Executive Summary

This book describes 207 ways in which the size of "electrical resources"—devices that make, save, or store electricity—affects their economic value. It finds that properly considering the economic benefits of "distributed" (decentralized) electrical resources typically raises their value by a large factor, often approximately tenfold, by improving system planning, utility construction and operation (especially of the grid), and service quality, and by avoiding societal costs.

The *actual* increase in value, of course, depends strongly on the case-by-case technology, site, and timing. These factors are so complex that the distribution of value increases across the universe of potential applications is unknown. However, in many if not most cases, the increase in value should change investment decisions. For example, it should normally far exceed the cost differences between, say, modern natural-gas-fired power plants and windfarms. In many applications it could even make grid-interactive photovoltaics (solar cells) cost-effective today. It should therefore change how distributed resources are marketed and used, and it reveals policy and business opportunities to make these huge benefits explicit in the marketplace.

The electricity industry is in the midst of profound and comprehensive change, including a return to the local and neighborhood scale in which the industry's early history is rooted. Through the twentieth century, thermal (steam-raising) power stations evolved from local combined-heat-and-power plants serving neighborhoods to huge, remote, electricity-only generators serving whole regions. Elaborate technical and social systems commanded the flow of electrons from central stations to dispersed users and the reverse flow of money to pay for power stations, fuel, and grid. This architecture made sense in the early twentieth century when power stations were more expensive and less reliable than the grid, so they had to be combined via the grid to ensure reliable and economical supply. The grid also melded the diverse loads of many customers, shared the costly generating capacity, and made big and urban customers subsidize extension of electric service to rural customers.

By the start of the twenty-first century, however, virtually everyone in industrialized countries had electric service, and the basic assumptions underpinning the big-station logic had reversed. Central thermal power plants could no longer deliver competitively cheap and reliable electricity through the grid, because the plants had come to cost *less* than the grid and had become so reliable that nearly all power failures originated *in* the grid. Thus the grid linking central stations to remote customers had become the main driver of those customers' power costs and power-quality problems—which became more acute as digital equipment required extremely reliable electricity. The cheapest, most reliable power, therefore, was that which was produced at or near the customers.

Utilities' traditional focus on a few genuine economies of scale (the bigger, the less investment per kW) overlooked larger *dis*economies of scale in the power stations, the grid, the way both are run, and the architecture of the entire system. The narrow vision that bigger is better ended up raising the costs and financial risks that it was meant to reduce. The resulting disadvantages are rooted in an enormous difference of scale between most needs and most supplies. Three-fourths of U.S. residential and commercial customers use electricity at an average rate that does not exceed 1.5 and 12 kilowatts respectively, whereas a single conventional central power plant produces about a million kilowatts. Resources better matched to the kilowatt scale of most customers' needs, or to the tens-of-thousands-of-kilowatts scale of typical distribution substations, or to an intermediate "microgrid" scale, thus became able to offer important but little-known economic advantages over the giant plants.

The capital markets have gradually come to realize this. Central thermal power plants stopped getting more efficient in the 1960s, bigger in the '70s, cheaper in the '80s, and bought in the '90s. Smaller units offered greater economies from mass-production than big ones could gain through unit size. In the '90s, the cost differences between giant nuclear plants—the last gasp of '70s and '80s gigantism—and railcar-deliverable combined-cycle gas-fired plants, derived from mass-produced aircraft engines, created political stresses that drove the restructuring of the industry. At the same time, new kinds of "micropower" generators thousands or tens of thousands of times smaller—microturbines, solar cells, fuel cells, wind turbines—started to become serious competitors, often enabled by information and telecommunications technologies. The restructured industry exposed the previously sheltered power-plant builders to brutal market discipline. Competition from micropower, uncertain demand, and the inflexibility of big, slow-to-build plants created financial risk well beyond the capital markets' appetite. Then in 2001, longstanding concerns about the inherent vulnerability of giant plants and the far-flung grid were reinforced by the 9/11 terrorist attacks.

The disappointing cost, efficiency, financial risk, and reliability of large thermal stations (and their associated grid investments) were leading their orders to collapse even before the cost difference between nuclear and combined-cycle costs stimulated restructuring that began to delaminate utilities. That restructuring created new market entrants, unbundled prices, and increased opportunities for competition at all scales—and thus launched the revolution in which swarms of microgenerators began to displace the behemoths. Already, distributed resources and the markets that let them compete have shifted most new generating units in competitive market economies from the million-kilowatt scale of the 1980s to the hundredfold-smaller scale that prevailed in the 1940s. Even more radical decentralization, all the way to customers' kilowatt scale (prevalent in and before the 1920s), is rapidly emerging and may prove even more beneficial, especially if it comes to rely on widely distributed microelectronic intelligence. Distributed generators do not require restructured electricity markets, and do not imply any particular scale for electricity business enterprises, but they are starting to drive the evolution of both.

Some distributed technologies like solar cells and fuel cells are still made in low volume and can therefore cost more than competing sources. But such distributed sources' increased *value*—due to improvements in financial risk, engineering flexibility, security, environmental quality, and other important attributes—can often more than offset their apparent cost disadvantage. This book introduces engineering and financial practitioners, business managers and strategists, public policymakers, designers, and interested citizens to those new value opportunities. It also provides a basic introduction to key concepts from such disciplines as electrical engineering, power system planning, and financial economics. Its examples are mainly U.S.-based, but its scope is global.

A handful of pioneering utilities and industries confirmed in the 1990s that distributed benefits are commercially valuable—so valuable that since the mid-'90s, most of the best conceptual analyses and field data have become proprietary, and government efforts to publish methods and examples of distributed-benefit valuation have been largely disbanded. Most published analyses and models, too, cover only small subsets of the issues. This study therefore seeks to provide the first full and systematic, if preliminary, public synthesis of how making electrical resources the right size can minimize their costs and risks. Its main findings are:

- The most valuable distributed benefits typically flow from financial economics—the lower risk of smaller modules with shorter lead times, portability, and low or no fuel-price volatility. These benefits often raise value by most of an order of magnitude (factor of ten) for renewables, and by about 3–5-fold for nonrenewables.
- Electrical-engineering benefits—lower grid costs and losses, better fault management, reactive support, etc.—usually provide another ~2–3-fold value gain, but more if the distribution grid is congested or if premium power quality or reliability are required.
- Many miscellaneous benefits may together increase value by another ~2-fold—more where waste heat can be reused.
- Externalities, though hard to quantify, may be politically decisive, and some are monetized.
- Capturing distributed benefits requires astute business strategy and reformed public policy.

Emerging electricity market structures can now provide the incentives, the measurement and validation, and the disciplinary perspectives needed to give distributed benefits a market voice. Successful competitors will reflect those benefits in investment decisions and prices. Nearly a dozen other technological, conceptual, and institutional forces are also driving a rapid shift toward the "distributed utility," where power generation migrates from remote plants to customers' back yards, basements, rooftops, and driveways. This transformation promises a vibrantly competitive, resilient, and lucrative electricity sector, at less cost to customers and to the earth—thus fulfilling Thomas Edison's original decentralized vision, just a century late.