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Critical Thinking About Energy: The Case for Decentralized Generation of Electricity

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Highly centralized generation of electrical power is a paradigm that has outlived its usefulness. Decentralized generation could save $5 trillion in capital investment, reduce power costs by 40 percent, reduce vulnerabilities, and cut greenhouse gas emissions in half.

Electricity was originally generated at remote hydroelectric dams or by burning coal in the city centers, delivering electricity to nearby buildings and recycling the waste heat to make steam to heat the same buildings. Rural houses had no access to power. Over time, coal plants grew in size, facing pressure to locate far from population because of their pollution. Transmission wires carried the electricity many miles to users with a 10 to 15 percent loss, a difficult but tolerable situation. Because it is not practical to transmit waste heat over long distances, the heat was vented. There was no good technology available for clean, local generation, so the wasted heat was a tradeoff for cleaner air in the cities. Eventually a huge grid was developed and the power industry built all-new generation in remote areas, far from users. All plants were specially designed and built on site, creating economies of scale. It cost less per unit of generation to build large plants than to build smaller plants. These conditions prevailed from 1910 through 1960, and everyone in the power industry and government came to assume that remote, central generation was optimal, that it would deliver power at the lowest cost versus other alternatives.

However, technology has improved and natural gas distribution now blankets the country. By 1970, mass-produced engines and turbines cost less per unit of capacity than large plants, and the emissions have been steadily reduced. These smaller engines and gas turbines are good neighbors, and can be located next to users in the middle of population centers. Furthermore, the previously wasted heat can be recycled from these decentralized generation plants to displace boiler fuel and essentially cut the fuel for electric generation in half, compared to remote or central generation of the same power.

But the industry had ossified. Electric monopolies were allowed to charge rates to give a fair return on capital employed. To prevent excessive or monopoly profits, the utilities have long been required to pass 100 percent of any gain in efficiency to the users. This leaves utilities with no financial incentive to adopt new technologies and build decentralized generation that recycles heat. In fact, such local generation erodes the rationale for continued monopoly protection—if one can make cheap power at every factory or high rise apartment house, why should society limit competition?

Congress tried to open competition a little bit in 1978, and some independent power companies began to develop on-site generation wherever they could find ways around the monopoly regulation. One author (Casten) was one of those early pioneers, working to develop more efficient decentralized generation since 1975. This article summarizes extensive research into the economically optimal way to build new power generation in each of the past 30 years, given then available technology, capital costs, and fuel prices, and concludes that the continuing near-universal acceptance of the "central generation paradigm" is wrong. The result is a skeptical look at the world's largest industry—the electric power industry—with surprising conclusions.

Power industry regulations largely derive from the unquestioned belief that central generation is optimal. However we believe the conventional "central generation paradigm" is based on last century's technology. Meeting the world's growing appetite for electric power with conventional central generation will severely tax capital markets, fossil fuel markets, and the global environment. The International Energy Agency's (IEA) 2002 World Energy Outlook Reference Case—based on present policies—presents a frightening view of the next thirty years. [1] The Reference Case says world energy demand will grow by two-thirds, with fossil fuels meeting 90 percent of the increase. World electrical demand doubles, requiring construction of nearly 5,000 gigawatts of new generating capacity, equivalent to adding six times current United States electric generating capacity. The generation alone will cost $4.2 trillion, plus transmission and distribution (T&D) costs of $6.6 trillion (2004 U.S. dollars). Under this projection, global carbon dioxide emissions increase by 70 percent; see figure 1.

The Reference Case assumes that the energy policies of each government in 2002 continue without change, a modest evolution of technology, and continued reliance on central generation of electric power, which is consistent with most existing policies and regulations. The IEA projections assume that central generation is the optimal approach, given today's technology.

The IEA report is silent on the need for (or capital cost of) new T&D, even though existing T&D is far from adequate. There were 105 reported grid failures in the U.S. between 2000 and 2003, and eleven of those outages affected more than a half million people. [2] U.S. consumers paid $272 billion for electricity in 2003, [3] plus power outage costs, estimated between $80 billion and $123 billion per year. Outages thus add 29 percent to 45 percent to the cost of U.S. power. [4] The T&D situation is worse in developing countries, where 1.6 billion people lack any access to electric power and many others are limited to a few hours of service per day. Satisfying expected load growth with central generation will clearly require at least comparable construction of T&D capacity.

Close examination of past power industry options and choices suggests that load growth can be met with just over half the fossil fuel and pollution associated with conventional central generation. *We had better get this world energy expansion right*. Consider these points:

- The power industry has not deployed optimal technology over the past thirty years.
- The universally accepted "Central Generation Paradigm" prevents optimal energy decisions.
- Decentralized generation (DG), using the same technologies used by remote central generation, significantly improves every key outcome from power generation.
- Meeting global load growth with decentralized energy can save $5 trillion of capital, lower the cost of incremental power by 35—40 percent, and reduce CO_2 emissions by 50 percent versus the IEA central generation dominated reference case.

A Brief History of Electric Generation

Figure 2 shows that United States net electric efficiency peaked in about 1910, when nearly all generation was located near users and recycled waste heat. That efficiency dropped to 33 percent over the next fifty years as the power industry moved to electric-only central generation. Industry efficiency has not improved in four decades. Technology improved, enabling conversion of fuel to electricity to rise from 7 percent at commercial inception to 33 percent by 1960. The best electric-only technology now converts more than 50 percent of the fuel to power, but the industry's average efficiency has not improved in forty-three years. No other industry wastes two-thirds of its raw material; no other industry has stagnant efficiency; no other industry gets less productivity per unit output in 2004 than it did in 1904.

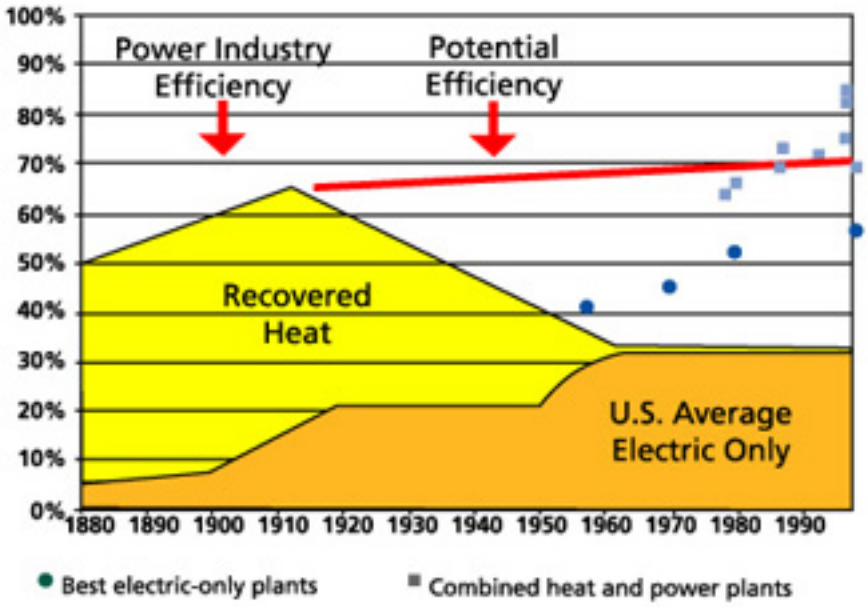

Figure 2. U.S. electricity generating efficiency, 1880 to present.

Early generating technology converted 7 percent to 20 percent of the fuel to electricity, making electric-only production quite expensive. To reduce fuel costs, energy entrepreneurs, including Thomas Edison, built generating plants near thermal users and recycled waste heat, increasing net electric efficiency to as much as 75 percent. A second wave of technical progress after World War II drove electric-only efficiencies to 33 percent (after distribution losses) and increased individual plant size to between 500 and 1,000 megawatts. Central or remote generation of electricity only, while still wasting two-thirds of the input energy, became the standard. Buttressed by monopoly protection, utilities fought competing on-site generation and, by 1970, replaced all but 3 to 4 percent of local generation, ending waste heat recycling. Government regulations, developed over the first 90 years of commercial electricity, institutionalized central generation.

The third wave of technical progress should have reversed the central generation trend. Modern power plants emit only 1 to 2 percent as much nitrogen oxides as 1970 plants, come in all sizes, burn all fuels, and are good neighbors. Many technical advances make local or distributed generation technically and economically feasible and enable society to return to energy recycling, displacing boiler fuel and doubling net electric efficiency. However, protected from competition and rewarded by obsolete rules, the power industry continues to build remote plants and ignores opportunities to recycle energy.

The squares in figure 2 represent the alternative to central or remote generation. These are actual plants employing central plant generation technologies that are located near users. These combined heat and power (CHP) plants deploy the best modern electric-only technology and achieve 65 percent to 97 percent net electrical efficiency by recycling normally wasted heat and by avoiding transmission and distribution losses. United States Energy Information Agency (EIA) records show 931 distributed generation plants with 72,800 megawatts of capacity, about 8.1 percent of U.S. generation. These plants demonstrate the technical and economic feasibility of doubling U.S. electricity efficiency.

Nevertheless, the U.S. and world power industry ignores—and indeed actively fights against—distributed generation. Conventional central generation plants dump two-thirds of their energy into lakes, rivers, and cooling towers, while factories and commercial facilities burn more fuel to produce the heat just thrown away. We believe the power industry has not made wise or efficient choices, and set out to test this thesis with data.

A Flawed Worldwide Heat & Power System

To determine whether the power industry made optimal choices, we analyzed EIA data on all 5,242 reported generation plants, separating plants built by firms with monopoly- protected territories and plants built by independent power producers. We calculated what price per KWh would be required for each of four central generation technologies, built in each year, to provide a fair return on capital. [5]

We also analyzed distributed generation (DG) technology choices. Several clarifications are necessary:

- Distributed generation is any electric generating plant located next to users.
- DG is not a new concept. Edison built his first commercial electric plant near Wall Street in lower Manhattan, and he recycled energy to heat surrounding buildings.

- DG plants employ all of the technologies that are used in central generation.
- DG plant capacities range from a few kilowatts to several hundred megawatts, depending on the users' needs. We have installed 40-kilowatt backpressure steam turbines in office buildings that recycle steam pressure drop, and managed a 200-megawatt coal-fired CHP plant serving Kodak's world headquarters in Rochester, New York.
- DG can use renewable energy, but not every renewable energy plant is DG. Solar photovoltaic panels on individual buildings or local windmills are distributed generation, while large hydro and wind farms are central generation requiring transmission and distribution (T&D).
- DG uses all fuels, including nuclear. Modern naval vessels generate power with nuclear reactors and then recycle waste heat to displace boiler fuel.

Power generated near users avoids the need for T&D. We have assumed each kilowatt of new DG will require net T&D investment equal to only 10 percent of a kilowatt, for backup services. [6] We assume DG plants require a 50 percent higher average cost of capital (12 percent versus 8 percent) due to risks and transaction costs. Industrial companies that install DG see power generation as a non-core activity and demand 35 percent to 50 percent rates of return, but this analysis focuses only on power companies' cost of capital.

Figure 3 depicts our findings. The line with asterisks shows the average price of power to all U.S. consumers in each year. The dashed lines show the retail price per megawatt-hour needed to fully fund new plants using four power generation technologies built as central stations, unable to recycle waste heat. (Note: Move the decimal one number left in price per megawatt-hour to equal cents per kilowatt-hour. For example, $65 per MWh is 6.5 cents per kWh.) The four highest solid lines show the retail prices per megawatt-hour needed to fully pay for power from the same technologies built near thermal users to recycle waste heat. The two lowest solid lines depict retail prices per MWh needed for power generated with recycled industrial process heat or flare gas, and power extracted from gas or steam pressure drop.

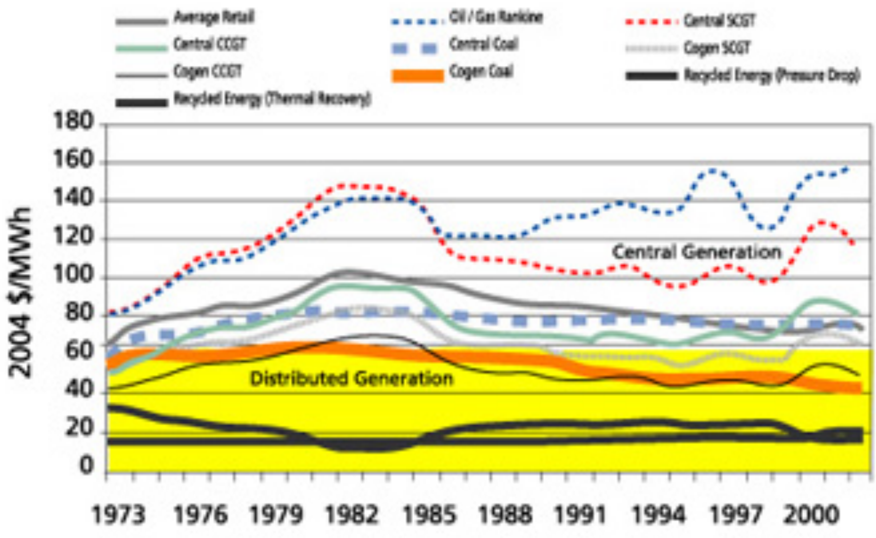

Figure 3. Long-term U.S. marginal cost of electronic generation options.

Thermal plants generate steam by burning fossil fuel in boilers. The steam then drives condensing steam turbines. Thermal generation technology matured in the mid-fifties, achieving maximum electric-only efficiency of 38 percent to 40 percent, before line losses. Over the entire period, new central oil and gas thermal plants (top dashed line) required prices well above average retail. Gas turbines use a different cycle; the technology improved dramatically over the period. Simple cycle gas turbine plants (dashed line) required similar prices to gas-fired thermal plants until 1985—90, when improving turbine efficiency reduced fuel and lowered required prices. New coal plants (dashed black line) could sell power for below average retail prices each year until 1998. However, environmental rules blocked coal plants in many states.

Combined cycle gas turbine plants (CCGTs) are the same gas turbines described above, but the plants also make steam with the turbine exhaust to drive a second power generation cycle—a condensing steam turbine. The first commercial applications of CCGTs were in 1974. These plants cost less to build than an oil and gas thermal plant and initially achieved 40 percent efficiency, which rose to 55 percent by 1995.

Distributed Generation Recycles Energy to Reduce Costs

The solid lines show retail prices required for distributed generation or DG—building the same technologies near thermal users and recycling normally wasted heat. The solid lines demonstrate the economic value of recycling energy. Burning coal in combined heat and power plants (solid black line) saves $11 to $27 per MWh versus burning coal in new central plants. Simple cycle gas turbine plants built near users (solid line) save $25 to $60 per MWh versus the same technology producing only electricity. Building combined cycle gas turbine plants near users and recycling waste heat saves even more money, reducing required costs by $25 per MWh versus the same technology built remote from users.

The lowest-cost power avoids burning any extra fossil fuel by recycling waste energy from process industries. Process industries use fossil fuel or electricity to transform raw materials and then discard energy in three forms including hot exhaust gas, flare gas, and pressure drop. Local “bottoming cycle” generation can recycle this waste into heat and/or power. The two lowest solid lines show the retail price per megawatt-hour needed for power recycled from waste heat, flare gas, and gas or steam pressure drop after credit for displacing boiler fuel with the recovered heat. These energy-recycling plants can earn fair returns on capital selling retail power at only 25 to 50 percent of average retail prices.

Power Industry Choices for New Capacity

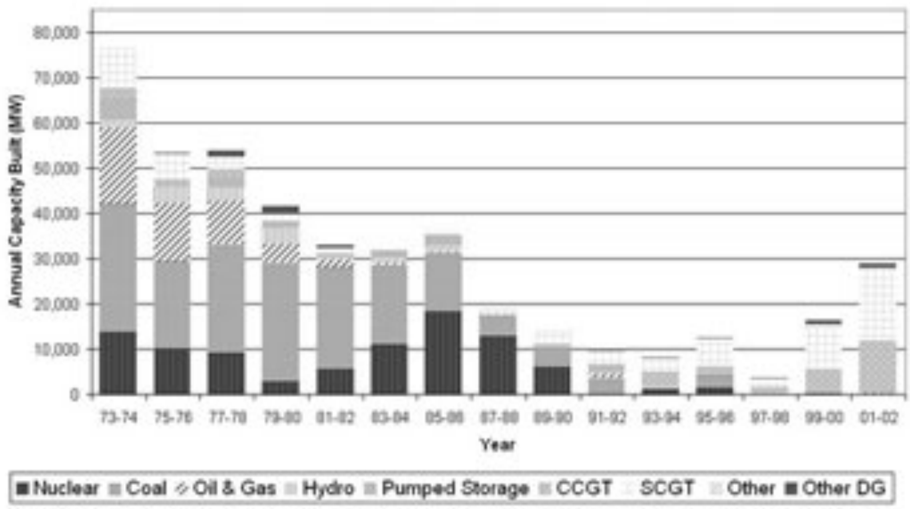

Figure 4. Annual U.S. utility additions of electricity generating capacity by technology, 1973-2002.

An ideal approach would build all possible plants requiring the lowest retail price per megawatt-hour first and then build plants with the next lowest needed retail price, etc.

To determine whether the electric power industry made optimal choices, we analyzed all power plants built since 1973. The new generation built in each two-year period by monopolies, which we defined as any utility with a protected distribution territory, is seen in figure 4. Monopoly utilities include investor-owned utilities, cooperatives, municipal utilities, and state and federally owned utilities. They collectively built 435,000 megawatts of new generation, but ignored energy recycling, even though it was always the cheapest option. They continued to build oil and gas thermal plants long after CCGT plants were a cheaper central option. Monopoly utilities were slow to make optimal choices among central plant technologies and completely ignored the more cost-effective distributed use of the same technologies.

Figure 5 shows the 175,000 MW of new generation built by independent power producers (IPP's) since 1973. Most new IPP plants were distributed generation and/or combined cycle plants until the last four years. The price spikes of 1998—2000 apparently induced IPP companies to install simple cycle gas turbines for peaking. Prior to 1978 passage of the Public Utility Policy Regulatory Policy Act (PURPA) it was illegal to build generation as a third party. Between 1978 and the law change in 1992, IPPs were allowed to build qualifying facilities—those that recycled at least 10 percent of the fuel's energy for heat use, or utilized certain waste fuels. After 1992, IPPs could legally build remote electric-only generation plants.

For another view of industry choices, we divided plants built since 1973 into those recycling and not recycling energy. Generating plants that recycle energy must be near thermal users or near sources of industrial waste energy. Figure 6 shows that only 1.2 percent or 5,000 of the 435,000 megawatts of new generation built by monopolies over the thirty-year period recycled energy. We doubt that these choices would be profitable in a competitive marketplace.

Independent power producers built 34 percent of their total capacity as DG plants, at or near users. Figure 7 depicts the mix of central and distributed power built by IPPs since 1978.

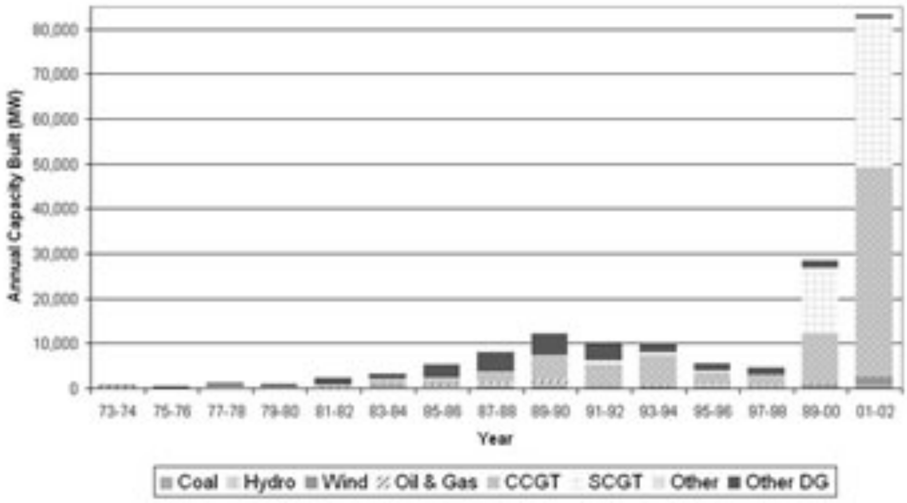

Figure 5. Total U.S. independent power producers utility additions of electronic generating capacity by technology, 1973-2002.

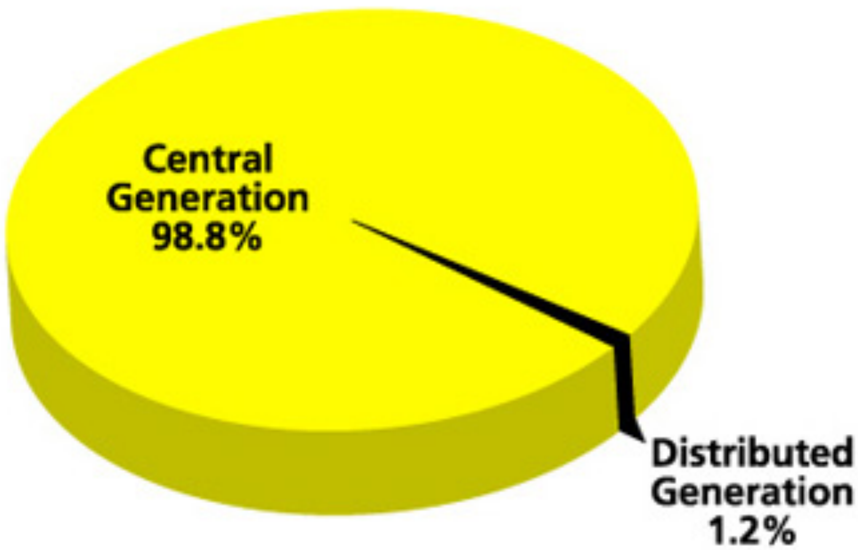

Figure 6. Total generation capacity built by U.S. electric utilities, 1973-2002.

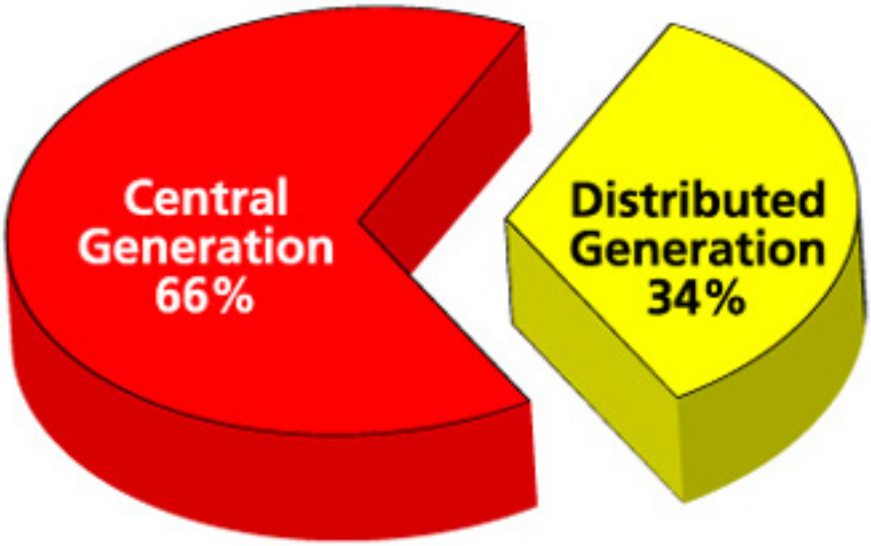

Figure 7. Generation capacity built by U.S. electric IPPs, 1973-2002.

Finally, we estimated the potential generation from the least-cost options—those plants that recycle industrial process waste energy. EPA aerometric data and other industry analyses suggest that U.S. industrial waste energy would power 40,000 to 100,000 megawatts with no incremental fossil fuel and no incremental pollution. [7] However, EIA plant data show only 2,200 megawatts of recycled industrial energy capacity, 2.2 percent to 5 percent of the potential. [8]

It seems clear that the power industry has made poor choices that have increased cost and decreased efficiency. These data show that utilities eschewed least-cost generating technologies, effectively increasing prices to all customers.

Meeting Expected U.S. Load Growth with Local Generation

Our colleagues built a model to determine the best way to satisfy projected load growth for any nation over the next two decades. [9] The model incorporates relevant factors for central and distributed electric generation technologies, including projected improvements in cost, efficiency, and availability of each technology. The model assumes new central generation will require 100 percent new transmission and distribution and new decentralized generation will require new T&D equal to 10 percent of added generating capacity. The model assumes 9 percent line losses for central power, equal to U.S. losses for 2002, and 2 percent net line losses for DG power.

Although the future surely includes some mix of central and decentralized generation, the model calculates the extreme cases of meeting all load growth with central generation, or meeting all growth with decentralized generation. Local generation that recycles energy improves every important outcome versus full reliance on central generation. Figure 8 compares the extreme cases. Full reliance on DG for expected U.S. load growth would avoid $326 billion in capital by 2020, reduce incremental power costs by $53 billion, NOx by 58 percent, and SO2 by 94 percent. Full DG lowers carbon dioxide emissions by 49 percent versus total reliance on new central generation.

Extrapolating U.S. Analysis to the World

We lack the data to run the U.S. model for the world, but have taken the percentage savings to be directionally correct and applied them to the IEA load growth projections through 2030. Detailed analysis by others will undoubtedly refine the estimates, and there will be some mix of central and decentralized generation. The analysis shows the extreme cases to provide guidance.

Figure 9 shows expected world load growth with conventional central plants that convert 100 units of fuel into 67 units of wasted energy and 33 units of delivered power. The text at the bottom reflects IEA's projected capital cost for 4,800 gigawatts of new generation, totaling $4.2 trillion. The International Energy Agency was silent on T&D, so we used estimates made for the United States Department of Energy on the all-in cost per kW of new transmission to forecast $6.6 trillion cost for new wires and transformers. Assuming U.S. average line losses (which are significantly lower than developing country line losses), 9 percent of the capacity will be lost, leaving 4,368 gigawatts delivered to users. To achieve the IEA Reference Case with central generation, the world must invest $10.8 trillion capital, roughly $2,500 per kW of delivered capacity.

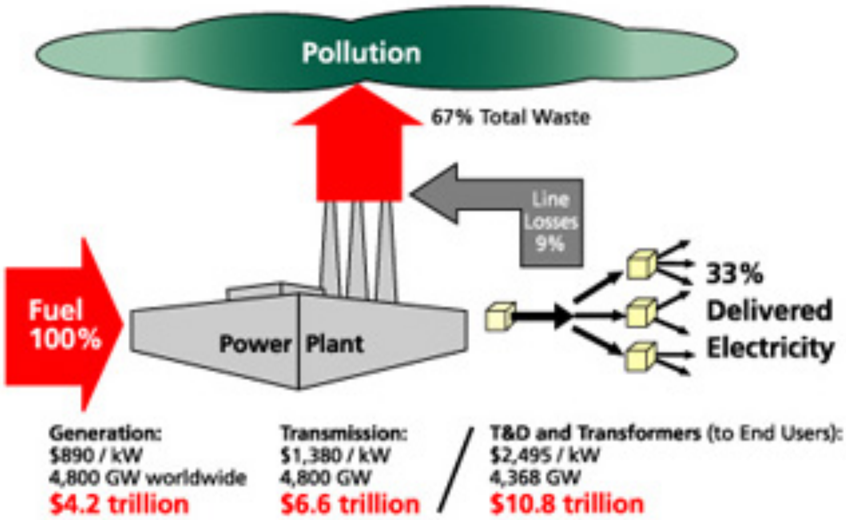

Figure 9. Conventional central generation flowchart.

Meeting IEA Reference Case load growth with decentralized generation will lower the need for redundant generation. An analysis by the Carnegie Mellon Electric Industry Center suggests building only 78 percent of the 4,800 gigawatts as DG would provide equal or better reliability. [10] However, in developing economies, reliability may not be the driver. To be conservative, we have ignored the potential reduction in generation due to increased reliability inherent in larger numbers of smaller plants in the DG case. However, we did reduce required generation for the DG case to 4,368 GW, since there are no net line losses.

Figure 10 depicts the process of meeting expected world load growth with distributed generation. We estimated average capital costs for decentralized generation of $1,200 per kW, $310 more capital cost than a kilowatt of new central generation. Even with 9 percent less DG capacity, the capital costs for generation increase to $5.2 trillion, $1.0 trillion more than building central plants. Looking only at generation costs, DG is not competitive. However, the full decentralized generation case requires only 430 GW of new T&D, costing $0.6 trillion, a $6 trillion savings on T&D. *End users receive 4,638 GW in both cases, but society invests $5 trillion less for the DG case.*

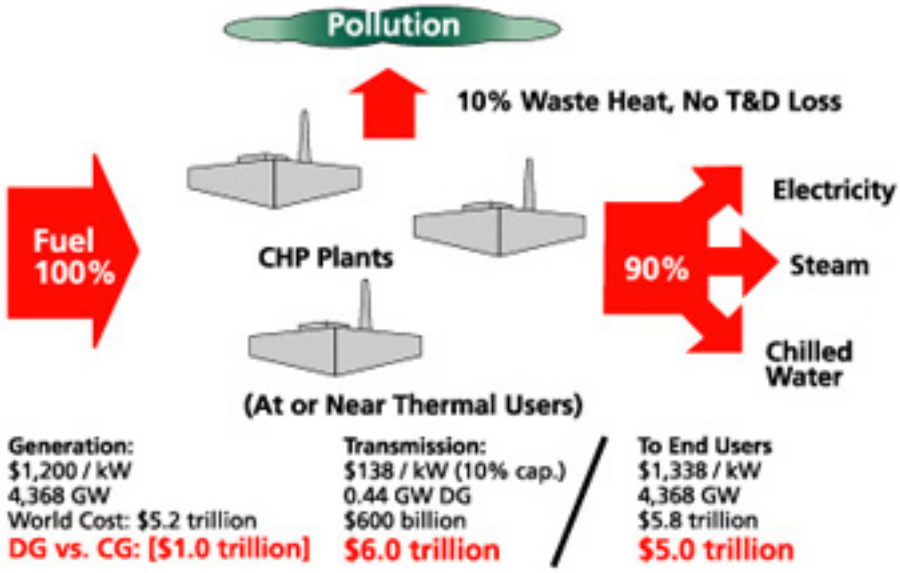

Figure 10. Combined heat and power flowchart.

Everyone knows that "you get what you pay for." What does the world give up by selecting a $5 trillion cheaper approach to meet projected electric growth? We extrapolated U.S. analysis to the IEA Reference Case and found the world would give up the following by adopting the cheaper DG case:

- Consume 122 billion fewer barrels of oil equivalent (half of known Saudi oil reserves)
- Lost fossil fuel sales of $2.8 trillion
- Lost medical revenues from air pollution-related illnesses
- Potentially lost savings if governments opt to supply electric services to entire population instead of leaving 1.4 billion people without electric access
- Less global warming due to 50 percent less CO2 emissions.

Recommended Actions

If this analysis survives critical review, then what policy reforms will steer the power industry toward optimal decisions, given available technology? We offer two potential approaches, hoping to start the policy debate.

Comprehensive Reform

Governments guide the electric industry with many rules, mandates, and limitations that collectively block competition and innovation, thus causing excessive costs and fuel usage. Small regulatory changes may nudge the power industry to slight course corrections, but are unlikely to break the central generation paradigm and optimize generation.

Immediately eliminating all current barriers to efficiency would cause the electric power industry to make better decisions. Each government could examine every rule that affects power generation and delivery and ask whether the social purpose behind that rule still exists. Then each state or country could enact comprehensive legislation that we term the Energy Regulatory Reform and Tax Act (ERRATA), to correct all of the mistakes in current law. ERRATA would deregulate all electric generation and sales, modernize environmental regulations to induce efficiency, and change taxation to reward efficiency. [11] Sadly, ERRATA legislation probably will not pass except in response to deepening environmental and economic pain.

Actionable Reform, National Fossil Fuel Efficiency Standards

A second possible approach simply rewards all fossil efficient power and penalizes fossil inefficient power. Each government could enact a Fossil Fuel Efficiency Standard covering all locally used electricity, regardless of origin. This standard does not favor fuels, technologies, or participants. Here are the essential elements:

- Give all delivered megawatt-hours an equal allowance of incremental fossil fuel, regardless of age of plant, technology or ownership. Start with the national average fossil fuel per MWh for the prior year.
- Spread allowances over all generation of each owner, allowing owners to comply by increasing efficiency of existing plants, deploying new highly efficient plants, or purchasing fossil allowances from others.
- Reward plants requiring little or no fossil fuel, such as solar, wind, hydro, nuclear, and industrial waste energy recycling, by allowing them to sell fossil fuel credits. [12]
- Penalize fossil inefficient plants by forcing them to purchase allowances for each MWh produced.
- Base allowances on delivered power to incorporate T&D losses from central generation.
- Credit displaced fuel to CHP plants that recycle heat.
- Force all generators to purchase adequate allowances or close their plants to ensure that the total allowance trading is economically neutral.
- Reduce the fossil fuel allowances per MWh each year according to a schedule.
- Adjust the schedule downward each year to correct for growth in total power delivered, guaranteeing that the total fossil fuel use will drop.

A Fossil Fuel Efficiency Standard would steer the power industry toward optimal choices. This will reduce power costs and emissions, which will improve local standard of living and improve the competitive position of local industry. Other states and nations will follow suit.

Conclusion

We have attempted to frame the consequences of meeting energy load growth with conventional central generation or deploying decentralized generation that recycles waste energy. The DG case saves the world $5 trillion in capital investment while reducing power costs by 40 percent and cutting greenhouse gas emissions in half. There are interesting implications for worldwide energy policy if this analysis stands up to critical review.

We hope readers and others will spell out concerns or suggest corrections so we can collectively improve the analysis of optimal future power generation. The needed policy changes are deep and fundamental and require a consensus about the best way to proceed. Together we might be able to change the way the world makes heat and power.

Notes

1. The IEA has issued an annual "World Energy Outlook" series since 1993. The publication projects many facets of the energy industry thirty years ahead. The projections are based on a "Reference Scenario that takes into account only those government policies and measures that had been adopted by mid-2002. A separate Alternative Scenario assesses the impact of a range of new energy and environmental policies that the OECD countries are considering."
2. *Energy Information Administration/Electric Power Monthly*, May 2004.
3. *Energy Information Administration/Monthly Energy Review*, June 2004.
4. Joseph Eto, of the Lawrence Berkeley National Laboratory, in a speech to NARUC, says outages cost the U.S. $80 billion per year. The EPRI Consortium for Electric Infrastructure to Support a Digital Society (CEIDS), *The Cost of Power Disturbances to Industrial & Digital Economy Companies,* June 2001, states power outages and other power quality disturbances are costing the U.S. economy more than $119 annually.
5. We assembled historical data for four central generating

technologies—oil and gas-fired thermal plants (Rankine cycle), coal fired thermal plants, simple-cycle and combined-cycle gas turbines. Data for each technology and each year include capital costs per kW, load factor, and efficiency. We assumed a 25-year life to calculate annual capital amortization and the future wholesale price per MWh that would yield an 8 percent weighted average return on capital. Since new central generation requires new T&D, we converted estimates of $1260 per kW for T&D in 2000 and adjusted for inflation, then assumed a 35-year life for T&D to calculate required T&D charges. EIA did not keep line loss statistics prior to 1989, so we estimated prior years slightly below the current 9 percent losses. Summing produces the retail price needed for power from a central plant using a specific technology installed in that specific year. Finally, we converted everything to 2004 dollars.

6. Typical DG plants employ multiple generators with expected unplanned outages of 2 percent to 3 percent each. The probability of complete loss of power is found by multiplying expected unit unplanned outages by each other. Given the existing 10,286 generators operating in the U.S. that are less than 20 megawatts of capacity, and the expectation, with barriers removed, of many DG plants inside every distribution network, spare grid capacity equal to 10 percent of installed DG should be more than adequate to cover unplanned outages.

7. *Recycled Energy: An Untapped Resource*, Casten and Collins, 2002; see www.primaryenergy.com.

8. Energy Information Administration, *Annual Energy Review* 2002, October 2003.

9. The "Optimizing Heat and Power" model has been adopted by the World Alliance for Decentralized Energy (WADE) and is being used by the European Union, Thailand, Nigeria, Canada, Ireland, and China to ask the best way to satisfy expected load growth. For model descriptions, contact Michael Brown, Director, atinfo@localpower.org.

10. Hisham Zerriffi. Personal communication. See *Distributed Resources and Micro-grids*by M. Granger Morgan of the Department of Engineering and Public Policy, Carnegie Mellon University, Sept. 25, 2003, for detailed analysis of how DG provides reliability with less spare capacity.

11. See Casten, Thomas R. *Turning Off The Heat* 1998, Prometheus Books, chapter 10 for a more complete description of ERRATA.

12. Producers of electricity are given fossil fuel usage credits, meaning they are allowed to use a given amount of fossil fuels corresponding to efficiency, size of unit and other environmental parameters. Thus, the higher the efficiency of a company's unit, the less fossil fuel credits that company needs to use. The highly efficient plants and generation plants using a non-fossil fuel energy such as solar, wind, or hydro power would not need the full allowance and could sell the unused portion to less efficient fossil fueled plants. Such a system would provide added economic value to the efficient and non-fossil fueled plants and economic penalties to the inefficient fossil fueled plants.

Glossary of Abbreviations and Acronyms

- CCGT—refers to a power plant that utilizes both the Brayton (gas-turbine) cycle and the Rankine (steam) cycle. The exhaust from the gas turbine is used to generate the energy for the Rankine cycle.
- CHP—the simultaneous and high-efficiency production of heat and electrical power in a single process.
- CO2—a gas produced by many organic processes, including human respiration and the decay or combustion of animal and vegetable matter.
- DG—a system in which electrical power is produced and distributed locally near users, largely avoiding T&D.
- DOE—the federal agency that oversees the production and distribution of electricity and other forms of energy.
- EIA—the statistical and data-gathering arm of the Department of Energy.
- EPA—the agency that oversees and regulates the impact of, among other things, the production of energy on the environment of the United States.
- ERRATA—a plan to deregulate the production and distribution of electricity, to update environmental laws regarding energy production, and to alter the existing tax structures.
- GW—one billion watts.
- GWh—the amount of energy available from one gigawatt in one hour.
- IEA—a twenty-six member union of national governments with the goal of securing global power supplies.
- IPP—companies that generate electrical power and provide it wholesale to the power market. IPPs own and operate their stations as non-utilities and do not own the transmission lines.
- KW—1,000 watts (one watt being the amount of power necessary to move

one kilogram one meter in one second).

- KWh—the amount of energy available from one kilowatt in one hour.
- MW—one million watts.
- MWh—the amount of energy available from one megawatt in one hour.
- NOX—assorted oxides of nitrogen, generally considered pollutants, that are commonly produced by combustion reactions.
- PM10 in the atmosphere that is between 2.5 and 10 micrometers in size.
- PURPA—an act of Congress that was intended to reduce American dependence on foreign oil through the encouragement of the development of alternative energy sources and the diversification of the power industry.
- T&D—the means by which electricity travels from the generating plant(s) to its end users.

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Brennan Downes is a project engineer at Primary Energy. Casten adapted this article from his keynote address to the International Association for Energy Economics in Washington, D.C., July 10, 2004. A somewhat different version as been published in the IAEE's journal *The Dialogue*.