reasons, mean, fully risked, economically recoverable estimates are the most meaningful measure of the region's oil potential.

The amount of economically recoverable oil resources from area 1002 depends strongly on the long-term market price of oil. Considering the range of prices from $15 to $25 a barrel (1996 dollars) yields a range of mean, fully risked, economically recoverable resources from 0 to 5.6 billion barrels. However, this range was only reflected by a handful of the news stories covering the topic in the last year, and most reports unwittingly left the impression that the amount of economically recoverable oil resources fell substantially above this range.

As the United States weighs multiple options for meeting its energy and mobility needs, it is vital that we have accurate information about different policy options. How much would it cost to find 3, 4, or 5.6 billion barrels of oil in the Arctic Refuge? How much would it cost to save that much oil through improved fuel efficiency or alternative fuel sources in vehicles? What environmental and employment impacts are associated with increased energy production or energy efficiency? Over what time period would each resource become available? How does the split between public and private costs and benefits compare in each case? The answers to these questions form the core of a meaningful debate over the Refuge and the basis for more comprehensive and accurate media coverage of that debate.

Discussion

This section reviews some of key points revealed in the preceding examples, focusing on the main headings of definitional and boundary issues, assessing the underlying assumptions and data, analyzing arguments, and media coverage. For extensive discussion on how to avoid the most common pitfalls, see References (1) and (2).

DEFINITIONAL AND BOUNDARY ISSUES The first step in interpreting any statistic is carefully defining terms and boundaries because that is where misinterpretations and misunderstandings most often arise. For example, much confusion in debates about how much oil will be found in the Arctic National Wildlife Refuge would be eliminated if four variables were explicitly specified: the geographical area (area 1002 versus the whole ANWR area), the type of assessment (resources in place, technically recoverable, or economically recoverable), the type of risk assessment (conditional or fully risked), and assumed future oil prices. Only rarely are these variables stated, but they underlie any claims about potential oil discoveries in the Refuge. By explicitly identifying definitional ambiguities, analysts can avoid creating inconsistent comparisons, which is one of the most common potential pitfalls in any policy analysis (1).

ASSESSING THE UNDERLYING ASSUMPTIONS AND DATA As shown in all four examples above, numbers frequently become disembodied—separated from the original source, detached from any caveats, and averaged or manipulated in inappropriate ways. These transformations can breed what Joel Best (2) calls “mutant statistics,” which have been twisted into new and incorrect forms.

Underlying data should be compared to other information already known to be true, as a first-order sanity check. The published documentation, cited sources, and simple back-of-the-envelope calculations should be sufficient to reproduce any number (1), and this process will either validate the number or reveal inconsistencies that prompt further investigation. Data should not be used unless their derivation is clear, the cited sources trustworthy, and the stated methods sound.

An important lesson from the examples above is that a range of estimates is not always what it seems to be—people summarize data in ranges but are careless about using consistent definitions, cite incomparable numbers, and extend the ends of the range to be conservative no matter what the original data say. Ranges (whether cited in the media or in analytical reports) should be checked against the original source before they are cited again.

ANALYZING ARGUMENTS Techniques that can help analysts avoid the most common pitfalls in assessing arguments fall under the general rubric of critical thinking skills. These skills are rarely explicitly taught. They involve investigating the premises and conclusions of an argument, asking whether the premises adequately support the conclusions, and exploring missing arguments and counterarguments (1).

Statistics are commonly misused to make arguments by selective reporting of results. In the case of potential for oil discoveries in the Arctic refuge, advocates on both sides of the debate frequently chose the results from the USGS report that were most convenient for their case and ignored those that did not support it.

Another common mistake is to take a number and then modify it in some way using a hand waving argument but no further analysis. For example, the *Forbes* article claimed (without any analysis) that the growth of electric power used by computers would cause it to comprise 50% of all electric power use in ten years. The Banc of America Securities report made the same type of error, by claiming without documentation that the costs of unreliable power would grow to $100 billion. Analysts should be especially wary of such claims when there is no documentation or analysis to back them up.

MEDIA COVERAGE Most analysts are overjoyed when popular and media attention shifts to focus on their work. Unfortunately, they are often unaware of how the media use information, which can lead to misunderstanding and disappointment when careful scientific statements are collapsed into short sound bites or subsumed into artificially created ranges. The extreme time constraints under which the media often operate are also foreign to many researchers, who are accustomed to having time to consider and analyze before drawing conclusions.

Journalists often assume that all debates have two equal sides, in part because conflict creates reader interest. In some areas (particularly in scientific fields), there are right and wrong answers, and by highlighting a few critics instead of presenting the balance of scientific opinion, journalists can do the public debate a disservice. The Internet electricity debate was one where the claims of one participant in the debate had been refuted in the peer-reviewed literature using measured data, but the media coverage of the dispute did not reflect that, which led to the incorrect impression that the debate was an arcane disagreement among experts. The coverage of the oil reserves in ANWR was similar, with the additional twist that there really was only one source of data (the USGS studies), and the various participants in the debate merely chose those numbers from the USGS studies that supported their positions. Here was surely a case where simply referring back to the original studies could have revealed credible information that was relevant to the public debate, but few if any journalists undertook that step.

As is customary for scientists, the USGS researchers gave ranges characterizing uncertainty for their estimates of recoverable oil reserves. However, this careful presentation of information may have allowed advocates on both sides of the debate to choose the numbers best suited to make their case. The media treatment of this issue encouraged this outcome because it focused on what certain individuals and institutions said, rather than what the scientific results were. It probably would have been difficult to avoid this result, given the political complexity of the issue, but it is at least worth noting that choices of how to present the scientific results may have consequences for the course of the political debate.

As shown in the examples above, respected publications can bestow credibility on a statistic merely by citing it. Subsequent readers then attribute the number to *The New York Times* or *Forbes,* and the statistic is on its way to becoming conventional wisdom. It is incumbent upon researchers to be especially precise in conveying the conclusions of their work to the media, to refute erroneous information when it appears, and to educate the public about the scientific process when they can. Most journalists do not have scientific training, but a small amount of effort on the part of researchers can help overcome that lack.

One of the issues emerging from the *Forbes* debate is the important role of companies and trade organizations in perpetuating the inappropriate use of statistics. At least two industry trade groups cited the *Forbes* numbers in their press releases, and many reporters simply repeated the press releases verbatim. This lesson is an important one. Many news items are actually regurgitated press releases—news organizations often reprint press releases without much critical evaluation of their content.

Conclusions

All statistics represent a simple summary of a complex world. Best (2) distinguishes between bad statistics, which "simplify reality in ways that distort our understanding," and good statistics, which do not. Implicit in this statement is his view that statistics should help us understand the world more completely, but they do not always contribute to that goal.

While it is difficult to prevent statistics from being misused, analysts can take steps to guard against such problems. Careful assessment of premises, underlying data, and arguments are essential for determining if a statistic is a good one. Definitions and boundaries are often ill defined and explanations incomplete, but careful critical thinking will help disentangle these puzzles. Insist on going back to the original source and checking the documentation. If there is none, then that source must be regarded as suspect.

Too often, technical topics are treated in the media as identical to political debates. There is a value-based political component to any debate over public policy (1), but there are also facts about which reasonable people do not disagree. For example, the power used by a typical personal computer is a quantity that can be measured, and when someone makes claims that are at odds with measured data, then his credibility should suffer. In scientific debates, the process of validation with measured data occurs all of the time, but sometimes in public policy debates, validation is more elusive.

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