22 U.S. Energy Conservation and Efficiency: Benefits and Costs

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Energy use in the United States increased nearly 40% from 1970 to 2000 (USBC, 2001). Projections are that it will increase by an additional 40% by the year 2020. The finite energy resources of petroleum, natural gas, coal, and other mined fuels provide the United States with about 93% of its energy needs at a cost of $567 billion/year (USBC, 2001). With increasing energy shortages and prices, this growth over the next two decades cannot continue (Abelson, 2000; Duncan, 2001).

The United States now imports more than 60% of its oil at an annual cost of about $75 billion driving the major trade imbalance (USBC, 2001). The United States has already consumed from 82% to 88% of its proved oil reserves (API, 1996; API, 1999). Projections are that the United States will have to import from 80% to 90% of its oil within 20 years, based on production, import, and consumption trends and forecasts (USBC, 2001; BP, 2001; M. Energy Rev.; 2001; W. Youngquist, consulting geologist, Eugene, Oregon, personal communication, 2002).

The entire U.S. economy, standard of living, and indeed national security depend on the availability of large quantities of fossil energy. Each American uses nearly 8000 L/year of oil equivalents for all purposes, including transport, industry, residential, and food (USBC, 2001). Furthermore, with the U.S. population adding 3.3 million people per year and projected to double in 70 years, providing energy resources will be increasingly difficult (USBC, 2001; Pimentel et al., 2002a).

The growing imbalance between declining energy supplies and growing energy use signals that the United States faces a serious and escalating energy crisis (based on data in USBC, 2001). This analysis focuses on current energy expenditures and opportunities to reduce U.S. fossil fuel consumption while maintaining a viable economy, environment, and continuing to protect national security.

TRANSPORTATION

The transportation sector is the largest sector for petroleum consumption in the United States, with an estimated 26.4 quads (1 quad = 10^{15} BTU = 1.05×10^{18} J =

293×10^9 kWh = 0.25×10^{15} kcal) consumed each year (DOE, 2000a). At the current growth rate of 2.3%/year, the total amount of oil consumption for transportation is projected to double in just 30 years (USDOT, 1999).

PASSENGER VEHICLES

The 140 million cars, SUVs, and pickup trucks driven by Americans are the largest consumers of fuel oil, an estimated 510 billion L/year of gasoline (USBC, 2001). Of this, approximately 78 million trucks consume slightly less than half the fuel amount (diesel) used by cars, or 150 billion L/year (USBC, 2001), while buses consume about 4 billion diesel L/year (USBC, 2001).

The average car, SUV, and pickup truck use 3640 L/year, and the average fuel economy is 8 km/L (USBC, 2001). Using proven engine design technologies, fuel economies of approximately 16 km/L could be achieved (Greene and DeCicco, 2000). This halving of fuel consumption, once all vehicles have been changed, would result in energy savings of 8 quads/year and consumer savings of about \$102 billion in direct gasoline costs at \$0.40/L (\$1.50/gal). In addition, the U.S. economy would save approximately \$54 billion in indirect, or external costs, from secondary effects such as reduced carbon emissions and reduced reliance on foreign oil imports (NAS, 2001).

Assessments of the introduction of new technologies into the automobile fleet suggest that 15 years are required for the technology to become fully integrated (USEPA, 2001). Projecting a straight-line annual adoption in fuel efficient technologies over 15 years, the total potential of the fuel savings over the first 10 years is estimated to be about 11.0 quads/year (Table 22.1).

There are approximately 770 billion L of gasoline available from Arctic National Wildlife Refuge (ANWR) based on the fact that nearly 74 L of finished gasoline are produced from 159 L (42-gallon barrel) of oil (DOE, 2001a,b). The approximately 775 billion L of gasoline that could be conserved by increased vehicle fuel economy by 2011 would more than replace the amount of oil that could be extracted by opening the ANWR to drilling.

Growing congestion and gridlock on U.S. highways are increasing fuel consumption by cars, trucks, and buses and reducing the productivity of the U.S. economy. For instance, each year in the Los Angeles metropolitan area 684,000 h of labor are lost to vehicle congestion (USBC, 2000). This costs the region about \$12.5 million for fuel and labor costs (TTI, 2001). On average, highway congestion in 70 metropolitan areas results in an annual delay of 40 h per driver per year (TTI, 2001). Those hours spent in traffic with the engine idling waste 318 L of fuel per driver and cost each driver nearly \$1000/year.

Simply to maintain a steady state of congestion, between 3% and 5% of vehicles with single drivers in operation need to convert to car pools or switch to public transportation annually (TTI, 2001). There is considerable opportunity to reduce energy consumption in the transportation sector.

If increased mileage targets for both cars and light trucks were achieved, this would provide societal benefits in reduced greenhouse emissions, reduced national security costs, reduced oil imports, and improved environmental quality (OTA, 1994).

TABLE 22.1
Estimated Primary Energy (Quads) and Dollars ($ Billions) Used and Saved per Year, after Energy-Efficient Technologies and Conservation Strategies Are Implemented after Approximately 10 Years

Energy System	Energy Used	Energy Saved	$ Saved
Transportation	26.4[a]	11.0[b]	181[c]
Automobiles	20.4	8.0	156
Commercial/Freight	6.0	3.0	50
Residential	18.4[a]	5.9[b]	59[c]
Heating and cooling	9.0	3.3	33
Appliances/Equipment	8.0	2.1	21
Lighting	1.4	0.5	5
Commercial	15.1[a]	3.4[b]	44[c]
Heating and cooling	6.5	2.0	20
Equipment	5.0	1.8	18
Lighting	2.1	0.6	6
Food system	(15.8)[d]	4.8[b]	48[c]
Industry	36.5[a]	5.9[b]	42[c]
General industry-wide	13.3	3.5	35
Paper and wood products	3.1	0.5	5
Chemicals	7.0	1.0	1
Metals	2.8	0.8	1
Plastics	2.0	0.1	0.1
Other	7.3	0.0	0
Energy subsidies withdrawn	—	1.0[b]	39[b]
Total	96.4	32.0	438

[a] USBC (2001).
[b] See text.
[c] Estimated.
[d] Energy inputs included in other sectors.

The various improvements mentioned, if implemented, could save an estimated 5 quads/year in U.S. energy consumption during the next decade.

Freight Transportation

Freight transportation is a major sector in the U.S. economy and uses a significant quantity of energy, about 6 of the 26.4 quads consumed by transportation each year (OTA, 1994). Trucks account for about 80% of the 6 quads of energy in the transportation sector and transports about 30% of total U.S. goods, typically characterized as nonbulk cargo, like food supplies (OTA, 1994; USBTS, 2000). Trucks generally are used to transport goods relatively short distances, or about 715 km (USBTS, 2000), and are relatively expensive in terms of energy used, requiring 0.82 kWh/ton/km, and costing about 16¢/ton/km (ORNL, 2000).

Railroads account for another 30% of the goods transported in the United States (OTA, 1994; USBTS, 2000). The average distance of goods transported by rail is 1345 km (USBTS, 2000). In comparison to trucks, railroads primarily accommodate bulk products that are shipped long distance in larger quantities. Rail transport is about four times more energy efficient than trucks, requiring only 0.24 kWh/ton/km and costing only 1.4¢/ton/km (USBTS, 2000; USBC, 2001).

Ships carry about 30% of all U.S. freight shipments of crude oil, refined petroleum products, and combined crude and petroleum products (USBTS, 2000). Ships are relatively energy efficient in the transport of goods, requiring 0.10 kWh/ton/km (Mintz and Vyuas, 1991) and costing only 0.46¢/ton/km (USBTS, 2000). Although more economical in the transport of goods than either trucks or rail, ships are relatively slow.

While petroleum and its products remain one of the primary commodities transported by maritime shipping, pipelines efficiently transport oil and natural gas, accounting for 60%–70% of oil shipments in the United States (USBTS, 2000). Transport by pipeline for these energy supplies costs 1.2¢/ton/km, with an efficiency of 0.21 kWh/ton/km (USBTS, 2000). Compared with trucks, transport of energy supplies by pipeline is four times more efficient.

Air cargo is the most energy-intensive mode of freight transport requiring 26.9 kWh/t/km and costing 53¢/ton/km (USBTS, 2000). Though airfreight transportation accounts for only 1% of total freight transportation energy use (OTA, 1994), it transports goods the longest distance of all freight modes, averaging 1400 km (USBTS, 2000). However, air freight is 112 times less energy efficient than rails.

If all the 490 billion ton-km of long-distance truck traffic shifted to rail, net savings would equal 0.3 quads when only considering propulsion energy (OTA, 1994). In addition, implementation of multimodal transportation may benefit the environment. For example, a $2.4 billion Alameda Corridor project proposes to consolidate 90 miles of track and roadway into one 20-mile direct railway route between Los Angeles and a Long Beach, California port, eliminating approximately 200 at-grade highway crossings and over 15,000 h of vehicle delays accumulated daily. The project also estimates to reduce traffic congestion and noise by 90%, alleviate train stopping by 75%, and truck traffic by 23% due to the ability to move cargo containers faster and more efficiently.

Improving efficiency in freight transport by trucks is targeted as a major potential contributor to savings in energy. Demonstration runs combining commercially available technology, highly trained drivers, and ideal operating conditions yield efficiencies 50%–70% greater than existing transport (OTA, 1994). If all heavy trucks achieved this level of energy efficiency, energy use would decline about 0.9 quads or 15% in total freight transport energy use, assuming that the most efficient heavy trucks available are used (OTA, 1994).

Current data suggest that trucks average about 2 km/L whereas President Clinton's objective was to reach an efficiency of about 9 km/L by 2010 (Wilson, 1999). If truck fuel efficiency quadrupled, about 3.6 quads could be saved along with about $45 billion every year (Wilson, 1999).

In sum, strategic regulation, policy, and improved energy-efficient technology may reduce truck transportation energy use up to 1 quad each year. Additional reductions are possible by energy-efficient innovations developed for alternative modes including air, pipeline, rail, and water. Total savings in commercial/freight energy are estimated to be about 3 quads/year (Table 22.1).

BUILDINGS SECTOR

Buildings account for about 20% total primary energy consumption in the United States (USBC, 2001). Significant energy savings are possible in both the residential and commercial sectors. Using cost-effective technologies, energy use in the residential sector can be significantly reduced, new commercial buildings can reduce their energy demand by 50%, and existing buildings could achieve a 20% reduction per year (Harris and Johnson, 2000).

HEATING AND COOLING

Residential

Approximately 9 quads of primary energy used yearly in the United States is expended for the space heating and cooling of 103 million households (DOE, 1999a; USBC, 2001). This is more than 50% of all energy consumed for all purposes in the residential sector. Although energy conservation and efficiency have improved significantly over the past 50 years (DOE, 1997), there remains significant potential for future energy savings.

Considerable energy used in residences is lost. For example, an estimated 20%–40% of home heating and cooling energy escapes through leaks in the building shell (Heede et al., 1995; Florman, 1991). Conservation practices, such as caulking and weather-striping can reduce wasteful air leaks from 20% to 50%, with minimal investments (Hafemeister and Wall, 1991; DOE/OBT, 1999; Wilson and Morrill, 1999). Air ducts located in uninsulated crawl spaces lose between 10% and 40% of heating and cooling energy (Cummings et al., 1990; Sherman, 2001). Advanced aerosol-based sealing technology can reduce air leaks by 60%–90%, and save up to 1 quad each year nationwide (CBECS, 1995). Air changes in houses are necessary but this can be achieved with minimal loss of heat or cooling using heat exchangers.

The majority of the homes are under-insulated, an estimated 22% of U.S. homes lack wall insulation and 12% lack ceiling insulation (OTA, 1992). If all residential buildings in the United States were insulated to current model energy code standards, an estimated 1.9 quads of primary energy could be saved each year (NAIMA, 1996). The marginal cost of such insulation in a new home averages $1160, a cost that is returned in less than 10 years (ASE, 2001). In addition in home construction, vinyl siding and windows reduce energy consumption, saving the average homeowner $150–$450 each year in heating and cooling costs compared to other types of windows (APC, 2001).

An estimated 25% or 2 quads of residential heating and cooling energy is lost through the windows (Bevington and Rosenfeld, 1990; Carmody et al., 1996). Window designs on the market today are more than four times as efficient than those sold 30 years ago (Carmody et al., 1996). Within 10 years, the accelerated installation of energy-efficient window technologies during new construction and re-modeling projects would reduce yearly energy losses by 25% (0.43 quads) (Frost et al., 1996).

Emerging window designs that combine high-insulating values with electrochromic technologies, that respond to electric current, temperature, or incident sunlight to control the admission of light energy are even more promising sources of potential energy savings (Roos and Karlsson, 1994). This new technology has the potential to transform residential windows from a $11 billion loss to only a $5 billion loss per year for U.S. homeowners as reduced loss of winter heat and summer cooling energy would more than pay for the window costs within a short period (Frost et al., 1996).

At present only about 0.3 quads of energy per year are being saved by technologies that employ passive and active solar heating and cooling of buildings (Pimentel et al., 2002b). Implementing current technologies and added improvements in passive solar technology will make this approach more effective and less expensive (Busch and Meier, 1986)—especially in the new home market.

As a part of new home construction, the use of new transparent materials in windows makes possible the transmission of from 50% to 70% of incident solar energy while at the same time contributing insulating values typical of 25 cm of fiberglass insulation (Chahroudi, 1992; Twiddell et al., 1994; Forest, 1991). Such materials have a wide range of applications beyond windows, including home heating with transparent, insulated collector-storage walls and integrated storage collectors for domestic hot water (Wittwer et al., 1991).

Over one-third of U.S. homes are heated with natural gas furnaces that have an average efficiency of only 65% (OTA, 1992; Kilgore, 1994). Yet furnaces are available today with efficiencies of 80%–90%. It takes as little as 9 years to repay the costs of replacing an old gas-powered furnace with an efficient one (Cohen et al., 1991).

In only 50% of U.S. households is the heat turned down at night during the winter (Heede et al., 1995; Florman, 1991). Simply lowering the night temperature reduces household energy used for heating by about 17% (about 1 quad) per year in U.S. northern climates (Socolow, 1978).

Over 72% of new homes have air conditioners (Latta, 2000). Air conditioners are available that are 70% more efficient than the average unit sold today (Thorne et al., 2000). This change would save about 40% of the primary energy used in air conditioners and would save 0.5 quads annually in about 10 years (Thorne et al., 2000).

Thus there are many techniques available to reduce heating and cooling losses in homes. New construction and remodeling can reduce energy consumption and save money. If energy conservation and efficient technologies were implemented, an estimated 3.3 quads/year would be saved in the next 10 years. The 3.3 quads is about 1.5 times the total amount of oil that is currently produced in Alaska each year (USBC, 2000).

Commercial

Opportunities for the reduction of heating and cooling energy use in the commercial sector exist through increased implementation of energy-efficient building shell and space conditioning technologies (Davis and Swenson, 1998). For example, at least 20% of commercial buildings are under-insulated (ACEEE, 1996). Upgrading all commercial buildings to insulation standards could save 0.3 quad annually (NAIMA 1996). Advanced computerized energy-management systems can increase energy efficiency by an estimated 25%–50% (ACEEE, 1996). The use of light-colored roofs and trees for shading of buildings could save energy (ACEEE, 1996). With about 6.5 quads of primary energy currently used in the commercial sector for heating and cooling, approximately 2 quads of energy could be saved per year by implementing the energy-efficient technologies and practices discussed in this section (Levine et al., 1996).

Equipment and Appliances

The federal government has made significant contributions to energy efficiency in equipment through the Energy Star standards program. By 2020, application of current commercial and residential standards is projected to result in savings of 4.2 quads/year, compared to 2000 (ACEEE 2001). The inclusion of additional standards for 13 appliances and other equipment not yet covered could save an added 0.72 quads/year by 2010 (ACEEE 2001). Thus, when both current and additional standards have been fully adopted by 2020, the total savings will amount to 5 quads of primary energy per year.

Residential

About 8 quads of primary energy (compared to electricity) are used annually to run appliances in the 103 million U.S. households (USBC, 2001). Taken together, appliances account for approximately 22% of electricity consumption in the U.S. residential sector (RECS, 1995). More than 99% of all households have a refrigerator, more than 97% operate a water heater, and a significant number have washing machines (77%), clothes dryers (70%), dishwashers (50%), and freezers (33%). Based on the relatively rapid turnover of home appliances, most appliances will be replaced with more energy-efficient models within a decade (RECS, 1995; Haase, 2001).

Currently, even though equipment prices have risen modestly since the implementation of Energy Star standards, for every dollar invested for an energy-efficient appliance, the consumer saves $3.50 in energy over the life of the appliances (Koomey, et al., 1998; IEA, 2000). In other words, the benefits are more than three times the costs on a net present value basis—yielding an estimated $50 billion in energy cost savings between 1990 and 2000 (LBNL, 2000).

Appliance standards rank with automobile fuel economy standards as the two most effective federal energy-saving policies (ACEEE, 2000). According to analyses by the DOE (2000a), these standards have reduced U.S. electricity use by 2.5% (88 billion kWh/year) by 2000. At present, appliance standards are saving about 1.2 quads of primary energy annually (ASE, 2001). As old appliances and equipment wear out and are replaced, savings from existing standards will steadily grow. By 2010, savings will total more than 250 billion kWh/year (6.5% of projected electricity use), or 2.6 quads of primary energy and reduce current peak demand by approximately 66,000 MW or a 7.6% reduction.

Evidence of the positive effect standards have had on energy efficiency is most apparent in the refrigerator market. In the early 1970s, the average U.S. refrigerator used just under 2000 kWh/year, while the average consumption of the newly designed refrigerators in 1998 used around 500 kWh/year (George et al., 1994; DOE, 2001c). Thus, upgrading refrigerators has the potential to save 1.4 quads/year of primary energy and over $120/year for consumers who replace a vintage model with a product that meets current standards (DOE, 2002a).

Clothes dryers consume the second-largest amount of electricity of the major appliances, costing about $85/year per owner and using more than 1200 kWh/year (DOE, 2002c) or a total of 0.2 quads/year of primary energy. Installing gas dryers that use about half as much primary energy as electric dryers (Cureton and Reed, 1995)—plus placing dryers in warm, dry areas of the home substantially reduces this amount. In addition, inserting sensors for "dryness" can save up to 15% of the energy used in drying clothes (Wilson and Morrill, 1999).

For washing machines, from 85% to 90% of the energy (and for dishwashers about 80%) is used to heat the water (Wilson and Morrill, 1999; DOE, 2002b). Thus, energy use in both washers can be reduced if the hot-water temperature is lowered from the customary 140°F to about 120°F (Wilson and Morrill, 1999; DOE, 2002c). Reducing the water temperature prevents the loss of heat while water is transferred through piping from the water heater to the dishwasher and washing machine. In addition, since newer models have a greater capacity to clean effectively, water hotter than 120°F is no longer necessary to efficiently wash dishes or clothes. Further savings are possible through the use of horizontal-axis washing machines because they use one-third less water than vertical axis machines (Sustainable Sources, 2002).

In addition to the major appliances, a broad array of numerous types of appliances (e.g., computers and other electronic equipment) are projected to account for over 90% of future residential energy growth in about a decade (Sanchez et al., 1998). Approximately 20% of residential electrical appliances are "leaking electricity" or energy is being consumed when the appliances are not performing. If standby power of all appliances with a standby mode were reduced to 1 W, the potential savings would be 21 Twh/year (0.2 quads of primary energy) and roughly $1– $2 billion annually (Sanchez et al., 1998).

Based on the use of new designs and new technologies for appliances it is possible to provide significant energy savings within 10 years (Mortier, 1997; Nadel, 1997; Haase, 2001). Allowing a decade for substantial turnover of the most inefficient appliances, DOE (2002d) estimates are that a 30% decrease in energy consumption (about 2.1 quads of primary energy) can be achieved, at savings of approximately $42 billion/year.

Commercial

Commercial equipment consumes an estimated 7 quads of primary energy per year. The main energy users are water heaters, refrigerators, and cooking stoves. Although previous energy conservation and efficiency efforts have focused on heating and cooling and lighting, commercial equipment represents an important opportunity for energy savings. Allowing a decade for substantial replacement of inefficient equipment with energy-efficient types, an estimated 1.5 quads/year of primary energy could be saved. Going beyond Energy Star implementation, other technologies could save an additional 0.1 quad/year by 2010 (LBNL, 1995). Estimates are that energy-saving software and power management practices have the potential to save about 0.2 quad/year (Levine et al., 1996).

Lighting

Lighting offers several opportunities to conserve energy (Turiel et al., 2001). Lighting consumes 14% of all electricity used in the United States (DOE, 2002f). For commercial buildings, lighting accounts for 40% of electricity use and requires another 10% of the electricity to cool the unwanted heat (Romm, 2002). In residential and commercial establishments, about 50% of lighting energy is wasted by obsolete equipment, poor maintenance, or inefficient use (DOE, 1995).

Residential

U.S. residential lighting consumes about 1.4 quads of primary energy per year and represents about 10%–15% of total U.S. residential electricity use (DOE, 2000b). Per household this translates to an average of 1023 kWh/year in lighting costs (DOE, 2002f; USBC, 2001). A small number of lighting fixtures in homes account for a disproportionate percentage of electricity use (Jennings et al., 1997). Thus, incandescent bulbs that are the least expensive to purchase but the most expensive to operate remain the most popular type of lighting (DOE, 1995; DOE, 1996). About 27% of incandescent fixtures account for over 80% of residential lighting electrical use (Jennings et al., 1997).

Compact fluorescent lights (CFL) use 25% as much electricity as incandescent lamps and last up to 10 times longer (EELA 1999). Although many households have installed some type of fluorescent light in an effort to conserve energy, the full efficiency benefits are not realized because the lights are often installed without consideration of usage times (Jennings et al., 1997). For maximum energy savings, lights that are on for four or more hours per day should be targeted for replacement with high-efficiency bulbs (Jennings et al., 1997). A look at the types of lighting by usage time reveals that 42% of households use some type of fluorescent light, but only 13% of lights used for one or more hours per day are fluorescent (DOE, 1996). There is also a connection between residential light fixture location and length of usage times (DOE 1996). The largest consumers of light energy by location and usage times were found to be ceiling and wall fixtures in kitchens, living rooms, and bathrooms, which suggests that replacing these lights with CFL lights will yield substantial savings (Jennings et al., 1997). If all residential incandescent bulbs used for 4 h or more per day were replaced with CFLs, about 1 quad of primary energy, or $8.4 billion, would be saved annually.

Halogen floor lamp torchieres have become popular in recent years, but unfortunately are extremely inefficient, converting only 10% of energy into visible light, as well as being a fire hazard. If the 50 million halogen torchieres in the United States were replaced with CFL torchieres, the energy savings over 5 years would be 53%, or 0.11 quads of primary energy (Kubo et al., 2001). If all these changes were implemented for residences, there would be an estimated savings of 0.47 quad of primary energy per year.

Commercial

In the commercial sector, lighting is an important energy application and accounts for 3.6 quads of primary energy use (DOE, 2002f). In contrast to homes, 77% of commercial floor space is lit by fluorescent lighting and only 14% by incandescent lights (CBECS, 1995). Thus, for commercial buildings, a good method of increasing energy savings would be to upgrade existing lights with more efficient hardware and better lighting maintenance. Historically, commercial lighting systems have been designed to provide about 20% more illumination than actually required (NLB, 2001). Better lighting system maintenance and replacing fluorescent bulbs and other lights on a routine basis could save

0.3 quads of primary energy per year (NLB, 2001). Replacing magnetic ballasts in fluorescent lights with improved electromagnetic ballasts would save from 25% to 40%, or about 0.3 quads of primary energy per year (RMI, 1994). About 48% of commercial floor space is lit using some type of energy-efficient ballast (CBECS, 1995). With implementation of these measures, a conservative estimated savings for the commercial sector would be 0.6 quads of primary energy per year, or about $6 billion annually (Table 22.1).

INDUSTRIAL SECTOR

The industrial sector consumes 24.5 quads of primary energy per year (DOE, 2000a). Three major sectors—paper and wood, chemicals (including plastics and rubber), and primary metals—account for over 85% of the total energy use in the industrial sector (DOE, 2000a). Energy use in the industrial sector is predicted to increase at an annual rate of 0.9%, with primary energy use being close to 30 quads by 2015 (DOE, 1999a).

Significant energy savings can be achieved across the entire sector by implementing broad-based improvements. Optimization of motor systems, compressed air and pumps, use of advanced combined heating and power systems, and improvements in lighting design and technology are some examples of improvements that could save the industrial sector 3.5 quads of energy by 2015 (Martin et al., 2000a). Implementing these changes is, in many cases, limited by a lack of knowledge (Martin et al., 2000a). However, most of these modifications and changes have payback periods of 1–5 years (Martin et al., 2000a).

Paper, Lumber, and Other Wood Products

The paper industry uses approximately 2.6 quads and the lumber and wood products industry consumes about 0.5 quads/year. The industry decreased primary energy use by 27% from 1970 to 1994 using new improved technologies, but there is potential to further decrease energy consumption (Martin et al., 2000b).

The production of paper is a multistep process requiring a large number of chemicals plus heat and electrical energy. Each paper product requires different energy inputs based on various pulping and drying needs. For example, estimates are that the production of corrugated paper requires 15 kWh/kg, while the production of bleached Kraft paper requires about 21 kWh/kg (Table 22.2).

Currently, approximately 42% of all U.S. paper products are recycled (USBC, 2001). The amount of recycled pulp that may be used for a given type of paper is limited due to the reduced strength in recycled pulp. Many items, like corrugated cardboard, may be produced from 100% recycled paper, but printing paper may only contain a maximum of 16% recycled pulp (Gunn and Hannon, 1983). Using recycled pulp results in a 27% energy saving per kilogram of recycled corrugated paper and 36% energy saving in printing paper (Selke, 1994; Gunn and Hannon, 1983). However, some high quality paper products are more efficiently produced from virgin fibers than recycled paper in terms of energy (Gunn and Hannon, 1983).

The paper industry has been successful in decreasing energy inputs by burning its biomass wastes, including bark, some wood chips, hogged fuel (unusable chunks of wood), and black liquor (a thick sludge containing lignin). Proven technologies

TABLE 22.2
Energy Inputs (kWh/kg) for Virgin and Recycled Materials

Materials	Virgin	Recycled	Source
Aluminum	15	1.5	International Aluminum Institute (2001); Facts at a Glance (1999)
Corrugated paper	15	11	Selke (1994)
Kraft paper	21	14	Gunn and Hannon (1983)
Steel	17	6	Doering (1980); Facts at a Glance (1999)
Glass	5.5	4.2	Selke (1994)
Plastic	12	5	DOE (2001h)

successfully dewater black liquor to a 65%–75% solids content so it can be burned in mills utilizing the Kraft chemical recovery process, the method by which 80% of pulp is manufactured in the United States (Martin et al., 2000b). The energy cost of dewatering and combustion can increase electricity demand from 0.5% to 1%, but can supply enough heat energy for a small amount of primary energy (Simonsen et al., 1995). The efficiency of biomass combustion can be further increased by co-generating electrical energy, making it possible for the mill to meet all of its energy demands through biomass fuel (Pimentel, 2001).

Because of the capital intensive nature of the paper industry, turnover of equipment is typically between 35 and 40 years, making it difficult for many new energy-saving technologies to rapidly achieve market penetration (Sheahen and Ryan, 1983). Energy-efficient technologies that are close to becoming feasible, such as black liquor gasification and improvements in heat recovery, are 20%–40% more efficient than current methods, but will only see limited (~20%) application by 2015 (Martin et al., 2000a). Adapting paper mill boilers to burn wood waste is one short-term possibility to reduce energy use with a minimum of additional expense (Martin et al., 2000b).

In the lumber and wood-product industry, the primary use of energy is for drying wood materials (NTIS, 2001). In the past, all wood was air dried, but as drying time has been reduced, energy demands have increased through the use of heated kilns. The combination of lowest operating cost and lowest energy cost has been found by combining air and kiln drying (DOE, 1999b). In many modern mills, sufficient wood waste is produced to provide all the heat needs and, in some cases, exceed energy demands (DOE, 1999b). As new technologies are implemented, the lumber industry may become a supplier of heat and electrical energy (DOE, 1999b).

Martin et al. (2000b) investigated energy efficiency in the paper and pulp industry. They examined 45 different technologies that could reduce energy use within the industry and calculated penetration rates, retrofit and implementation costs. At current energy prices, they estimate that 16%–22% of the primary energy used in the paper and pulp industry could be saved by about 0.5 quad/year (Martin et al., 2000b). The 22% represents an increased use of recycled paper in new paper production. A further 5% saving of primary energy use could be achieved by 2015, using new emerging energy-efficient technologies (Martin et al., 2000a).

Chemical Industry

The chemical industry uses about 7 quads/year (DOE, 2000d,e) to produce more than 70,000 different chemicals. Although there are seven major chemical sectors within the chemical industry, the major energy consumers are the production of organic chemicals and inorganic chemicals (DOE, 2000c). Just over half of the fuel consumed in the chemical industry is used as a feedstock (e.g., petroleum) consisting of liquefied gases, heavy liquids, and natural gas (Worrell et al., 2000). The main sources of processing energy are natural gas (64%) and electricity (18%) (Worrell et al., 2000).

Although improvements in energy efficiency in the chemical industry have been relatively stagnant for the past 15 years, the industry has demonstrated some significant efficiencies (CMA, 1998). Due to high energy prices in the early 1970s, the industry improved efficiency by 35% from 1974 to 1986 (CMA, 1998). Much of this gain came about with overall improved energy management and increased use of co-generated heat. Current energy improvements may be more difficult or more reaction specific, as many of the broad-based efficiency programs have already been instituted.

The production of organic chemicals requires a large expenditure of energy (2.1 quads or 34% of the energy used in the chemical industry) part of which is petroleum-derived products. The major organic chemicals produced are ethylene and propylene, used as precursors for plastics and alcohols, solvents, and acids, used in other chemical and industrial processes (DOE, 2000e). The production of ethylene and its coproducts consumes nearly 30% of the total energy used by the chemical industry (Worrell et al., 2000). Nearly 72% of this energy goes into the feedstock or petroleum required for ethylene production (PNNL, 1994), but improvements in efficiency are possible (Worrell et al., 2000).

About 18 million tons of nitrogen fertilizer are used in U.S. agriculture each year (CMA, 1998). With nitrogen fertilizer being one of the most energy-intensive products, improving the efficiency of production should be a priority. There are several viable energy-efficient options regarding ammonia synthesis (ammonia being the primary nitrogen source for fertilizer). Currently, ammonia is catalytically made by the Haber-Bosch process. Catalyst improvements could significantly increase efficiency (PNNL, 1995). Implementing the autothermal reforming of ammonia, which combines the partial oxidation of methane and steam reforming, could reduce fuel used in ammonia production by 24%, and reduce the primary feedstock input by 20% (Martin et al., 2000b).

Within the inorganic chemical segment, the production of chlorine and sodium hydroxide is the largest energy consumer. These chemicals are produced through the electrolysis of brine solutions. The most commonly used electrolytic cells, the diaphragm-type, are approximately 6% less efficient than the state-of-art ion-selective membrane cells (DOE, 2000e). Therefore, with the widespread use of the ion-solution membrane, considerable energy can be saved.

Overall, the chemical industry has great potential for improvements in catalytic efficiencies because catalysts are used in about 80% of the chemical industry and consume significant amounts of energy (Martin et al., 2000b). Future catalysts could lower energy consumption 10% or more during the next 10 years (PNNL, 1995; Martin et al., 2000b).

The expanded use of heat recovery systems could save 4% of total energy use in the chemical industry (Martin et al., 2000b). The industry currently uses cogeneration, but more efficient technologies would allow for heat exchangers to be placed in environments previously too harsh to support them. These environments include the production of sodium hydroxide/chlorine and nitric acid (Reay, 1999). In addition, new heat exchangers use novel alloys and designs to prevent corrosion. Payback time on these devices is approximately 2.4 years, thus making the changes economic (Martin et al., 2000b).

In the United States, approximately 9% of the consumed plastics are recovered (Martin et al., 2000b). This figure is low because collection and reuse of postconsumer plastics is often more expensive than the use of virgin material (Martin et al., 2000b). Much of the unrecycled plastic comes from discarded automobiles. Current research is focused on technology processes that allow for plastics of similar density to be separated. Due to the high energy demand of processing plastics like polyethylene, the energy savings from the recycling could be as high as 70% in primary energy savings (Martin et al., 2000b).

The potential energy savings possible for the U.S. chemical industry in the next decade is estimated to be about 1 quad/year.

Metals

In 1997, the production of steel, aluminum, and other metal products accounted for approximately 2.5–2.8 quads of primary energy expended in the entire industrial sector (USBC, 2001). Most of the energy used is in the recovery and manufacturing processes. New methods and technologies have encouraged the metal industry to invest in secondary metals. Secondary or recycled metals consume less energy to produce (Ayres, 1997).

Steel production uses 1.8 quads of the total energy used in the metals industry (DOE, 2000f, 2001g) or 7.5% of the energy used in the industrial sector. The steel industry accounts for 2% of total US energy consumption (DOE, 2001g). For all metals, approximately 60% of that energy is derived from coal for all metals, while electricity and natural gas supply the remaining energy used (AISI, 2001). The production of 1 t of steel requires 5560 kWh (AISI, 2001). From 15% to 20% or approximately $55 per ton is spent on the energy costs (AISI, 2001). The aluminum industry consumes 1.8% of energy in the industrial sector (DOE, 2001d,e,f). In 1995, the primary production of aluminum used nearly 0.5 quads/year of primary energy (DOE, 1997). Nearly 85% of the energy used by the aluminum industry is electricity (DOE, 2000b). Approximately one-third of manufacturing costs are spent on the energy necessary for production.

Through a variety of methods and currently available technologies, the iron and steel industry should be able to decrease energy use by 0.32 quads, or 16% (Worrell et al., 1999). By 2010, the steel industry hopes to reduce energy expenditure from 4760 to 3970 kWh/t (DOE, 2000f). The methods involved in saving energy include simple measures, such as preventive maintenance, better control and recovery of heat through improvements in insulation, controls and sensors, plus cogeneration (Worrell et al., 1999; AISI, 2001). Producing 1 kg of recycled steel saves about 65% of the energy needed to produce 1 kg of virgin steel (Table 22.2). In 2000, the use of 70 million tons of steel scrap conserved 0.8 quads of energy or almost 40% of the total energy used in steel production (Danjczek, 2000). That same year, 58% (1.5 million tons) of steel cans, 84% (2.0 million tons) of appliances, and 95% (14.0 million tons) of automobiles were made from recycled steel (SRI, 2001). For the automobile industry, the steel industry has developed stronger and more corrosion resistant products, which will help automobile manufacturers to improve fuel efficiency (AISI, 2001).

Over the past decade, the amount of energy required to produce primary aluminum has dropped from 26.4 to 15.4 kWh/kg, with the most efficient smelters able to produce at 13 kWh/kg (Aluminum Association, 2001a; DOE, 1997). Most of the future energy savings will come from recycling scrap metal. In 2001, 33% of the 10.69 million metric tons of aluminum was reclaimed each year (Aluminum Association, 2001b). Recycled aluminum uses only 10% of the energy needed to produce aluminum from virgin materials (Table 22.2). Reclamation of aluminum cans has risen to 62% and recycled aluminum comprises about 33% of the sector (DOE, 1997). Aluminum recovery is cost-effective and economically profitable; the industry pays around $990 million to recyclers each year (Aluminum Association, 2001a). If the other 38% of aluminum cans was recycled instead of the additional production of primary aluminum, the amount of primary energy used in the aluminum sector could be reduced by another 12%.

The recovery, reuse, re-manufacturing and recycling of metals is the most promising technology to increase energy (Ayres, 1997). The re-manufacturing, reuse, and repair of products use half of the energy input, but need double the labor input (Ayres, 1997). Although to date resource scarcity has not been a major issue for the metal industries, the cost to extract and mine ores and mineral deposits will increase and become more energy intensive in the future (Ayres, 1997; Youngquist, 1997). Through a combination of recycling, improved methods and technology, we estimate that the metals industry could save about 0.8 quads/year during the next decade.

Plastics and Rubber

About 4% of total U.S. energy consumption is used to produce raw plastic materials (APC, 2001; APME, 2001). Polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS) are the six primary resins for plastic manufacturing. The highest consumers of plastic products are automobiles, appliances, food packaging, and the building and construction industries (EPA, 1995). The lightweight durability and versatility of plastics have increased energy efficiencies for many products. As a result, industries have reduced the costs for production, handling, shipping, and transportation (APC, 2001). For food packaging and other packaging, less energy is needed for plastics as compared to other materials. For example, 30% less energy is used to produce foam polystyrene containers, than paperboard containers (APC, 2001).

Substantial energy savings can be gained through the recovery and reuse of plastics. In 2000, the United States recycled 687 million kg of post-consumer plastic bottles such as milk, shampoo, detergent, and soft drinks. However, the average recycling rate is only 27% (APC, 2001).

The major obstacle for more energy gains is the difficulty of available cost-effective recycling technologies (DOE, 2001g). Plastics in housing construction uses the largest volume of material, but little is recycled compared to metals used in construction (DOE, 2001h). Similarly, only 2% of plastics in computers are recovered because of cost-ineffectiveness (DOE, 2001h). Mixed-plastics also pose a significant recycling problem because of hand separation, which is both costly and time-consuming. With assistance from the U.S. Department of Energy and the American Plastics Council, a new system has been developed for the recovery of plastics from mixed plastic streams (DOE, 2001g). If a quarter of the plastics manufacturing sector implements this technology, 0.11 quads can be conserved per year (DOE, 2001g). As its use expands, future capital and installation costs will decrease, and the savings to the entire plastics manufacturing industry could reach $750 million/year (DOE, 2001g).

The energy input for natural rubber production is about 4.2 kWh/kg; this also includes energy input for transport (IRRDB, 2001). Oil is the main component used to manufacture synthetic rubber (Collins, 2000; Jones, 2001). For synthetic rubbers such as butyl rubber, 3.2 kWh/kg is consumed (IRRDB, 2001). Currently the United States consumes 67% of the world's natural rubber production (EP Rubber, 2000). The majority (68%) of natural rubber production is used for tire production while latex products uses 8%, engineering products 7.8%, footwear 5%, and adhesives 3.2% (Jones, 2001).

In 2000, 273 million tons of scrap tires were collected (RMA, 2001). Out of the 273 million, 196 million tons were recycled, while 25 million tons were used to produce tire-derived fuel, and the remaining quantities were used for civil engineering applications such as landfill covers and liners (RMA, 2001).

Retreading tires is cost-effective and environmentally advantageous. Retreading of average truck tires requires 30% less energy than new tires, and saves at least 0.04 quads/year (0.04 quad) (ITRA, 2001). On an average, it takes 83 L of oil (24 kWh/kg) to produce one new truck tire, while retreading one truck tire requires only 26 L (7.6 kWh/kg) (ITRA, 2001).

FOOD SYSTEMS

Each person in the United States consumes about 920 kg (2023 lbs) of food annually, or about 3800 kcal per person per day (USDA, 2001). Supplying this food requires the expenditure of about 15.8 quads of energy per year (USBC, 2001). Put another way, about 13 kcal of fossil energy is expended per kilocalorie of food supplied to each American.

Approximately 7.2 quads/year are expended in the production of crops and livestock (Pimentel et al., 2002a). About two-thirds of the energy used in crop production is for fertilizers plus mechanization (Pimentel et al., 2002a). Excessive use of nitrogen fertilizer is economically and energetically costly to farmers and pollutes the environment (e.g., eutrophication, nitrate contamination of drinking water, and greenhouse gas emissions) (Socolow, 1999). Through proper timing and dosages, the estimate is that nitrogen fertilizer use could be reduced by 25% without reducing crop yields, especially in grain crops (Matson et al., 1998). In addition, if the current soil erosion rate of 13 t/ha/year were reduced to the sustainable level of 1 t/ha/year, this would conserve nearly 17 million tons of fertilizer nutrients and save about 1.5 quads in energy (Troeh et al., 1991; Pimentel et al., 1995). The application of these and other sustainable farming practices hold promise for substantial energy savings (Pimentel et al., 2002a).

Energy conservation is possible while maintaining high crop yields. Currently about 8140 kWh is required to produce 1 ha of conventional corn (Pimentel, 2001). Producing corn using ecologically sound technologies that conserve fertilizers, soil, water, and pesticides, plus reduce the inputs of agricultural mechanization, reduced fossil energy use as much as 50% and the economic costs of production by 33% (Pimentel, 1993). A conservative estimate is that 2.3 quads of energy per year can be saved.

An estimated 7.2 quads of energy are used in food processing and packaging (Pimentel and Pimentel, 1996). At least 10% of the energy in food processing could be conserved through improved efficiency with existing equipment (Casper, 1977). Implementing cogeneration throughout the food processing industry would save up to 40% of current energy inputs (Walshe, 1994). Currently, only 6% of the electricity used in the food industry is produced through cogeneration (Okos et al., 1998). Other promising technologies for energy savings include the use of cold pasteurization and electron beam sterilization, evaporation and concentration by extraction, more efficient drying technologies, and more refrigeration by controlled atmosphere packaging (Okos et al., 1998). Assuming that appropriate technologies were implemented, more than 1 quad of energy might be saved per year (Dalzell, 1994). In total an estimated 4.8 quads/year of energy could be saved in the entire food system each year.

ENERGY SUBSIDIES

Our assessment of subsidies focuses on direct subsidies and does not include subsides allocated to energy-consuming industries and defense energy costs. Federal energy subsidies in the United States total about $39.3 billion each year (Table 22.3). This amounts to $420 per family in taxpayer money per year. Subsidies to the energy industry have the overall effect of making the price of fuels cheaper at the point of purchase. However, the taxpayer pays for this reduction and the negative aspect is that it encourages the consumer to burn more fuel.

The oil industry alone receives as much as $11.9 billion/year in subsidies (Hamilton, 2001) (Table 22.3). This subsidy results in a 3¢ (11¢/gal) price reduction for each liter of gasoline ($1.50/gal). If the consumer were forced to pay the unsubsidized price of gasoline, this would reduce the number of miles driven per consumer. For every 1% increase in the price of gasoline, the number of vehicle-miles traveled is estimated to decline from 0.25% to 0.38% (Merriss, 2001). If the customer paid the unsubsidized price of gasoline, then gasoline consumption would be reduced about 65 billion L/year. This saving would amount to 0.3 just by removing the taxpayer subsidies that the U.S. government pays to oil companies. The most important point is that the public would be paying the real price of gasoline. If less oil were consumed, this could reduce our dependency on imported oil.

TABLE 22.3
Shares of Total Subsidies for Energy Systems

Energy Source	× billion($)	Source
Oil	11.9	Hamilton (2001)
Nuclear	11.0	Koplow (1993)
Coal	8.0	Koplow (1993)
Natural gas	4.3	Koplow (1993)
Energy efficiency	1.2	Koplow (1993)
Ethanol	>1.0	Bioenergy (1996) Reuters (2001)
Renewable energy	0.9	Koplow (1993)
Hydroelectric	0.6	Koplow (1993)
Other	0.4	Koplow (1993)
Total	39.3	

Natural gas has a similar average price elasticity as gasoline. For every 1% increase in price there is approximately a 0.25% decline in consumption (Mackinac, 2001). Electricity has a similar elasticity in the residential sector; thus, for every 1% increase in price there is approximately a 0.23% decline in consumption of electricity (DOE, 2002e).

If the $39 billion in tax subsidies for energy were removed during the next decade, an estimated 1 quad of energy would be conserved.

OIL SUPPLY

The foregoing analyses highlight the dependency of the United States on fossil fuels, not only for personal needs and transportation but also for supporting U.S. industries. In total, Americans use 36.3 quads (1.12×10^{12} L) of oil per year (USBC, 2001). The United States with only 4% of the world population uses 26% of all oil used in the world (BP, 2001). At present, 61% of U.S. oil is imported and this negatively impacts the U.S. balance of payments.

Estimates are that the United States has the potential to ultimately produce only 32.6 to 35.0×10^{12} L of oil before the resources are depleted (MacKenzie, 1996; Deffeyes, 2001). These data suggest that from 82% to 88% of U.S. crude oil reserves have already been utilized, with U.S. oil production peaking in 1970 (API, 1999).

Drilling for oil is energetically and economically costly. Currently, U.S. oil wells are drilled to an average depth of 1708 m (over 1 mile) and cost about $604,000 for each well (API, 1999). Recently, increased drilling effort in the United States has not resulted in increased reserves. U.S. oil discoveries peaked in 1930 (Nehring, 1981). Oil production efficiencies in the United States are illustrated by the fact that the United States has more than 563,000 wells operating, while Saudi Arabia has only about 1600 wells operating (Deffeyes, 2001). Even with 360 times more wells, the United States produces only 80% of the amount that Saudi Arabia does (BP, 2001).

Global oil reserves are estimated to peak in production sometime between 2007 and 2015 with most of the world oil supply lasting approximately 50 years (Duncan and Youngquist, 1999; BP, 2001; Duncan, 2001; Laherrere, 2001; Stone, 2002). The small amount of oil remaining after 2050 will probably be used only for producing plastics and other petrochemicals. Obviously rapid human population growth and increased oil use will determine how long oil resources will last.

CONCLUSION

Through energy conservation and implementation of new energy-efficient technologies, about 32 quads or nearly 33% of U.S. energy consumption and about $438 billion can be saved per year in approximately 10 years (Table 22.1). The sectors having the potential to provide major energy savings are transportation, heating and cooling of residences, industries, and the food system. Other energy-use systems where energy conservation and energy-efficient technologies are possible include chemicals, paper and lumber, household appliances, lighting, and metals. Reducing the $39 billion in taxpayer money spent on subsidies of the energy industries would stimulate the use of conservation and energy-efficient technologies (Tables 22.1 and 22.3).

We are confident that the President and the U.S. Congress working with the people could reduce our energy consumption in approximately a decade by 32 quads/year, about 33% of present energy use. Yet we would be remiss not to point out that continued U.S. population growth (70% of the growth is due to immigration) will generally overwhelm much of proposed energy savings. However, saving fossil energy is fully justified because it would help reduce American dependence on foreign sources of energy and improve national security, improve the environment, reduce the threat of global climate change, and save approximately $438 billion/year which would help support the U.S. economy.

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