In this chapter, we project the implications of the information and communications technology (ICT) scenarios for electricity consumption in the United States over the next 20 years and compare our results with the forecasts made by the U.S. Energy Information Administration (EIA) in the AEO 2002 (Energy Information Administration, 2001). Our focus is on electricity use in the residential, commercial, and industrial sectors, because other sectors (notably, transportation) account for only a small percentage of current and projected electricity use.\(^1\) Appendix B presents the assumptions we used in generating these projections.

### 4.1 HOW ICT INFLUENCES ELECTRICITY AND OTHER ENERGY USE

ICTs have three distinct influences on the use of electricity and other energy:

- Direct consumption of electricity by ICT equipment;

\(^1\)We specifically do not include projections of net electricity consumption by electric or fuel-cell vehicles, primarily because we do not expect them to be significant purchasers or sellers of electricity in the United States by 2021. Some disagree with this assessment—see, for example, Hawken, Lovins, and Lovins, 1999. Consequently, we suggest in Chapter Six that subsequent research on ICT-driven electricity usage include prospective power purchases and sales by electric or fuel-cell vehicles.
• Changes in electricity use that are brought about by ICT-facilitated energy management systems (EMSs) in buildings;
• Changes in electricity and other energy usage that stem from business and societal changes associated with increased use of ICTs and the transition toward a digital society.

Electricity consumption by ICT equipment is the most direct and visible but not necessarily the most important of these three influences. Over time, the other two—energy management and broader socioeconomic trends—will likely have much more consequential effects on electricity and other energy use (Allenby and Unger, 2001). However, the fact that these two imply behavioral as well as technological changes makes them much more difficult to estimate. This is a principal reason for our developing several scenarios rather than a single projection. As one illustration, consider the enthusiasm for an ICT-driven “new economy” in the late 1990s that led some to forecast significant decreases in commercial floor space resulting from widespread adoption of e-commerce and telework, with large accompanying reductions in requirements for electricity and other forms of energy. Our Cybertopia scenario generally reflects this perspective, whereas the other three scenarios forecast smaller changes in shopping and commuting behaviors. Other factors, such as changing energy prices, demographics, and consumer preferences, will also strongly influence electricity use in a more digital society.

4.2 ELECTRICITY USE IN THE RESIDENTIAL SECTOR, 2001–2021

The AEO 2002 projects that U.S. residential electricity consumption will increase from 1,230 billion kWh, or 1,230 terawatt-hours (TWh), in 2001 to 1,670 TWh in 2020—an average annual growth rate of 1.7 percent. More important for this analysis, the household electricity intensity—measured as the annual kilowatt-hours consumed per household (kWh/hh)—is projected to grow from 11,600 kWh/hh in 2001 to 13,200 kWh/hh in 2020 (Figure 4.1). This represents an average annual growth rate of 0.7 percent, which is well below the 4 percent average growth over the past 50 years as refrigerator/freezers, washers, dryers, televisions, and other electrical appliances became ubiquitous in American households.
4.2.1 Residential Electricity Use by ICT Equipment

Electricity in the home is used mostly for space heating and cooling, water heating, lighting, and refrigeration. Recent studies at Lawrence Berkeley National Laboratory (LBNL) (Kawamoto et al., 2001; Rosen, Meier, and Zandelin, 2001; and Rosen and Meier, 1999 and 2000) estimate that ICT equipment accounted for only about 7 percent of total residential electricity use in 1999 (Figure 4.2), and that television and video equipment represented well over half of household ICT electricity use in 1999 (Figure 4.3).

Starting from the LBNL baseline data for 1999, we projected household ICT equipment inventories and electricity consumption for 2001 to 2021 for each of our scenarios.2 Bottom-up estimates were developed for the four groups of ICT devices shown in Figure 4.3:

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2Our projections through 2005 are generally consistent with those developed by Jon Peddie Associates for ICT devices in the home with “networking potential” (see Arrington, 2001).
38 Electricity Requirements for a Digital Society

Total household electricity use, 1999: 1,150 TWh

- Space heating/cooling: 24%
- Lighting: 9%
- Other: 36%
- Refrigerators/freezers: 14%
- ICT devices: 7%
- Water heating: 10%

SOURCES: EIA, 2001; Kawamoto et al., 2001; Rosen, Meier, and Zandelin, 2001; Rosen and Meier, 1999 and 2000.

Figure 4.2—Electricity Use in the Residential Sector, 1999

1. **Computer and office equipment:** desktop, laptop, and notebook computers; personal digital assistants (PDAs); and printers, copiers, scanners, storage devices, and other computer peripherals or home office machinery.

2. **Television and video equipment:** both analog and digital television receivers; set-top boxes for receiving signals from terrestrial broadcast, satellite, cable, fiber optic, or other networks; VCRs, DVD players, video digital recorders, and other video devices; and game consoles.

3. **Audio equipment:** component, compact, and portable stereo systems; music recording and playing devices, such as current CD and MP3 players; and clock radios.
Total household ICT electricity use, 1999: 83 TWh

Communications/ home network 7%
Audio equipment 25%
Computer and office equipment 11%

SOURCES: Kawamoto et al., 2001; Rosen, Meier, and Zandelin, 2001; Rosen and Meier, 1999 and 2000.

Figure 4.3—Electricity Use by Residential ICT Equipment, 1999

4. Communications and home network equipment: wired, cordless, and wireless phones; answering machines; fax machines (if not integrated with other home office equipment); home security systems; home networks connecting computer, office, and entertainment devices; and other home networks connecting appliances, lighting, and HVAC equipment.

We expect ICT devices that are separate in 2001 to undergo a good deal of technical convergence and integration. For example, our scenarios assume that one-third of cell phones will have true PDA features by 2006, and that essentially all handheld (or smaller) wireless devices will have integrated voice and data capabilities by 2015.
Similarly, today’s analog audio and video equipment—stereo components and systems, television receivers, video recorders, and most set-top boxes—will become digital and largely integrated as households adopt digital television and replace their analog components.

At the same time, special-purpose ICT devices will proliferate in the home. Our Reference scenario posits that smart appliances will have more marketing pizzazz than actual use in the next five years, but that appliances purchased in 2006 or later will have embedded processors ready to be programmed and controlled over home networks and/or the Internet. Smart, networked devices for entertainment, communications, and information will substitute for general-purpose computers in many applications. Most households will still have at least one “old-fashioned” general-purpose computer in 2021, but they will also have dozens of specialized ICT devices for specific tasks and functions.

Future electricity use by ICT equipment in the home depends on a complex net balance between different, conflicting trends that favor higher (+) or lower (−) consumption. These trends include

+ Twenty-year growth in the U.S. population and in U.S. households of 18 and 21 percent, respectively;
+ Greater numbers of ICT devices at home in each of the four groups listed above;
− Faster growth of wireless than of wired devices;\(^3\)
+ Larger, more-powerful devices that consume more electricity in both active and standby mode, such as digital instead of analog television receivers;
− More energy efficient chips and devices in all categories that cut active and standby power requirements;
+ Longer on-times for ICT equipment—e.g., computer and office equipment used by home workers and teleworkers, and comput-

\(^3\)See, for example, Standage, 2001.
ers and other networked devices used for shopping, communicating, and playing games;\textsuperscript{4} 
  – Use of ICT sensors and controls to manage electricity consumption more efficiently.

We took each of these trends into account in our projections of residential electricity use by ICT equipment. The projections are presented in Table 4.1 and discussed below (see Appendix B for further details).

4.2.1.1 Home computer and office equipment. Trends increasing electricity use include the continuation of Moore’s Law: packing more components and functions into chips and devices,\textsuperscript{5} near-ubiquitous penetration of more-powerful home computers with

\begin{table}[h]
\centering
\caption{Residential Electricity Use by ICT Equipment, 2001–2021}
\begin{tabular}{lcccc}
\hline
\textbf{Electricity Use (TWh)} & \multicolumn{4}{c}{\textbf{2021 Scenario}} \\
\hline
 & 2001 & 2006 & Reference & Zaibatsu & Cybertopia & Insecurity \\
\hline
Computer and home office equipment & 14 & 19 & 25 & 29 & 30 & 22 \\
TV and video equipment & 47 & 55 & 88 & 89 & 88 & 117 \\
Audio equipment & 20 & 22 & 28 & 28 & 28 & 30 \\
Communications and network equipment & 8 & 14 & 52 & 56 & 58 & 43 \\
Total ICT equipment & 89 & 110 & 193 & 202 & 205 & 213 \\
\hline
\end{tabular}
\end{table}

\textsuperscript{4}Whether increased use of some devices will lead to decreased use of others remains an unanswered question. The UCLA Center for Communication Policy (2001) reports from its survey that Internet users in 2001 watched 4.5 fewer hours of television per week than did non-users. However, other studies, from the United States and Europe, did not find such differences. See, for example, Aebischer and Huser, 2000.

\textsuperscript{5}Simple extrapolation of energy consumption in today’s (2001) computer chips to that of much more powerful chips in five or ten years would lead to chip meltdown (see Corcoran, 2001). We assume in these scenarios that new chip designs, new materials, and better cooling methods will allow continued exploitation of Moore’s Law for the next two decades.
larger displays, always-on broadband connections to the Net, broadband home networks, more home offices, and (except in the Net Insecurity scenario) teleworking. These are balanced to a great extent by the more-energy-efficient design of chips and equipment with built-in power management, universal adoption of flat-panel displays using less than half the power per square inch of CRT displays (Norford et al., 1990; and Groot and Siderius, 2000), and a general trend away from high-power desktop computers and toward wireless laptop and handheld devices.

Without these mitigating trends, electricity use by home computer and office equipment in 2021 would be more than 50 percent higher than the figures shown in Table 4.1. With them, electricity use by home computer and office equipment in the Reference scenario grows from 14 TWh in 2001 to 25 TWh in 2021—an average annual growth rate of 3.1 percent. Our estimates are somewhat below the AEO 2002 EIA (2001) estimates, which project that electricity use by residential computers will increase from 15 TWh in 2001 to 34 TWh in 2021, for an average annual increase of 4.2 percent. Compared with those projections, ours assume more rapid growth in the number of home computers over the 20 years, but less average power consumption per unit as wireless devices capture a larger share of the home market.

Even in the high-ICT-use scenarios of Cybertopia and Zaibatsu, power consumption in 2021 by home computer and office equipment amounts to less than 15 percent of the total power needed for residential ICT equipment, and less than 2 percent of total residential electricity consumption. On the basis of kilowatt-hours demanded, the greatly expanded role that both we and EIA project for computers and other information appliances in the home will not heavily burden U.S. electricity supplies. However, the need for higher power quality and reliability (PQR) for these digital devices does represent an important issue, one that we consider in Chapter Five.

4.2.1.2 Television, video, and audio equipment. Electricity consumption by television and video equipment grows more rapidly

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6Displays based on organic light-emitting devices (OLEDs) that are in development at IBM and elsewhere would consume less energy per square inch than do current flat-panel liquid crystal displays (LCDs).
after 2006 in all four of our scenarios as digital television equipment becomes cheaper and its household penetration increases. The 2001–2021 average annual growth rate in the Reference scenario is 3.2 percent, which is very close to that in the AEO 2002 projections. The benefits from conversion to flat-panel displays and from general energy efficiency improvements are outweighed by consumers’ desire for more-integrated video equipment with larger screens in more rooms. Electricity consumption in 2021 is 34 percent greater in the Net Insecurity than in the Reference scenario, because consumers choose even more-elaborate digital video systems rather than investing in equipment connected to an insecure Net. We project similar but less important differences among the scenarios for electricity use by home audio equipment.

4.2.3.3 Home communications and network equipment. At present, electricity consumption by communications and network equipment in the home (primarily telephones, answering machines, fax machines, and security systems) accounts for less than 9 percent of the total power consumed by all ICT equipment. We project that the 9 percent will grow to more than 25 percent by 2021 in the Reference, Zaibatsu, and Cybertopia scenarios, when nearly all residences will have always-on broadband networks using a combination of wired and wireless links. Home networks generally will first be used to interconnect computer, home office, and entertainment equipment; but by 2021, most will also control the home environment (heating, ventilation, air conditioning, and lighting) and many appliances. The result will be large increases in electricity consumed to power not only 120 million home networks, but also the 20 to 25 billion wired or wireless sensors, actuators, controllers, and human interfaces that these applications will demand.

4.2.2 Electricity Savings from ICT-Facilitated Energy Management in Residences

While adding to electricity consumption, a home network can also contribute to electricity savings as part of a home energy management system (EMS) that includes such features as programmable control of heating, cooling and lighting systems, remote control via the Internet, and responsiveness to weather conditions, household
routines and electricity prices (Lewis, 2000). Following a recent paper by Rabaey et al. (2001), we outline here the three phases in home network EMS development that we used to estimate reductions in residential electricity consumption in the scenarios.

In phase 1, which largely entails passive monitoring, the EMS gathers data from various sensors about local conditions (temperature, lighting, equipment usage), displays the data, and implements control decisions made by the end user. These decisions may be made manually on a case-by-case basis (e.g., turn on the air conditioning in the master bedroom) or automatically using simple devices such as timers or thermostats. The growing availability of cheap (wired or wireless) sensors linked together on the home network allows such monitoring and control at the level of individual rooms or appliances.

The phase 2 EMS goes beyond passive monitoring, providing current data about energy consumption and prices and computing current and/or projected costs to the household. This encourages users to make cost-saving decisions when prices are high. This phase requires installation of digital electricity meters in the home that are linked to the home EMS, implementation of time-of-use (TOU) or real-time pricing (RTP),7 and provision of the means to make price data routinely available to the home EMS (e.g., over the Internet).

The phase 3 EMS actively manages energy use, gathering local and external data and applying the household’s programmed rules and preferences (e.g., keep bedroom temperatures between 65 and 72 degrees when occupied, but turn down the air conditioning if the electricity price goes above 15 cents/kWh). Phase 3 embodies the “smart home” concept that has been demonstrated and widely publicized but not yet widely deployed. The technical path seems clear, however: home EMSs will use distributed sensors, actuators, and other microprocessor-based devices to manage the home environment and appliances under the supervision of a central control unit.

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7Time-of-use pricing refers to electricity pricing that varies predictably by time of day (e.g., a high peak-load rate between 8am and 6pm on weekdays, and a lower off-peak rate at other times). Real-time prices are set more frequently (usually hourly) to reflect the underlying wholesale price of power, and can rise steeply when demand peaks or supply is curtailed. See Reed, 2001.
Over time, home EMSs will evolve to become considerably more capable, complex, and autonomous.

Estimates of the energy savings from phase 1, 2, and 3 home EMSs vary greatly and are supported by few empirical data from the residential sector. A few pilot projects with residential TOU electricity pricing have been conducted (e.g., Aubin et al., 1995), and a larger program involving some 300,000 customers is now under way in the state of Washington (Brock, 2001). RTP, which economists expect to match electricity supply and demand more efficiently than TOU does, has primarily been implemented in voluntary programs for large industrial and commercial customers. Data from such programs at Georgia Power, Duke Power, and GPU Energy show peak load reductions of 10 to 50 percent, with consistently larger responses at higher prices (EPRI, 2001). At the residential level, the Edison Electric Institute estimated in the mid-1990s that RTP could reduce overall electricity consumption by as much as 5 percent (National Institute of Standards and Technology, 1994). This upper bound is consistent with one RTP “natural experiment” among residential customers in San Diego, California, who reduced electricity consumption by an average of 5.2 percent during August 1999 when their rates more than doubled (EPRI, 2001).

However, except for situations in which electricity prices become very high such as was the case in San Diego, there is scant evidence that residential customers will actually use RTP when it is available. Consumers are generally risk averse and favor simple, predictable prices for utility-like services; e.g., they favor flat-rate over measured-use telephone service, and fixed monthly charges over pay-per-view for premium movie channels on satellite or cable TV. As one energy consultant reports: “[w]hen we listen to customers discuss what they need and what is important to them, we find RTP is seldom a good fit. In fact, most customers are willing to pay a premium over RTP for more simplicity and certainty in their pricing” (EnerVision, 1998). This suggests that there is an intermediary role for distribution utilities or other energy service companies that buy power at variable rates and repackage it to sell to consumers at (presumably higher) fixed rates, in addition to selling other home energy management services. In Zaibatsu, the vertically integrated utilities provide such services, whereas in Cybertopia, many large and small firms compete to offer them to residential customers.
Most studies of phase 3 EMS focus on commercial buildings, where the prospective economic returns are more clear-cut than they are for residences. At the high end, Raebey et al. (2001, p. 3) estimate that smart commercial buildings could reduce “lighting power consumption by 40%” and “energy dissipation for space conditioning . . . by 44%.” Romm (1999, p. 18) cites estimates of potential 25 percent savings in energy consumption from installing digital EMSs in 24 commercial buildings in Texas. However, EPRI’s Consortium for Electric Infrastructure to Support a Digital Society (2001a, p. 20) projects only “up to 2.5%” savings from EMSs in commercial buildings. Kris Pister, leader of a University of California at Berkeley research project on tiny wireless sensors for energy monitoring and management, estimates that using this “smart dust” on the Berkeley campus could cut “power use by at least 5 percent” (Ainsworth, 2001).

For our scenarios, we estimate reductions in electricity consumption for space conditioning and lighting of 3, 9, and 15 percent for households that adopt phase 1, 2, and 3 EMSs, respectively. We assume the distribution of phase 1, 2, and 3 EMS households is as shown in Table 4.2, which leads to the power savings also shown there. Only in Cybertopia do the electricity savings from EMSs exceed the power consumed by home networks. This finding reflects our view that households install home networks primarily to connect computer and office equipment and entertainment devices, with energy management usually following as an ancillary objective. But besides lowering overall electricity use, home EMSs linked to real-time prices reduce peak electricity demand and cut consumption of gas and other residential fuels. These savings have more important implications for energy and economic efficiency than do the changes in total kilowatt-hours consumed.

4.2.3 Changes in Residential Electricity Use from Telework

Cheaper, faster, and better ICTs enable more people to work from home on at least a part-time basis.8 Based on the Telework America Survey 2000, which was conducted in the summer of 2000, the Inter-

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8For an introduction to the substantial body of literature that has arisen on teleworking over the past two decades, see Nilles, 1998.
Table 4.2
Electricity Savings from Home Energy Management, 2001–2021

<table>
<thead>
<tr>
<th>2021 Scenario</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Households with EMS (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1 (3% savings)</td>
<td>2</td>
<td>7</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Phase 2 (9% savings)</td>
<td>0</td>
<td>2</td>
<td>20</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Phase 3 (15% savings)</td>
<td>0</td>
<td>1</td>
<td>30</td>
<td>35</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>10</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>Electricity savings (TWh)</td>
<td>–0.3</td>
<td>–2.5</td>
<td>–39</td>
<td>–45</td>
<td>–62</td>
<td>–25</td>
</tr>
<tr>
<td>Home network power use (TWh)</td>
<td>7.9</td>
<td>14</td>
<td>52</td>
<td>56</td>
<td>58</td>
<td>43</td>
</tr>
</tbody>
</table>

The national Telework Association and Council estimates that some 16.5 million regularly employed U.S. adults, about 9 percent of the adult workforce, used ICT to work outside their offices at least one day per month (Nilles, 2000). More than 90 percent teleworked from home, using a combination of telephone, fax, computer, and the Internet. Fewer than 20 percent were full-time teleworkers.

The first-order effect of telework is greater electricity consumption at home. Both the Telework America Survey 2000 and a recent study of telework in Switzerland by Aebischer and Huser (2000) found that teleworking households have an average of one computer more than non-telework households. Not surprisingly, they also found that teleworkers use computers as well as home printers, scanners, and other ICT devices much more intensively than do non-teleworkers. Based on these studies and our projections for teleworking through 2021, we arrived at estimates, shown in Table 4.3, of the incremental home electricity use for teleworking for each of the four scenarios.9

Space conditioning and lighting, both directly in the home office and indirectly in the rest of the house, consume more power than does

---

9Power consumption estimates in all categories are incremental to those projected without teleworking. Power for space conditioning also assumes that the size of the average house increases by 6 percent between 2001 and 2021, an estimate taken from EIA, 2001.
### Table 4.3
Annual Incremental Home Electricity Use for Telework, 2001–2021

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teleworkers (million)</td>
<td>17</td>
<td>25</td>
<td>40</td>
<td>30</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>% of adult work force</td>
<td>9</td>
<td>13</td>
<td>18</td>
<td>13</td>
<td>28</td>
<td>9</td>
</tr>
<tr>
<td>avg. telework days/week</td>
<td>2.0</td>
<td>2.1</td>
<td>2.5</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Electricity use (TWh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home office</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICT equipment</td>
<td>3.0</td>
<td>4.4</td>
<td>7.2</td>
<td>4.3</td>
<td>13</td>
<td>2.9</td>
</tr>
<tr>
<td>Lighting</td>
<td>2.0</td>
<td>2.9</td>
<td>4.4</td>
<td>2.6</td>
<td>7.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Space conditioning</td>
<td>6.8</td>
<td>11</td>
<td>20</td>
<td>12</td>
<td>36</td>
<td>8</td>
</tr>
<tr>
<td>Home office–subtotal</td>
<td>12</td>
<td>18</td>
<td>32</td>
<td>19</td>
<td>57</td>
<td>13</td>
</tr>
<tr>
<td>Rest of house</td>
<td>8</td>
<td>12</td>
<td>21</td>
<td>13</td>
<td>38</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>30</td>
<td>53</td>
<td>32</td>
<td>95</td>
<td>21</td>
</tr>
</tbody>
</table>

the teleworker’s ICT equipment. Sixty percent of the total incremental electricity is used in the home office, with the remaining 40 percent used for space conditioning, hot water, lighting, and appliances in the rest of the house (Aebischer and Huser, 2000, p. 40).

In 2001, our average teleworker’s home office used an additional 870 kWh, compared with the 750 kWh estimated by Romm (1999). Total incremental consumption in the teleworker’s home is 1,450 kWh, compared with an estimate of 1,650 kWh cited by Aebischer and Huser (2000).

While teleworking increases electricity use at home, it also permits employers to cut back on floor space and ICT equipment at their offices. These effects are discussed in Sections 4.3 and 4.4, which cover commercial and industrial electricity consumption. The net impact on electricity consumption depends on the division of time between work at the office and work at home. A once-a-week teleworker usually has a home office and exclusive use of an office that he/she commutes to, and the electricity consumption for the two offices in this case will generally exceed that for a one-office, full-time commuter. A four-day-a-week teleworker, however, most often shares an
office away from home with other workers, producing lower net electricity consumption.\textsuperscript{10} And teleworkers use less fuel commuting to and from work, although they make more local trips on days they telecommute from home.\textsuperscript{11}

4.2.4 Summing Up: ICT-Driven Residential Electricity Use, 2001–2021

The combined effects on residential power consumption for ICT equipment, EMSs, and telework, which constitute our “ICT-driven subtotal,” are shown in Table 4.4 and Figure 4.4. To use 2001 as a baseline for comparing our projections with those in the \textit{AEO 2002}, we assume that our results for audio equipment and home communications/network equipment are included in the \textit{AEO 2002} estimates for “other uses,” and that our results for EMSs and telework in 2001 are included in the \textit{AEO 2002} estimates for space heating, space cooling, and lighting. This makes our 2001 total match that in the \textit{AEO 2002}, although the components differ: our ICT-driven subtotal is larger than the one in the \textit{AEO 2002}, and our non-ICT subtotal is smaller. For consistency with the \textit{AEO 2002} projections beyond 2001, our non-ICT subtotal in future years increases at the same rate as the non-ICT subtotal in the \textit{AEO 2002}.

The effect of increased business-to-consumer (B2C) e-commerce on residential electricity use is largely captured in the ICT equipment category. We expect other e-commerce effects on residential power consumption to be quite limited, although B2C e-commerce will affect vehicle miles traveled (VMT) and thus fuel consumption by consumer and delivery vehicles. We have made separate projections for \textcolor{red}{\underline{e}}-commerce effects on commercial and industrial electricity use (see Sections 4.3 and 4.4).

\textsuperscript{10}Aebischer and Huser (2000, p. 41) discuss a 2000 study of telework in a Swiss bank that was conducted by Schmeider et al. That study assumes that four teleworkers save three office work desks and estimates that the net change in annual electricity use is +115 kWh for a one-day-a-week teleworker and −282 kWh for a four-day-a-week teleworker.

\textsuperscript{11}Mokhtarian (1998) estimates that a day spent teleworking from home reduces the worker’s vehicle miles traveled on that day by at most 60 percent.
Table 4.4
ICT Effects on Residential Electricity Use, 2001–2021

<table>
<thead>
<tr>
<th>Electricity Use (TWh)</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT equipment</td>
<td>89</td>
<td>110</td>
<td>193</td>
<td>202</td>
<td>205</td>
<td>213</td>
</tr>
<tr>
<td>EMSs</td>
<td>0</td>
<td>–3</td>
<td>–39</td>
<td>–45</td>
<td>–62</td>
<td>–25</td>
</tr>
<tr>
<td>Telework</td>
<td>20</td>
<td>30</td>
<td>53</td>
<td>32</td>
<td>95</td>
<td>21</td>
</tr>
<tr>
<td>Subtotal ICT-driven</td>
<td>108</td>
<td>137</td>
<td>207</td>
<td>188</td>
<td>237</td>
<td>208</td>
</tr>
<tr>
<td>Subtotal non-ICTa</td>
<td>1,120</td>
<td>1,240</td>
<td>1,520</td>
<td>1,520</td>
<td>1,520</td>
<td>1,520</td>
</tr>
<tr>
<td>Total residentiala</td>
<td>1,230</td>
<td>1,380</td>
<td>1,720</td>
<td>1,700</td>
<td>1,750</td>
<td>1,720</td>
</tr>
</tbody>
</table>

EIA total residentiala | 1,230| 1,370| 1,700 | 1,700 | 1,700 | 1,700 |
Difference from EIA   | 0    | 8    | 23    | 4     | 53    | 24    |
Difference from EIA as a % | 0.0 | 0.6 | 1.3 | 0.2 | 3.1 | 1.4 |

a Rounded to three significant figures.

For the Reference scenario, the ICT-driven subtotal in Table 4.4 nearly doubles between 2001 and 2021, representing an average annual growth rate of 3.3 percent. The percentage of residential electricity consumption that is ICT-driven rises from 9 percent in 2001 to 11 percent in 2021, due principally to increased power consumption from digital video equipment, home networks, and telework-related office equipment. The total residential consumption projected for the Reference scenario for 2021 is 23 TWh, or 1.3 percent, above that projected in the AEO 2002.12

With more telework than the other scenarios have, Cybertopia shows the highest residential power consumption: 237 TWh, representing 13.5 percent of the total for the residential sector. The totals for Zaibatsu and Net Insecurity fall between those for the Reference and Cybertopia scenarios. However, even Cybertopia’s total is only 53 TWh, or 3.1 percent, higher than that projected in the AEO 2002. And as discussed in the next two sections, the increases are more than

---

12 We used the AEO 2002 average annual growth rate of 1.7 percent to extend the AEO 2002 projected total for residential electricity consumption from 1,672 TWh in 2020 to 1,700 TWh in 2021.
OFFSET BY DECREASES IN ELECTRICITY CONSUMPTION IN THE COMMERCIAL AND INDUSTRIAL SECTORS FROM ICT-DRIVEN ENERGY MANAGEMENT, E-COMMERCE, AND TELEWORK.

4.3 ELECTRICITY USE IN THE COMMERCIAL SECTOR, 2001–2021

The commercial sector comprises all activities other than those classified as residential, industrial, or transportation. It includes education, health care, lodging, telecommunications, professional services, wholesale and retail trade, government services, religious groups, and other private, nonprofit, and public organizations.
The vast majority of energy use in the commercial sector occurs in buildings, both to maintain the building environment and to provide building-based services. The *AEO 2002* projects that electricity intensity in the commercial sector—defined as kilowatt-hours consumed annually per square foot of commercial floor space—will increase from 17.7 kWh/ft² in 2001 to 20.1 kWh/ft² in 2020, an average annual increase of 0.6 percent (Figure 4.5).

ICT can influence commercial electricity use in two principal ways: by changing the electricity intensity in commercial buildings and by changing the amount of floor space required for commercial activities. The power demands of ICT equipment and the electricity savings from EMSs in commercial buildings affect electricity intensity; such ICT-driven changes as e-commerce and telework primarily affect floor space requirements.
4.3.1 Commercial Electricity Use by ICT Equipment

Baseline 1999–2000 estimates of electricity consumption by ICT equipment in the commercial sector can be found in the AEO 2002 (EIA, 2001), LBNL studies by Kawamoto et al. (2001) and Koomey et al. (1999), and a study by Roth, Goldstein, and Kleinman (2000) published by Arthur D. Little, Inc. (ADL). These estimates differ substantially (see Table 4.5) because of different years of estimation, different sector definitions, and several other factors.

To develop a baseline estimate for our scenario projections, we started with the ADL figures for 2000 (shown in Table 4.5), since they represent the most recent and most disaggregated, bottom-up esti-

### Table 4.5

<table>
<thead>
<tr>
<th></th>
<th>Estimated Electricity Use (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EIA</td>
</tr>
<tr>
<td>Office computer equipmenta</td>
<td>47</td>
</tr>
<tr>
<td>Other office equipment</td>
<td>94</td>
</tr>
<tr>
<td>Network equipmentb</td>
<td>n/a</td>
</tr>
<tr>
<td>Total ICT equipment</td>
<td>141</td>
</tr>
</tbody>
</table>

aIncludes portable and desktop computers, terminals, monitors, and printers.
bIncludes both computer network and telecommunications network equipment.
cNot applicable.


---

13The EIA and ADL figures are for 2000. The LBNL estimates are for 1999, except in the case of the Koomey et al. estimate of electricity used by telephone central offices, which is for 1997.

14The EIA and LBNL estimates are for the commercial sector, whereas the ADL estimate is for both the commercial and the industrial sector.

15These include different assumptions about standby and active use, different definitions of “other” office equipment, and different methods of estimation (Alan Meier, LBNL, personal communication, 2001).
mates. We adjusted these data to cover the commercial sector only, using the ratios of commercial/industrial electricity use by ICT equipment developed in the LBNL study by Kawamoto et al. (2001). We then extrapolated the results to 2001 using the 2000–2001 growth rates in the AEO 2002 for electricity consumption by commercial sector ICT equipment.

These calculations yield a baseline estimate for our 2001 Reference scenario of 92 TWh for electricity consumption by ICT equipment in the commercial sector, which constitutes less than 8 percent of the 1,170 TWh estimated in the AEO 2002 for total sector consumption in 2001 (Figure 4.6). The estimates in the AEO 2002 show ICT equipment accounting for 152 TWh, or 13 percent, of commercial sector consumption in 2001; but we believe this figure is much too high in light of the recent LBNL and ADL data.

![Figure 4.6—Electricity Use in the Commercial Sector, 2001](https://example.com/fig46.png)

**SOURCES:** RAND calculation for ICT equipment; EIA, 2001, for other estimates.
The electricity use projections through 2021 in our scenarios fall well below those in the *AEO 2002* (Table 4.6). While much of the difference results from our lower baseline in 2001, we also project lower growth in power consumption by office ICT equipment over time than does EIA, principally because we assume that greater efficiency improvements and more telework will result in lower numbers of office computers and related ICT equipment.

We project growing electricity consumption in Internet data centers and by computer and telecommunications network equipment, which the EIA projections do not capture. The rapid growth of “Web server farms,” “Internet hotels,” and other data centers during the Internet boom of the late 1990s was thought likely to stress electricity distribution systems in places such as Silicon Valley, New York City, and Austin, Texas. These facilities have very high power densities, run continuously, and require more reliable power than do other electricity users.\(^{16}\) As shown in Table 4.6, electricity consumption by

<table>
<thead>
<tr>
<th>Electricity Use (TWh)</th>
<th>2021 Scenario</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office computer equipment</td>
<td>45</td>
<td>50</td>
<td>65</td>
<td>70</td>
<td>50</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Other office equipment</td>
<td>29</td>
<td>35</td>
<td>45</td>
<td>50</td>
<td>40</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Data centers</td>
<td>4</td>
<td>10</td>
<td>26</td>
<td>30</td>
<td>20</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Network equipment</td>
<td>14</td>
<td>20</td>
<td>42</td>
<td>46</td>
<td>38</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Total ICT equipment</td>
<td>92</td>
<td>115</td>
<td>178</td>
<td>196</td>
<td>148</td>
<td>219</td>
<td></td>
</tr>
<tr>
<td>EIA total ICT equipment</td>
<td>152</td>
<td>204</td>
<td>346</td>
<td>346</td>
<td>346</td>
<td>346</td>
<td></td>
</tr>
</tbody>
</table>

data centers in 2001 is estimated at about 4 TWh, or about one-third of 1 percent of total sector use.

Simply extrapolating the 1998–2000 growth of data centers forward in time, however, would have them using more power than all the rest of the commercial sector well before 2010. This will not happen, of course. Data center expansion has slowed considerably since the dot.com bubble burst in 2000. The largest Web server farm company declared bankruptcy in 2001, and many Internet hotels remain vacant.

From a technical perspective, low-power computer chips will improve the energy efficiency of ICT equipment in data centers (IBM, 2001), but higher-performance equipment will require greater power density. The net effect in our projections for data centers is a modest increase in power density and restrained growth in square footage. Overall, we project that power used by data centers, along with commercial use of the Net in general, will continue to grow over the next 20 years. We estimate that by 2021, data centers will account for between 1 percent of commercial sector electricity consumption (Net Insecurity scenario) and 1.7 percent (Zaibatsu scenario).

Network equipment consists of the routers, switches, and hubs used in local area networks (LANs) and wide area networks (WANs), as well as the switches and other ICT equipment found in telephone central offices, PBXs, fiber optic transmission facilities, cellular base stations, and cable headends.\(^\text{17}\) We anticipate considerable technological convergence among these categories over the next 20 years, as well as movement of network equipment from dedicated telephone and cable facilities into the more general-purpose data centers discussed above.

Countervailing power consumption trends again include greater energy efficiency at the component and device levels, offset by higher capacity, performance, and reliability requirements that demand more power. For example, each new generation of fiber optic terminals is much more energy efficient than the last on a watt-per-bit

\(^{17}\text{Roth, Goldstein, and Kleinman (2002, pp. 66–96) provide detailed estimates of electricity consumption in 2000 by these components of computer networks and telecommunications networks.}\)
basis, but a fiber optic transmission facility still draws more power than the wire or cable facility it replaces. This becomes important in our scenarios as digital, always-on fiber-to-the-curb or fiber-to-the-home begins to penetrate the residential market after 2006.

As shown in Table 4.6, the differences between our projections and those in the AEO 2002 for electricity consumption by commercial sector ICT equipment increase over time as a result of the various factors discussed above. Starting from a 2001 baseline estimate that is 60 TWh (39 percent) below that of the AEO 2002, the difference by 2021 is −168 TWh (−49 percent) for the Reference scenario and from −127 TWh (−37 percent) to −198 TWh (−57 percent) for the other three scenarios.

4.3.2 Electricity Savings from ICT-Facilitated Energy Management in Commercial Buildings

Building EMSs will become more generally adopted over the next 20 years and will use much more sophisticated ICT. Our projections for electricity savings in commercial buildings use the three EMS phases previously described for the residential sector:

- Phase 1: largely passive monitoring;
- Phase 2: real-time pricing;
- Phase 3: active, “intelligent” monitoring and management.

The electricity savings from each phase are assumed to be higher in the commercial than in the residential sector for several reasons. First, EMS savings come principally from space conditioning and lighting, which account for more than one-half of electricity consumption in the commercial sector, versus one-third in the residential sector. Commercial buildings generally use more power per square foot than do residences. Second, commercial building owners and/or tenants have clear bottom-line interests in managing their electricity use when the savings justify the EMS investment. Stated differently, commercial firms generally are more willing than households to pay up-front costs that will generate positive returns over the longer run. The commercial sector also offers better prospects for energy service companies or other intermediaries who may assume
some of the initial EMS costs in return for downstream payments. Finally, using better sensors, faster microprocessors, and Internet-based monitoring reduces EMS costs while increasing performance, thus making EMS cost effective for niche commercial building applications.  

For commercial buildings with phase 1, 2, and 3 EMS, we estimate 6, 16, and 24 percent reductions, respectively, in electricity consumption for space conditioning and lighting. If we then assume the distribution of EMS phase 1, 2, and 3 buildings shown in Table 4.7, electricity savings for the Reference scenario increase from 2.6 TWh in 2001 to 76.4 TWh in 2021. Cybertopia, with abundant Net services and efficient markets for electricity management, has 36 percent greater electricity savings than does the Reference scenario. Even Net Insecurity exhibits a respectable 64 TWh in savings, although its commercial buildings must use more-costly private networks for EMS.

<table>
<thead>
<tr>
<th>2021 Scenario</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Net</th>
<th>Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings with EMS (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1 (6% savings)</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Phase 2 (16% savings)</td>
<td>0</td>
<td>15</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Phase 3 (24% savings)</td>
<td>0</td>
<td>5</td>
<td>30</td>
<td>35</td>
<td>50</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Total EMS buildings (%)</td>
<td>10</td>
<td>40</td>
<td>75</td>
<td>80</td>
<td>90</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Electricity savings (TWh)</td>
<td>-3.6</td>
<td>-31</td>
<td>-91</td>
<td>-100</td>
<td>-120</td>
<td>-77</td>
<td></td>
</tr>
</tbody>
</table>

For example, a hotel can set up its EMS so that the front-desk clerk turns on the space conditioning unit in an individual room when a guest checks in, and sensors subsequently readjust the temperature whenever the room is vacant for more than 15 minutes. A residential analogue might be the use of a cell phone to turn on air conditioning in one room five minutes before arriving home, but we do not expect this to be an important home application.
4.3.3 Changes in Commercial Electricity Use from E-Commerce

E-commerce has the potential to lower commercial sector electricity consumption, primarily by reducing the amount of commercial floor space required for Internet sales vis-à-vis in-store sales. According to the most recent Commercial Buildings Energy Consumption Survey (CBECS) (1995), retail establishments represent 15.5 percent of commercial floor space and 13.7 percent of commercial electricity consumption. Online sellers of books, music, computer hardware and software, and other items do not need large, well-lit, fully stocked retail stores to draw customers. Instead, their operations require data centers, upstream warehouses, and fulfillment and delivery services.

Comparing the floor space needs of these two very different ways of doing business is tricky, particularly since e-commerce operations are still evolving rapidly.\(^{19}\) Although some early estimates claim floor space reductions of 80 to 90 percent for B2C online sales,\(^{20}\) these seem overstated when total enterprise space needs, rather than the marginal space required to sell an additional unit, are considered.\(^{21}\) Consequently, our scenarios estimate that an average of 50 percent less commercial floor space is needed for B2C e-commerce sales, which in the Reference scenario are projected to grow from 2 percent of retail sales in 2001\(^{22}\) to 20 percent in 2021 (Table 4.8). The resulting reduction in electricity consumption is 15.6 TWh, or close to 1 percent of the total projected for the commercial sector in 2021.

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\(^{19}\)As an illustration, Amazon.com, the leading online bookstore, has invested heavily in its own warehouses. Other B2C sellers rely more on drop-shipping from distributors or manufacturers.

\(^{20}\)For example, based on a 1998 case study of Amazon.com by the Kellogg Graduate School of Management at Northwestern University, Romm, Rosenfeld, and Herrmann (1999, p. 26) state that "a plausible estimate for the ratio of commercial building energy consumption per book sold for traditional stores versus online stores is 16 to 1" (emphasis in original).

\(^{21}\)The trend toward enterprises selling both online and through traditional stores also acts to moderate the floor space differences between channels, especially if and as e-commerce grows to become a substantial fraction of total sales.

\(^{22}\)The 2 percent estimate is based on surveys conducted through November 2001 (see Forrester Research, 2002). Forrester’s and several other projections of e-commerce revenues through 2005 are available at eMarketer, http://www.emarketer.com.
Table 4.8
Changes in Commercial Electricity Use from E-Commerce, 2001–2021

<table>
<thead>
<tr>
<th>2021 Scenario</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business-to-consumer (B2C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales online (%)</td>
<td>2</td>
<td>7</td>
<td>20</td>
<td>25</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>Retail floor space saved with online sales (%)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Change in electricity consumption (TWh)</td>
<td>-1.5</td>
<td>-5.5</td>
<td>-15.6</td>
<td>-19.5</td>
<td>-27.3</td>
<td>-5.5</td>
</tr>
<tr>
<td>Business-to-business (B2B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales online (%)</td>
<td>5</td>
<td>20</td>
<td>70</td>
<td>75</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Warehouse space saved with online sales (%)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Change in electricity consumption (TWh)</td>
<td>-0.4</td>
<td>-1.5</td>
<td>-5.4</td>
<td>-5.8</td>
<td>-6.2</td>
<td>-4.6</td>
</tr>
<tr>
<td>Change in electricity consumption: B2C+B2B (TWh)</td>
<td>-1.9</td>
<td>-7.0</td>
<td>-21</td>
<td>-25</td>
<td>-34</td>
<td>-10</td>
</tr>
</tbody>
</table>

Projected reductions are 25 percent higher in Zaibatsu (19.5 TWh) and 50 percent higher in Cybertopia (27.3 TWh), but 65 percent lower in Net Insecurity (5.5 TWh), where consumers have lost confidence in B2C e-commerce.

B2B e-commerce can reduce inventories throughout the commercial and industrial sectors by streamlining distribution, shortening sales cycles, and improving marketing models. Lower inventories affect the industrial sector the most (see Subsection 4.4.3), but they also result in the need for less warehouse space in the commercial sector. Warehouses represent 14.4 percent of commercial floor space and 6.8 percent of commercial electricity consumption (Commercial Buildings Energy Consumption Survey, 1995). Our scenarios assume that B2B e-commerce sales reduce warehouse floor space require-
ments by 10 percent. The resulting reduction in commercial sector power consumption in 2021 is between 4.6 TWh (Net Insecurity) and 6.2 TWh (Cybertopia). Here, the narrow range of impacts results from the relatively high penetration of B2B e-commerce by 2021 in all scenarios—even in Net Insecurity, where businesses still find economic benefits in using high-cost private networks to make B2B transactions.

4.3.4 Changes in Commercial Sector Electricity Use from Telework

As discussed in Subsection 4.2.3, telework increases residential electricity consumption and, because it reduces the need for office floor space, lowers commercial and industrial electricity consumption. Teleworkers still require office space, however, since most telework is part-time. We assumed a 20 percent reduction in office floor space and associated electricity consumption for each day per week spent teleworking—i.e., a 20 percent reduction for a one-day-per-week teleworker and an 80 percent reduction for a four-day-per-week teleworker. This estimate falls between other estimates of reduced office space for teleworkers. We also used the CBECS (1995) figure of 387 ft² for average office size. Based on CBECS and EIA data (EIA, 2001, Table 5) on past and projected office electricity consumption, we project that annual electricity use per square foot of office space will increase from 19.6 kWh in 2001 to 22.3 kWh in 2020. Finally, applying the projections of numbers of teleworkers from our scenarios and assuming that 75 percent of teleworkers are in the commercial sector, we arrive at the changes in commercial sector electricity consumption shown in Table 4.9.

---

23 Romm (1999, p. 33) estimates that B2B e-commerce will yield a net reduction in warehouse floor space of 1 billion square feet, or about 12 percent, by 2007.

24 JALA International, Inc. (1998), a consulting firm specializing in telework, estimates that a 1.5-day-per-week teleworker saves 150 ft², or 38 percent of the 387 ft² average office. Aebischer and Huser (2000, p. 41) estimate 75 percent office space savings for a four-day-per-week teleworker.

25 Workers can telework more easily in some job categories (e.g., computer programmers) than in others (e.g., food service employees). Our review of Bureau of Labor Statistics data and projections on job categories (Bureau of Labor Statistics, 1999) led us to conclude that roughly 30 percent of workers in both the commercial and the industrial sector have high or moderately high potential for teleworking. The 75
Table 4.9
Changes in Commercial Electricity Use from Telework, 2001–2021

<table>
<thead>
<tr>
<th>2021 Scenario</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teleworkers in sector (million)</td>
<td>12.8</td>
<td>18.8</td>
<td>30</td>
<td>22.5</td>
<td>45</td>
<td>15</td>
</tr>
<tr>
<td>Change in electricity use per teleworker (MWh)</td>
<td>–3.0</td>
<td>–3.3</td>
<td>–4.3</td>
<td>–3.5</td>
<td>–5.2</td>
<td>–3.5</td>
</tr>
</tbody>
</table>

The reduction in commercial floor space associated with telework is significantly greater than that associated with e-commerce in all scenarios. Telework’s effect is particularly striking in Cybertopia, where high ICT usage among a dispersed population leads to more teleworkers who spend more days away from the office. For this scenario, telework brings savings of nearly 200 TWh in electricity use in 2021 compared with 2001, or more than 12 percent of Cybertopia’s total 2021 commercial power consumption. In contrast, Zaibatsu’s investments in intelligent transportation systems make commuting easier and result in less telework than in the Reference scenario. As a consequence, Zaibatsu’s reduction in electricity use from telework in 2021, compared to that in 2001, is 39 TWh, or only about 2 percent of total consumption in the commercial sector.

4.3.5 Summing Up: ICT-Driven Commercial Electricity Use, 2001–2021

The combined effects on commercial power consumption of ICT equipment, EMSs, e-commerce, and telework are shown in Table 4.10 and Figure 4.7. To use 2001 as a baseline for comparing our projections with those in the AEO 2002, we assumed that our results for computer and telephone network equipment were included in the AEO 2002 estimates for “other uses” and that our results for percent/25 percent division of teleworking between the commercial and industrial sectors reflects the ratio of workers in each sector; see U.S. Census Bureau, 2001b.
### Table 4.10

**ICT Effects on Commercial Electricity Use, 2001–2021**

<table>
<thead>
<tr>
<th>Electricity Use (TWh)</th>
<th>2021 Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
</tr>
<tr>
<td>ICT equipment</td>
<td>92</td>
</tr>
<tr>
<td>Building EMS</td>
<td>–4</td>
</tr>
<tr>
<td>E-commerce</td>
<td>–2</td>
</tr>
<tr>
<td>ICT-driven subtotal</td>
<td>47</td>
</tr>
<tr>
<td>Non-ICT subtotala</td>
<td>1,120</td>
</tr>
<tr>
<td>Total commerciala</td>
<td>1,170</td>
</tr>
<tr>
<td>EIA total commerciala</td>
<td>1,170</td>
</tr>
<tr>
<td>Difference from EIA</td>
<td>0</td>
</tr>
<tr>
<td>Difference from EIA as a %</td>
<td>0</td>
</tr>
</tbody>
</table>

⁎Rounded to three significant figures.

EMSs, e-commerce, and telework were included in the *AEO 2002* estimates for space heating, space cooling, ventilation, and lighting. This makes our 2001 total match that of the *AEO 2002*, although the components differ in size: our ICT-driven component is much smaller than the one in the *AEO 2002*, and our non-ICT component is larger. For consistency with the *AEO 2002* projections beyond 2001, our non-ICT subtotal in future years increases at the same rate as the non-ICT subtotal in the *AEO 2002*.

The ICT-driven subtotal in Table 4.10 shows that in our projections for the Reference scenario, greater electricity consumption by ICT equipment in 2006 and 2021 is offset by usage decreases resulting from EMSs, e-commerce, and telework. The net effect is that our projected 2021 total electricity use by the commercial sector is 14 percent below that of the *AEO 2002*. Cybertopia’s increased energy management and telework cause its total to be 24 percent less than

---

26We used the *AEO 2002* average annual growth rate of 2.3 percent to extend the *AEO 2002* projected total for commercial electricity consumption from 1,800 TWh in 2020 to 1,840 TWh in 2021.
the AEO 2002’s, Net Insecurity’s reduced telework brings its total closer to the EIA projection. As Figure 4.7 shows, electricity reductions from e-commerce are much less significant than those from energy management and telework in all four scenarios.

4.4 ELECTRICITY USE IN THE INDUSTRIAL SECTOR, 2001–2021

The industrial sector includes more than three million establishments engaged in manufacturing, construction, agriculture, forestry, fishing, and mining. The AEO 2002 projects that industrial electricity consumption will increase at an average annual growth rate of 1.4 percent, from 1,023 TWh in 2001 to 1,416 TWh in 2020. The AEO 2002 also projects that improved efficiencies throughout the sector will
lower industrial electricity intensity (measured as kilowatt-hours consumed per dollar of output) about one-third from 2001 to 2020, taking it from 0.21 to 0.14 kWh/$ of output (EIA, 2001, Table 6).\textsuperscript{27}

ICT’s most significant applications in the industrial sector are to increase both production levels and productivity, primarily through better process controls. Throughout the 20th century, ICT use accompanied industrial electrification, which resulted in more electricity consumption along with vast improvements in output and productivity. But now that virtually all U.S. industrial production is electrically driven, the 21st century will see ICT applied to make production equipment and processes “smarter,” which generally will translate into electricity savings (Commission on Engineering and Technical Systems, 1986, p. 116). As Huber and Mills (2001, p. 5) recently wrote:

\begin{quote}
The old gear and pulley drives are rapidly being replaced with silicon driven power devices that allow manufacturers to cut more sharply, paint more finely and run a more reliable, more productive assembly line. Here again, energy efficiency will undoubtedly improve, so the transformation can be called conservation. But the change is a \textit{conversion}, and it is impelled, first and foremost, by a quest for better performance.
\end{quote}

According to the 1998 \textit{Manufacturing Energy Consumption Survey (MECS)} (EIA, 1998a), manufacturing represented more than 85 percent of purchased electricity in the industrial sector in 1998, and machine drives accounted for more than half of the power consumed in manufacturing.\textsuperscript{28} Space conditioning and lighting used only 16 percent of the total electricity in manufacturing, compared with 33 percent and 50 percent, respectively, in the residential and commercial sectors. Thus, in addition to affecting building EMSs, e-commerce, and telework, ICT, when applied to machine drives and related process controls, can have a large impact on electricity consumption in manufacturing.\textsuperscript{29} Other ICT applications, those using GPS location

\begin{footnotesize}
\textsuperscript{27}Output is measured in 1992 dollars.

\textsuperscript{28}In addition to purchasing electricity, manufacturers generated 13 percent of the electricity they used.

\textsuperscript{29}Some speculate that in the future (the time frame is generally unspecified), manufacturing instructions will be sent over ICT networks to production machines in
\end{footnotesize}
devices and networked sensors, are important to the mining, agriculture, forestry, and fishing components of the industrial sector. Finally, increased use of ICT equipment throughout the economy generally implies the need for more electricity to manufacture the equipment.

### 4.4.1 Industrial Electricity Use by ICT Equipment

Neither the AEO 2002 nor the 1998 MECS breaks out industrial electricity use by computers and other ICT equipment, but Kawamoto et al. (2001) and Roth, Goldstein, and Kleinman (2002) include industrial office equipment in their power consumption estimates for 1999 and 2000, respectively. To develop a 2001 baseline estimate for the industrial sector, we started with the disaggregated data from Roth, Goldstein, and Kleinman and adjusted them to the industrial sector only, using the ratios of industrial/commercial electricity use by office equipment developed by Kawamoto et al. We then extrapolated to 2001 assuming a 4 percent growth rate. This process, which is similar to what we used for the commercial sector (see above), yields a 2001 baseline estimate of 13 TWh for electricity use by industrial office ICT equipment.

ICT sensors, processors, actuators, and transceivers are also embedded in growing numbers of industrial robots, machine drives, and other equipment used in industrial production and processes. Such industrial equipment is not classified as “ICT equipment,” and we found no data on the electricity consumption of the ICT components.

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30More-indirect effects of ICT on U.S. industrial sector electricity use include ICT-driven changes in the demand for industrial outputs (e.g., paper, compact disks, or other physical recording media) and ICT-facilitated outsourcing of industrial production offshore. For further discussion of possible substitutions of ICT network services for physical goods, see Romm, 1999, pp. 38–52.

31Although few data exist on this topic, Roth, Goldstein, and Kleinman (2002, p. 131) cite a Carnegie Mellon University estimate that 43 TWh were used to manufacture computers and office equipment in 1997. Estimating the changes in electricity needed for higher levels of ICT equipment manufacturing requires estimates of and/or assumptions about exports and imports, productivity improvements, and changes in the product mix of such equipment, which are beyond the scope of this study.
in this equipment. However, these ICT components use very little power, which means that even with an upper bound estimate of 50 million smart industrial machines continuously consuming an added 10 W per machine in 2001, their total incremental electricity use would be less than 5 TWh, or less than 0.5 percent of the industrial sector total. We assume 4 TWh for our 2001 baseline estimate, which is probably high.

For the Reference scenario, we project that electricity use by office ICT equipment will increase by about 2 percent per year, a rate similar to that for commercial sector office equipment. Consumption by the ICT components of production equipment will grow at a faster rate through 2010, but will then flatten as smart machines become the norm throughout the sector. Total power consumption by ICT equipment will remain less than 3 percent of the 2021 industrial sector total in all four scenarios.

4.4.2 Changes in Electricity Consumption from ICT Process Control

In contrast to our projection of a small increase in electricity consumption by the ICT equipment itself, we project large electricity savings from the improved control of industrial processes that ICT makes possible. Applications include better control of process heat, refrigeration, compressed air and steam systems, and (especially) motors and machine drives that represent more than 50 percent of industrial power consumption. Digital controls on machine drives continuously adjust motor speeds to follow loads more closely and thereby improve production quality. Adjustable speed motors also increase operating efficiency and reduce standby and operating power consumption; but it is improved quality and overall productivity, rather than energy savings, that drive their installation.

Our projections assume that adjustable speed motors improve machine drive efficiency by an average of 10 percent in 2001 and 20 percent in 2021 (Consortium for Electric Infrastructure to Support a Digital Society, 2001b, p. 15); and that in the Reference scenario, their penetration increases from 10 percent of industrial machine drives in 2001 (EIA, 1998b) to 40 percent in 2021. Because of the greater efficiency of adjustable speed motors, the percentage of industrial
power consumed by machine drives decreases from 51 percent in 2001 to 49 percent in 2021. Total electricity savings in 2021 are 56 TWh in both the Reference and the Net Insecurity scenarios. Penetration of adjustable speed drives in 2021 is greater in Zaibatsu (45 percent) and Cybertopia (50 percent) than in the Reference case, leading to greater electricity savings—63 and 70 TWh, respectively—in these higher-ICT-use scenarios.

### 4.4.3 Electricity Savings from ICT-Facilitated Energy Management in Industrial Buildings

According to the *1998 MECS* (EIA, 1998b), 11 percent of manufacturing establishments had installed energy efficiency equipment that affected space conditioning and lighting. Using this figure as a base, we followed the process we used for commercial buildings (see Subsection 4.3.2) to project electricity savings from EMSs in industrial buildings (Table 4.11). The savings in 2021 range from 22 TWh (Reference and Net Insecurity) to 25 TWh (Zaibatsu) to 29 TWh (Cybertopia). All are considerably below the comparable estimates for commercial buildings, because the industrial sector uses far less electricity for space conditioning and lighting than does the commercial sector.

<table>
<thead>
<tr>
<th>2021 Scenario</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Net Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings with EMS (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1 (6% savings)</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Phase 2 (16% savings)</td>
<td>1</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Phase 3 (24% savings)</td>
<td>0</td>
<td>5</td>
<td>25</td>
<td>30</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>Total EMS buildings (%)</td>
<td>11</td>
<td>30</td>
<td>65</td>
<td>70</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Electricity savings (TWh)</td>
<td>−1.2</td>
<td>−6.7</td>
<td>−22</td>
<td>−25</td>
<td>−29</td>
<td>−22</td>
</tr>
</tbody>
</table>
4.4.4 Changes in Industrial Electricity Use from E-Commerce

E-commerce’s largest effects on electricity consumption are floor space reductions for retail stores and warehouses and power increases for data centers, both of which are counted in the commercial sector (see Subsection 4.3.3). However, B2B e-commerce and ITC-facilitated supply chain management can also reduce the amount of finished inventory needed per dollar of sales, which in turn can reduce the industrial sector electricity required to produce that inventory.32

In 1998, Ernst & Young estimated that e-commerce has the potential to reduce U.S. inventory levels by $250 to $350 billion, or 25 to 35 percent (Margeherio et al., 1998, p. 16).33 Although this estimate seems overoptimistic to us, we used the 35 percent figure for Cyberopia, along with estimates of 20, 25, and 15 percent, respectively, in the Reference, Zaibatsu, and Net Insecurity scenarios. Our scenarios also use the AEO 2002 (EIA, 2001) projections that, from 2001 to 2021, industrial sales will increase 75 percent in constant dollars, and electricity intensity (terawatt-hours per billion dollars of output) will fall 50 percent. The results (Table 4.12) show electricity savings from re-

<table>
<thead>
<tr>
<th>2021 Scenario</th>
<th>2001</th>
<th>2006</th>
<th>Reference</th>
<th>Zaibatsu</th>
<th>Cybertopia</th>
<th>Net Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Online sales (%)</td>
<td>5</td>
<td>20</td>
<td>70</td>
<td>75</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Inventory saved with online sales (%)</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Change in electricity consumption (TWh)</td>
<td>–1.1</td>
<td>–6.9</td>
<td>–34</td>
<td>–49</td>
<td>–59</td>
<td>–29</td>
</tr>
</tbody>
</table>

32 Industrial inventories in 2001 were valued at about $1 trillion. See Bureau of Economic Analysis, 2001.
33 This estimate has subsequently been widely quoted; for example, see Romm, 1999, p. 51; and OECD, 1999, p. 63.
duced inventory levels in 2021 ranging from 2 percent (29 TWh) of total sector consumption (Net Insecurity) to 4 percent (59 TWh (Cybertopia)).

4.4.5 Changes in Industrial Electricity Use from Telework

Our analysis of the changes in electricity consumption that will result from telework in the industrial sector follows the analysis we used for the commercial sector (see Subsection 4.3.4). As in the earlier analysis, we estimate that 25 percent of teleworkers in each scenario are in the industrial sector, thus arriving at the results shown in Table 4.13.

4.4.6 Summing Up: ICT-Driven Industrial Electricity Use, 2001–2021

Table 4.14 and Figure 4.8 show the combined effects on industrial power consumption of ICT equipment, digital process controls, building EMSs, e-commerce, and telework. As with the residential and commercial sectors, for 2001 we matched our total to that in the AEO 2002 to provide a baseline for comparison of projections in subsequent years. We also matched our non-ICT subtotal’s rate of increase to that in the AEO 2002.

Because power consumption by ICT equipment itself is small in the industrial sector, greater ICT use lowers total electricity consumption in all four scenarios. Digital process controls, building EMSs, e-commerce, and telework all yield significant electricity savings. Total sector consumption in the 2021 Reference case is 112

Table 4.13
Changes in Industrial Electricity Use from Telework, 2001–2021

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Teleworkers in sector (million)</td>
<td>4.3</td>
<td>6.3</td>
<td>10</td>
<td>7.5</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Change in electricity use per teleworker (MWh)</td>
<td>-3.0</td>
<td>-3.3</td>
<td>-4.3</td>
<td>-3.5</td>
<td>-5.2</td>
<td>-3.5</td>
</tr>
<tr>
<td>Electricity savings (TWh)</td>
<td>-13</td>
<td>-21</td>
<td>-43</td>
<td>-26</td>
<td>-78</td>
<td>-17</td>
</tr>
</tbody>
</table>
Table 4.14
ICT Effects on Industrial Electricity Use, 2001–2021

<table>
<thead>
<tr>
<th>Electricity Use (TWh)</th>
<th>2021 Scenario</th>
<th>Net Insecurity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
<td>2006</td>
</tr>
<tr>
<td>ICT equipment</td>
<td>17</td>
<td>21</td>
</tr>
<tr>
<td>Digital process controls</td>
<td>–8</td>
<td>–19</td>
</tr>
<tr>
<td>E-commerce inventory</td>
<td>–1</td>
<td>–7</td>
</tr>
<tr>
<td>Telework</td>
<td>–13</td>
<td>–21</td>
</tr>
<tr>
<td>Subtotal, non-ICT²</td>
<td>1,030</td>
<td>1,140</td>
</tr>
<tr>
<td>Total industrial³</td>
<td>1,020</td>
<td>1,110</td>
</tr>
<tr>
<td>EIA total industrial⁴</td>
<td>1,020</td>
<td>1,130</td>
</tr>
<tr>
<td>Difference from EIA</td>
<td>0</td>
<td>–26</td>
</tr>
<tr>
<td>Difference from EIA as a %</td>
<td>0</td>
<td>–2</td>
</tr>
</tbody>
</table>

²Rounded to three significant figures.

NOTE: Electricity savings (e.g., from EMSs) are shown as negative TWh/yr. The “net” lines show the sum of the negative and positive components for each year and scenario.

Figure 4.8—ICT-Driven Industrial Electricity Use, 2001–2021
Electricity Requirements for a Digital Society

TWh, or 8 percent, below that extrapolated from the AEO 2002 projections. The projections for the other 2021 scenarios range from 5 to 13 percent below those of the AEO 2002. These results are similar to but smaller than those shown in Subsection 4.3.5 for the commercial sector.

4.5 PROJECTED ELECTRICITY USE IN THE RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL SECTORS, 2001–2021

Table 4.15 and Figure 4.9 show our projections for ICT-driven and total electricity consumption in all three sectors. In the Reference scenario, the projected total in 2021 of 4,630 TWh is 346 TWh, or 7 percent, below the extrapolated AEO 2002 projection.³⁴ Building

Table 4.15
ICT Effects on Residential, Commercial, and Industrial Electricity Use, 2001–2021

<table>
<thead>
<tr>
<th>2021 Scenario</th>
<th>Electricity Use (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
</tr>
<tr>
<td>Computer, office, and network equipment</td>
<td>118</td>
</tr>
<tr>
<td>Other ICT equipment</td>
<td>79</td>
</tr>
<tr>
<td>Digital process controls</td>
<td>–8</td>
</tr>
<tr>
<td>Subtotal, ICT-driven</td>
<td>149</td>
</tr>
<tr>
<td>Subtotal, non-ICTa</td>
<td>3,270</td>
</tr>
<tr>
<td>Totala</td>
<td>3,420</td>
</tr>
<tr>
<td>EIA totala</td>
<td>3,420</td>
</tr>
<tr>
<td>Difference from EIA</td>
<td>0</td>
</tr>
<tr>
<td>Difference from EIA as a %</td>
<td>0</td>
</tr>
</tbody>
</table>

³⁴We used the AEO 2002 average annual growth rate of 1.8 percent to extend the AEO 2002 projected total for electricity consumption from 4,880 TWh in 2020 to 4,980 TWh in 2021.
EMSs and telework are responsible for the greatest electricity savings, with digital process controls and e-commerce also making substantial contributions.

Of the other three scenarios, Net Insecurity uses the most electricity in 2021 (4,810 TWh), primarily because the 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 leads to power usage that is 400 TWh less than that of Net Insecurity, or a total of 4,410 TWh. Zaibatsu’s total, 4,670 TWh, is closer to that of the Reference scenario but reflects both greater power consumption by ICT equipment and greater savings from EMSs, e-commerce, and telework than does the Refer-
Figure 4.9 compares the relative importance of each component of ICT-driven electricity use within and among the scenarios.

A perhaps surprising outcome for an analysis based on future scenarios is that all four of our scenarios show lower total power consumption in 2021 than that projected in the AEO 2002, ranging from 3 percent lower (Net Insecurity) to 11 percent lower (Cybertopia). This difference stems principally from our baseline 2001 estimates for power use by computer, office, and network ICT equipment being more than 75 TWh, or 45 percent, below those in the AEO 2002 (for the reasons discussed above, in Subsection 4.3.1). The difference widens to more than 200 TWh when projected forward to 2021.35 If not for this systematic difference stemming from our lower baseline estimate, the 2021 projected electricity use for our Reference scenario would be only 2.5 percent lower (and for our Net Insecurity scenario, 1.3 percent higher) than that projected in the AEO 2002. In addition, the relatively narrow range of 400 TWh, or about 9 percent, between our lowest and highest projections for power use in 2021 reflects our assessment that ICT represents a roughly 5 to 6 percent factor in explaining total U.S. electricity consumption.

For the important category of computer, office, and network ICT equipment, our 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 consistent with the data in Roth, Goldstein, and Kleinman, 2002, and Kawamoto et al., 2001, from which our baseline was derived.36 Looking forward, we see that greater power demands from larger numbers of more-powerful digital devices will be moderated by trends toward the use of more electricity-efficient components, low-power embedded devices, and wireless equipment and networks. Reflecting these offsetting trends, the 2021 Reference scenario projects that power consumption of computer, office, and network ICT

35The differences pertain to the residential and commercial sectors, since the AEO 2002 does not estimate power use by computer, office, and network ICT equipment for the industrial sector.

36Roth, Goldstein, and Kleinman (2002, p. 3) estimate that computer, office, and network ICT equipment in the commercial and industrial sectors accounted for 3 percent of national electricity consumption in 2000. Including residential computers and home office equipment would add about 0.4 percent more to that estimate.
equipment will rise to 222 TWh, or 4.8 percent of total usage. Comparable projections for the Zaibatsu, Cybertopia, and Net Insecurity scenarios are 246 TWh (5.3 percent), 199 TWh (4.5 percent), and 261 TWh (5.4 percent), respectively.

Table 4.15 also shows power usage projections for other ICT equipment, which includes residential audio and video systems, home networks, and the ICT portion of industrial production equipment. Home audio and video systems, the largest components in this category, are today mostly analog devices whose power reliability requirements are different from and considerably less stringent than those for computers and other digital equipment. Over the next 20 years, however, audio and video equipment essentially will become all-digital and connected to digital home networks. Although home audio and video systems do not demand the same level of power quality and reliability (PQR) as do data centers and other mission-critical business systems, they represent another component of electricity requirements for digital ICT equipment in an increasingly digital society.

From the perspective of total kilowatt-hours consumed, we find that very large increases in the number of digital devices and in the use of digital networks over the next 20 years will only modestly increase the demand for electricity. What will keep the increase in demand modest is primarily the use of ICT equipment that is more energy efficient, the growth of wireless systems, and the other offsetting trends discussed in this chapter. We looked for, but did not find, a set of plausible assumptions that might support a fifth 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. However, the rapid growth of ICT networks and equipment will dramatically increase the demand for high-quality and high-reliability power, which we explore in the next chapter.

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38We also did not include a “radical transformation” scenario in which greater efficiency, energy conservation, and lifestyle changes reduce ICT network and equipment use to below 3 percent of the national total. While plausible from a technological standpoint, such a scenario would require large-scale behavioral changes that are not supported by current studies or data.
Our analysis also led to several additional findings that seem reasonably robust across the scenarios:

- Telework and ICT-facilitated energy management can have large effects on electricity consumption;
- Both expanded use of digital process controls in manufacturing and B2B e-commerce bring power savings that are not as large as those for telework and EMSs but that are more consistent among scenarios with quite different assumptions;
- B2C 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 responses to time-of-use and real-time pricing, which today seem highly uncertain;
- Telework increases electricity consumption in the residential sector and lowers it in the commercial and industrial sectors, the net effect depending on both the number of teleworkers and the average number of days spent teleworking.

All our projections are, of course, rough estimates based on incomplete data and numerous assumptions about how the future might unfold. Nonetheless, further efforts to reduce uncertainties surrounding the factors identified above should help improve electricity demand projections made by the EIA and other, both public and private, forecasters.