Assessing the Potential of Information Technology Applications To Enable Economy-Wide Energy Efficiency Gains

REPORT

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INTRODUCTION AND OVERVIEW

Information technologies are ubiquitous in modern society. That they should find increasing application which enabling energy efficiency improvements throughout the economy, whether in Europe, the United States, Japan or elsewhere in the world, should not be surprising. IT is already embedded in numerous devices, software tools and networked systems that directly or indirectly contribute to energy productivity gains in building, industrial, transportation, and energy supply systems. The evidence indicates that these uses have been growing especially as both energy supply and energy prices have become increasingly volatile.

In many instances, the IT applications that bring energy gains are integral parts of larger IT-based systems established to provide services, improve performance, increase productivity and quality, and achieve other goals of sectoral institutions. The most mundane consumer products, from toys to refrigerators, stoves and coffee makers have embedded microprocessors. Digital control devices and sensors have been rapidly replacing analog electronic devices in numerous industrial sectors whenever economically and technologically feasible. Digital electronics have become critical components in auto vehicle and most other transportation systems.

In numerous applications, sophisticated analog systems employing the latest advances in materials technology and mechanical systems have merged with digitally-based and/or IP-addressable control devices. Sensors have become increasingly solid-state, with the capability of linking to analog-to-digital converters within digital control systems consisting of embedded microprocessors, application specific integrated circuits (ASICs), other solid-state components, and that can guide the actions or movements of ubiquitous mechanical systems such as motors, pumps, fans, compressed air systems, etc. or more sophisticated industrial equipment such as machine tools, mixers, conveyors, robots, etc. Indeed, sensors and automatic controls have widespread use in every sector of the economy, including buildings, transportation, electric power generation, consumer appliances, entertainment, etc.

The primary driver in the spread of IT has been the microprocessor revolution, which stems back to the 1950s and 1960s, but really took off in the 1970s and 1980s. The evolution of microprocessor technology has been governed by Moore's "Law" which stipulates that number of circuits on an integrated circuit chip--and therefore, roughly, its computing power per unit cost- will double every 18 to 24 months. Microprocessors made possible the desktop PCs and peripheral devices (such as printers), but as they became more miniaturized and inexpensive, they have steadily found their way into a wide array of devices and systems. A huge away of products embed ASICs, designed to process data and information to serve the special requirements or purpose of these products (e.g., direct digital controllers on HVAC equipment).

The invention of the Internet was a revolution that emerged out of the microprocessor revolution. The origins of the Internet lie in federally funded research that began in the early 1960s. Researchers funded by the Defense Advanced Research Projects Agency (DARPA) started to explore how geographically dispersed computers could communicate with each other. By the 1990s the Internet had become widespread, and with the invention of the web-browser, the World-Wide Web came into being. Today, the Internet has become an indispensable part of modern life, spurred by the growing power of inexpensive, miniaturized microprocessors and advances in communications technology and software tools.

Distributed computer networks, applying a set of standards called Electronic Data Interchange (EDI), began to be applied in the 1980s to exchange communications between and within businesses, organizations, government entities and other groups. Today, most large enterprises have installed internal digital information networks connecting workplaces, offices, and machine processes to monitor and control their operations, most of which increasingly are web-enabled. Most electronic commerce between companies and their customers and suppliers are EDI-based, and again, increasingly web-enabled.

The Electric Power Research Institute (EPRI) observes that the "concept of automated interactive communication and control is extremely powerful, and many believe that networked intelligence will eventually come to dominate daily life." For example, an *EPRI Journal* article cites Cisco CEO John Chambers' "grand vision of the home in the twenty-first century that is based on a highly networked 'digital lifestyle'" [EPRI, 2006]. It further notes that major hardware and software suppliers such as Intel and Microsoft predict that "every consumer device that can be networked will be networked." These interconnected appliances will be used "in the home for entertainment, convenience, health care, and energy management." Meanwhile, building control systems will employ networked appliances for lighting, comfort, and energy management.

In this review of energy efficiency enabling IT applications, the notion of interactive digital communication and control networks for the management of energy demand and supply, appears as a prominent vision in every major sector. Demand for IT products will no longer just involve standalone components, devices, and software tools. Energy management driven by policy goals to dramatically reduce energy use and increase energy efficiency in every part of the economy will increasingly rely on the creation of advanced networks linking multiple IT-enabled monitoring, measuring and control technologies and applications across and within factories, businesses, buildings, energy generation, transmission and distribution, and transportation systems.

The evolution and expansion of "smart" energy management networks--often linked to or embedded within other networked systems designed to achieve other ends (e.g., productivity and quality improvements in industry; safer, more comfortable, affordable and efficient transportation)--in the end will be the primary drivers of demand for a very large range of IT-innovations designed to save energy and promote energy efficiency across the economy. The IT applications can be characterized as a series of layers. Lower layers consisting of digital devices and software tools can stand alone as important energy efficiency innovations, but many also serve as integral components of higher layers characterized by increasing levels of networked operations.

At the highest level are broad visions of integrated advanced communication and control systems such as the "smart grid" in electricity generation, energy management information systems (EMIS) in manufacturing, energy information systems (EIS) and energy management systems (EMS) linking buildings to utilities and internal building energy management controls and smart end use devices, and "intelligent highway systems." The goals of these visions are far from being accomplished. However, over the next 10-15 years, substantial progress towards achieving these goals will likely be made, especially if driven by government policies requiring significant gains in energy efficiency and reduced GHG emissions on economy-wide bases. At the same time, it is likely that government policies also will be needed to provide incentives and regulations that encourage and enable the movement towards these visions (e.g., R&D investments, tax incentives, subsidies, interoperability and other technical standards, etc.), a full discussion of which is beyond the scope of this paper, however.

The tables presented in this study were developed from an extensive survey of relevant literature on IT applications that could enable gains in energy efficiency and energy savings across multiple sectors, over a time horizon spanning the present to a decade or more. Specifically the tables are structured to present the following information:

- The major sectors and energy service demands associated with these sectors;
- The principal IT applications and innovations that can enable energy efficiency gains in these sectors and energy service demand areas;
- The primary information technologies employed in these applications;
- The primary modes of enabling energy efficiency gains associated with each application;
- The time horizons for their implementation and widespread diffusion.

EXPLANATION OF CATEGORIES, CODES AND CONVENTIONS

The sector tables which follow evaluate a wide-range of information technology (IT)-enabled applications that can directly or indirectly cost-effectively improve energy efficiency -- in short, improve overall energy productivity -- in each of the four major energy-using sectors: buildings, industry, transportation, and energy supply. The key energy service demands -- the primary reasons for using energy such as heating, cooling, lighting, travel, and industrial processes -- are identified and described within each sector; and for each, one or more IT applications that can improve energy productivity are identified and described. In addition, the principal information technologies that underlie and characterize each application are identified. Finally, the tables provide an estimate of the time horizon for when these applications and their underlying technologies are likely to be developed, diffused and widely adopted. The categories associated with each of the analytical dimensions—technology, mode of enabling, and time—are described and explained below, as are the "grey dot" conventions used to visually indicate the relative importance and emphasis of the categories within each dimension.

Principal Sectors and Energy Service Demands

The four sectors in the table account for most of the greenhouse gas emissions generated in modern economies. Buildings, industrial processes, and transportation systems all rely heavily on energy for their operation, and there remain significant opportunities for making improvements in how energy is managed and used in these sectors, as well is in the energy supply sector.

Buildings *(Residential, Commercial, and Industrial)*

The building sector consists of three major types of structures that serve different purposes: residential buildings which range in scale from single homes to condominiums and apartment buildings, commercial buildings which range from small store-front businesses to large high-rise office buildings; and industrial facilities which house the production processes, offices and other operations of industrial firms. Although for each sector, and within each sector, there numerous special purpose energy service demands, there are common types of energy use common to all. All use electric power, and all contain similar types of energy-using end-use devices, such as lighting, heating, ventilation and air condition (HVAC), boilers and water heaters, and electric and electronic appliances. Energy efficiency applications therefore would aim at reducing electricity use of buildings as a whole, and increasing the energy efficiency of end-use devices used in buildings. Some applications also aim to help builders design and construct new energy efficient buildings, or retrofits existing buildings to make them more energy efficient.

Industry

The table mainly emphasizes reducing energy use in manufacturing industries, which rely on electricity for operating their machinery and processes. (Electricity use for powering industrial buildings is addressed in the Buildings section.) Other energy fuels, such as oil, natural gas, coal and biomass are used to generate heat or serve as feedstock for production processes, especially in energy-intensive manufacturing industries such as steel, chemicals, and paper and pulp. Electric power is critical however, for all these processes. IT applications can enable more efficient use of the other fuels by making process energy systems more efficient. In particular, IT applications for more efficient process heating and more energy efficient energy conversion equipment and components are examined.

Transportation

The transportation sector includes the automotive (cars and trucks), aviation, railroad, and marine sector. Applications that make automotive vehicles more energy efficient are the most important, as they can greatly help reduce the use of petroleum-based fuels (gasoline, diesel) and reduce GHG emissions. Intermodal shipping (where two or more different modes of transportation are used in the transport of freight) and in aviation are also sectors where IT applications can have important impacts on fossil fuel use.

Energy Supply

The energy supply sector primarily consists of the petroleum, natural gas, coal, and electric power generation industries, though it might also include biomass and ethanol fuels. The table focuses solely on the electric power sector, which produces GHG emissions primarily by burning the other fuels, especially coal and natural gas. IT applications also are likely to have their greatest effect in the electricity sector. Energy savings in electricity production will translate into lower demand for the other fuels (as will energy efficiency gains in industry and transportation). In addition, because IT itself is electricity based, it can more easily be applied to helping utilities more efficiently and effectively manage electric power supply and demand, and also to make the electricity generation, transmission and distribution processes more efficient.

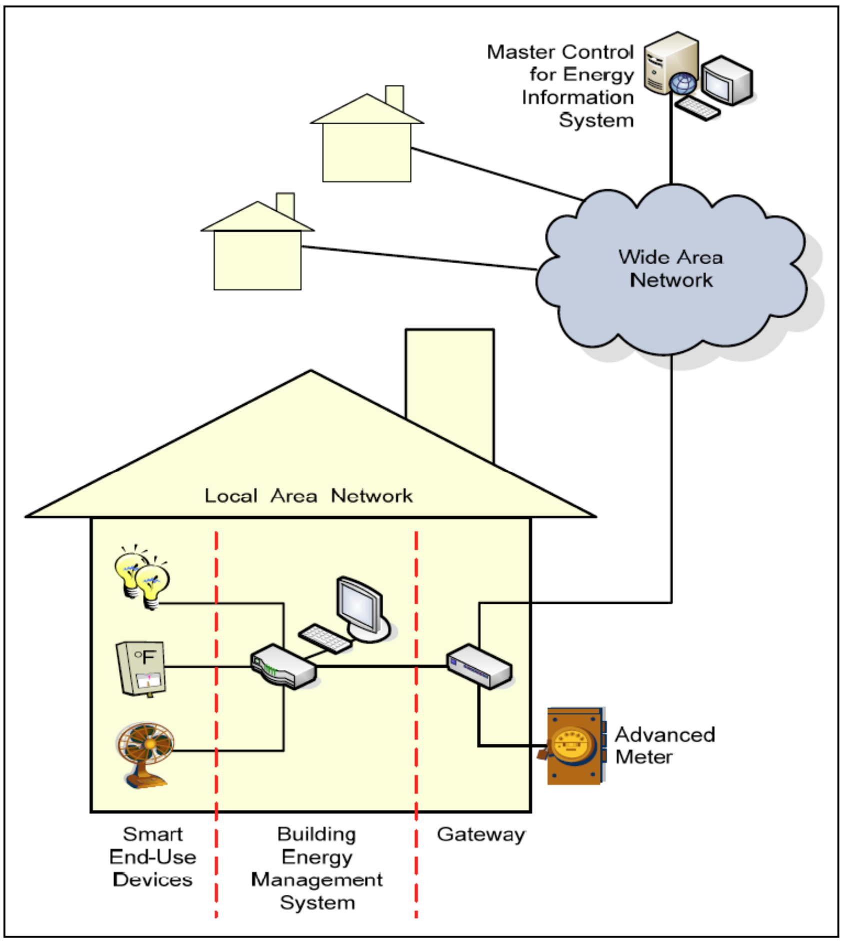
Energy Efficiency Applications

The IT applications examined in the table fall into six broad types that largely can be characterized as layers. Although each layer has its own characteristic features, many applications at one level may also be integral components of higher layers. For example, figure 1 illustrates the different layers of applications in buildings sectors integrated into a utility controlled energy information systems.

Integrated Energy Management Systems

At the highest level are IT-based energy management systems consisting of an integrated set of advanced communications, computer systems, sensors, meters and controls, digitally addressable and efficient end-use devices, and software technologies. These are broad networked systems designed to monitor and control energy use throughout a sector. The basic elements and character of these systems in each sector are very similar to those in other sectors--and may in fact be electronically linked and integrated with each other.

Figure 1 – IT Applications Used in Buildings



Source: EPRI, 2007a

Advanced Communications Systems

Central to all integrated energy management systems are advanced digitally-based communications technologies. These include the Internet, power-line based broadband, and wide-area networks, which link through gateways and switching devices to local area networks, which in turn hook-up sensors, meters and control devices, as well as electronic end-use devices within sector or part of a sector. Advanced wireless systems are increasingly being applied in energy management and control networks, in some instances replacing wired communications equipment. Each communications technology requires associated software operating systems, applications, protocols and tools.

Advanced Sensors, Meters and Controls

Advanced sensors linked to digital controllers and electronic meters are required applications for monitoring, managing and reducing energy use in all sectors. Many are linked in networks restricted to a particular building, or part of a building, an industrial process system, a transportation vehicle or portions of the electrical grid.

Digitally Addressable Devices

Demand is growing for Internet-addressable end-use devices (such as a lighting system or boiler in buildings, or industrial process heater in manufacturing), capable of linking to higher level communications networks that form the backbone of energy management and control systems.

High Energy Efficiency End-Use Devices

These are energy-efficient end-use devices such as lighting systems, HVAC equipment, process equipment, smart vehicles, appliances electronic equipment, and the like, employing advanced sensors, digital controllers, microprocessors and other technologies that reduce their energy use. They may be stand-alone devices or tied to localized energy management systems that monitor and control their operation to optimize their energy use. Some of these devices may be replaced by newer, Internet-addressable models, which enable them to tie-into web-based energy management systems.

Design and Simulation Tools

Software design and simulation tools already exist to help engineers, designers and managers of energy systems design, configure, retrofit and modify structures, equipment, and devices to be more energy efficient. New, more advanced software tools will be needed to meet the growing demand for more energy efficient systems in all sectors.

Information Technologies

These are the basic generic types of information technologies that constitute the principal components of the IT applications reviewed in the tables. Multiple technologies can be employed in individual applications (e.g., Building Energy Management Systems), and individual types of technologies can be employed in a wide-range of applications (e.g., sensors and controls).

Code	Technologies	Description
SC	Sensors and Controls	Sensors and controls have ubiquitous use in all sectors, which should be distinguished from sector-specific sensor and control applications.
SW	Software Systems & Applications	Software applications and tools are employed in multiple types of applications throughout all sectors.
AC	Advanced Communications and Internet	Internet and advanced communications technologies enable a wide range of applications, though specific applications may require specially-tailored software protocols and applications and enabling devices.
IT	IT Equipment & Systems	General purpose computers, peripherals and related computing equipment.
MP	Microprocessors & ASICs	Microprocessors and Application Specific Integrated Circuits (ASICs) are embedded in most of the devices employed in the applications.
DE	IT Enabled Devices	Many applications involve integrating special digitally-based devices (e.g., advanced meters)

Energy Efficiency Enabling Modes

Each application enables reductions in energy use and energy efficiency gains in one or more ways. These are described, and the associated codes used in the tables are given, below.

Code	Enabling Mode	Description
1	End-Use Products & Processes	The application directly or indirectly improves the energy efficiency of end-use products and processes.
2	Energy Management	The application enables improvements in the management of energy supply or demand resulting in reduced energy use and greater energy efficiency.
3	Energy Supply	The application enables more energy efficient production and distribution of energy.
4	Behavioral Choices	The application enables or influences choices by individuals or groups that directly or indirectly result in reduced energy use and improve energy efficiency.

Time Horizons for Technology Adoption

Based on a review of the literature, and other information, a projection is made regarding the extent applications are likely to diffuse and find widespread use over different time frames. In some instances, an application may find earlier widespread use in some markets but not in others. For example, while building applications may apply to residential, commercial and industrial structures, they will likely be more cost-effective and employed earlier in larger buildings, especially commercial and industrial buildings, than in residential homes.

Code	Time Horizon	Description
NT	Current or Near-Term	The application already is being deployed in some form.
SM	Short-to-Mid-Term	The application will find greater use over the short-to-mid-term, i.e., 3-5 years.
OH	Over-the-Horizon	The application will not be developed or become widespread until at least 5 or more years.

What the Grey Dots Mean

The table employs different sized grey dots to schematically illustrate the relative emphasis or importance of different characteristics for each application. The dots represent a best "guestimate" based on the literature and logical inference. Larger dots signify greater importance or relevance or degree than smaller dots. The meaning of the dots is explained below for each category. These are meant to be suggestive, not precise measures.

IT Technologies

The dots reflect the relative importance of a technology in an application. Usually one technology is predominant, though other technologies may be important as well.

●	The technology is central to the application.
•	The technology is an important supportive technology, but not necessarily a central component of the application
·	The technology is embedded in the application but plays primarily a relatively small supportive role.

Energy Efficiency Enabling Mode

The dots reflect the primary modes of how an application enables energy gains. Sometimes an application will enable energy efficiency in more than one way. However, one mode is usually more important than the others, reflected by the larger dot.

●	Reflects a major mode, if not the primary mode, that an application enables energy gains.
●	Reflects an important, but not primary mode of enabling energy efficiency.
●	Suggests a less important, secondary mode of enabling.

Time Horizon

●	The application is likely to become widespread during this period
●	The application has achieved some degree of diffusion into the economy, but is still not widespread.
●	The application exists and being employed, but is in an early stage in its evolution.

IT-ENABLED ENERGY EFFICIENCY APPLICATIONS
BUILDINGS (including Commercial, Industrial and Residential)

Table 1A—IT Application Descriptions—Buildings

Energy Service Demand	EE Application	Description
Electric Power Use	Energy Information Systems [EIS]	Dynamic web-enabled system that allows real-time integration of consumers and their building energy systems into utility company systems and market operations. Includes software, data acquisition hardware, and communications systems administered by a utility company to provide energy-related information to building managers (including households), facility managers, financial managers and electric utilities.
	Advanced Communications Networks	Two-way communications systems that allow automated control of building end-use devices in response to pricing or emergency demand reduction signals. Includes wide area networks (WANs) that provide data communications over broad areas (metropolitan or regional) used to connect local area networks (LANs) and other types of networks. It's a building block of EIS's, linking utility servers, LANs inside buildings and meters through gateways, i.e., devices that handle communications between the utility and devices on customer premises (e.g., thermostats, water heaters, pool pumps).
	Advanced Meters and Metering Infrastructure (AMI)	Advanced meters are devices for recording or communicating actual electric use during minutes, hours, days or weeks, which enables time-of-day, on peak/off peak or other billing rates. AMI systems measure, collect and analyze energy use data from advanced meters (connected to WANs and LANs through gateways). Includes hardware, software, communications, customer associated systems, data management software.
	Building Energy Management Systems (EMS)	Enables end users to monitor, analyze and control building systems and equipment to achieve energy efficiency gains. An information and control system to coordinate and optimize operations of end-use equipment, e.g., turns them off when not needed. Includes Local Area Networks (LANs) which link servers, computers and digital end-use devices within a small geographic area like a home, office, group or buildings. Also requires application software, custom-programmed databases, and series of control devices and data sensors.
End-Use Devices and Equipment	Smart and Efficient End-Use Devices and Equipment	Internet protocol (IP) addressable or standalone digitally controlled energy end use devices and equipment. IP addressable devices can link via LANs to building EMS's, and through gateways and WANs to utility-operated EIS's. Standalone devices have digital controllers and often embedded smart sensors to automatically control device use in accordance with consumer energy management needs. IP-addressable or digitally controlled devices can include lighting systems, thermostats, motors and fans, window shades, smart appliances, among others.

Table 1A—IT Application Descriptions—Buildings (cont'd)

Energy Service Demand	EE Application	Description
Lighting	*IP-Addressable Lighting Systems*	Includes IP-addressable lamps, ballasts, and window shades, linked to smart sensors (occupancy sensors, photo sensors), digital controllers, and building EMS, governed by sophisticated lighting control protocols, to automatically deliver appropriate amount of light where and when it is required. Could be applied to fluorescent lamp-ballast systems, controllable and dimmable electronic High-Intensity Discharge and other dimmable lamps, such as light-emitting diode lamps (LEDs), cold cathode fluorescent lamps, and compact fluorescents.
	Direct Digital Controlled (DDC) Lighting Systems	Automated standalone lighting systems (within a room or area) controlled through a combination of direct digital controllers and smart sensors (e.g., occupancy sensors).
Heating, Ventilation and Air Conditioning (HVAC)	*IP-Addressable Devices for Monitoring and Controlling HVAC Equipment*	This includes IP-addressable thermostats for air temperature HVAC control, and addressable adjustable speed drives which control the speed of motors and fans or cut off the load of electric equipment (e.g., air conditioners).
	Direct Digital Controllers (DDC)	Use sensors to match demand, heat requirement and burner cycle times of HVACs to increase efficiency of the system. Can be standalone DDCs which do not require information from other controllers or computers to maintain control. Distributed DDCs are usually located near equipment they control. Building level DDCs may be accessed remotely from workstations over LANs or telephone lines, allowing maintenance departments to remotely troubleshoot HVAC systems.
Boilers and Water Heaters	*Direct Digital Control (DDC) and Sensor Systems*	Consists of sensors, digital controllers, computers, and software that proves real-time data needed to maximize boiler system efficiency. Intelligent setback controllers turn off water heaters when hot water is not required. Allows logic-intense control functions to be carried out, such as temperature reset, optimizing fuel/air mixture, managing combustion, controlling feedwater and drum levels. Other smart control devices include intelligent digital setback controller that turns off a water heater when hot water not required; automatic blow-down controls, and automatic controls that sense and respond to boiler water conductivity and pH.
Appliances and Electronics	*Smart Appliances*	Includes smart home appliances that have communications and controls capabilities, including refrigerator, washers/dryers, water heaters, etc.
	Energy Star Compliant Devices with Low-Power IT Components	Appliances and electronics designed to comply to Energy Star standards, with embedded low-power digital components and controls.
Whole buildings	Web-Based Building Design Software Tools	Software and web-based tools to help building industry design new or retrofit existing buildings for greater energy efficiency. Computer tools also can help building managers improve the operation of buildings and diagnosis of problems. Building diagnostics and commission software helps builders work through procedures when a building is new to ensure all systems--lighting, heating, ventilation, air conditioning--are operating according to design specifications.

Table 1B—Information Technologies and Enabling Modes—Buildings

Energy Service Demand	EE Application	Information Technologies						EE Enabling Mode			
		SC	SW	AC	IT	MP	ED	1	2	3	4
Electric Power Use	Energy Information Systems [EIS]		●	⬤	⬤		●		⬤	●	●
	Advanced Communications Networks		●	⬤			•		⬤		•
	Advanced Meters and Metering Infrastructure (AMI)		•	●	•	•	⬤		⬤		
	Building Energy Management Systems (EMS)	•	●	⬤	⬤		⬤		⬤		●
End-Use Devices and Equipment	Smart and Efficient End-Use Devices and Equipment	⬤	•			•		⬤			
Lighting	*IP-Addressable Lighting Systems*	⬤				•		⬤			
	Direct Digital Controlled (DDC) Lighting Systems	⬤				•		⬤			
Heating, Ventilation and Air Conditioning (HVAC)	*IP-Addressable Devices for Monitoring and Controlling HVAC Equipment*	●				•		⬤			
	Direct Digital Controllers (DDC)	⬤	•			•		⬤			

Table 1B—Information Technologies and Enabling Modes—Buildings (cont'd)

Energy Service Demand	**EE Application**	**Information Technologies**						**EE Enabling Mode**			
		SC	**SW**	**AC**	**IT**	**MP**	**ED**	**1**	**2**	**3**	**4**
Boilers and Water Heaters	*Direct Digital Control (DDC) and Sensor Systems*	●	·		·	·		●			
Appliances and Electronics	*Smart Appliances*	●	·			·		●			
	Energy Star Compliant Devices with Low-Power IT Components	•	·			•		●			
Whole Buildings	Web-Based Building Design Software Tools		●	•	•			●	•		·

Table 1C—Diffusion Time Horizons—Buildings

Energy Service Demand	EE Application	Time Horizon			Comments
		NT	SM	OH	
Electric Power Use	Energy Information Systems [EIS]	•	●	⬤	Residential sector will adopt later than commercial and industrial. Will be developed, tested and applied in mid-to-large sized buildings. As costs go down, then will be made more available to residences.
	Advanced Communication s Networks	•	●	⬤	Same as above regarding residential building adoption.
	Advanced Meters and Metering Infrastructure (AMI)	•	●	⬤	Same as above regarding residential building adoption.
	Building Energy Management Systems (EMS)	•	●	⬤	
End-Use Devices and Equipment	Smart and Efficient End-Use Devices and Equipment	•	●	⬤	
Lighting	*IP-Addressable Lighting Systems*	•	●	⬤	
	Direct Digital Controlled (DDC) Lighting Systems	●	⬤	●	
Heating, Ventilation and Air Conditioning (HVAC)	*IP-Addressable Devices for Monitoring and Controlling HVAC Equipment*	•	●	⬤	Several smart thermostats are commercially available, and can be addressed via one-way communications over power lines. AMI's will enable thermostats with 2-way communication capabilities more common.
	Direct Digital Controllers (DDC)	●	⬤	●	DDC's have been replacing pneumatic and electric control systems that traditionally had been used by HVAC industry. More than 90% of new construction in the US uses DDC. Digital solutions for machine control and motion control, especially board-mounted controllers to provide adjustable speed control potentially improve efficiency from 70% to 90%. [EPRI-2007c]

Table 1C—Diffusion Time Horizons—Buildings (cont'd)

Energy Service Demand	EE Application	Time Horizon			Comments
		NT	SM	OH	
Boilers and Water Heaters	*Direct Digital Control (DDC) and Sensor Systems*	●	⬤	•	
Appliances and Electronics	*Smart Appliances*	•	●	⬤	
Appliances and Electronics (cont'd)	*Energy Star Compliant Devices with Low-Power IT Components*	•	●	⬤	
Whole Buildings	Web-Based Building Design Software Tools	●	⬤	⬤	

Table Codes

Information Technologies		EE Enabling Mode		Time Horizon	
SC	Sensors & Controls	1	Energy Use	NT	Current or Near Term
SW	Software Systems & Applications	2	Energy Management	SM	Short-Mid-Term *[2-5 years]*
AC	Adv. Communications &/Internet	3	Energy Supply	OH	Over-the-Horizon *[>5 years]*
IT	IT Equipment & Systems	4	Behavioral Choices		
MP	Microprocessors & ASICs				
ED	IT-Enabled Devices				

IT-ENABLED ENERGY EFFICIENCY APPLICATIONS

INDUSTRIAL PROCESSES

Table 2A—IT Application Descriptions—Industrial Processes

Energy Service Demand	EE Application	Description
Process Energy Systems Process	Energy Management Information Systems (EMIS)	Integrated system to detect, measure, store data, and benchmark energy used in manufacturing processes, with goal of providing relevant information to key individuals and departments, to enable them to improve energy performance. Elements include sensors, energy meters, hardware, and software that may already be integrated into existing process and business performance monitoring systems. Sensors and instruments include energy meters (electricity, gas, oil, steam), other utility measures directly associated with energy use (cooling flow, compressed air flow) and temperature, pressure, flow, composition and similar devices to measure factors that influence energy use. Usually connected to a monitoring system, such as a distributed control system or a supervisory control and data acquisition (SCADA)/programmable logic control (PLC) installation.
	Advanced Sensors and Automatic Controls Systems	Measurement and control systems are key components of virtually every industrial process, essential to the proper operation and profitability of most industries. Integrated measurement devices linked to intelligent control systems and process automation improve plant energy efficiency while also boosting productivity by increasing throughput, yield and product quality. Advances in sensors, controls, automation, information processing and robotics can make significant gains in industrial energy efficiency and cut energy costs.
	Inferential Process Controls	Uses a variety of data--on line process measurements, delayed product property measurements, and customer feedback--to predict, or infer, ultimate production quality. Instead of a delayed response to a problem with product properties or customer feedback, an inferential control system would use selected data to anticipate and correct for the problem to eliminate any variation in the output and customer response. By controlling final product quality, inferential process control will improve quality, minimize waste and save energy and cost. Technologies involve data management, inference technology, control systems (to take information for the inference technology to manipulate the process), and supervisory system (involving process and sensor fault detection and identification).
Process Conversion Equipment and Components	*Software Assessment Tools*	Tools that help plant managers make good decisions about implementing efficient practices in manufacturing facilities. The DOE's Industrial Technology Program makes available tools to assess and make decision about selecting and managing the most energy efficient equipment such as compressed air systems, motors, pumps, steam systems, and insulation for heating and steam systems.

Table 2A—IT Application Descriptions—Industrial Processes (cont'd)

Energy Service Demand	EE Application	Description
Cross-Cutting	Wireless Sensor Networks and Micro-Electromechanical Systems (MEMS)	Intelligent sensors with built-in communications capabilities that can wirelessly communicate with industrial controls. Sensor nodes can dynamically adapt to and compensate for device failure or degradation, manage movement of sensor nodes, and react to task and network requirement changes. Wireless sensor networks can enable practical deployment of MEMS, avoiding failure modes resulting from attaching bulky wires to the miniature devices. Continuous, high-resolution ubiquitous sensors with distributed intelligence have the potential to autonomously monitor and control industrial processes, maximizing product quality and yield while minimizing waste, emissions and costs. Relatively new, wireless technologies hold the potential to help U.S. industry use energy and materials more efficiently.

Table 2B—Information Technologies and Enabling Modes—Industrial Processes

Energy Service Demand	EE Application	Information Technologies						EE Enabling Mode			
		SC	SW	AC	IT	MP	ED	1	2	3	4
Process Energy Systems	Energy Management Information Systems (EMIS)	●	●	•	•		•		●		•
	Advanced Sensors and Automatic Controls Systems	●	●	•	•		•		●		•
	Inferential Process Controls	●	●	•	•		•		●		•
Process Conversion Equipment and Components	*Software Assessment Tools*		●					●	•		•
Cross-Cutting	Wireless Sensor Networks and Micro-Electromechanical Systems (MEMS)	●	•	•		●		●	•		

Table 2C—Diffusion Time Horizons—Industrial Processes

Energy Service Demand	EE Application	Time Horizon			Comments
		NT	SM	OH	
Process Energy Systems	Energy Management Information Systems (EMIS)	•	●	⬤	
	Advanced Sensors and Automatic Controls Systems	•	●	⬤	The DOE estimates that if recommended investments are made in developing and adopting advanced sensors, controls, automation, information, and robotics technologies throughout the manufacturing sector, a 5% gain in energy efficiency ultimately would be possible. One DOE report in 2004 estimated benefits of 12 trillion BTU savings per year by 2010.
	Inferential Process Controls	•	●	⬤	
Process Heating	*Process Heating Sensors and Automatic Controls*	•	●	⬤	In 1998, a U.S. steel mill replaced antiquated equipment with modern, state-of-the-art, computer-controlled systems monitored from a central control center, allowing the plant to save energy and use fewer generators, boilers and blowers. The new controls enabled the capture and use of waste steam and heat and for generating electricity and additional steam instead of relying on purchased fuel. Blast furnace gases and waste steam released were cut by an estimated 30%, purchased fuels were cut 50%, resulting in $12 million in annual fuel savings. [DOE-OIT 2000]
Process Conversion Equipment and Components	*Software Assessment Tools*	•	●	•	
Cross-Cutting	Wireless Sensor Networks and Micro-Electromechanical Systems (MEMS)	•	●	⬤	Wireless sensor networks are a cross-cutting technology that will have application in all other sectors (buildings, energy supply, transportation) in energy information and management systems, as well is in a wide-range of applications involving sensors, controls and information processing to achieve other production and service objectives.

Table Codes – Industrial Processes

Information Technologies		EE Enabling Mode		Time Horizon	
SC	Sensors & Controls	1	Energy Use	NT	Current or Near Term
SW	Software Systems & Applications	2	Energy Management	SM	Short-Mid-Term *[2-5 years]*
AC	Adv. Communications &/Internet	3	Energy Supply	OH	Over-the-Horizon *[>5 years]*
IT	IT Equipment & Systems	4	Behavioral Choices		
MP	Microprocessors & ASICs				
ED	IT-Enabled Devices				

IT-ENABLED ENERGY EFFICIENCY APPLICATIONS

TRANSPORTATION

Table 3A—IT Application Descriptions—Transportation

Energy Service Demand	EE Application	Description
Automotive	Intelligent Transportation Systems (ITS)	ITS' (aka Intelligent Vehicle Highway Systems (IVHS)) are designed to better manage traffic on well-traveled roads to reduce congestion and ensure safer, quicker, less expensive, and more energy efficient travel. ITS encompasses a broad range of wireless and wire-line communications-based information, control and electronics technologies. Navigational systems with display panels in cars help drivers around heavy traffic and help them avoid accidents. Automated controls that will enable vehicles to run safely with greater speed and shorter inter-car distances. Computers watching and channeling traffic in communication with vehicles acting as display terminals can keep thing running more smoothly than current highway systems. Software-based traffic management technologies communicate with drivers on busy interstate highways through navigational systems and variable message signs. Advanced software tools will address complex traffic control and management issues—i.e., helping management centers anticipate and avert traffic congestion--in an information-based, dynamic ITS environment. Basic technologies for an ITS that need further research include (1) automated lane keeping technology based on magnetic markers; (2) vehicle on-board devices for assistant driving; (3) vehicle to roadside and inter-vehicle communications; (4) roadway surveillance technologies for incident, obstacle, road surface conditions, etc.; and (5) infrastructure data bus and in-vehicle data bus technology.
	Smart Vehicles	Future cars in the ITS environment will contain increasing information and communications technology--more than a mode of transportation, they also will be a communications device, melding the functionality of transport and wireless communications. With on-board wireless technology smart cars will be able to communicate with others on the road to share road data, travel information, traffic conditions, etc. Instrumental panels will display vehicle data, location, and position based on information, attributes, and paths of nearby smart cars.

Table 3A—IT Application Descriptions—Transportation (cont'd)

Energy Service Demand	EE Application	Description
Automotive (cont'd)	*On-Board Communications Equipment, GPS, Sensors and Processors for Smart Cars*	Many technologies exist today for making "smart" vehicles a reality. New more advanced technologies will be needed, and in larger numbers than are embedded in vehicles today. Advanced sensors, processors and communications equipment will interact with the ITS infrastructure systems, and other vehicles on the road. Global Positioning Systems (GPS) receivers will be a key part of the system. They are already in many cars coupled to sensors and digitized maps to provide on-screen maps for driver navigation. Telematics systems i.e., GPS integrated with mobile communications and computer technologies coupled with remote monitoring and control services (e.g., the GM OnStar service) are becoming more common. Radio-frequency identification (RFID) tags--which use low-power short-range transmitters and receivers to communicate identification numbers, allow a vehicle to identify itself. Many autos already have them allowing for automatic toll taking.
	Sensors and Digital Controls for Fuel Efficiency	Smart vehicle technology can help make vehicles more fuel efficient, also enabling advanced vehicles (hybrids, plug-in hybrid electric vehicles), whose electrical requirements will drive the need for higher power and higher performance digital content. Sensors will monitor vehicle data such as location, speed, engine speed, temperature, transmission gear, fuel and oil levels, tire pressure and emissions. Advanced systems will include sensors for longitudinal or lengthwise distance measurements with radar, laser, or infrared (IR) detectors. Sensors provide inputs into microprocessor-based electronic control units (ECUS), enabling more efficient subsystems such as engine management, climate controls, air quality controls, battery monitoring, and braking systems. The electronic content in engine controls, for example, creates a networked, close-loop system that manage the emissions and fuel economy of the vehicle by creating the perferct ratio of fuel/air mixture.
	Flash Microcontroller Electronic Control Units (ECUs)	Flash-based microcontrollers are the command centers for ECUs. Their reprogramability allows system designers the flexibility to implement software upgrades, monitoring and diagnostic capabilities, and distributed intelligence systems in response to changing customer needs or government mandates. A typical vehicle uses an average of 25-30 microcontrollers; some luxury vehicles contain as many as 70. This number will grow, as microcontroller ECUs replace relays, switches, and traditional mechanical functions with higher-reliability components, cutting the cost and weight of copper wire. They enable more efficient subsystems such as engine management, climate controls, air quality controls, battery monitoring and braking systems. In the emerging networked vehicle, greater communication and coordination between these subsystems will be required.

Table 3A—IT Application Descriptions—Transportation (cont'd—1)

Energy Service Demand	EE Application	Description
Automotive (cont'd)	*Embedded Processors and Electronic Motors*	Electronic motor technologies have been replacing mechanically actuated automotive systems, such as power steering and fuel and water pumps. Brushless direct current (BDLC) motors, a type of synchronous motor, are designed for automotive applications, such as pumps, cooling fans, and stepper motors. The heart of the BDLC is an embedded microprocessor, and a numerous embedded-processor solutions are available to automotive design engineers. The 16-bit digital signal controller (DSC), is particularly ideal for BLDC motor control. The DSC platform provides the control of a microcontroller with the computation and throughput capabilities of a digital signal processor (DSP). DSC's also provide the capability of processing complex, high-speed mathematical functions required by many automotive electronic systems.
	Smart Plug-in Hybrid Electric Vehicle (PHEV) Link to Smart Grid	A PHEV gains its primary energy directly from the electricity grid. It will have an onboard charger that plugs into an electric outlet or it can be plugged into a charger installed in a service garage. A smart PHEV would be Internet-ready, allowing the owner to communicate with his/her car via text messages to check if the battery needs charging. When a PHEV is plugged in and idle, utilities' computer-based energy management system would note any surges during peak demand period and signal cars to send back their power, and would charge the vehicles when electricity demand is low.
	Tire Inflation System	Trucking fleets are concerned with maintaining proper tire inflation pressures. A 10-psi drop in inflation pressure can result in a 1 % drop in fuel economy. Electronic pressure monitoring and inflation systems for commercial vehicles are an option to address the problem. Some systems provide real time tire pressure monitoring and send pressure and temperature data to off-board communications systems. Recordkeeping functions and temperature monitoring allows systems to automatically compensate for fluctuation and ensure proper inflation regardless of tire temperature. A warning lamp alerts the driver if a tire deviates from manufacturer's recommended pressure. Each tire's condition can be graphically indicated on a dash display unit, allowing the driver to see the current pressure of each tire. A control system module with an integrated driver display also enables tires to deflate and inflate under different road conditions (soft soil, severe grades, sand, snow). Other systems include hand-held and drive-by readers, allowing tires to be tracked electronically, providing accurate tire pressure maintenance information instantly.

Table 3A—IT Application Descriptions—Transportation (cont'd—2)

Energy Service Demand	EE Application	Description
Intermodal Shipping [trucking, aviation, marine and railroad freight transport]	Freight Transport Logistics Management	Truck freight transport companies are using route-planning software to reduce emissions and internet matching systems to fill empty vehicles. Such systems can employ underlying map databases to reengineer their fleet routing, and help retailers and logistics providers cut back on wasted "backhaul," when vehicles return home after a delivery with no cargo. In Europe, one in three vehicles run empty, according to some estimates.
	Intermodal Logistics Tools	Intermodal shipping, comprising moving freight by at least two different modes of transport--usually involving the shipment of containers and trailers by rail, truck, barge, or ship, is the fastest growing segment of the transportation industry. The real potential for cutting carbon emissions may lie in enabling shippers to switch amoung modes of transport, such as shifting from trucks to lower emissions carriers such as water and rail transport. Researchers are working on geographic intermodal freight transport models to determine the most energy efficient strategies and help shippers choose among shipping options.
	GPS and IT-Enabled Logistics	On-board GPS, electronics communications and display systems, RFID, and other smart vehicle technologies are essential components for enabling smart logistics monitoring, planning and management for truck freight transport.
Aviation	Air Traffic Control Modernization Technologies	Aircraft fuel has risen to 20-30% of airline operating costs. Modernization of air traffic control systems to more accurately and efficiently route and manage airspace can reduce fuel burn. For example, an on-board technology allows pilots to fly more direct point-to-point routes reliably and accurately. More efficient trajectories allow aircrat to operate on better time tracks, with less excess fuel reserves, allowing them to carry extra payload. Another software tool enables controllers to predict potential aircraft-to-aircraft and aircraft-to-airspace conflicts earlier, allowing them to construct alternative flight paths with fewer deviations to the route or altitude and less restrictive climb or descent profiles.
	Automatic Dependent Surveillance-Broadcast Technology	This technology uses GPS to determine a plane's position and lets pilot space out their aircraft more efficiently during landing. Aircraft are at their most fuel-efficient at cruise altitude, reducing the time spent circling at lower levels substantially cutting emissions.

Table 3B—Information Technologies and Enabling Modes—Transportation

Energy Service Demand	EE Application	Information Technologies						EE Enabling Mode			
		SC	SW	AC	IT	MP	ED	1	2	3	4
Automotive	Intelligent Transportation Systems (ITS)	•	⬤	⬤	⬤		●	●	⬤		●
	Smart Vehicles	●	●	⬤			⬤	•	⬤		●
	On-Board Communications Equipment, GPS, Sensors and Processors for Smart Cars	⬤	●	⬤		●	⬤	•	⬤		●
	Sensors and Digital Controls for Fuel Efficiency	⬤	•			●		⬤			
	Flash Microcontroller Electronic Control Units (ECUs)	⬤	•			⬤		⬤			
	Embedded Processors and Electronic Motors	⬤				⬤		⬤			
	Smart Plug-in Hybrid Electric Vehicle (PHEV) Link to Smart Grid	●		⬤			•		●	⬤	
	Tire Inflation System	⬤		•			●	⬤	●		•

Table 3B—Information Technologies and Enabling Modes—Transportation (cont'd)

Energy Service Demand	EE Application	Information Technologies						EE Enabling Mode			
		SC	SW	AC	IT	MP	ED	1	2	3	4
Intermodal Shipping [trucking, aviation, marine and railroad freight transport]	Freight Transport Logistics Management		⬤		•				●		⬤
	Intermodal Logistics Tools		⬤						•		⬤
	GPS and IT-Enabled Logistics			•		•	⬤		•		⬤
Aviation	Air Traffic Control Modernization Technologies		⬤	•			●		•		⬤
	Automatic Dependent Surveillance-Broadcast Technology		●				⬤		•		⬤

Table 3C—Diffusion Time Horizons—Transportation

Energy Service Demand	EE Application	Time Horizon NT	Time Horizon SM	Time Horizon OH	Comments
Automotive	Intelligent Transportation Systems (ITS)	•	●	⬤	
	Smart Vehicles	•	●	⬤	
	On-Board Communications Equipment, GPS, Sensors and Processors for Smart Cars	●	⬤	⬤	
	Sensors and Digital Controls for Fuel Efficiency	●	●	⬤	
	Flash Microcontroller Electronic Control Units (ECUs)	●	●	⬤	
	Embedded Processors and Electronic Motors	•	●	⬤	
	Smart Plug-in Hybrid Electric Vehicle (PHEV) Link to Smart Grid	•	•	●	
	Tire Inflation System	•	●	⬤	A return on investment analysis by the U.S. Dept. of Transportation, Federal Motor Carrier Safety Administration (FMCSA) indicates an ROI period of 1-2 years on a $1,000 per tractor-trailer combination for a pressure monitoring and automatic inflation system for commercial vehicles. Even for fleets with relatively good tire maintenance practices, with lower than average costs of improper inflation, the ROI period is still less than 3 years. [Skydel, 2006]

Table 3C—Diffusion Time Horizons—Transportation (cont'd)

Energy Service Demand	EE Application	Time Horizon			Comments
		NT	SM	OH	
Intermodal Shipping [trucking, aviation, marine and railroad freight transport]	Freight Transport Logistics Management	●	●	⬤	Software by Roadnet, a division of UPS, helps logiistics managers at companies such as Pepsi and Anheuser-Busch re-engineer their fleet routing. In one application, Roadmap customers reportedly save an estimated 54.4 million gallons of fuel/year and can cut about 85,000 trucks and cars out of their logistics systems. [Murray, 2007]
	Intermodal Logistics Tools	•	●	⬤	
	GPS and IT-Enabled Logistics	●	●	⬤	
Aviation	Air Traffic Control Modernization Technologies	•	●	⬤	
	Automatic Dependent Surveillance-Broadcast Technology	•	●	⬤	

Table Codes

Information Technologies		EE Enabling Mode		Time Horizon	
SC	Sensors & Controls	1	Energy Use	NT	Current or Near Term
SW	Software Systems & Applications	2	Energy Management	SM	Short-Mid-Term *[2-5 years]*
AC	Adv. Communications &/Internet	3	Energy Supply	OH	Over-the-Horizon *[>5 years]*
IT	IT Equipment & Systems	4	Behavioral Choices		
MP	Microprocessors & ASICs				
ED	IT-Enabled Devices				

IT-ENABLED ENERGY EFFICIENCY APPLICATIONS
ENERGY SUPPLY

Table 4A—IT Application Descriptions—Energy Supply

Energy Service Demand	EE Application	Description
Electric Power Generation, Transmission and Distribution	Smart Grid Technologies	A smart electric grid envisions an electronically controlled, self-healing electricity supply system that is fully capable of responding in real time to the billions of decisions made by consumers and their increasingly sophisticated, digital, microprocessor-controlled appliances and devices. It also would employ advanced sensors, metering, controls and communications over the grid to monitor and switch power flows, enhanced demand-side management applications and advanced metering initiatives, and for identifying potential problematic transformers and predict other equipment failure. Major breakthrough innovations needed include digital electronic controls for the power delivery network; integrated communications; AMIs; integrated distributed energy resources; advances in digital end use devices.
	Broadband-Over-Power Lines (BPL)	Broadband over power lines (BPL) is the use of power line communications technology to provide broadband Internet access through ordinary power lines. A utility can use the BPL network for utility functions like enhanced monitoring and communication with customers as part of a broader smart grid initiative, and to bring new technologies to their transmission and distribution networks. Some of the utility functions that can be supported by the new BPL system include voltage sensing on a real-time basis, aggregation of meter reading, peak load reductions and demand side management, stray voltage detection, and partial discharge detection, which can be a key part of avoiding cable failures or other faults that have led to outages in the past. Voltage sensing is useful for energy management, monitoring the health and efficiency of transformers, and identifying problematic transformers and predicting possible equipment failure.
Electric Power Demand Management	Energy Information Systems [EIS]	See **Buildings** sector discussion Table 1A
	Advanced Communications Networks	
	Advanced Meters and Metering Infrastructure (AMI)	

Table 4B—Information Technologies and Enabling Modes—Energy Supply

Energy Service Demand	EE Application	Information Technologies						EE Enabling Mode			
		SC	SW	AC	IT	MP	ED	1	2	3	4
Electric Power Generation, Transmission and Distribution	Smart Grid Technologies	•	⬤	⬤	•		●		⬤	●	
	Broadband-Over-Power Lines (BPL)	•	⬤	⬤	•		●		●	⬤	
Electric Power Generation, Transmission and Distribution	Smart Grid Technologies		●	⬤	⬤		●		⬤	●	●
	Broadband-Over-Power Lines (BPL)		●	⬤			•		⬤		•
	Smart Grid Technologies		•	●	•	•	⬤		⬤		

Table 4C—Diffusion Time Horizons—Energy Supply

Energy Service Demand	EE Application	Time Horizon			Comments
		NT	SM	OH	
Electric Power Generation, Transmission and Distribution	Smart Grid Technologies	•	●	⬤	
	Broadband-Over-Power Lines (BPL)	•	●	⬤	
Electric Power Demand Management	Energy Information Systems [EIS]	•	●	⬤	See **Buildings** sector discussion Table 1C.
	Advanced Communications Networks	●	●	⬤	
	Advanced Meters and Metering Infrastructure (AMI)	●	●	⬤	

Table Codes

Information Technologies		EE Enabling Mode		Time Horizon	
SC	Sensors & Controls	1	Energy Use	NT	Current or Near Term
SW	Software Systems & Applications	2	Energy Management	SM	Short-Mid-Term *[2-5 years]*
AC	Adv. Communications &/Internet	3	Energy Supply	OH	Over-the-Horizon *[>5 years]*
IT	IT Equipment & Systems	4	Behavioral Choices		
MP	Microprocessors & ASICs				
ED	IT-Enabled Devices				

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