Information Technology Impacts on the U.S. Energy Demand Profile

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The growth of information technology (IT) and the internet may dramatically change society and the energy sector. Effective energy policies require sound research and development (R&D) to investigate these changes. This paper explains how viewing IT and energy in the context of a social system allows us to recognize that the indirect and unexpected effects of IT may dwarf the direct impacts on energy consumption. It also makes recommendations for the difficult task of divining the future of energy demand.

Prognosticating the future of energy use can be dangerous business because, as the old adage goes, "the forecast is always wrong," especially in an era of rapidly emerging and immature technologies (Fraser, 1998; de Neufville, 1990). IT is one of these emerging technologies and is ubiquitous enough to be involved in all sectors of energy use, including transportation, heating, electric power, construction, communication, and manufacturing. It promises to be the newest wave of "creative destruction" by causing business and societal upheaval and by creating openings for new goods, new methods of production, new transportation, and entirely new market and living scenarios (Schumpeter, 1942). Although precise predictions are likely to be inaccurate, it is still possible and advisable to establish a framework to evaluate the impact of IT on the US energy profile. To create this framework, this paper

- provides background on the IT-energy debate
- assesses of the state of relevant data.
- explains and exemplifies the nature of complex and counterintuitive system effects

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[1] Note that the contents present the views of their authors, not necessarily those of the Department of Energy, RAND, or any other organization with which the authors may be affiliated.

- evaluates the substitution of IT for energy
- recommends a research plan

Background

Two major conflicting views exist on the effect of IT on the US energy demand profile. The first view states that the use of more electronic equipment will increase energy consumption and intensity. This school of thought argues that internet machinery constitutes an 8% share of US electricity demand and is likely to grow (Mills, 1999). The opposing school of thought attempts to use more realistic data in estimating that IT is replacing labor and energy as factors in US productivity, and thus drives down energy intensity (Romm, 2000). The views are mutually exclusive and based on significantly different data sources, but neither has enough facts to make reliable predictions.

In addition to these two major views, other work focuses on the link between IT and economic growth or concern themselves with the impact of electronics on the demand for reliability in electric power. These are clearly important issues, but are largely superseded by the larger question of how IT impacts electricity demand while simultaneously spurring enormous social changes and impacting energy use patterns.

Given these two conflicting views, the secondary energy and electricity concerns, and the prospect of social change, DOE faces three major issues in the face of proliferating IT. First, DOE can address the electric load due to electronic equipment. This is relatively simple to research but yields the least useful information regarding broad trends of the future. Second, DOE can address how increased dependence on electronics creates demand for more reliable power. Sensitive electronics may require improving the electric grid or changing the current generation framework. Both of these issues, however, are electricity-specific and limited to narrow economic sectors. The third area of interest is how IT affects social changes and how those social changes affect energy use across sectors and sources. These social factors become the underlying variable, and are also the most difficult to map.

Of these three major issues, energy use by electronic equipment is the most simple and least important. The internet and e-commerce have shown dramatic growth: over 250 million people are estimated to be on-line worldwide, with the numbers expected to grow to 350 million by 2005. Retail e-commerce in the US alone was conservatively estimated by the US Department of Commerce to be $5.3 billion in the fourth quarter of 1999, representing 0.64 percent of retail purchases. Estimates of the electricity cost of all the electronic equipment used to make this happen, including computers, servers, routers, and switches, range from 1% to the previously mentioned 8% of US energy use (Matthews, 2000; Kawamoto, 2000). Although clear data for this is not yet available, it is reasonable to expect accurate estimates of the internet's electricity demands soon. These are reasonable research expectations because the average power consumption of computers and other electronic equipment is known and their aggregate quantities can be tallied. Given the limited range of the internet's electricity needs, the overall change in quantity is likely to be negligible relative to the broad energy demand changes promised by a developing internet society.

The second issue, electric reliability, is a growing concern as sensitive electronics become embedded in society. Complex electronic systems are considerably less tolerant of power fluctuations than light bulbs and other traditional electric devices; disturbances of even less than one cycle (1/60 of a second the US, 1/50 of a second in many other countries) can interfere with IT functionality. Three solutions present themselves to this problem. First, electronics may be designed to be less sensitive to power fluctuations with additional time and development. Second, additional generation systems and distributed generation may play more important roles in the electricity profile of the future. Finally, the US transmission and distribution grid may require significant investment and upgrading to ease congestion and ensure more reliable and higher quality power (Casazza, 2000) . Tradeoffs between these three choices involve cost differences, convenience, power quality, efficiency, and environmental effects. However, this field limits itself to the electric sector. Broader effects of IT can be seen by expanding the scope of investigation to societal effects and other energy sectors.

The third and most daunting of the challenges involves managing entire societal changes that will dramatically reshape the energy demand profile. Will telework decrease energy use in transportation and offices? If so, will those changes be moderated or counteracted by home and lifestyle energy use? In another field, will e-commerce and direct shipping reduce energy use in retail stores and inventory warehouses, and will those reductions be offset by increased energy consumption in distribution and packaging? How energy intensive will people's lives be in an online world? Given today's tools and knowledge, it is impossible to predict accurately these long-term and overall societal effects of internet use. The best we can do is establish a framework and plan for assessing these changes. This socio-economic-energy system is the primary focus of this paper.

The State of Relevant Data

The challenges of societal change are made more difficult by the lack of accurate data. Metrics are unclear as we make predictions about an online age. Some metrics, such as overall energy demand or energy consumption per mile of object transported, are likely to remain constant. Other metrics, such as electricity use per megabyte of information transferred, are relatively new. Even given clear metrics, data is lacking. There is a dearth of definitive data on internet use, and even less information on energy consumption due to this use or energy consumed per unit of information transferred

Data so far are insufficient. Even the simple electricity demand of all internet-related electronic equipment is not accurately assessed yet, and it is only one small part of the overall system. Assessments to date are inaccurate because some studies have exaggerated the power consumption of electronics in claiming that the internet is fundamentally fueled by coal (Mills, 1999). Other studies have more reasonable data, but have them only for short periods of time and by their own admission do not yet credibly reflect established energy intensity trends. (Romm, 2000) Data is also not calibrated, with different studies examining different energy forms; some examine broad energy patterns while others restrict their views to electricity use in the commercial sector.

To the credit of researchers, IT and e-commerce data is not easy to uncover and clarify. Take, for example, the difficulty encountered in just one small subsystem within the overall e-commerce issue: online music. This is an ideal IT subsystem for study because of its transformative social popularity, potentially vast economic consequences, and lack of credible data despite tremendous attention. It has major economic and societal implications and is under heavy scrutiny, yet even here clear data is difficult to discern and the future of this issue is unpredictable. Napster, a files-trading program and eponymous company, is the target of a lawsuit by major record companies concerned about the frequent pirating of copyrighted music. Napster maintains that it provides a legal service and that illegal transfers of music files are not significantly detrimental to music distributors and companies. Record labels claim that CD sales are dropping as a direct result of increased Napster use. Yet the data conflict. One side points to reports that consumers are “swamping” music stores and that the three fastest-selling albums in music history have all appeared in the past year. Another side cites reports that the “swapping of computer files [is] affecting disc sales,” by reducing sales by up to 4% near college campuses where Napster is most frequently used (Lamb, 2000; Learmonth, 2000). Both sources of data are contested by opponents for being inaccurate or misleading. There is no consensus yet.

If a small subsystem under as much scrutiny as music-trading creates so much disarray in relatively simple data, then the overall changes in society due to internet proliferation are clearly beyond simple measure. Music is merely an early indicator of future net debates because its format and information quantity allow for easy transfer over today's internet connections; similar issues will arise in other media later. Whether this issue is called "the canary down the digital mineshaft" or "the tip of a far bigger iceberg, the implication is clear that this is just a small part of a larger system (Economist 2000, 10/5, 6/22). But even here internet data is lacking.

From the musical microcosm to the overall internet, there is still no accurate metric for the amount of information transferred, much less the energy used in doing so. Simple results from small subsystems, such as fuel saved due to telecommuting, remains unclear. Meanwhile, reliable estimates of per-capita energy intensity remain a dream in the rapidly-growing internet society.

It is encouraging that attention is being devoted to the long-term impacts of IT on energy demand. Although data is lacking, basic information and an intelligent framework for thinking about energy challenges may keep the future from surprising us too badly. We currently do not know enough about the internet, or even its basic building blocks. Achieving accurate data even of present trends is a laudable goal. However, most changes occur because of societal changes resulting from new technology. We do have frameworks for social change, and should analyze this case within this larger arena.

Complexity and Counterintuitive System Effects

The introduction of IT to society results in a complex system with such a wide array of possibilities that it is difficult to identify specific cause-and-effect relationships resulting from its use. We do not know, for example, whether telecommuters use less energy at home than they do at offices, or even if they use less fuel in driving for their new lifestyles. We do not know whether improved communication via IT will increase or decrease the desire for personal mobility. We also do not know whether the energy savings from having virtual, online stores mitigate the extra energy used in packaging and shipping products to consumers. Although some data exists on these subjects, it is not comprehensive and especially weak if we were to extrapolate across societies and cultures.

These examples are all indicative of a complex system, one in which linear predictions and solutions are unlikely to work. Indeed, trying to view the IT-energy system piece-by-piece will lead to myopia and missed avenues. A holistic systems view is the best way to address the issue, although this is by nature interdisciplinary and difficult for a single agency to handle.

Myopia in Action: Office Equipment

One extended example of a piecemeal, rather than system approach, can be seen in debates over office equipment. One estimate of total power use by office equipment and network equipment is about 74 Twh per year, or about 2% of the total electricity use in the US (Kawamoto, 2000). Within the business world alone, the EPA estimates that office equipment accounts for 7% of commercial electricity used and maintains that "office equipment, computers in particular, is the fastest-growing source of electricity consumption in businesses and homes" (S.F. Chronicle, 2000).

This sensationalist approach to the electric load of office equipment has the odd effect of masking an even larger sensation: the broader energy effects of the use of electronic equipment. Computers and IT equipment do represent additional energy load, but predictions of resulting surges in electricity demand have been dampened by increased efficiencies, technology advances, manufacturing reductions, and social changes (Harris & Crawley, 2000).

Computer equipment can lead to energy consumption effects orders of magnitude higher than the energy consumption of the equipment itself. A networking card, for example, might require 200 milliwatts, or 4.8 W-hr per day, to operate its internal circuitry. However, the use of the networking card could cause its owner to leave his or her 50 W computer in constant operation, thus leading to a load of 1.2 kW-hrs per day.[2] Thus, the card's impact on the energy consumption of the computer can be 250 times greater than the consumption of the card itself.

Thinking about the card's broader effects on energy use, the same owner may choose to telecommute instead of driving to work each day. One gallon of gasoline could be saved in a 30 mile round trip. The chemical energy in the gasoline, 125 MJ, could be used to generate approximately 11.5 kW-hrs of electricity. This is almost 10 times the energy used to keep the computer on continuously and almost 2400 times the energy consumed by the networking card itself. Clearly, the effect of individual pieces of electronic equipment on the

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[2] 50 watts may be a conservative average figure for computer energy consumption, but also includes part-time monitor use. The EPA estimates that a typical desktop computer uses about 45 watts and a monitor an additional 110 watts. Dell, the largest PC vendor in the United States, figures an average of about 40 watts for its PCs and 70 to 80 watts for a 17-inch monitor. The monitor, however, may switch into an energy-saving mode more often.

energy consumption of a society can be tremendous and considerably larger than the integral of the power flows into those devices. One must consider how the equipment is used, what other energy flows are involved or negated, and how the device affects the manner in which people work and live (Sullivan, 1994). Unfortunately, the borders of the complex system we are contemplating are large: the previous example could have potentially included home heating, server energy use, other car trips, or even a fraction of the energy used in manufacturing and disposing of the car and computer.

Pursuit of these complex systems may initially seem like a fool's folly, but complex systems analysis is eminently possible. Societal effects can sometimes be modeled as an complex engineering system. Part of understanding why this modeling is achievable lies in understanding a systems approach to problem-solving.

IT in the Context of Systems Analysis

The introduction of IT can be easily viewed as a systems challenge. Several systems sciences have been developed in the last half-century to handle difficult input-output questions with many variables, actors, feedback loops, and uncertain consequences. These schools of thought include complex systems analysis and earth systems engineering and management, both of which can be helpful in assessing IT.

Classic science was essentially concerned with two-variable problems: one way causal trains with one cause and one effect or with a few variables at most. The classical example is mechanics. It gives perfect solutions for the attraction between two celestial bodies, a sun and a planet, and thus permits exact prediction of future constellations and even the existence of still undetected planets. However, even a "simple" three-body problem of mechanics no longer allows for a closed solution by the analytical methods of mechanics and can only be approached by approximations (von Bertalanffy, 1969). Given the relative simplicity of three-body mechanical problems, it is readily understandable that complex effects of IT on society must be viewed from a broad, systems-oriented perspective. Like the civil rights movement and the breakup of the Soviet Union, the introduction of IT represents the edge of chaos, that is, the balance point between order and chaos in a complex system and where new ideas and innovation are nibbling away at the edges of the status quo (Waldrop, 1992).

Complex systems belie their name because despite their holistic nature, they can still be disassembled into three elements. The first elements are components, which are operating parts consisting of inputs, processes, and outputs.

Individual IT capabilities are components, as are human reactions and production processes. Each component then has attributes, which are properties or manifestations of the components. Attributes may include such disparate examples as energy consumption levels or desire to travel. Finally relationships are the elements that link components and attributes. These include the complicated cause-and-effect feedback loops and tradeoffs that describe, for example, how IT changes in one sector can affect fuel consumption in another (Blanchard and Fabrycky, 1981). These complex social systems may be daunting, but their analyses are necessary in order to understand the impacts of IT on energy.

Technology and Socioeconomic Interaction

Viewing IT and energy as part of a complex system allows us to recognize that the indirect effects of IT may dwarf the direct impacts on energy consumption. These second order effects are tremendous socioeconomic changes—termed "second" order in this paper only because they are links between IT and massive energy demand changes. They are not of second order importance; instead, socioeconomic links lend added measures of complexity—and understanding—to the introduction of new technologies. This section explains how IT can force social changes, but then again how well-understood and predictable social patterns may then help shape the energy effects of IT.

IT can cause revolutionary social changes in the same way that other major technologies have changed the pattern of life. Automobiles, for example, became so ingrained in American society that they have molded US socioeconomics. They have become ubiquitous and affected nearly every aspect of American life, including which industries are largest, where we choose to live, and what our cities, suburbs, and nation look like. Technology can even change major societal definitions and attitudes, as witnessed by how automobiles altered basic premises of freedom by incorporating mobility into the definition.

Cars became a symbol for freedom, with mobility acting as an important linking factor between automotive technology and the freedom whose definition transformed as a result. It is possible that IT may also become a vehicle for freedom if personal access and virtual mobility rise in importance in this arena. However, the important lesson from internal combustion technology is that its introduction alone did not directly create a world virtually dependent on petroleum. Rather the second-order socially-developed need for freedom and mobility did, demonstrating how technology can help shape social entire socioeconomic patterns.

If technologies can forge and trace socioeconomic patterns, then the reverse can also be true: understandings of socioeconomics can help predict technological trends. Social and economic changes in the US sometimes do follow distinct stages of development that can be measured and modeled and therefore framed and predicted. Even social and economic upheavals can sometimes lead to predictable outcomes and transition patterns (Schumpeter, 1942). These frameworks allow us to draw some parallels in between IT and economic trends. Specifically, the IT-energy framework may follow a broad trend of US industrial-economic developments.

A parallel can be drawn between IT and the development of American socio-economic phases. The US, like many other countries, followed a typical socio-economic path. It started as a primarily agrarian economy that developed with the industrial revolution into a more manufacturing-dependent and urban system. More recently, the US has shifted from an industrial to a more service-intensive economy. The US is not alone in this shift, and now some less developed countries are following similar transformations from agrarian to industrial or even service economies.

IT parallels a service economy because it is the latest stage of economic progression and can also add value to a process even when no manufacturing occurs. This is because both IT and service industries rely on a knowledge economy, with knowledge as the key scarce resource instead of capital or labor. Like service economies, IT promises, albeit without guarantees or proof yet, to be less energy intensive than heavy manufacturing and construction.

The link between poorly-understood technologies and well-understood socioeconomic patterns suggests that technology metering and road-mapping activities can be useful strategies for understanding technology trends and their connections with economic growth. Similarly, economic road-mapping can shed light on the integration and future of new technologies. As recommended by previous scientific and government panels, these societal and technological road-mapping activities should be continued by government with expanded efforts to share perspectives across fields and sectors (NRC, 1999).

Examples of the Complex and Counterintuitive Effects

History is littered with the corpses of predictions and conventional wisdom gone awry in the wake of society-shifting new technologies. These upcoming examples serve to illustrate not the futility of prediction, but rather the importance of including as many features as possible for fear of leaving out critical factors.

An earlier example in this paper dealt with Napster and the proliferation of on-line music trading. Yet this is similar in some ways to the popularization of music on radio. The free broadcast of music by radio was initially perceived by the music industry as a threat. In fact, the opposite was true because radio played a large role in the popularization and sale of music albums. This marketing factor had not been considered, yet it led to a new system by which consumers heard the product for free before purchasing new music albums. The exclusion of this feature from the system model lead to an entirely erroneous prediction.

The popularization of phones in the 19th and early 20th centuries was predicted by some to lead to less travel due to improved communication. Here again, the expected cause and effect relationship failed to materialize. The missing factor this time was that people made more personal and business contact over large distances and thus demanded more travel instead of less. A more recent research trend anecdotally views transport and telecommunications systems to be synergistic and focuses on how increases in email correspond with air transport.

While the above two examples were predictions at complete odds with reality because of missing factors, there are many complex systems hypotheses which are partially right. One example comes from paper. Since paper is very energy intensive to produce, any reductions in paper due to IT could be very important to the overall US energy profile. Popular predictions for paperless offices during the computer revolution appeared doomed to failure for the past two decades. During that time, office demand for paper has increased significantly alongside the rise of workplace computers (Cusomano, 2000). What was missing from systems calculations? The ability to effectively transfer information in the correct medium. People still wanted to read reports on real paper. The reduction of paper is finally beginning to occur not with reading material, but rather with the elimination of entire paper chains in e-commerce. AT&T estimates indicate, for example, that some 15 million pages of paper use per month have been eliminated by going to paperless, internet-based, billing systems for AT&T customers. On the business-to-business side, AT&T will eliminate the use of over 1.5 million pages of paper per year by going to e-commerce links with just one major supplier. According to a study by the Boston Consulting Group, the internet will reduce the demand for paper by approximately 2.7 million tons by 2003, a full 20 years after the enthusiastic paper prognosticating began. Anecdotal data suggests demand of paper per unit of information appears to be decreasing.

How Converging System Components Cause Unexpected Interactions

Proper systems analysis requires consideration of all the components in a system, but these components are not always easy to identify. One example of this difficulty can be seen in the power industry itself. This section examines the unusual path of gas turbine technology, which surprised many by revolutionizing the power market almost as radically as IT may revolutionize society and energy demand.

Gas turbines are now a common and expanding form of electricity generation in the $220 million US power market, but many would not have foreseen this leap one generation ago. These machines are fundamentally different from their steam turbine predecessors in terms of engineering, thermodynamic cycle, environmental output, economics, operation, and social impact. As in IT, the footprint of this technology is considerably larger than the technology alone; it is argued that the technology allowed for a whole new way of doing business in the generation market, thus leading to power deregulation, industry restructuring and radical consumer and social choice in the power industry (Unger, 2000).

Perhaps not surprisingly, the causes of this minor revolution are numerous. To predict the outcome, one would have to know about all of the factors—a critical part of complex systems analysis. In the case of gas turbine technology, there were four major system components, or causes, which helped usher in the new era and fundamentally change an entire industry network (DOE, 1998). These four components included specific technological developments, fuel availability and policy, environmental regulations, and consumer choices. Individually, the forces would not have led to the revolutionary consequence, but change occurred when the four forces converged.

The first component, technological developments in gas turbines, included both predictable improvements and radical changes. Predictable improvements, such as the iterative substitution of metal alloys to allow for higher operating temperatures and improved efficiencies, were numerous throughout the second half of the 20th century. These improvements were almost expected as a matter of course. However, a technological leap occurred with the introduction of cooling systems in the 1960s, which proved to be the catalyst for great increases in temperatures and operating efficiencies. Some engineers would have been able to predict this step-function, but it took many by surprise (Unger, 2000). However, technological improvement alone would not lead to major change.

The second component was a series of laws regarding the availability and use of natural gas. Natural gas is the primary fuel for gas turbines, and this fossil fuel underwent dramatic cost increases during the energy crises of the 1970s. Furthermore, perceived shortages led to the federal Fuel Use Act of 1978, which put a virtual moratorium on the installation of many new gas turbines. Utilities turned to traditional, cheap, coal-fired steam power plants to serve electricity generation needs. This action was a clear signal to turbine manufacturers to reduce effort towards gas turbines, since the future of the technology was significantly jeopardized. Later, beginning during the mid-1980s, the shocks of gas deregulation ended, new gas resources were discovered, complementary industries (such as the gas pipeline and distribution business) had developed further, and gas prices fell back to competitive levels, spurring the market once again. The Fuel Use Act was rescinded and the gates were once again open for the pursuit and introduction of new turbomachinery.

The third component that contributed to the turbine technology revolution was a series of environmental regulations. Tough new anti-pollution laws, including the Clean Air Act and its subsequent amendments, heaped new costs (of externalities) on traditional coal power plants and provided a competitive advantage to gas turbines because of their relatively clean-burning fuel. Thus, environmental policy helped to promote a new era of power production and consumption.

The fourth component that led to industry and social changes was electric deregulation and the introduction of competition to the electric power industry. The Energy Policy Act of 1992 and state level competition-promoting electric regulatory changes, helped to spur renewed interest in and sales of gas turbines in the 1990s. This is because gas turbines are smaller and more modular than traditional steam turbines, thus representing smaller capital investments and quicker rates of return in a power industry that suddenly must care about its profitability in a new, competitive age.

These four components involved many actors, including manufacturers, generators, regulators, and the public. The components also acted as both causes and effects, with complicated interactions and feedbacks between them. Individually they would not have led to major societal or industrial changes, but their interaction and system relationships led to a major restructuring. Furthermore, each of the components would have been difficult to predict, and would only have been forecast by experts in the individual fields. Those experts would not have been able to reach the same conclusions about the other, disparate components, and thus would not (and did not) forecast the fundamental changes to come.

Of course, IT also impacts the power generation field, but the important relationship here is how both information technology and turbine technology can have complex systems effects far beyond what initially appears. Furthermore, critical system analysis requires examining all the converging components and network effects, even though some may appear distant or unimportant. This example did so in hindsight, but a similar framework can also work for predictions. Also, this example demonstrates that identifying individual components is a critical step in identifying relationships in a system. The same must be done for IT and energy.

The Substitution of IT for Energy

We would ideally like to manage the complex and societal changes heading our way due to IT, but from an energy perspective, what do these changes mean for the US energy demand profile? Simple first order effects may include increases in electricity demand in certain areas and the need for more reliable energy grids to supply electricity to sensitive electronic components. However, the last two sections of this paper demonstrate that the largest effects may be second order or system effects resulting from IT-induced societal changes. This fundamentally means that societal changes may facilitate the de facto substitution of IT for labor and energy.

This section examines five ways in which the substitution of IT for energy may occur. First, IT may offset the need for energy consumption via telework. Second, the substitution may be seen in "virtual" stores and e-commerce, exemplified by Amazon books and HomeRuns.com. Third, IT might reduce energy consumption in conventional stores by streamlining product inventory, distribution and sales cycles, thus reducing waste and increasing efficiency. Fourth, IT may help create more intelligent buildings and machines which may operate more efficiently. Finally, IT can lead to dematerialization of goods, thus saving the energy of those goods' production and distribution.

Telework

Telework offers the possibility of energy demand changes by allowing people to avoid having to commute to an office. One telework energy example was examined earlier in this paper in a simplified two-variable comparison between the energy use of a networking card and the energy saved through not driving. Although our understanding of the social and environmental dimensions of some service areas such as telework is improving, we are far from understanding the social, environmental and cultural impacts of information infrastructure, and the services it enables. Nevertheless, telework is increasingly recognized as an important “triple bottom line” technology in many companies. It benefits firms economically, because they save on rent and can retain valuable employees, and because teleworking employees are generally more productive. It provides social benefits because employees and their families enjoy a higher quality of life. Moreover, traffic congestion, a major problem in many urban and suburban areas, is reduced, which benefits everyone who uses the roads. It provides energy and environmental benefits because fuel use and emissions are reduced if unnecessary commuting is limited (Allenby and Richards, 1999; FIND/SVP, 1997).

The data underlying these telework conclusions are sparse and incomplete to some degree, and the extent to which societal patterns will change over time in unpredictable ways must be considered in any comprehensive cost/benefit assessment. Thus, a systems approach might lead one to ask whether in the longer term the availability of internet infrastructure, combined with the delinking of place with work, might not lead to completely different patterns of energy use with corresponding implications for demand for products (enhanced e-commerce); transportation systems (more dispersed populations requiring greater private transport); and impacts on the breadth and vitality of urban centers. Again, IT makes telework possible, which in turn creates social changes. The social changes, though still unclear, promise further changes in the US energy profile.

E-Commerce

IT can also change the energy demand profile by potentially replacing conventional, or meatspace, stores with cyberspace e-commerce. E-commerce may lead to some substitution of IT for energy, but may also create some additional energy needs. Once again, a systems approach is necessary to assess the likely overall impact. The analytical difficulties of the complex e-commerce scenario become notably acute given how e-commerce has exploded in recent years (Bodman, 1999). Here, there are no analytical structures or methodologies by which to begin evaluating the energy implications of such a complex phenomenon (Cohen, 1999; Rejeski, 1999). Nevertheless, the outlines of a framework can be seen in several examples.

Two examples of common on-line purchases can be seen with food and books. In the book business, Amazon began a trend by selling books through its website. Conventional bookseller Barnes and Noble responded by establishing its own e-commerce capabilities, while both companies also compete with other online retailers of related products, such as Pennsylvania-based music retailer CDNow. In the food business, companies such as HomeRuns.com compete against traditional supermarkets and local grocers by offering online purchases followed by home delivery. In all of these cases, websites vie against concrete-and-glass stores—and against each other—as areas of browsing and purchase. The simplest of energy analyses would compare the energy use of a website with the energy use of a meatspace store, yet even this is difficult. Anecdotally, the website requires a small fraction of the energy (almost all in the form of electricity) to operate in comparison to a store, which requires a variety of energy forms for heating, lighting and operation. A more comprehensive analysis would compare the energy used in the construction of a computer server to the energy consumed in construction of a retail store—or the energy saved in not constructing the retail store at all. Proceeding further, a full life-cycle analysis would include the (upstream) changed inventory structure of the store and the (downstream) differences in energy consumption if personal travel to stores for purchases yields to the individual packaging of goods followed by air-and-truck distribution to individual customers' homes. Although this energy-intensive distribution is indirectly caused by IT, energy expenditure may also be reduced by improved distributing routing algorithms and mitigated by a reduction in personal travel to retrieve purchases. Finally, a systemic study could also include the changes in land-use patterns and the dispersion of population that may occur if remote living becomes easier. The energy implications of such large social changes are tremendous, but will not be clear without additional study and systemic comparisons.

E-commerce is not limited to website versus store comparisons. IT can also reduce energy consumption in conventional stores by streamlining distribution, sales cycles, and business to business (B2B) marketing models, thus reducing waste and increasing efficiency (Kumar and Kromer, 2000). Consider Home Depot, which has shifted from simply selling home and construction equipment to small contractors—its most important customer segment—to offering a purchase sizing service. Contractors can log in to enter details of their job and Home Depot software then calculates what they will need and arranges for just-in-time delivery to the job site, eliminating the usual industry practice of over-estimating materials, which then get wasted. What's ordered gets used as a result of a more efficient, IT-aided process (Allenby, 2000).

Intelligent Systems

IT can also change the energy demand profile by creating intelligent or responsive control systems that can optimize energy use in buildings and machines. Examples abound, but the fundamental driver is cost-saving. Sometimes this economic efficiency leads to energy efficiency also, but it should be noted that one does not always lead to another.

The most heralded example of intelligent IT energy systems, that of electric metering in a deregulated market, offers the promise of selective purchases so that consumers can respond to real-time electric pricing. This allows consumers to reduce their demand (within limits) during price peaks by identifying the peaks through IT and then adjusting their building or factory controls correspondingly. The cost advantages for this system are clear, especially if consumers have flexibility in the time of their demand. The overall energy advantages, however, are more complicated. Delayed electric demand may not mean a change in aggregate demand over longer periods if conservation is limited to narrow time windows.

The ability to "game" electric prices, could impact energy demand more profoundly if the energy profile of electricity generation changes as a result. This can happen in two ways. First, price peaks usually induce generating companies to increase their supply and gain additional revenue while prices are high. To do this, they start running their most expensive, frequently least-energy-efficient equipment. If IT systems can cause consumers to shave these price peaks, the bursts of inefficient generation may fall also, thus reducing the fuel demands of generating companies. The caveat to this is that the advantages of load-leveling are independent of aggregate improvements power plant efficiency. High electricity prices do not have a standardized effect on efficiency; rather, the effects depend primarily on the supply profile and status of generator competition.

The second way in which intelligent IT metering could affect the energy profile is that it can facilitate and buttress discretionary electric supply choice. Consumers in several states, for example, have the option of selecting their choice of generation companies. Although the contract path of electricity does not remotely match the actual electron path from generators to consumers, it is possible to "select" alternate generation technologies such as biomass, solar, or wind. Electricity is more expensive from these sources than from traditional coal- and gas-fired power plants, but a thriving green power market is facilitated when consumers can make environmental choices while being spared the pain of price peaks mentioned earlier.

Of course, electric metering is only one example of intelligent IT energy systems. Other examples, such as building thermostats, may have nothing to do with electricity and may save fossil fuels directly instead. However, all these systems revolve around cost savings. Whether these cost savings convert to higher energy efficiencies depends on the systems.

Dematerialization

In the Amazon, Barnes and Noble, and HomeRuns.com examples earlier, stores are "dematerialized" into the realm of IT, but products remain real and solid. This section deals with how IT can dematerialize goods as well as stores, and the energy impacts of these changes. Unlike the case before, where changes in the very existence of buildings can lead to enormous social, mobility, and housing dispersal choices, here the immediate effects can be as important as second order impacts.

Dematerialization allows items that are primarily based on information to remain in electronic form. Thus, items that are constituted of information or intellectual property, such as printed specifications or forms, audiovisual material and books, are prime candidates for dematerialization. Any of these items or products can be digitized and electronically transmitted instead of printed, packaged, or physically placed on any solid medium. With no packaging or manufacturing, energy consumption goes down per unit product.

Earlier, the music industry and Napster were used as examples of poor and conflicting data. Here, we use the same area to illustrate a fundamental material and social change as a result of IT. The electronic transfer of music files threatens not only those who seek revenue for intellectual property, but those who make the hardware necessary for carrying that property. CDs themselves become extraneous. The energy savings of not manufacturing them can extend up the product life cycle to include metal mining energy, smelting energy, factory production energy, and packaging and distribution energy. The same is true for the petroleum plastics in videotapes no longer necessary and pulp in newspapers and books no longer printed.

Dematerialization can also apply to inventory waste, but with a slightly different definition of dematerialization so as to include the elimination of the need for inventory. One example of this can be seen in Dell Computers. The usual practice in the computer industry is to maintain a 60 to 80 day average inventory. Especially given the rapid pace of technological evolution in that industry, that translates into a lot of inventory that never gets sold, thus becoming waste (and the warehouse space and transportation systems that are used, as well as the manufacturing impacts embedded in the product, are also wasted). Dell, on the other hand, uses its e-commerce systems, both upstream and downstream, to operate on about 6 days of inventory. This e-commerce system has created a profound shift in the economics of Dell's operations: in 1990, Dell had sales of $546M and required $126M in net operating assets to run its business. By 1998, however, Dell had $18.2B in sales using only $493M in net operating assets. Operating assets as a percent of sales declined from 23% to 3%, while return on invested capital was up from 36% in 1990 to over 400% in 1998 (Bodman, 1999). In short, as in the case of energy consumption per unit economic activity, anecdotal evidence suggests that the Internet could be a powerful dematerialization technology (Allenby, 2000).

Framing Efficiency

As demonstrated, IT may affect energy consumption in both direct and indirect ways. It consumes electricity directly, although this is only a small fraction of the overall energy influence. It also makes fundamental shifts in production and society that prevent some products from even being manufactured and changes the way other goods are transported, thus affecting energy consumption. However, many of the illustrations of the previous section actually deal with improving the energy efficiencies of entire processes or product chains, such as saving energy not used in retail sales and unnecessary inventories. This raises an interesting question of the value of pursuing efficiency alone.

A focus on how IT increases energy efficiency may lead to an ideological problem. Although increasing energy efficiency is a worthwhile interim goal, it may not achieve longer term objectives of a genuinely sustainable energy future. Here, we may benefit from a review of a similar situation of a technological revolution in England's history. Like IT, the introduction of the steam engine prompted widespread societal growth while promising efficiency and decreased energy intensity.

England began the 18th century with the Savery steam engine, a crude and inefficient forerunner of the more successful and celebrated machine devised 67 years later by the Scottish engineer James Watt. The Savery engine was nevertheless the state-of-the-art machine in the first part of the 1700's, helping England become the leading industrial power in the world. England burned great quantities of its coal reserves, prompting some fears that the nation's coal seams would someday be "emptied to the bottom and swept clean like a coal-cellar." Many of these fears dissipated with the introduction of the Watt engine, which ran almost 20 times more efficiently than the Savery version. When the Watt engine was put into wide service, coal consumption initially diminished by one-third. However, history showed that the market entrance of the new and efficient engine eventually prompted demand for coal to rise tenfold. It was the flip side of the Savery scenario—far greater energy efficiency made engines much less expensive to run, which led to an extraordinary increase in the use of coal and a net increase in energy consumption (Inhaber, 1994).

The steam engine example may parallel some aspects of IT introduction. Many of the examples of IT cited above, including dematerialization, intelligent systems, and some aspects of e-commerce, are potential improvements in efficiency alone. The short term and long term implications of these improvements are still unclear. IT efficiency may not be the end goal from a DOE perspective. As the Savery example demonstrates, cumulative long-term effects are also important.

Recent data do show improving trends in national energy efficiency, and the examples above show how IT can contribute to energy efficiency, but we are unable to attribute the national trend to IT yet. More definitive proof is necessary to establish this link.

Conclusions and Recommendations

There is good reason to believe that IT is a revolutionary phenomenon that is already reshaping US energy needs. Although IT relates directly to the energy sector through its own electric demand and need for reliability, IT's overall impacts on energy demand are dominated by indirect and complex socioeconomic system effects.

Accurate data on a variety of fronts is scarce, leading to several competing views of IT's impact on energy demand. The simple comparisons of office equipment energy use are a useful first step, but the systemic and social impacts of IT reach far beyond what is currently being studied. The greater effects of IT may include land use changes, a greater dependence on electronics, increases or decreases in personal mobility and travel, a reduction of waste through IT efficiency, and the dematerialization of some goods. Complex systems analysis of these interactions is challenging, but it is feasible and necessary to discover how IT interacts with socioeconomic forces and, in turn, affects energy demand profiles across sectors. There are several tools and system frameworks at our disposal, including relatively well-understood economic patterns that make social and technological roadmapping possible.

Table 1 summarizes the research needs identified in this paper. Combined, they form a research plan which DOE can implement in an effort to manage and predict how IT will impact the US energy demand profile. The nature of complex systems dictate that most of these research areas are interdisciplinary

Table 1

Information Technology Research Needs

Area or Concern	Research Need
Direct Links Between Information Technology and Energy	
Electric load of IT equipment	Standardized metrics (energy/unit of data transfer)
	Credible basic and aggregate data on energy use
Electric reliability	Research on the desensitization of IT equipment to short electric fluctuations
	Optimization of investments enhancing existing transmission and distribution grid
	Analysis of competitive and independent system operator effects on electric reliability
	Projection of reliability impacts and costs of distributed generation
Indirect, Societal, and Complex System Links Between IT and Energy[a]	
Socioeconomic and energy impacts of IT[b]	Technology and socio-economic roadmapping
	Identification of IT, socioeconomic, and energy system components (including elements, attributes, and relationships)
	Identification of IT correlations with sectoral switch to service-based economy
	Substitution of knowledge for capital and labor
	Long term vs. short term value of incremental increases in energy efficiency
	Long-term analysis of correlation of decreasing energy intensity and the rise of IT
Telework	Balance of energy costs and benefits of telework on several levels
	Simple comparison of energy equipment use
	Comprehensive life cycle analysis including equipment construction and disposal energy
	Complex system analysis of resulting changes in land use patterns, traffic patterns, travel preferences, fuel use, and energy demand
E-commerce	Simple analysis (Conventional store energy consumption vs. website energy consumption)
	Life cycle analysis (Conventional store construction and disposal vs. server construction and disposal)
	Systems analysis (Customer driving energy vs. goods packaging and delivery energy)
	Complex social systems analysis (Changes in land use or population dispersion)
	Energy impacts of waste reduction and B2B efficiency gains

Table 1—Continued

Area or Concern	Research Need
Intelligent systems	Effects of electric gaming on retail electric generation choice and fuel use (i.e. green power)
Dematerialization	Life cycle energy savings and aggregate quantities of material not produced
	Inventory (i.e., Dell)
	Goods (i.e., CDs, paper)
	Paper (i.e., AT&T)
	Survey personal preferences (Do people want dematerialized goods?)
	Transition costs (Social cost and effects of companies left behind wave of creative destruction)

[a] Potential substitution of IT for energy.

[b] Analysis of general complex systems interactions.

and do not fall into traditional agency research categories. Many components of analysis span issues of commerce, energy, labor, and social desire. Complexity and breadth are not valid excuses to avoid studying these systems. We have proven abilities to tackle systems analysis, and they must be applied to IT and energy as well.

Our success at energy planning and management depends on making reasonable projections. Our frequent inability to understand the future except in terms of the past is a limitation that becomes especially apparent during times of rapid technological evolution. Despite this handicap, we now have tools and a framework for analyzing the impacts of IT on the US energy profile.

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Disruptive Civil Technologies. Six Technologies with Potential Impacts on US Interests out to 2025. Biogerontechnology Energy Storage Materials Biofuels and Bio-Based Chemicals Clean Coal Technologies Service Robotics The Internet of Things.Â Geopolitical: Energy storage materials could have a profound impact on the geopolitical balance of power.Â Cheap reliable sources of alternative energy storage could reduce the demand for oil, particularly for transportation, though other primary sources of energy (specifically, electricity) will be necessary to supply the energy to recharge batteries, provide the charge for ultracapacitors, or generate hydrogen. Reduced oil demand would insulate the United States from its dependency on foreign sources of oil. Electricity demand has grown over the past few years and will continue to grow in the future. The increase in electricity demand is mainly due to industrialization and the shift from a conventional to a smart-grid paradigm. The number of microgrids, renewable energy sources, plug-in electric vehicles and energy storage systems have also risen in recent years. As a result, future electricity grids have to be revamped and adapt to increasing load levels.Â Demand-side management (DSM) programs offer promising solutions to these issues and can considerably improve the reliability and financial performances of electrical power systems. This paper presents a review of various initiatives, techniques, impacts and recent developments of the DSM of electrical power systems. Energy demand management, also known as demand-side management (DSM) or demand-side response (DSR), is the modification of consumer demand for energy through various methods such as financial incentives and behavioral change through education. Usually, the goal of demand-side management is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times such as nighttime and weekends. Peak demand management does not necessarily decrease total energy