Many Americans believe the country is moving toward a “digital society” that entails increased use of the Internet and other information and communications technologies (ICTs) in their daily lives. While it is widely accepted that ICTs will have a profound effect on individuals and organizations over the next two decades, there is little agreement about what those changes imply in terms of electricity and other energy needs. Would a dramatic shift to an electronic marketplace along with “ultra-wired” households, schools, and workplaces sharply increase electricity use?

Our study examined the potential impact of expanded ICT use on electricity consumption and system capability in the United States. We conclude that even large growth in the deployment and use of digital technologies will only modestly increase electricity consumption in the United States over the next two decades. The more pressing concern for an emerging digital society will be meeting increased need for higher-quality and more-reliable power.

FOUR SCENARIOS FOR ASSESSING ICT IMPACT ON ELECTRICITY NEEDS

To create a framework for assessing the links between future ICT growth and electricity requirements, we built four scenarios describing different paths of ICT development through 2021. The scenarios differ primarily in two ways: the extent of ICT use at home and at work, and how society regulates or otherwise controls ICT use—i.e., in a centralized or decentralized manner. We chose the scenario approach because we believe changes in ICTs are happening too fast
and with too much turbulence to permit technology forecasting, mapping, or assessment over 20 years.

Our four ICT scenarios make different assumptions about levels of ICT ownership and use, the growth of e-commerce and other ICT applications, and the principal ICT-related issues society must deal with. In brief:

- **Reference scenario.** This scenario describes a relatively straightforward, “few surprises” extrapolation of current technology and application trends, leading to widespread societal use of ICTs and networked services, with an overall balance between centralized and decentralized control. Security, privacy, and other ICT-related problems persist, but U.S. society has achieved generally workable solutions for them.

- **Zaibatsu scenario.** In this scenario, large conglomerate corporations (known as Zaibatsu in Japan) own and operate the ICT (and electricity) infrastructures. They control e-commerce, ICT-intensive “intelligent transportation systems,” and most other ICT applications. ICT usage is even higher in this centralized scenario than in the Reference scenario, and although the Zaibatsu and the federal government exercise strong economic and social controls, most Americans accept the Zaibatsu for the security and stability they have brought to society.

- **Cybertopia scenario.** In this scenario, there is equally high use and trust of networked ICT as in Zaibatsu, but control of the technology is more distributed, to individuals as well as large and small organizations. Tens of billions of embedded ICT devices linked by wireless networks have been deployed for public and private applications. Economic markets and consumer preferences largely determine individual use of ICT products and services, with light government regulation and modest subsidies for low-income and other targeted groups.

- **Net Insecurity scenario.** This scenario is less optimistic than the others. Persistent, unresolved security problems reduce public trust in and use of networked ICT applications and services. Large businesses, government agencies, and individuals who can afford to do so rely on highly secured private networks for information, communications, and transactions. Others mostly avoid
interactive services and watch digital high-definition television displayed on large flat screens at home.

For each of these scenarios, we developed estimates of ICT-driven electricity use through 2021 and compared them with projections made by the U.S. Energy Information Administration (EIA) in its most recent Annual Energy Outlook (which we refer to as the AEO 2002).

The projections we made in this study consider three distinct kinds of ICT influence: (1) electricity consumption by ICT equipment, (2) changes in electricity use brought about by ICT-facilitated energy management systems (EMSs), and (3) implications for electricity usage of ICT-driven trends such as e-commerce and telework. Consumption by ICT equipment is the most direct and visible effect, but not necessarily the most important. Over time, ICT influences on energy management and on broader socioeconomic trends will likely have much more consequential effects on electricity and other energy use. However, they imply behavioral as well as technological changes and thus are much more difficult to estimate. This was a principal reason for developing several scenarios rather than making a single projection.

**GROWTH IN ICT USE WILL ONLY MODESTLY INCREASE TOTAL ELECTRICITY USE**

From the perspective of kilowatt-hours consumed, we found that very large increases in the number of digital devices over the next 20 years will have only modest effects on electricity demand. We looked for, but did not find, a set of plausible assumptions that might support another scenario, one with ICT networks, computers, and office equipment using 10 percent or more of the national electricity total by 2021. In none of our 2021 scenarios does this percentage exceed 5.5 percent.

All four of our scenarios show lower total power consumption in 2021 than was projected in the AEO 2002, ranging from 3 percent less in Net Insecurity to 11 percent less in Cybertopia. This difference stems principally from our baseline 2001 estimates for power use by computer, office, and network ICT equipment being more than 75 terawatt-hours (TWh), or 45 percent, below those in the AEO 2002.
The difference widens to more than 200 TWh when projected forward to 2021.

For 2021, our electricity use projections, compared to those extrapolated from the AEO 2002, are higher for the residential sector and lower for the commercial and industrial sectors. In our Reference scenario, the 2021 projected total for all three sectors is 4,630 TWh, which is 7 percent below the AEO 2002 projection. EMSs in buildings and telework are responsible for the greatest electricity savings, with digital industrial process controls and e-commerce also making substantial contributions.

Of the scenarios, Net Insecurity uses the most electricity, primarily because this scenario’s loss of trust in public networks results in lower power savings from EMSs, e-commerce, and telework. In contrast, Cybertopia’s much higher use of EMSs, e-commerce, and telework brings power savings that are 400 TWh (9 percent) greater than those of Net Insecurity and 570 TWh (11 percent) greater than those of the AEO 2002 projection. The relatively narrow range of 400 TWh between our lowest and highest projections for power use in 2021 reflects our analysis that ICT represents a factor of roughly 5 to 6 percent in explaining U.S. total electricity consumption. Of course, all these projections are rough estimates based on incomplete data and a large number of assumptions about how the future will unfold.

For the important category of computer, office, and network ICT equipment, the projections indicate relatively modest increases in power consumption over the 20-year period. Our 2001 estimate of 118 TWh represents 3.4 percent of total electricity use, which is far below some earlier estimates but consistent with recent data. Looking forward, greater power demands from larger numbers of more powerful digital devices will be moderated by greater use of more electricity-efficient components, low-power embedded devices, and wireless equipment and networks.

Our analysis also led to additional findings that appear robust across the scenarios:

- Telework and ICT-facilitated energy management can have large effects on electricity consumption;
• Expanded use of both digital process controls in manufacturing and business-to-business e-commerce brings power savings that while not as large as those for telework and EMS are more consistent among scenarios with quite different assumptions;

• Business-to-consumer e-commerce has smaller effects on overall electricity consumption;

• The power-saving effects of EMSs in the residential sector depend less on ICT advances than on consumers’ behavioral response to time-of-use or real-time pricing;

• Telework increases electricity consumption in the residential sector while lowering it in the commercial and industrial sectors, the net effect depending both on the number of teleworkers and the average number of days spent teleworking.

THE ELECTRICITY SYSTEM NEEDS TO FOCUS ON HIGHER POWER QUALITY AND RELIABILITY

In addition to making quantitative projections of electricity use, our analysis identified four important, cross-cutting energy supply issues:

• Assurance of power quality for very large numbers of digital devices;

• Use of ICT to improve grid reliability and operations;

• Use of ICT to support distributed generation and storage;

• Reduction of the vulnerability of the ICT and electricity infrastructures.

Previous debate has focused largely on the issue of how much electricity will be needed to power the Internet and related ICT equipment. Our analysis, however, concludes that meeting the increased demand for higher power quality and reliability (PQR) will be a more important issue for a digital society. We thus recommend that the Office of Energy Efficiency and Renewable Energy (EERE) explicitly include the goal of improving power quality in its strategic plan, as well as in appropriate R&D and technology programs.
A related conclusion: The electricity supply and distribution systems necessary to support a digital society will increasingly rely on power electronics and other ICT developments for improved power measurement, monitoring, and control. These ICT advances are essential to improving PQR for digital loads, increasing grid reliability, enabling the growth of distributed energy resources, and making electricity and ICT infrastructures more robust and resilient.

**POLICY IMPLICATIONS: EXPANDED USE OF R&D TO DEVELOP ICTs AND DEPLOY THEM IN THE ELECTRICITY SYSTEM**

EERE may need to pay greater attention to accelerating the development of ICTs and their deployment in the U.S. electric power system. Our scenarios emphasize the importance of bringing the results of R&D into commercial practice to support the increased future demands of digital loads, especially in the two high-ICT-use, Zaibatsu and Cybertopia scenarios. In-time deployment of ICT in the electricity infrastructure depends on R&D success in reducing costs as well as in increasing performance. While EERE supports a number of projects in these areas, most of the relevant R&D is industry funded and has been under financial pressure as the industry restructures. Electricity industry restructuring may well lead to underinvestment in R&D and infrastructure improvements, although we cannot conclude that such possible market failures will seriously constrain ICT growth.

We recommend that EERE assess the goals, schedules, obstacles, and likely outcomes of current government and industry R&D programs in such areas as

- Power electronics for transmission and distribution (T&D);
- Power sources for very small, wireless digital devices;
- Energy storage for high PQR applications;
- Self-healing microgrids and T&D networks.

If the analysis finds evidence for underinvestment, or for mismatches between likely availability and need, a good case can be made for
supporting additional R&D or providing incentives to deploy ICT in the electricity infrastructure.

Achieving EERE’s ambitious goals for distributed energy resources may also demand more attention to ICTs that can be used to monitor and control the interconnection of distributed generation and storage units. We again recommend that EERE assess industry and government R&D to ascertain whether current efforts are likely to be sufficient. We specifically see a need to simulate and then demonstrate the technical and economic feasibility of interconnecting large numbers of distributed generation units that can export power during peak periods. Our Reference and Cybertopia scenarios also show the importance of ICTs for supporting real-time or other efficient markets for power sales by distributed generation units.

The Net Insecurity scenario most directly shows the added burdens and losses caused by continued infrastructure vulnerability, but improved infrastructure protection is important in each of our scenarios. We recommend that EERE further explore how ICTs can support a larger role for distributed energy resources in reducing the vulnerability of the electricity infrastructure. Self-healing microgrids, secure communication links among distributed energy resources, and autonomous local agents for balancing electricity supply and demand—all of these deserve serious study and possibly increased R&D support. Given the increased national commitment to infrastructure protection and security since September 11, additional effort in this area could have a high payoff.

A digital society’s reliance on high PQR brings with it the need to better quantify and understand the dimensions of the so-called “digital load”—i.e., the portion of the electricity demand that, because it comes from ICT equipment and other applications, requires higher PQR than the electricity grid now provides. We subdivided the digital load into two components with different PQR requirements:

- The high PQR load, which includes most home and office computers, copiers, and other office equipment; digital television and audio systems; home networks; and the digital controls for growing numbers of networked sensors and appliances.
- The ultra-high PQR load, from network operators, financial service providers, e-commerce firms, semiconductor fabricators,
and other businesses relying on digital ICT equipment that must operate continuously without interruption.

At present, the data are insufficient for estimating either component of the digital load or for making sensible future projections. Consequently, we recommend that both EERE and EIA give high priority to efforts to collect such data and that they consider including estimates of the digital load as a separate category in the *Annual Energy Outlook*.

We also recommend that the focus of additional analysis to improve projections of ICT-driven electricity consumption be on how ICT influences energy management and broader societal changes, as well as on direct power use by digital equipment. Specific topics deserving further study include actual measurements of and projected trends for

- Telework in specific occupational categories and industry sub-sectors;
- Effects of telework on electricity consumption in the residential, commercial, and industrial sectors, and on vehicle fuel consumption;
- Electricity savings from introducing adjustable speed drives and other digital controls in manufacturing processes;
- Inventory reductions resulting from business-to-business e-commerce;
- Warehouse and other commercial space reductions resulting from business-to-consumer e-commerce;
- Vehicle fuel savings resulting from business-to-consumer e-commerce;
- Consumer behavioral responses to time-of-use or real-time pricing of electricity;
- Effects of electric and fuel cell vehicles, in terms of both purchases of electricity for vehicle use and sales of electricity generated by these vehicles for other uses.
Each of these factors can have a significant impact on power use over a 20-year period, so better ways to estimate their effects can lead to improved overall projections of future U.S. electricity consumption.

One final note: This study should be seen as an exploratory effort to create scenarios that illuminate potentially important ICT developments and to assess their implications for future electricity supply, demand, and delivery. Further research should consider additional driving factors, such as industry restructuring (in both electricity and ICT). It should also consider lower-probability, high-consequence events, such as widespread chip-to-brain implants in humans or the use of fuel-cell-powered vehicles as distributed generators of electricity when garaged or otherwise not in motion. Additionally, the ICT drivers could be melded more fully with demographic, cultural, and lifestyle variables to produce more-integrated future scenarios for both strategic planning and multiyear energy projections.