Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances

Final Report

Submitted to:
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Building Technologies Program

Navigant Consulting, Inc.
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Disclaimer

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List of Acronyms

AC	Alternating Current
ADL	Arthur D. Little
AEC	Annual Energy Consumption
AES	Annual Energy Saving
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Automated Teller Machine
BLS	Bureau of Labor Statistics
BT	Building Technologies Program
Btu	British Thermal Unit
CARB	California Air Resources Board
CAT	Computed Axial Tomography
CBECS	Commercial Buildings Energy Consumption Survey
CCW	Commercial Clothes Washer
CEE	Consortium for Energy Efficiency
CFL	Compact Fluorescent Light Bulbs
CO_2	Carbon Dioxide
COP	Coefficient of Performance
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CSA	Canadian Standards Association
CT	Computed Tomography
CTIA	Cellular Telecommunications & Internet Association
DC	Direct Current
DOE	U.S. Department of Energy
DVS	Dynamic Voltage Scaling
EERE	U.S. Department of Energy – Office of Energy Efficiency and Renewable Energy
EIA	U.S. Department of Energy – Energy Information Administration
EMSD	Electrical and Mechanical Services Department of Hong Kong
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act
EPCA	Energy Policy and Conservation Act
EPRI	Electric Power Research Institute
EUL	Expected Useful Life
EVA	European Vending Association
FEMP	Federal Energy Management Program
FSTC	Food Service Technology Center
GAMA	Gas Appliance Manufacturing Association

GE	General Electric
GPM	Gallons per Minute
HP	Hewlett-Packard
Hp	Horse Power
HPWH	Heat Pump Water Heater
HT	High Temperature (Dishwasher)
HVAC	Heating, Ventilation and Air Conditioning
IT	Information Technology
kBtu	Thousand British Thermal Units
kWh	Kilowatt-hour
L	Rated Load
LAN	Local Area Network
LBNL	Lawrence Berkeley National Laboratory
LCD	Liquid Crystal Display
LED	Light-emitting Diode
LT	Low Temperature (Dishwasher)
MFD	Multifunction Devices
MLA	Multi-housing Laundry Association
mmBtu	Million British Thermal Units (sometimes written MMBtu)
MPS	Managed Printing Service
MRI	Magnetic Resonance Imaging
NAFEM	North American Association of Food Equipment
NAMA	National Automatic Merchandising Association
NBECS	Non-Residential Buildings Energy Consumption Survey
NCI	Navigant Consulting, Inc.
NRA	National Restaurant Association
OPL	On-Premise Laundry
PC	Personal Computer
PC	Personal Copier (Imaging Device Classification)
PCE	Perchloroethylene
PM	Power Management
POS	Point-of-Service
psi	Pounds Per Square Inch
psig	Pounds Per Square Inch (Gauge)
Quad	Quadrillion (10^15) British Thermal Units
RAM	Random Access Memory
RMC	Remaining Moisture Content
RPM	Rotations per Minute
TBtu	Trillion (10^12) British Thermal Units
TWh	Terawatt-Hour
UEC	Unit Annual Energy Consumption
UES	Unit Energy Saving
UPS	Uninterruptible Power Supply

UTRC	United Technologies Research Center
V_c	Rated Speed
VDI	Association of German Engineers
WAN	Wide Area Network
WF	Water Factor

Executive Summary

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Program (BT) commissioned this characterization and technology assessment of appliances used in commercial buildings. The primary objectives of this study were to document the energy consumed by commercial appliances and identify RD&D opportunities for efficiency improvements. For the purposes of this analysis, "commercial appliances" are defined as energy-consuming appliances and equipment used in commercial buildings, excluding HVAC for comfort conditioning, building lighting (interior or exterior), commercial refrigeration equipment[1], and distributed generation systems (including combined heat and power systems). Commercial appliances represent a significant portion of commercial building energy consumption—about 6.92 Quadrillion Btu (Quad) annually in the US, or almost 40 percent of commercial building energy consumption reported in the 2008 Buildings Energy Databook (DOE, 2008).

National Energy Consumption

Figure ES-1shows the 2008 U.S. commercial sector primary energy consumption, indicating that commercial appliances account for nearly 40 percent, or 6.92 quadrillion Btu (quad), of U.S. commercial building energy consumption.

Figure ES-2 shows our estimates of the 2008 national energy consumption for commercial appliances, segmented by appliance type. In this figure, we exclude from laundry equipment and dishwashers the energy used to heat the water supplied to the equipment. This avoids double counting some of the energy consumption reported under water heating. With the exception of the miscellaneous equipment category, estimates are based on our bottom-up analyses. Our analyses of appliances in the miscellaneous equipment category (detailed on the right side of the figure) accounted for only about 9 percent of the energy consumption in the miscellaneous equipment category. The total consumption for this category is taken from the 2008 Buildings Energy Databook "other" category (DOE, 2008). DOE's Energy Information Administration (EIA) is the original source for the Buildings Energy Databook estimates.

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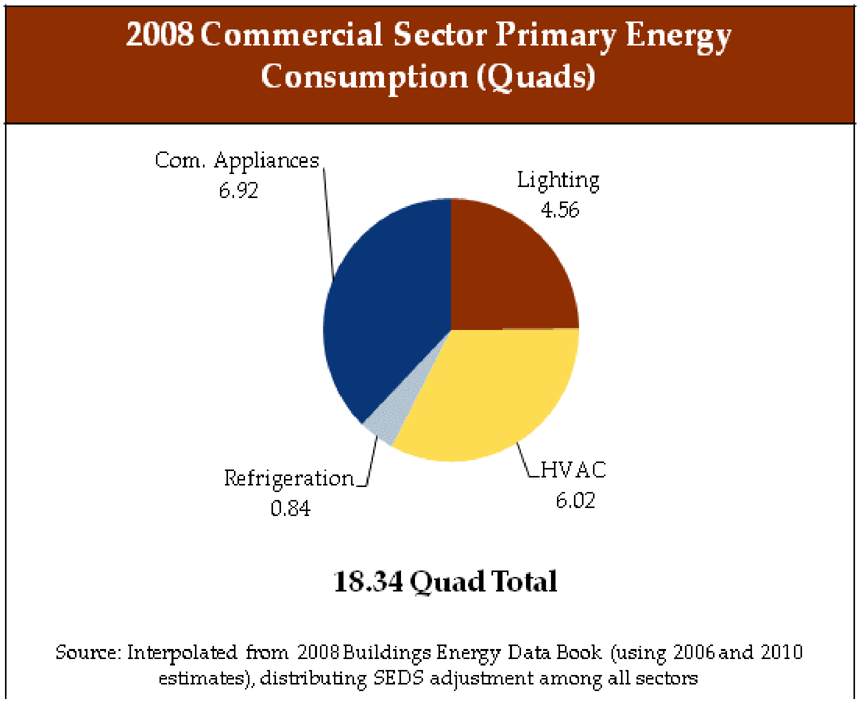
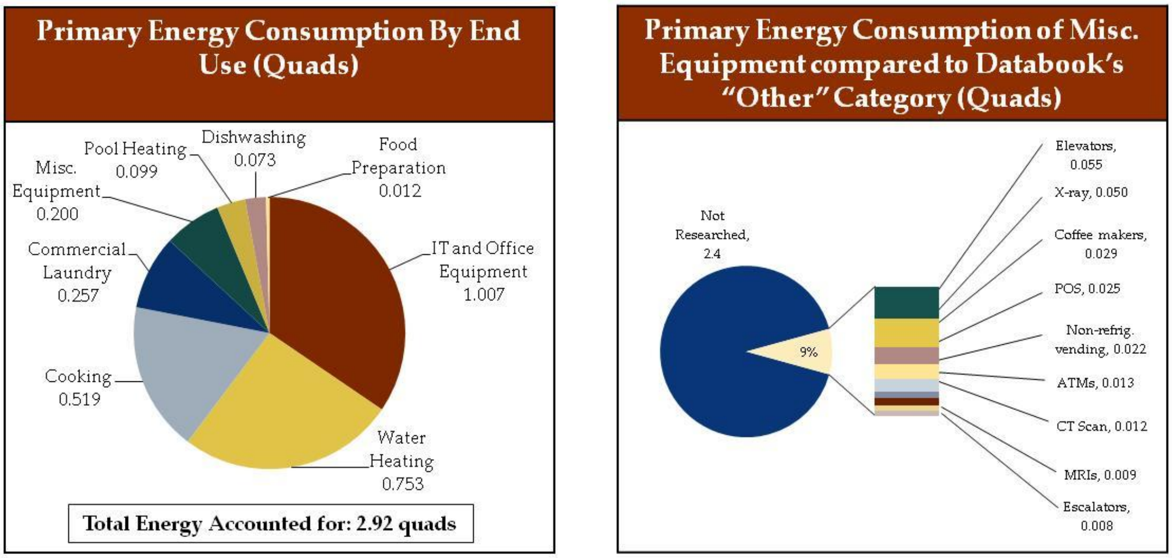
[1] Navigant Consulting recently characterized commercial refrigeration equipment in a separate report. (NCI 2009)

Figure ES-1: 2008 U.S. Commercial Sector Primary Energy Consumption



Source: Interpolated from 2008 Buildings Energy Data Book (using 2006 and 2010 estimates), distributing SEDS adjustment among all sectors

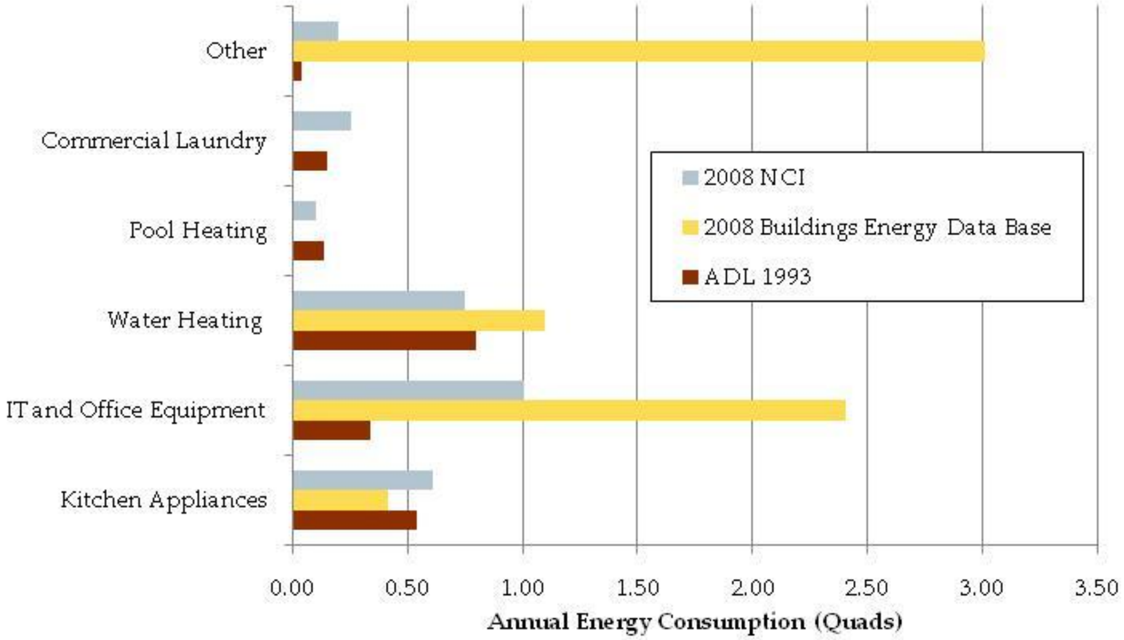
Figure ES-2: 2008 National Primary Energy Consumption for Commercial Appliances



We compare our estimate of total energy consumption to the 2008 Buildings Energy Databook and the last BT report that characterized commercial appliances (ADL 1993). Compared to the 2008 Buildings Energy Databook estimate of 6.92 Quad (see Figure ES-1 above), our analysis accounts for only about 2.92 Quad (42 percent). As shown in Figure ES-3, the discrepancies between the Building Energy Data Book estimates and ours (about 4 Quad) lie primarily in two categories:

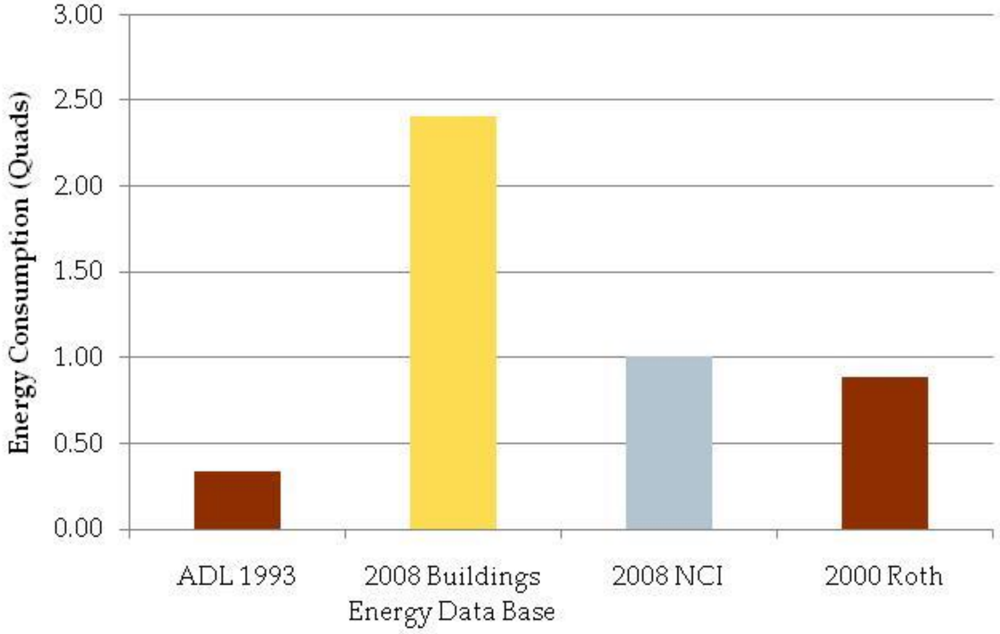
- IT and Office Equipment (about 1.4 Quad difference)
- Miscellaneous Equipment (about 2.4 Quad difference).

Figure ES-3: Summary Comparisons of National Primary Energy Consumption Estimates



As illustrated in Figure ES-4 and discussed in Section 5.7, our national consumption estimate for IT and Office Equipment (1.01 quad in 2008) is consistent with Roth's estimate (0.89 quad in 2000) (Roth, et. al., 2002). Our estimate of computer energy consumption (0.72 Quad) agrees well with the Building Energy Data Book estimate (0.73 Quad). Electronics, as defined by the Data Book (totaling 1.67 Quad), may include non-computer-related display equipment, telephone network equipment, broadband network equipment, and other equipment that we did not include. However, it is unclear whether these additional equipment types can account for the differences in estimates.

Figure ES-4: Consumption Comparisons for IT and Office Equipment



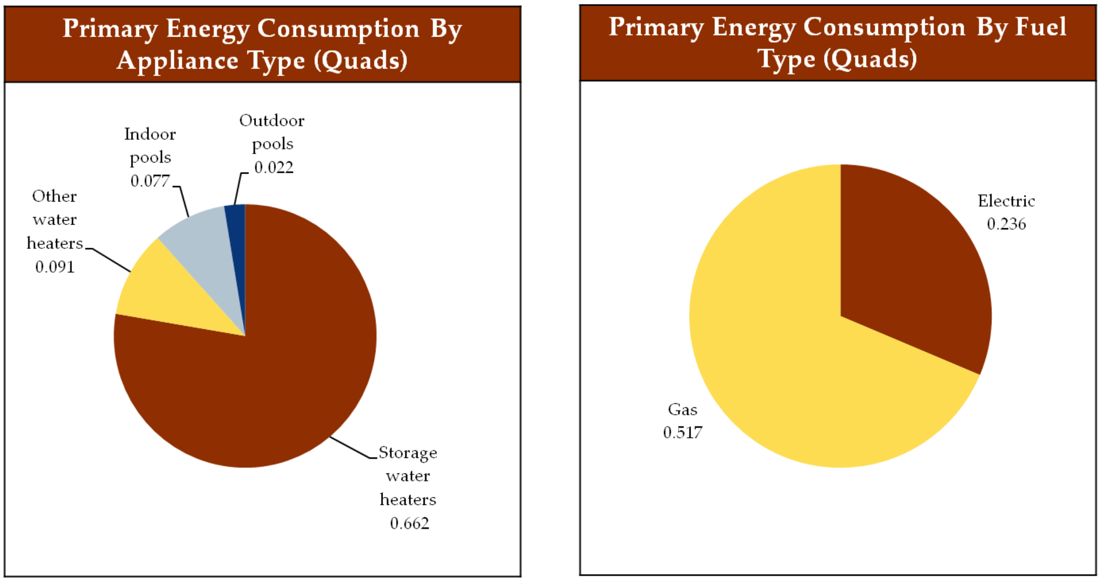
As discussed further in Section 9, we believe that the Miscellaneous Equipment consumption for which we have not accounted is distributed among a broad range of equipment types either outside of this analysis's scope (e.g. emergency electric generators) or attributable to many smaller energy loads which individually are not significant contributors.

As shown in Figure ES-5, water heating and pool heating account for about 0.85 Quad of commercial building primary energy consumption. At about 0.75 Quad, service water heating (including storage tank heaters only) constitutes the bulk of this consumption. Approximately 69 percent of this is natural gas, and the remainder is electricity. We did not consider other fuels such as oil, propane, or renewable fuels.

As illustrated in Figure ES-6, information technology (IT) and office equipment also account for about 1.0 Quad (all electricity) of commercial building energy consumption. Server and personal computers account for about 65 percent of this consumption.

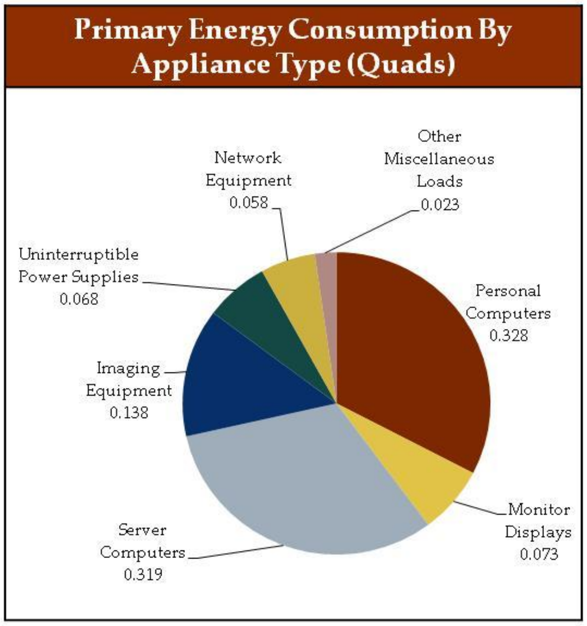
Cooking and food-preparation equipment account for about 0.5 Quad of commercial building energy consumption, as indicated in Figure ES-7. The energy consumption associated with food-preparation equipment is a very small contributor compared to the various cooking appliances.

Figure ES-5: 2008 National Primary Energy Consumption for Commercial Service Water Heating and Pool Heating


Primary Energy Consumption By Appliance Type (Quads)

Primary Energy Consumption By Fuel Type (Quads)

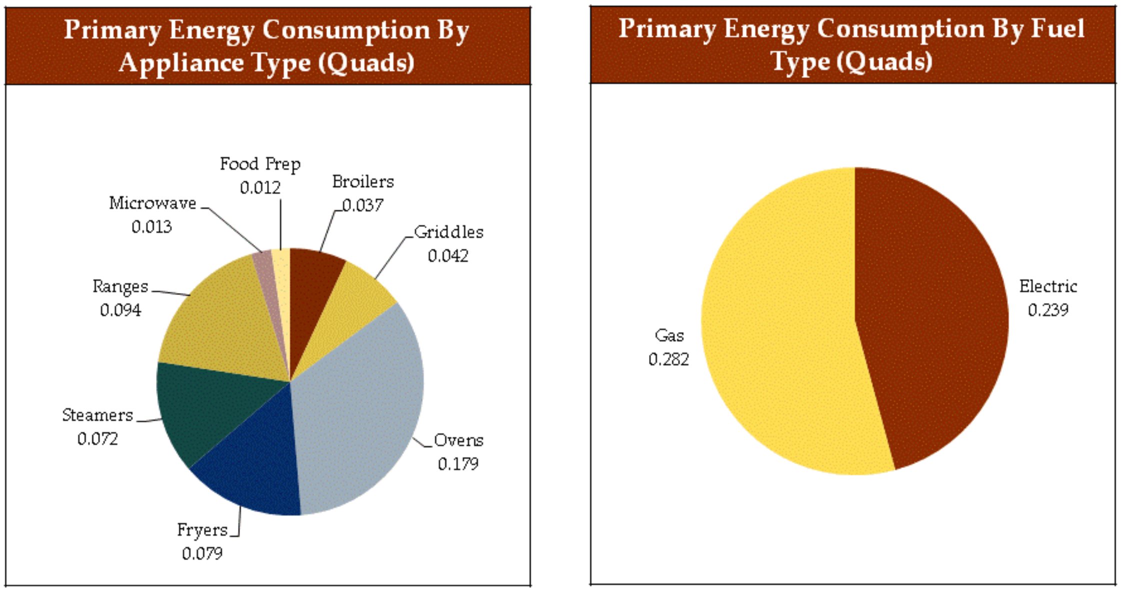
Figure ES-6: 2008 National Primary Energy Consumption for Commercial IT and Office Equipment


Primary Energy Consumption By Appliance Type (Quads)

Appliance Type Definitions

- Personal Computers
  - Desktop PCs
  - Laptop PCs
- Desktop Monitors
  - CRT Monitors
  - LCD Monitors
- Server Computers
  - Volume Servers
  - Mid-Range Servers
  - High-End Servers
- Imaging Equipment
  - Multifunction Devices
  - Laser Printers
  - Inkjet Printers
  - Fax Machines
  - Scanners
  - Impact Printers
  - Other Printers
- Network Equipment
  - LAN switches
  - WAN switches
  - Routers
- Uninterruptible Power Supplies
  - Standby UPSs
  - Line-Interactive UPSs
  - Double Conversion UPSs
- Miscellaneous Loads
  - Voice Mail Systems
  - Handheld Devices
  - Electric Typewriters
  - Desktop Calculators

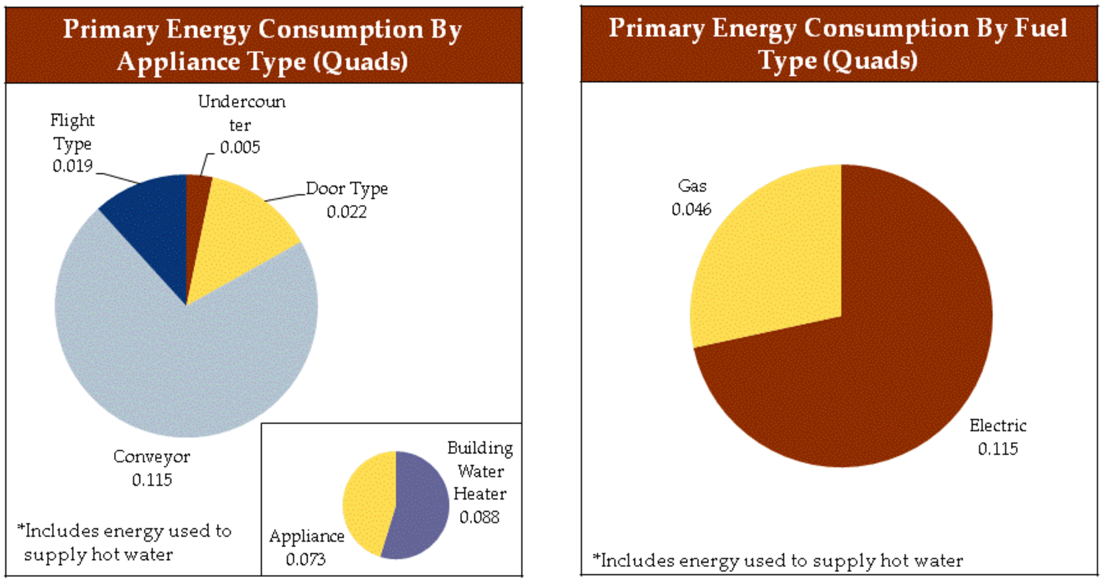
Figure ES-7: 2008 National Primary Energy Consumption for Commercial Cooking and Food-Preparation Equipment


Primary Energy Consumption By Appliance Type (Quads)

Primary Energy Consumption By Fuel Type (Quads)

As shown in Figure ES-8, dishwashers account for about 0.16 Quad of commercial building energy consumption. Over 70 percent of this energy consumption is associated with large, conveyor-type dishwashers. These figures include the energy associated with heating the water supplied to the dishwasher (which accounts for over 50% of total energy). Electricity accounts for over 70 percent of dishwasher energy consumption, as shown in the right side of the figure. This is because dishwashers themselves use electricity generally to maintain the water temperature or heat it further to temperatures required for sanitization.

Figure ES-8: 2008 National Primary Energy Consumption for Commercial Dishwashers


Primary Energy Consumption By Appliance Type (Quads)

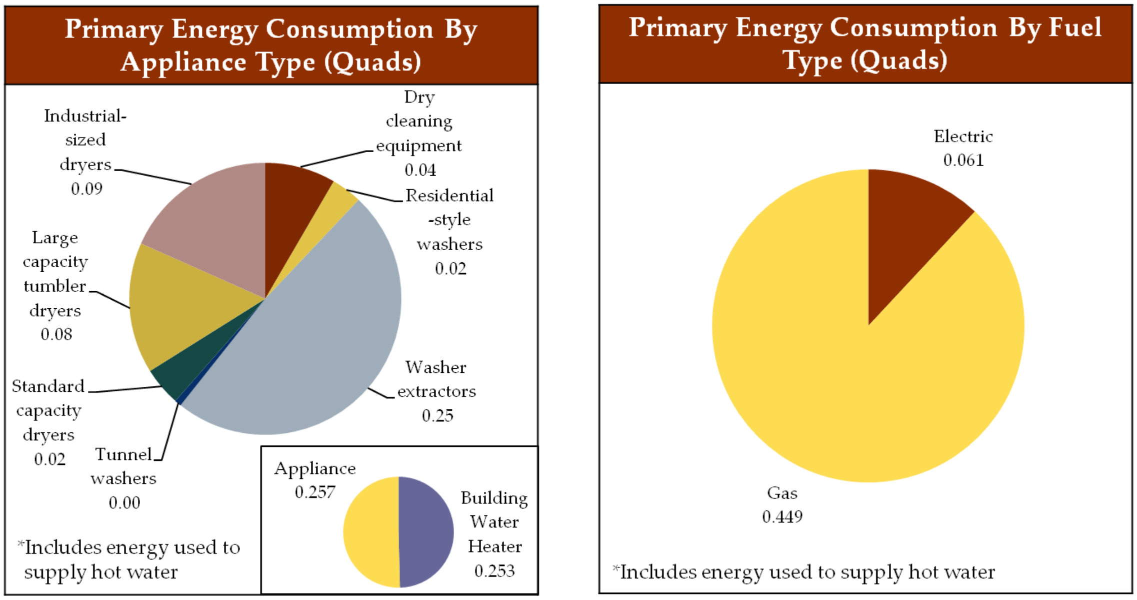
Primary Energy Consumption By Fuel Type (Quads)

*Includes energy used to supply hot water

*Includes energy used to supply hot water

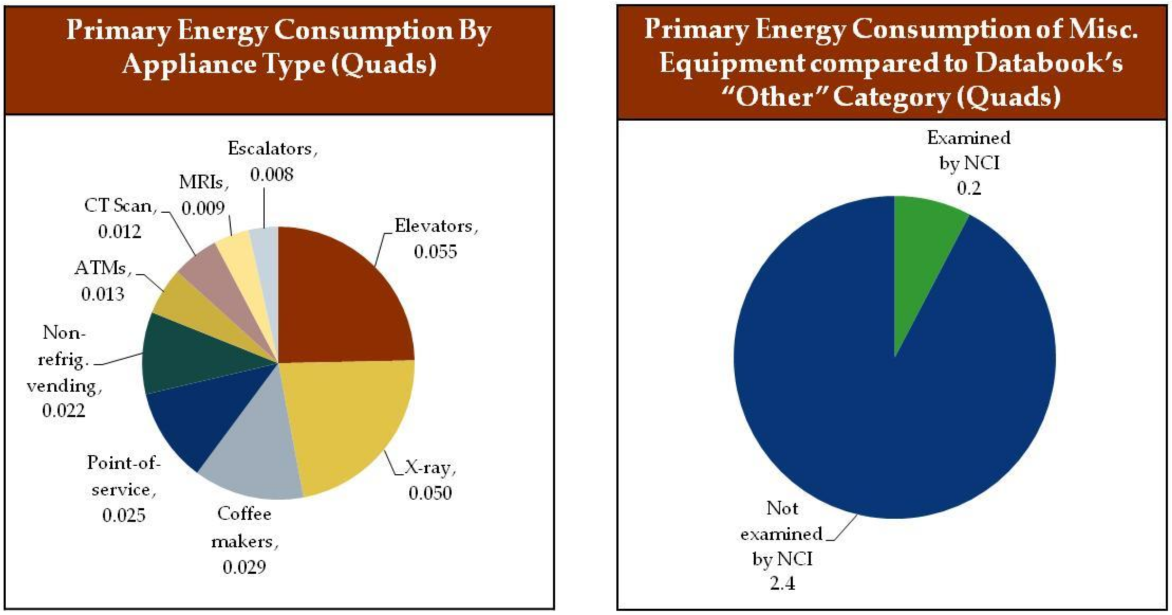
As illustrated in Figure ES-9, laundry equipment accounts for about 0.5 Quad of commercial building energy consumption, including the energy used to heat water supplied to clothes washers. Almost 90 percent of this is natural gas (or other fossil fuels), and the remainder is electricity.

Figure ES-9: 2008 National Primary Energy Consumption for Commercial Laundry Equipment



The miscellaneous equipment we analyzed consume about 0.2 Quad of commercial building energy consumption, as shown in Figure ES-10. This accounts for only about 8 percent of the 2.6 Quad miscellaneous equipment energy consumption reported by the 2008 Buildings Energy Databook. As mentioned above and discussed in Section 9, we believe that the consumption for which we have not accounted is distributed among a broad range of equipment types, none of which is a significant individual contributor.

Figure ES-10: 2008 National Primary Energy Consumption for Commercial Miscellaneous Equipment



Technical Potential for Energy-Saving Technologies

Figure ES-11 plots technology maturity versus technical potential[2] for the top 30 energy-saving technologies investigated. The top 30 are based on technical potential. Technology maturity ratings are based on the judgments of Navigant Consulting (NCI) experts. As the figure shows, most of the energy-savings potential resides in technologies that are already mature. However, in some of these cases, the energy-saving technology may not be currently used in the targeted appliance, and some design and demonstration work may be needed to incorporate the technology.

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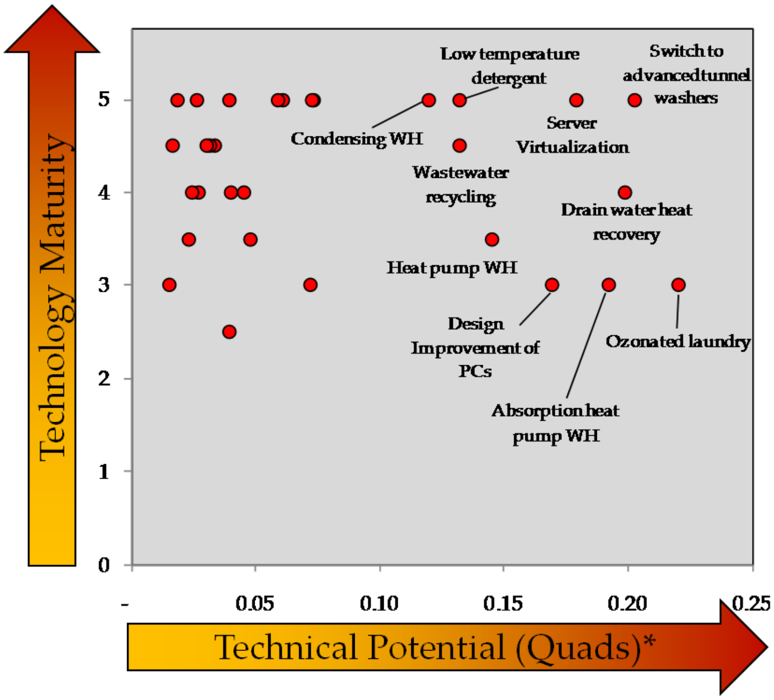
[2] Technical potential is the theoretical national primary energy savings that could be achieved if all technically suitable appliance/equipment installations are replaced with a particular energy-saving technology. In this report, we calculate technical potential relative to the efficiency of typical new equipment, so that we do not double count the savings that will be achieved anyway, through normal equipment replacement cycles.

Figure ES-11: Technology Maturity versus Technical Potential Selected Energy-Saving Technologies

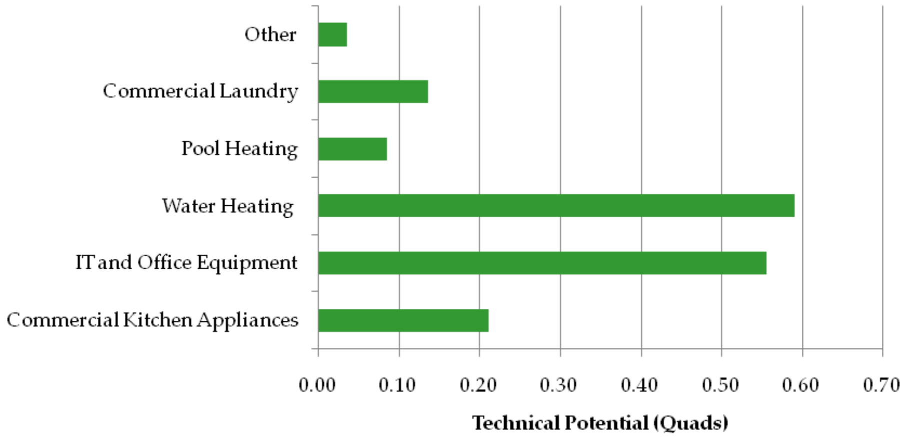


Note: Only selected technology labels are displayed for figure clarity.
Maturity ranking guidelines:
5 - Commercially available technology; high efficiency models are competitive with typical models.
4 - Commercial available though only available from 1-2 manufacturers; low market penetration, high costs.
3 - Near Term technology: Proven technology though not commercialized in application, possibly in pilot stage or product development
2 - Long Term: Proven technology though only in a lab setting or based on engineering fundamentals, limited field testing
1 - R&D: Unproven technology for application, energy savings is a preliminary estimate, costs are uncertain.

Figure ES-12 shows technical potential by end-use category, accounting for all the energy-saving technologies that we evaluated for each end-use category. The total technical potential of all the end-use categories combined amounts to 1.5 Quad. The figure corrects for the interactive effects of technologies and competing technologies. Interactive effects include:

- Competing energy-saving technologies that are not physically compatible with each other within a single appliance
- Reductions in technical potential as multiple energy-saving technologies are applied to a single appliance
- Overlaps in allocation of energy consumption by end-use category, such as water heating energy that also applies to clothes washers or dishwashers

Figure ES-12: Technical Potential by End-Use Category



The figure illustrates that the greatest technical potentials are in water heating and IT/office equipment, each of which has a technical potential approaching 0.6 Quad. Technical potentials for laundry, pool heating, and kitchen appliances are also significant.

Recommendations

Based on the results above and consideration of key barriers (discussed in Sections 2 through 9 below), we developed recommendations for DOE programs that can promote energy savings in commercial appliances. Figure ES-13 shows the three categories by which we sorted recommendations. We did not include rebate or tax-incentive programs.

Figure ES-13: Groupings used for Recommended DOE Programs[a]

a) Ongoing organizational changes at DOE may shift some of DOE's responsibilities for the ENERGY STAR program to EPA. If this occurs, some of the ENERGY-STAR-related recommendations made may be more applicable to EPA.

Table ES -1 through Table ES - 6 summarize our recommended DOE actions in each end use category.

Table ES-1: Water-Heater Recommendations

	Technology/ Program	Recommended DOE Action
RD&D Programs	Solar Thermal Water Heater Demonstrations	Demonstrate performance and cost savings benefits by installing Solar Thermal Water Heaters on federally owned or institutional facilities and distribute results to appropriate private sector decision makers. An example program would work with the Hospital Energy Alliance to target federally owned medical facilities. Potential savings: 0.4-0.6 Quads.
	Drain Water Heat Recovery Demonstrations	Demonstrate performance and cost savings benefits by installing commercialized Drain Water Heat Recovery on federally owned or institutional facilities which are particularly well-suited to the technology and distribute results to private sector decision makers. An example program would work with the Hospital Energy Alliance to target federally owned medical facilities. Potential savings: 0.2-0.3 Quads.
	Advanced Materials and Designs for Drain Water Heat Recovery	Coordinate and solicit feedback from manufacturers to research alternative materials and design applications for drain water heat recovery technology. Potential savings: 0.2-0.3 Quads.
	Heat Pump Water Heaters	Coordinate with researchers and manufacturers to leverage past research and recent residential product introductions to further develop heat pump water heater technology for commercial applications in the US. Potential savings: 0.2-0.3 Quads.
	Absorption Heat Pump Water Heaters	Work with water heater manufacturers to develop absorption heat pumps specifically for water heating applications. Potential savings: 0.1-0.2 Quads.
	Integrated HVAC and Water Heating Systems	In cooperation with ASHRAE, sponsor a research program focused on the integration of water heating equipment and HVAC equipment to more efficiently manage heat transfer within commercial buildings.
Voluntary Programs	ENERGY STAR for Commercial Water Heaters	Develop ENERGY STAR programs for commercial size water heaters (e.g. solar thermal, heat pump, and condensing water heaters). Potential savings: 0.1-0.6 Quads depending on technology type.
Regulatory Programs	Minimum Efficiency for Water Heaters	Continue the commercial water heating conservation standards program and coordination effort with ASHRAE.

Table ES-2: Pool-Heater Recommendations

	Technology/ Program	Recommended DOE Action
RD&D Programs	Relevant Water Heating Technologies	Sponsor research and/or demonstration programs for pool heating equipment that overlap with existing or other planned water heating demonstration programs.
Voluntary Programs	ENERGY STAR for Commercial Pool Heaters	Expand the ENERGY STAR program to include commercial pool heaters.
	Educational Outreach for Commercial Pool Equipment	Work with FEMP to launch an educational outreach program similar to the previous DOE RSPEC program to increase awareness of energy- and cost-saving opportunities for commercial pools.
Regulatory Programs	Minimum Efficiency Standards for Commercial Pool Heaters	Implement minimum efficiency standards for commercial pool heaters.

Table ES-3: IT and Office Equipment Recommendations

	Technology/ Program	Recommended DOE Action
RD&D Programs	Data Center HVAC Efficiency RD&D	Establish an R&D program to address research needs in the area of data center HVAC efficiency. Data center infrastructure load (mainly HVAC) which accounts for over 50% of the overall data center energy consumption, is a cross-cutting topic between IT and HVAC efficiency.
Voluntary Programs	ENERGY STAR Inclusion of Power Management	Include power management as a part of the future ENERGY STAR standards for personal computers and desktop monitors. As a part of the deliberation, DOE should work with industry stakeholders and consumer interest groups to identify and evaluate impact on the market, IT industry and end users. Potential savings: 0.07 – 0.24 Quads/yr
	IT Network Efficiency Performance Program	IT Network Efficiency Performance Program: Establish a LAN- or a buildings-level IT network efficiency performance program to act as a clearinghouse of best network design practices. While there is a strong market demand for efficiency improvements at individual device level, an IT network system must be designed to optimize and fully capture the collective energy efficiency potential of the overall network. Potential savings: 0.3 Quads/yr.
	Energy Study	Investigate further the discrepancy between the national consumption estimates reported herein and those reported in the Building Energy Data Book (a difference of about 1.4 quad). This will require close collaboration with D&R International, Ltd., the organization that updates annually the Building Energy Data Book, to understand the sources and assumptions used in developing the Data Book estimates.
Regulatory Programs	Monitor Industry Activities	Monitor market developments to determine if any type of federal standards would add value to ongoing industry initiatives. There are compelling market drivers to continuously improve efficiency of IT and office equipment (See Section 5.12.1) even without minimum efficiency standards.

Table ES-4: Commercial Kitchen Recommendations

	Technology/ Program	Recommended DOE Action
RD&D Programs	Supercritical CO_2 Dishwashing	Sponsor research to assess its energy saving potential and its viability to meet the cleaning needs of the commercial food service sector. Technology eliminates the need to heat water for use in dishwashers and targets 0.125 Quads of energy use.
	Electric Ignition	Partner with the Retail Energy Alliance (REA) and industry to develop a reliable electric ignition system for use in all commercial cooking appliance types. Potential savings: 0.014 Quads
	Broiler Idle energy reduction	Partner with the Retail Energy Alliance and industry to develop a reliable durable control system to reduce idle energy consumption in commercial Broilers. Potential savings: 0.008 Quads.
Voluntary Programs	Manufacturer/ Chain Customer cooperation	Create a framework through which cooking equipment manufacturers and chain restaurants can work to overcome food quality and cost barriers of high efficiency appliances. The DOE should work through the Retail Energy Alliance to bring both parties together.
	ENERGY STAR for Cooking Appliances	Continue ENERGY STAR Steamer, Dishwasher, Fryer, and Oven programs and encourage more utilities to rebate Dishwashers. Potential savings: 0.135 Quads.
Regulatory Programs	Monitor State Activities	Monitor success of regulatory activities in California. Current California regulations are limited, and only apply to a subset of commercial kitchen appliances.

Table ES-5: Commercial Laundry Recommendations

	Technology/ Program	Recommended DOE Action
RD&D Programs	Commercial Ozone Laundry Systems	Review the safety and efficacy of existing commercial ozone laundry systems on the market. Potential savings: 0.10 Quads.
	Dryer End-of-Cycle Sensors	In cooperation with commercial dryer and sensor manufacturers, sponsor a demonstration project for a dryer sensor able to measure RMC below 15% and accurately detect end-of-cycle in single-load and commercial tumble dryers. Potential savings: 0.015 Quads
	Modulating Gas Burners	In cooperation with dryer manufacturers, sponsor a demonstration project for modulating gas burners in commercial single-load and tumbler dryers. Potential savings: 0.013 Quads.
	Facility-Scale Dryer Inlet Air Preheating	In cooperation with dryer manufacturers and commercial laundry facilities, sponsor a research project that examines the feasibility of facility-scale inlet air preheating for coin-operated, on-premise and off-premise laundries. Potential savings: 0.011 Quads.
Voluntary Programs	ENERGY STAR for Commercial Washers	Continue the ENERGY STAR program for single-load commercial washers.
	ENERGY STAR for Commercial Dryers	Consider creating an ENERGY STAR program for single-load commercial dryers and larger capacity tumbler dryers.
Regulatory Programs	Minimum Efficiency Standards	Continue mandatory standards programs for commercial single-load washers.
		Consider implementing minimum efficiency standards for multi-load washers.
		Consider implementing efficiency standards for single-load commercial dryers and larger capacity tumbler dryers.

Table ES-6: Miscellaneous Equipment Recommendations

	Technology/ Program	Recommended DOE Action
RD&D Programs	Smart Controls and Proximity Sensors	Analyze the effectiveness of control systems and proximity sensors for the commercial sector. This project would further research savings potential, relevant applications, and effectiveness of this technology in the commercial sector to determine whether a follow-on voluntary program is worthwhile.
Voluntary Programs	Energy Study	Investigate further the possible discrepancy between the national consumption estimates reported herein and those reported in the Building Energy Data Book (a difference of about 2.4 Quads). This will require close collaboration with D&R International, Ltd., the organization that updates annually the Building Energy Data Book, to understand the sources and assumptions used in developing the Data Book estimates.
Regulatory Programs	Motors	Continue to develop standards for small electric motors and assess the impact of motor efficiency standards established by EISA 2007 once they go into effect to determine if additional regulatory efforts or a voluntary program (e.g. ENERGY STAR program promoting premium efficiency) is needed.

1 Introduction

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Program (BT) commissioned this characterization and technology assessment of appliances for commercial buildings to:

- Determine the energy consumption of the various segments of the commercial appliance and equipment market
- Identify and characterize substantial energy savings opportunities, and estimate their magnitude
- Identify barriers to implementation and analyze economics
- Recommend BT activities that can address these savings opportunities, which may include R&D, demonstration projects, standards activities, tool development, or other efforts.

For the purposes of this analysis, "commercial appliances" are defined as energy-consuming appliances and equipment used in commercial buildings, excluding HVAC for comfort conditioning, building lighting (interior or exterior), commercial refrigeration equipment[3], and distributed generation systems (including combined heat and power systems).

1.1 Report Organization

This report is organized as shown in Table 1-1. Given the diverse nature of the equipment analyzed, we organized the report by equipment type. In each equipment-type section, we cover:

- Equipment descriptions
- Manufacturers and market shares
- Major end users
- Typical distribution chain
- Annual shipments and installed base
- Baseline energy consumption (i.e., energy consumption of the current nationwide installed base)
- Life, reliability, and maintenance characteristics
- Regulatory programs
- Voluntary programs
- Energy-saving opportunities.

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[3] Navigant Consulting recently characterized commercial refrigeration equipment in a separate report. (NCI 2009)

Table 1-1: Report Organization

Section	Content/Purpose
Executive Summary	Top-level report summary
1	Introduction—work scope/objectives, report organization, background, and overall approach
2	Cooking Appliances (conventional ovens, ranges, fryers, steamers, broilers, griddles, microwave ovens)
3	Food-Preparation Equipment
4	Dishwashers
5	Information Technology and Office Equipment (personal computers, desktop monitors, server computers, imaging equipment, network equipment, uninterruptible power supplies, voice-mail systems, handheld devices, electric typewriters, desktop calculators)
6	Water Heaters
7	Pool Heaters
8	Laundry Equipment (clothes washers, clothes dryers, dry-cleaning equipment)
9	Miscellaneous equipment (escalators, elevators, x-ray machines, coffee makers, point-of-service equipment [i.e., cash registers], non-refrigerated vending machines, automated teller machines, CT scanners, MRI machines)
10	Recommendations (RD&D initiatives, voluntary programs, regulatory programs)
References	List of references cited in report
Appendix A	Primary Cooking
Appendix B	Food Preparation
Appendix C	Commercial Dishwashers
Appendix D	Office and IT Equipment
Appendix E	Water Heaters
Appendix F	Laundry Equipment

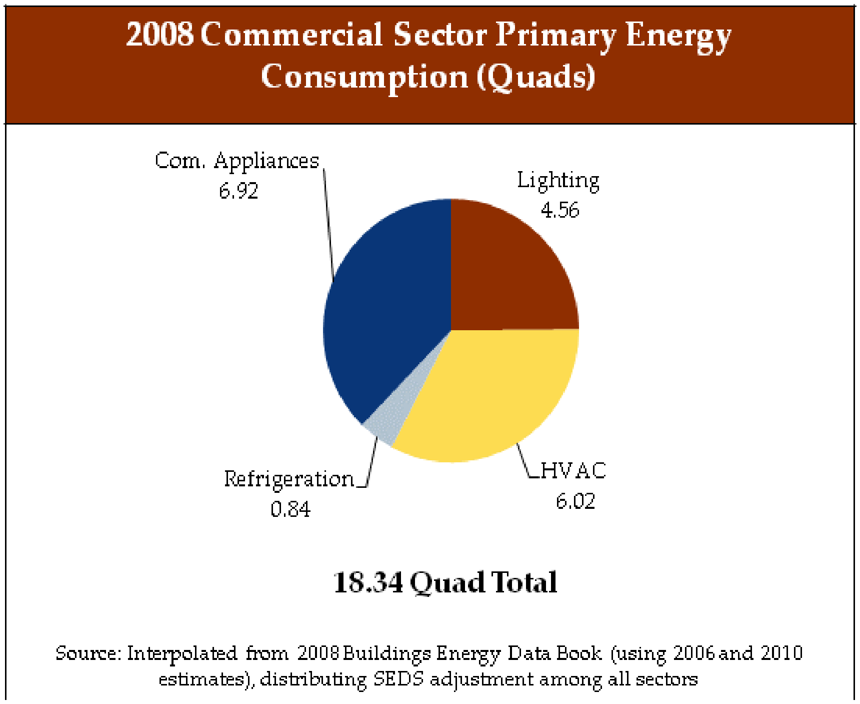
1.2 Background

Figure 1-1: 2008 U.S. Commercial Sector Primary Energy Consumption shows that commercial appliances represent nearly 40 percent (6.92 Quads) of U.S. commercial building primary energy consumption. Commercial appliances encompass a broad range of appliances and equipment categories, including:

- Cooking appliances
- Food-preparation equipment
- Dishwashers
- Water heaters
- Pool heaters
- Laundry equipment
- Miscellaneous equipment.

BT last characterized commercial appliances in a 1993 report (ADL 1993). Since that time, commercial appliance technology characteristics have changed significantly, especially for IT and office equipment. Therefore, BT determined it needed an updated characterization upon which to base its multi-year plan.

Figure 1-1: 2008 U.S. Commercial Sector Primary Energy Consumption



Source: Interpolated from 2008 Buildings Energy Data Book (using 2006 and 2010 estimates), distributing SEDS adjustment among all sectors

1.3 *Overall Approach to Estimating Energy Consumptions and Energy Savings*

Commercial appliances, as defined above, include an extensive range of diverse appliances and equipment types. The diversity of commercial appliances and variations in the availability of information required a tailored approach to each appliance/equipment category. Below we outline the common areas of our approach to estimating energy consumption and energy savings potential, and in Sections 2 through 9 we detail the tailored approach used for each appliance/equipment category.

1.3.1 Baseline Technology

We start by defining a baseline technology. The "baseline technology" is the technology against which we wish to compare the performance of an energy-saving technology. Since new equipment is generally more efficient than the installed base (because of appliance and equipment energy-conservation standards, or simply because of advances in product design), some energy savings will accrue simply through normal replacement cycles, without additional DOE action. In order to avoid double counting this portion of the energy savings associated with high-efficiency technology options, we calculate energy savings relative to typical new equipment, rather than the installed base.

1.3.2 Unit Energy Consumption

Using primarily third-party sources (technical literature and industry interviews), we estimate Unit Energy Consumption (UEC) for a product employing the baseline technology (as defined in Section 1.3.1 above). In reality, UEC can vary widely depending on climate, capacity, usage patterns and other factors, but we try to find a value that we believe is representative of typical conditions in the U.S. If data are only available for the installed base, we may assume that the UEC's of the baseline technology and the installed base are similar. UEC is generally based on site energy consumption, but in some cases we also report UEC based on primary energy consumption[4].

1.3.3 National Energy Consumption

To estimate national energy consumption, we need to estimate the installed base of the appliance/equipment type. We may obtain this based on technical literature and industry interviews, or estimate it based on shipment data and typical equipment replacement cycles. We then multiply the installed base by the UEC to obtain national energy consumption. We generally express national energy consumption in terms of primary energy.

1.3.4 Unit Energy Savings (UES)

Again, using primarily third-party sources (technical literature and industry interviews), we identify alternative technologies that can reduce energy consumption, estimate their UECs, and then calculate their unit energy savings (UES) compared to the baseline technology. UES may be expressed as a percentage or an absolute savings.

1.3.5 Technical Potential

The "technical potential" energy savings associated with an energy-saving technology is the national primary energy savings that would accrue if all technically suitable applications are replaced with the energy-saving technology. Technical potential is expressed relative to the baseline technology (as defined in Section 1.3.1 above). We calculate technical potential by multiplying the UES (in absolute savings) for a particular energy-saving technology by the installed base. If both electric and fossil fuels are used, we may need to split up the calculation so that electricity consumption can be converted to primary energy.

In practice, the technical potential energy savings can only be achieved if an energy-conservation standard is put into effect, and then would be achieved only after the entire installed base is replaced with new products. When combined with a qualitative understanding of the complexity and risks associated with the energy-saving technology, technical potential provides a basis for prioritizing DOE investments in the technology.

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[4] Primary energy accounts for the losses in generation, transmission and distribution. We generally only account for these losses for electricity, as the transmission and distribution losses for natural gas and other fossil fuels tend to be small. Primary energy does not account for the losses associated with extraction.

1.3.6 Economics

We report cost data for both the baseline and energy-savings technologies when those data are available. We then estimate simple payback periods for the energy-saving technology. When cost data are not available, we generally calculate an allowable first-cost premium based on what we assume to be an acceptable payback period. While this calculation cannot tell us whether the allowable cost premium is achievable, it can give a sense of the cost challenge involved and can help establish cost targets for potential RD&D programs.

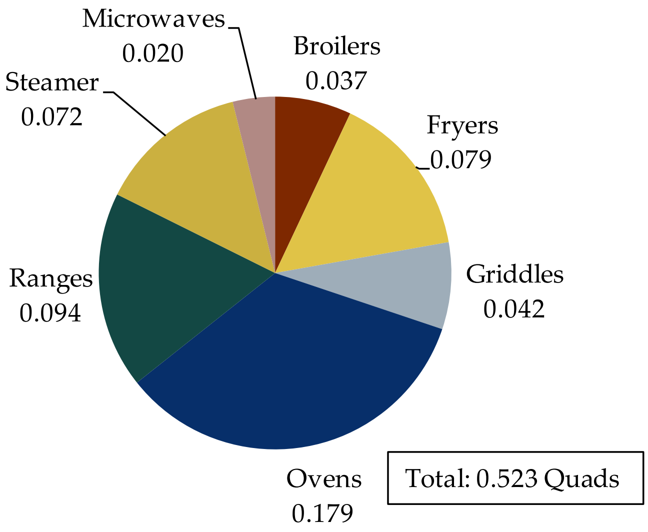
2 Commercial Cooking Appliances

Commercial cooking appliances can use natural gas, electricity, or both. These appliances are often referred to as primary cooking appliances; their job is to cook foods starting from their "raw" state. This chapter focuses on seven major cooking appliance categories: fryers, broilers, griddles, ovens, ranges, steamers, and microwaves. There are a variety of appliances within each category, though annual energy estimates are made only for a "representative" appliance in each of the seven categories.

2.1 *Summary Cooking Appliances*

Figure 2-1 and Table 2-1 provide a summary of the total US primary energy consumption by these seven cooking appliance types. Details and sources are described in the following sections.

Figure 2-1: Summary of Cooking Energy Consumption by Appliance Type for 2008



All values from Table 2-1

Table 2-1: US Cooking Appliance Installed Base and Energy Consumption for 2008

Cooking Equipment	Installed Base			Annual Energy Consumption (Quads)
	Total	Gas	Electric	
Broilers	200,000	182,000	18,000	0.037
Fryers	1,120,000	649,000	470,000	0.079
Griddles	552,000	276,000	276,000	0.042
Ovens	1,830,000	1,010,000	825,000	0.179
Ranges	822,000	748,000	74,000	0.094
Steamer	591,000	195,000	396,000	0.072
Microwave	978,000		978,000	0.020
Total	**6,090,000**	**3,060,000**	**3,040,000**	**0.523**

All values from Table 2-27 and Table 2-29

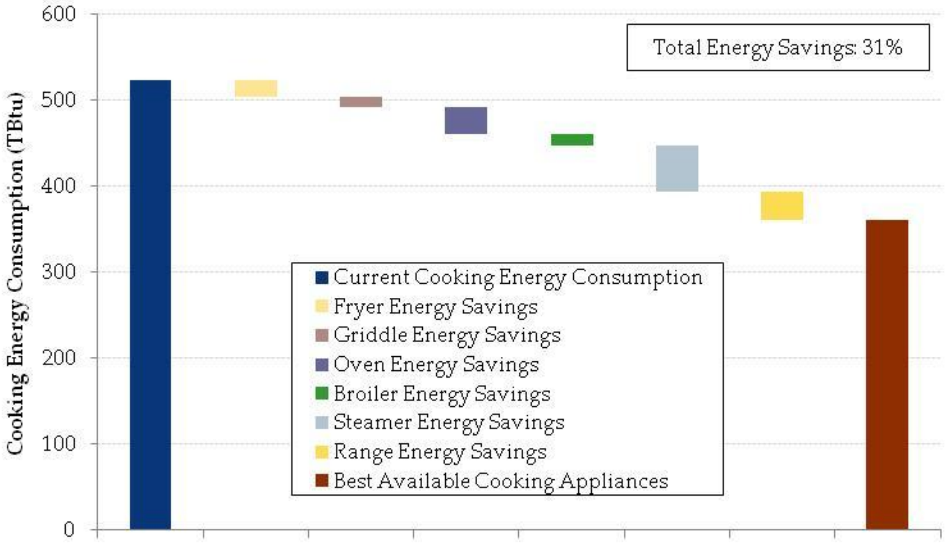
We have identified several promising energy efficiency technologies to reduce energy consumption in the cooking end use. The top technologies identified are combined in packages that target certain appliances. The technical potential energy savings for each appliance is summarized in Table 2-2 and Figure 2-2.

Table 2-2: Technical Potential for Cooking Equipment

Cooking Equipment	Fuel	Percent Savings	Annual Primary Energy Consumption (TBtu)	Technical Potential Energy Savings (TBtu)
Broilers	Gas	45.4%	31.7	14.4
	Electric	0	4.9	0.0
Fryers	Gas	38.3%	42.2	16.2
	Electric	7.0%	37.3	2.6
Griddles	Gas	43.1%	16.3	7.0
	Electric	18.4%	25.3	4.7
Ovens	Gas	35.1%	88.2	31.0
	Electric	0	90.6	0.0
Ranges	Gas	40.5%	83.3	33.8
	Electric	0	11.0	0.0
Steamer	Gas	73.5%	20.6	15.1
	Electric	73.0%	51.6	37.6
Microwaves	Electric	0%	20	0
All	**All**	**31%**	**523**	**162**

Source: Table 2-53

Figure 2-2: Cooking Sector Technical Potential, by Appliance Type



Note: Appliances shown in no particular order

2.2 *General Description*

Each of the seven broad cooking appliances is described below. The energy consumption is relatively small for kitchen appliances that are used to keep cooked food warm, so we do not include them in our analysis.

Listed cooking efficiencies are those described by ASTM testing standards. More details on the definition of cooking efficiency can be found in Appendix A, Section A.1.

Rated efficiencies are not a good indicator of actual, field energy use for most cooking appliances. Efficiencies are measured during a cooking event; however, it is common practice for chefs to turn on appliances in the morning and leave them idling throughout the day. This ensures that the appliances are always in their preheated state allowing restaurants to process orders faster as preheat times are typically 15-20 minutes.

2.2.1 Fryers

Fryers cook foods by immersing them in oil heated to about 350°F. The surrounding oil heats the moisture in the food and begins to cook the food from the inside. When the moisture begins to boil, water vapor vents from the food into the oil, and travels up to the oil's surface where it escapes to the air. Fryers are available in gas and electric models; gas models account for 58% of the market share. "Fire tubes" (Figure 2-3) provide heat to the oil in gas-fired model. Fire tubes are sealed metallic tubes immersed in the oil at the bottom of the kettle. They enclose gas burners and serve a dual purpose to separate the flame from the oil and act as a heat exchanger to the oil. Fire tubes can also be situated vertically along the side walls. Electric fryers heat oil using electric heating elements located at the bottom of the kettle, in direct contact with the oil.

These elements differ from oven heating elements in that they are designed to prevent oil from burning.

Figure 2-3: Fire Tubes in a Gas-Fired Fryer and Electric Resistance Heaters in an Electric Fryer

a) Fire Tubes (Keating of Chicago 2009) b) Resistance Heaters (FSTC 2007)

The majority of energy used by fryers is used by the burners or heating elements to maintain oil temperature. Additional energy is used by pilot lights, timers, temperature controls and sensors, (in some models) motors to lower and raise the frying basket, and (in some models) oil pumps to aid the filtering process. The oil pump cycles oil through a filter for three to five minutes during the filtering process. Filtering can be performed while the oil is hot, and is recommended daily. Some fryers have a small processor to a) regulate temperature, b) store programmed cook times for various foods, and c) operate an LCD display. Some basic fryers have no temperature feedback or timer controls.

Fryers are typically turned on in the morning, left on all day regardless of the cooking load, and turned off at night. Fryers can idle for 75% of the time even in a busy fast-food restaurant. Fryers take 10-15 minutes to reach the proper cooking temperature--this is known as the preheat time. Most standard gas fryers have a standing pilot light; the industry favors these for reliability. Electric ignition is not trusted to light all the time, and durability is an issue. This is also true for the majority of other gas cooking appliances.

Fryers are usually sized based on their oil capacity, ranging from 15-200 lbs of oil (most are less than 80 lbs). Large-capacity fryers are used in high-volume establishments, or are used to cook larger foods like chicken. Smaller-capacity fryers are used in restaurants where production volume is lower.

The three common fryer classifications used by industry are: floor mounted, pressure, and countertop fryers. Specialty fryers (for example, to fry donuts and potato chips at very high volumes) are not common in commercial kitchens.

Floor-Mounted Fryers

Floor-mounted fryers (Figure 2-4) are the most common fryers used in the cooking industry. They are often referred to as "open deep fat fryers". They are used to prepare all types of fried foods. The pot containing the oil is not generally insulated, thus energy can be lost not only from the surface of the oil but from the sides of the fryer as well.

Figure 2-4: Typical Floor Mounted Fryer (Frymaster GF-40)

Source: Frymaster 2009

Countertop Fryers

Countertop fryers (Figure 2-5) are similar to floor-mounted fryers, but are designed to be placed on existing counter space. They are smaller in capacity and used for lower-volume food production or where floor space is limited. Countertop models to not have electric-driven oil filtering systems, instead users must manual filter oil with specially designed sieves.

Figure 2-5: Typical Countertop Fryer (Cecilware EL-170)

Source: Cecilware 2009

Pressure Fryers

Pressure fryers come in either floor mounted or countertop models. Pressure fryers (Figure 2-6) are less common than atmospheric fryers, and are mostly used to cook chicken. A heavy lid is lowered and sealed on top of the oil kettle after food is placed in the fryer. Steam escaping from the food is trapped above the oil and builds up pressure. The increasing pressure raises the boiling point of water; thus, moisture in the food reaches a higher temperature before escaping to the oil, cooking the food faster. Pressure fryers do not have automatically lifting baskets due to the requirement of a sealed lid.

Figure 2-6: Typical Countertop Pressure Fryer (Alpina SCE 6)

Source: Alpina 2009

Specialty Fryers

Other fryers include specialty fryers such as donut fryers and continuous fryers (used in industrial-scale production such as potato chip production) though these are in limited use. Donut fryers are in use in some commercial food service establishments (independent and chain donut stores); potato chip fryers are more common in the industrial sector than in the commercial. These specialty fryers are not considered in our analysis due to their limited use in the commercial sector.

Fryer Energy Efficiency

Table 2-3 summarizes the energy efficiency range and other metrics (such as oil capacity and idle energy rate) for the fryers described above.

Table 2-3: Fryer Capacities, Input Rate, and Efficiencies

Cooking Equipment	Fuel	Typical Oil Capacity (lb)[a]	Typical Cooking Capacity (lb/hr)	Rated Input (kBtu/hr)	Efficiency Range[b]	Idle Energy Rate (kBtu/hr)[d]
Floor Mounted	Gas	30-80	60-70	40-60	75-85%	2.5-3.5
	Electric	30-80	30-45	80-120	25-35%	8-12
Pressure	Gas	30-75	30-40	30-50	65-85%	1.5-4
	Electric	30-75	25-30	55-80	25-35%	10-15
Countertop[c]	Gas	15-30	15-40[a]	unknown	unknown	unknown
	Electric	15-30	15-40[a]	18-60	unknown	unknown

Source: FSTC 2002 (Unless otherwise noted)

a) Source: Survey of available models from manufacturer websites
b) Efficiency range for currently available models as defined by ASTM testing methods (FSTC 2002)
c) There is limited test data on the energy consumption of countertop fryers.
d) Energy consumption rate during the idle mode (maintaining oil at the temperature required for frying)

2.2.2 Broilers

Broilers are used to cook meat and seafood, brown foods, reheat plated food, and melt cheese. A standard underfired broiler is used to "grill" foods, it gives meats their stripped "grill marks". Other types of broilers include overfired and salamander; these are used to heat food using radiant energy from above. Broilers are available in gas and electric models, though gas models dominate the market with a 91% share.

The majority of energy used in broilers is by the burners or heating elements. Additional energy use can be attributed to, pilot lights, timers, temperature controls, and sensors. Like fryers, broilers are typically turned on in the morning, left on all day regardless of the cooking load, and turned off at night. This is because broilers take 15-20 minutes to preheat; time that cannot be wasted while customers are waiting. Most standard gas broilers have a standing pilot light.

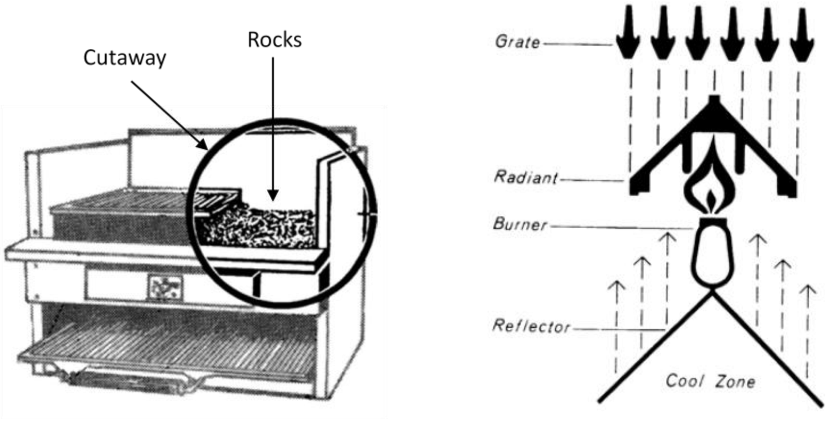
Underfired Broilers

Underfired broilers, also known as charbroilers (depicted in Figure 2-7), have the highest production capacity of all broilers and are the most versatile; hence they are the most widely used. Gas charbroilers are built similarly to residential grills, with burners in a bed of rocks providing heat to the food and the metal grate above. Food is placed directly on the metal grate, which can reach a temperature of 600°F. An alternative heating method uses a radiant heater (instead of a bed of rocks) to heats a metal shield that, in turn, radiates heat to the grate above (see Figure 2-8). Electric models have resistive heating elements directly in the grate. Fats and oils from cooking meat drip into the flames, creating a considerable amount of smoke, requiring adequate kitchen ventilation to exhaust.

Figure 2-7: Typical Underfired Broiler

Source: FSTC 2002

Figure 2-8: Underfired Gas Broiler Heating Methods



a) Using rocks to diffuse heat

b) Radiant style burner

Source: FSTC 2002

Overfired Broilers

Overfired broilers (Figure 2-9) heat foods from above without contact. Compared to underfired broilers, they rely primarily on radiant heating rather than conductive heating of a charbroiler. The grates holding food can be adjusted up or down to increase or decrease the speed of cooking. Standard overfired broilers are used for high production capacity. Their heat output allows them to broil inch-thick steaks or other meats.

Figure 2-9: Overfired Broiler (American Range AORB-48)

Source: American Range 2009

Salamander Broilers

Salamander broilers (Figure 2-10) are lower-capacity overfired broilers. They are used to prepare the same foods in the same amount of time, but at a lower volume. Salamander broilers are often mounted above other equipment, or on shelves, to save kitchen space.

Figure 2-10: Typical Salamander Broiler

Source: Garland 2009

Broiler Energy Efficiency

Table 2-4 summarizes the energy efficiency and rated input of the above-described broilers. Gas underfired broilers have particularly low efficiencies because of their design--the heated surface is large and exposed to the room atmosphere. Additionally, as seen in Figure 2-8, heat must be transferred from the gas burners to rocks (or a metal radiator) before it reaches the food (the metal grate also absorbs some of the heat). Electric broilers have a more direct heating path to reach the food (resulting in higher efficiencies as defined by ASTM testing methods) as the heating elements are in the grate.

Table 2-4: Broiler Input Rate and Efficiencies

Type	Fuel	Rated Input – Site Energy (kBtu/hr)	Baseline Efficiency Range [a]	Source
Underfired	Electric	21-46	35-65%	FSTC 2002
	Gas	90-120	15-30%	FSTC 2002
Overfired	Electric	41	unknown	FSTC 2002
	Gas	80-110	unknown	FSTC 2002
Salamander	Electric	17-22	unknown	FSTC 2002
	Gas	28-49	unknown	FSTC 2002

a) There are limited test data on the efficiencies of broilers. No federal minimum efficiency standards exist, thus few manufactures report efficiency. Efficiencies of gas and electric models should not be compared without accounting for electricity generation and transmission losses.

2.2.3 Griddles

Griddles are used for many purposes including crisping, browning , searing, warming, and toasting. Food is cooked by contact with a hot plate that is heated either by gas burners or electric heating elements below. The griddle surface is heated to temperatures between 350-450°F.

The majority of energy used in griddles is by gas burners or electric heating elements to provide heat to the cooking surface. Additional energy use can be attributed to pilot lights, timers, temperature controls, and sensors. Griddles are typically turned on in the morning, left on all day regardless of the cooking load, and turned off at night. Griddles can idle for long periods of time even in a busy fast food restaurant. Griddles can take up to 25 minutes to preheat. Most standard gas griddles have a standing pilot light.

Standard Griddles

Standard griddles (Figure 2-11) have a single heated plate on which to cook food. The plate is heated from below by gas burners or electric resistance heaters. Double-sided griddles (Figure 2-11) are sometimes used by the fast-food industry. These models have a second heating plate that is lowered on top of the food and used to simultaneously cook both sides. Double-sided griddles have higher cooking efficiency; less heat is lost to the surroundings during the cooking process as the food is “sandwiched” between the two heated plates. They also have a higher production rate making them ideal for the fast-food segment. The upper plate is usually heated using electric resistance elements regardless of the fuel source used for the bottom plate. Griddles may have additional electronics to regulate temperature and store programmed cook times for various foods.

Figure 2-11: Typical Standard and Double-Sided Griddles

a) Standard Griddle (Garland E24) b) Double-Sided griddle (Garland 24XE)

Source: Garland 2009

Other Griddles

Other griddle types include sandwich grills and hot dog grills (Figure 2-12) which are generally electric powered. Sandwich grills are used to toast flatbread sandwiches by heating them by contact from above and below. Hot-dog grills are used to cook multiple hot dogs at once and are normally found in convenience stores and concession stands. Hot-dog grills use heated, rolling metal tubes to rotate and cook hot dogs in mass quantities, requiring little operator interaction. These make up a minority of the appliances in the griddle category, and little information is available on their energy consumption characteristics.

Figure 2-12: Typical Other Griddles

a) Hot-Dog Grill b) Sandwich Grill

Source: Star Manufacturing 2009

Griddle Energy Efficiency

Table 2-5 summarizes the energy efficiency range and rated input of the above described griddles and grills.

Table 2-5: Griddle Input Rates (Operating and Idle), and Efficiencies

Type	Fuel	Input Rate (kBtu/hr)		Baseline Efficiency Range[a]	Source Comments
		Maximum	Idle Mode		
Standard	Electric	25-60	5-9	65-75%	FSTC 2002
	Gas	40-80	15-18	35-45%	FSTC 2002

a) Efficiencies of gas and electric models should not be compared without accounting for electricity generation and transmission losses.

2.2.4 Ovens

Ovens are the most versatile of all cooking appliances and are, therefore the most widely used cooking device for commercial cooking applications. There are many types of ovens in use, utilizing all three forms of heat transfer: conduction, convection, and radiation. Small volume production ovens (batch ovens) are enclosed to retain heat while continuous ovens that allow high volume production are open to the kitchen.

The majority of energy used in ovens is by gas burners or electric heating elements to provide heat to the oven cavity, though each type of oven uses additional energy. Gas ovens account for 55% of the market. Most standard gas ovens have a standing pilot light.

Convection Oven

Convection ovens (Figure 2-13) use a fan to force convection instead of relying on natural convection alone to cook foods.[5] In conventional ovens, a layer of cooler air surrounds the food slowing the cooking process. The fans in convection ovens disrupt the layer of cool air resulting in faster and more even cooking. Convection ovens reduce cooking time and increase cooking capacity. They typically come in two sizes: “full” and “half” size. Full size can accept larger (18” x 26”) baking pans; half size accepts smaller (18” x 13”) baking pans. Beyond cooking, these ovens use energy to power the convection fan, operate sensors and timers, and fuel the pilot light.

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[5] While all ovens rely on convection to cook, this refers to forced convection ovens.

Figure 2-13: Convection Oven (Garland MCO)

Source: Garland 2009

Deck Oven

Deck ovens (Figure 2-14) are smaller in height than convection ovens; the baking cavity is approximately 6-10 inches tall. The bottom of the deck oven is heated with burners or elements the walls and ceiling are designed to absorb and re-radiate heat back into the food. Deck ovens can be freestanding or stacked up to three high. Deck ovens can be used for various types of baking and cooking. Standard deck ovens have simple controls – usually only for changing temperature and turning on the broiler. Some models have electronic temperature sensors for feedback to the cook.

Figure 2-14: Deck Oven (Garland G2000)

Source: Garland 2009

Combination Oven

A combination oven, also known as a "combi-oven" (Figure 2-15), injects steam into the cooking cavity to assist the cooking process. Combination ovens also have heating elements. They can cook using dry heat (heating elements and no steam), moist heat (heating elements with steam), or can be used to just steam foods (no heating elements used). Combi-ovens generate their own steam. Most combi-ovens are electric, though a few gas models are now available. These ovens use energy to power heating elements and to control the injection of steam. Additionally, a small processor can control cooking times and when to inject steam in the cooking process.

Figure 2-15: Typical Combination Oven

Source: FSTC 2002

Rack and Rotating Rack Ovens

Rack ovens (Figure 2-16) are large volume cooking units used in institutional foodservice facilities. Food trays are loaded on a mobile rack and then rolled into the oven. Rack ovens are ideal for reheating food or baking and roasting foods in very large quantities. Some rack ovens have a rotating mechanism that slowly spins the rack during the cooking process to speed the process and heat food evenly. Rack ovens may have a steam injection system (generating their own steam) to mimic the functionality of a combi-oven. Beyond cooking, energy is used to control the injection of steam and power the rotating racks. Additionally, a small processor can control cooking times and when to inject steam during the cooking process.

Figure 2-16: Typical Rotating Rack Oven

Source: FSTC 2002

Cook-and-Hold Ovens

Cook-and-hold ovens (Figure 2-17) are designed to roast meats and then hold them at a low enough temperature to retain their moisture and tenderness. These ovens maintain a high level of humidity during the cooking process to retain moisture in meats. A water reservoir at the bottom of the oven provides moisture while a blower circulates moist air during the cooking process. Beyond cooking, energy is used to circulate air and power a processor that controls the cooking process, including time and temperature.

Figure 2-17: Typical Cook and Hold Oven

Source: FSTC 2002

Conveyor Oven

Conveyor ovens (Figure 2-18) have a baking chamber open on opposite sides and a conveyor system that carries food through the baking chamber on a wire rack. Conveyor ovens typically use one of four heating processes:

1. Infrared
2. Natural convection with a ceramic baking hearth
3. Forced convection (also known as air impingement)
4. A combination of infrared and forced convection

Conveyor ovens can be controlled by adjusting the speed of the conveyor and the temperature of the chamber. Some manufacturers offer an air-curtain feature at the open ends of the chamber to help keep the heated air inside the baking chamber. The curtains help to conserve energy (both oven energy and kitchen cooling energy) by reducing heat losses from the oven. Beyond cooking, energy is used to drive the conveyor and (if applicable) power air curtains.

Figure 2-18: Conveyor Oven (Blodgett B2136)

Source: Blodgett 2009

Oven Energy Efficiency

Table 2-6 summarizes the energy efficiency range and rated input of the ovens described above.

Table 2-6: Oven Input Rate and Efficiencies

Type	Fuel	Rated Input – Site Energy (kBtu/hr)	Baseline Efficiency Range[b]	Source Notes
Deck	Electric	20-41	40-60%	FSTC 2002
	Gas	20-120	20-30%	FSTC 2002
Convection	Electric	20-136	50-80%	FSTC 2002
	Gas	20-100	30-40%	FSTC 2002
Combination	Electric	20-136	50-80%	FSTC 2002
	Gas	20-100	30-40%	FSTC 2002
Rotating Rack[a]	Electric	unknown	unknown	
	Gas	unknown	unknown	
Cook and Hold[a]	Electric	unknown	unknown	
	Gas	unknown	unknown	
Conveyor	Electric	102-153	20-40%	FSTC 2002
	Gas	120-150	10-20%	FSTC 2002

a) There are limited test data on the efficiency of these appliances. Their share of the oven market is relatively low (see Table A-3 in Appendix A).

b) Efficiencies of gas and electric models should not be compared without accounting for electricity generation and transmission losses.

2.2.5 *Ranges*

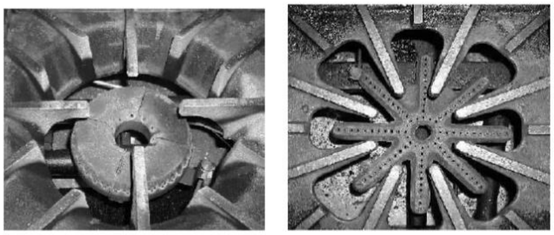
Commercial ranges typically consist of six open burners or heating elements with a standard oven incorporated underneath (Figure 2-19). They are available with either gas or electric fuel sources, although gas dominates the market with a 91% share. Due to their high frequency of use, they are generally designed to be more durable than residential stoves. The top portion of the stove with the burners is known as the "range top", while the bottom portion is known as "range oven."

Figure 2-19: Six-Burner Range (Garland C836)

Source: Garland 2009

Standard gas ranges come with one of two types of burners (both are atmospheric): ring burners and star burners (Figure 2-20). Both burners emit a non-premixed flame; star burners generate a more dispersed flame for more even heating.

Figure 2-20: Range-Top Ring and Star Burner



a) Ring Burner b) Star Burner

Source: FSTC 2002

The majority of energy used by ranges is attributed to the burners (or heating elements in the case of electric). Additional energy use can be attributed to timers, temperature controls, and sensors. In contrast to other cooking appliances, range tops are generally not left to idle for long periods of time. This is because their preheating times are much shorter than other appliances.

Ranges are classified as light/medium duty or heavy duty. Light-duty or medium-duty ranges are not as durable as heavy-duty ranges, and typically have lower energy inputs. Heavy-duty ranges are built for high-volume and frequent use in large restaurants, hospitals, and schools. These ranges must be of sturdy construction resilient to high frequencies of use. Table 2-7 summarizes the energy efficiency and rated input of ranges.

Table 2-7: Typical Range Input Rate and Efficiencies, 2008

Type	Fuel	Rated Burner/Coil Input	Typical Cooking Efficiency[b]	Source Comments[c]
Light/Medium Duty	Electric	6.8 kBtu/h (2 kW)[a]	65-85%	FSTC 2002
	Gas	20-25 kBtu/h	25-35%	FSTC 2002
Heavy Duty	Electric	6.8 kBtu/h (2 kW)[a]	65-85%	FSTC 2002
	Gas	25-30 kBtu/h	25-35%	FSTC 2002

a) Coils are rated at 2kw; units converted to Btus using 3.413 Kbtu/KWh
b) Efficiencies of gas and electric models should not be compared without accounting for electricity generation and transmission losses.
c) Rated input and efficiencies are assumed to be unchanged in 2008 from 2002

2.2.6 Steamers

Steamers (Figure 2-21) cook food primarily using steam generated from separate boilers (boiler-based steamers); some newer models use self-generated steam (connectionless steamers). Hot steam condenses on the surface of the food, transferring heat from the vapor to the food. Two basic categories of steamers exist on the market, pressure-less (atmospheric) and pressurized (low and high). Each is described further below.

Figure 2-21: Typical Steamer

Source: FSTC 2002

The majority of energy used by steamers is to provide steam for cooking. Steam is generated outside the cooking compartment in a separate boiler. This boiler provides steam directly to the steamer and is part of the appliance (see Figure 2-21). The boiler automatically fills with water from building plumbing. After steam is sent to the steamer compartment it is vented through the drain (with condensate) to the sewer. Condensate and steam is not recycled.

Steamers use additional energy for timers, temperature controls, sensors, and programmable cooking controls. Timers are an important part of steamers as food should not be checked during the cooking process or steam will escape the appliance, which can increase cook times or reduce food quality. Low-pressure and high-pressure models are available in electric and gas-fueled configurations

Atmospheric Steamers

Atmospheric steamers, also known as pressure-less steamers, maintain the cooking compartment pressures between 0-2.9 psig. Atmospheric steamers circulate steam to achieve faster and more even cooking. Many use a fan to accomplish this. Some boiler-based steamers direct jets of incoming steam at the food to faster cooking.

Pressure Steamers

Pressure steamers employ a closed system to allow the steam to build pressure inside the cooking compartment. Heavy sealed doors ensure pressure is maintained. Steam is not allowed to vent to the drain, only condensate. Low-pressure steamers operate between 3-9 psig while high-pressure steamers operate between 10-15 psig. Pressure steamers are smaller in size than atmospheric steamers. While they cook smaller volumes of food, cook times can be faster.

Steamer Energy Efficiency

Table 2-8 summarizes the energy efficiency and rated input of steamers described above.

Table 2-8: Steamer Input Rate and Efficiencies

Type	Fuel	Rated Input – Site Energy (kBtu/hr)[a]	Typical Efficiency[b]
Pressure-less	Electric	61-123[c]	15%
	Gas	170-250	26%
Pressure	Electric	123-164[c]	15%
	Gas	170-250	26%

a) Source: FSTC 2002
b) Source: EPA 2009b. Efficiencies of gas and electric models should not be compared without accounting for electricity generation and transmission losses.
c) Units converted to kBtu/hr using 3.413 Kbtu/KW

2.2.7 *Microwave Ovens*

Commercial microwave ovens are larger and higher in power output compared to those used in residences. Magnetrons powered by electricity generate microwaves inside the appliance to heat foods. While typical residential models have only one magnetron, commercial microwaves use up to six to handle larger foods and heat them faster. Magnetrons require high voltages to produce microwaves (supplied by a high-voltage transformer inside the unit). Most commercial microwaves are user programmable--cooks can store multiple heat times and power settings to different “quick-start” buttons, enabling faster operation.

The majority of microwave-oven energy is consumed by the magnetron to provide heat to the cooking chamber; some energy is used in idle mode to power a processer that holds preset cooking times. Table 2-9 details power draw of a baseline unit. We use these data in Section 2.7 to estimate annual energy consumption.

Table 2-9: Power-Draw Characteristics of Commercial Microwaves

	Value	Source Comments
Rated (Operational) Power Draw Range	1000 – 3200 watts[a]	Survey of current models available on manufacturer websites
Average of Operational Range Above	2100 watts	Calculated: Average of Power Draw Range
Idle Power Draw	3 watts	Assumed to be the same as residential models (TIAX 2006)

a) Only a select few models are 3000-3200 Watts, the majority of models available are less than 2200 W

2.3 *Manufacturers and Market Shares*

Exact market shares of the manufacturers are unknown at this time; however industry experts identified top manufactures for several appliance classifications.

Frymaster is the largest fryer manufacture followed by Pitco Frialator (Table 2-10). The remaining manufacturers produce smaller volumes.

Table 2-10: Fryer Manufacturers

Fryer Manufacturers	Top Manufacturers[a]
Alto-Shaam, Inc.	
Eagle	
Frymaster L.L.C.	X
Henny Penny Corporation	
Hobart Corporation	
Keating of Chicago, Inc.	
Pitco Frialator	X
Star Manufacturing	
Ultrafryer Systems, Inc.	
Vulcan-Hart Company	
Wells Manufacturing	

a) Source: Primaira, LLC 2009

Table 2-11 and Table 2-12 identify broiler and griddle manufactures, respectively. We were unable to identify the top manufactures for these categories due to limited market information.

Table 2-11: Broiler Manufacturers

Broiler Manufacturers
Anvil
Garland
Magikitch'n
Southbend
Star-Max
Vulcan-Hart
Wolf

Source: Survey of Manufacturer Websites

Table 2-12: Griddle Manufacturers

Griddle Manufacturers
AccuTemp
Garland
Hobart
Star Manufacturing
Taylor
Toastmaster
Vulcan-Hart
Wolf
Source: Survey of Manufacturer Websites

Table 2-13 details the major oven manufactures; Garland and Blodgett are the two largest and are estimated to have 90% of the market share combined.

Table 2-13: Oven Manufacturers

Oven Manufacturers	Top Manufacturer[a]
Blodgett	X
Duke	
Electrolux	
Garland	X
Hobart	
Vulcan-Hart	
Source: Primaira, LLC 2009	

Table 2-14 and Table 2-15 present the major range and steamer manufactures, respectively.

Table 2-14: Range Manufacturers

Range Manufacturers	Top Manufacturers[a]
Garland	X
Blodgett	X
Wolfe	X
Vulcan-Hart	
Source: Primaira, LLC 2009	

Table 2-15: Steamer Manufacturers

Steamer Manufacturers	Top Manufacturer[b]
AccuTemp Products, Inc.	X
Blodgett Oven Company	
Cleveland Range, LLC	X
Crown Food Service Equipment Ltd.	
Hobart Corporation	
Intek Manufacturing, LLC	X
Market Forge Industries, Inc.	
Solaris Steam	
Southbend	
Stellar Food Equipment	
Unified Brands, Inc	
Vulcan-Hart	

a) Source: NCI, 2009

Commercial microwaves are manufactured by the same companies that make residential microwaves. However, not all residential model manufactures offer commercial sized microwaves. Table 2-16 lists major commercial manufacturers.

Table 2-16: Microwave Manufacturers

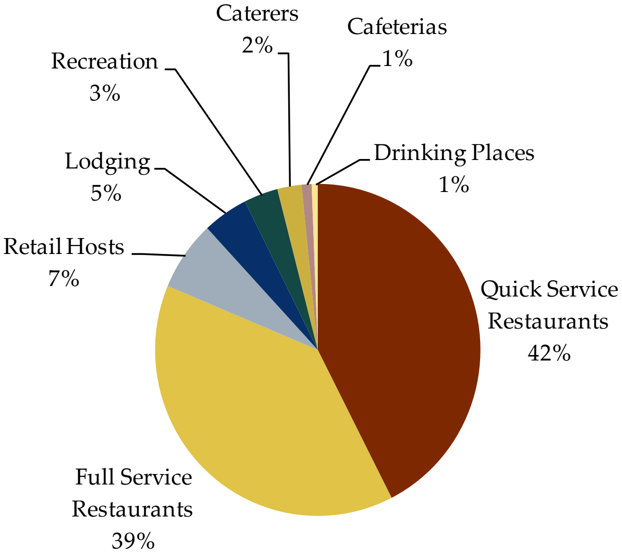
Major Microwave Manufacturers
Amana
Panasonic
Samsung
Sharp

Source: Survey of Manufacturer Websites

2.4 *Major End Users*

Fast-food chains, restaurant chains, hotels, universities, and independent food service establishments are major end users of cooking appliance. Data from the Consortium for Energy Efficiency (Figure 2-22) show the majority of cooking equipment sales is to quick-service and full-service restaurants.

Figure 2-22: Distribution of Cooking Equipment Sales (2003)



Source: CEE 2008

2.5 *Equipment Purchase Decision Making*

Cooking equipment manufacturers typically sell through regional sales offices or manufacturer sales representatives. Manufacturers sell directly to large restaurant chains and other large end-use customers that have established contracts. For example, Frymaster was once the sole provider of fryers to the McDonalds franchise, they provided one model to all retail locations.[6] It has not been confirmed if this exclusive arrangement still exists. Manufacturers also rely on trade shows sponsored by NAFEM and the National Restaurant Association (NRA) to market their products directly to customers.

Purchase decisions for commercial cooking appliances vary between chain and independent restaurants. Each relies on information sources in different ways when making decisions about what to purchase (see Table 2-17).
Figure 2-23 illustrates the relationships between the different ownership types (independent and franchises) and those parties that affect their purchasing decisions.

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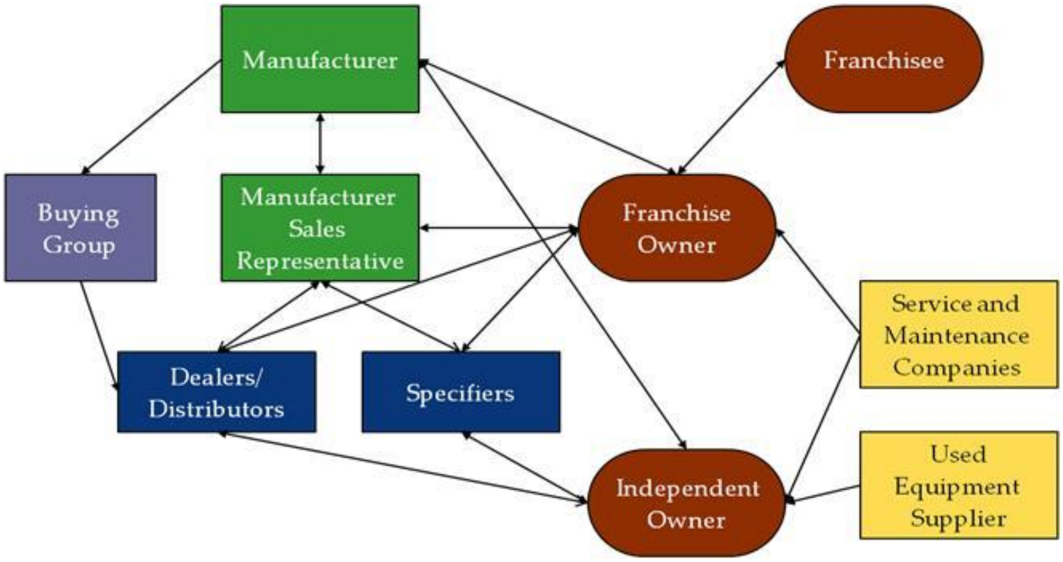
[6] Primaira, LLC 2009

Table 2-17: Factors Affecting Cooking Appliance Purchase Decisions (1998)

Information Source for Decision Making	Percent of decision makers that relied on information source	
	Centrally Managed Chain	Individually Operated Restaurants
Manufacturer Representatives	52%	13%
Trade Shows	46%	3%
Past Experiences	45%	27%
Trade Journals	21%	4%
Company Staff	21%	23%
Electric Utilities	10%	1%
Distributors, Dealers and Suppliers	4%	12%

Source: Energy and Environmental Analysis, Inc. 2003

Figure 2-23: Relationship among Parties in Cooking Appliance Purchase Decisions



Source: CEE 2007

Local owners of chain restaurants tend to have little say in the appliances they use because of franchise agreements. Chains strive to serve the same tasting food at each location; that means not only must the ingredients be exactly the same, the equipment should be too. Thus, the ultimate purchase decision in a franchise is often made at the corporate level. The decision making process typically focuses on first cost, performance, and quality of food product. Replacing appliances with different models may change quality of the food, thus presenting a barrier to high efficiency replacements.

In addition to food-quality issues, first cost is a large factor in upgrading to high-efficiency equipment chain wide. Franchises also have the option of spending available capital on expanding the chain. Conventional wisdom across the industry suggests that expanding the franchise will lead to better returns than investing in energy efficiency.[7] Thus, capital investments in chain restaurants tend to be made on expanding the franchise with less emphasis on energy efficiency.

Independent restaurant owners have more options to consider, including used equipment. Typically, they seek advice of outside consultants, or "specifiers" to design their kitchens and specify equipment. Owners have input in the decision process, but generally dictate only an overall appliance budget. Chefs at independent restaurants often have a say in the cooking appliances specified for retrofits, but have limited input in new construction. The decision process for independent restaurants depends heavily on the relationship between owner and chef.

2.6 *Annual Shipments and Installed Base*

2.6.1 Annual Shipments

Estimates for cooking appliance shipments were obtained from the North American Association of Food Equipment Manufactures (NAFEM). The NAFEM report estimates total shipments by North American manufactures; including international shipments (outside of North America). We made adjustments to estimate the total shipments within the US only, summarized in Table 2-18.

Table 2-18: Cooking Appliance Shipments, 2008

Appliance Type	Shipments Reported by NAFEM[a]	NCI Estimated US Shipments[b]
Broilers	15,182	7,680
Fryers	129,349	63,900
Griddles	19,581	10,200
Ovens	346,780	183,000
Ranges	83,192	44,900
Steamers	33,483	18,300
Microwaves	202,680	97,800

a) Source: NAFEM 2008
b) Estimated by NCI, Adjustments were made using percentage of shipments outside of North America and population scaling. See Appendix A Section A.2 for detailed calculations.

2.6.2 Installed Base

Data on the current installed base of cooking appliances were not available, thus, we estimated installed using the method presented in ADL (1993). The ADL report references two "food

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[7] Equipoise Consulting Inc. 2004

equipment census" reports from NAFEM that provide ownership percentage estimates, the basis of the estimate. NAFEM published these reports in 1989, but has not updated them since. Microwave ovens were not included in ADL's analysis.

ADL used three pieces of data to estimate the inventory of each appliance type. These numbers when multiplied together, equal the total installed base. We follow this same method, updating numbers where possible. These three pieces of data are:

1. **Saturation** - Percent of establishments that use the appliance
2. **Building Stock** - Number of food service establishments that have annual sales greater than $100,000[8]
3. **Ownership** - Average number of units per establishment that uses the appliance

ADL provides estimates for saturation and ownership for non-microwave appliances; they are separated into commercial and institutional class building types. We assumed saturation and ownership levels are unchanged since the time these data were collected.

We obtained from the building stock from ADL and scaled it up from 1993 to 2008. The scaling factor is based on the growth in total commercial floorspace reported by the Commercial Buildings Energy Consumption Surveys (CBECS) published by the EIA. A scaling factor of 1.15 from 1993 to 2008 was determined from trends in CBECS data (shown in Figure 2-24). The results of the scaling are presented in Table 2-19.

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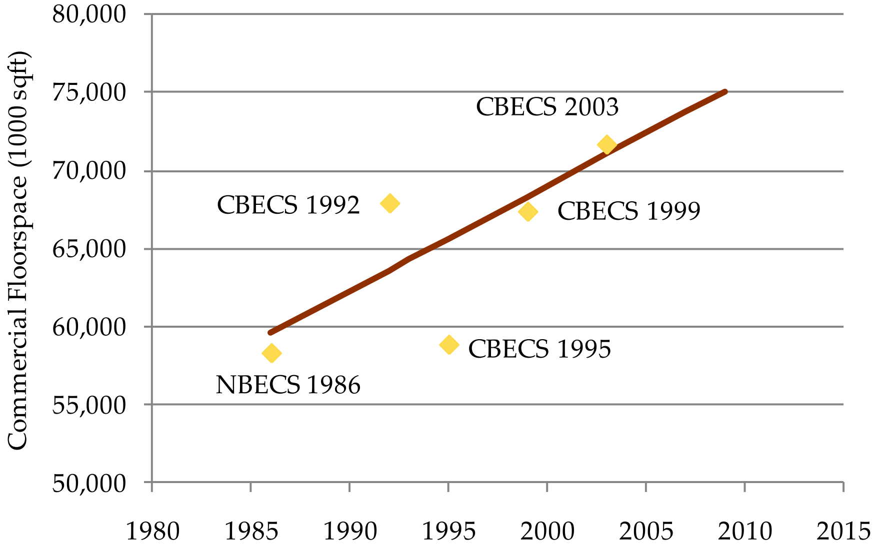
[8] This cutoff point is designed to exclude small establishments that do not tend to use commercial cooking equipments such as small concession stands.

Figure 2-24: Trend in Total Commercial Building Floorspace



Note: Graph shows trend in total commercial building floorspace including all commercial buildings as captured in the Commercial Buildings Energy Consumption Surveys by the EIA. A total growth of 15.8% occurs between 1993 and 2008.

Sources: EIA 1986, 1992, 1995, 1999, 2003

Table 2-19: Projected Number of Commercial and Institutional Establishments with Food Sales Greater than $100,000

Year	Commercial Establishments[a]	Institutional Establishments[a]	Source
1993	240,000	87,000	ADL 1993
2008	280,000	100,000	NCI Calculation scaled using Figure 2-24
a) Establishments with greater than $100,000 in sales			

We used this updated building stock and the ADL saturation and ownership estimates to estimate installed base in 2008. Appendix A, Table A-3 details total installed base calculations for each appliance in each sector. Table A-4 summarizes these results including the breakdown for gas and electric-fueled units. Figure 2-25 illustrates the installed base results.

We estimated the installed base of microwaves using a separate bottom-up approach as ADL did not include microwaves in their study. We estimated installed based two ways; first, from the total number of commercial buildings that have cooking as an end use; and second, using the 2008 annual shipments.

Table 2-20 summarizes the first method: multiplying the number of buildings with cooking as an end use by the estimated microwave ownership. CBECS 2003 was used to find the total number of Restaurant, Hotels, Grocery Stores, Retail Stores, and Office Buildings that have cooking as an end use. We scaled these up to 2008 using a linear projection consisting of data from CBECS 2003 and NBECS 1986 (the source for data for ADL's study). This scaling can be found in Appendix A, Table A-5.

Table 2-32 summarizes the second method: estimating the installed base by multiplying the 2008 annual shipments by the effective useful life. We approximate that the shipments of commercial microwaves has been constant for the last 10 years (historic shipment data was not available). We feel this second method is an overestimate of the installed base, thus our two estimates serve as bounds for the installed base of microwaves.

Table 2-20: Installed Base of Commercial Microwaves (Method 1)

Building Type	2008 Number of Buildings with Cooking as an End Use[a]	Microwave ownership[b]	Installed Base
Restaurant	313,000	50%	156,000
Hotel	49,600	50%	24,800
Grocery	95,500	50%	47,700
Retail	84,500	50%	42,300
Office	23,900	50%	11,900
Total			**283,000**

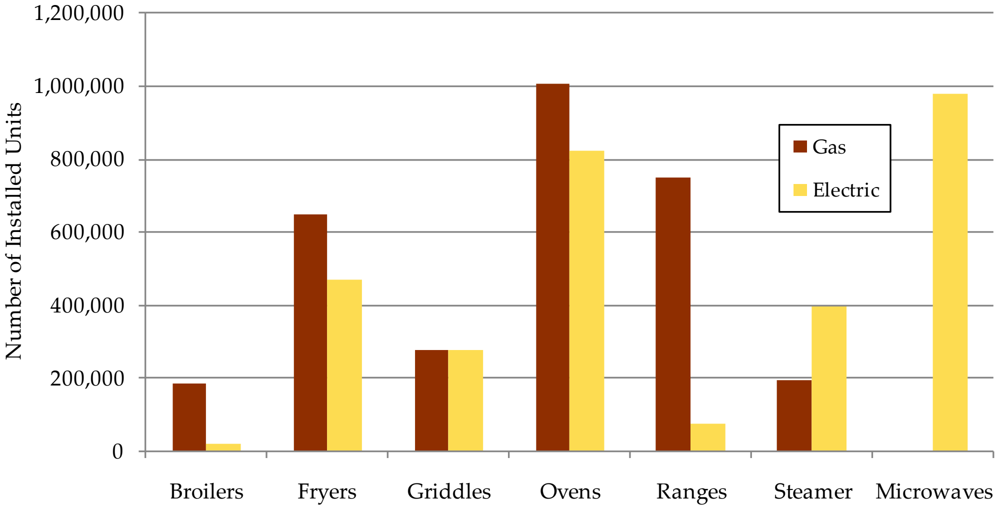
a) Table A-5
b) NCI Estimate: we estimate at maximum 50% of building with cooking have one commercial microwave while the rest have none

Table 2-21: Installed Base of Commercial Microwaves (Method 2)

Building Type	Value	Source Comments
2008 Annual Shipments	97,800	Table 2-18
Effective Useful Life	10	Estimated to be the same as ovens
Total Installed Base	**978,000**	NCI Calculation

Figure 2-25 illustrates the total appliance installed base for all cooking equipment discussed in our report. We estimate microwave installed base with Method 2. Although we feel this is an overestimate, Method 1's estimate is far too low compared to the annual shipment data obtained from NAFEM.

Figure 2-25: 2008 Installed Base by Appliance and Fuel Type



Note: Microwaves are shown calculated with Method 2

Source: Table A-4, Table 2-21

2.7 *Baseline Energy Consumption*

We calculated annual energy consumption using an updated version of a model developed by ADL (1993). The general model structure remains the same while assumptions are updated with more recent data from sources such as the EPA and the FSTC.

Annual energy consumption by cooking appliances varies drastically across different building types due to different usage patterns. Energy consumption depends on hours of operation per year, utilization factor, and baseline rated input capacity. To account for varying usage patterns, the installed base of each appliance was split into seven building types: Restaurants, Hotels, Hospitals, Schools, Grocery Stores, Retail Stores, and Offices. Detailed information at this level for commercial microwaves was not available. We used a simpler method to estimate the energy consumption by microwaves described later.

ADL calculated the annual energy consumption for each non-microwave appliance in each building type as follows:

$$\textit{Annual Energy Consumption}_{ij} = \textit{Installed base}_{ij} \times \textit{Operating hours per year}_{ij} \times \textit{Input Capacity}_{i} \times \textit{Utilization factor}_{i}$$

Where:

i = appliance type
j = building type

Section 2.6 calculated the first component of the AEC calculation, installed base. However, we distributed the installed base into various building types using estimates from ADL updated by NCI. Table 2-22 presents the results of this distribution.

Table 2-22: Installed base by Appliance, Fuel, and Building Type

Building Type	Percent of Total Inventory[a]	2008 Inventory (Gas)[b]	2008 Inventory (Electric)[b]
Broilers			
Subtotal		**182,000**	**18,000**
Restaurant	57.7%	105,000	10,400
Hotel	9.2%	16,700	1,650
Hospital	2.2%	4,040	399
School	13.1%	23,900	2,360
Grocery	0.0%	0	0
Retail	15.6%	28,400	2,810
Office	2.2%	4,020	397
Fryers			
Subtotal		**649,000**	**470,000**
Restaurant	53.6%	348,000	252,000
Hotel	8.5%	55,200	40,000
Hospital	1.0%	6,670	4,830
School	12.2%	78,900	57,200
Grocery	8.2%	53,000	38,400
Retail	14.5%	93,900	68,000
Office	2.0%	13,300	9,610
Griddle			
Subtotal		**276,000**	**276,000**
Restaurant	50.1%	138,000	138,000
Hotel	7.9%	21,900	21,900
Hospital	1.9%	5,300	5,300
School	22.7%	62,700	62,700
Grocery	0.0%	0	0
Retail	13.5%	37,300	37,300
Office	3.8%	10,500	10,500
Ovens			
Subtotal		**1,010,000**	**825,000**
Restaurant	50.1%	504,000	413,000
Hotel	7.9%	80,100	65,500
Hospital	1.9%	19,400	15,800
School	22.7%	229,000	187,000
Grocery	0.0%	0	0
Retail	13.5%	136,000	112,000
Office	3.8%	38,500	31,500

Building Type	Percent of Total Inventory[a]	2008 Inventory (Gas)[b]	2008 Inventory (Electric)[b]
Ranges			
Subtotal		**748,000**	**74,000**
Restaurant	40.0%	299,000	29,600
Hotel	12.7%	95,000	9,400
Hospital	3.1%	23,000	2,270
School	18.2%	136,000	13,400
Grocery	12.2%	91,300	9,030
Retail	10.8%	80,900	8,000
Office	3.1%	22,800	2,260
Steamers			
Subtotal		**195,000**	**396,000**
Restaurant	46.4%	90,400	184,000
Hotel	14.7%	28,700	58,300
Hospital	1.8%	3,470	7,040
School	21.1%	41,100	83,300
Grocery	0.0%	0	0
Retail	12.5%	24,400	49,600
Office	3.5%	6,900	14,000

a) Source: Table A-6

b) Subtotals obtained from Table A-4, building specific figures calculated from: Percent of Total Inventory, distribution between gas and electric (Table A-4) and Subtotals for each appliance type

ADL estimated the second component of the AEC calculation, operating hours per year, for all combinations of appliances and building types. We updated these estimates for restaurants and hotels with more reliable data from the FSTC. FSTC estimated daily hours of operation for each appliance type in a typical restaurant. ADL assumed restaurants and hotels have the same usage patterns; thus, our updates also pertain to hotel cooking appliance use. Table 2-23 summarizes ADL assumptions and our updated values for hours of operation. We assumed operating hours for all other building types to remain the same as ADL's assumptions.

Table 2-23: Updated Annual Operating Hours for Appliances in Restaurants and Hotels, 2008

Cooking Equipment	Fuel	ADL Restaurant & Hotel Operation Hours/Year	Hours of Operation per Day[a]	Updated Restaurant & Hotel Operation Hours/Year[b]
Broilers	Gas	3650	8	2496
	Electric	3650	10	3120
Fryers	Gas	3650	12	3744
	Electric	3650	12	3744
Griddles	Gas	3650	12	3744
	Electric	3650	12	3744
Ovens	Gas	2920	8	2496
	Electric	2920	8	2496
Ranges	Gas	4380	12	3744
	Electric	4380	12	3744
Steamer	Gas	3650	14	4368
	Electric	2190	14	4368

Note: Hours of operation for all other building types are taken from ADL and presented in Appendix A.

a) Source: FSTC 2002

b) Calculation: Hours of Operation x 6 days/week x 52 weeks/year. Assumption of 6 days/week of operation comes from FSTC 2002

ADL estimated the third component of the AEC calculation, input capacity; we updated some of these assumptions as well. The updates are based on increases in baseline cooking efficiency since 1993 or available published data from FSTC. ADL assumed the same baseline input capacity for a given appliance is used by all building types; we made this assumption as well.

We estimate the 2008 typical input capacity using increases in typical efficiency with the equation:

$$Capacity_{2008} = Capacity_{1993} \frac{Typical\ Efficiency_{1993}}{Typical\ Efficiency_{2008}}$$

FSTC (2002) directly provides some typical capacities for which the above equation did not need to be used. Table 2-24 summarizes ADL estimates and our updated assumptions for typical capacity.

Table 2-24: Updated Cooking Appliance Input Capacities

Cooking Equipment	Fuel	Typical Cooking Efficiency		Typical Input Capacity (Btu/hr)		2008 Capacity Source
		1993[a]	2008[b]	1993[a]	2008[c]	
Broilers	Gas	25%	25%	90,000	90,000	ADL 1993
	Electric	50%	50%	45,000	45,000	ADL 1993
Fryers	Gas	35%	35%	100,000	100,000	ADL 1993
	Electric	60%	75%	50,000	40,000	Calculated
Griddles	Gas	40%	40%	90,000	60,000	Average of range presented in FSTC 2002
	Electric	58%	70%	50,000	41,000	Calculated
Ovens	Gas	40%	40%	85,000	85,000	ADL 1993
	Electric	68%	68%	50,000	50,000	ADL 1993
Ranges	Gas	45%	45%	160,000	160,000	ADL 1993
	Electric	70%	75%	60,000	56,000	Calculated
Steamer	Gas	50%	50%	160,000	210,000	Average of range presented in FSTC 2002
	Electric	65%	65%	90,000	90,000	ADL 1993

a) 1993 Baseline efficiency and capacity taken from ADL 1993
b) 2008 Baseline efficiency obtained from FSTC 2002, EPA 2008a, and EPA 2008b
c) 2008 Baseline capacity calculated from efficiency changes, updated using FSTC 2002 report, or kept the same from ADL 1993 if no update was available (see last column for specific source)

ADL also estimated the fourth component of the AEC calculation, utilization factor. This is the fraction of the rated input capacity at which cooking appliances typically operate when they are being used. We updated ADL's estimates with more recent data published by the FSTC (see Table 2-25). ADL assumes the same utilization factor is used by all building types; we made this assumption as well.

Table 2-25: Cooking Appliance Utilization Factor

Cooking Equipment	Fuel	1993 Utilization Factor[a]	2008 Utilization Factor[a]
Broilers	Gas	0.6	0.8
	Electric	0.6	0.7
Fryers	Gas	0.15	0.2
	Electric	0.15	0.2
Griddles	Gas	0.2	0.34
	Electric	0.2	0.25
Ovens	Gas	0.75	0.5
	Electric	0.5	0.35
Ranges	Gas	0.2	0.2
	Electric	0.2	0.25
Steamer	Gas	0.2	0.15
	Electric	0.2	0.15

a) Source: ADL 1993

b) Source: FSTC 2002. 2008 utilization factors assumed to be unchanged from 2002

An example of energy consumption calculations in the Restaurant segment can be seen in Table 2-26. Table 2-26 calculations are repeated for each appliance in each building type (see Appendix A for all tables). Table 2-27 shows the summary of the total energy consumption by each appliance type.

Table 2-26: Restaurant Cooking Appliance Energy Consumption, 2008

Cooking Equipment	Fuel	2008 Inventory[a]	Operating Hrs./yr.[b]	Utilization Factor[c]	Rated Capacity (Btu/hr)[d]	Rated Capacity (kW)[e]	US Annual Electricity Consumption (kWh)[f]	US Annual Primary Energy Consumption (Btu)[g]
Broilers	Gas	105,000	2496	0.8	90,000			1.89E+13
	Electric	10,400	3120	0.7	45,000	13	3.00E+08	3.12E+12
Fryers	Gas	348,000	3744	0.2	100,000			2.60E+13
	Electric	252,000	3744	0.2	40,000	12	2.21E+09	2.30E+13
Griddles	Gas	138,000	3744	0.34	60,000			1.05E+13
	Electric	138,000	3744	0.25	41,000	12	1.57E+09	1.63E+13
Ovens	Gas	312,000	2496	0.5	85,000			3.31E+13
	Electric	255,000	2496	0.35	50,000	15	3.27E+09	3.40E+13
Ranges	Gas	299,000	3744	0.2	160,000			3.59E+13
	Electric	29,600	3744	0.25	56,000	16	4.55E+08	4.73E+12
Steamer	Gas	90,400	4368	0.15	210,000			1.24E+13
	Electric	184,000	4368	0.15	90,000	26	3.17E+09	3.30E+13
Total	**Gas**							**1.37E+14**
Total	**Electric**						**1.10E+10**	**1.14E+14**
Total	**All**							**2.51E+14**

a) Source: Table 2-22
b) Source: Table 2-23
c) Source: Table 2-25
d) Source: Table 2-24
e) Converted from Btu/hr to KW using 3,413 Btu/KWh
f) 2008 Inventory x Operating Hrs/yr x Utilization Factor x Rated Capacity (KW)
g) Gas appliance: 2008 Inventory x Operating Hrs/yr x Utilization Factor x Rated Capacity (Btu/hr).
Electric Appliance: US Annual Electricity Consumption x 10,405 btu/kwh

Table 2-27: Annual Energy and Unit Energy Consumption of Non-Microwaves, 2008

Cooking Equipment	Fuel	2008 Inventory[a]	US Annual Energy Use (Btu/yr)[b]	Calculated UEC (mmBtu for Gas, kWh for Electric)[c]
Broilers	Gas	182,000	3.17E+13	174
	Electric	18,000	4.91E+12	26,200
Fryers	Gas	649,000	4.22E+13	65
	Electric	470,000	3.73E+13	7,630
Griddles	Gas	276,000	1.63E+13	59
	Electric	276,000	2.53E+13	8,820
Ovens	Gas	1,010,000	8.82E+13	88
	Electric	825,000	9.06E+13	10,600
Ranges	Gas	748,000	8.33E+13	111
	Electric	74,000	1.10E+13	14,300
Steamer	Gas	195,000	2.06E+13	105
	Electric	396,000	5.16E+13	12,500

a) Source: Table A-4
b) Primary Energy Use (Appendix A)
c) Site Energy Use (Appendix A)

As mentioned earlier, ADL's method did not analyze microwaves; thus, a new approach is required. Microwave energy consumption is estimated based on active power consumption, idle power consumption, and hours of operation. Table 2-28 uses these parameters to estimate unit energy consumption.

Table 2-28: Commercial Microwave Unit Energy Consumption

Data	Value	Source Comments
Active Power consumption (watts)	2,100	Table 2-9
Idle Power Consumption (watts)	3	Table 2-9
Hours/Day in use	3	NCI Estimate[a]
Days/Week Kitchen is being used	6	FSTC 2002[b]
Hours Per Year Active[c]	936	Calculation
Hours Per Year Idle	7,824	Calculation
Unit Annual Energy Consumption (kwh/yr)	2000	Calculation[d]

a) NCI estimates that commercial microwaves are in operation 50% of the time during peak meal service times (6 hours of peak meal service time a day)
b) Assumption for all cooking equipment
c) As a comparison, residential microwaves are in operation 70 hours a year (TIAX 2006)
d) (Hours/Year Active x Active Power Consumption) + (Hours/Year Idle x Idle Energy Consumption)

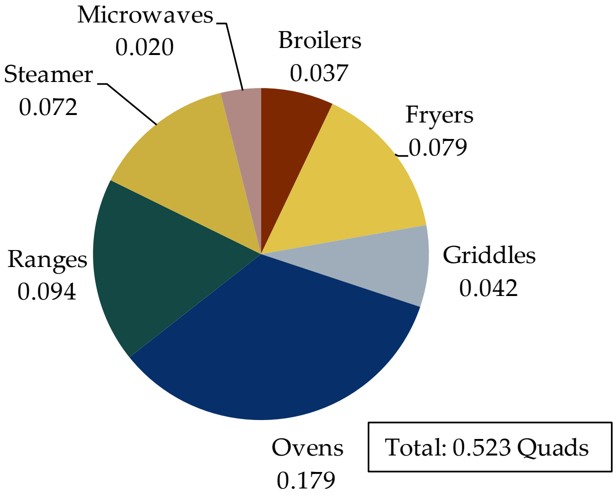
Table 2-29 calculated annual energy consumption using the UEC and the two values of installed base we estimated in Method 1 and Method 2.

Table 2-29: Microwave Annual Energy Consumption

	Method 1	Method 2	Source Comments
Unit Annual Energy Consumption (kwh/yr)	2000	2000	Table 2-28
Installed Base	283,000	978,000	Table 2-20 and Table 2-21
Total Energy Consumption – Site (kWh)	5.63E+08	1.95E+09	Calculated
Primary Energy Consumption (Btu)	5.86E+12	2.02E+13	Calculated[a]
Primary Energy Consumption (Quads)	0.006	0.020	Calculated
a) Converted from KW to Btu/hr using 10,405 btu/kwh			

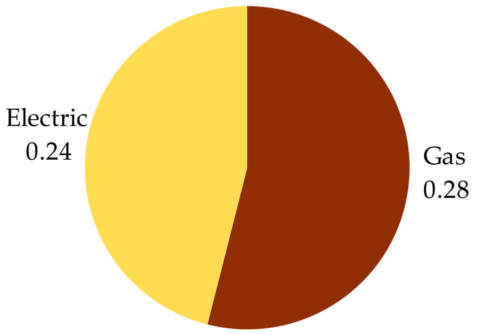
Figure 2-26 and Figure 2-27 display summary data on the energy consumption of all commercial cooking appliances.

Figure 2-26: Summary of Cooking Energy Consumption (Quads) by Appliance Type



Source: Table 2-27 and Table 2-29

Figure 2-27: Cooking Energy Consumption (Quads) by Fuel Type



Note: although electricity makes up nearly half of the primary energy consumption; on a site basis, gas dominates. This is because site electricity consumption is multiplied by 3,413 Btu/KWh to obtain primary energy consumption, the metric used throughout this report.

Source: Table 2-27 and Table 2-29

2.8 *Comparison of Baseline Energy Consumption to Previous Studies*

We compared our bottom up estimate of annual energy consumption to estimates for several other sources; these include Arthur D. Little (1993) and DOE Buildings Energy Database (2008). Table 2-30 and
Figure 2-28 illustrate the comparison.

Our total cooking energy consumption estimate is slightly lower than ADL 1993; this is mainly due to different assumptions about the efficiency and usage patterns of commercial cooking equipment. We followed the same methodology to estimate AEC as ADL, though we update to reflect the total installed base in 2008. While the installed base increases, two factors contribute to decreasing AEC:

1. More refined assumptions on usage patterns that show a smaller number of operating hours per year compared to ADL assumptions
2. Increasing baseline efficiency and subsequent decreases in rated input capacity

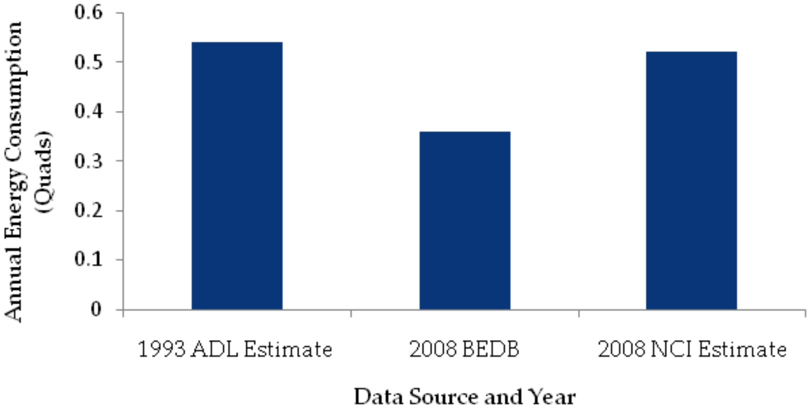
The 2008 Buildings Energy Database estimate for cooking energy (based on CBECS 2003) is lower than our estimate. As CBECS is based on survey data, it does not perform a bottom up analysis incorporating estimates of installed base and baseline efficiency.

Table 2-30: Comparison of National Cooking Annual Energy Consumption (AEC) Estimates

End-use Category/Appliance	1993 ADL Estimate for cooking equipment[a]	2008 DOE Buildings Energy Data Book Estimate - Cooking[b]	2008 NCI Estimate for Cooking[c]
Cooking Equipment AEC (Quads/yr.)	0.540	0.360	0.523

a) Source: ADL 1993
b) Source: DOE 2008
c) Source: Figure 2-26

Figure 2-28: Estimated National Energy Consumption for Cooking End Uses by Various Sources



Source: Table 2-30

Further comparisons can be made at the appliance level. Table 2-31 compares our energy consumption estimates to ADL's estimates from 1993. This comparison locates key areas of differences beyond those that are simply attributed to growth over the time period.

Key changes are attributed to new assumptions obtained from FSTC 2002:

- Oven energy consumption is smaller than ADL 1993 due to a decrease in hours of operation (Table 2-23) and a significant decrease in utilization factor (Table 2-25).
- Gas fryer and gas griddle energy consumption is higher than ADL 1993 due to assumptions that increase hours of operation (Table 2-23) and utilization factor (Table 2-25).
- Steamer energy consumption is higher than ADL 1993 as our assumptions show a significantly higher number of hours in operation per year (Table 2-23) and a higher baseline input capacity for gas steamers (Table 2-24).

Differences in assumptions about ovens are the biggest factor in accounting for the the difference between our total cooking energy use estimate and ADL's.

Table 2-31: Annual Energy Consumption (AEC) Estimates Compared to ADL Estimates

Cooking Equipment	Fuel	1993 ADL Estimate for cooking equipment (TBtu)[a]	2008 NCI Estimate for Cooking (TBtu)[b]	Percent Difference[c]
Broilers	Gas	28.0	31.7	13%
	Electric	4.5	4.9	9%
Fryers	Gas	27.5	42.2	54%
	Electric	32.7	37.3	14%
Griddles	Gas	13.7	16.3	19%
	Electric	25.0	25.3	1%
Ovens	Gas	123.1	88.2	-28%
	Electric	139.8	90.6	-35%
Ranges	Gas	80.4	83.3	4%
	Electric	9.8	11.0	12%
Steamer	Gas	16.6	20.6	24%
	Electric	39.3	51.6	31%
Microwave	Gas	NA	NA	NA
	Electric	NA	20.0	NA

a) ADL 1993
b) Source: Table 2-27 and Table 2-29
c) Calculated: (NCI – ADL) / ADL

2.9 *Lifetime and Maintenance Characteristics*

Most commercial cooking appliances have a 10-year effective useful life as shown in Table 2-32.

Table 2-32: Cooking Appliance Effective Useful Life

Appliance	Effective useful life (years)	Source
Fryer	12	EPA 2008a
Griddle	10	LBNL 2008
Broiler	10	LBNL 2008
Oven	10	LBNL 2008
Range	10	LBNL 2008
Steamer	10	LBNL 2008
Microwave	10	NCI Estimate

Most manufactures recommend regular preventive maintenance from local dealers. However, the approximate cost of this procedure is not well documented, nor are statistics available regarding how often customers follow this advice. The ENERGY STAR program estimates no default maintenance costs in the energy savings calculators they publish for cooking appliances.

2.10 *Regulatory and Voluntary Programs*

There are currently no federal regulatory programs governing the energy consumption of commercial cooking appliances. However, the State of California has several regulatory programs. In California, any gas cooking appliance that has an electric cord cannot have a standing pilot light. This, however, does not require all gas cooking appliance to utilize electric ignition. Additionally, California regulates hot food holding cabinets. Since 2006 the idle energy rate of commercial hot food holding cabinets is required to be less than 40 watts per cubic foot of interior volume (CEC, 2009).

The ENERGY STAR® program is a voluntary program that offers several targets for various cooking appliances. Most electric and gas utilities use the classification as a basis for offering customer incentives a little information exists otherwise on the efficiency of these appliances.

ENERGY STAR® Fryers was launched in 2003; today eight manufactures offer 161 models that account for 7% of fryer sales. There is also an ENERGY STAR® target for steamers; 12 companies offer 135 models that account for 12% of steamer sales.

The EPA recently (May 2009) established ENERGY STAR® targets for commercial ovens and griddles; though information on manufacturers, models, and market penetration is not yet available.

2.11 *Energy Saving Technologies*

We examined multiple energy efficiency technologies applicable to the commercial cooking sector; the top energy efficiency technologies are listed below. Many of these technologies are currently available or have been developed but are not commercialized. Some technologies are applicable across multiple appliances while others are best applied to one appliance type.

- Technologies applicable to multiple appliances:
    - Infrared Burners
    - Power Burners
    - Pulse Combustion
    - Appliance Insulation
    - Electric Ignition
- Technologies most applicable to a specific appliance:
    - Heat Pipes Griddles
    - Induction Griddles
    - Broiler Idle Energy Reduction
    - Connectionless Steamers
    - Stock Pot Heat Transfer Fins

Energy savings of these technologies was obtained in various ways depending on data available:

1. **Obtain percent energy savings estimates from third party sources**

   Studies by the ENERGY STAR® program, the Food Service Technology Center, and other groups estimate percent energy savings of high efficiency appliances based on their own documented calculations.

2. **Obtain annual energy savings estimates and calculate percent savings**

   Studies estimate the annual energy savings of high efficiency appliances. This data is combined with the unit annual energy consumption of baseline appliances to calculate percent savings.

3. **Determine percent savings based off of unit annual energy consumption estimates by third party sources**

   Annual energy consumption estimates for baseline and high efficiency appliances are combined to estimate percent energy savings. These data points are often from the same source.

4. **Estimate percent savings using efficiency ratings of baseline and high efficiency appliances**

   When limited information exist on annual energy consumption, energy savings can be estimated from the efficiency ratings using the below formula

$$Percent\ savings = \frac{E_{Baseline}}{E_{High\ Effecieny}}$$

This method is not as accurate as appliance efficiencies are measured during a set cooking event. It does not take into account idle energy use and preheat energy use. Actual percent savings may be lower.

2.11.1 Cooking Efficiency Technologies

Infrared Burners

Infrared burners (Figure 2-29) burn gas through a fine metal or ceramic honeycomb matrix. Its design creates many small flames that are low and close to matrix heating the matrix material to temperatures above 1600°F. The matrix glows "red hot" and radiates heat to the surface being heated. Compared to standard burners that use convection for heat transfer, infrared burners transfer additional heat via radiation.

Figure 2-29: Infrared Burners in Operation

Source: Texas Gas Grill 2009

Table 2-33 summarizes the potential energy savings of infrared burner technology applications.

Table 2-33: Energy Savings from Infrared Burners

Appliance	Percent Energy Savings	Source Comments
Gas Fryers	30%	EPA 2008b
Gas Broilers	37%	NCI Calculation
Gas Ovens	30%	Estimated to be same as Gas Fryer
Gas Range	39%	NCI Calculation
See Appendix A Section A.5 for NCI Calculations		

Infrared burners were developed in the 1960's for use in industrial heating processes. They are on the market in some cooking applications, these include: fryers, broilers, and ovens. Details are summarized in Table 2-34. Infrared range burners have not been successfully commercialized as they face clogging issues from spilled food.

Table 2-34: Commercialization of Infrared Burner Applications

Infrared Appliance	Commercialization
Gas Fryers	5-10% of market
Gas Broilers	Commercially Available
Gas Ovens	Commercially Available
Gas Range	Not commercialized
Source: FSTC 2002	

Infrared burner technology generally has a high first cost and long paybacks. There is limited cost data available on these appliances. We calculated the required incremental cost to achieve a payback period of 3 years in Table 2-35.

Table 2-35: Cost Required for a 3 Year Payback of Infrared Burner Applications

Infrared Appliance	Site Unit Energy Consumption (mmBtu/yr)[a]	Annual Energy Savings (mmBtu/yr)[b]	Incremental Cost Required[c]
Gas Fryers	64	19	$750
Gas Broilers	162	40	$1,700
Gas Ovens	86	26	$1,000
Gas Range	110	43	$1,700

a) Source: Table 2-27
b) Site Unit Energy Consumption x Percent Energy Savings (Table 2-33)
c) Annual Energy Savings x cost of gas x 3 years. Cost of gas assumed to be: $12.76/mmBtu

Power Burners

Power Burners use a blower to force a premixed air-fuel mixture into the burner. They have an air-fuel ratio closer to stoichiometric than atmospheric burners. Higher combustion gas temperature can be reached as the fuel mixture contains less excess air. The higher temperature allows more heat to be transferred to the surfaces being heated. Table 2-36 presents energy savings estimates.

Table 2-36: Energy Savings from Power Burners

Appliance	Percent Energy Savings	Source Comments
Gas Fryers	31%	NCI Calculation
Gas Ranges	34%	FSTC 2002

See Appendix A Section A.5for NCI Calculations

Power burners have been in the market for more than 20 years, they are used in non-cooking applications as well such as in space heating units and industrial processes. Commercialization of power burners in the in the cooking industry is summarized in Table 2-37.

Table 2-37: Commercialization of Power Burner Applications

Power Burner Appliance	Commercialization
Gas Fryers	Commercially Available
Gas Range	Commercially Available

Source: Survey of available models on manufacturer websites

Power burner application in ranges has a notable barrier. Because power burners give off a more intense heat than regular burners, foods can overcook, pots can boil dry and pans can warp if cooks do not pay attention. This delayed earlier commercial releases of power burner ranges. This can be overcome with temperature feedback, though the technology has not been successfully developed.

There are limited cost data available on power burner appliances. The American Gas Association Laboratory that developed the power burner range estimated a 2 year payback, though the assumptions behind this are not longer available for review. However, industry experts today estimate the cost of power burners to be $500 per unit. Fryers tend to only need one burner hence; however, ranges need multiple independent burners thus have a higher cost. Cost and payback details are presented in Table 2-38.

Table 2-38: Incremental Cost and Payback of Power Burner Applications

Infrared Appliance	Incremental Cost[a]	Site Unit Energy Consumption (mmBtu/yr)[b]	Annual Energy Savings (mmBtu/yr)[c]	Payback Period[d]
Gas Fryers	$500	64	20	1.9
Gas Range[e]	$3,000	110	37	6.2

a) FSTC Appliance Experts, 2009.
b) Source: Table 2-27
c) Site Unit Energy Consumption x Percent Energy Savings (Table 2-36)
d) Annual Energy Savings x cost of gas/Incremental Cost. Cost of gas assumed to be: $12.75/therm
e) Assuming 6 burners per range

Pulse Combustion

Pulse combustion is a technology that has been in use in boilers and furnaces. Combustion occurs in a series of controlled explosions 40-80 times per second as opposed to the steady burn of atmospheric burners. Pulse combustion creates turbulence in the exhaust gas; this increases the heat transfer rate between exhaust gases and the surfaces with its heating. Larger heat transfer rates improve energy efficiency. Table 2-39 summarizes energy savings of pulse combustion applications.

Table 2-39: Energy Savings from Pulse Combustion Burners

Appliance	Percent Energy Savings	Source Comments
Gas Fryers	31%	NCI Calculation
Gas Griddles	31%	Estimated to be same as Gas Fryer

See Appendix A Section A.5 for calculations

Pulse combustion burners are an emerging cooking technology as indicated in Table 2-40. One manufacturer of fryers was scheduled to release a pulse combustion fryer in May 2009. Pulse combustion griddles were deemed too expensive by manufacturers compared to infrared burners that offer similar savings.

Table 2-40: Commercialization of Pulse Combustion Applications

Power Burner Appliance	Commercialization
Gas Fryers	Recently introduced to the market
Gas Griddle	Research and Development
Source: Survey of manufacturer websites	

There is limited cost data available on pulse combustion applications in the cooking sector. We estimate the incremental cost required for a payback of 3 years in Table 2-41.

Table 2-41: Incremental Cost Required for a 3 Year Payback of Pulse Combustion Applications

Infrared Appliance	Site Unit Energy Consumption (mmBtu/yr)[a]	Annual Energy Savings (mmBtu/yr)[b]	Incremental Cost Required[c]
Gas Fryers	65	20	$760
Gas Griddle	59	18	$690

a) Source: Table 2-27
b) Site Unit Energy Consumption x Percent Energy Savings (Table 2-39)
c) Annual Energy Savings x cost of gas x 3 years. Cost of gas assumed to be: $12.75/mmBtu

Appliance Insulation

Insulation at major heat loss locations in cooking appliances can reduce standby heat loses by 25% in both electric and gas powered models.[9] Insulation is not typically used on commercial fryer, griddles, broilers, and ranges for unspecified safety reasons. Most steamers and ovens make use of insulation as well as a few "high-end" appliances and ENERGY STAR® models. Table 2-42 documents the largest remaining potential for insulation in cooking appliances.

Table 2-42: Energy Savings from Appliance Insulation

Appliance	Percent Energy Savings	Source Comments
Gas and Electric Fryers	7%	NCI Calculation
Gas and Electric Griddles	7%	Estimated to be same as Fryer
See Appendix A Section A.5 for calculations		

The concept of using insulation in appliances is not new. However, there is limited use in the appliance where it has the most remaining potential. (Table 2-43)

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[9] FSTC, 2002

Table 2-43: Commercialization of Appliance Insulation

Appliance Insulation	Commercialization
Gas and Electric Fryers	Limited Commercial Availability
Gas and Electric Griddles	Limited Commercial Availability
Source: Survey of available models on manufacturer websites	

There is limited cost data available on the individual use of appliance insulation in the cooking sector. However, we have calculated the required incremental cost to achieve a payback period of 3 years in Table 2-44.

Table 2-44: Incremental Cost Required for a 3 Year Payback of Appliance Insulation

Appliance	Site Unit Energy Consumption per year[a]	Annual Energy Savings per year[b]	Incremental Cost Required[c]
Gas Fryers	64 mmBtu	4.5 mmBtu	$170
Gas Griddle	87 mmBtu	6.1 mmBtu	$230
Electric Fryers	7524 kWh	527 kWh	$160
Electric Griddle	8597 kWh	1118 kWh	$340

a) Source: Table 2-27
b) Site Unit Energy Consumption x Percent Energy Savings (Table 2-42)
c) Annual Energy Savings x cost of gas x 3 years. Cost of gas assumed to be: $12.75/therm, cost of electricity assumed to be $0.10/kWh

Electric Ignition

Electric ignition can replace the need for a standing pilot light reducing gas use in commercial cooking appliances. Standing pilot lights dominate gas appliances in the commercial cooking industry.

Pilot lights burn gas 24 hours a day; they waste gas during downtime, which could be up to 14 hours a day depending on the appliance and usage patterns. Estimates for typical pilot light energy rate and downtime are presented in Table 2-45. These values are used to calculate annual energy savings and percent energy savings in Table 2-46.

Table 2-45: Pilot Light Energy Consumption

Appliance	Pilot Light Energy Rate (Btu/hr)	Typical Hours of operation per day[a]	Typical Downtime per day	Pilot Light Energy Rate Source
Gas Fryer	500	12	12	Assumed Same as Broiler
Gas Griddle	500	12	12	Assumed Same as Broiler
Gas Oven	1100	8	16	FSTC 1996
Gas Broilers	500	9	15	FSTC March 2003
Gas Range	1400	12	12	FSTC 1998
Gas Steamer	500	14	10	Assumed Same as Broiler

a) Source: FSTC 2002

Table 2-46: Energy Savings from Electric Ignition

Appliance	Annual Energy Savings (mmBtu)[a]	Appliance Unit Energy Consumption (mmBtu)[b]	Percent Energy Savings[c]
Gas Fryer	2.2	65	3%
Gas Griddle	2.2	59	4%
Gas Oven	6.4	88	7%
Gas Broilers	2.7	174	2%
Gas Range	6.1	111	6%
Gas Steamer	1.8	105	2%

a) Source: Calculated using data from Table 2-45 (Energy rate x downtime x 365)
b) Source: Table 2-27
c) Calculated (Energy Savings/Unit Energy Consumption)

Electric ignition is currently applicable for all gas cooking appliances but is only in use in several models; these include some ENERGY STAR® models. In early 2009, DOE established standards requiring electric ignition in new gas cook tops and ovens for the residential market eliminating standing pilot lights. However there is little discussion on extending this to the commercial sector.

There is limited information on the incremental cost of commercial electric ignition technology. The DOE estimated the incremental cost for residential electric ignition to be $15-25 in its technical support document for the residential sector. The heavy use in commercial settings would require a more durable igniter than residential igniters; thus, the incremental cost would most likely be higher. The incremental cost required for a 3 year payback is calculated in Table 2-47.

Table 2-47: Incremental Cost Required for a 3 Year Payback of Electric Ignition

Infrared Appliance	Annual Energy Savings (mmBtu/yr)[a]	Incremental Cost Required[b]
Gas Fryer	2.2	$84
Gas Griddle	2.2	$84
Gas Oven	6.4	$250
Gas Broilers	2.7	$110
Gas Range	6.1	$240
Gas Steamer	1.8	$70

a) Source: Table 2-45
b) Annual Energy Savings x Cost of gas x 3 years. Cost of gas assumed to be: $12.75/mmBtu

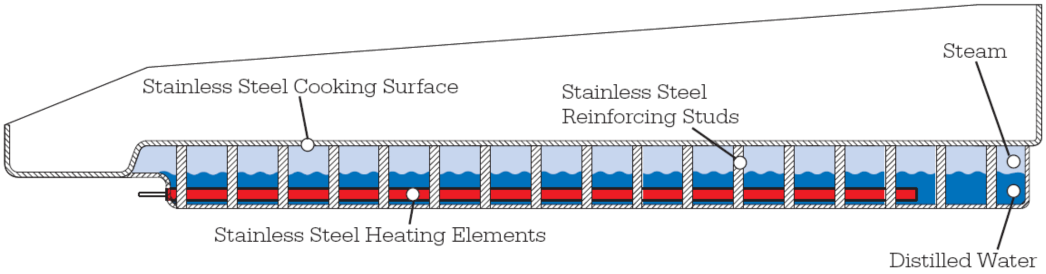
Appliance Specific Technologies

Several technologies apply to specific appliances. These are each described below; following the descriptions are details on energy savings and cost.

Gas Heat-Pipe Griddles

Heat-pipe griddles heat the griddle plates indirectly using a working fluid. The working fluid is contained in a partially filled, sealed reservoir and is heated until it boils by burners or heating elements (see Figure 2-30). The vapor travels upwards to the underside of the griddle plate where it condenses transferring heat evenly the plate. Even heating of the griddle allows more food to be cooked on the same surface area. When cold food is placed on the griddle plate a cold spot develops. More of the working fluid vapor travels to this spot delivering more energy to the food than the surrounding griddle surface.

Figure 2-30: Heat Pipe Griddle Cut-away



Source: AccuTemp 2009

Induction Griddles

Induction technology has been on the market for several decades, though it use in the commercial cooking sector is limited. Electro-magnetic coils below the griddle plate generate a magnetic field. This magnetic field reaches the griddle plate generating eddy currents in the plate that produce heat. The heat is generated in the metal plate itself, eliminating the need to transfer heat from burner exhaust to the griddle plate. This reduces the amount of heat lost and increases efficiency.

Broiler Idle Energy Reduction

As previously described, broilers are often left idling at their full input rate to remain preheated, wasting a significant amount of energy. Broiler idle energy reduction schemes set the idle energy rate at 65% of full output, this still allows the surface to stay preheated while reducing energy consumption.

Broiler idle energy reduction controls were previously developed and commercially available in the 1990's when appliance control technology was less advanced that it is today. The model idled at 65% of the maximum output as a default; however, it is no longer commercially available. Cooks had to press a button when they were ready to cooking to bring the broilers back to full power for a brief 10-15 minute period, ample time for most cooking needs. The appliance required a behavioral change for cooks.

Other implementation options exist. A weight sensor on the grill can detect when food is placed on the grill to be cooked and signals the burners to return to their full output. However weight sensors may be unreliable for the heavy use in commercial cooking applications.

Connectionless Steamer

Connectionless steamers generate their own steam as opposed to drawing on a separate boiler. Steam is generated as gas burners or electric heating elements boil water from an internal reservoir. The steam is constantly recycled and reheated in the device as opposed to boiler dependant steamers that use "once through" heating. In addition to energy savings, significant water savings (close to 90%) are also achieved. Most connectionless steamers meet the ENERGY STAR® standard.

Stock Pot Heat Transfer Fins[10]

Stock pots can be equipped with heat transfer fins on the bottom (see Figure 2-31) to increase heat transfer from range tops to the pot. Heat transfer fins increase the surface area of the bottom of the pots capturing more heat from the flames. Less heat is lost to the atmosphere increasing efficiency.

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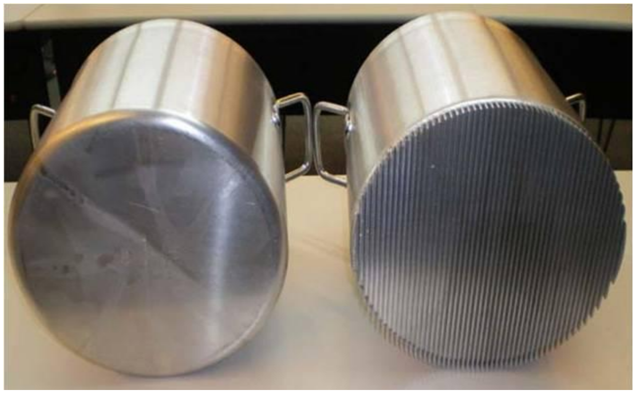
[10] We recognize pots and pans aren't typically classified as part of a cooking appliance. However, in the interest of completeness we did not want to leave out this potential energy savings opportunity in the commercial cooking end use sector.

Figure 2-31: Stock Pot Heat Transfer Fins



Left: Standard Pot. Right: Pot with Heat Fins
Source: Eneron 2009a

Table 2-48 summarizes the energy savings from each of the appliance specific technologies.

Table 2-48: Energy Savings from Appliance Specific Technologies

Technology	Appliance	Fuel	Percent Energy Savings	Source Comments
Heat Pipe Griddle	Griddle	Gas	4.3%	NCI Calculation
Induction griddle	Griddle	Electric	6.3%	NCI Calculation
Idle energy reduction	Broilers	Gas	26%	NCI Calculation
Connectionless steamer	Steamer	Gas	73%	EPA 2009b
Connectionless steamer	Steamer	Electric	73%	EPA 2009b
Stock Pot Heat Transfer Fins	Range	Gas	4.5%	NCI Calculation

See Appendix A Section A.5 for NCI Calculations.

The incremental costs of connectionless steamers are well documented; however, there is little information on the cost of other appliance specific technologies. Table 2-49 documents the incremental cost of connectionless steamers while Table 2-50 documents the incremental cost required for a 3 year payback for other appliance specific technologies.

Table 2-49: Incremental Cost and Payback of Connectionless Steamers

Connectionless Steamer	Incremental Cost[a]	Site Unit Energy Consumption[b]	Annual Energy Savings[c]	Payback Period[d]
Gas	$3,700	105 mmBtu/yr	77 mmBtu/yr	3.8
Electric	$2,500	12,500 Kwh/yr	9,140 Kwh/yr	2.7

a) Source: EPA 2009b
b) Source: Table 2-27
c) Site Unit Energy Consumption x Percent Energy Savings (Table 2-48)
d) Annual Energy Savings x cost of gas/Incremental Cost. Cost of gas assumed to be: $12.75/therm, cost of electricity assumed to be $0.10/kWh

Table 2-50: Incremental Cost Required for a 3 Year Payback of Appliance Specific Technologies

Technology	Site Unit Energy Consumption per year[a]	Annual Energy Savings per year[b]	Incremental Cost Required[c]
Heat Pipe Griddle	59 mmBtu	5 mmBtu	$190
Induction Griddle	8820 kWh	550 kWh	$170
Broiler Idle Energy Reduction	174 mmBtu	45 mmBtu	$1,700
Stock Pot Heat Transfer Fins	111 mmBtu	5 mmBtu	$200

a) Source: Table 2-27
b) Site Unit Energy Consumption x Percent Energy Savings (Table 2-48)
c) Annual Energy Savings x cost of gas x 3 years. Cost of gas assumed to be: $8/therm

Table 2-51 summarizes the commercialization of the above appliance specific technologies.

Table 2-51: Commercialization of Appliance Specific Technologies

Technology	Commercialization	Source Comments
Heat Pipe Griddle	Limited Commercial Availability	Survey distributor websites
Induction griddle	Limited Commercial Availability	Survey distributor websites
Idle energy reduction	Developed and Tested in the 1990s, though discontinued	FSTC 2002
Connectionless steamer	Widespread Commercial Availability	NCI Appliance Experts 2009
Connectionless steamer	Widespread Commercial Availability	NCI Appliance Experts 2009
Stock Pot Heat Transfer Fins	Recently introduced to the market	Eneron 2009b

Total Segment Technical Potential

We identified several technologies that may apply to more than one appliance type. Additionally each appliance type may have multiple technologies that can reduce its energy consumption. Table 2-52 summarizes the applicable technologies mentioned in this report as they relate to each appliance.

Table 2-52: Energy Efficiency Technologies by Appliance Type

Appliance	Gas Savings Technology	Electric Saving Technology
Fryer	Electric Ignition Infrared Burners Power Burner Fryer Pulse Combustion Appliance Insulation	Appliance Insulation
Griddle	Electric Ignition Pulse Combustion Heat Pipe Griddle Appliance Insulation	Induction griddle Appliance Insulation
Oven	Electric Ignition Infrared/convection oven	None
Broilers	Electric Ignition Infrared Burner Idle energy reduction	None
Range	Electric Ignition Power burners Infrared Burners Stock Pot Heat Transfer Fins	None
Steamer	Electric Ignition Connectionless steamer	Connectionless steamer
Microwave	N/A	None

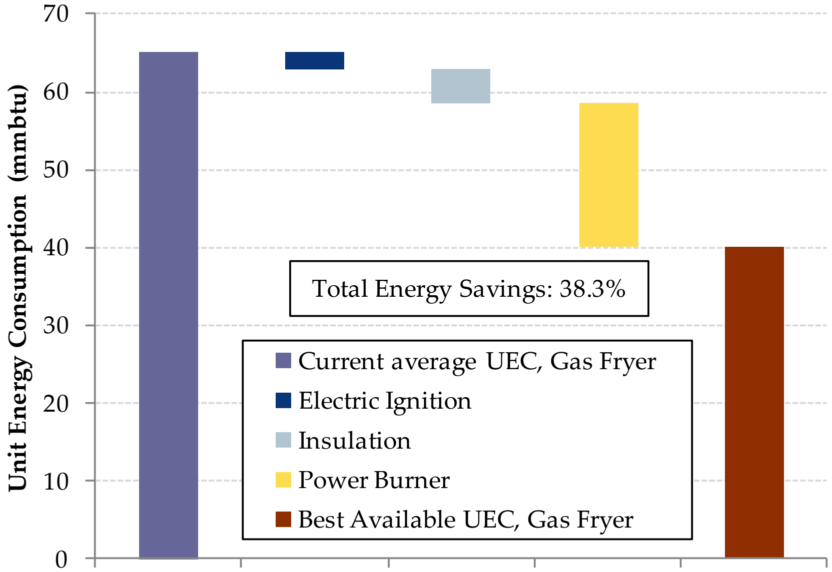
The total energy efficiency potential of cooking end uses is not a simple summation of the individual technology energy savings in this chapter. Several technologies target the same aspect of energy use within an appliance; they are essentially competing technologies. The implementation of one would physically exclude the implementation of the other. For example, if a fryer is built with an infrared burner, it cannot also utilize a power burner. Additionally, the implementation of one technology may reduce the energy savings of another, this is the interactive effect.

We estimate the total unit energy savings for an appliance type by analyzing the interactive effects of the applicable technologies starting with the lowest cost technology. When two technologies are competing, we chose to use the one that is most applicable (notes on these selections accompany each appliance type). The percent energy savings from 2 or more technologies implemented in the same appliance is not the simple summation of the two savings. The unit energy savings is calculated by successively multiplying the percent energy savings of a technology by the unit energy consumption starting with the baseline UEC then using the lower UEC that results from the previous energy efficiency technology.

Fryers

We identified five efficiency technologies for improving gas fryers; however, three of them are competing burner technologies. Of the competing burner technologies, power burners offer the greatest savings and are currently available on the market. Power burners offer the greatest savings of the applicable technologies shown in Figure 2-32.

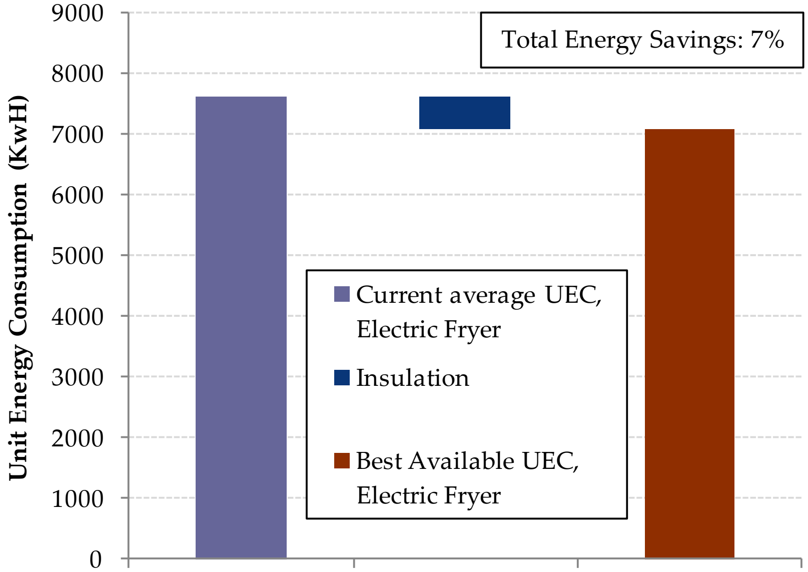
Figure 2-32: Gas Fryer Total Unit Energy Savings



UEC Obtained from Table 2-27

We have identified one significant electric fryer efficiency technology, this is appliance insulation. The energy saving of this technology in an electric fryer is summarized in Figure 2-33.

Figure 2-33: Electric Fryer Total Unit Energy Savings

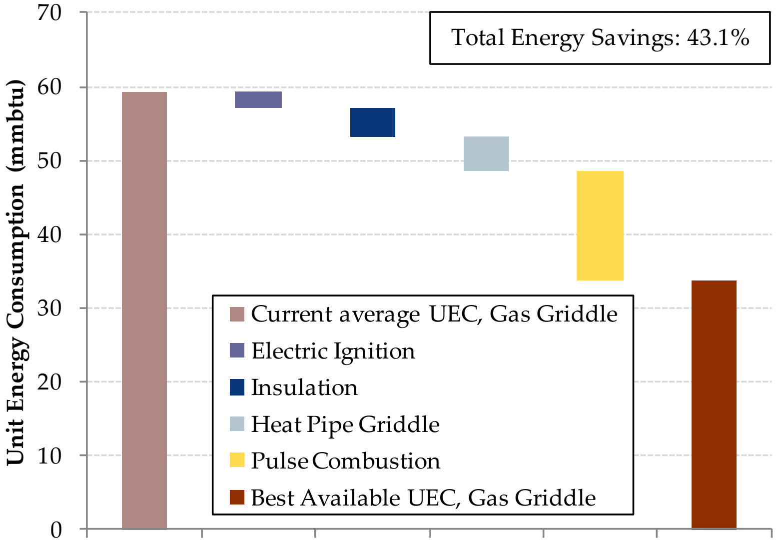


UEC Obtained from Table 2-27

Griddles

We identified four efficiency technologies to improve gas griddles. Although all four are included in our calculation of total energy savings, two of them (heat pipe and pulse combustion) are relatively new technologies with limited use in the current market. The energy saving of these technologies in a gas griddle is summarized in Figure 2-34.

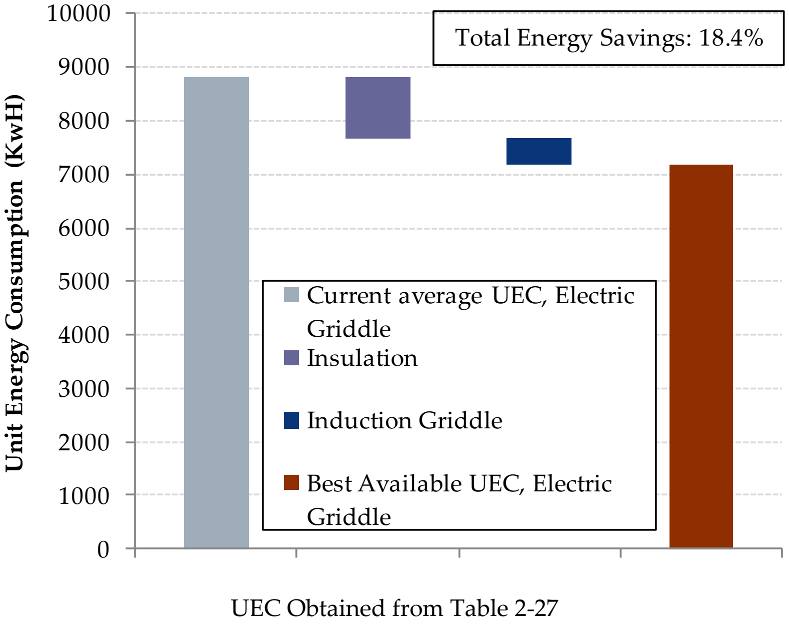
Figure 2-34: Gas Griddle Total Unit Energy Savings



UEC Obtained from Table 2-27

We identified two efficiency technologies to improve electric griddles. Relatively inexpensive insulation offers greater savings than induction heating technology as summarized in Figure 2-35.

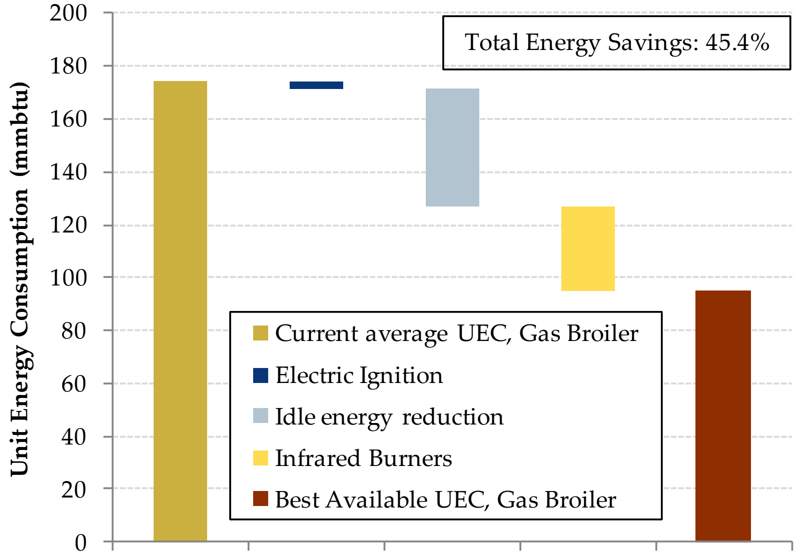
Figure 2-35: Electric Griddle Total Unit Energy Savings



Broilers

We identified three efficiency technologies to improve gas broilers: electric ignition, idle energy reduction and infrared burners. Idle energy reduction offers the greatest savings as shown in Figure 2-36. We found no technologies that offer a significant nationwide impact on electric broilers.

Figure 2-36: Gas Broiler Total Unit Energy Savings

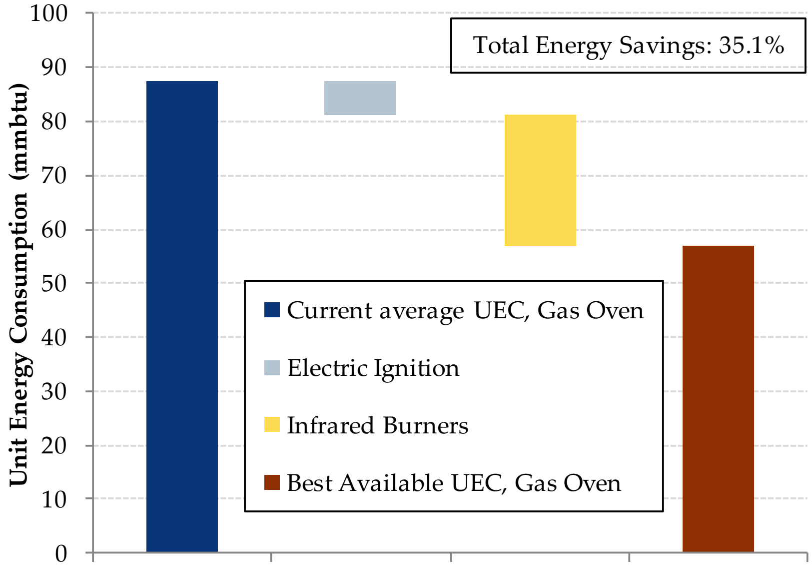


UEC Obtained from Table 2-27

Ovens

We identified two efficiency technologies to improve gas ovens and found no technologies that offer a significant nationwide impact on electric ovens. Infrared burners offer the greatest savings as shown in Figure 2-37.

Figure 2-37: Gas Oven Total Unit Energy Savings

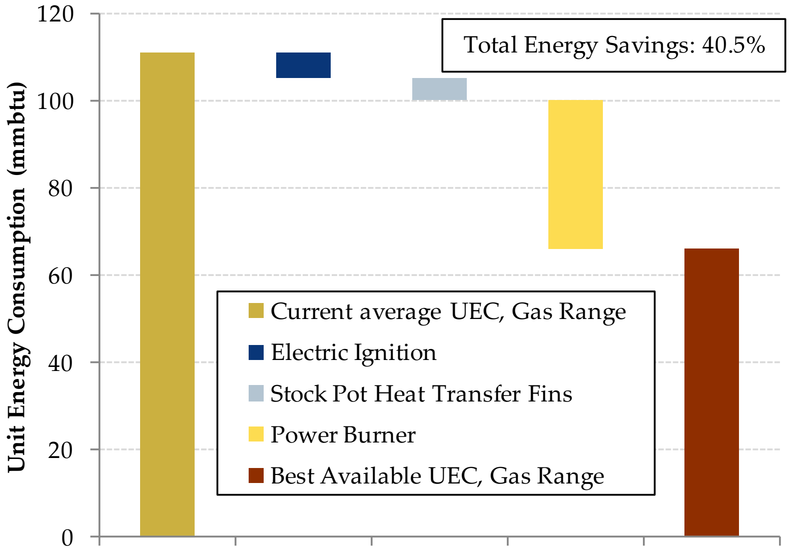


UEC Obtained from Table 2-27

Ranges

We identified three efficiency technologies to improve gas ranges and found no technologies that offer a significant nationwide impact on electric ovens. One of the gas range technologies is not a technology that modifies the range itself, this is stock pot heat transfer fins. Power burners offer the greatest energy savings (Figure 2-38), however as mentioned earlier there barriers to their application in ranges.

Figure 2-38: Gas-Range Total Unit Energy Savings

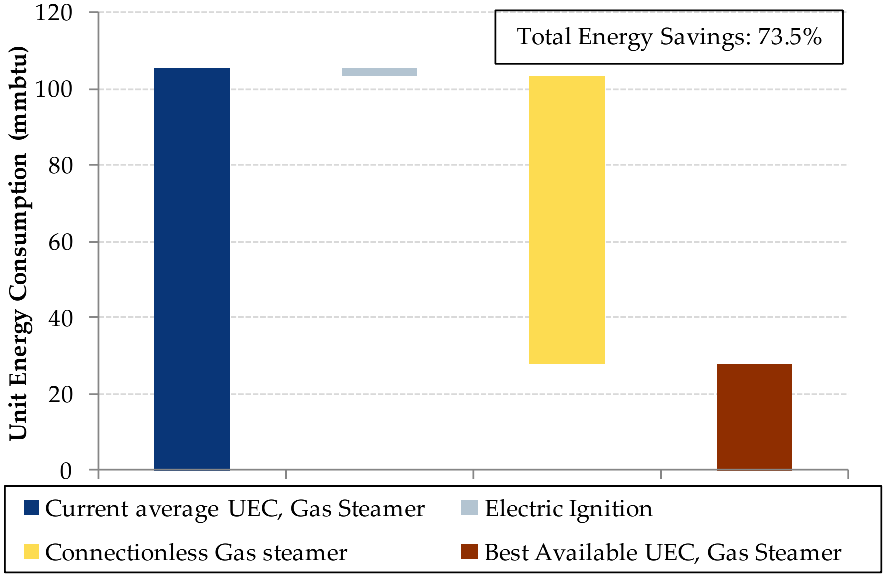


UEC Obtained from Table 2-27

Steamers

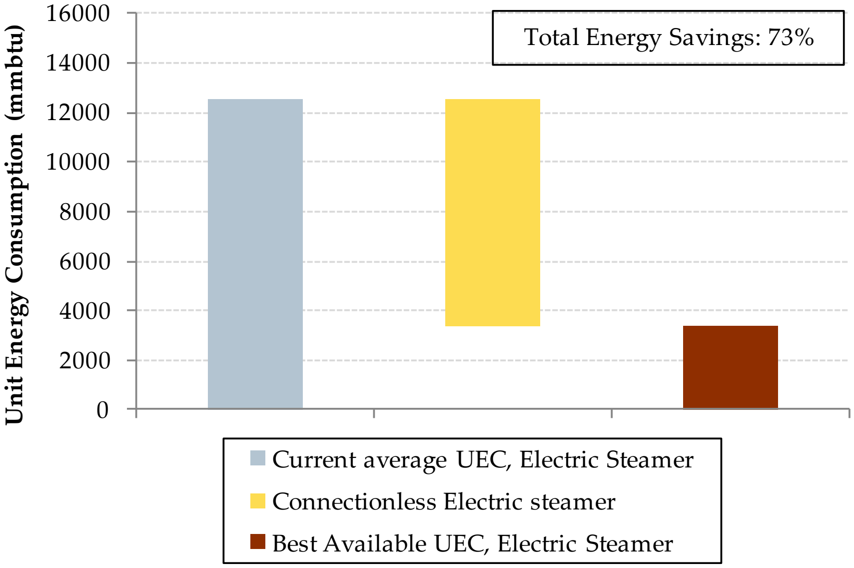
Connectionless steamer technology has the potential to reduce energy consumption in both electric and gas models significantly. Additionally, electric ignition was identified to reduce energy consumption in gas steamers. Figure 2-39 and Figure 2-40 summarize the total savings in gas and electric steamers respectively.

Figure 2-39: Gas Steamer Total Unit Energy Savings



UEC Obtained from Table 2-27

Figure 2-40: Electric Steamer Total Unit Energy Savings



UEC Obtained from Table 2-27

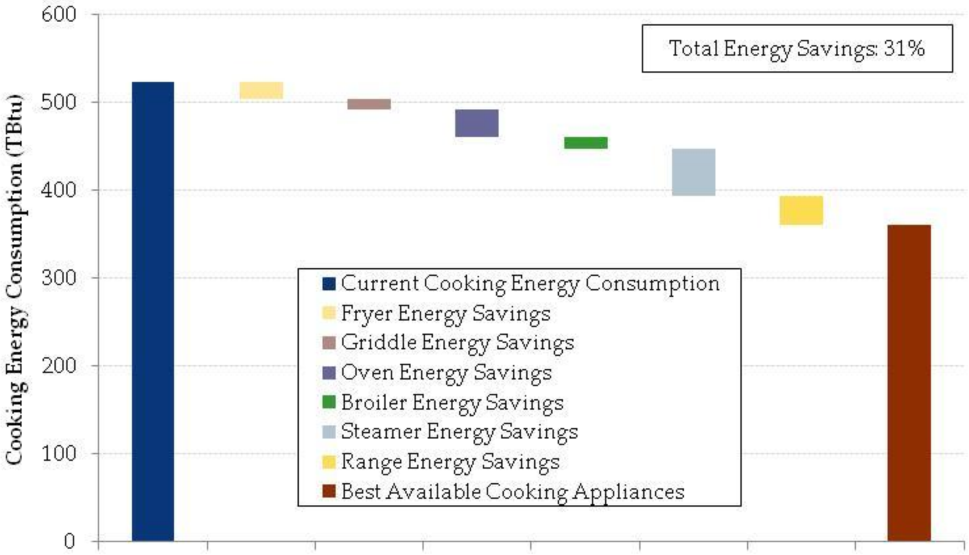
The national energy efficiency potential of primary cooking equipment is calculated in Table 2-53. Figure 2-41 shows the technical potential of each appliance class and the resulting reduction in energy consumption possible by the entire cooking sector.

Table 2-53: National Energy Savings of Cooking Appliances

Cooking Equipment	Fuel	Percent Savings[a]	Annual Energy Consumption (TBtu)[b]	National Energy Savings (TBtu)[c]
Broilers	Gas	45.4%	31.7	14.4
	Electric	0	4.9	0.0
Fryers	Gas	38.3%	42.2	16.2
	Electric	7.0%	37.3	2.6
Griddles	Gas	43.1%	16.3	7.0
	Electric	18.4%	25.3	4.7
Ovens	Gas	35.1%	88.2	31.0
	Electric	0	90.6	0.0
Ranges	Gas	40.5%	83.3	33.8
	Electric	0	11.0	0.0
Steamer	Gas	73.5%	20.6	15.1
	Electric	73.0%	51.6	37.6
Microwaves	Electric	0%	20	0
All	**All**	**31%**	**523**	**162**

a) Source: Figure 2-32 though Figure 2-40
b) Source: Table 2-27
c) Calculated: Percent Savings x Annual Energy Consumption

Figure 2-41: Cooking-Sector Technical Potential



Note: Appliances shown in no particular order
Source: Table 2-53

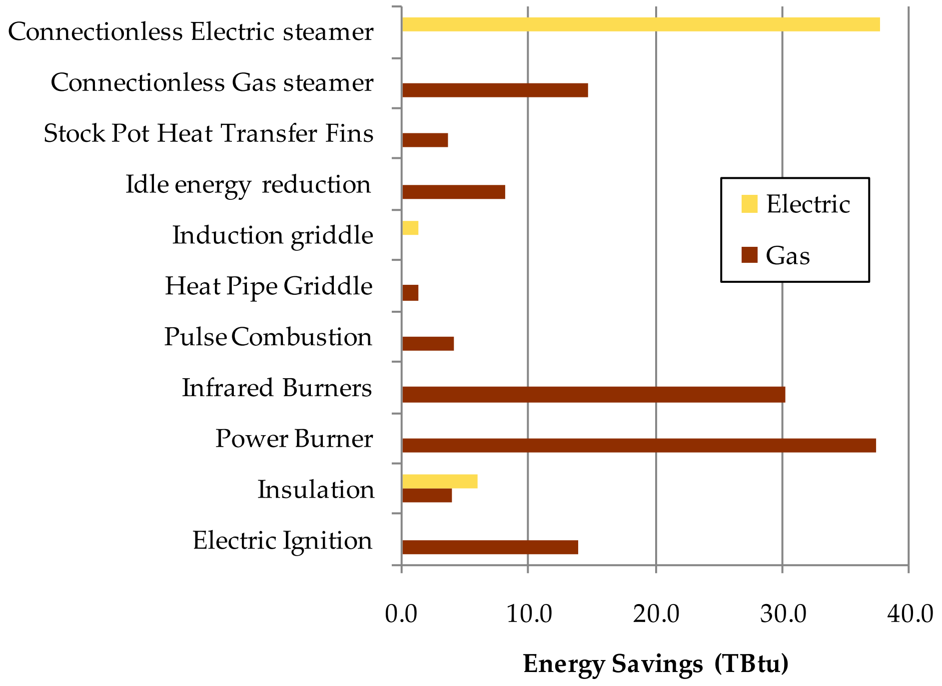
Energy savings by technology type was also calculated. These values are presented in Table 2-54 and illustrated in Figure 2-42.

Table 2-54: National Technical Potential by Cooking Efficiency Technology

Technology	Energy savings (TBtu)	
	Gas	Electric
Electric Ignition	13.9	0
Insulation	4.0	5.9
Power Burner	37.4	0
Infrared	30.3	0
Pulse Combustion	4.1	0
Heat Pipe Griddle	1.2	0
Induction griddle	0	1.4
Idle energy reduction	8.1	0
Stock Pot Heat Transfer Fins	3.6	0
Connectionless Gas steamer	14.8	0
Connectionless Electric steamer	0	37.6

Note: Unit energy consumption savings values for each technology presented in Figure 2-32 through Figure 2-40 are multiplied by the installed base (Table 2-22) of the appliance they apply to. Energy savings for a technology that applies to multiple technologies are added to come up with a technology specific energy savings value presented in this table.

Figure 2-42: National Technical Potential by Cooking Efficiency Technology



Data Source: Table 2-54

2.12 *Peak Demand Considerations*

Approximately half of the installed base of cooking appliance is electric powered; the biggest appliance category is microwaves (see Table 2-55). Non-microwave electric cooking appliances are operated 8-14 hours a day depending on the appliance type and application. Cooking appliances are heavily used during meal times often coinciding with peak times for electric utilities during the mid day and early evening.

Table 2-55: Electric Appliance Installed Base

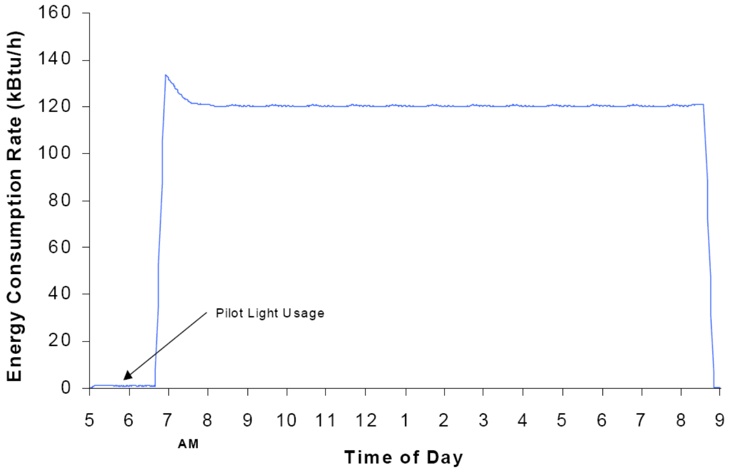
Cooking Equipment	Electric Powered Installed Base
Broilers	18,000
Fryers	470,000
Griddles	276,000
Ovens	825,000
Ranges	74,000
Steamer	396,000
Microwave	978,000
Total	**3,040,000**

Source: Table 2-21 and Table 2-22

Although many cooking appliances (with the exception of microwaves) are left to idle for long periods of time of the day, peak power draw occur either during preheating or actual cooking events.

Figure 2-43 shows the energy consumption rate of a gas broiler throughout the day; it is illustrative of an electric model as both gas and electric broilers are operated in the same fashion. The peak is located at the end of the preheat stage; the broiler continues to idle at a full rate throughout the day.

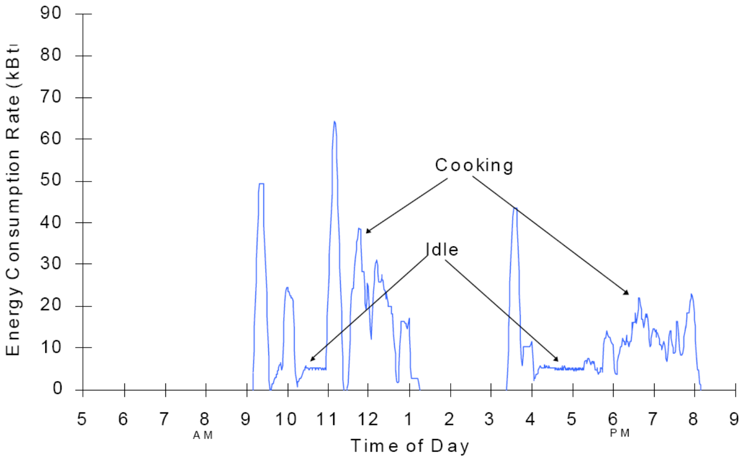
Figure 2-43: Broiler Energy Consumption Daily Profile



Source: FSTC 2002

Figure 2-44 shows the energy consumption rate of a fryer throughout the day. The fryer idles at a much lower energy rate than full capacity (as opposed to the broiler from Figure 2-43). However, the peak draws are during different preheat and cooking stages throughout the day. This indicates that even if cooking energy rate and idle energy rates are controlled, preheating events still account for the peak load.

Figure 2-44: Fryer Energy Consumption Daily Profile



Source: FSTC 2002

Thus for most cooking appliances, peak demand can be reduced through technologies that reduce the input power required for preheating or cooking. This could include efficient heat exchangers, efficient burners, and insulation. Reducing idle energy consumption alone (although having significant energy savings) will not reduce peak demand.

Peak demand for microwaves occurs during heating events when the magnetron is powered. Reductions in peak demand can be realized through more efficient magnetrons and cooking compartment design. However, there is minimal annual energy savings from these technologies in comparison to other cooking equipment. Microwave efficiency technologies are not analyzed in any detail in this report.

3 Commercial Food Preparation

3.1 General Description

Food preparation appliances do not cook food. Rather they are used in commercial kitchens to cut, process, and combine ingredients. These appliances typically perform the following functions: mixing, slicing, cutting, peeling, grinding, and food processing. Examples of these appliances are pictured in Figure 3-1.

Figure 3-1: Food Preparation Equipment

Mixer **Slicer** **Food Processor** **Meat Grinder**

Source: Hobart 2009

There are numerous types of food preparation equipment; NAFEM divides the appliances into the following categories:

- Blenders, Spindle Mixers, Bar Mixers, Drink Mixers
- Bread Slicers
- Breading Machines
- Coffee Grinders/Mills
- Power Cutters/Choppers/Grinders/Shredders, Power (Potato, French Fry, Vegetable, Meat, etc.)
- Dough Molders, Rounders, Kneaders, Rollers/Sheeters
- Powered Food Processors
- Juicers
- Meat Saws
- Mixers (Counter Top, Floor Mounted, Hand Held
- Powered Peelers
- Powered Slicers

Almost all of these appliances are electric powered. Energy is mostly used to drive motors, though some goes to powering timers and other electronic controls. Most equipment uses motors with a rated output of 7.5 Hp or less.

In most applications, food preparation appliances are turned on when they are needed and turned off when not in use; this is in contrast to primary cooking appliances that are generally left on the whole day regardless of cooking load.

3.2 Manufacturers and Market Shares

Hobart and Middleby Corporation are the two largest manufacturers of commercial food preparation equipment. There are numerous smaller manufacturers as well.

3.3 Major End Users

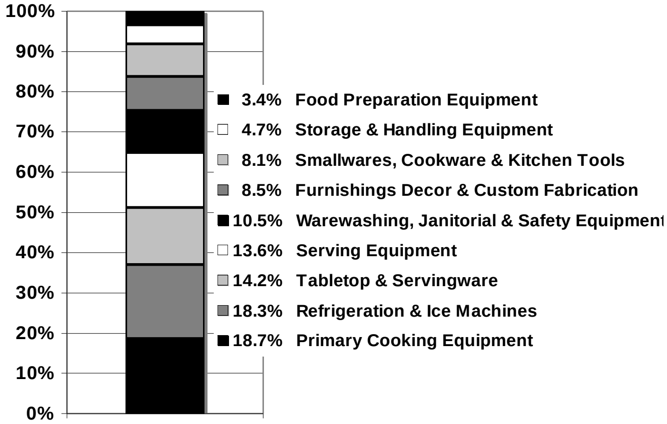
Most establishments that cook and serve food have some use of food preparation equipment. Restaurants, hotels, hospitals, and schools are all major end users. The notable exception is the fast-food industry. Most fast-food chains receive most of their food pre-cut and pre-formed, reducing on-site preparation needs. Compared to full service restaurants, their need for and use of food preparation equipment is much smaller.

3.4 Installed Base

We found no data indicating the installed base of food preparation equipment, thus we made our own estimate. We estimate the annual shipments of food preparation equipment from the total dollar value of sales estimated by NAFEM and a survey of retail prices for food preparation equipment.

Out of all restaurant equipment sold, the dollar value spent on food preparation equipment is the smallest. It's smaller than food storage equipment, kitchen utensils and tools, and dishwashing equipment as illustrated in Figure 3-2. The total dollar value of food preparation equipment in 2008 is estimated in Table 3-1.

Figure 3-2: Value of Restaurant Equipment Sales in 2007



Source: NAFEM 2008

Table 3-1: Sales of Food Preparation Equipment

	Value	Source
Total Restaurant Equipment Sales in 2007	$9,090,000,000	NAFEM 2008
Total Food Prep Sales in 2007	$309,060,000	Calculated [a]
Estimated Food Prep Sales in 2008	$320,800,000	Calculated [b]

a) Total sales x 3.4% (from Figure 3-2)
b) Calculated using a 3.8% growth rate from 2007 to 2008. This is the estimated growth rate of primary cooking equipment reported by NAFEM, we assume food preparation equipment sales will grow at the same rate.

The retail price range for several appliance types were obtained from equipment distribution websites. Table 3-2 is not an all inclusive list, though we assume it covers the range of costs for most food preparation appliances.

Table 3-2: Retail Prices of Food Preparation Equipment, 2008

Appliance	Price Range	Average
Processor	$400-4,500	$2,450
Countertop Mixer	$500-5,000	$2,750
Meat Grinder	$700-3,000	$1,850
Slicers	$900-5,500	$3,200
Food Prep Average		**$2,560**

Source: Retail prices from distributor websites (http://bigtray.com/)

Table 3-3 estimates the annual shipments based on the total dollar value of food preparation equipment shipments and our estimated average appliance cost from Table 3-2.

Table 3-3: Annual Shipments of Food Preparation Equipment, 2008

	Value	Source
2008 Shipment Value	$320,800,000	Table 3-1
Average Retail Price	$2,560	Table 3-2
2008 Units Shipped	**125,000**	Calculated

We estimate the installed base making assumptions about the number of units in a typical food service establishment and the total number of food services establishments. First, we estimate the total number of buildings with cooking as an end use. Then we assume a typical set of food preparation equipment in used in each building type, this specifies an installed number per building. Table 3-4 shows these values and our total estimate for installed base.

Table 3-4: Food-Preparation Equipment Installed Base, 2008

Building Type	Number of Buildings with food sales (2008 Estimate)[a]	Typical Installed Appliances[b]	Number of Food Preparation Appliances[b]	Installed Base
Restaurant	313,000	Mixer, Blender, Processor, Slicer, Peeler	5	1,565,000
Hotel	49,600	Mixer, Blender, Processor, Slicer, Peeler	5	248,000
Hospital	12,000	(Mixer, Processor, Slicer, Peeler) x 2	8	96,000
School	142,000	Mixer, Processor, Slicer	3	426,000
Grocery	95,500	Mixer, Slicer, Peeler	3	286,500
Retail	84,500	Slicer, Blender	2	169,000
Office	23,900	Slicer, Blender	2	47,800
Total				**2,800,000**

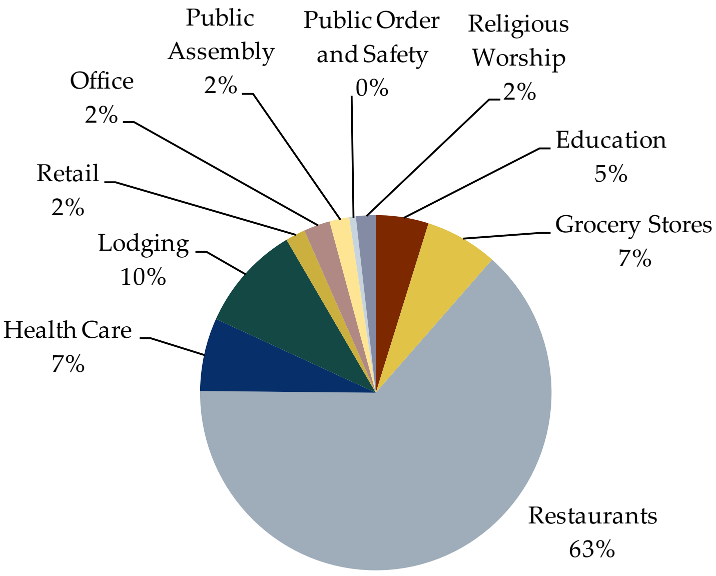
a) Table A-5
b) NCI Assumption

3.5 *Baseline Energy Consumption*

Energy consumption by food preparation equipment is not well documented. A bottom-up analysis to calculate energy consumption is not possible due to the lack of data on the unit energy consumption. Thus, we used a top-down estimate.

We assume the majority of food preparation is performed along with cooking activities; it is important to identify the sectors that are the largest cooking end users. CBECS reveals the majority of cooking energy is used in food service buildings (restaurants, cafes, fast food, bars, etc.) as illustrated in Figure 3-3.

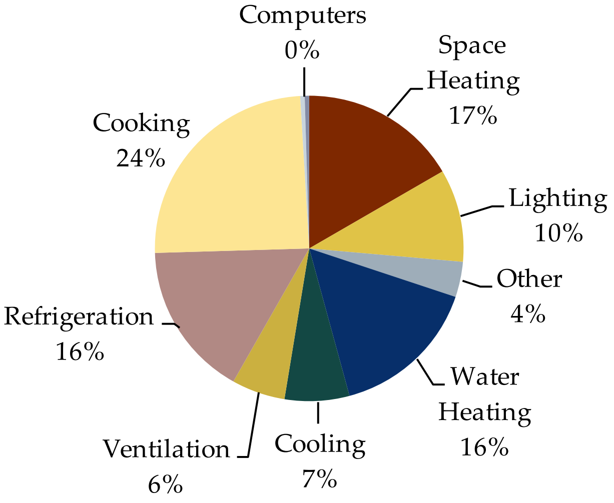
Figure 3-3: 2003 Distribution of Cooking Energy by Building Type



Source: EIA 2003

A further breakdown of energy use within restaurants shows the largest portion of energy use is for cooking (24%), as shown in Figure 3-4. A very small amount (4%) falls under the "Other" category. The Other category contains all plug loads that are not computers or office equipment; this is where the energy consumption of food preparation equipment would be accounted. However we assume the Other category would also include energy consumption by dishwashers, cash registers, sound systems, and lighted restaurant signage. At most food preparation can consume 4% of a restaurant's total energy use.

Figure 3-4: 2003 Distribution of Energy Use within the Food Service Sector



Source: EIA 2003

The distribution of energy use in restaurants gives the best estimate of the ratio between energy used for cooking and energy used for food preparation. This ratio is calculated in Table 3-5. We assume there are a limited number of energy-consuming appliances in restaurants that fall under the "other" category, thus the majority of energy consumption will be food preparation equipment.

Table 3-5: Ratio of Food Preparation to Cooking Energy Consumption

	Value	Source Comments
Percent of Restaurant energy used for cooking	24%	EIA 2003
Percent of Restaurant energy used by "Other" appliances	4%	EIA 2003
Ratio of Other to cooking energy	0.167	Calculation

An upper limit to the energy consumption by food preparation equipment can be estimated using the ratio of Other to Cooking energy. The upper limit is calculated in Table 3-6.

Table 3-6: Upper Bound of Food Preparation Energy Consumption

	Energy Consumption (Trillion Btu)	Source
Total US cooking Energy Consumption	523	Figure 2-26
Upper Bound of Energy Used for Food Preparation	87	Calculation[a]

a) Total US cooking Energy Consumption x Ratio of Other to Cooking energy (Table 3-6)

A total of 87 trillion Btu is used by equipment in commercial kitchens that does not include: primary cooking, lighting, HVAC, refrigeration, water heating, and office equipment. This figure still includes energy used by commercial dishwashers. To get a better estimate of the energy used for food preparation alone, energy used by dishwashers (not including building water heater energy) can be subtracted. This operation is detailed in Table 3-7 and Table 3-8.

Table 3-7: Dishwasher Energy Consumption

	Value	Source
Dishwasher Appliance Energy Consumption	35 TBtus	Table 4-16
Booster Water Heater Energy Consumption	37 TBtus	Table 4-16
Dishwasher (Excluding Building Water Heater) Energy Consumption	72 TBtus	Calculation

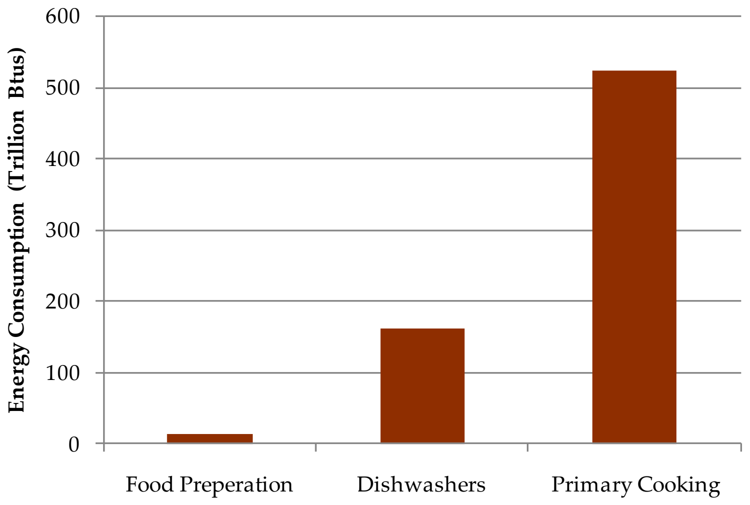
A more refined estimate for the energy consumption of food preparation equipment is calculated by subtracting dishwasher energy consumption from the upper bound estimate.

Table 3-8: Food Preparation Energy Consumption

	Trillion Btu's	Source
Maximum Energy Used for Food Preparation	87	Table 3-6
Dishwasher (Excluding Building Water Heater) Energy Consumption	72	Table 3-7
Refined Estimate of Food Preparation Energy Consumption	**15**	**Calculation**

Figure 3-5 illustrates that total energy consumption by food preparation appliances is small compared to other energy uses in commercial kitchens such as primary cooking and dishwashing.

Figure 3-5: Energy Use in Commercial Kitchens



3.6 *Comparison of Baseline Energy Consumption to Previous Studies*

We found no existing previous research on estimates of the annual energy consumption by food preparation equipment. As mentioned previously, the majority of these plug loads fall under the "Other" category in analyses from the DOE (Building Energy Database) and ADL.

3.7 *Energy Saving Technologies*

Little potential exists to reduce the energy consumption of food preparation appliances. We assume most of the energy consumption in these appliances is by motors; most of these appliances operate by spinning a shaft to drive a slicer, mixing arm, grinder, chopping bladed, or some other accessory.

Energy can reduced through the use of high efficiency motors. However, these would offer minimal energy savings as baseline motors are already quite efficient (they are regulated by federal minimum efficiency standards.) Additionally, high efficiency motors will become the federal minimum efficiency standard in 2010. The national energy savings is estimated in Table 3-9.

Table 3-9: Food Preparation Efficiency Potential

	Value	Source
Percent Energy Savings from High Efficiency Motors	2.2%	Table B-1
Food Preparation Energy Consumption	13 TBtu	Table 3-8
Efficiency Potential	**0.29 TBtu**	**Calculation**

3.8 Peak Demand Considerations

Food preparation equipment usually runs during the same 8-14 hour window that primary cooking equipment operates. As opposed to cooking equipment, food preparation equipment is not constantly in operation or consuming significant amounts of energy while idling. Nevertheless, food preparation equipment can draw significant amounts of power for a short period of time. For example a 7.5 Hp motor with an efficiency of 87.5% can draw up to 6.4 KW when operating at full capacity.

High efficiency motors decrease the amount of input electric power required for a given motor output. Thus high, efficiency motors can decrease peak electric demand by food preparation equipment.

4 Commercial Dishwashers

Commercial dishwashers use building supplied hot water, gas, and electricity in conjunction with detergents and chemical agents to clean dishes. These appliances are often referred to as "warewashers" in the restaurant industry. This section focuses only on dishwasher appliances.

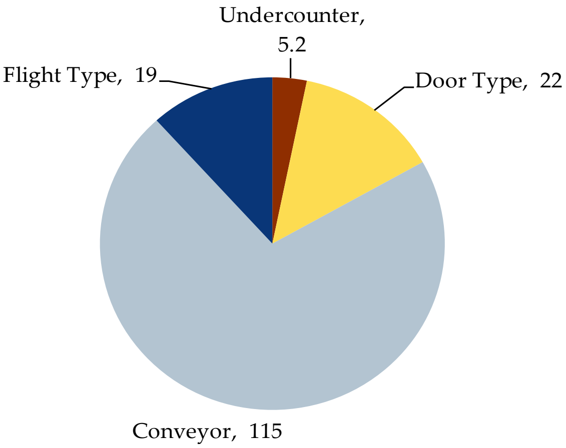
Summary energy-consumption data are shown in Table 4-1, Figure 4-1, and Figure 4-2. The majority of energy is consumed by conveyor dishwashers as they are the most common of the dishwashers. Flight type washers have the smallest installed base but the highest per unit energy consumption. The total attributable energy reported in Table 4-1 includes energy used by the dishwashers units (machine), booster water heaters, and building water heaters. Machine energy consumption includes only electricity used for motors, pumps, heating elements, and controls in the actual dishwasher. Building water heater energy only includes energy used to heat water that is specifically used by the dishwashers; this energy is not actually consumed inside the dishwasher. Booster water heater energy is the energy used by the auxiliary booster heater to heat water building–supplied hot water to higher temperatures.

Table 4-1: Total Attributable Energy Consumption by Technology

End-Use Technology	2008 Installed Base[a]	2008 Annual Energy Consumption (Trillion Btu)[b]	2008 Average UEC (mmBtu/unit)[c]
Under Counter	58,100	5.2	89.3
Door Type	87,100	22	252
Conveyor	314,000	115	364
Flight Type	24,200	19	780
Total	**483,400**	161	

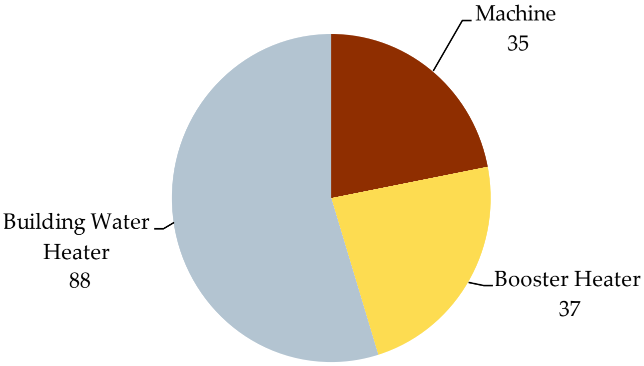
a) Source: Table 4-9
b) Source: Table 4-16
c) Calculated: Energy Consumption/Installed base

Figure 4-1: National Annual Energy Consumption (TBtus) by Dishwasher Type



Source: Table 4-16

Figure 4-2: Energy Consumption (Btus) by Component (Average for all Washer Types)



Source: Table 4-16

We identified several efficiency technologies to reduce the annual energy consumption of dishwashers. These technologies are combined in packages that apply to certain types of dishwashers. Table 4-2 summarizes the technologies and the washers they apply to. Table 4-3 details the energy savings potential (technical potential) for each washer type.

Table 4-2: Dishwasher Energy Efficiency Technology Applications

Energy Efficiency Technology	High Efficiency Dishwasher Type			
	Under-counter	Door-Type	Conveyor	Flight Type
Low flow sprayers	x	x	x	x
Redesigned tanks to reduce heat loss		x	x	x
Automatic sprayer shutoff			x	
Wall insulation		x	x	x
Waste heat recovery			x	x

Source: Table 4-21

Table 4-3: High Efficiency Dishwasher Technical Potential

Washer Type	Technical Potential (TBtu)	
	Low Temperature	High Temperature
Undercounter	0.30	0.95
Door-Type	4.63	2.85
Conveyor	11.2	22.6
Total	**16.4**	**26.4**

Source: Table 4-23

4.1 *General Description*

There are four main types of dishwashers used in commercial buildings, with two washing strategies. The four main types are: under-counter, door-type, conveyor-type, and flight-type; the two washing strategies are low-temperature (LT) and high-temperature (HT) washing. Commercial dishwashers differ from their residential counterparts in several ways: 1) they must sanitize dishes using high temperature water or chemical agents, 2) they have much shorter cycles, and 3) they do not typically dry dishes (though some use chemical agents to assist the process.) Since the primary purpose of a dishwasher is to wash dishes, efficiency is measured in gallons of water used per rack of dishes cleaned. A standard dish rack is approximately 20 in x 20 in x 4 in and is pictured in Figure 4-3.

Figure 4-3: Typical Dish Racks

Source: Carlisle 2009

4.1.1 Washing Strategies

The two strategies for dishwashing are high-temperature and low-temperature sanitization. Low-temperature uses hot water supplied by the kitchen's existing water heater, which is typically supplied at 140°F, and a chemical sanitizing agent to accomplish sanitization needs. High-temperature dishwashers use a booster heater (powered by either gas or electricity) to heat water up to 180°F, this temperature is sufficient enough to sanitize dishes without the need of any chemicals.

Fresh water does not continually flow to the dishwasher during the wash process. A tank or sump holds a water-detergent mixture that is sprayed onto the dishes, this water flows back to the tank to form a continuous loop recycling wash water. However, fresh water is used for the final rinse cycle. Both low and high temperature models must maintain water temperatures in their tanks using electric resistance heaters. For this reason, energy consumption by high-temperature models is higher than low-temperature models as more energy is required to sustain the 180°F temperature.

4.1.2 Dishwasher Types

Undercounter dishwashers

Undercounter dishwashers are the smallest commercial dishwashers available, they are similar in design to residential dishwashers (they are place underneath counters and have a door that opens downwards with dish racks that pull out.) However, these machines have a much shorter cycle time than their residential counterparts; the total wash time ranges from 2-5 minutes. Additionally, unlike residential models, these machines to not dry dishes. Undercounter dishwashers are used in smaller establishments that serve less than 100 meals per hour; common uses are in nursing homes, churches, small food service areas, office buildings, and bars.

A revolving arm (Figure 4-4) sprays water on dishes during the wash and rinse cycles. Water for the wash cycle is supplied by the holding tank while fresh water is used for the rinse cycle. The holding tank is drained after each cycle and replenished with fresh water; timers control cycle length. Under-counter models come in both low temperature and high temperature variations, the low temperature dominates the market.

Figure 4-4: Undercounter Dishwasher (Hobart LX Series)

a) Undercounter Dishwasher b) Sprayer Arms

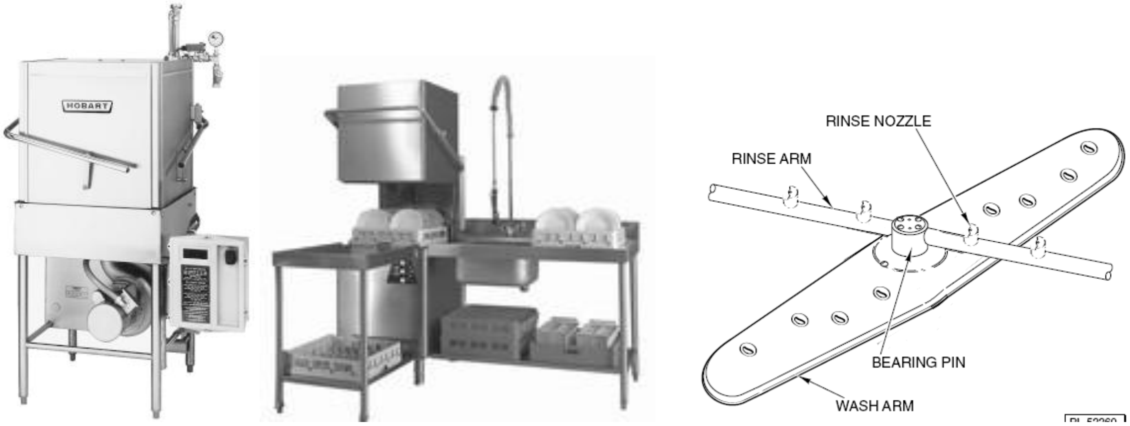
Source: Hobart 2000

Door-type dishwashers

Door-type dishwashers are machines that have one or several doors that slide vertically for loading and unloading racks of dishes (see Figure 4-5). Their design allows for faster and easier loading and unloading compared undercounter dishwashers; they are typically part of a washing “assembly line”. Dishes are loaded in racks prior to placing the rack in the dishwasher. Racks slide from a table into the dishwasher with no lifting required by the user. After washing is complete the rack can slide back out onto a table. These are used in establishments that serve between 100 and 500 meals per hour; common uses are in schools, hospitals, churches, restaurants, catering businesses, and fast-food establishments.

These machines have a single tank for water and detergent and two revolving spray arms (one above and one below the dish rack) spray the water-detergent solution onto the dishes. The tank typically contains 14-15 gallons of water and is continuously used to wash multiple loads; it’s not fully drained after each cycle. Instead water is constantly added to it during the rinse cycle. The rinse cycle uses 1-2 gallons of fresh, this water flows to the tank displacing some of the existing wash water. The total amount of water consumed for each dish load is only that amount which is used during the rinse cycle. Door-type models are available in both low temperature and high temperature variations, it is estimated there is an even split between the two in the market.

Figure 4-5: Door-Type Dishwasher (Hobart AM14)



a) Door-Type Unit b) Washing "Assembly line" c) Sprayer Arms

Sources: Hobart October 2000

Conveyor Dishwashers

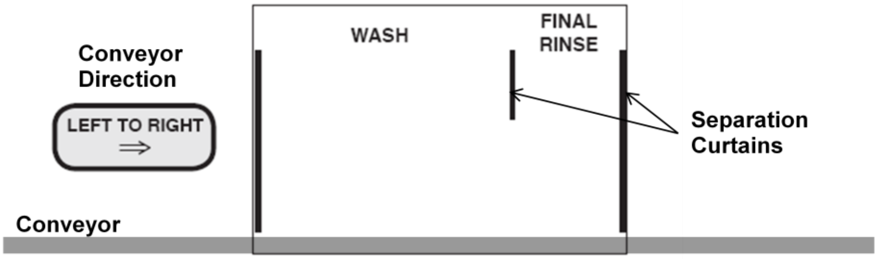
Conveyor dishwashers (Figure 4-6) use a motor driven conveyor belt to move rack-loaded dishes through the machine. These dishwashers have separate wash and rinse compartments inside the unit. They come in varying sizes, with available additions such as pre-wash units, side-loading trays, condensers, and dryers. These are used in establishments that serve between 500 and 2,000 meals per hour; common uses are in hotels, large restaurants, hospitals, schools, and universities.

Figure 4-6: Conveyor Dishwasher (Elframo ETE 20)

Source: Dishwashers Direct Ltd. 2009

The conveyor carries the dishes though different sections of the machine that wash and rinse dishes (see Figure 4-7). The wash section usually has a single tank to hold water and detergent at a set temperature. In a typical machine, the wash solution from the tank is pumped through multiple spray arms that run constantly once the machine is turned on. This water flows back to the tank after it cleans the dishes to be recycled. Some conveyor washers have multiple wash sections or multiple rinse sections progressively cleaning dishes.

Figure 4-7: Example Conveyor Dishwasher Sections



Source: Hobart 2008 (with additions by NCI)

In the rinse section the machine sprays fresh water on the dishes, this water then flows to the wash tanks displacing some of the wash water in a process similar to door type washer operation. In machines with multiple washing sections, water is recycled in a cascading method from the rinse section though the various wash sections ultimately draining after the first wash section.

In standard equipment, the spray arms are operating regardless of the presence of a dish rack. Conveyor models are available in both low temperature and high temperature variations, though high temperature models dominate the market.

Flight type dishwashers

Flight type dishwashers are the highest capacity dishwashers available. They are similar to conveyor machines in that they use a conveyor belt to move dishes through the machine. However, dishes are loaded directly onto the conveyor belt (outfitted with dish-holding prongs) instead of being loading into racks, see Figure 4-8. These dishwashers are often custom built to fit a facility's needs and layout. These are used in establishments that serve over 2,000 meals per hour; common uses are in universities, prisons, and other large commercial, institutional, and industrial facilities.

Flight type dishwashers operate in a similar fashion to conveyor washers, with the noted exception of the use of racks. These dishwashers are typically only offered as high temperature models. Due to the custom nature of these products, information on efficiency and baseline energy consumption is limited.

Figure 4-8: Flight-Type Dishwasher (Blakeslee F-Series)

Source: Blakeslee 2009

4.1.3 Dishwasher Efficiency

Table 4-4 summarizes the wash capacity, and minimum and maximum efficiencies of each dishwasher type.

Table 4-4 Summary of Washer Types, Capacities, and Efficiency Levels, 2008

Washer Type	Temperature	Capacity Range (meals/day)[a]	Average Racks/day[b]	Efficiency of Available Models (gal/rack)[c]		
				Min[d]	Max[d]	Median[d]
Undercounter	Low	<100	75	0.74	2.68	1.75
	High	<100	75	0.73	4.34	1.57
Door-Type	Low	100-500	280	0.50	5.17	1.24
	High	100-500	280	0.52	5.44	1.24
Conveyor	Low	500-2,000	400	0.53	1.83	0.95
	High	500-2,000	400	0.28	2.20	0.90
Flight Type[e]	Low	>2,000	N/A	unknown	unknown	unknown
	High	>2,000	N/A	unknown	unknown	unknown

a) CEE, 2008
b) EPA, 2009b
c) National Sanitation Foundation, 2006
d) Min, Max, and Median are based market available products in 2006. Products in 2008 are assumed to be similar to those available in 2006.
e) Flight type dishwashers do not use racks to hold dishes. Due to their custom nature, information does not exist on the typical minimum and maximum efficiency.

4.1.4 Dishwasher Market Shares

Interviews with industry experts enabled us to estimate the breakdown of low and high temperature models for each appliance type. Additionally, we obtained information on the fuel used for water heating. This information is summarized in Table 4-5 and Table 4-6.

Table 4-5: Estimated Distribution Between High and Low Temperature

	Undercounter	Conveyor	Door Type	Flight Type
Low Temp	70%	50%	70%	0%
High Temp	30%	50%	30%	100%
Source: FSTC Dishwasher Experts 2009				

The decision to choose an LT machine over an HT machine can be driven by several factors. Low temperature washers have a lower capital cost as they do not need a booster water heater. However, HT models offer a cleaner finish on glassware and silverware.

Table 4-6: Water Heater Fuel Type Distribution

	Booster Water Heaters[a]	Building Water Heaters[b]
Gas	5%	70%
Electric	95%	30%

a) Source: FSTC Dishwasher Experts 2009
b) Percent calculated from total Restaurant floorspace served by gas vs. electric water heating from CBECS (EIA 2003)

4.2 *Manufacturers and Market Shares*

There are many players in the commercial dishwasher market, though five have been identified as the major market players in Table 4-7. Information on market shares for commercial dishwasher sales is not available.

Table 4-7: Manufacturers of Dishwashers and Major Market Players

Manufacturer	Top Manufacturer
American Dish Service	
Auto-Chlor System	
Blakeslee	
Champion Industries	
Classeq Glass	
CMA Dishmachines	X
DIHR S.p.a	
Ecolab	X
Electrolux Professional	
Fagor Commercial	
Hobart Corporation	X
Insinger Machine Company	
Jackson	X
KROMO S.r.l	
Knight, LLC	
Meiko USA	
Moyer Diebel Ltd.	X
National Conveyor Corporation	
Stero	
Valu-Clean	
Winterhalter, Inc.	

Source: NCI Appliance Experts 2009

4.3 *Major End Users*

Major end users of dishwashers are restaurants (mainly non-fast food), hotels, schools, universities, prisons, and hospitals. Each appliance type is more suited for a certain establishment, see Table 4-8 for details.

Table 4-8: Typical End Users

Dishwasher Type	Typical End User
Undercounter	Small restaurants Bars Nursing homes Churches
Door-Type	Schools Hospitals Restaurants Catering businesses
Conveyor	Hotels Large restaurants Hospitals Schools Universities
Fight-Type	Universities Prisons Large hotels

Source: CEE 2008

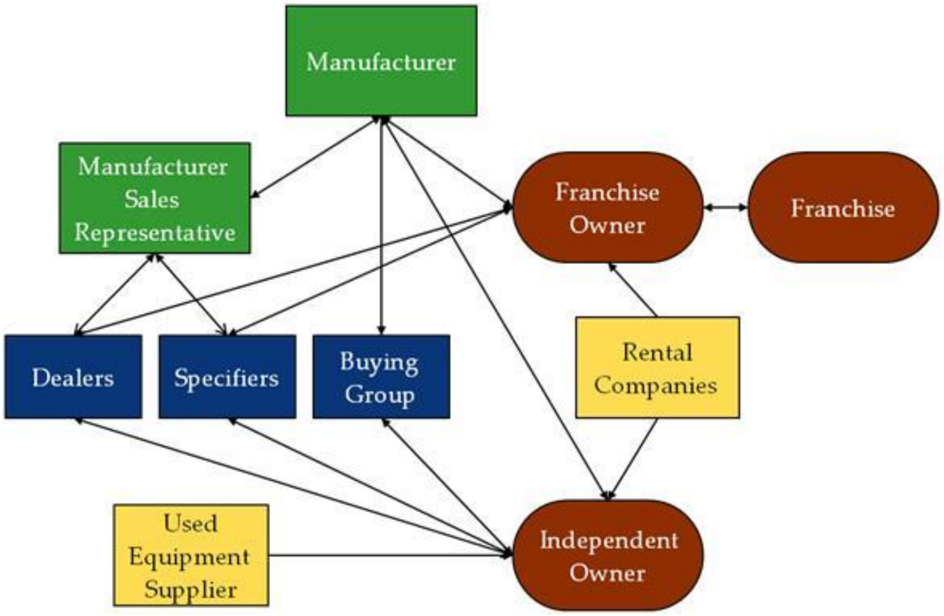
4.4 *Dishwasher Marketing and Purchase Decisions*

Dishwasher manufacturers typically work through regional sales offices or manufacturer sales representatives. Manufacturers sell directly to large restaurant chains and other large end-use customers. Manufacturers use some direct marketing for other customers, but also rely heavily on trade shows such as NAFEM and NRA.

Approximately 30-50% of dishwashers currently in use are customer-owned. Large institutional customers (universities, hospitals, and prisons) are more likely to own their dishwashers. The remaining users (typically small business customers) rent or lease their equipment from third party companies. These leases often include a contract to supply detergent, sanitizing agents (for low temperature models), and drying agents to the customer. Lease customers pay a monthly fee for all their dishwashing needs as the machine, supplies, and maintenance are included in a package at one price.

Purchase (or rental) decisions for commercial dishwashers can be simple or involve a large number of parties, depending on the size and type of the business. The relationship of parties involved in purchase decisions made in chain and independent restaurants is illustrated in Figure 4-9.

Figure 4-9: Relationship among Parties in Cooking Appliance Purchase Decision



Source: CEE 2009 with additions from NCI

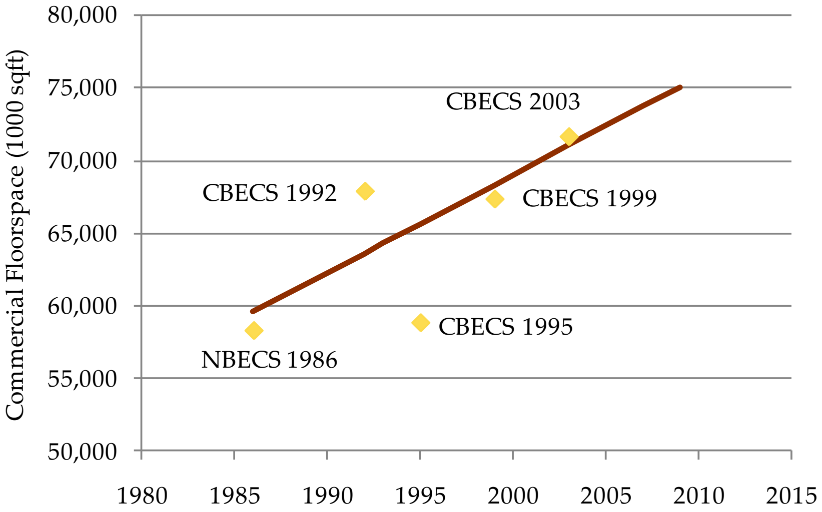
Independent restaurants have some direct communication with the manufacturer, most often through a buying group. Most of their interaction is with dealers and “specifiers” (kitchen design consultants). Independent owners often consider used equipment or a rental program.

Franchise (chain) restaurants have significantly more direct communication with the manufactures. Franchises sometime seek out the services of specifiers and rental companies but rarely consider used equipment.

4.5 Installed Base and Annual Shipments

Installed base and annual shipments in 2006 were reported by the EPA. We project these to 2008 using the percent increase in commercial floorspace obtained from historic CBECS data presented in Figure 4-10. The resulting installed base and shipments are summarized in Table 4-9 and Table 4-10, respectively.

Figure 4-10: Trend in Total Commercial Building Floorspace



Note: Graph shows trend in total commercial building floorspace including all commercial buildings as captured in the Commercial Buildings Energy Consumption Surveys by the EIA. A total growth of 1.9% occurs between 2006 and 2008.
Sources: EIA 1986, 1992, 1995, 1999, 2003

Table 4-9: Estimated Installed Base in 2006 and 2008

	2006 US Installed Base[a]	2008 US Installed Base[b]
All Models	475,000	484,000
Undercounter	57,000	58,000
Door Type	85,500	87,100
Conveyor	308,750	314,000
Flight Type	23,750	24,200

a) EPA 2006
b) NCI Calculations based on 1.9% growth (Figure 2-24)

Table 4-10: Estimated Annual Unit Shipments in 2006 and 2008

	2006 US Shipments[a]	2008 US Shipments[a]
All Models	39,000	40,000
Undercounter	12,870	13,100
Door Type	7,020	7,150
Conveyor	18,720	19,100
Flight Type	390	400

a) EPA 2006
b) NCI Calculations based on 1.9% growth (Figure 2-24), assumes shipments grow at the same rate as the total commercial floorspace.

We divided the total inventory from Table 4-9 into low and high temperature models fuels by gas and electric based on the data presented in Table 4-5 and Table 4-6. We assumed that the ownership of LT and HT dishwashers in buildings is independent of the building water heater fuel source. We also assumed the distribution of booster water heater fuel source is independent of the building water heater fuel source. These assumptions allowed us to calculate the total installed base by temperature and fuel type using the below equation:

Installed Base = *Total Installed Base of Type* x
Temperature Distribution x
Building Water Heater Distribution x
Booster Water Heater Distribution

Example calculations using the above methodology can be seen below:

Undercounter LT with electric building water heater:

58,000 x 70% x 30% = 12,200

Conveyor HT with gas building water heater and electric booster water heater:

314,000 x 50% x 70% x 95% = 105,000

Results for all dishwasher types and all building types can be found in Table 4-11.

Table 4-11: Dishwasher Inventory by Machine and Fuel Type

Type	Temperature	Building WH Type	Booster Heater Type	Distribution of Installed Base	Installed Base
All	**All**	**All**	**All**	**100%**	**484,000**
Undercounter	**All**	**All**	**All**	**12.0%**	**58,100**
	Low	Gas	N/A	5.9%	28,400
	Low	Electric	N/A	2.5%	12,200
	High	Gas	Gas	0.1%	610
	High	Gas	Electric	2.4%	11,600
	High	Electric	Gas	0.1%	260
	High	Electric	Electric	1.0%	4,960
Conveyor	**All**	**All**	**All**	**65.0%**	**314,000**
	Low	Gas	N/A	22.8%	110,000
	Low	Electric	N/A	9.8%	47,200
	High	Gas	Gas	1.1%	5,500
	High	Gas	Electric	21.6%	105,000
	High	Electric	Gas	0.5%	2,360
	High	Electric	Electric	9.3%	44,800
Door Type	**All**	**All**	**All**	**18.0%**	**87,100**
	Low	Gas	N/A	8.8%	42,700
	Low	Electric	N/A	3.8%	18,300
	High	Gas	Gas	0.2%	910
	High	Gas	Electric	3.6%	17,400
	High	Electric	Gas	0.1%	390
	High	Electric	Electric	1.5%	7,450
Flight Type	**All**	**All**	**All**	**5.0%**	**24,200**
	Low	Gas	N/A	0.0%	0
	Low	Electric	N/A	0.0%	0
	High	Gas	Gas	0.2%	850
	High	Gas	Electric	3.3%	16,100
	High	Electric	Gas	0.1%	360
	High	Electric	Electric	1.4%	6,890

Notes:

Installed Base = (Total Installed Base of Type) x (Temperature Distribution Factor) x (Building Water Heater Distribution Factor) x (Booster Water Heater Distribution Factor)

Calculation assumes Temperature type, Building WH type, and Booster WH type are independent factors

Total installed base for each appliance type obtained from Table 4-9.

Distribution factors obtained from Table 4-5 and Table 4-6.

4.6 *Baseline Energy Consumption*

The ENERGY STAR® Calculator estimates baseline energy use for undercounter, door type, and conveyor washers. The calculator does not analyze flight type dishwashers. We estimate the energy consumption of flight type washers with our own method described later.

The ENERGY STAR® Calculator estimates total gas and electric consumption of a combination of dishwasher types. Calculator users can select among washer type (undercounter, door type, conveyor), temperature (low or high), building water heater fuel (gas or electric) and booster water heater fuel (gas or electric). However the calculator does not explicitly reveal how much energy is consumed by various components such as the machine, the booster water heater, or the building water heater. These component energy consumptions, however, can be derived from the calculator output as shown in Table 4-12 and Table 4-13.

Table 4-12: Energy Star Calculator Outputs for HT Undercounter Dishwashers

	Undercounter High Temperature Dishwasher Energy Consumption		
	Water heater: Gas Booster Heater: Gas	Water heater: Electric Booster Heater: Gas	Water heater: Gas Booster Heater: Electric
Electricity consumption (kWh)	2,325	11,799	7,738
Gas consumption (therm)	658	219	439
Source: EPA 2009b			

Table 4-13: Calculated Component Energy Consumption of HT Undercounter Washers

Individual Component	Calculation[a]	Result
Machine Electricity Consumption (kWh)	None	2,325
Gas Building water heater energy consumption (therms)	= 658-219	439
Electric Building water heater energy consumption (kWh)	= 11,799-2,325	9,474
Gas Booster water heater energy consumption (therms)	= 658-439	219
Electric Booster water heater energy consumption (kWh)	=7,738-2,325	5,414
a) Values come from Table 4-12		

Calculations similar to those in Table 4-12 and Table 4-13 were also performed for LT Undercounter, LT and HT Door-Type, and LT and HT Conveyor Dishwashers. These results are presented in Table C-1 in Appendix C.

Flight type dishwasher energy consumption is not analyzed by the ENERGY STAR ® calculator as the equipment is often custom designed and their energy consumption can vary widely. Thus, we developed our own estimate of the annual energy consumption of flight type washers.

They are similar in construction and operation to conveyor dishwashers though larger in capacity. We estimate the energy consumption of flight type machines by scaling up the energy consumption of conveyor machines. We index energy consumption of all components by capacity (meals/hour).

Table 4-14: Energy Scaling Factor for Flight Type Dishwashers

Dishwasher Type	Capacity Range (meals per hour)	Assumed Typical Capacity (meals per hour)
Conveyor	500-2000	1,250[a]
Flight Type	>2,000	2,000[b]
Energy Scaling Factor[c]		**1.6**

a) Assumed to be the average value of the capacity range
b) Assumed to be the minimum capacity (2000 meals per hour) as the upper bound is unknown thus it's not possible to estimate an average.
c) Calculated: Flight Type Typical Capacity/Conveyor Typical Capacity

Table C-1 in Appendix C details unit energy consumption (UEC) by component for each dishwasher type. These values are obtained following the methods illustrated in Table 4-12 and Table 4-13.

We estimate national on-site energy consumption by component by multiplying the component UECs (Table C-1 in Appendix C) by installed base (Table 4-11), the results of this calculation are presented in Table C-2 in Appendix C.

Table 4-15 summarizes Appendix C, showing the national primary energy consumption by appliance configuration and fuel type. Additionally, Table 4-16 totals national energy consumption by dishwasher type.

Table 4-15: National Energy Consumption by Machine Configuration, 2008

Type	Wash Temperature	Building Water Heater Fuel	Booster Heater Fuel	US Primary Energy Consumption[a] Gas (Trillion Btus)	Electricity (Trillion Btus)	Total (Trillion Btus)	Total Excluding Building Water Heaters (Trillion Btus)
Undercounter	Low Temp	Gas	none	1.23	0.25	1.48	0.25
	Low Temp	Electric	none	0	1.29	1.29	0.11
	High Temp	Gas	Gas	0.04	0.01	0.05	0.03
	High Temp	Gas	Electric	0.51	0.93	1.44	0.93
	High Temp	Electric	Gas	0.01	0.03	0.04	0.01
	High Temp	Electric	Electric	0	0.89	0.89	0.4
Conveyor	Low Temp	Gas	none	16	4.55	20.6	4.55
	Low Temp	Electric	none	0	17.4	17.4	1.95
	High Temp	Gas	Gas	1.1	0.76	1.86	1.13
	High Temp	Gas	Electric	14	32.3	46.3	32.3
	High Temp	Electric	Gas	0.16	1.03	1.19	0.48
	High Temp	Electric	Electric	0	27.3	27.3	13.9
Door Type	Low Temp	Gas	none	6.53	0.2	6.73	0.2
	Low Temp	Electric	none	0	6.37	6.37	0.09
	High Temp	Gas	Gas	0.16	0.02	0.19	0.08
	High Temp	Gas	Electric	2.07	3.09	5.16	3.09
	High Temp	Electric	Gas	0.02	0.11	0.14	0.03
	High Temp	Electric	Electric	0	3.32	3.32	1.32
Flight Type	Low Temp	Gas	none	0	0	0	0
	Low Temp	Electric	none	0	0	0	0
	High Temp	Gas	Gas	0.27	0.19	0.46	0.28
	High Temp	Gas	Electric	3.44	7.96	11.4	7.96
	High Temp	Electric	Gas	0.04	0.25	0.29	0.12
	High Temp	Electric	Electric	0	6.72	6.72	3.41
Total				**45.6**	**115**	**161**	**72.6**

a) Data obtained by summing appropriate columns in Table C-2 and converting electric site energy to primary energy with a conversion factor of 10,405 Btu/kWh (when necessary)

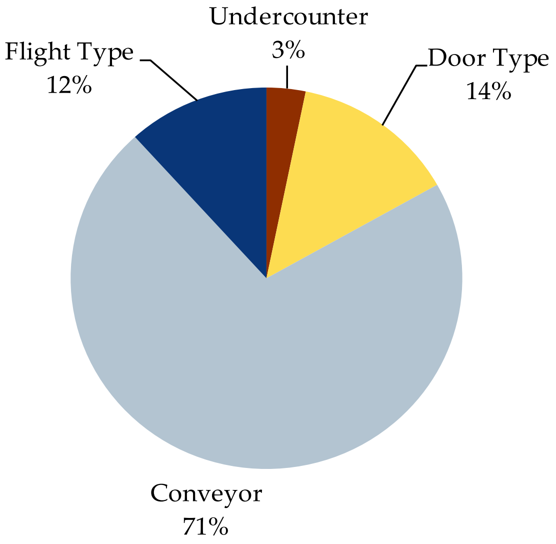
Table 4-16: National Energy Consumption by Machine and Fuel Type, 2008

		Gas Consumption (TBtu)[a]			Electricity Consumption (TBtu)[a]			
Washer Type	**Temperature**	**Machine**	**Booster**	**Building**	**Machine**	**Booster**	**Building**	**Total**
Undercounter	LT	0.0	0.0	1.2	0.4	0.0	1.2	2.8
	HT	0.0	0.0	0.5	0.4	0.9	0.5	2.4
	Subtotal	***0.0***	***0.0***	***1.8***	***0.8***	***0.9***	***1.7***	***5.2***
Conveyor	LT	0.0	0.0	16.0	6.5	0.0	15.4	37.9
	HT	0.0	0.5	14.7	21.7	25.6	14.2	76.7
	Subtotal	***0.0***	***0.5***	***30.7***	***28.2***	***25.6***	***29.6***	***115***
Door Type	LT	0.0	0.0	6.5	0.3	0.0	6.3	13.1
	HT	0.0	0.1	2.2	0.7	3.8	2.1	8.8
	Subtotal	***0.0***	***0.1***	***8.7***	***0.9***	***3.8***	***8.4***	***21.9***
Flight Type	LT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	HT	0.0	0.1	3.6	5.3	6.3	3.5	18.9
	Subtotal	***0.0***	***0.1***	***3.6***	***5.3***	***6.3***	***3.5***	***18.9***
Total		**0.0**	**0.8**	**44.8**	**35.2**	**36.6**	**43.1**	**161**

a) Data obtained by summing appropriate columns in Table C-2 and converting electric site energy to primary energy with a conversion factor of 10,405 Btu/kWh (when necessary)

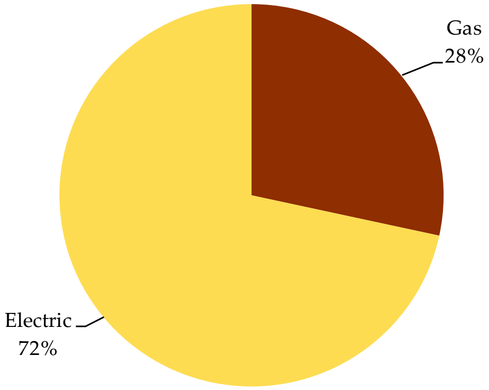
Data in Table 4-16 reveals the majority of energy consumption by dishwashers is attributable to conveyor dishwashers; this is illustrated in Figure 4-11. Furthermore the breakdown of energy consumption by fuel type is illustrated in Figure 4-12. Electricity is dominant.

Figure 4-11: US Dishwasher Primary Energy Consumption by Washer Type, 2008 (Including Building Water Heaters)



Source: Table 4-16

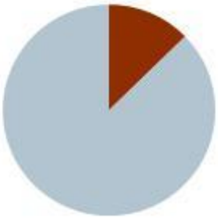
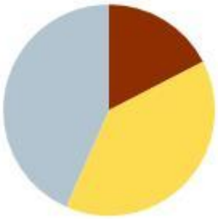
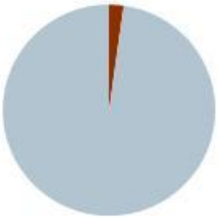
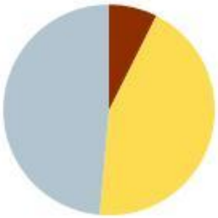
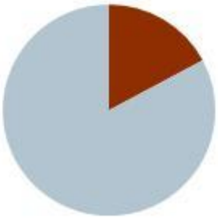
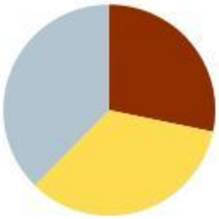
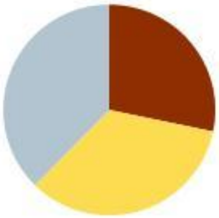
Figure 4-12: US Dishwasher Primary Energy Consumption by Fuel Type, 2008 (Including Building Water Heaters)



Note: Gas consumption only occurs in building water heaters and booster water heaters.
Source: Table 4-15

Table 4-17 shows energy attributable to each component for each appliance type. Machine energy consumption is a small part of energy consumption attribuatable to dishwashers. High temperature dishwashers consume more electricity for use in the machine than low temperature model. This is because their electric resistive heaters must maintain higher water temperatures inside the machine.

Table 4-17: Energy Consumption by Machine and Component Type

	Low Temperature	High Temperature
Undercounter		
Door Type		
Conveyor		
Flight Type	Not Applicable	
	Legend 🟫 Machine 🟨 Booster Heater ⬜ Building Water Heater	
Source: Table 4-16		

4.7 *Comparison of Baseline Energy Consumption to Previous Studies*

We found no existing previous research on estimates of the annual energy consumption by dishwashing equipment. We assume the majority of this the machine energy consumption would fall under the "Other" category in analyses from the DOE (Building Energy Database) and ADL. Additionally, dishwasher energy attributed to building water heating would fall under the "Water Heating" category in other studies. However these studies to not estimate what portion of that is attributed to dishwashers, thus no comparison can be made.

4.8 *Appliance Costs*

Table 4-18 summarizes the total retail costs for each dishwasher type and washing strategy.

Table 4-18: Typical Unit Costs, 2008

Dishwasher Type	Temperature	Approximate Cost[a]	Source Comments
Under Counter	Low	$4,800	EPA 2009b
	High	$5,000	EPA 2009b
Door Type	Low	$6,500	EPA 2009b
	High	$6,900	EPA 2009b
Conveyor	Low	$11,000 - 18,000	EPA 2009b
	High	$12,000 - 20,000	EPA 2009b
Flight Type	Low	N/A	
	High	Up to $100,000	NCI Appliance Experts 2009

Note: Costs in 2008 are assumed to be the same as those in 2009

a) Does not include cost of booster water heater

4.9 *Lifetime, Reliability, and Maintenance Characteristics*

Table 4-19 summarizes the estimated lifetime of each dishwasher type.

Table 4-19: Baseline Effective Useful Life

Dishwasher Type	Effective Useful Life (years)
Undercounter	10
Door-Type	15
Conveyor	20
Flight Type	20

Source: CEE 2008

The ENERGY STAR® calculator assumes no regular maintenance costs for typical models as a default. However, regular maintenance is recommended by manufacturers. This includes: de-liming on a regular basis to remove mineral buildup, removing and cleaning wash arms when needed, daily cleaning and inspection for conveyor and flight type machines, regular lubrication of conveyor mechanisms. There is little information on the costs of this maintenance. There are also no statistics on how many customers actually follow these maintenance plans.

4.10 Regulatory and Voluntary Programs

There are no federal regulatory programs that govern the energy efficiency or energy use of commercial dishwashers.

The US EPA established a voluntary ENERGY STAR® program for undercounter, door type, and conveyor dishwashers. The products were made available in 2008; currently 17 manufacturers offer 249 different models. Data on market penetration of ENERGY STAR® models will be made available in late 2009. The criteria set by the programs are summarized in Table 4-20.

Table 4-20: Current Efficiency Requirements for ENERGY STAR® Dishwashers

Machine Type	High Temperature		Low Temperature	
	Idle Energy Rate	Water Consumption	Idle Energy Rate	Water Consumption
Under Counter	≤ 0.90 kW	≤ 1.00 gal/rack	≤ 0.5 kW	≤ 1.70 gal/rack
Single Tank Door-Type	≤ 1.0 kW	≤ 0.950 gal/rack	≤ 0.6 kW	≤ 1.18 gal/rack
Single Tank Conveyor	≤ 2.0 kW	≤ 0.700 gal/rack	≤ 1.6 kW	≤ 0.790 gal/rack
Multiple Tank Conveyor	≤ 2.6 kW	≤ 0.540 gal/rack	≤ 2.0 kW	≤ 0.540 gal/rack

Source: EPA 2009a

4.11 Energy Saving Technologies

We analyzed several energy efficiency technologies for commercial dishwashers, they are listed below. Some technologies are applicable to multiple dishwasher types:

- Low flow sprayers
- Redesigned tanks to reduce heat loss
- Automatic sprayer shutoff
- Wall insulation
- Waste heat recovery

Each technology contributes to dishwasher energy savings; however there is no reliable data that attributes a set amount of energy saved to an individual technology. These technologies are often used as a package achieving significant savings working together. Examples are those models that meet or surpass the ENERGY STAR® standard.

4.11.1 Technology Details

Low Flow Sprayers

These specially designed sprayers reduce water needs while maintaining cleaning power. Reduced water needs cut back on the energy needed by the building water heater to produce hot water. Several sprayer strategies exist to reduce water flow; one example is a sprayer that emits an oscillating "S" shaped stream (Figure4-13) covering the same area as a conventional sprayer with less water.

Figure4-13: Low Flow Sprayers

Source: Hobart 2009

Redesigned Tanks to Reduce Heat Loss

Energy is used by resistive heaters to maintain the required water temperature in the dishwasher water tanks. Tanks can be redesigned to be narrower and deeper to reduce heat loss. These tanks have less surface area exposed to the air inside the dishwasher; minimizing this area reduces its heat loss.

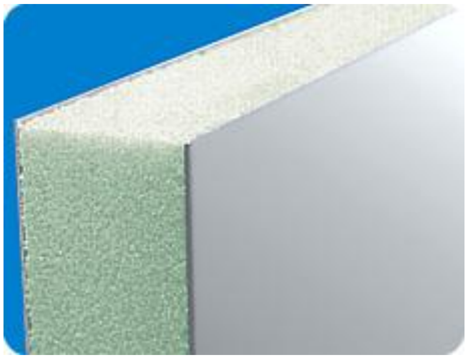
Automatic Sprayer Shutoff

In standard efficiency conveyor dishwashers, sprayers are always in operation when the dishwasher is turned on regardless of the presence of dishes. Automatic sprayer shutoff uses sensors to detect when no dish racks are being passed through the dishwasher. The sensors can turn off water pumps and sprayers saving energy and water.

Wall Insulation

The outside walls of the dishwashers can be insulated to reduce heat loss to the washroom (Figure 4-14). Heat can be lost from the hot water to the air inside the washer as it is sprayed onto dishes, this heat can then escape though poorly insulated dishwasher wall. Insulation retains more heat in the air inside the washer causing less heat to be lost by the water requiring less energy reheat the water.

Figure 4-14: Dishwasher Walls with Insulation (Meiko Flight Type Washer)



Source: Meiko 2009

Waste Heat Recovery

Warm air and steam vented from the machine can be used to preheat cold inlet water (illustrated in Figure 4-15). This reduces the amount of energy consumed by booster water heaters in high temperatures conveyor and flight type dishwashers.

Figure 4-15: Waste Air Heat Recovery System (Meiko Flight Type Washer)

Source: Meiko 2009

The technologies described above apply only to certain types of dishwashers, as listed in Table 4-21. For example smaller undercounter and door type dishwashers are not able to incorporate waste heat recovery and do not have need for automatic sprayer shutoff. However, some technologies are relatively crosscutting such as low flow sprayers and redesigned tanks.

Table 4-21: Dishwasher Energy Efficiency Technology Applications

Energy Efficiency Technology	High Efficiency Dishwasher Type			
	Under-counter	Door-Type	Conveyor	Flight Type
Low flow sprayers	X	x	x	x
Redesigned tanks to reduce heat loss		x	x	x
Automatic sprayer shutoff			x	
Wall insulation		x	x	x
Waste heat recovery			x	x

4.11.2 High-Efficiency Dishwasher Energy Savings and Cost

The technologies described above are most often lumped together in packages to reduce energy consumption in commercial dishwashers. These technologies combined allow dishwashers to achieve the ENERGY STAR® targets. The ENERGY STAR® calculator documents high efficiency models and their potential; thus, we used calculator to obtain incremental cost, energy savings, and payback period. Table 4-22 summarizes these figures. The ENERGY STAR® calculator documents door type, undercounter, and conveyor dishwashers, but does not estimate savings for flight-type dishwashers. The customized nature of flight-type dishwashers leads to uncertainty in the energy savings that can be achieved from high-efficiency dishwasher technologies. Thus, we do not include energy-savings estimates for flight-type dishwashers in our analysis.

Table 4-22: High Efficiency Dishwasher Energy Savings and Cost, 2008

High Efficiency Appliance Type	Incremental Cost	Percent Energy Savings	Payback Period (years)
Undercounter LT	$1,000	11%	7-10
Undercounter HT	$1,000	40%	1-2
Door-type LT	$2,000	36%	1.5-2.5
Door-type HT	$2,100	33%	1.5-2.6
Conveyor LT	$3,000-4,000	30%	2-4
Conveyor HT	$3,000-4,000	30%	1.5-2.5
Source: EPA 2009b			

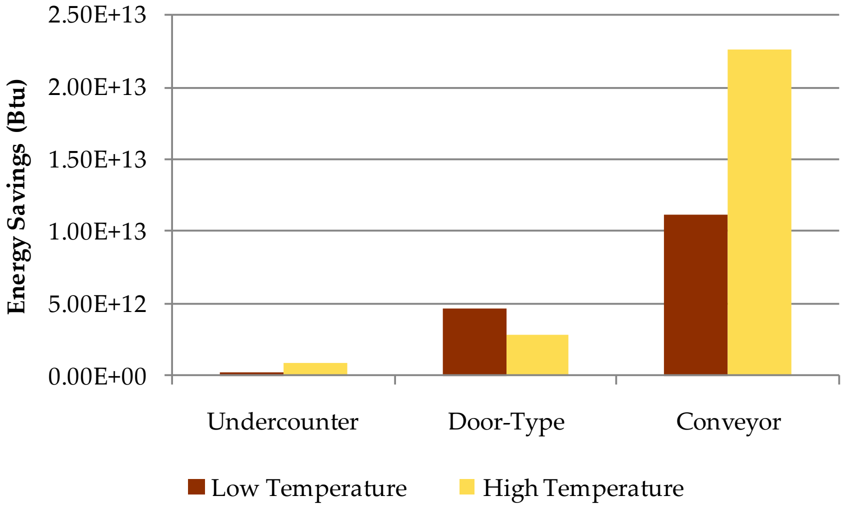
Technical Potential

Table 4-23 and Figure 4-16 estimate the technical potential of high efficiency dishwashers. These estimates are made using the total energy consumption from Table 4-15 and the energy savings estimates from Table 4-22.

Table 4-23: High Efficiency Dishwasher Technical Potential, 2008

	Technical Potential (Btu)	
Washer Type	**Low Temperature**	**High Temperature**
Undercounter	2.99E+11	9.51E+11
Door-Type	4.63E+12	2.85E+12
Conveyor	1.12E+13	2.26E+13
Technical Potential = Annual energy consumption (Table 4-15) x percent energy savings (Table 4-22)		

Figure 4-16: Technical Potential of High Efficiency Dishwashers, 2008

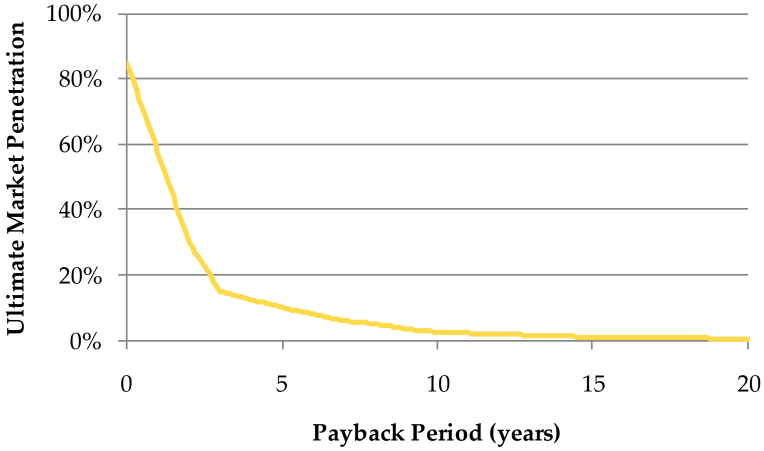


Source: Table 4-23

Achievable Potential

The achievable potential is estimated correlating the technology payback to the ultimate market penetration. This correlation is made by using a payback acceptance curve that estimates the market penetration of a commercial energy efficiency technology based on its payback. The payback acceptance curve is depicted in Figure 4-17 below. Market penetration for high efficiency dishwashers are estimated in Table 4-24.

Figure 4-17: Payback Acceptance Curve of Commercial Energy Efficiency Technologies



Source: ADL 1995

Table 4-24: High Efficiency Dishwasher Projected Market Penetration

High Efficiency Appliance Type	Payback Period Range (years)[a]	Average Payback Period (years)[b]	Market Penetration[c]
Undercounter LT	7-10	8.5	4%
Undercounter HT	1-2	1.5	44%
Door-type LT	1.5-2.5	2.0	30%
Door-type HT	1.5-2.6	2.0	30%
Conveyor LT	2-4	3.0	15%
Conveyor HT	1.5-2.5	2.0	30%

a) Source: Table 4-22
b) Average or Payback Period Range
c) Calculated using Average Payback Period and Figure 4-17

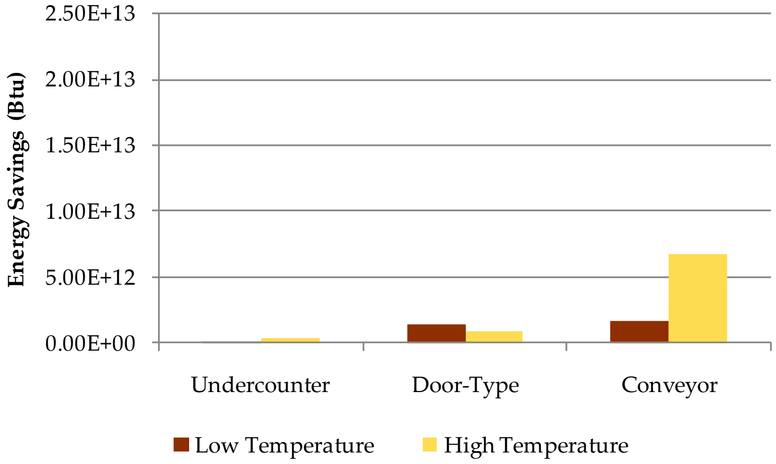
Achievable potential is presented in Table 4-25, Figure 4-18, and Figure 4-19.

Table 4-25: High Efficiency Dishwasher Achievable Potential, 2008

	Achievable Potential (Btu)	
Washer Type	Low Temperature	High Temperature
Undercounter	1.27E+10	4.16E+11
Door-Type	1.39E+12	8.55E+11
Conveyor	1.67E+12	6.77E+12

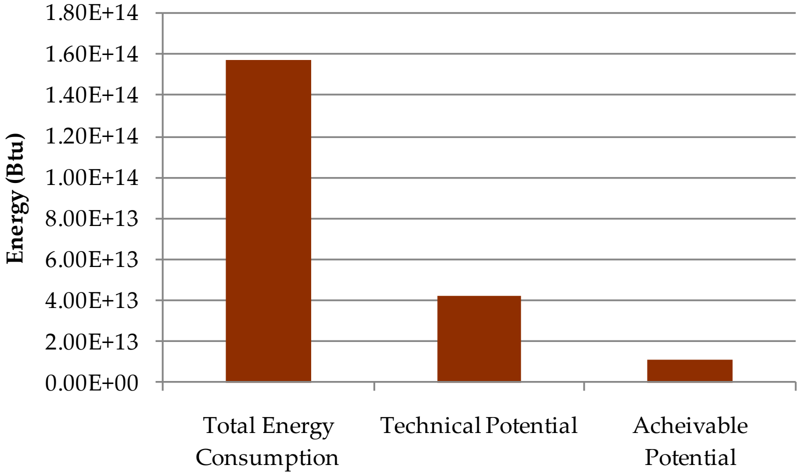
Achievable Potential = Technical Potential (Figure 4-16) x Market Penetration (Table 4-24)

Figure 4-18: Achievable Potential of High Efficiency Dishwashers, 2008



Source: Table 4-25

Figure 4-19: Comparison of Energy Consumption and Potentials, 2008



Source: Table 4-16, Table 4-23, and Table 4-25

4.11.3 Research and Development Technologies

While several options to reduce energy consumption are market-ready, we have identified one technology for research and development. This is "Waterless Dishwashing" using supercritical carbon dioxide.

Carbon dioxide can reach its supercritical state at a temperature above 88°F (critical temperature) and a pressure above 1070 psi (critical pressure). Supercritical CO_2 has a very low surface tension and can dissolve oils and grease. Using supercritical CO_2 in the dishwashing process will remove the need to use water and detergent, thus removing the need to heat water. This technology aims to reduce the 0.125 Quads per year used to heat water for commercial dishwashers. However, this technology may require additional energy to compress CO_2 to significant pressures and minimally heat it to its critical temperature.

A project team at the University of New South Wales conceptualized a residential sized unit in 2004 as part of a design competition sponsored by Electrolux. However, a fully working model was not built and no analysis of energy consumption or savings was performed. The use of supercritical CO_2 as a cleaning agent also has applications in dry-cleaning and medical sanitization; however no products are commercially available.

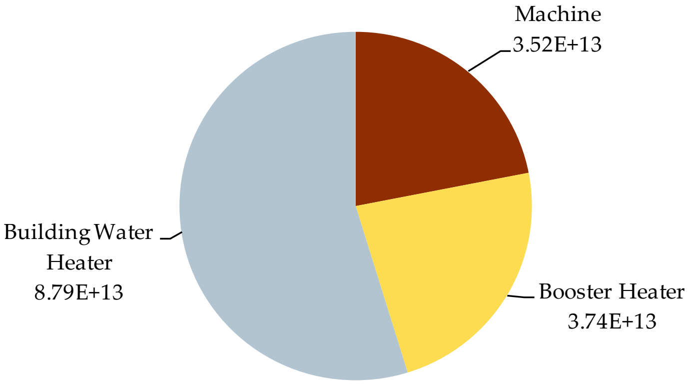
4.12 Peak-Demand Considerations

Commercial dishwashing equipment usually runs during an 8-14 hour window during and after meal serving times in food service establishments. Heavy dishwasher use usually occurs during and after meal serving times and can occur during peak electric demand periods at midday and early afternoon. There is no published information available on the detailed power use profile of commercial dishwashers.

Energy attributed to dishwasher use is broken up into machine, booster heater, and building water heater (see

Figure **4-20**). Some high efficiency dishwashing technologies can reduce peak consumption attributed to each component. However, no research is available on how these effects combine and their relative magnitudes.

Figure 4-20: Energy Consumption by Component (in Btu)



Source: Table 4-16

Machine peak draw occurs from motors and electric resistive heaters used to keep hot water at the required temperatures. Insulation of the machine can reduce the peak power consumption by resistive heaters as heat input would be needed to maintain water temperatures. Reduction in water needs can reduce pump sizes; smaller horsepower motors draw less peak power.

Ninety five percent of the installed booster water heaters are electric. High-efficiency electric booster heaters may have the potential to decrease peak power, though they were not discussed above due to their relatively low energy savings.

Building water-heating energy accounts for the majority of energy attributed to dishwashers. Technologies to reduce water use may decrease peak demand, but this is highly dependent on the water heater and building characteristics. Refer to Section 6 for more on peak-demand considerations for water heaters.

5 IT and Office Equipment

5.1 General Overview

Information technology (IT) and office equipment covers wide range of machines and peripheral equipment that supports daily business operations. We identify major equipment types in Table 5-1.

Table 5-1: IT/Office Equipment Technology Types and Descriptions

Major Equipment Types	Descriptions	Equipment Types Covered
Personal Computers (PCs)	Computers intended for regular use by an individual or individuals	Desktop and laptop computers
Desktop Monitors	Standalone monitor display auxiliary to a PC unit.	LCD and CRT monitors
Server Computers	High-capacity computers dedicated to support a network computing environment	N/A
Imaging Equipment	Devices used to print, copy or electronically transmit images	Multifunction devices (MFDs), printers, fax machines and scanners
UPS Systems	Back-up power supply to improve the quality and reliability of power supply	Stand-by, line-interactive and double conversion UPS systems
Network Equipment	Devices that control data flow within and among different IT networks	LAN switches, WAN switches and routers
Other Miscellaneous Equipment	Other devices that do not fall into the categories above	Electronic typewriters, voice mail systems and smart handheld devices

This report does not address telecommunication equipment, since most such equipment, much like utility infrastructure equipment, resides outside of commercial buildings to support broad infrastructure operations.

Table 5-2 and Figure 5-1 present the breakdown of IT and office equipment unit energy consumption (UEC) and annual energy consumption (AEC) by equipment type. The following sections discuss the derivation of these values in detail.

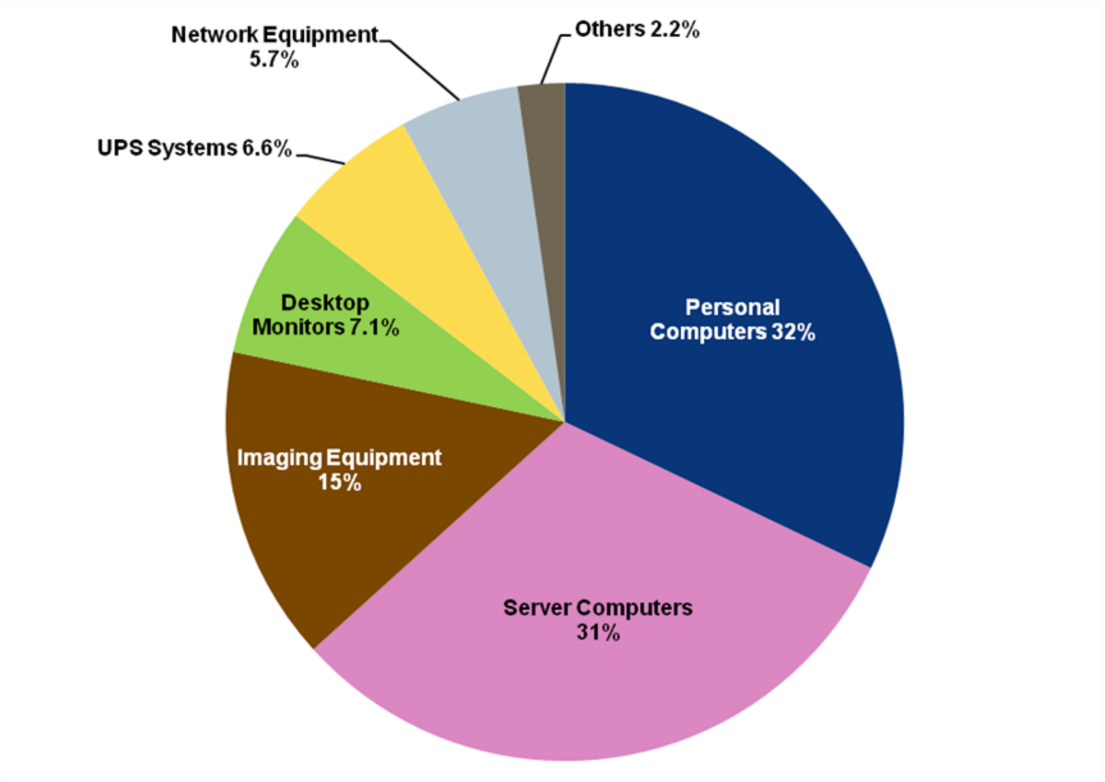
Table 5-2: Current IT/Office Equipment Energy Consumption Summary

Equipment Types	Average UEC (kWh/yr, range in paren.)	Installed Base (1,000s)	AEC—Site Energy (TWh/yr)	AEC—Primary Energy[a] (TBtu)
Personal Computers	290	108,000	32	328
Desktop PCs	*500*	*60,381*	*30*	*314*
Laptop PCs	*28*	*47,619*	*1.3*	*14*
Desktop Monitors	110	64,787	7	73
LCD Monitors	*84*	*51,283*	*4.3*	*45*
CRT Monitors	*200*	*13,504*	*2.7*	*28*
Server Computers	2,300 (2,100 - 81,000)	13,152	31	319
Imaging Equipment	470	59,551	13	138
Multifunction Devices	*890* *(510 - 2,000)*	*8,563*	*7.6*	*79*
Laser Printer	*440* *(330 - 550)*	*6,817*	*3*	*31*
Fax Machines	*320*	*16,124*	*1.1*	*11*
Inkjet Printers	*44*	*12,848*	*0.57*	*5.9*
Scanners	*37*	*12,265*	*0.46*	*4.8*
Impact Printers	*120*	*2,934*	*0.36*	*3.7*
Other Printers	*N/A*	*N/A*	*0.18*	*1.9*
UPS Systems	440,000	15	6.5	68
Stand-By	*130,000*	*9*	*1.2*	*12*
Line Interactive	*160,000*	*4*	*0.7*	*7.3*
Double Conversion	*3,700,000*	*1*	*4.6*	*48*
Network Equipment	N/A	N/A	5.6	58
Other Misc. Loads	N/A	N/A	2.2	23
Total	**N/A**	**N/A**	**97**	**1,010**

Note: Numbers do not add up due to rounding.

a. Site-to-source conversion based on 10,405 Btu/kWh based on US DOE (2008).

Figure 5-1: Percentage Breakdown of IT and Office Equipment Primary Energy Consumption by Major Equipment Type, 2008



Total Primary Energy AEC = 1,010 TBtu/yr = 1.01 Quad/yr

5.1.1 Personal Computers

Personal computers (PCs) are computers intended for direct operation by an individual end-user. In commercial buildings, PCs come in two forms, desktop PCs, which are designed for regular use at a single location (see Figure 5-2), and laptop PCs, which are designed for mobile use (see Figure 5-3). A typical desktop today comes either in a vertical chassis (or tower case), or integrated with monitor display. A typical laptop is in a shape of a notebook, and is compact enough to be used on the user's lap.

Figure 5-2: HP RP5700 Desktop Computers (with auxiliary equipment)

Source: can de Meer (2007)

Figure 5-3: Everex StepNote C1500 Laptop Computer

Source: Thomas (2006)

There are five major components that draw power within a typical commercial PC:

- Central processing unit (CPU), which is an electronic circuit that execute computing programs and functions;
- Random access memory storage (RAM) that allows the stored data to be accessed at any order;
- Hard disk drive;
- optical drive; and
- Ethernet network card.

In addition, laptop PCs include a built-in LCD monitor display. A desktop PC requires a separate monitor display unit as peripheral equipment; in this report, we consider the energy consumption characteristics of these auxiliary monitor display units separately.

5.1.2 Desktop Monitors

A computer monitor is a peripheral visual display unit for a personal computer. It consists of the display that presents a visual image to the user and the circuitry that transmits and converts an electric signal from the computer to the display into a visual image. Although older computer monitors are based around a cathode ray tube (CRT), most models today have a flat-panel liquid crystal display (LCD) screens. In this section, we discuss standalone desktop monitor displays intended to be used as peripheral equipment, and do not consider the built-in monitors for laptop PCs.

5.1.3 Server Computers

Server computers are high-capacity computers that provide services to other PCs and network devices that are interconnected in a network environment. Typical services include running multiple software applications and hosting shared information within the network. Server computers are found either within an office building, typically in a dedicated room with or without a dedicated cooling system, or in a data center, which is a building dedicated to housing a fleet of server computers. Figure 5-4 shows server racks in one of Google’s data centers.

Figure 5-4: Server Racks in a Data Center

Source: Chan (2007)

5.1.4 Imaging Equipment

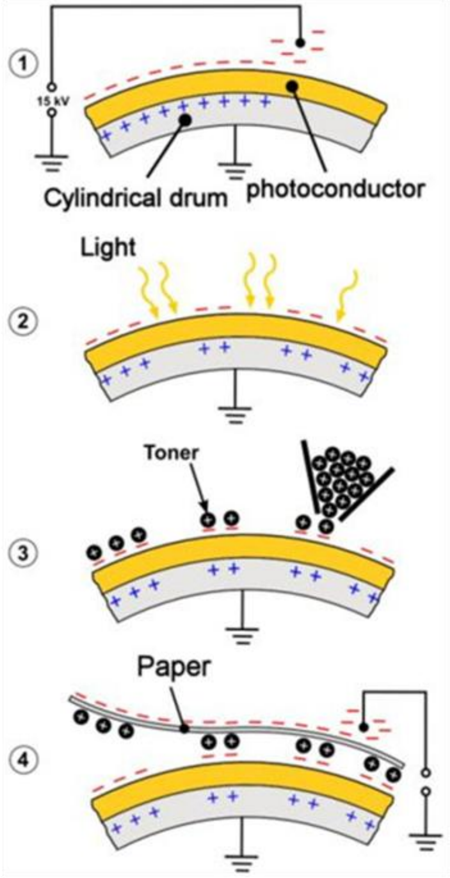
Imaging equipment are office machines that produce a permanent reproduction of electronic or hard-copy documents. Commercial buildings in the US today typically utilize various types of imaging equipment to print, duplicate, scan, and electronically send images. In this report, we focus our analysis of imaging equipment energy consumption on the three most popular types of commercial imaging equipment: multifunction devices (MFDs), laser printers, and inkjet printers.

All laser printers and most MFDs – two equipment types that account for over 80% of the total imaging equipment energy consumption combined (see Section 5.6.4 for more details) – employ electrostatic or xerographic imaging to put an image onto paper. The mechanism of xerography process is presented in Figure 5-5.

Laser printing works in a fashion similar to photocopiers. Instead of illuminating a document, the laser system inside a laser printer or an MFD receives electronic data from the terminal where the document is saved (e.g. a PC), and emits a pulse of light onto the drum to create a photoelectric image.

To bond the toner to the paper, the fusing temperature can be as high as 400° F during printing. More importantly, the fuser rollers must remain at high temperatures while idle to avoid delays in response to a print request while heating up. According to Riso (2009a), energy consumption associated with the managing fusing temperature accounts for approximately 60% of the total energy consumption of a typical xerography machine, because of is high heat requirement during the final fusing process.

Figure 5-5: Xerographic Photocopy Process



1) A photocopier has a cylindrical drum with photoconductive coating that will retain the image in static electricity on its surface for each reproduction. First, the surface of the drum becomes electrostatically charged.

2) Once the document to be reproduced is fed into the machine, a bright light illuminates the document. The light is then reflected from white areas of the document onto the drum. Photoconductive coating on the drum discharges the positive charge on the areas of the drum exposed to the reflected light.

3) Positively charged, dry paint pigment called toner is then spread over the surface of the drum, and the pigment particles is attracted and stick to the positive charges that remain in the areas of the drum not exposed to the reflected light.

4) A negatively charged sheet of paper then passes over the surface of the drum, attracting the toner pigments away from the drum. The paper is then heated and pressed as it travels through hot fuser rollers to melt and bond the toner pigments unto the paper's surface.

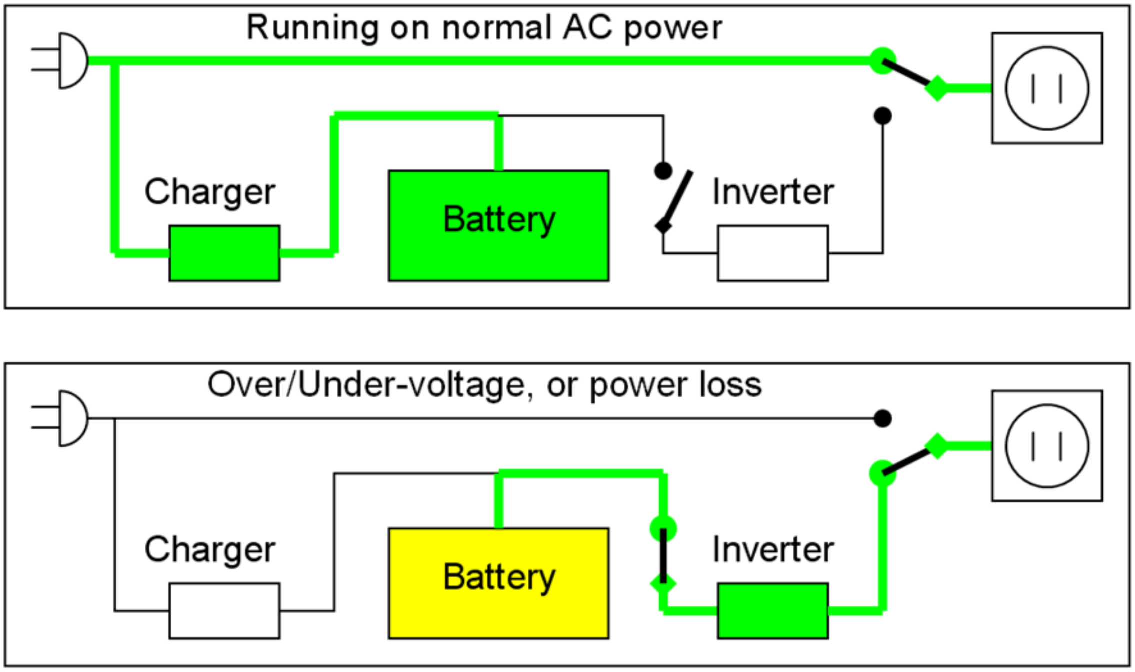
Image Source: Wikimedia Commons (2007)

5.1.5 Uninterruptible Power Supply

An uninterruptible power supply (UPS) system provides backup power in an emergency situation. The purpose of an UPS system is not to act as an auxiliary power unit. Rather, it is intended to protect devices that require high power quality from a momentary power interruptions or fluctuations, such as voltage surges, voltage sags, power failures and other power quality and reliability shortcomings.

There are three major types of UPS systems in use for commercial applications today: Standby, Line-Interactive, and Double Conversion systems. Standby UPS, or sometimes referred to as online UPS, is the oldest UPS system and offers the most basic features. A standby UPS typically offer no capabilities beyond standing by in case of power supply disruption. While the main power supply is deemed acceptable, the standby UPS system allows the connected load to draw power from the main supply, while drawing a small amount of power itself to keep the batteries charged. Without self monitoring or self-testing capability, a standby UPS is less reliable than other UPS system topology alternatives. Figure 5-6 shows standby UPS system schematics.

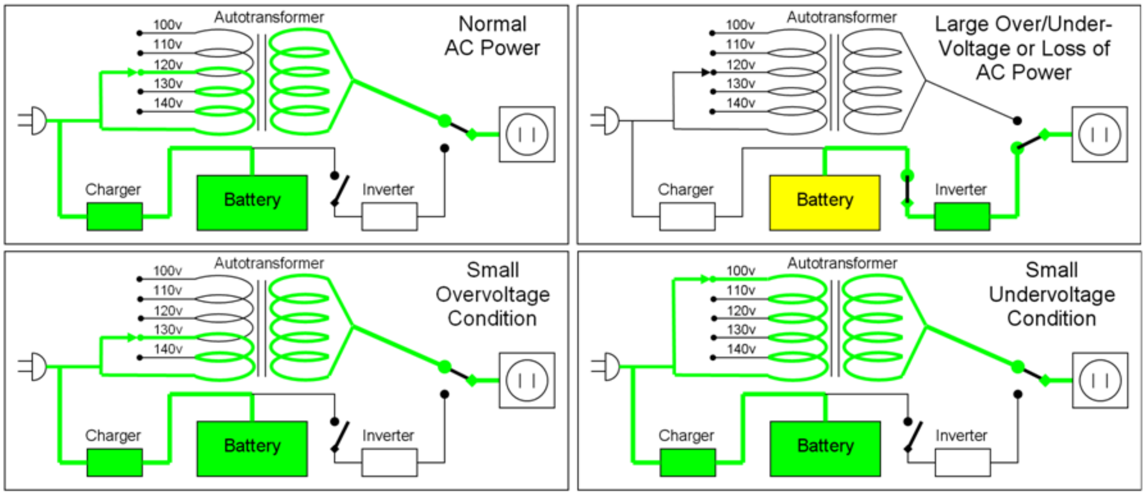
Figure 5-6: Standby UPS System Schematics



Source: Wikimedia Commons (2008a)

A line-interactive UPS system operates in a fashion similar to a standby UPS, but is also capable to condition power from the main power supply. A line-interactive UPS system accomplishes this by interacting with the incoming utility electricity using a variable-voltage autotransformer, which allows the system to adjust the output voltage of the transformer to an appropriate level. This type of UPS system can compensate extended undervoltage or overvoltage episodes from the utility power without consuming the reserve battery power. Figure 5-7 presents a visual summary of line-interactive UPS system schematics.

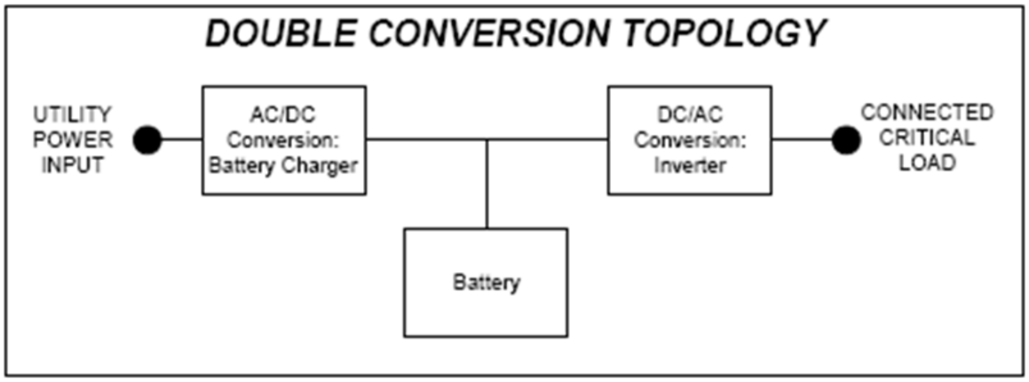
Figure 5-7: Line-Interactive UPS System Schematics



Source: Wikimedia Commons (2008a)

A double-conversion UPS system is designed to protect sensitive loads from unconditioned utility power supply by always controlling the output voltage and frequency regardless of input voltage and frequency. As the name suggests, a double-conversion system converts unconditioned utility power twice: from AC to DC, and then back to AC, which will be highly conditioned. Since double-conversion UPS systems provide highly conditioned AC power, they are common in industrial or data center settings, where high power quality is essential. Figure 5-8 shows double-conversion UPS system schematics.

Figure 5-8: Double-Conversion UPS Systems Schematics



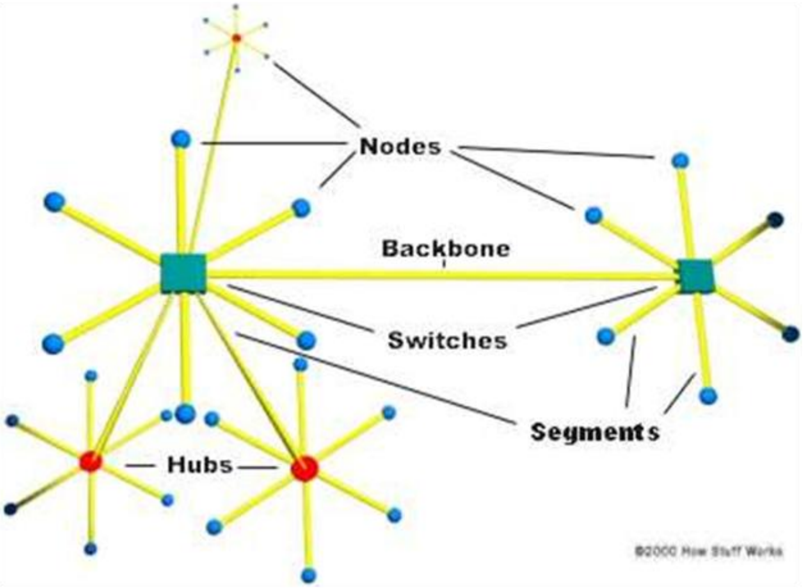
Source: Ton, et. al. (2005)

5.1.6 Network Equipment

An IT network employs a range of equipment to connect and manage the communications among the interconnected devices. In this report, we cover three major equipment groups: LAN switches, WAN switches, and routers.

According to Cisco (2003), a Local area network (LAN) is a high-speed data network that covers a relatively small geographic area. It typically connects workstations, personal computers, printers, servers, and other devices. Figure 5-9 graphically presents the general scheme of a typical LAN system.

Figure 5-9: Typical LAN Topology Switches and Hubs



Source: Tyson (2001)

In the figure above, "nodes" are devices that are interconnected to a LAN, which typically include PCs and imaging equipment. The communication among these different nodes is managed by LAN gears. Figure 5-9 shows two types of LAN gears: switches and hubs. LAN switches (sample graphic shown in Source: Tolly (2008)
) were introduced to the market in the 1990s as a more flexible and faster alternative to network hubs (Tyson, 2001; Metzler, 2008). With the price for LAN switches dropping, hubs are now obsolete, and have almost completely been phased out in corporate IT network settings (Davis, 2009).

Routers provide an additional level of control over network communication. A router's functions include examining, filtering and transmitting data packets to ensure appropriate data is sent to appropriate recipients (Tyson, 2001).

Finally, a Wide Area Network (WAN) is a data communications network that covers a relatively broad geographic area and that often uses transmission facilities provided by common carriers, such as telephone companies (Cisco, 2003). In a fashion similar to LAN switches and hubs (see Figure 5-10), WAN switches manage the communication among different networks interconnected to WAN.

Figure 5-10: Nortel BES50GE-24T PWR LAN Switch

Source: Tolly (2008)

5.2 Manufacturers and Market Shares

5.2.1 Personal Computers

Hewlett-Packard (HP), Dell, Acer, Apple and Toshiba are the top five computer manufacturers in the US PC market[11] today, according to Gartner estimates as cited by Gartner (2007a), Gartner (2007b), Gartner (2007c), Gartner (2007d), Marsal (2008), AppleInsider (2008), Malley (2008), Jade (2009), Gartner (2009) and Marsal, et. al. (2009). Dell and HP are the two biggest manufacturers, and account for nearly 55% of the US market every quarter (for both residential and commercial applications). Dell's market share, however, has declined since 2006. Dell was the top PC manufacturer in the US and claimed nearly 34% of the market in 1Q 2006, but its market share diminished to 26% and surrendered its top position to HP in 1Q 2009. Quarterly US PC market share data from 2006 through the first quarter of 2009 are presented in Figure 5-11.

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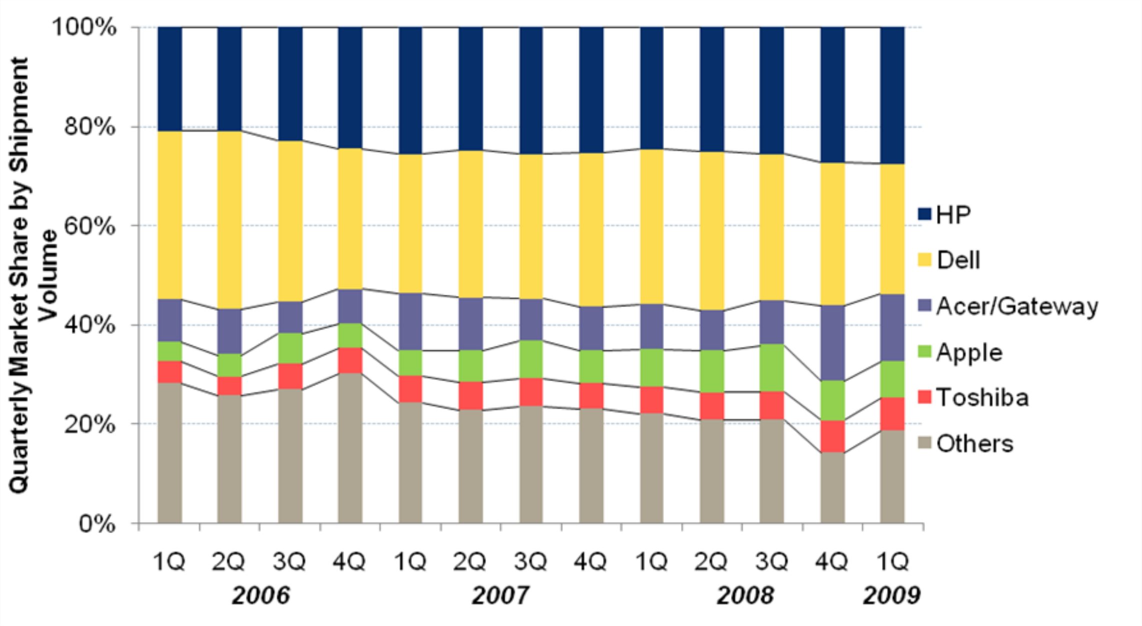
[11] Residential and commercial markets combined.

Figure 5-11: Historical US PC Market Share Breakdown by Shipment Volume, 1Q 2006 through 1Q 2009

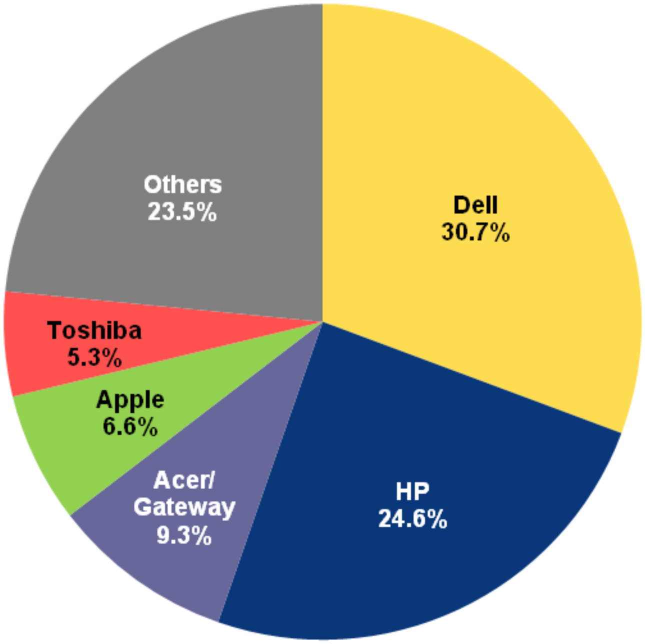


Data Source: Gartner data cited by Gartner (2007a), Gartner (2007b), Gartner (2007c), Gartner (2007d), Marsal (2008), AppleInsider (2008), Malley (2008), Jade (2009), Gartner (2009) and Marsal, et. al. (2009)

Note: The data include sales to residential market.

The top five PC manufacturers dominate the US PC market. HP, Dell, Acer, Apple and Toshiba combined accounted for over 85% of the market share in Q4 2008, and, as shown in Figure 5-12, have shipped over 75% of the PCs sold in the US since 2006. Other smaller players in the US PC market have seen decline in their combined shipment volume and market share since the beginning of 2006 (see Figure 5-13), and now claims less than 20% of the market share of as Q1 2009.

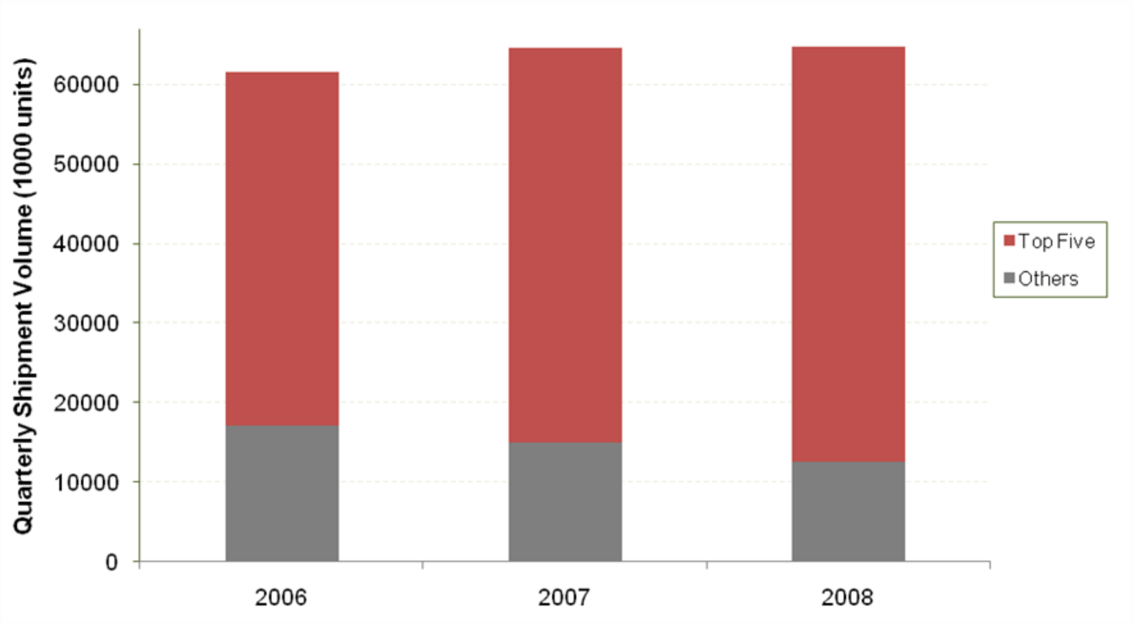
Figure 5-12: US PC Market Share by Total Shipment Volume, January 2006 through March 2009



Data Source: Gartner data cited by Gartner (2007a), Gartner (2007b), Gartner (2007c), Gartner (2007d), Marsal (2008), AppleInsider (2008), Malley (2008), Jade (2009), Gartner (2009) and Marsal, et. al. (2009)

Note: The data includes sales to residential market.

Figure 5-13: Annual US Shipment Volumes of the Top Five PC Manufacturers vs. Other Manufacturers, 2006 through 2008

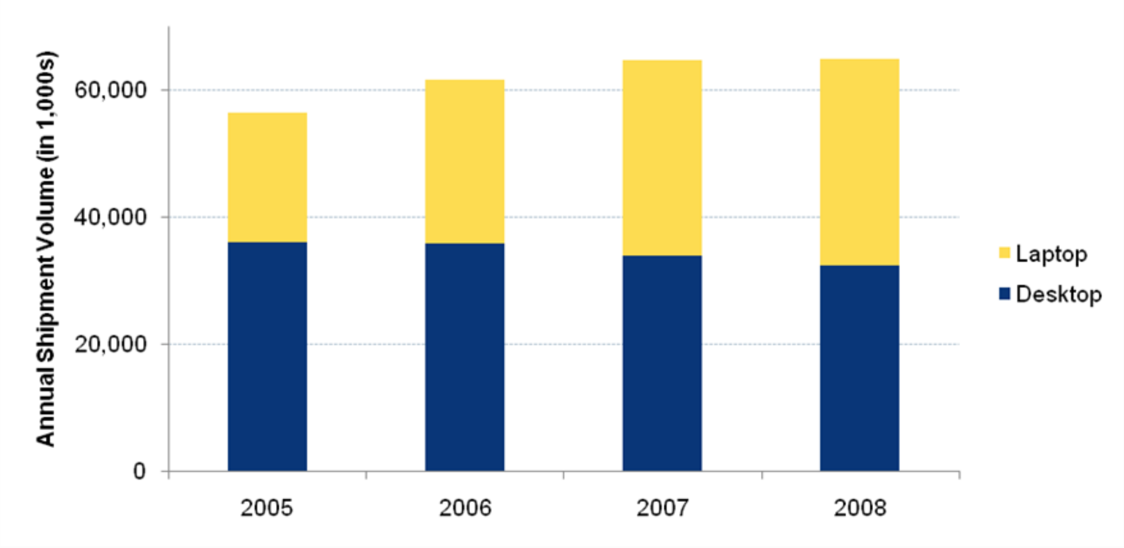


Data Source: Gartner data cited by Gartner (2007a), Gartner (2007b), Gartner (2007c), Gartner (2007d), Marsal (2008), AppleInsider (2008), Malley (2008), Jade (2009), Gartner (2009) and Marsal, et. al. (2009)

Note: The data includes sales to residential market.

In terms of market share breakdown between desktop and laptop PCs (for residential and commercial markets combined), the consumer preference has in recent years begun to trend much moretoward laptop PCs (see Figure 5-14).

Figure 5-14: Market Breakdown of Desktops versus Laptop PC Shipment Volumes, 2005-2008



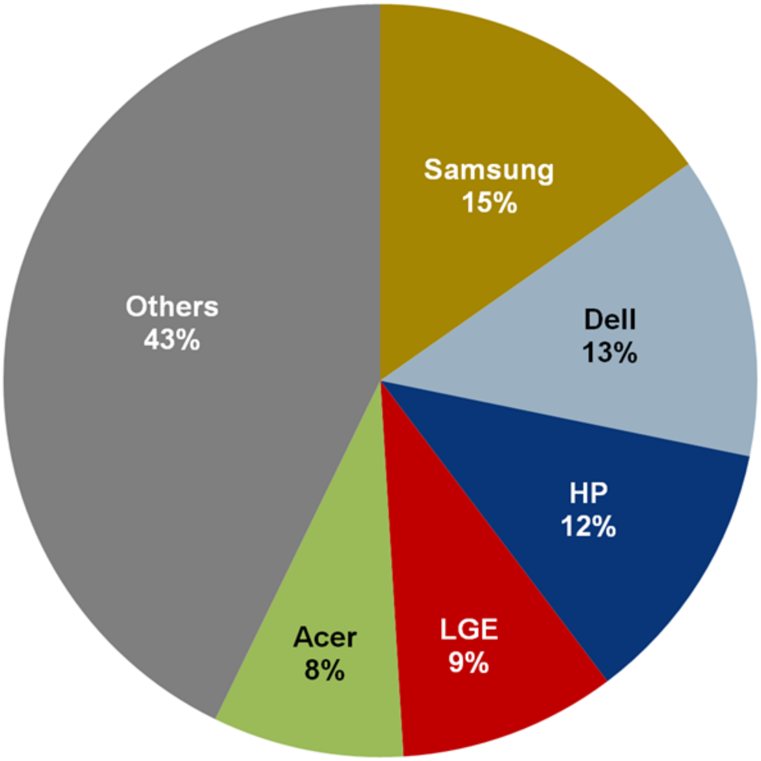
Data Source: Gartner data cited by Gartner (2007a), Gartner (2007b), Gartner (2007c), Gartner (2007d), Marsal (2008), AppleInsider (2008), Malley (2008), Jade (2009), Gartner (2009) and Marsal, et. al. (2009)

Note: The data includes sales to residential market.

5.2.2 Desktop Monitors

As of 2008, the four leading manufacturers of computer monitors include Samsung, Dell, HP, LG Electric and Acer. According to data provided by DisplaySearch (2009a), an IT market research firm, these five manufacturers claimed nearly 60% of the global market share in the latter half of 2008 (See Figure 5-15).

Figure 5-15: Q3/Q4 Worldwide Desktop Monitor Market Share, 2008



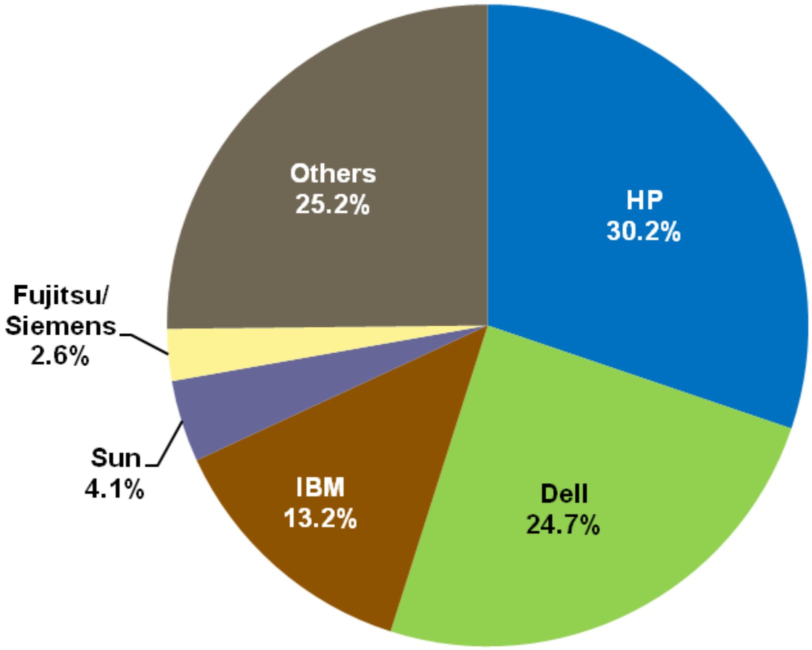
Data Source: DisplaySearch (2009a)

Note: The data includes sales to residential market.

5.2.3 Server Computers

According to Hruska (2008b) and Gonsalves (2008), the top five server computer manufacturers are HP, Dell, IBM, Sun Microsystems and Fujitsu Technology Solutions (formerly Fujitsu Siemens Computers), based on their global shipment volume. As presented in Figure 5-16, these five manufacturers account for approximately 75% of the total worldwide server computer market.

Figure 5-16: Worldwide Server Computer Market Share by Shipping Volume, Q2 2008



Source: Hruska (2008b)

5.2.4 Imaging Equipment

According to Global Industry Analyst (2008), the share leaders in the US imaging equipment market include, in no particular order, HP, Canon, Xerox, Dell, Konica-Minolta, Brothers, and Ricoh. HP is the market share leader for printers and MFDs, with 46% share as of Q1 2008, according to Rutherford (2008). Dixon, et. al. (2008) of Gartner evaluates major printer manufacturers in the US based on two criteria: their *completeness of vision*[12] and their *ability to execute* or capitalize on their vision[13]. They conclude that based on known strength and weaknesses associated with different imaging equipment manufacturers, Xerox, HP, Ricoh and Canon will be the leaders in the imaging industry in the foreseeable future.

The imaging equipment market has trended toward integration of manufacturing, retailing and servicing to follow the trend that has now become a norm for the personal computer industry. Manufacturers that have acquired new distribution channels by merging with a distributor that caters to large and medium-sized businesses are expected to excel in the industry going

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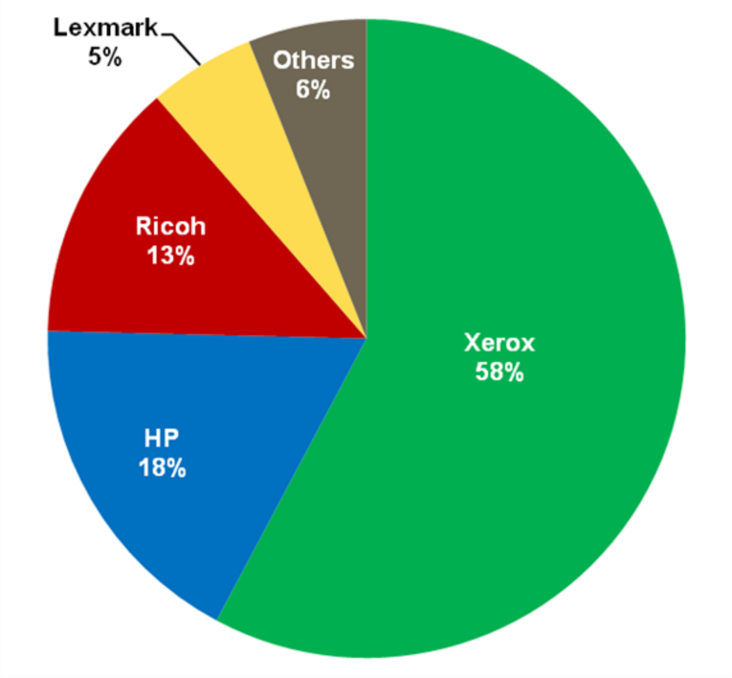
[12] Dixson, et. al. (2008) defines this as the manufacturer's "understanding of how market forces can be exploited to create opportunity for the provider and for its clients."

[13] Dixson et. al. (2008) defines this as "the quality and efficacy of the [manufacturer's] processes, systems, methods and procedures that enable their products' performance to be competitive, efficient and effective, and to positively impact revenue, retention and reputation."

forward. For instance, Layne (2008) reports that Ricoh's merger with Ikon Office Solutions is expected to adversely impact Canon, which represented 60% of all imaging equipment handled by Ikon Office Solutions at the time of the acquisition.

Emergence of managed print service (MPS) is another market trend that has recently become apparent within the imaging equipment industry. MPS is a service offered by an external service provider to manage, control and optimize an organization's imaging and reproduction output. It typically involves outsourcing maintenance, monitoring and servicing, and often includes focused support to meet business objectives such as cost reduction, efficiency improvement and reduce internal IT workload (Weilerstein, et. al., 2008). The MPS market is growing rapidly; Photizo, a market research firm, estimates revenue from MPS to grow 36% between 2008 and 2009 to $15.7 billion (Bulkeley, 2009). As Figure 5-17 indicates, Xerox dominates the MPS market according to Drew, et. al. (2008).

Figure 5-17: US Managed Print Service Market Share by Revenue, 2007



Source: Drew, et. al. (2008)

5.2.5 Uninterruptible Power Supplies

The power supply industry is a fairly consolidated market, especially in the UPS subsector, according to Mankikar (2007). Schneider Electronic leads the market with approximately 50% market share as of 2007, with Emerson and Eaton following suit. These three market leaders account for more than 80% of the market share combined. The UPS market continues to trend toward further consolidation, with further attempts by the market leaders to acquire smaller niche players in the market (Miller, 2008).

5.2.6 *Network Equipment*

Cisco is the incumbent market leader in the IT network equipment area today, accounting for over 60% of global router and LAN equipment according to estimates by Dittberner and Gartner (Dittberner, 2008; Malykhina, 2007). However, the rate of their revenue growth (Dittberner, 2008) and their aggressive patent management (Thomson, 2009) suggest that Huawei Technologies is the fastest-growing company in this market today. Other major players in this market include, in no particular order, Nortel, Juniper Networks, Alcatel-Lucent and Ericsson, according to Dittberner (2008) and Nortel (2006).

5.3 *Major Users*

Data suggest that IT and office equipment are extremely prevalent in the commercial sector. For instance, personal computers may be near market saturation, if we assume the commercial sector saturation limit of personal-use IT device equals one device per employee. Based on the PC installed base estimate by 1E (2009) and employment statistics provided by US BLS (2009), we estimate that there is one computer available for every 1.3 employed persons in the US as of 2008.

Desktop monitors, which are required peripheral equipment to operate desktop PCs, have also achieved a similar level of deep market penetration within the commercial sector. In addition to their use with desktop units, stand-alone desktop monitors are used as an auxiliary display unit for laptop units to improve worker productivity.

Users typically do not use server computers directly; rather, multiple users (within a business organization and beyond) leverage the computing capability of server computers. While some server computers reside in office building settings, many higher capacity units are housed in dedicated facilities, such as data centers.

Various single-function and multifunction imaging devices are prevalent in the US commercial sector today. They are typically used for printing, copying and scanning purposes. Some niche devices may be found in particular types of businesses (e.g., impact printers at rental car service locations, or thermal printer attached to cash registers at grocery stores) as well.

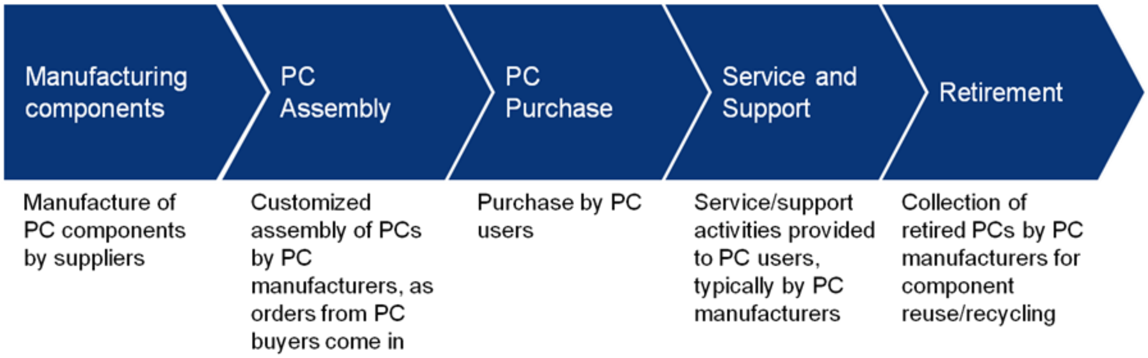
UPS systems are used for various commercial applications. Smaller UPS units (with output power smaller than 1kVA) are typically used to back up smaller IT equipment such as personal computers to allow safe shut-down. Larger UPS systems are used to protect critical loads or electronic equipment, such as server computers, industrial loads, health service equipment and telecommunication equipment.

Network equipment, much like server computers, does not lend itself to exclusive use by individual end users. Network equipment supports smooth and effective use of IT and office equipment by providing integral support for the communication infrastructure that interconnects different devices.

5.4 *Typical Distribution Chain*

Distribution chains for IT and office equipment are trending toward vertical integration from manufacturing and retail through retirement of the equipment. At the forefront of this trend is the PC industry, where customers typically deal directly manufacturers throughout the equipment lifetime. This holds true in commercial sector as well, where a company's IT department interfaces directly with PC manufacturers, allowing them to purchase custom-build PC units tailored for their specific purposes. Major PC manufacturers typically provide service and support throughout the lifetime of the equipment, from custom assembly to equipment servicing through retirement of the PC units. Figure 5-18 shows the PC manufacturing value chain.

Figure 5-18: Typical Value Chain of Commercial PC Manufacturing



Modified from Thompson and Strickland (1999)

Historically, the distribution network for imaging equipment was more diverse, according to Global Industry Analyst (2008), with three major distribution channels for the imaging equipment industry: contract distribution, direct marketing and retail. Contract distributors cater to large and medium-sized businesses, where as direct marketers and retailers focus on supplying to home office and residential customers. Major contract distributors also provide equipment support and maintenance service to the purchasers as well.

However, the distribution network in imaging equipment industry is trending toward integration as well, where all major contract distributors in the industry are now subsidiaries of manufacturers. The latest manufacturer-distributor merger occurred in August of 2008, when Ricoh purchased IKON Office Solutions (MacIntosh, 2008). Dentch (2008) reports that IKON was the last of the three major imaging equipment distributors and service providers to be bought up by a manufacturer, following Global Imaging Systems (by Xerox) and the US unit of Danka Business Systems (by Konika-Minolta).

5.5 Installed Base

5.5.1 *Personal Computers*

We calculated the total installed base for commercial desktop computers based on estimated total computer stock in commercial buildings (from 1E, 2009). We then segregated the desktop PC installed base from the laptop PC installed base based on the shipment volumes of desktop and laptop PCs over the last four years[14]. Table 5-3 presents the installed base calculation for commercial PCs.

Table 5-3: Commercial PC Installed Base Calculation

Stock Segregation Calculation	Value	Source
Total Commercial Computer Stock, Desktop and Laptop (1,000s)	108,000	1E (2009)
% of Desktops within Existing Computer Stock, Comm. and Res. Sectors	56%	See Table D-9 in Appendix D.2
% of Laptops within Existing Computer Stock, Comm. and Res. Sectors	44%	
Total Commercial Desktop Stock (1,000s)[a]	**60,381**	
Total Commercial Laptop Stock (1,000s)[a]	**47,619**	

a. Assume the percentage breakdown between desktops and laptops is consistent between commercial and residential sectors

5.5.2 *Desktop Monitors*

Roth et. al. (2002) estimates that there were approximately 62.9 million desktop computer monitors and 58.6 million desktop computers for commercial applications in 2000. We assumed that the ratio of desktop computer monitors to desktop computers in 2000 remained consistent through 2008. Table 5-4 presents the estimated installed base of desktop computer monitors in 2008.

Table 5-4: Commercial Desktop Monitor Installed Base in 2008

Data	Value (1,000s)	Source/Comments
Number of Commercial Desktop PCs, 2000	58,591	Roth et. al. (2002)
Number of Desktop Monitors, 2000	62,866	
Monitor-Desktop Ratio	1.073	Assumes that the ratio of desktop computer monitors to desktop computers in 2008 was the same as in 2000.
Number of Commercial Desktop PCs, 2008	62,583	See Table 5-3
Number of Desktop Monitors, 2008	**67,149**	

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[14] Energy Star estimates the expected useful life of a PC to be four years.

DisplaySearch estimates as cited in Business Wire (2006), Hachman (2007) and DisplaySearch (2009b) report a significant decline in the market share of CRT monitors between 2005 and 2008 (see Table 5-5). In determining the share of CRT monitors among the monitors currently in use within commercial buildings, we took the average of CRT market share figures during the four-year period between 2005 and 2008, which corresponds with expected useful life of an average desktop computer monitor.

Table 5-5: US Market Share of CRT Monitors in Shipment Volume, 2005-2008

Year	CRT Monitor Market Share	Source
2005	46%	DisplaySearch estimate as cited by Business Wire (2006)
2006	22%	NCI estimate based on Hachman (2007)[a]
2007	10%	DisplaySearch estimate as cited by Hachman (2007)
2008	5%	DisplaySearch (2009b)
Average	**21%**	
a. According to Hachman (2007), 2007 market share of CRT monitor declined by 46% compared to 2006.		

The breakdown of CRT and LCD monitors is presented in Table 5-6.

Table 5-6: Breakdown of Monitor Installed Base

	Data (1,000s)	Source
Total Monitor Installed Base	64,787	See Table 5-4
CRT Installed Base	13,504	21% of the total # of monitors (See Table 5-5)
LCD Installed Base	51,283	Calculated

5.5.3 *Server Computers*

We estimated the current installed base of server computers based on Koomey (2007) and US EPA (2007). Both reports classify server computers by their costs, a convention employed by market reports provided by IDC, an IT market research firm: volume servers cost less than $25,000 per unit, mid-range systems cost between $25,000 and $500,000 per unit, and each high-end system costs more than $500,000 per unit. The existing installed base of server computers for 2008 was estimated based on the historical data from 2000 through 2006 and installed base projection for 2010 by IDC (see Table 5-7).

Table 5-7: Year-by-Year Server Installed Base by IDC Classifications

Year	Installed base (1,000s) by Server Classification[a]				Comments
	Volume (<$25K)	Mid-range ($25K-$500K)	High-end (>$500K)	Total	
2000	4,927	663	23	5,613	IDC estimate as cited by Koomey (2007)
2001	5,907	701	23	6,631	
2002	6,768	574	23	7,365	
2003	7,578	530	21	8,129	
2004	8,658	432	23	9,113	
2005	9,897	387	22	10,306	
2006	10,597	367	21	10,985	
2007	11,641	356	19	12,017	NCI estimate (interpolated based on IDC estimates)
2008	**12,789**	**346**	**18**	**13,152**	
(2009)	14,049	336	16	14,401	
(2010)	15,434	326	15	15,775	IDC estimate as cited by US EPA (2007). Included for reference.

a. Based on IDC server classification.

5.5.4 *Imaging Equipment*

Table 5-8 presents calculations of the total commercial installed base of MFDs broken down by speed segments. MFDs, following the convention of digital photocopy machines, are categorized into seven groups, or segments, based on their printing speed. The Personal Copier (PC) segment is the lowest-end segment and includes machines with speeds between one and 12 images per minute (ipm). Segment 6 copiers are the highest-end copy machines, with speeds above 90 ipm. We referred to Roth, et. al. (2006) to estimate and segregate the residential installed base from the total installed base to estimate the commercial MFD installed base. We assumed that all residential MFDs are smaller in size and slower in speed, and thus would be distributed in the slowest speed segments.

Table 5-8: Commercial MFD Installed Base Calculation

Data	Installed Base (1,000s) by Speed Segment							Sources
	PC	1	2	3	4	5	6	
Total Installed Base	950	14,816	7,843	2,998	4,255	670	232	See Table D-33
Total Res. Installed Base	950	14,816	7,435	0	0	0	0	See Table D-36
Total Comm. Installed Base	**0**	**0**	**408**	**2,998**	**4,255**	**670**	**232**	

Table 5-9 displays the total installed base of single-function printers, broken down by residential and commercial stocks.

Table 5-9: Commercial Single-Function Printer Installed Base Calculation

Data	Installed Base (1,000s) by Printer Type				Source
	Inkjet	Laser (Color)	Laser (B/W)	Impact	
Total Installed Base	75,848	6,562	7,372	2,934	See Table D-28 in Appendix D.5
Residential Installed Base	63,000	3,351	3,765	0	See Table D-35 and Table D-36 in Appendix D.7
Commercial Installed Base	**12,848**	**3,210**	**3,607**	**2,934**	

5.5.5 *Uninterruptible Power Supplies*

Table 5-10 and Table 5-11 present installed base data for UPS systems by type and assumed output power rating.

Table 5-10: Estimated Installed Base of Data Center UPS Systems by Assumed Output Power Range

UPS Types	Installed Base (1,000s) by Range of Nameplate Rating[a b]					
	5.1-20	21-50	51-100	101-200	201-500	>500
Standby	0	0	0	0	0	0
Line-Interactive	142.5	0	0	0	0	0
Double Conversion	92.25	40.68	24.42	13.35	7.728	3.329

a. Range of nameplate rating is expressed in kVA.
b. See Table D-41 and Table D-42 in Appendix D.9 for detailed calculation.

Table 5-11: Estimated Installed Base of Non-Data Center UPS Systems by Assumed Output Power Range

UPS Types	Installed Base (1,000s) by the Range of Nameplate Rating[a b]			
	<0.5	0.5-0.9	1.0-2.9	3.0-5.0
Standby	8,984	0	0	0
Line-Interactive	300.8	2,825	1,007	166.0
Double Conversion	164.7	639.0	229.7	57.96

a. Range of nameplate rating is expressed in kVA.
b. See Table D-43 and Table D-44 in Appendix D.9 for detailed calculation.

5.5.6 *Network Equipment*

Table 5-12 presents our LAN gear installed base calculation.

Table 5-12: LAN Switch Installed Base Calculation (in terms of number of ports)

Data	Installed Base (1,000s)	Source
LAN Switch and Hub Installed Base (# ports), 2000	188,500	Roth, et. al. (2002)
Number of Interconnected Devices, 2000	95,932	NCI estimate based on Roth, et. al. (2002)[a]
Number of Interconnected Devices, 2008	198,400	NCI estimate based Table 5-3, Table 5-8 and Table 5-9[a]
Total LAN Switch Installed Base (# ports), 2008	**390,000**	Extrapolated based on the increase in the number of interconnected devices.

Note: We based our estimate of the LAN gear installed base on the 2000 installed base for LAN switches and hubs from Roth, et. al. (2002), and extrapolated relative to the total number of devices interconnected to LAN (i.e., PCs and imaging equipment).

a. Total number of installed PCs and imaging equipment.

Our installed base estimate for WAN switches (see Table 5-13) is based on shipment projection by Dittberner (2002).

Table 5-13: WAN Switch Installed Base Calculation

Year	Shipments (1,000s)	Source
2001	24.8	Dittberner (2002)
2002	33.0	NCI estimate (interpolation based on Dittberner, 2002)
2003	41.2	
2004	49.4	
2005	57.6	
2006	65.8	
2007	74.0	
2008	82.2	Dittberner (2002)
WAN switch installed base (1,000s)	**428**	Assume EUL of seven years (Roth, et. al., 2002)

Finally, we estimated the router installed base using the same approach as our LAN switch installed base calculation (see Table 5-14).

Table 5-14: Router Installed Base Calculation

Data	Installed Base (1,000s)	Source
Router Installed Base, 2000	3,257	Roth, et. al. (2002)
Number of Interconnected Devices, 2000	95,932	NCI estimate based on Roth, et. al. (2002)[a]
Number of Interconnected Devices, 2008	198,400	NCI estimate based Table 5-3, Table 5-8 and Table 5-9[a]
Router Installed Base, 2008	**6,736**	Extrapolated based on the increase in the number of interconnected devices.
a. Total number of installed PCs and imaging equipment.		

5.6 *Baseline Energy Consumption*

5.6.1 *Personal Computers*

We calculated Unit Energy Consumption (UEC) (see Table 5-16 and Table 5-17) based on field measurement data collected by Sanchez (2009). Sanchez (2009) presents average power draw under three operational modes, which we will call in this report *Active*, *Low* and *Off*. Table 5-15 defines these three modes.

Table 5-15: Definitions of Operational Modes for Office/IT Equipment with Power Management Feature

Operational Mode	Description	Equivalent Mode for Windows PC
Active	The equipment is fully functional and is ready to respond to the user's request	*Standby* mode, where the PC continues to run on low power while maintaining the ongoing session.
Low	The equipment's power management feature is activated, and the equipment is not immediately ready to respond to the user's request	*Hibernate* mode, where the ongoing session is temporarily saved on data storage so that the PC can turn its power off almost completely
Off	The equipment is turned off but still plugged in.	N/A

Table 5-16 and Table 5-17 present unit energy consumption calculation for desktop and laptop PCs based on the power draw data from Sanchez (2009).

Table 5-16: Typical Commercial Desktop UEC

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)[a]	79	6.1	2.9	Sanchez (2009)
Average Usage Pattern (hr/yr)	6,221	346	2,193	See Table D-6
Average UEC by Mode (kWh/yr)	491.5	2.1	6.4	Calculated
Total Average UEC (kWh/yr)	**500**			
a. Average based on actual sample measurements.				

Table 5-17: Typical Commercial Laptop UEC

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)[a]	19	1.4	0.9	Sanchez (2009)
Average Usage Pattern (hr/yr)	1,078	828	6,854	See Table D-6
Average UEC by Mode (kWh/yr)	20.8	1.2	6.2	Calculated
Total Average UEC (kWh/yr)	**28.2**			
a. Average based on actual sample measurements.				

Table 5-18 presents the derivation of national AEC of all commercial PCs based on the installed base and UEC calculations above.

Table 5-18: 2008 Commercial PC AEC

Data	Data by PC Type		Source
	Desktop	Laptop	
2008 Installed Base (1,000s)	60.381	47,619	See Table 5-3
Average UEC (kWh/yr)	500	28.2	See Table 5-16 and Table 5-17
Total AEC—Site Energy (TWh/yr)	30.2	1.35	
Total AEC—Primary Energy (TBtu/yr)	**314**	**14.0**	
Commercial PC Total AEC—Primary Energy (TBtu/yr)	**328**		

5.6.2 Desktop Monitors

Table 5-19 and Table 5-20 present the average power draw data by operational mode for LCD and CRT monitors, according to Sanchez (2009) and Socolof, et. al. (2009). These values are based on measurements taken by the Lawrence Berkeley National Laboratory for US EPA, and are weight averaged by monitor display size. The three modes are defined in the same way as for the commercial PC (see Table 5-15).

Table 5-19: Typical Commercial LCD Monitor UEC

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	31.6	0.9	0.7	Sanchez (2009)
Average Usage Pattern (hr/yr)	2,483	5,043	1,234	See Table D-6
Average UEC by Mode (kWh/yr)	78.4	4.8	0.9	Calculated
Total Average UEC (kWh/yr)	**84.0**			
a. Average based on actual sample measurements.				

Table 5-20: Typical Commercial CRT Monitor UEC

Data	Data by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	73	3.4	1.1	Sanchez (2009)
Average Usage Pattern (hr/yr)	2,474	4,093	2,193	See Table D-6
Average UEC by Mode (kWh/yr)	181.7	13.9	2.3	Calculated
Total Average UEC (kWh/yr)	**198**			
a. Average based on actual sample measurements.				

Table 5-21 presents the derivation of national AEC of all commercial desktop monitors based on the installed base and UEC calculations above.

Table 5-21: 2008 Commercial PC AEC

Data	Desktop Monitor Type		Source
	LCD	CRT	
2008 Installed Base (1,000s)	51,283	13,504	See Table 5-6
Average UEC (kWh/yr)	84.0	198	See Table 5-19 and Table 5-20
Total AEC—Site Energy (TWh/yr)	4.31	2.67	
Total AEC—Primary Energy (TBtu/yr)	**44.8**	**27.8**	
Commercial PC Total AEC—Primary Energy (TBtu/yr)	**72.7**		

5.6.3 Server Computers

Table 5-22 presents the average power draw of a typical server computer for each server class in 2008, based on historical average power draw data between 2000 and 2006 (available from US EPA (2007)). As Table 5-7 indicates above, high-end servers do not account for a significant portion of the total installed base today; however, their unit energy consumption is an order of magnitude greater than the volume and mid-range servers because of their performance specification.

Table 5-22: Average Server Unit Power Draw

Year	Power Draw (W) by Server Classification[a]			Source
	Volume	Mid-range	High-End	
2000	186	424	5,534	IDC estimate as cited by US EPA (2007)
2001	193	457	5,832	
2002	200	491	6,130	
2003	207	524	6,428	
2004	213	574	6,973	
2005	219	625	7,651	
2006	225	675	8,163	
2007	232	729	8,709	NCI estimate, extrapolated based on historical growth rate
2008	**240**	**788**	**9,292**	

a. Based on IDC server classification. See Section 5.5.3 for details.

Based on the data in Table 5-7 and Table 5-22, Table 5-23 presents the UEC and AEC calculations for server computers in 2008.

Table 5-23: Server UEC and 2008 AEC

Data	Data Value by Server Classification[a]			Source
	Volume	Mid-range	High-End	
Annual Average Unit Power Draw (W)	240	788	9,292	See Table 5-22
Server UEC[b] (kWh/yr)	**2,100**	**6,904**	**81,400**	
2008 Total Installed Base (1,000s)	12,789	346	18	See Table 5-7
Server AEC by Classification—Site Energy (TWh/yr)	**26.9**	**2.4**	**1.4**	
Total Server AEC—Site Energy (TWh/yr)	**30.7**			
Server AEC—Primary Energy (TBtu/yr)	**319**			

a. Based on IDC server classification. See Section 5.5.3 for details.
b. Assume annual usage of 8,760 hr/yr, since the power draw is an average value over the course of a year.

5.6.4 Imaging Equipment

Table 5-24 and Table 5-25 present the average typical MFD usage data and power draw by operational mode, respectively. The power draw data estimate provided by Riso (2009b) is an average of major MFD products found in the market today. Due to the lack of reliable data on *off*-mode power draw for MFD devices, we have substituted the equivalent data for digital photocopiers from Roth, et. al. (2002).

In similar exercises for digital photocopy machines, Kawamoto, et. al. (2001) and Roth et. al. (2002) do not account for printing power by calculating "active" mode hours per year, but instead by accounting for small incremental energy consumption per photocopied image. Our study follows their approach as well, accounting for printing energy separately from UEC calculation based on power draws and usage patterns.

Table 5-24: Average MFD Usage Pattern

Operational Mode	Usage Pattern (hr/yr)	Source
Printing[a]	N/A	
Active	1,314	See Table D-6
Low	6,406	
Off	1,040	
a. We are accounting printing energy separately. See Appendix D.8 for details.		

Table 5-25: MFD Power Draw by Segment

Operational Mode	Power Draw (W) by Speed Segment					Source
	2	3	4	5	6	
Active	177	177	313	313	313	Riso (2009b)
Low	42	68	68	199	199	
Off	0.5	0.6	0.6	2.3	2.3	Roth et. al. (2002)

Table 5-26 presents the UEC calculation for commercial MFDs by segment, based on Table 5-8, Table 5-24 and Table 5-25.

Table 5-26: MFD Unit Energy Consumption by Segment

Operational Mode	UEC (kWh) by Speed Segment					Source
	2	3	4	5	6	
Printing	10	17	25	89	353	See Table D-40 in Appendix D.8
Active	233	233	411	411	411	Calculated based on Table 5-24 and Table 5-25
Low	269	436	436	1,275	1,275	
Off	0.5	0.6	0.6	2.4	2.4	
Total	**512**	**686**	**872**	**1,777**	**2,041**	

Table 5-27 presents the AEC calculation for MFDs, including energy required to print images onto paper.

Table 5-27: MFD Annual Energy Consumption Calculation

Data	Data Value by Speed Segment					Source
	2	3	4	5	6	
Installed Base (1,000s)	408	2,998	4,255	670	232	See Table 5-8
UEC by Segment (kWh/yr)	512	686	872	1,777	2,041	See Table 5-26
Total AEC by Segment—Site Energy (TWh/yr)	**0.21**	**2.05**	**3.71**	**1.19**	**0.47**	
Total AEC—Site Energy (TWh/yr)		**7.6**				
Total AEC—Primary Energy (TBtu/yr)		**79.5**				

There are no reliable recent studies on power draw and usage patterns for laser printers. However, US EPA (2008c) provides the UECs of an average commercial color laser printer and an average commercial monochrome laser printer. Table 5-28 presents the AEC calculation for laser printers.

Table 5-28: Laser Printer Annual Energy Consumption Calculation

Data	Data Value by Printer Type		Source
	Laser (Color)	Laser (B/W)	
UEC (KWh/wk)	10.6	6.4	US EPA (2009b)
UEC (kWh/yr)	551.2	332.8	Calculated based on US EPA (2009b)
Installed Base (1,000s)	3,210	3,607	See Table 5-9
AEC by Printer Type—Site Energy (TWh/yr)	1.77	1.20	
Total AEC—Site Energy (TWh/yr)	**2.97**		
Total AEC—Primary Energy (TBtu/yr)	**30.9**		

We referred to US EPA (2009b) for inkjet printer power draw data to determine the UEC. Like our approach for MFDs, we accounted for printing energy for inkjet printers separately. Table 5-29 displays the non-printing UEC calculation for inkjet printers.

Table 5-29: Inkjet Printer Non-Printing Unit Energy Consumption

Data	Data Value by Operational Mode[a]		Source
	Standby	Off	
Usage Pattern (hr/yr)	7,118	1,643	See Table D-6
Power Draw (W)	5.3	2.3	US EPA (2009b)
Non-Printing UEC (kWh/hr)	37.7	3.8	Calculated
Total Non-Printing UEC (kWh/hr)	**41.5**		

a. Printing energy is accounted separately: see Table D-37 in Appendix D.8 and Table 5-30 for more detail.

Given the information on Table 5-29, Table 5-30 presents the AEC calculation for Inkjet Printers.

Table 5-30: 2008 Inkjet Printer Annual Energy Consumption

Data	Data Value	Source/Note
Non-Printing UEC (kWh/yr)	41.5	See Table 5-29
2008 Installed Base (1,000s)	12,848	See Table 5-8
Non-Printing AEC—Site Energy (TWh/yr)	0.53	Calculated
Printing AEC—Site Energy (TWh/yr)	0.04	See Table D-37 in Appendix D.8
Total Inkjet Printer AEC—Site Energy (TWh/yr)	**0.57**	
Total Inkjet Printer AEC—Primary Energy (TBtu/yr)	**5.91**	

Table 5-31 summarizes AECs for all imaging equipment discussed in this report. Note that we covered AEC derivations for fax machines, scanners, impact printers and other miscellaneous printers in Appendix D.10.

Table 5-31: 2008 Imaging Equipment Annual Energy Consumption Summary

Imaging Equipment Types	AEC (TWh/yr)	Source
MFD	7.64	See Table 5-27
Laser Printers	2.97	See Table 5-28
Fax Machines	1.07	See Table D-45 in Appendix D.10
Inkjet Printers	0.57	See Table 5-30
Scanners	0.46	See Table D-48 in Appendix D.10
Impact Printers	0.36	See Table D-50 in Appendix D.10
Other Printers	0.18	See Table D-51 in Appendix D.10
Total AEC, All Imagine Equipment types (TWh/yr)	**13.2**	
Total AEC, All Imagine Equipment types (TBtu/yr)	**138**	

5.6.5 Uninterruptible Power Supplies

"Energy consumption" of an UPS system stems from the efficiency loss associated with the system. Ton, et. al. (2005) estimates the average load factor[15] of a typical data center UPS system at 0.38. Table 5-32 presents UPS system efficiency associated with the load factor of 0.38.

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[15] Load factor is the ratio of the average load to the peak load

Table 5-32: UPS System Efficiency by System Type, Data Center Applications (Load Factor = 0.38)

UPS Types	Efficiency	Source
Standby	N/A	No Standby UPSs used in data centers
Line-Interactive	95.0%	NCI estimate based on Ton, et. al. (2005)
Double Conversion	85.2%	Ton, et. al. (2005)

While Ton, et. al. (2005) does not discuss non-data center UPS system efficiencies, Roth, et. al. (2002) estimates the load factor of a typical non-data center UPS system at 0.5. Table 5-33 provides the efficiency data for UPS systems at the load factor of 0.5.

Table 5-33: UPS System Efficiency by System Type, Non-Data Center Applications (Load Factor = 0.5)

UPS Types	Efficiency	Source
Standby	92.5%	Roth, et. al. (2002)
Line-Interactive	97.0%	Ton, et. al. (2005)
Double Conversion	90.0%	

In calculating the UPS energy consumption, Roth, et. al. (2002) assumes that the actual power output of an UPS system is 80% of the nameplate power rating. Table 5-34 presents data center UPS UEC calculation based on the load factor of 0.38 and the efficiency in Table 5-32.

Table 5-34: Data Center UPS System Unit Energy Consumption Calculation by Nameplate Output Power Range and Type

Data	Data Value by Range of Nameplate Rating[a]						Comment
	5.1-20	21-50	51-100	101-200	201-500	>500	
Avg. Nameplate Power rating (kW)	12.5	35	75	150	350	500	Average of the range
Avg. Actual Power Output (kW)	10	28	60	120	280	400	NCI estimated based on Roth, et. al. (2002)[b]
Standby UPS UEC (kWh/yr)	N/A[c]	N/A[c]	N/A[c]	N/A[c]	N/A[c]	N/A[c]	
Line-Interactive UEC (kWh/yr)	1,664	N/A[d]	N/A[d]	N/A[d]	N/A[d]	N/A[d]	
Double Conversion UEC (kWh/yr)	4,927	13,795	29,560	59,119	137,945	197,065	

a. Range of nameplate rating is expressed in kVA.
b. Roth, et. al. (2002) estimates that actual power output of a typical UPS system is 80% of the nameplate power output.
c. No installed base of standby system for data center application.
d. No installed base of line-interactive system greater than 20 kVA.

Similarly, Table 5-35 presents non-data center UPS UEC calculation based on the load factor of 0.5 and the efficiency number in Table 5-33.

Table 5-35: Non-Data Center UPS System Unit Energy Consumption Calculation by Assumed Output Power Range and Type

Data	Data Value (1,000s) by Range of Nameplate Capacity[a]				Comment
	<0.5	0.5-0.9	1.0-2.9	3.0-5.0	
Avg. Nameplate Power Rating (kW)	0.5	0.75	1.5	4	Average of the range
Avg. Actual Power Output (kW)	0.4	0.6	1.2	3.2	NCI estimated based on Roth, et. al. (2002)[b]
Standby UPS UEC (kWh/yr)	131	N/A[c]	N/A[c]	N/A[c]	No installed base of standby system greater than 0.5 kVA
Line-Interactive UEC (kWh/yr)	53	79	158	420	
Double Conversion UEC (kWh/yr)	175	263	526	1,402	

a. Range of nameplate rating is expressed in kVA.

b. Roth, et. al. (2002) estimates that actual power output of a typical UPS system is 80% of the nameplate power output.

c. No installed base of standby system greater than 0.5 kVA.

Given the installed base data in Table 5-10 and Table 5-11, and the UEC data in Table 5-34 and Table 5-35, Table 5-36 presents annual energy consumption summary for commercial UPS systems.

Table 5-36: 2008 Commercial UPS System Annual Energy Consumption

UPS Type	AEC by UPS Application—Site Energy (TWh/yr)		
	Non-Data Center	Data Center	Total
Standby	1.18	0	1.18
Line-Interactive	0.47	0.24	0.70
Double Conversion	0.40	4.25	4.65
Total AEC	**2.0**	**4.5**	**6.5**
		Total AEC—Primary Energy (TBtu/yr)	**68.0**

5.6.6 Network Equipment

To calculate the annual energy consumption of LAN switches, we estimated the power draw per port of a typical LAN switch based on Tolly (2008).

Table 5-37: LAN Switch Annual Energy Consumption Calculation on per Port Basis

	Data	Source/Note
Average power draw[a] (W)	1.5	NCI estimate based on Tolly (2008)[b]
Installed Base (1,000s)	390,000	See Table 5-12
Usage (hr/yr)	8,760	NCI estimate
Total AEC—Site Energy (TWh)	**5.2**	

a. Annual average power draw per port.
b. Per-port average power draw of three LAN switch models detailed in Tolly (2008): Nortel BES50GE-24T PWR, HP ProCurve Switch 2626-PWR, and Cisco Catalyst Express 500.

To calculate the annual energy consumption of WAN switches, we estimated the power draw of a typical WAN switch based on Tolly (2009).

Table 5-38: WAN Switch Annual Energy Consumption Calculation

	Data	Source/Note
Average power draw (W)	238	Tolly (2009)[a]
Installed Base (1,000s)	428	See Table 5-13
Usage (hr/yr)	8,760	NCI estimate
Total AEC—Site Energy (TWh)	**1.0**	

a. Power draw of Cisco ISR 3845 as reported by Tolly (2009).

To calculate the annual energy consumption of routers, we estimated the power draw of a typical router based on icrontic.com (2008).

Table 5-39: Router Annual Energy Consumption Calculation on per Port Basis

	Data	Source/Note
Average power draw[a] (W)	12	icrontic.com (2008)
Installed Base (1,000s)	6,736	See Table 5-14
Usage (hr/yr)	8,760	NCI estimate
Total AEC—Site Energy (TWh)	**0.71**	

a. Annual average power draw per port.

Table 5-40 summarizes the network equipment AEC. As indicated, LAN switches account for majority of the network equipment AEC.

Table 5-40: Network Equipment Annual Energy Consumption Summary

Network Equipment Type	Data Value	Source
LAN Switches AEC—Site Energy (TWh/yr)	5.2	See Table 5-37
WAN Switches AEC—Site Energy (TWh/yr)	1.0	See Table 5-38
Routers AEC—Site Energy (TWh/yr)	0.71	See Table 5-39
Total AEC—Site Energy (TWh/yr)	**5.6**	
Total AEC—Primary Energy (TBtu/yr)	**58.2**	

5.7 *Comparison of Baseline Energy Consumption to Previous Studies*

Table 5-41 provides the comparison between our AEC estimates and those according to Roth, et. al. (2002) as well as ADL (1993).

Table 5-41: Annual Primary Energy Consumption of IT/Office Equipment Comparison against Roth, et. al. (2002)

End-Use Technology	IT/Office Equipment AEC by Year—Primary Energy (Quads/yr)		
	1990[a]	2000[b]	2008[c]
Personal Computers	0.06[d]	0.20	0.33
Desktop Monitors	N/A	0.23	0.07
Server Computers	0.08[e]	0.11	0.32
Imaging Equipment	0.17[f]	0.20	0.14
UPSs	N/A	0.06	0.07
Network Equipment	N/A	0.06	0.06
Others	N/A	0.03	0.02
Totals	**N/A**	**0.89**	**1.01**

a. According to ADL (1993).
b. According to Roth, et. al. (2002).
c. Estimates from this study.
d. Sum of primary energy consumption associated with "Desktop Computers", "Workstations" and "Laptops" in ADL (1993).
e. Primary energy consumption associated with "Mainframe &Mini computers" in ADL (1993).
f. Sum of primary energy consumption associated with "Printers", "Copiers" and "Facsimile" in ADL (1993).

The biggest difference in AEC between the 2000 estimate and the 2008 estimate is server computer AEC, which could be attributed to the significant growth in the need for faster computing capacity between 2002 and 2008. Two other notable differences between the 2000 and 2008 estimates are for personal computers and desktop monitors. Although our estimate of PC energy consumption is higher than Roth, et. al. (2002) by over 60%, this is mostly driven by the increase in the installed base of PCs; the commercial PC installed base grew by approximately 53%, from 70 million to 108 million between 2002 and 2008. Desktop monitor's decline in AEC is attributed to increasing share of LCD monitors. Roth, et. al. (2002) estimates the market share of LCD monitors at approximately 3% as of 2002, whereas our estimate for 2008 is nearly 80% (see Table 5-6).

5.8 Cost Breakdown

Cost information in this section covers hardware costs associated with IT and office equipment, and does not include maintenance cost. Typically, maintenance costs associated with commercial IT and office equipment are included as a part of bulk customized purchase contracts signed by an organization's IT department. Our contacts at manufacturers and IT departments were unwilling or unable to disclose maintenance costs for these devices.

5.8.1 Personal Computers

According to US EPA (2009a), the estimated retail price of an average desktop PC unit is $742 per unit, based on an industry survey conducted by US EPA. The same industry survey suggests that the estimated retail price of an average desktop PC unit that would qualify for ENERGY STAR version 4.0 is $784[16].

5.8.2 Desktop Monitors

According to US EPA (2009c), the estimated retail price of an average desktop LCD monitor is $189 per unit. US EPA also indicates that there is no incremental cost associated with purchasing ENERGY STAR 4.0-qualifying LCD monitor as of 2009. The estimated retail price of an average desktop CRT monitor is $111.

5.8.3 Server Computers

There are no publicly available reports that document the average retail price of a typical server computer. While server computer prices vary widely depending on computing capacity, the worldwide average price of server computers in 2006 grew from $7,308 to $7,690 per unit, according to Shankland (2007). Shankland reports that the IT industry's demand for higher-performance servers to accommodate virtualization is the main contributor to the raise in the price.

5.8.4 Imaging Equipment

The price of imaging equipment varies depending on its printing speed. For instance, according to US EPA (2008d), the estimated retail price of an average office copy machine is $5,000 for slower unit (printing speed under 50 ipm), and $15,000 for a faster unit. US EPA (2009d) also indicates that there is no incremental cost associated with purchasing ENERGY STAR 4.0-qualifying equipment as of 2009.

5.8.5 Uninterruptible Power Supplies

While there is no publicly available market data on the prices of UPS systems in 2008, Ton, et. al. (2005) provides average market price data from 2005, estimated by Frost and Sullivan for commercial UPS systems by the range of their nameplate power output (see Table 5-42).

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[16] Energy Star for PCs are now in its fifth version effective July 1, 2009. However, there is no industry-average cost data available yet for Energy Star version 5.0.

Table 5-42: Price Ranges of Commercial UPS systems, by the Range of Assumed Power Output

Range of Nameplate Power Rating	Typical 2005 Price Range	Source
5.1 – 20 kVA	$4,000 - $16,500	Frost and Sullivan estimate, as cited by Ton, et. al. (2005)
20.1 – 50 kVA	$8,000 - $37,000	
50.1 – 200 kVA	$19,000 - $98,000	
>200 kVA	$30,000 - $207,000	

5.8.6 Network Equipment

We found no publicly available reports that document average retail price of different network equipment geared toward applications in commercial buildings. Much like server computers and imaging equipment, the price of network equipment, such as switches, vary widely based on their communication bandwidth. A review of several retailer websites indicates that LAN switch costs range from under $20 for small, residential-scale units to over $15,000 for a fast switches more suited for deployment in large corporate network-type setting. Costs of advanced, high-speed WAN switches can also range up to $15,000.

5.9 Lifetime, Reliability, and Maintenance Characteristics

According to Barry (2008), in practice, the expected useful life (EUL) of commercial sector IT equipment is typically determined by one of the three factors: budgetary limitation of the purchasing organization; warranty expiration for the equipment; and equipment failures. Anecdotal evidence suggests that prevalent practice in the commercial sector is to align IT equipment lifecycle decisions with expiration of warranty (Missouri, 2004; IUK, 2008), which generally does not exceed three years after the time of the purchase.

Furthermore, Barry (2008) and Wagner (2003) suggest lifecycles of the operating systems and essential business software applications have an indirect influence on the hardware lifecycle for personal and server computers. This probably has indirect effect on lifecycle management for imaging equipment as well.

Table 5-43 summarizes the EUL of major IT and office equipment.

Table 5-43: Expected Useful Lifetime of IT and Office Equipment

Equipment Types	Average EUL (year)	Source
Personal Computers	4	US EPA (2009a)
Desktop Monitors	4	US EPA (2009c)
Server Computers	4	Ecos (2008) and Intel (2008)
Multifunction Devices	6	US EPA (2008)
Single-Function Printers	5	US EPA (2009b)
UPS Systems	6 to 11	Roth, et. al. (2002)
Network Equipment	4 to 7	

5.10 Regulatory Programs

No mandatory energy efficiency standards exist today for any of the IT and office equipment discussed in this section.

Though not a mandatory efficiency standard, the Alliance for Telecommunications Industry Solutions (ATIS) has established standards and methodologies to determine energy efficiency for various types of telecommunication equipment (ATIS, 2009).

5.11 Voluntary Programs

ENERGY STAR program is the leading voluntary efficiency program for IT and office equipment. According to Thibodeau (2009), ENERGY STAR criteria are designed such that 25% of the products on the market would qualify for the ENERGY STAR label. Other major environmental footprint reduction programs, such as EPEAT, base the energy portion of their rating criteria on ENERGY STAR standards.

Another cross-cutting efficiency standard program is 80PLUS, which is a voluntary program that rates efficiency of AC-DC conversion unit within personal and server computers.

5.11.1 Personal Computers

The current ENERGY STAR standard for PCs is in its fifth version, which came in effect on July 1, 2009. It replaced ENERGY STAR version 4.0 for PCs, which had been the working voluntary efficiency standard for both desktop and laptop PCs since July 2007 (Ng, 2009). Table 5-44 and Table 5-45 each present two sets of power draw data for PCs from Sanchez (2009): an average power draw of a typical new PC unit available in the market in 2008[17], and an estimated power requirement under ENERGY STAR version 5.0.

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[17] Based on actual sample measurements.

Table 5-44: Desktop PC Power Draw by Mode, Typical New Units and ENERGY STAR-Qualifying Desktop PC Units

PC Types	Power Draw (W) by Operational Mode			Source
	Active	Low	Off	
Typical New Units in 2008[a]	62	3.1	1.6	Sanchez (2009)
ENERGY STAR 5.0[b]	46	2.5	1.5	

a. Based on actual sample measurements.
b. Estimated power draw based on ENERGY STAR specifications.

Table 5-45: Laptop PC Power Draw by Mode, Typical New Units and ENERGY STAR-Qualifying Laptop PC Units

PC Types	Power Draw (W) by Operational Mode			Source
	Active	Low	Off	
Typical New Units in 2008[a]	19	1.5	1.0	Sanchez (2009)
ENERGY STAR 5.0[b]	14	1.4	0.8	

a. Based on actual sample measurements.
b. Estimated power draw based on ENERGY STAR specifications.

5.11.2 Desktop Monitors

The effective ENERGY STAR standard for desktop LCD monitors as of August 2009 is in its fourth version. However, the current ENERGY STAR standard will be replaced by version 5.0 effective October 30, 2009. Furthermore, a new specification specifically targeting larger professional displays (30- to 60-inch diagonal) will be effective January 10, 2010 (US EPA, 2009e). Table 5-46 presents two sets of power draw for desktop monitors from Sanchez (2009): an average power draw of a typical new desktop monitor unit available in the market in 2008[18], and estimated power requirement under ENERGY STAR version 5.0.

Table 5-46: Desktop Monitor Average Power Draw by Mode, Typical New Units and ENERGY STAR-Qualifying Desktop Monitor Units

PC Types	Power Draw (W) by Operational Mode			Source
	Active	Low	Off	
Typical New Units in 2008[a]	31	0.7	0.7	Sanchez (2009)
ENERGY STAR 5.0[b]	25	0.7	0.6	

a. Based on actual sample measurements.
b. ENERGY STAR requirements vary depending on monitor size and other factors. Values listed are Sanchez (2009) estimates of the ENERGY STAR requirements for a typical unit.

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[18] Based on actual sample measurements.

5.11.3 Server Computers

ENERGY STAR launched its first set of requirements for enterprise server computers in 2009. Gralla (2009) reports that, according to a US EPA estimate, a typical ENERGY STAR server computer would be 30% more energy efficient than a typical non-ENERGY STAR server. However, the current set of ENERGY STAR requirements, referred to as Tier 1 Requirements, is only a part of the new ENERGY STAR standard. The EPA is planning to release additional sets of standards, referred to as Tier 2 Requirements, to complement Tier 1 Requirements on October 15, 2010 (US EPA, 2009f).

The Tier 1 Requirements have several shortcomings, according to Gralla (2009). First, they do not cover blade servers, which are expected to account for more than 25% of annual shipments by 2011 according to McCafferty (2009). Blade servers are typically used for web hosting and cluster computing, and are at the core of virtualization projects[19]. Furthermore, the current standard only addresses idle power consumption and not active power consumption. According to US EPA (2009f), EPA intends to expand the coverage of Tier 2 Requirement beyond Tier 1 coverage, and is considering inclusion of blade servers as well as other data center devices such as storage equipment, network equipment and other server appliances.

5.11.4 Imaging Equipment

ENERGY STAR version 1.0 is the existing voluntary efficiency standard for most imaging equipment today, and covers MFDs, laser printers, inkjet printers, fax machines and scanners. ENERGY STAR version 1.1 for imaging equipment is currently under development and is slated to be finalized in 2009.

5.11.5 Uninterruptible Power Supplies

No voluntary energy efficiency standards exist today for UPS systems. However, CEC (2008a) points to the UPS efficiency label system proposed by Ton, et. al. (2005) as a potential guide for a future voluntary labeling program (see Figure 5-19).

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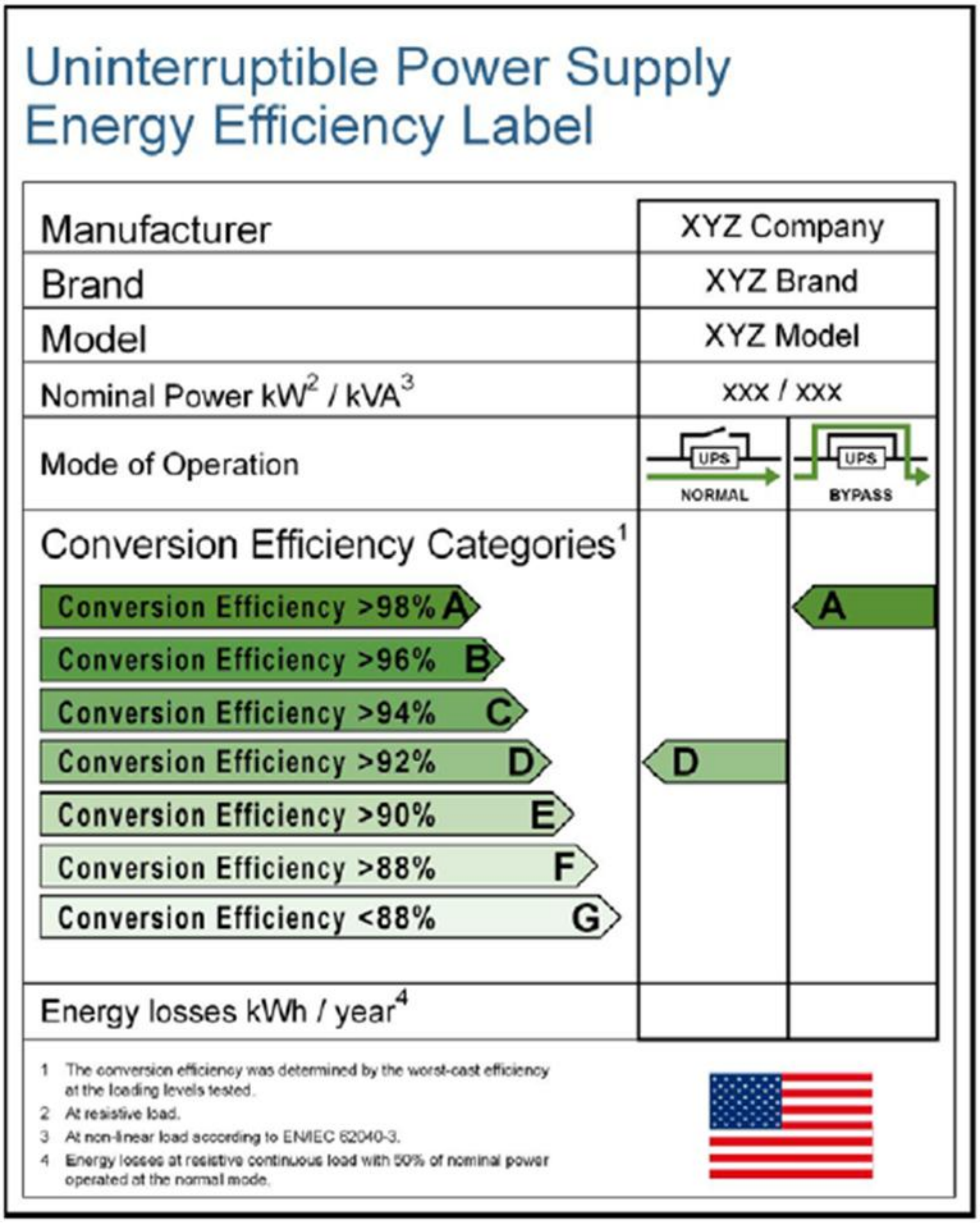
[19] See Section 5.12.5 for more details on virtualization.

Figure 5-19: Proposed UPS Efficiency Label



Uninterruptible Power Supply
Energy Efficiency Label

Manufacturer	XYZ Company	
Brand	XYZ Brand	
Model	XYZ Model	
Nominal Power kW[2] / kVA[3]	xxx / xxx	
Mode of Operation	UPS NORMAL	UPS BYPASS
Conversion Efficiency Categories[1]		
Conversion Efficiency >98% A		A
Conversion Efficiency >96% B		
Conversion Efficiency >94% C		
Conversion Efficiency >92% D	D	
Conversion Efficiency >90% E		
Conversion Efficiency >88% F		
Conversion Efficiency <88% G		
Energy losses kWh / year[4]		

1 The conversion efficiency was determined by the worst-cast efficiency at the loading levels tested.
2 At resistive load.
3 At non-linear load according to EN/IEC 62040-3.
4 Energy losses at resistive continuous load with 50% of nominal power operated at the normal mode.

Source: Ton, et. al. (2005) via CEC (2008a)

5.11.6 Network Equipment

No voluntary energy efficiency standards exist today for network equipment. However, development of ENERGY STAR standard for network equipment planned, according to US EPA (2009f).

5.12 *Energy Saving Opportunities*

5.12.1 Overview

Improving energy efficiency for IT equipment is a critical mission for IT and office equipment manufacturers today, not only because of the cost savings opportunities associated with UEC reduction, but also in order to meet the market demand for faster computing speed while maintaining performance reliability. Particularly for devices intended for use by individual end users, non-energy factors are dominant drivers for efficiency improvements, given continuous consumer demand for new computer products with improved performance. The manufacturers must meet this demand without increasing heat dissipation, since excess waste heat can adversely affect the performance reliability of the computer unit.

Furthermore, some equipment types present additional considerations that increase the significance of efficiency improvements. For instance, the laptop PC market constantly demands longer battery life. Reduction of PC energy consumption is crucial for manufacturers to improve battery life of their new products. Another example is the growth of data centers. As we discuss later in this section, the increasing use of server computers in data centers increases cooling requirements, adding to cooling equipment costs and energy consumption.

5.12.2 Design Improvement for Personal Computers

Given the intrinsic motivations within the industry to improve energy efficiency, PC manufacturers are investing significant R&D resources to improve component efficiency. As we discuss in this section, implementing component efficiency measures offers significant energy savings potential, even without technology breakthroughs.

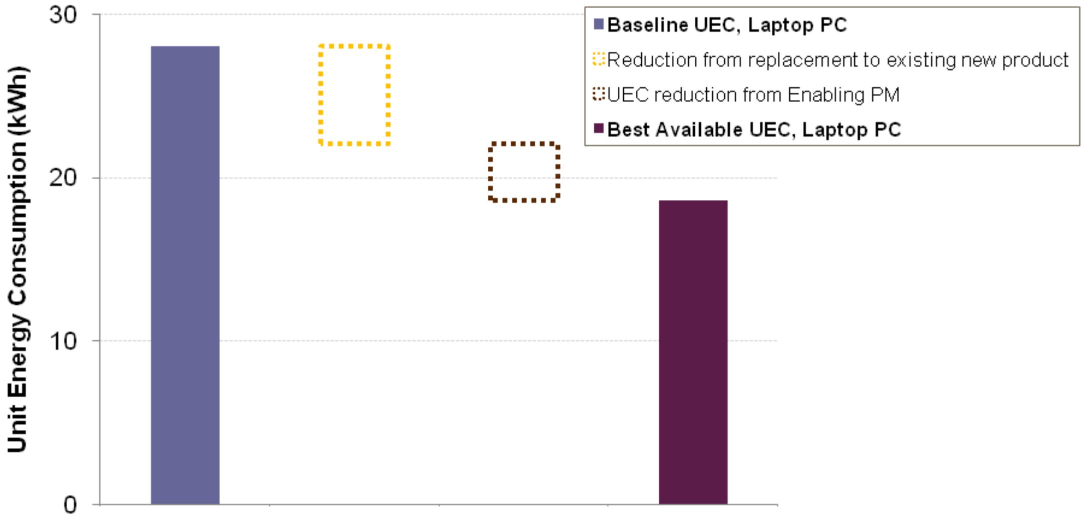
Laptop PCs

Horowitz, et. al. (2003) reports that key laptop components with opportunity for major efficiency benefit include display unit, power supply unit, CPU and battery system. For desktop PCs, Table 5-47 and Figure 5-20 present the breakdown of energy savings associated with replacing a typical new laptop PC unit with an ENERGY-STAR-5.0-qualifying unit.

Table 5-47: Estimated UEC Reduction for Energy-Star Commercial Laptop PCs

Efficiency Opportunities	UEC (kWh/yr)	% Reduction from Baseline	Source
Average Stock Unit	28.2	N/A	Included for reference (See Table 5-17)
Typical New Unit in 2008 (Baseline)	28.0	N/A	See Table D-15 in Appendix D.3
Replacement with ENERGY STAR 5.0	**22.1**	**21%**	See Table D-16 in Appendix D.3

Figure 5-20: Energy Savings for Laptop PC, Replacement with Best Available



Desktop PCs

In a study funded by the California Energy Commission, EPRI (2008) collaborated with PC manufacturers to test and demonstrate state-of-the-art efficiency in desktop computers by implementing innovative design improvements. The study provides power draw data for their two high-efficiency prototype office productivity desktop PCs.

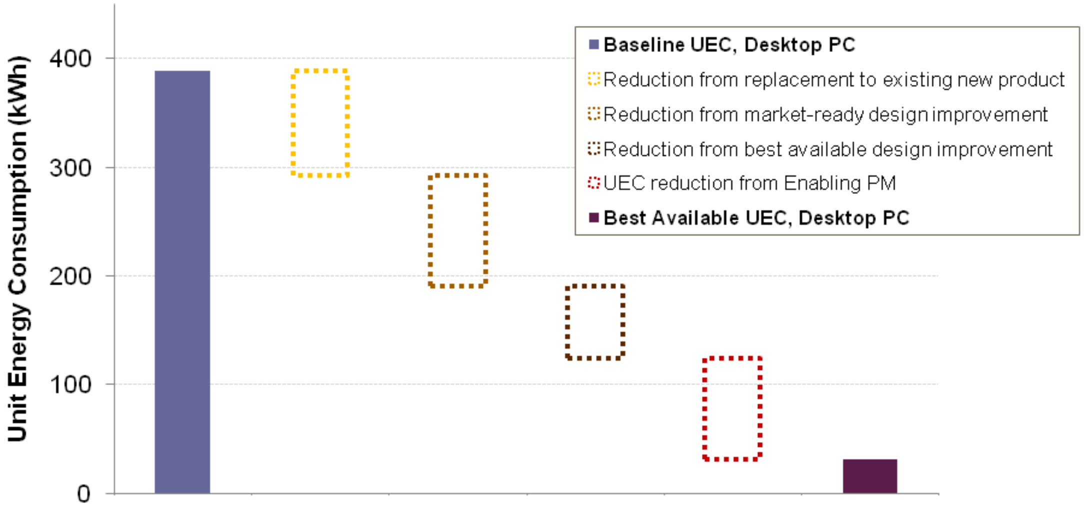
- **"Market-Ready Computer"**: This computer uses today's desktop PC technologies at price points comparable to typical enterprise desktop computers.
- **"Ultimate Efficiency Computer"**: This computer represents a blend between desktop and mobile computing platform that maximizes desktop PC energy efficiency.

"Ultimate Efficiency" computers could reduce desktop PC UEC by nearly 70%. Table 5-48 and Figure 5-21 present the potential energy savings for desktop PCs.

Table 5-48: UEC Reduction Potential for Commercial Desktop PCs

Efficiency Opportunities	UEC (kWh/yr)	% Reduction from Baseline	Source
Average Stock Unit	500	N/A	Included for reference (See Table 5-16)
Typical New Unit in 2008 (Baseline)	388	N/A	See Table D-10 in Appendix D.3
Replacement with ENERGY STAR 5.0	289	25%	See Table D-11 in Appendix D.3
"Market Ready" Design Improvements	190	51%	See Table D-12 in Appendix D.3
"Ultimate Efficiency" Design Improvements	**123**	**68%**	See Table D-13 in Appendix D.3

Figure 5-21: Energy Savings Potential for Desktop PCs, from Average Stock to "Ultimate Efficiency"



All of the above energy saving opportunities, except for the "Ultimate Efficiency" design improvements, are based on products or technologies that are cost-competitive with conventional alternatives available, off the shelf, today. ENERGY STAR-qualifying products have a $42 incremental cost over an average conventional unit (US EPA, 2009a) and EPRI's "Market-Ready" computer has an incremental cost of approximately $50 (EPRI, 2008). According to EPRI (2008), the "Ultimate Efficiency" design improvements also involve commercially available technologies, but their costs are not competitive in the market today, given the estimated incremental cost of approximately $200.

Table 5-49 summarizes the collective technical annual energy savings (AES) potential associated with improving the design of PCs using existing technologies, based on the unit energy savings (UES) derived from Table 5-47 and Table 5-48.

Table 5-49: Technical Potential Energy Savings from PC Design Improvements (existing Technologies Only)

Data	Laptop PC	Desktop PC	Source
Baseline UEC (kWh/yr)	28.0	388	See Table 5-47 and Table 5-48
Reduced UEC (kWh/yr)	22.1	123	
UES (kWh/yr)	5.9	265	
Installed Base (1,000s)	60,381	47,619	See Table 5-3
AES Potential—Site Energy (TWh/yr)	16.0	0.28	
Total AES Potential—Site Energy (TWh/yr)	**16.3**		
Total AES Potential—Primary Energy (TBtu/yr)	**170**		

5.12.3 LED Backlighting for LCD Monitors

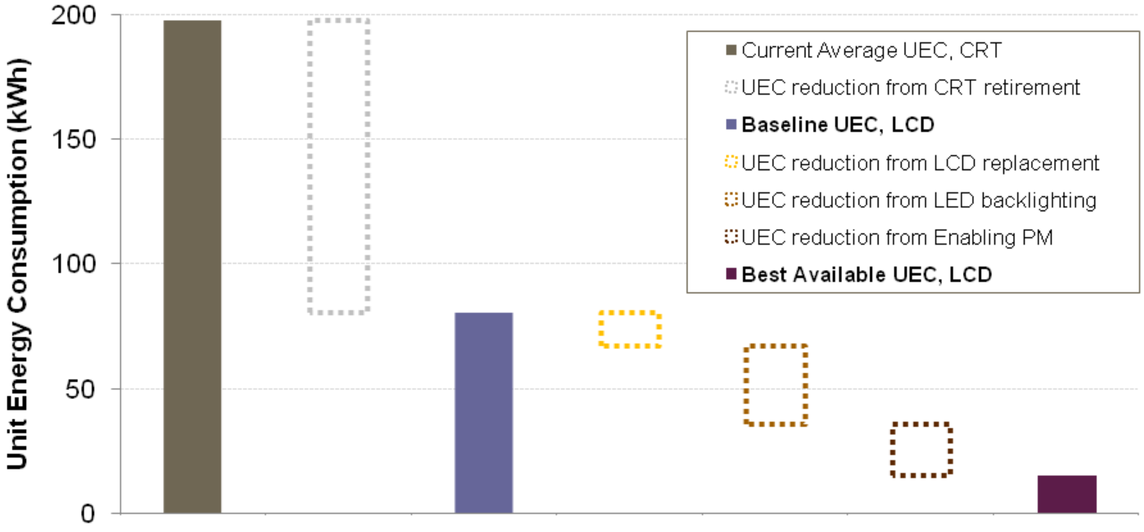
The desktop monitor market has almost completely transitioned away from CRT monitors to LCD monitors today. As previously shown in Table 5-5, CRT monitors accounted for only 5% of the market in terms of shipment volume in 2008. As CRT monitors that are currently in use reach the end of their useful life, most, if not all, of them will be replaced with LCD monitors, significantly reducing UEC without additional RD&D investment.

In addition to retirement of CRT monitors, another market-driven trend is the introduction of LCD monitors with LED backlighting (Franklin, 2009). LED backlighting is currently available in monitor displays integrated with a laptop PC from major manufacturers, and manufacturers estimate it could save as much as 60% of the energy consumed in active mode for a standalone desktop LCD monitor with traditional cold cathode fluorescent light backlighting (Lim, 2009). Figure 5-22 breaks down the technical potential of UEC reduction for desktop monitors.

Table 5-50: UEC Reduction Potential of Commercial Desktop LCD Monitor

Efficiency Opportunities	UEC (kWh/yr)	% Reduction from Baseline	Source
Average UEC, CRT Monitor	198	N/A	Included for reference (See Table 5-19)
Average UEC, LCD Monitor	84.0	N/A	Included for reference (See Table 5-20)
Typical New LCD Monitor in 2008 (Baseline)	80.8	N/A	See Table D-20 in Appendix D.4
Replacement with ENERGY STAR 5.0	67.1	17%	See Table D-21 in Appendix D.4
ENERGY STAR 5.0 + LED Backlighting	**35.8**	**56%**	See Table D-22 in Appendix D.4

Figure 5-22: Technical Potential of UEC Reduction for Desktop Monitors



All of these opportunities combined would result in up to 81% UEC reduction for a typical LCD monitor in use today, and as much as 92% reduction for a typical CRT monitor today. Table 5-51 presents technical AEC impact potential of LED backlighting.

Table 5-51: Technical AEC Savings Potential from LED Backlighting

Data	LCD Monitors	Source
Baseline UEC (kWh/yr)	80.8	See Table 5-50
Reduced UEC (kWh/yr)	35.8	
UES (kWh/yr)	55.0	
Installed Base (1,000s)	64,787	See Table 5-4
AES Potential—Site Energy (TWh/yr)	**2.91**	
AES Potential—Primary Energy (TBtu/yr)	**30.3**	

5.12.4 Power Management

Power management (PM) is a feature that typically comes with personal computers, desktop monitors and imaging equipment. When enabled, PM features automatically place monitors and computers into a low-power mode after a pre-set period of inactivity. As summarized in Table D-1 only a limited portion of the personal IT equipment has PM enabled when the product is sold, although there is no incremental cost associated with doing so. Chetty, et. al. (2009) suggests there are various barriers to achieve higher use of PM, including: inconvenience associated with longer boot-up times, need for remote access, need to run computing jobs while the user is away, and, perhaps most importantly, insufficient economic incentives. The issue of savings associated with PM may be a greater challenge in a commercial setting, since the users are typically not directly responsible for their company's energy costs.

However, the total technical potential of AEC savings associated with PM across applicable equipment types is significant. Table 5-52 summarizes the technical AEC savings potential associated with PM for PCs and desktop monitors. Note that the baseline UEC for this calculation assumes that all available efficiency improvements possible have been implemented.

Table 5-52: Technical AEC Savings Potential from Personal IT Equipment Power Management

Data	Desktop PC	Laptop PC	LCD Monitor	Source
Baseline UEC (kWh/yr)	123[a]	22.1[a]	35.8[a]	See Table 5-47, Table 5-48 and Table 5-50
Reduced UEC (kWh/yr)	31.1	18.6	15.0	See Table D-14, Table D-17 and See Table D-23
UES (kWh/yr)	92.1	3.50	20.7	
Installed Base (1,000s)	60,381	47,619	64,787	See Table 5-3 and Table 5-4
AES Potential—Site Energy (TWh/yr)	5.56	0.17	1.34	
Total AES Potential—Site Energy (TWh/yr)		**7.07**		
Total AES Potential—Primary Energy (TBtu/yr)		**73.6**		

a. Assume all possible design improvements have been implemented.

5.12.5 *Server Virtualization*

Server virtualization is a commercially viable IT solution, and presents significant energy efficiency opportunities for server computers in data centers. Virtualization in the IT industry broadly refers to the separation of a resource, or request for a service, from the underlying physical delivery of that service (VMWare, 2006). By enabling network administrators to consolidate computing resources across the network, virtualization could increase the utilization rate of servers and thus reduce the number of server computers required. Laitner, et. al. (2008) estimates that a virtualized data center could reduce energy consumption associated its server computers by as much as 70%. There are challenges in virtualizing data centers, such as inadequate bandwidth of the legacy power circuit and reduced redundancy in computing capability.

A survey conducted by Blum (2009) indicates that approximately 60% of IT professionals worldwide are either deploying or are in the process of deploying server virtualization. Assuming that server virtualization is not an appropriate solution for half of the remaining 40% for operational or technical reasons, Table 5-53 presents the technical AEC savings potential associated with virtualizing server computers in the US.

Table 5-53: Technical AEC Savings Potential from Server Virtualization

Data	Value	Source
Baseline AEC—Site Energy (TWh/yr)	30.7	See Table 5-23
Relevant Market Share	80%	NCI estimate[a]
Expected % AEC Savings	70%	Laitner, et. al. (2008)
Total AES Potential—Site Energy (TWh/yr)	**17.2**	
Total AES Potential—Primary Energy (TBtu/yr)	**178.8**	

a. Assume that virtualization cannot be implemented for the 40% of server computers operating in non-virtualized environment for operational or technical reasons.

5.12.6 Other Server Computer Energy-Saving Strategies

Fan, et. al. (2007) proposes two energy efficiency approaches for server computers:

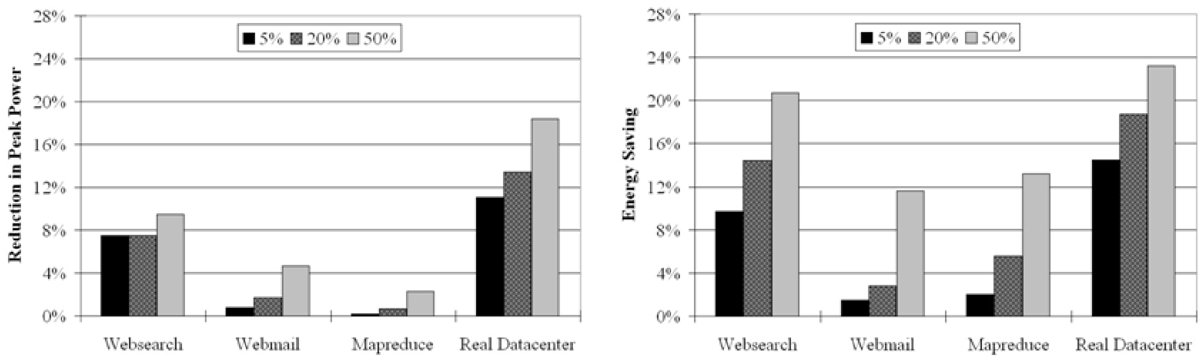
1. Power management through dynamic voltage scaling (DVS)
2. Reduction of off-peak energy consumption.

These energy-saving approaches can have significant energy-savings benefits.

Power management through DVS

Power management through DVS would power down a server computer's CPU when its utilization falls below a predetermined level. Fan, et. al. (2007) modeled the impact of DVS on server computer peak-power draw and energy consumption for three CPU utilization thresholds: 5%, 20% and 50% (see Figure 5-23). They conclude in their study that power management could result in as much as 20% reduction on energy consumption and 9% reduction in peak demand for standalone servers. The savings increase to nearly 24% and 19%, respectively, when evaluated at a data center scale with mixed computational tasks.

Figure 5-23: Impacts of CPU DVS on Peak-Power Draw (left) and Energy Consumption (right)

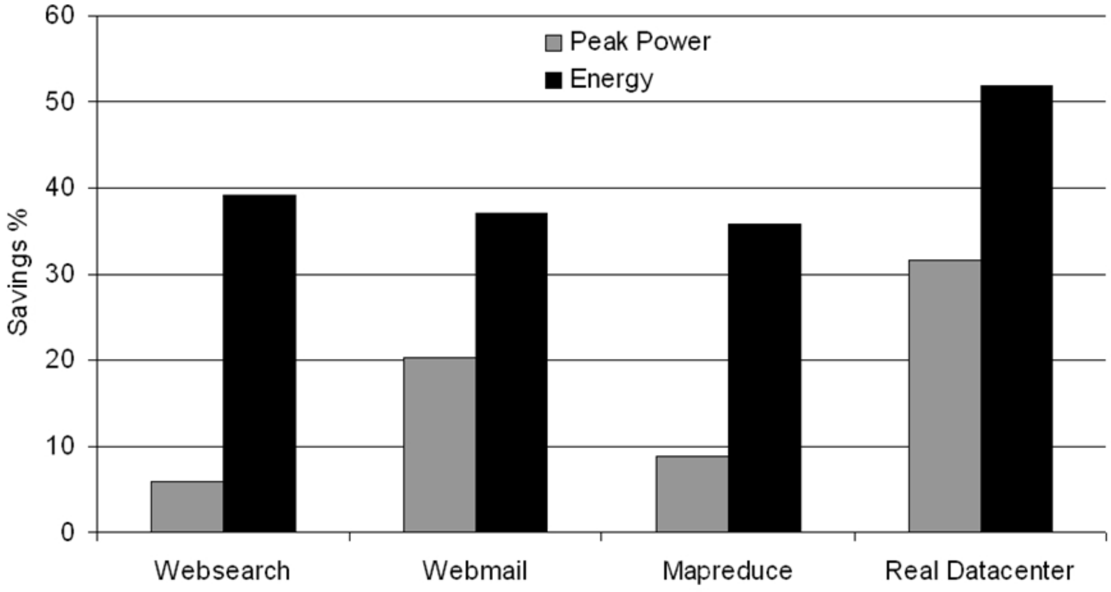


Source: Fan, et. al. (2007)

Reduction of non-peak energy consumption

Fan, et. al. (2007) estimates that server computers in idle state draw no less than 50% of their actual peak power draw. Figure 5-24 shows the percent energy and peak power saving estimate in a scenario where the ratio of idle state power draw to active power draw is reduced to 10%. In this scenario, non-peak power consumption could result in as much as 50% reduction in energy consumption and over 30% reduction in peak power draw.

Figure 5-24: Power and Energy Savings Achievable by Reducing Idle Power Consumption to 10% of Peak



Source: Fan, et. al. (2007)

These server power-provisioning strategies compete with server virtualization, since they aim to reduce power draw when server utilization is low (whereas virtualized servers are utilized at a much higher rate), and to reduce power draw while servers are idle (whereas virtualized server would not be idle, by definition). Assuming these power-provisioning technologies could capture up to the 20% of the server computers in an environment where virtualization is not feasible, Table 5-54 summarizes the technical AEC savings potential associated with server computer power provisioning.

Table 5-54: Technical AEC Savings Potential from Server Power Provisioning

Data	PM through DVC	Idle Power Reduction	Source
Baseline AEC (TWh/yr)	30.7		See Table 5-23
Relevant Market Share	20%		NCI estimate[a]
Expected % AES	24%	50%	Fan, et. a. (2007)
AES Potential—Site Energy (TWh/yr)	1.5	3.1	
Total AES Potential—Site Energy (TWh/yr)	**4.5**		
Total AES Potential—Primary Energy (TBtu/yr)	**31.9**		

a. We assumed that efficiency of all servers residing in IT networks that cannot be virtualized can be improved through these technologies. See Table 5-53 for derivation of 20%.

It is worth noting that energy consumption of server computers should be examined in the context of data center operations. Based on IDC estimates adopted by Koomey (2007) and US EPA (2007), nearly two-thirds of all server computers today are installed in data centers as opposed to server rooms in commercial buildings not dedicated to housing server computers. Site infrastructure load (e.g., cooling and lighting) accounts for over 50% of the annual data center energy consumption in the US over the past eight years based on data presented by Koomey (2007). This is due to the significant cooling requirement associated with the waste heat from dozens to hundreds of server computers installed in a room. This issue of dissipated heat in data center presents a complex energy efficiency challenge. Section 10.2.2 of this report discusses potential R&D opportunities on this topic in greater detail.

5.12.7 Imaging Equipment

Most significant energy efficiency opportunities for imaging equipment involve managing the fuser roller temperature of laser imaging devices. There are two approaches to reduce energy consumption associated with fuser temperature management: 1) use of advanced toner that requires lower fusing temperature; and 2) implementation of fast warm-up technology from low-power mode, which could promote higher use of power management.

The use of advanced toner such as Emulsion Aggregation High Grade toner could reduce energy consumption associated with laser image reproduction process by 40%, and overall energy consumption of an imaging device by up to 30% (Fuji Xerox, 2008). Similarly, manufacturers are exploring faster warm-up technologies options, such as HP's Instant-On technology (HP, 2008).

5.12.8 Reducing Efficiency Losses of Data Center Uninterruptible Power Supplies

As discussed in Section 5.6.5, energy consumption associated with a UPS system is the efficiency loss associated with operating the system. According to Malone, et. al. (2009), Google is minimizing efficiency losses of its data center UPS systems through two means: elimination of double conversion (from AC to DC back to AC current), and minimizing UPS system sizing.

DC Power Distribution for Data Centers: Double-conversion UPS systems are popular for data center use because the double-conversion process provides high-quality AC power to server computers. However, these data center UPS systems suffer lower efficiency because of the double-conversion process. CEC (2008b) estimates that converting the power distribution of a traditional data center to DC-based power distribution can reduce the total UPS system energy use by 28%.

Minimizing UPS System Sizing: In an effort to improve data center efficiency, Google has eliminated central UPS systems dedicated to an entire site and, instead, installed smaller UPS systems dedicated to each machine (Malone, et. al., 2009 and Chan, 2009). Since distributed UPS systems are sized for each machine, this approach would increase the load factor of a UPS system beyond the current industry average of 0.38. Furthermore, this scheme eliminates unnecessary current conversion that would otherwise occur with a centralized UPS system layout.

Table 5-55 presents the technical AEC savings potential associated with server computer power provisioning.

Table 5-55: Technical AEC Savings Potential from UPS Efficiency Loss Reduction in Data Centers

Data	Line-Interactive	Double Conversion	Source
AEC—Site Energy (TWh/yr)	0.24	4.25	See Table 5-34
Typical Efficiency Loss %	5%	14.8%	See Table 5-32
Minimum efficiency loss %	0.01%	0.01%	Malone, et. al. (2009)[a]
AES Potential—Site Energy (TWh/yr)	**0.23**	**4.22**	
Total AES Potential—Site Energy (TWh/yr)		**4.45**	
Total AES Potential—Primary Energy (TBtu/yr)		**43.9**	

a. Malone, et. al. (2009) claims that Google's data center UPS systems achieve up of 99.99% efficiency.

5.12.9 Design Improvements for Network Equipment

Fodale, et. al. (2008) identifies four components of energy efficiency approaches for network equipment: processors, power adaptors, cooling fans, and software. According to Fordale, et. al., a typical power adaptor may have an efficiency rating of 70%, but higher efficiency products with up to 90% efficiency ratings are available today. EPRI (2008) suggests that improvement in cooling fan efficiency in a desktop computer could reduce power and energy consumption by approximately 8%. Using EPRI's data as a proxy for cooling-related savings potential for network equipment, Table 5-56 presents potential efficiency gain associated with the use of high-efficiency power adaptor and cooling fan.

Table 5-56: Network Equipment Efficiency Opportunities

Efficiency Improvement Opportunities	Efficiency Gain	Comments
High-Efficiency Power Adaptor	22%	70% ÷ 90%, based on Fodale, et. al. (2008)
High-Efficiency Cooling Fan	8%	Based on EPRI (2008)
Overall Efficiency Gain	**28%**	

There are no reliable data publicly available for energy efficiency potential associated with the use of new processors or software for network equipment.

Given the efficiency gain potential for network equipment, the technical AEC reduction potential associated with improving the efficiency of IT network equipment is 1.59 TWh/yr, or 28% of the total network equipment AEC (see Table 5-56).

5.13 Peak Demand Considerations

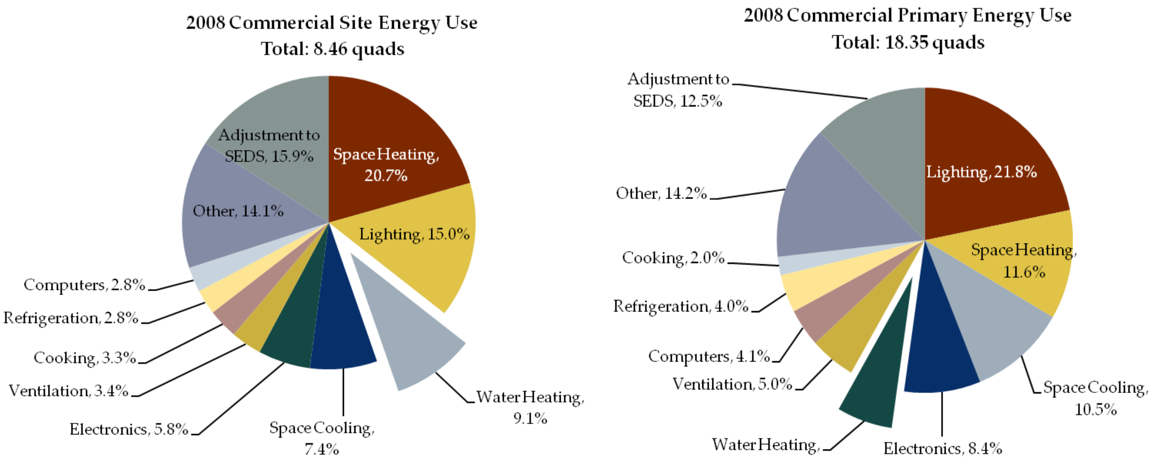
IT and office equipment could have large impact on peak demand because most of these devices are used primarily during business hours, and many equipment types typically remain in their active mode for majority of the day (see Table D-6). However, lower-power idle mode could replace some active mode periods through improved power management and operational practices (see Table D-1).

A key consideration is the continued growth of data centers. As data centers take on greater responsibility in providing web-based storage, computing and other processing needs, the peak demand contribution of data centers will grow tremendously. Industry leaders have made some efforts to address this issue through network virtualization. For instance, Google's fleet of data centers can shift computing loads across the globe (Miller, 2008b). This approach could potentially shift computing loads to other regions to avoid running servers during peak-demand periods.

6 Water Heaters

Water heating constitutes a significant portion of the nation's energy consumption. In 2006, water heating represented approximately 10% of the U.S. buildings sector primary energy consumption. Within the commercial building sector, water heating represents approximately 9% of site energy consumption and 6% of the total primary energy consumption. Figure 6-1 shows the projected 2008 U.S. commercial site and primary energy end-use splits from the 2008 Buildings Energy Data Book (DOE 2008).

Figure 6-1: 2008 Commercial Sector Energy End-Use Splits



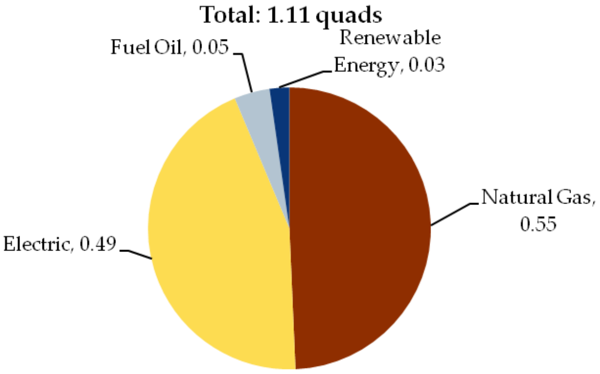
Source: 2008 Buildings Energy Data Book.
Data interpolated from 2006 and 2010 figures

This chapter focuses primarily on natural gas and electric commercial water heaters. Nearly all commercial water heaters use either natural gas or electricity as the energy source. Other less common fuel sources include propane, fuel oil, and renewable sources such as solar and geothermal energy. Propane and fuel oil represent a steadily declining share of the installed base, while renewable energy sources are expected to slowly increase in market share. This chapter does not focus on residential-style water heaters, which are sometimes used in commercial buildings with small hot water heating needs.

6.1 General Description

Traditional commercial water heating equipment includes storage tank heaters, booster heaters, instantaneous, and stand-alone heaters. Most are fueled by either natural gas or electricity. Figure 6-2 below shows the estimated water heating primary energy use by fuel type (DOE 2008).

Figure 6-2: 2008 Commercial Water Heating Energy Use by Fuel Type (Quads)



Source: DOE 2008
Data interpolated from 2006 and 2010 figures

Most water heaters are classified by their energy input capacity, which is reported either as Btu/hr or MMBtu/hr for natural gas heaters and kW for electric heaters. Table 6-1 below summarizes the typical storage capacities and energy inputs for the most common types of commercial water heaters. The figures in the table are approximate and represent ranges of water heater models available at leading manufacturers' websites. The energy efficiency of each type of water heater is discussed in the Energy Use section of this chapter.

Table 6-1: Typical Capacities and Energy Input Ranges for Commercial Water-Heating Equipment

Water Heater Type	Energy Source	Tank Capacity Range[a] (gal)	Input Capacity Range[a]
Storage Heater	Natural Gas	25 – 600	45,000 – 2,500,000 [Btu/hr]
	Electric	40 – 2,500	5 – 3,000 [kW]
Booster Heater	Natural Gas	3 – 30	55,000 – 200,000 [Btu/hr]
	Electric	6 – 20	6 – 58 [kW]
Instantaneous	Natural Gas	14 [gpm]	15,000 – 380,000 [Btu/hr]
	Electric	12 [gpm]	2 – 100 [kW]
Stand-Alone	Natural Gas	—	145,000 – 2,000,000 [Btu/hr]

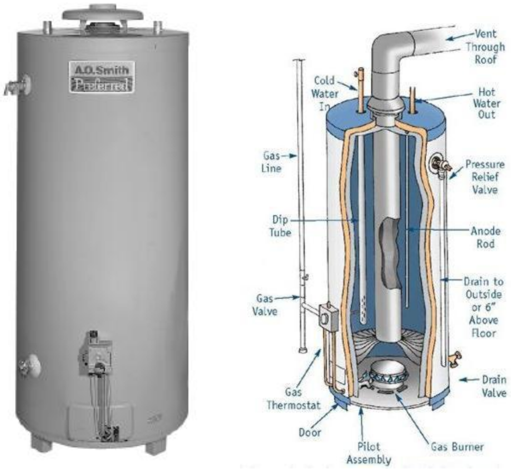
a. Figures obtained from leading manufacturers' websites

6.1.1 *Storage-Tank Water Heaters*

Natural-Gas Storage-Tank Water Heaters

Natural-gas storage-tank water heaters are the most common type of water heaters for commercial applications. Figure 6-3 below shows a typical gas storage water-heater design. In a natural-gas water heater, cold water enters the bottom of the tank through the dip tube. At the bottom of the tank, a gas burner heats the surrounding air, which rises vertically through the flue inside the tank. Heat is transferred from the hot air through the flue wall to the cold dense water at the bottom of the tank. As the water becomes heated, it rises to the top of the tank as its density decreases. Hot water is drawn from the tank through the hot water outlet tube, which is much shorter than the cold water dip tube. This ensures that only the hottest water is drawn from the tank. Most tanks also have a metal rod called a sacrificial anode, which is fastened to the top of the tank and extends deep into the tank. Its purpose is to draw corrosion to itself instead of the metal components of the tank.

Figure 6-3: Natural-Gas Storage-Tank Water-Heater Design



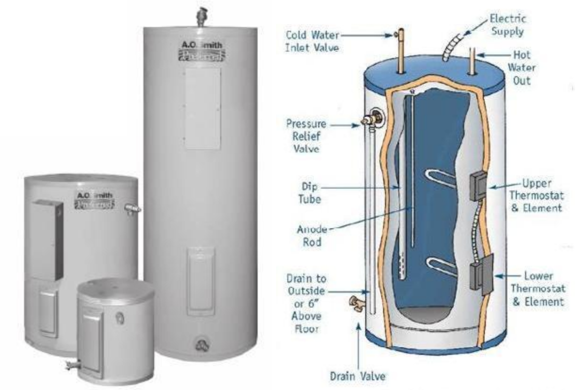
Sources: Left: A.O. Smith (AOSmith 2009); Right: Calaway Plumbing (Calaway 2009)

The input capacity of natural gas water heaters is typically measured in Btu/hour. Capacities for commercial natural gas water heaters range from 45,000 to 2,500,000 Btu/hour. Internal storage tank sizes range from 25 gallons for small-capacity units to 600 gallons for the highest-capacity units.

Electric Storage-Tank Water Heaters

Electric water heaters operate in much the same fashion as gas water heaters, except that the water is heated by resistive heating elements inside the tank. Figure 6-4 below shows a typical electric storage water heater design. As with gas water heaters, the cold water enters through the dip tube to the bottom of the tank, and hot water is drawn from the top of the tank. Small commercial water heaters may have just one or two heating elements, while the highest-capacity units may have up to 200 individual heating elements.

Figure 6-4: Electric Storage-Tank Water-Heater Design



Sources: A.O. Smith (AOSmith 2009); Right: Calaway Plumbing (Calaway 2009)

The input capacity of electric water heaters is measured in kW. Capacities for commercial electric water heaters range from 5 to 3,000 kW. Internal storage tank sizes range from 40 gallons for small-capacity units to 2,500 gallons for the highest-capacity units.

6.1.2 Booster Heaters

Some commercial buildings also use booster water heaters for high-temperature applications. Figure 6-5 below shows a typical booster water heater design. Booster water heaters are typically smaller water heating units used by commercial dishwashers, laundry facilities, hospitals, and car washes where water temperatures must reach 180 degrees Fahrenheit or higher. Booster water heaters accept pre-heated water from the storage water heater and raise it to the desired temperature. This is often more cost-effective and energy-efficient than heating the water to 180 degrees using the storage water heater. Sales of booster water heaters are small due to the limited number of applications. Natural gas booster water heaters have capacities of 3 to 30 gallons and inputs of 55,000 to 200,000 Btu/hr. Electric booster water heaters have capacities of 6 to 20 gallons and inputs of 6 to 58 kW.

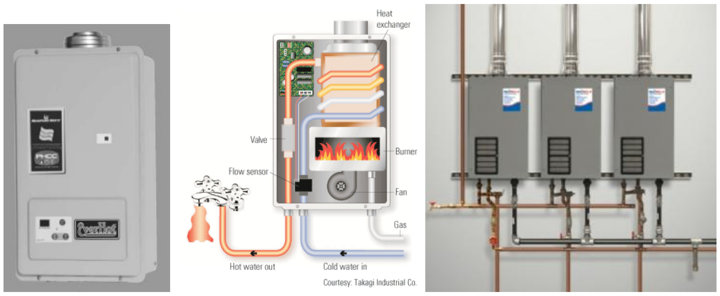
Figure 6-5: Booster Water Heaters

Sources: Left: Energy Solutions Center (ESC 2009); Right: PrecisionTemp (Precision 2009)

6.1.3 *Instantaneous Heaters*

Instantaneous water heaters—also called tankless or on-demand water heaters—heat the water supply as it is drawn through the unit, without using a storage tank. Figure 6-6 below shows a typical instantaneous water heater design. Instantaneous water heaters run a water supply pipe through a heat exchanger, producing a constant supply of hot water. Electric instantaneous water heaters are less practical for large-capacity applications because of the high power-draw requirements. However, as shown in the figure below, for higher-capacity applications multiple units can be installed in parallel to produce the required water flow rates.

Figure 6-6: Natural Gas Instantaneous Water Heaters



Sources: Left: Bradford White (Bradford 2009); Center: Takagi Industrial Co. (Takagi 2009); Right: Low Energy Systems, Inc. (LES 2009)

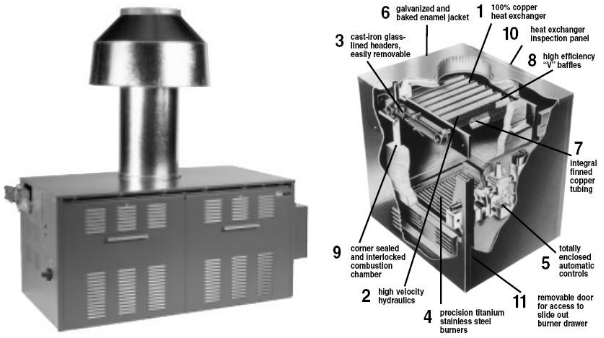
Natural gas instantaneous water heaters range in capacity from 15,000 to 380,000 Btu/hr, providing water flow rates up to 14 gpm. Electric instantaneous water heaters range in capacity from 2 – 100 kW and can provide water flow rates up to 12 gpm.

6.1.4 *Stand-Alone Heaters*

For certain applications, the water heater may function as a stand-alone heating unit attached to a separate insulated water storage tank. Figure 6-7 below shows an indoor high-capacity water supply heater with an input of 1,826,000 Btu/hr. Stand-alone gas heaters range in capacity from

145,000 to 2,000,000 Btu/hr. Stand-alone water heaters use external storage tanks for water storage. Standard insulated storage tanks range from 80 to 12,500 gallons.

Figure 6-7: Stand-Alone High-Capacity Natural Gas Heater



Source: Rheem (Rheem 2009)

Table 6-2 below shows the typical thermal efficiencies of the installed base of commercial water heating equipment (Navigant 2007).

Table 6-2: Thermal Efficiencies of Installed Base of Commercial Water Heating Equipment, 2007

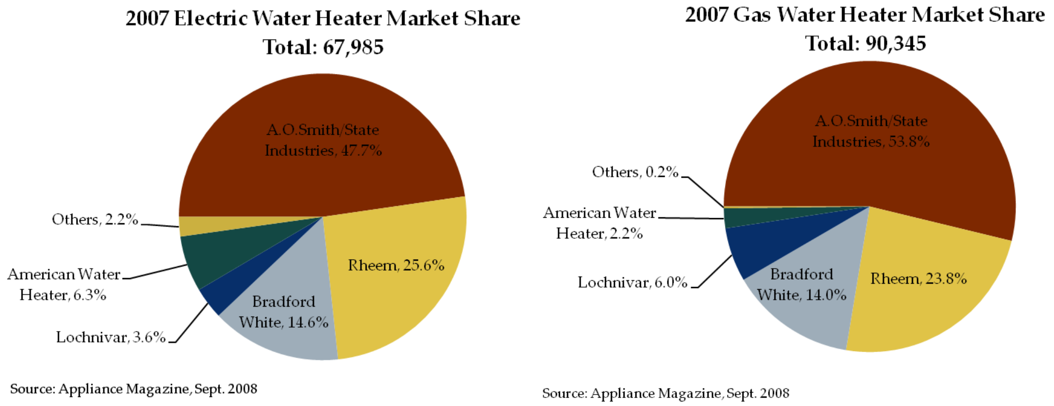
Commercial Water Heating Equipment	Thermal Efficiency (%))
Gas Storage	77
Gas Booster	79
Gas Instantaneous	76
Electric Storage	97
Electric Booster	98
Electric Instantaneous	99

Source: Navigant Consulting, Sept 2007 (Navigant 2007)

6.2 *Major Manufacturers and Market Shares*

The major manufacturers of commercial water heating equipment are A.O. Smith/State Industries, Rheem, Bradford White, Lochnivar, and American Water Heater. Figure 6-8 shows the market shares of the major manufacturers of electric and gas water heaters in 2007 (Appliance 2008).

Figure 6-8: Major Manufacturer Market Shares for Electric and Gas Commercial Water Heaters



Source: Appliance Magazine (Appliance 2008)

These major manufacturers focus primarily on electric and natural gas storage water heaters, with some sales of tankless water heaters. Many manufacturers offer both conventional and high-efficiency product lines, with the majority of sales encompassing conventional water heating products. Manufacturers of enhanced-efficiency water heating systems are often smaller companies without the resources to conduct major national education and marketing programs (EPRI 1992).

6.3 *Major End-Users*

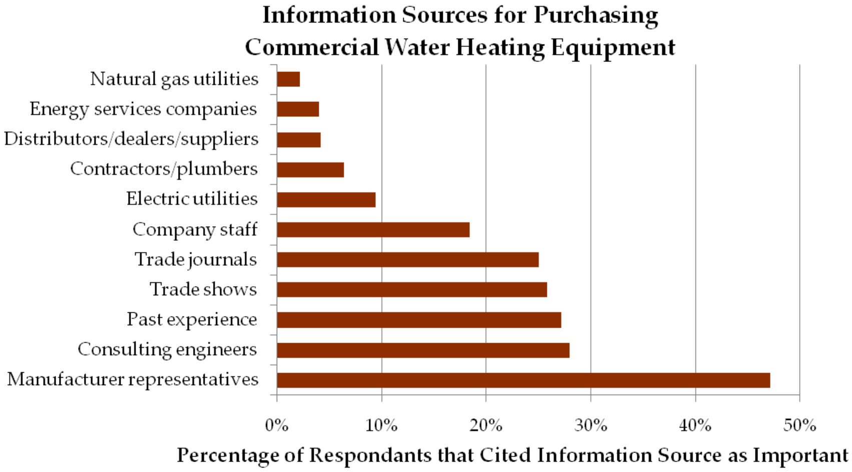
Water heaters are used by a wide range of commercial building types. The 2003 Commercial Buildings Energy Consumption Survey (CBECS 2003) includes the following commercial building categories:

- Education
- Food sales
- Food service
- Heath care (Inpatient & Outpatient)
- Lodging
- Retail
- Office
- Public assembly
- Public order and safety
- Religious worship
- Service
- Warehouse and storage

Decisions about the purchasing of energy-consuming equipment, including water heaters, can be made at a regional or national level—for example, by a company's headquarters—or at individual locations by members of the local staff. In most cases, the groups or individuals with the most important role in purchasing new equipment are members of the engineering or maintenance departments, facility managers, or senior managers within the company. This applies for both new construction and renovation or replacement of existing water heaters (EEA 2003).

Information about water heating equipment is obtained from a variety of sources, including manufacturers, contractors, consultants, trade shows and journals, utilities, and prior experience. Figure 6-9 below shows the relative importance of each information source for making decisions about commercial water heater purchases. These results are based on surveys of supermarkets, health care providers, hotels, restaurants, and retail chains. The surveys were conducted by Opinion Dynamics Corp in 1998. The survey results are based on responses from decision makers responsible for 3,000 chain health care facilities; 20,000 grocery stores; 7,000 chain lodging facilities; 41,000 chain restaurants; and 31,000 chain retail stores nationwide. The data in the figure represents the average across the five commercial segments (EEA 2003).

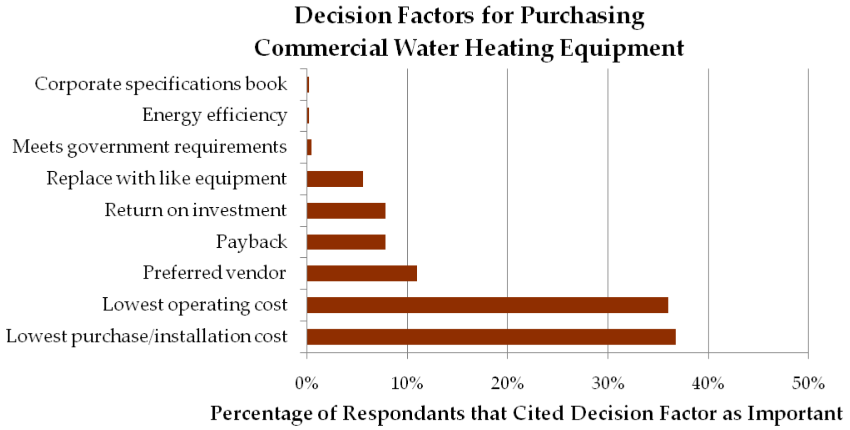
Figure 6-9: Important Sources of Information for Commercial Water Heater Purchases



Source: Energy and Environmental Analysis, Inc. (EEA 2003).
Results based on a survey of supermarkets, health care providers, hotels, restaurants, and retail chains. Data in the figure represents the average across the five commercial segments surveyed.

Customers use a variety of criteria when selecting which water heating equipment to purchase. Figure 6-10 below shows the relative importance of each criterion when making decisions about commercial water heater purchases. The data in the figure represents the average across the five commercial segments listed above (EEA 2003).

Figure 6-10: Important Criteria for Making Commercial Water Heater Purchases



Source: Energy and Environmental Analysis, Inc. (EEA 2003).
Results based on a survey of supermarkets, health care providers, hotels, restaurants, and retail chains. Data in the figure represents the average across the five commercial segments surveyed.

Figure 6-10 above indicates that by far the most important decision factors for water heater purchases are installation costs and operating costs. However, these factors tend to be mutually exclusive. Our interpretation is that consumers simply want low costs overall, but that the survey results don't indicate the first-cost vs. operating cost tradeoffs that the consumers might be willing to make. The results also suggest that consumers don't necessarily link high efficiency with low operating costs.

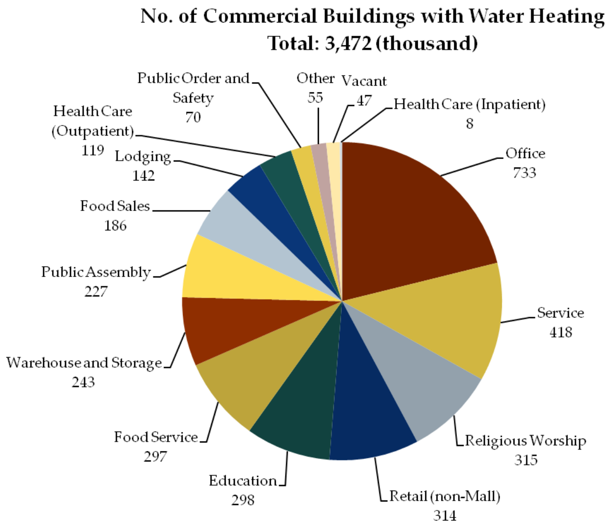
6.4 *Typical Distribution Chain*

Commercial water heaters are typically sold to end-users through wholesale distribution channels. For example, A.O. Smith Corporation, the largest manufacturer of commercial water heaters, has a distribution channel that includes more than 1,100 independent wholesale plumbing distributors, with more than 4,600 selling locations serving residential, commercial, and industrial markets. In addition, the company also sells its residential water heaters through the retail channel, which includes five of the seven largest national hardware and home center chains (AOSmith 2009).

6.5 *Annual Shipments and Installed Base*

The 2003 CBECS estimates that 3,472,000 commercial buildings use water heating. Figure 6-11 shows a more detailed estimate categorized by principal building activity. Note that these figures include non-Mall buildings only, and thus are not directly comparable to CBECS from previous years (CBECS 2003).

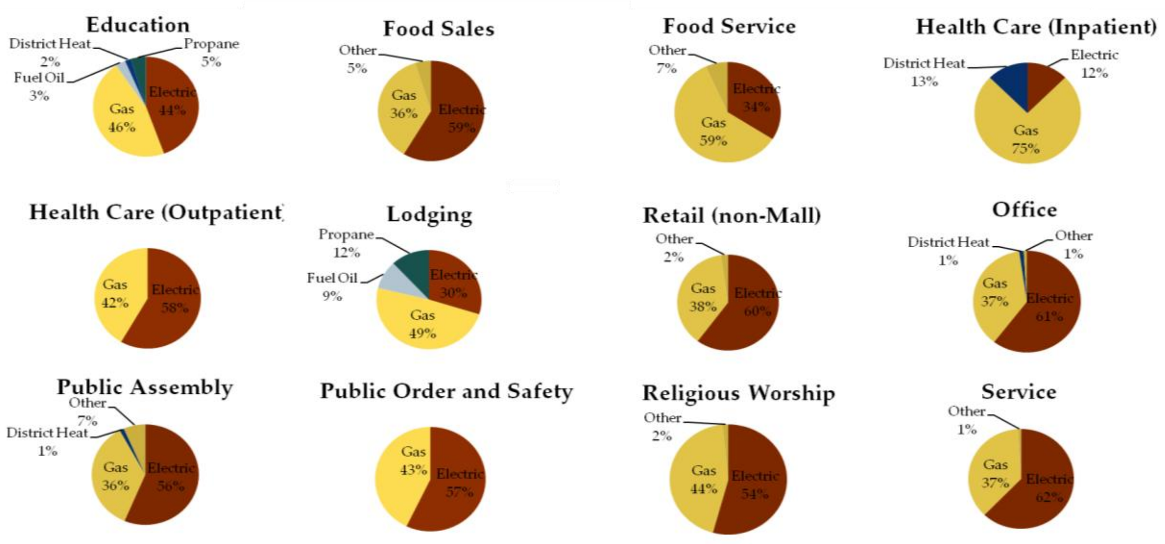
Figure 6-11: Number and Type of Commercial Buildings with Water Heating



Source: CBECS 2003, Table B31
These figures include non-Mall buildings only, and thus are not directly comparable to CBECS from previous years.

The share of water heating energy consumption of each building type differs dramatically from the share of total number of buildings shown above. The energy consumption of each building type is discussed in the Energy Use section of this chapter. Figure 6-12 shows the percentage of buildings using each water-heating energy source, by building type (CBECS 2003).

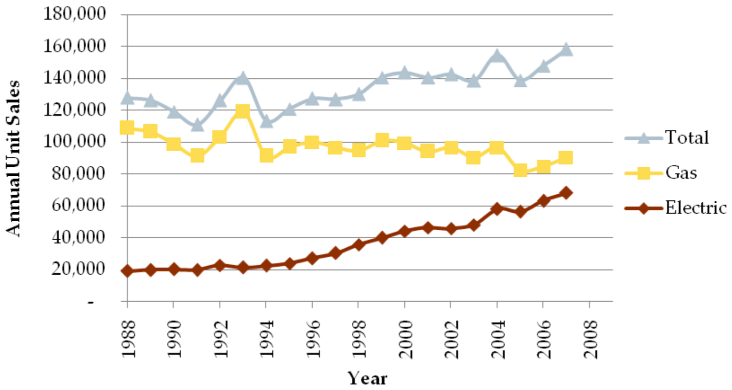
Figure 6-12: Water Heating Energy Source by Building Type



Source: CBECS 2003. More than one energy source may apply to each building type.

Figure 6-13 below shows the annual sales of commercial electric and gas water heaters provided by Gas Appliance Manufacturers Association (GAMA), now a part of the Air Conditioning, Heating, and Refrigeration Institute (AHRI). These figures include traditional commercial storage water heaters only and do not include high-efficiency or instantaneous water heaters. Residential style systems are excluded from the GAMA commercial sales data (AHRI 2009). On average, gas storage water heaters have slowly lost market share to electric storage water heaters over the past twenty years.

Figure 6-13: Annual Sales of Commercial Storage Water Heaters



Source: GAMA/AHRI shipment data. These figures include traditional commercial storage water heaters only and do not include high-efficiency or instantaneous water heaters. Residential-style heaters used in commercial buildings are not accounted for in this data.

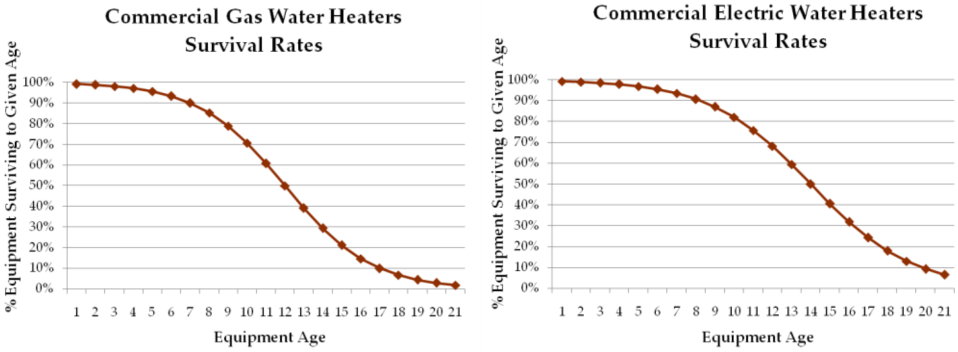
We estimated the current installed base of storage water heaters based on the GAMA/AHRI annual shipment data. We believe that this provides a more reliable estimate than an interpolation of the CBECS data. To estimate the current installed base of storage water heaters, we created a water heater survival rate model based on the annual shipment data and average equipment lifetimes, shown below in Table 6-3. We created water heater equipment survival curves shown below in Figure 6-14 to estimate the fraction of equipment surviving to a given age.

Table 6-3: Average Useful Lifetimes for Commercial Water Heaters

Water Heater Type	Average Useful Life (years)
Commercial Gas Water Heaters	11
Commercial Electric Water Heaters	13

Source: 2008 Buildings Energy Data Book, Table 5.7.15 (DOE 2008)

Figure 6-14: Equipment survival rates used to estimate currently installed base



Source: Navigant Consulting water heater survival rate model

This model was used derive estimates for the current installed base of commercial storage water heaters, as shown in Table 6-4 below.

Table 6-4: Estimated Installed Base of Commercial Storage Water Heaters in 2008

Water Heater Type	Installed Base
Commercial Gas Storage Water Heaters	1,200,000
Commercial Electric Storage Water Heaters	600,000
Total	**1,800,000**
Estimates based on GAMA/AHRI shipment data and Navigant Consulting water heater survival model	

The estimate of 1,800,000 commercial storage water heaters represents roughly 50 percent of the 3,472,000 commercial buildings with water heaters reported in the 2003 CBECS. The remaining 50 percent of buildings are believed to use water heaters not included in GAMA/AHRI shipment data such as high efficiency technologies, instantaneous water heaters, and residential water heaters for smaller commercial buildings.

The DOE estimates that instantaneous water heaters represent roughly one-third of commercial water-heater shipments (DOE 2000). Using this assumption, we estimate there are roughly 600,000 installed instantaneous water heaters, as shown in Table 6-5 below.

Table 6-5: Estimated Installed Base of Commercial Instantaneous Water Heaters in 2008

Water Heater Type	Estimated Installed Base
Commercial Instantaneous Water Heaters	600,000
Based on DOE Screening Analysis estimate of share of water heater shipments attributed to instantaneous water heaters (DOE 2000).	

The Electric Power Research Institute (EPRI) estimates that approximately 80 percent of water heater sales are replacement units for existing buildings, and the remaining 20 percent are installed during new construction (EPRI 1992).

6.6 *Baseline Energy Consumption*

We developed a model that calculates total annual energy consumption of commercial storage tank water heaters using estimates of the installed base of heaters, number of annual operating hours for each commercial sector, and typical water heater capacities. Table 6-6 below summarizes the results for electric and gas-fired commercial water heaters. For the purposes of estimating baseline energy consumption, we focused on traditional storage tank heaters because storage tank heaters represent the vast majority of the current market and total energy consumption. In addition, advanced technology and instantaneous heaters are already highly energy efficient. Residential-style water-heating equipment, while used in some commercial buildings, represents a small share of the total energy use and is not included in the table.

Table 6-6: Estimated Primary Annual Energy Consumption of Commercial Electric and Gas-Fired Storage Water Heaters, 2008

Fuel Type	Primary Annual Energy Consumption [Quads/yr]
Natural Gas	0.383
Electricity (Primary)	0.280
TOTAL	**0.662 Quads**

The following sections describe the derivation of the annual energy consumption results.

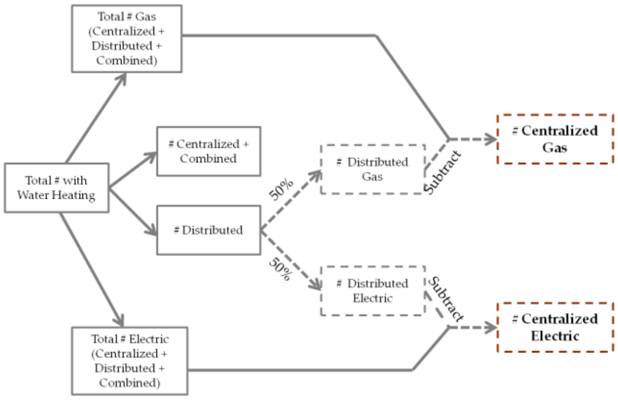
6.6.1 *Installed Base Breakdown by Commercial Sector*

To estimate the installed base of electric and gas storage water heaters, we first calculated the installed base implied by the 2003 CBECS data, which includes the following:

- Total number of buildings with water heating
- Number of buildings with gas water heating
- Number of buildings with electric water heating
- Number of buildings with "Distributed" water heating systems
- Number of buildings with "Centralized" water heating systems
- Number of buildings with both "Combined" distributed and centralized systems

The flow chart shown below in Figure 6-15 describes our calculation process.

Figure 6-15: Flow Chart for Installed Base Calculations



Solid lines represent data directly available from CBECS.
Dashed lines represent calculations performed by NCI.

The CBECS data classifies storage tank water heaters as "Centralized" water heating systems. Instantaneous and residential-size water heaters are classified as "Distributed" water heating systems. For our model, we assume that half of the distributed or unclassified systems are electric, and half are natural gas. We based this on the fact that sales of residential storage water heaters are split roughly equal between electric and natural gas. We then subtracted the estimated number of distributed water heaters for each fuel type from the total number of water heaters for each fuel type, which was available from the CBECS data. This produced the implied number of electric and natural gas storage tank water heaters for each commercial building sector. These calculation steps are shown in Table E-1 in Appendix E.

Finally, we adjusted the number of water heaters for each commercial sector such that the total number of heaters equals our estimated installed base, shown previously in Table 6-4. For each sector, we used the same proportion of total heaters implied by the CBECS data. This is the same method used in the 1993 ADL report (ADL 1993). The last two columns of Table E-1 below show the number of electric and natural gas storage water heaters for each commercial sector based on our model.

Hot water usage varies widely throughout the commercial sector, and the best options for modifying or replacing existing water heating equipment depend on the specific needs of each location. The 1993 ADL report includes a table of commercial sector water heating energy use by building type and by fuel type. We reproduced the ADL table and substituted updated figures for number of buildings and water heater efficiencies. Table E-1 in Appendix E shows our estimated operating hours and input capacities for commercial storage water heaters. Table 6-7 below shows our calculations for determining commercial water heating energy consumption.

Table 6-7: Commercial Water Heating Energy Consumption Calculations

Building Type	Fuel Type	Annual Operating Hours[a]	Input Rated Capacity[b,c] (Btu/hr)	Unit Energy Consumption[d] (Btu/yr)	Total Site Energy Consumption[e] (Btu/yr)	Total Primary Energy Consumption[a] (Btu/yr)
Education	Gas	1600	250,000	4.00E+08	5.12E+13	5.12E+13
	Electric	2200	125,000	2.75E+08	1.16E+13	3.67E+13
Food Sales	Gas	1400	100,000	1.40E+08	7.98E+12	7.98E+12
	Electric	2150	50,000	1.08E+08	3.87E+12	1.23E+13
Food Service	Gas	3200	290,000	9.28E+08	1.59E+14	1.59E+14
	Electric	4900	150,000	7.35E+08	2.13E+13	6.78E+13
Health Care – Inpatient	Gas	3650	510,000	1.86E+09	1.12E+13	1.12E+13
	Electric	5550	200,000	1.11E+09	0.00E+00	0.00E+00
Health Care – Outpatient	Gas	1100	120,000	1.32E+08	6.20E+12	6.20E+12
	Electric	1700	65,000	1.11E+08	2.65E+12	8.43E+12
Lodging	Gas	2100	350,000	7.35E+08	5.66E+13	5.66E+13
	Electric	3200	140,000	4.48E+08	6.72E+12	2.14E+13
Retail (Other than Mall)	Gas	1100	120,000	1.32E+08	1.15E+13	1.15E+13
	Electric	1700	65,000	1.11E+08	6.52E+12	2.07E+13
Office	Gas	1100	100,000	1.10E+08	2.44E+13	2.44E+13
	Electric	1700	40,000	6.80E+07	9.86E+12	3.14E+13
Public Assembly	Gas	1100	120,000	1.32E+08	8.32E+12	8.32E+12
	Electric	1700	65,000	1.11E+08	4.42E+12	1.41E+13
Public Order and Safety	Gas	1600	250,000	4.00E+08	8.80E+12	8.80E+12
	Electric	2200	100,000	2.20E+08	2.42E+12	7.70E+12
Religious Worship	Gas	1100	120,000	1.32E+08	1.54E+13	1.54E+13
	Electric	1700	65,000	1.11E+08	5.86E+12	1.86E+13
Service	Gas	1100	120,000	1.32E+08	1.32E+13	1.32E+13
	Electric	1700	65,000	1.11E+08	8.51E+12	2.71E+13
Warehouse and Storage	Gas	600	100,000	6.00E+07	3.54E+12	3.54E+12
	Electric	920	50,000	4.60E+07	2.39E+12	7.61E+12
Other	Gas	1100	120,000	1.32E+08	2.11E+12	2.11E+12
	Electric	1700	65,000	1.11E+08	1.11E+12	3.51E+12
Vacant	Gas	1100	120,000	1.32E+08	3.56E+12	3.56E+12
	Electric	1700	65,000	1.11E+08	7.74E+11	2.46E+12
TOTAL					**4.71E+14**	**6.62E+14**

a) Annual operating hours the same estimates used by ADL.(ADL 1993)

b) Adjusted from ADL's estimated input rated capacity such that the total output capacity remains the same using a higher efficiency value of 77% versus 60% in the ADL report.

c) Our model includes more categories than the ADL model. We assumed that Health Care Outpatient, Public Assembly, Religious Worship, Other, and Vacant use the same size equipment as the Service sector; and Public Order and Safety use the same size equipment as Education.

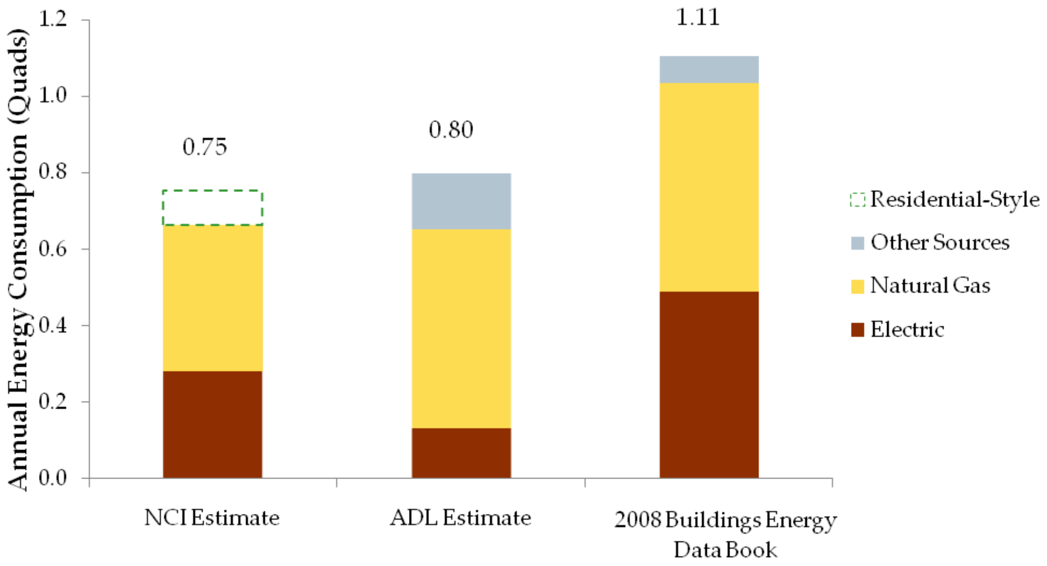
d) Unit energy consumption calculated by multiplying the input capacity rating by the annual operating hours for each type of water heater.

e) Total site energy consumption calculated by multiplying the unit energy consumption by the number of installed units from Table E-1.

f) Assumes electricity production factor of 3.18

Our water heating model yields a primary energy consumption of 0.662 Quads for commercial electric and gas storage water heaters. Figure 6-16 compares these figures to estimates from the ADL 1993 report and the 2008 Buildings Energy Data Book. The figure includes an estimate for residential-style water heater energy usage in commercial buildings, which are described in Appendix E. Including the residential-style water heater energy consumption, we estimate commercial building storage tank water heating energy usage of 0.75 Quads annually.

Figure 6-16: Comparison of commercial water heating energy consumption figures



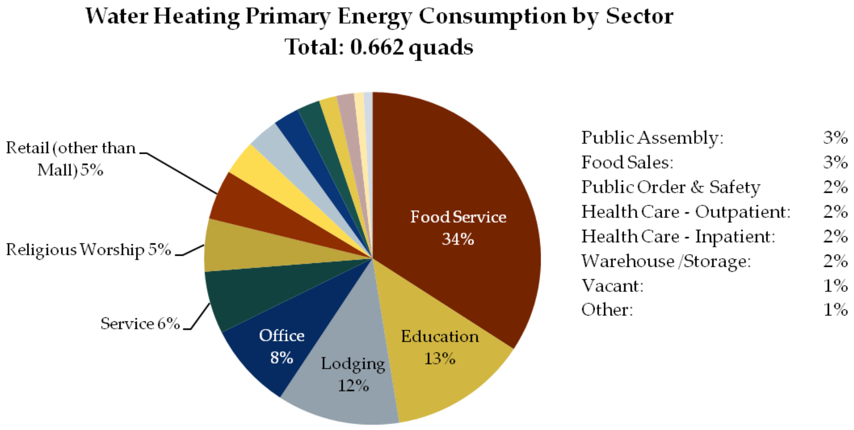
Sources: ADL 1993, DOE 2008

Note: Includes energy usage of electric and gas commercial storage tank water heaters only. Estimates for residential-style water heaters are described in Appendix E. Energy usage from other sources were not considered in this report. Other sources include: propane, oil, renewable sources.

Our estimate is in line with the 1993 ADL estimate, which is to be expected since we based the structure of our energy consumption model on the ADL model. We also have not accounted for any other fuel sources such as oil or renewable fuels. However, both the NCI and ADL estimates are significantly lower than the 2008 Buildings Energy Data Book estimate of 1.12 Quads. Because the Buildings Data Book does not provide sufficient explanation of its data, we are unable to isolate the source of the discrepancy. Based on this analysis, we believe that the Buildings Data Book may overestimate commercial water heating energy usage.

Finally, it is useful to examine the differences in water heater usage among commercial building sectors. Figure 6-17 shows the total annual water heating energy consumption by sector. Food service, education, lodging, and office buildings together account for two-thirds of the total annual water-heating energy consumption.

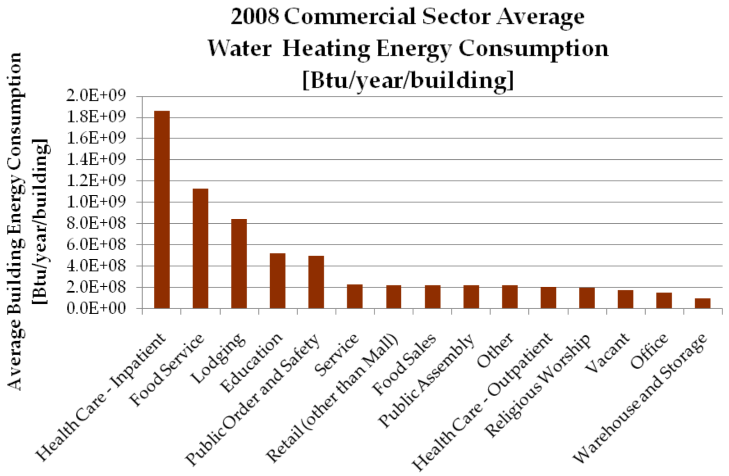
Figure 6-17: Water Heating Primary Energy Consumption by Sector



Source: Navigant Consulting energy consumption model

It is also useful to examine the average water heating energy consumption of each commercial building type. This helps identify the individual commercial building types that consume the most water heating energy, which is important to understand for future net-zero energy commercial building programs. Figure 6-18 below shows the average building energy consumption within each sector. This was calculated by dividing the total sector primary energy consumption by the number of installed water heaters in that sector.

Figure 6-18: Average Building Water Heating Primary Energy Consumption for 2008



Average water heating energy consumption is calculated by dividing total sector primary energy usage by number of installed water heaters in that sector

This figure shows that inpatient health care buildings, which includes primarily hospitals, have the highest per-building water heating energy usage, followed by food service and lodging. This is to be expected, since hospitals, hotels and motels use large amounts of hot water for laundry, showers, and other purposes. Food service buildings use large amounts of hot water during the preparation of food and for dish washing. These three commercial building sectors should be highlighted in future DOE energy saving programs.

6.7 *Cost Breakdown*

Table 6-8 below shows the typical cost breakdown for standard commercial water heating equipment as of 2007 (Navigant Consulting 2007).

Table 6-8: Typical Cost Breakdown for Standard Commercial Water Heating Equipment, 2007

Commercial Water Heating Equipment Type	Retail Equipment Cost	Total Installed Cost	Annual Maintenance Cost
Gas Storage	\$2,000 - \$4,000	\$2,500 - \$4,500	\$100 - \$200
Gas Booster	\$3,800 – \$5,500	\$4,100 – \$5,800	Negligible
Gas Instantaneous	\$800 - \$1,000	\$950 - \$1,250	Negligible
Electric Storage	\$2,400 - \$3,000	\$3,000 - \$3,500	\$50
Electric Booster	\$1,150 - \$1,550	\$1,350 - \$1,750	Negligible
Electric Instantaneous	\$150 - \$250	N/A	N/A

Source: Navigant Consulting, Inc., "Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case Second Edition (Revised), Sept 2007

6.8 *Lifetime, Reliability, and Maintenance Characteristics*

Table 6-9 below shows the average equipment lifetime for commercial water heating equipment (Navigant Consulting 2007).

Table 6-9: Average Lifetime of Commercial Water Heating Equipment

Commercial Water Heating Equipment Type	Avg. Equipment Lifetime (yrs)
Gas Storage	12
Gas Booster	3 – 8
Gas Instantaneous	20
Electric Storage	14
Electric Booster	3 – 8
Electric Instantaneous	20

Source: Navigant Consulting, Inc. (Navigant 2007)

6.9 *Regulatory Programs*

Commercial water heating equipment must conform to the efficiency standards described in the direct final rule from October 21, 2004 (69 FR 61974), shown below in Table 6-10. The table omits the standards for oil-fired equipment.

Table 6-10: Efficiency Standards for Commercial Water Heating Equipment

Product[a]	Size	Minimum thermal efficiency	Maximum standby loss (Btu/hr)[b]
Electric storage water heaters	All	N/A	0.30 + 27/Vm (%/hr)
Gas-fired storage water heaters	≤ 155,000 Btu/hr	80%	$Q/800 + 100(Vr)^{1/2}$
	> 155,000 Btu/hr	80%	$Q/800 + 100(Vr)^{1/2}$
Gas-fired instantaneous water heaters and hot water supply boilers	< 10 gal	80%	N/A

a. This table omits the standards for oil-fired equipment

b. Vm is the measured storage volume and Vr is the rated volume, in gallons. Q is the nameplate input rate in Btu/hr.

6.10 *Voluntary Programs*

AHRI has an energy efficiency certification program that independently measures and verifies manufacturer performance claims. Manufacturers voluntarily participate in AHRI's certification programs to demonstrate to their customers that their equipment and component performance claims have been verified by an independent, third party. This program, however, does not establish target energy efficiency levels.

6.11 *Energy-saving Technologies*

Energy efficiency improvements to commercial water heaters can be achieved with modifications to existing water heating systems or with alternative water heating technologies to replace systems currently in use. For this report, we did not include modifications to the design of hot water distribution systems, which can also provide efficiency improvements. The following sections describe technologies that reduce standby heat loss, heat recovery technologies, and alternative water heating technologies. Table 6-11 below summarizes the primary energy savings potential and technical potential of all the technologies covered in this chapter. The technologies in the table are arranged from highest to lowest technical potential. The sections following the table provide detailed descriptions of each technology and our energy savings estimates.

Table 6-11: Summary of Primary Energy Savings Potential of all Water Heating Technology Options

Technology	Unit Energy Savings Potential vs. Traditional Gas Storage Water Heater	Total Primary Energy Savings Technical Potential (Btu/yr)
Solar Thermal Water Heaters	50%	3.13E+14
Drain Water Heat Recovery	30%	1.99E+14
Absorption Heat Pump	40%	1.92E+14
Heat Pump Water Heaters	50%	1.45E+14
Condensing Water Heaters	18%	1.20E+14
Instantaneous Water Heaters	15%	7.27E+13
Desuperheaters	11%	7.22E+13
Storage Tank Jacket	40% (standby losses)	1.09E+13
Heat traps	25% (standby losses)	6.80E+12
Piping Insulation	3% (standby losses)	0.80E+12

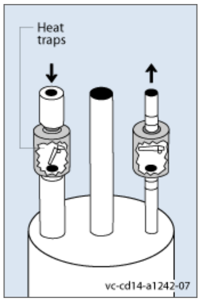
6.11.1 Technologies that Reduce Standby Heat Loss

The technologies described in this section save energy primarily by reducing the standby heat loss associated with storage tank water heaters. A summary of the potential energy savings is provided after the descriptions of each option below.

Heat traps

Heat traps, shown in Figure 6-19, are one-way valves that prevent convective heat losses through the water heater inlet and outlet pipes. They allow cold water to flow into the tank but prevent unwanted hot water from flowing out of the tank. Heat traps contain valves with balls inside that either float or sink into a seat, which stops the flow of water. Separate valves are used on the hot and cold water lines.

Figure 6-19: Heat Traps for Storage-Tank Water Heaters.



Source: DOE Energy Savers website (EERE 2009)

A pair of heat traps costs around $30, not including installation costs, and are most cost effective when installed at the same time as the water heater. Many new storage tank water heaters have factory-installed heat traps, or they are available as an option. DOE estimates that heat traps can prevent up to 25% of a water heater's standby losses (EERE 2009).

Piping insulation

Insulating hot water pipes reduces the heat loss that occurs from the pipes to the surrounding air. Heat loss from the pipes is an additional source of standby heat loss for all types of water heaters. Pipe sleeves made with polyethylene or neoprene foam are the most commonly used types of pipe insulation. Insulation is very inexpensive and can be easily installed around pipes, assuming the pipes can be accessed. Figure 6-20 below shows typical usage of pipe insulation.

Figure 6-20: Typical Use of Piping Insulation

Sources: Left: Energy Circle (EC 2009); Right: EcoFinancing website (EcoFinancing 2009)

Heat loss occurs any time the hot water pipes contain hot water. Piping insulation is especially beneficial for buildings that use hot water recirculation loops. A recirculation loop periodically replaces the cool water in the pipes with fresh hot water, so that sinks or other hot water fixtures located far from the water heater do not have to waste as much water waiting for hot water to travel from the storage tank to the fixture. Since recirculation loops constantly keep the pipes filled with hot water, piping insulation is especially important for reducing the cumulative heat loss from the pipes.

Using piping insulation allows the water heater to be set at a lower temperature setting, since less heat is lost to the surrounding air. It also results in water savings since less water is wasted waiting for hot water to arrive at the sink or water fixture. DOE estimates that using pipe insulation allows the water heater to be set 2-4°F lower on average (EERE 2009). Assuming the water heater heats the water by 75°F, this represents roughly 2-5% decrease in water tank temperature. This energy savings would apply primarily to the standby losses in the tank. For our calculations we assumed an energy savings of 3% of standby losses, recognizing that this could be highly variable based on the particular setup and hot water usage patterns.

Storage tank jacket

A storage tank jacket is an insulated jacket that can be installed around a storage tank heater to decrease the rate of standby heat loss. Storage tank jackets are easily installed and cost around $20 or less. Storage tank jackets are most useful for uninsulated storage tanks, but can also provide energy savings for insulated storage tanks with low insulation R-values. DOE estimates that adding insulation to a storage tank heater with an insulation rating less than R-24 can reduce standby heat losses by 25%-45% (EERE 2009). NCI is unaware of any data regarding the average insulation rating of the installed base of commercial storage water heaters; although, we believe the majority of commercial storage water heaters have at least some level of insulation. We assumed a standby heat loss savings of 40% for all commercial storage tank water heaters.

Summary of energy savings

Table 6-12 below provides a summary of the standby loss energy savings we assumed for each of the three technologies above. All three types of equipment are commercially available and in use among some of the installed base.

Table 6-12: Summary of Standby Loss Energy Savings Potential of Each Technology Option

Water Heater Addition	Standby Energy Savings
Heat traps	25%
Piping insulation	3%
Storage tank jacket	40%

The GAMA/AHRI Water Heater Efficiency Certification Program maintains a database of commercial water heaters that lists the certified values for thermal efficiency and standby loss for each water heater model (AHRI 2009). Based on the information in this database, the average energy loss due to standby losses is approximately 1,000 Btu/hr per unit, for a total of 8,760,000 Btu/year/unit (site energy usage). Table 6-13 below provides an estimate of the total energy savings potential for the estimated installed base of 1,200,000 commercial gas heaters and 600,000 commercial electric heaters.

Table 6-13. Energy Savings Potential of Technologies That Reduce Standby Heat Loss

Technology Option	Annual Unit Standby Loss (Btu/yr)	Standby Loss Savings Potential (%)	Total Annual Gas Savings[a] (Btu/yr)	Total Annual Site Electric Savings (Btu/yr)	Total Annual Primary Electric Savings[b] (Btu/yr)	Total Primary Energy Savings Technical Potential (Btu/yr)
Heat traps	8.760,000	25%	2.6E+12	1.3E+12	4.2E+12	6.8E+12
Piping Insulation	8.760,000	3%	0.3E+12	0.16E+12	0.5E+12	0.8E+12
Storage Tank Jacket	8.760,000	40%	4.2E+12	2.1E+12	6.7E+12	1.09E+13

a. Assuming 1,200,000 commercial gas storage tank heaters
b. Assuming 600,000 commercial electric storage tank heaters

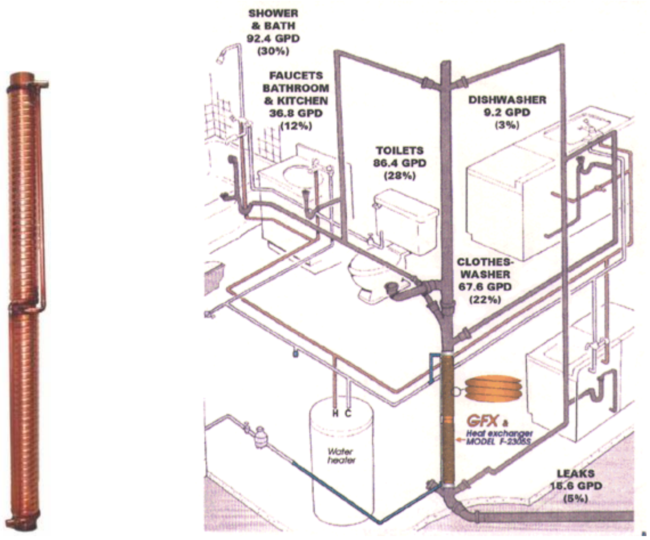
6.11.2 Heat Recovery Technology Options

Heat recovery technology options can be added to existing storage tank water heating equipment to increase the overall efficiency of the system. These technology options primarily recycle waste heat that would otherwise be lost to drain water or the atmosphere. A summary of the potential energy savings due to heat recovery technology options is provided after the descriptions of each option below.

Drain-Water Heat Recovery and Storage

Drain-water heat-recovery systems recover the heat from hot water in drain-water pipes and use it to pre-heat the incoming water supply. One way to achieve this is to wrap the incoming cold water pipe around the outgoing drain pipe using highly conductive pipe material such as copper. Figure 6-21 below shows an example of a commercially available drain water recovery system for residential water heaters and a typical installation in a single-family home.

Figure 6-21: Drain-Water Heat-Recovery System for Residential Use



Source: WaterFilm Energy Inc. (WaterFilm 2009)

One of the drawbacks to this type of system is that it works best only during simultaneous long-duration flows of hot water down the drain and cold water into the storage tank, such as during a shower. The system would not work well for a bath, for example, because there may not be a simultaneous flow of cold water into the water heater during the time that the bathtub is draining.

Another way to implement drain water heat recovery is locally at each faucet or shower head, such that the heat exchanger transfers heat from the drain pipe to the incoming cold water pipe directly at the site. With this type of implementation, the incoming cold water would be raised to a higher temperature, which would allow the user to use less hot water in order to achieve the desired water temperature. This would allow the system to work for almost all applications.

One of the current barriers for widespread implementation is the lack of knowledge among consumers, which translates into lack of demand for the technology. Consequently, there are only a few, small manufacturers that currently produce and sell this technology. Of those, most target the residential market.

Test data on the GFX drain water heat recovery system shows a heat recovery efficiency of 42%, at standard conditions of 2.5 gallons per minute flow rate at 96.8°F (WaterFilm 2009). For our calculations, we used an energy savings potential of 30% to account for slightly lower performance in real-world applications. We assumed that all commercial buildings could retrofit their hot water heating systems to accommodate a drain water heat recovery system.

While several vendors sell drain water heat recovery technology, it is still in the early stages of commercialization. High material cost and retrofit restrictions limit the extent to which market penetration can be achieved in retrofit applications and make it better suited for new construction. In particular, facilities with high hot-water demands (e.g. health clubs and hospitals) tend to have the quickest returns on investment. Leading suppliers include WaterFilm Energy, RenewABILITY Energy, Water Cycles Energy Recovery, ReTherm Energy Systems, and Winston Works. The main barriers that have prevented this technology from achieving wide-scale adoption in the commercial sector include:

- Limited retrofit feasibility
- High and volatile material costs (i.e., copper)
- Lack of awareness

Desuperheaters

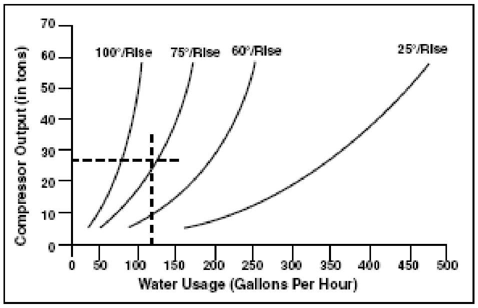
A desuperheater heats water by recovering waste heat from a vapor-compression space-cooling or refrigeration system. Typically, this heat exchange occurs by passing the hot refrigerant discharged from the compressor in the vapor-compression system through a heat exchanger that transfers the heated water to the storage tank. Alternatively, as shown below in Figure 6-22, the refrigerant can be piped to a heat exchanger built into the storage tank. This approach, however, safety codes require the heat exchanger to be double-wall, vented if the heat exchanger is immersed in a tank used to hold potable water.

Figure 6-22: Desuperheater Design That Surrounds a Storage Tank Heater, Transferring Heat from the Refrigerant to the Water in the Storage Tank

Source: Therma-Stor (ThermaStor 2009)

Energy savings estimates can be made by using temperature rise plots provided by the desuperheater manufacturer. Figure 6-23 below shows an example of this plot for a system sized for a supermarket (ThermaStor 2009).

Figure 6-23: Temperature Rise Plot for Desuperheater that Recovers Heat From Central HVAC System



Source: ThermaStor product brochures (ThermaStor 2009)

A typical desuperheater can recover between 2,000-3,000 Btu per ton-hr from a building air-conditioning system (e.g., a desuperheater could recover 20,000-30,000 Btu/hr from a 10-ton air conditioning system). We estimate that desuperheaters can provide roughly 10-15% total energy savings if implemented across all commercial building types. The derivation of this estimate is shown in Appendix E.

Summary

Table 6-14 below provides a summary of the development status of the heat recovery technology options described above.

Table 6-14: Development Status of Water Heater Modifications

Heat Recovery Technology Option	Development Status
Drain Water Heat Recovery & Storage	Limited commercial availability for residential applications.
Desuperheaters	Commercially available.

Table 6-15 below summarizes the estimates of the total energy savings potential of the water heating modification equipment options.

Table 6-15: Total Energy Savings Potential of Water Heating Modifications

Heat Recovery Technology Option	Energy Savings Potential (%)	Applicable Size Water Heater	Applicable Energy Consumption (Btu/hr)	Total Primary Energy Savings Technical Potential (Btu/yr)
Drain Water Heat Recovery	30%	All Sizes	6.62E+14	1.99E+14
Desuperheaters	11%	All Sizes	6.62E+14	7.22E+13

6.11.3 Alternative Water Heating Technologies

Alternative water heating technologies are advanced, higher-efficiency water heating technologies that offer significant energy savings compared to traditional gas or electric storage water heaters. For this report we considered replacement instantaneous water heaters, condensing gas water heaters, electric heat pump water heaters, and gas absorption heat pump water heaters.

Instantaneous Water Heaters

Instantaneous water heaters can be used to supplement hot water heaters for water fixtures located far from the water heater, or they can serve as a complete replacement for water heaters serving modest water heating loads. Instantaneous water heaters are available as both electric and natural gas units. Electric units are often used for sinks in lavatories or other remote locations. Natural gas units are often used as replacements for storage water tanks due to their higher heating capacities compared to the storage water heaters they replace.

As described in the first section of this chapter, instantaneous water heaters heat the water supply as it is drawn through the unit, without using a storage tank. This greatly reduces standby losses that occur with storage tanks. Therefore, in buildings with low hot water usage where standby losses represent a large fraction of the water heating energy use, instantaneous water heaters can provide a significant energy savings. In buildings with heavy hot water usage, standby losses represent a much smaller fraction of annual hot water energy costs, and instantaneous water heaters would not provide as much relative energy savings.

We evaluated the potential energy savings from replacing small commercial water heaters with instantaneous water heaters. DOE estimates that a residential home using 41 gallons or less of hot water would save 24%-34% by switching to an instantaneous water heater; and a home using up to 86 gallons a day would achieve 8%-14% savings (EERE 2009).

We assumed that the commercial buildings with small water heating needs could replace their storage tank heaters with instantaneous heaters. We applied this assumption to the 10 commercial sectors with the lowest per-building water usage, as shown previously in Figure 6-18 (i.e. the Service sector and everything below). We used DOE's energy savings estimates for large households to calculate the energy savings estimates for these 10 commercial sectors. We believe that this is a conservative estimate, since many smaller commercial buildings may have hot water usage rates that are far less than that of a large residential household. Thus, based on the DOE estimates described above, we estimated a 15% energy savings potential for all commercial buildings with small water heaters.

Condensing Water Heaters

Condensing water heaters are an improvement on traditional natural gas water heaters and have efficiencies up to 96%. Condensing water heaters extract additional energy by condensing the water vapor in the flue gases. Typically, a second heat exchanger is used to extract the remaining heat from the flue gases. This heat exchanger must be made of corrosion-resistant materials and requires a condensate drain. The additional heat is transferred to the water, which boosts the overall system efficiency. Figure 6-24 below shows a cut-away view of a typical condensing gas water heater. Condensing water heaters can produce up to 18% energy savings over traditional gas water heaters.

Figure 6-24: Condensing Gas Water Heater

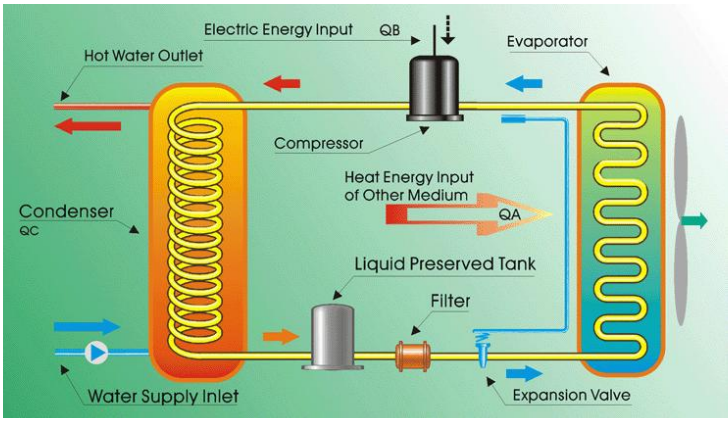
Source: ENERGY STAR website (ENERGYSTAR 2009)

Because of the additional heat exchanger, condensate lines, replacement flues, and other installation requirements, the installed cost of condensing water heaters can be over twice the cost of a traditional gas storage water heater. Also, retrofits tend to be more expensive than new installations because of the additional condensate drains, pumps, flues, and other equipment that may need to be added or replaced. While condensing water heater technology has been commercialized for several years, costs have restricted its wide-scale adoption. The main barriers that have prevented this technology from achieving wide-scale adoption in the commercial sector include high first cost and retrofit limitations (e.g. new flue, drain access, installation concerns among plumbers).

Heat-Pump Water Heaters

Heat-pump water heaters (HPWHs) use a vapor-compression heat pump to transfer heat from the surrounding air to the water, versus a standard electric water heater that uses resistive heaters to heat the water. Figure 6-25 below shows a schematic of a HPWH.

Figure 6-25: Schematic of Heat-Pump Water Heater



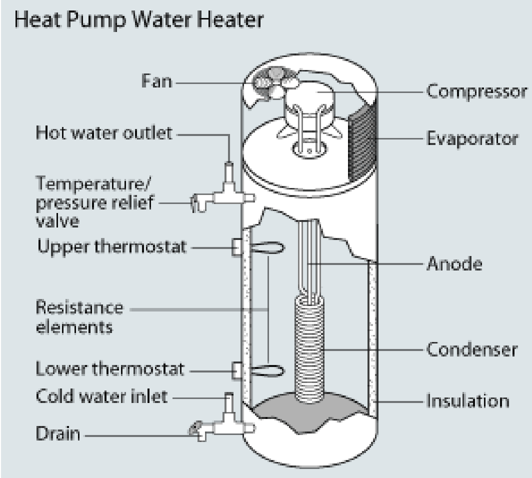
Source: DIY Trade website (DIYTrade 2009).

A low-pressure, cool two-phase refrigerant flows through the heat-pump evaporator, where it absorbs heat from the outside air and vaporizes. The refrigerant gas is then compressed by the compressor, which raises its temperature. The heated refrigerant gas then flows through a condenser coil within the storage tank, where the heat is transferred to the water. As the refrigerant cools, it condenses and passes through an expansion valve, where the pressure is reduced and the refrigerant returned to the evaporator.

Some HPWHs use outdoor air as the heat source to reduce the secondary impacts on space-conditioning loads. Most HPWHs have resistance heaters for back up, when the heat-pump capacity is not sufficient to meet the water-heating demand. HPWHs can be integrated with the storage tank, or be separate units that are plumbed to a storage tank.

Figure 6-26 illustrates a HPWH integrated with the storage tank.

Figure 6-26. Heat-Pump Water Heater Integrated with Storage Tank



Source: JC Winnie website (JCWinnie 2009).

HPWH coefficients of performance (COP) typically range from 2.0-4.0, versus a COP of 1.0 for traditional electric water heaters (FEMP 1997; UTRC 2007). Use of back-up resistance heat, operating temperatures, and water-use patterns all impact energy savings. A HPWH with COP of 2.0 would be expected to lower energy consumption by 50% compared to electric resistance water heaters. HPWH performance can be affected by a variety of factors, including air temperature, water temperature, and desired change in water temperature.

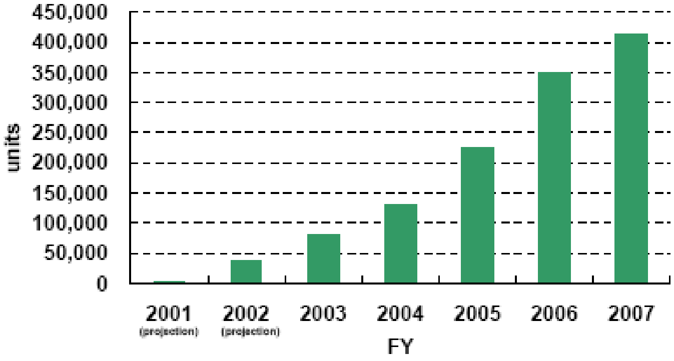
HPWHs using conventional refrigerants are commercially available. For example, Applied Energy Recovery Systems (AERS) sells commercial E-TECH heat pump water heaters units with a COP ranging from 3.3-3.4 and claim 50-80% energy savings over conventional water heaters. These systems use R-134a refrigerant with maximum tank temperatures of 140°F and have capacities ranging from 49,000-424,000 Btu/h (AERS 2009).

Alternative refrigerants, such as carbon dioxide, can also be used in HPWHs. Residential CO_2 HPWHs are popular in Japan, and are sold under the brand name "Eco Cute," (see Figure 6-27 below.) Major manufactures of CO_2 HPWHs include Panasonic, Daikin, Mitsubishi, Corona, and Hitachi. It is estimated that by 2010, 5.2 million units will be in use in Japan. Figure 6-28 below shows the annual sales of the EcoCute as of 2007 (Kusakari 2008).

Figure 6-27: Japanese "Eco Cute" CO_2 Heat Pump Water Heater

Image source: GWB 2009

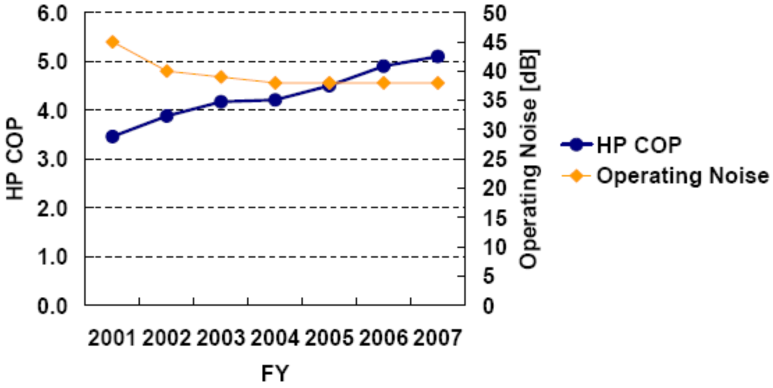
Figure 6-28: Annual Sales of Ecocute in Japan



Source: Kusakari 2008

As shown below in Figure 6-29, the performance of the EcoCute has continually improved since its introduction. In 2007 the Eco Cute had a maximum COP of 5.1 by Japanese standards. A survey of 36 households in Japan showed an annual average COP of 3.16 (Kusakari 2008). It is unclear how Japanese performance standards compare to U.S. performance standards.

Figure 6-29: Performance of Japanese Heat Pump Water Heaters



Source: Kusakari 2008

There are currently no commercially available CO_2 heat pump water heaters marketed in North America. Under a DOE-funded project, United Technology Research Center (UTRC) developed and demonstrated a prototype CO_2 HPWH that was intended to reduce the barriers to adoption. The prototype system exhibited COP of 2.8; the target COP value for this system was 3.6 (UTRC 2007). Reasons for not achieving the target performance level include leaks and poor reliability. However, the success of the EcoCute in Japan demonstrates that these design challenges can be successfully overcome. We believe there is nothing inherent to HPWH technology that prevents the design and manufacture of a safe, reliable product in the United States.

Similarly, the International Energy Agency’s Heat Pump Center (IEA 2004) and University of Maryland have conducted research on CO_2 HPWH technology. The University of Maryland’s recent research, which was co-funded by DOE, tested CO_2 HPWH under various heating scenarios and found CO2 refrigerants to have superior thermodynamic properties water heating applications compared to conventional refrigerants (UMD 2009). Further work should be done to assess the overall benefits of CO_2 versus conventional refrigerants for HPWHs.

In general, the main barriers that have prevented heat pump water heaters of all refrigerant types from achieving wide-scale adoption in the US commercial sector include:

- High first cost relative to standard water heaters
- Lack of knowledge partly due to lack of manufacturer marketing

Solar Thermal Water Heaters

Solar thermal water heaters use sunlight to heat water. There are several types of solar thermal water heater architectures. Five types are described in this section. The numbers in the figures below highlight the common components among the system configurations:

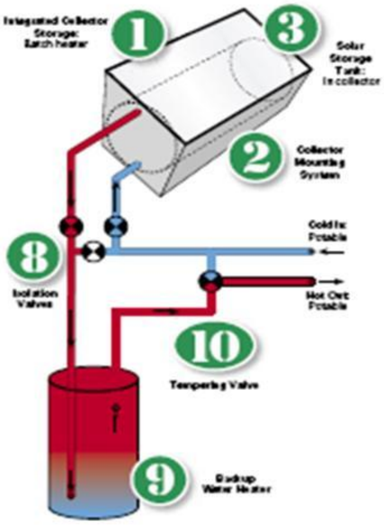
1. Solar Collector
2. Collector Mounting System
3. Solar Storage Tank
4. Water Pump
5. Heat Exchanger
6. Expansion Tank
7. Control
8. Solar Bypass Valve
9. Backup Water Heater
10. Tempering Valve

Batch Collector

In a batch collector, also known as integral collector storage, the sun heats dark tanks or tubes containing water within an insulated box until the water is needed. Water can remain inside the collector for long periods of time if the water demand is low, allowing the water to become very hot. This type of system is a direct system, meaning the water is directly heated by the sun.

Since pumps are not typically used on these systems, water flows by means of facility water pressure. It is useful for warmer climates only, because the water might freeze in cooler climates. Figure 6-30 depicts a batch collector system.

Figure 6-30: Batch Collector Solar Thermal Water Heater Architecture



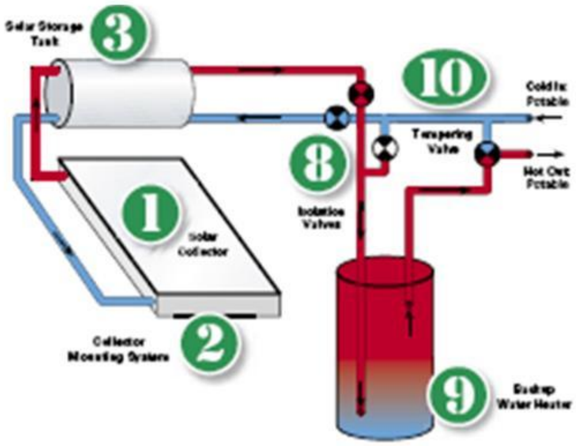
Source: Homepower 2005

Thermo-syphon

A thermo-syphon system is characterized by a separate storage tank located above the collector. Since pumps are not typically used on these systems, water flows by means of thermal convection. Like the batch collector, thermo-syphon systems have few components which often make them less expensive than other solar thermal water heater systems.

Figure 6-31 below depicts a thermo-syphon configuration.

Figure 6-31: Thermo-Syphon Solar Thermal Water Heater Architecture

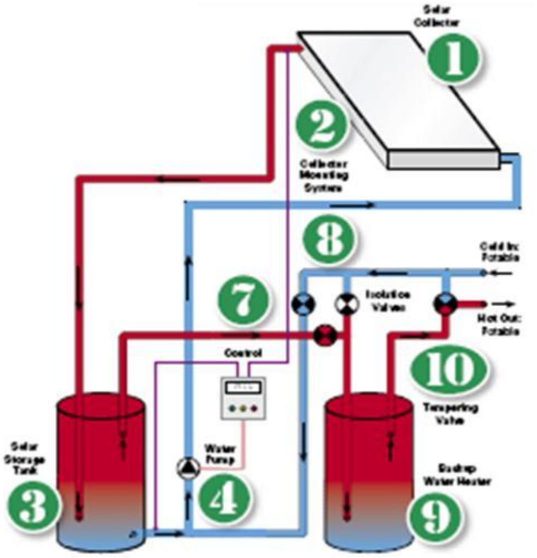


Source: Homepower 2005

Open-loop Direct

An open-loop direct system uses a solar collector to feed and heat water in a storage tank. Water from the storage tank then preheats water fed to a backup water heater. Figure 6-32 depicts an open-loop configuration.

Figure 6-32: Open-Loop Direct Solar Thermal Water Heater Architecture

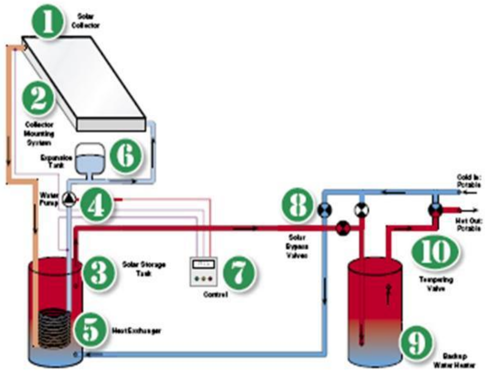


Source: Homepower 2005

Pressurized Glycol

Pressurized glycol operates in the same way as an open-loop direct, except that the solar collector circuit uses glycol antifreeze and a heat exchanger to preheat the water in the storage tank. The glycol prevents the water from freezing in cooler climates. Figure 6-33 depicts a pressurized glycol configuration.

Figure 6-33: Pressurized Glycol Solar Thermal Water Heater Architecture

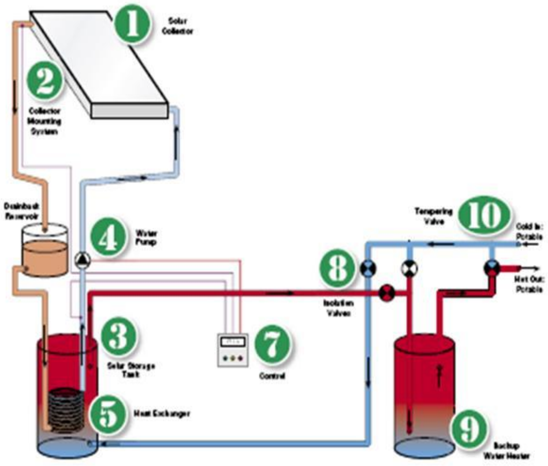


Source: Homepower 2005

Closed-Loop Drainback

Closed-loop drainback operate the same as pressurized glycol, but instead of using antifreeze, the water in the solar collector drains back to a reservoir to prevent freezing. Figure 6-34 depicts a closed-loop drainback configuration.

Figure 6-34: Closed-Loop Drainback Solar Thermal Water Heater Architecture



Source: Homepower 2005

There are several types of solar collectors that can be used with solar water heating systems. Three major types include batch, flat plate, and evacuated tube collectors. Figure 6-30 above depicts a batch collector system. Figure 6-35 below shows a second type of collector called a flat-plate connector.

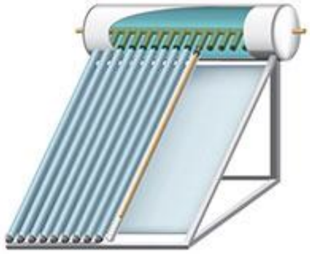
Figure 6-35: Flat-Plate Collector for Solar Thermal Water Heating System

Source: ENERGY STAR website

Flat-plate collectors typically consist of copper tubes fitted to flat absorber plates. The most common configuration is a series of parallel tubes connected at each end by inlet and outlet manifolds. The entire assembly is contained within an insulated box covered with glass.

Another common collector type, shown in Figure 6-36, is an evacuated tube collector. In an evacuated tube collector system, a glass or metal tube containing water or a heat transfer fluid is surrounded by a larger glass tube. The space between the two tubes is a vacuum, so very little heat is lost from the fluid.

Figure 6-36: Evacuated Tube Collector for Solar Thermal Water Heating System



Source: ENERGY STAR website

Solar water heating systems are commonly sized to provide 50% of the total hot water needs of the building. The size is usually limited to space constraints, or more commonly, cost. The most cost-effective size for an individual installation depends on many factors such as annual water usage, climate, sunlight exposure, and energy prices. We assumed an energy savings potential of 50% for our calculations.

Solar thermal water heaters may cost four to five times a traditional gas or electric water heater (ACEEE 2009). This is a serious barrier for implementation in commercial buildings, which place such a high emphasis on initial cost when installing new water heating equipment. One potential benefit for solar water heating technology is that consumers seem to have a much greater awareness of solar technologies than other energy-efficient technologies. This likely helps drive the purchase of solar heating systems despite their high initial cost. In addition, many states and utilities offer rebates or other incentives for purchasing solar water heating systems.

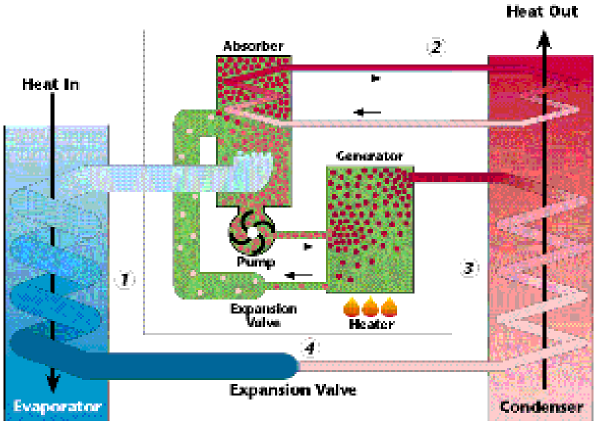
The main barriers that have prevented solar thermal water heaters from achieving wide-scale adoption in the commercial sector include:

- High first cost
- Reliability concerns
- Product availability
- Insufficient Contractor training
- Lack of field experience

Absorption Heat-Pump Water Heaters

Absorption heat-pump water heaters use thermally activated heat pumps and, therefore, are a potential replacement technology for natural gas water heaters. Absorption heat pump water heaters are the only option we identified that has the potential for significant energy savings over traditional gas-fired water heaters. While condensing gas water heaters can provide an 18% efficiency improvement, absorption heat pump water heaters have the potential to leapfrog other gas technologies and provide more than 40% energy savings, as described further below. In this regard, replacing a gas-fired water heater with an absorption heat-pump water heater is analogous to replacing an electric water heater with an electric heat-pump water heater.
The absorption refrigeration cycle predates the vapor-compression refrigeration system, and is used in many space-conditioning applications. However, the absorption cycle is typically not used for dedicated service water heating. The concept is similar to an electric heat pump water heater, except that it uses a heat source instead of an electric compressor to drive the refrigeration cycle. Figure 6-37 below shows an absorption heat-pump cycle.

Figure 6-37: Absorption Heat-Pump Cycle



Source: IEA Heat Pump Centre

Absorption systems utilize the ability of liquids or salts to absorb the vapor of a working fluid. Common working pairs for absorption systems include:

- Water (working fluid) and lithium bromide (absorbent)
- Ammonia (working fluid) and water (absorbent)

Lithium bromide (LiBr) is not a likely candidate for dedicated service water heating since LiBr can crystallize with heat-rejection temperatures in the range required for water heating. Therefore, ammonia/water shows the most potential; although, there may be safety concerns with ammonia due to its toxicity (IEA 2009).

The system that drives the absorption cycle consists of an absorber, a solution pump, a generator, and an expansion valve. Low-pressure vapor from the evaporator is absorbed by the absorbent, which generates heat. The solution is then pressurized using a pump and enters the generator, where the working fluid is boiled off using an external heat supply. The heat to drive the cycle could be provided from a variety of sources such as natural gas, high pressure steam, or waste heat. The working vapor is then condensed in the condenser, while the absorbent is returned to the absorber via the expansion valve. Heat is extracted from the surrounding air in the evaporator. Heat from the absorber and the generator is transferred to the cold water in the condenser, which provides the hot water supply.

While the theory behind an absorption heat pump is well understood, there are currently limited stand-alone absorption heat pump water heater options on the market. Historically, the emphasis on absorption heat pump technology research has been on cooling and refrigeration applications. The natural gas industry funded most of the initial research in order to develop cooling technologies that use gas instead of electricity. For this reason, combined heating/cooling units are the only absorption heat pump technology options currently available on the market.

Robur and Energy Concepts are two suppliers of absorption heat pump technology. Robur manufactures absorption boilers and coolers in Europe and currently sells a 5-ton gas fired unit with ammonia refrigerant to the US market (Robur 2009). This system is designed for radiant floor and forced-air heating and cooling systems in residential and commercial applications. Energy Concepts also offers an absorption system—ThermoSorber—which co-produces hot water and chilling. While the ThermoSorber is designed for large commercial facilities, it is not specifically designed for water–heating-only applications (Energy Concepts 2009). Additional research is needed to produce a cost-competitive stand-alone absorption heat pump specifically for commercial-scale water-heating.

Absorption heat pump technology is scalable for most commercial applications, but due to high first costs it tends to be more economical for installation in facilities with high water heating demands. The main barriers that have prevented this technology from achieving wide-scale adoption in the commercial sector include:

- Cost
- Emerging Technology
- Retrofit limitations
- Consumer/industry understanding
- Shipping/installation limitations for ammonia (the working fluid)

We view absorption water heating technology as a high-risk, high-reward technology. As described above, the major challenges for this technology are developing a cost-effective product and a viable market.

Based on personal communication with Energy Concepts, the Thermosorber is estimated to provide roughly 40% energy savings (Energy Concepts 2009). This is also consistent with a recent report from ASHRAE (Dieckmann 2005). Therefore, for our technical potential calculations we assume absorption heat pump water heaters can provide a 40% energy savings compared to traditional gas storage water heaters.

Summary

Table 6-16 below summarizes the development status of the alternative water heating technologies described above.

Table 6-16: Alternative Water Heating Technologies Development Status

Alternate Water Heating Technology	Development Status
Instantaneous Water Heaters	Commercially available; Actual savings in the field are widely disputed and may be worthy of further investigation.
Condensing Water Heaters	Commercially available; High initial costs have prevented widespread penetration
Heat Pump Water Heaters	Available as integrated and add-on systems. Widely available in Japan. Available from smaller manufacturers in the US.
Solar Thermal Water Heaters	Commercially available, indirect systems add significantly to the cost
Absorption Heat Pump Water Heaters	Dedicated absorption water heaters are not yet commercially available. Combined heating/cooling systems are available.

Table 6-17 shows an estimate of the total energy savings potential of the alternative water heating technologies.

Table 6-17: Total Energy Savings Potential of Alternate Water Heating Technologies

Alternate Water Heating Technology	Unit Energy Savings Potential (%)	Applicable Fuel Type	Applicable Energy Consumption (Btu/yr)	Total Primary Energy Savings Technical Potential (Btu/yr)
Instantaneous Water Heaters	15%	Small	2.42E+14	3.64E+13
Condensing Water Heaters	18%	Gas	4.81E+14	8.65E+13
Heat Pump Water Heaters	50%	Elec	1.45E+14	1.45E+14
Solar Thermal Water Heaters	50%	Elec, Gas	6.25E+14	3.13E+14
Absorption Heat Pump	40%	Gas	4.81E+14	1.92E+14

6.12 *Economic Analysis*

While cost data are not readily available for all water heating technologies analyzed in this section, we calculated the allowable cost premium to achieve a three to five year payback. We used estimated energy savings for each technology and the cost of fuel to estimate what consumers looking for a three to five year payback should be willing to pay for the efficiency gain. The key barriers for each technology were described in the preceding sections.

6.12.1 Technologies that Reduce Standby Heat Loss

Table 6-18 displays the allowable cost premium of the three technologies we identified that reduce standby heating loss. The cost premium includes additional installation costs and is calculated assuming a three to five year investment payback.

Table 6-18: Maximum Cost Premium to Achieve Target Payback Period for Technologies That Reduce Standby Heat Loss

Efficiency Addition	Savings Potential (%)	Average Annual Tank Stand-by Losses (MMBtu/yr)[a]	System Savings (MMBtu/yr)	System Savings/ year ($)[b]	Target Payback (Yr)	Maximum Cost Premium to Achieve Target Payback ($)[c]
Heat traps	25%	8.76	2.19	28	3-5	$80-$140
Piping Insulation	3%	8.76	0.26	3	3-5	$10-$20
Storage Tank Jacket	40%	8.76	3.50	45	3-5	$130-$220

a. Assumes average standby losses per tank equals 1,000 Btu/hr. (AHRI 2009)
b. Based on $12.75/MMBtu cost of energy, the average 2008 gas price for the middle 50% of states (EIA)
c. Includes installation cost and calculation assumes a 3-5 year target payback

6.12.2 Heat-Recovery Technology Options

Table 6-19 displays the maximum cost premium for the two heat-recovery technologies we identified. The cost premium includes additional installation costs and is calculated assuming a three to five year investment payback.

Table 6-19: Maximum Cost Premium to Achieve Target Payback Period for Heat-Recovery Technology Options

Efficiency Modification	Savings Potential (%)	Unit Energy Usage (MMBtu/yr) [a]	Saving per Machine (MMBtu/yr)	System Savings/ year ($)[b]	Target Payback (Yr)	Maximum Cost Premium to Achieve Target Payback ($)[c]
Desuper-heaters	10%	520	52	663	3-5	$1,990-$3,320
Drain Water Heat Recovery	30%	520	156	1,989	3-5	$6,000-$10,000

a. Assumes medium system size (520 MMBTU/yr) except for instantaneous water heaters which uses a small system average assumption.

b. Based on $12.75/MMBtu cost of energy, the average 2008 gas price for the middle 50% of states (EIA)

c. Includes installation cost and calculation assumes a 3-5 year target payback

Table 6-20 summarizes costs for drain water heat recovery technology based on a manufacturer interview. High material cost and retrofit restrictions limit the extent to which market penetration can be achieved in retrofit applications and make it better suited for new construction.

Table 6-20: Drain Water Heat Recovery Costs

Efficiency Measure	Installed Cost[a]
Drain Water Heat Recovery	$500-$700 per 4 gpm capacity of pipe

a. Source: NCI Interview (WaterFilm Energy 2007)

6.12.3 Alternative Water Heating Technologies

Table 6-21 displays the maximum cost premium of the alternative water heating technologies described in this report. The system cost includes installation and is calculated assuming a three to five year investment payback.

Table 6-21: Maximum Cost Premium to Achieve Target Payback Period for Alternative Water Heating Technologies

Alternative Technology	Savings Potential (%)	Unit Energy Usage [MMBtu/yr][a]	Saving per Machine (MMBtu/yr.)	System Savings/ year ($)[b]	Target Payback (Yrs.)	Maximum System Cost to Achieve Target Payback ($)[c]
Absorption Heat Pump	40%	520	208	$2,652	3-5	$8,000-$13,300
Condensing Water Heaters	25%	520	130	$1,658	3-5	$5,000-$8,300
Heat Pump Water Heaters	50%	520	260	$3,315	3-5	$10,000-$17,000
Instantaneous Water Heaters	15%	150	23	$287	3-5	$860-$1,430
Solar Thermal Water Heaters	50%	520	260	$3,315	3-5	$9,900-$16,600

a. Assumes medium system size (520 MMBTU/yr).
b. Based on $12.75/MMBtu cost of energy, the average 2008 gas price for the middle 50% of states (EIA)
c. Includes installation cost and calculation assumes a 3-5 year target payback

Table 6-22 summarizes the estimated cost of a 5 ton absorption heat pump based on existing commercialized products, but does not reflect the potential savings resulting from mass production of the technology. While this cost estimate is above the targeted cost premium, costs are expected to decrease with mass production of the technology.

Table 6-22: Absorption Heat-Pump Costs and Market Barriers

Efficiency Measure	Cost[a]
Absorption Heat Pump ($)	>$10,000 + installation

a. Assumes $2,000/ton for a 5 ton unit, which does not include potential savings from mass production (Energy Concepts, 2009)

Table 6-23 summarizes the condensing water heater costs. While the technology has a reasonable payback, high firstcosts and retrofit limitations (e.g. new flue, drain access, installation concerns among plumbers) have prevented this technology from achieving wide-scale adoption in the commercial sector.

Table 6-23: Condensing-Water-Heater Costs

Efficiency Measure	Gallons	Cost ($)[a]
Condensing Water Heaters	60	$4,000-$6,000 + installation
	100	$6,000-$7,000 + installation
	130	$10,000-$12,000 + installation

a. Source: Distributor website for A.O. Smith Cyclone XHE Water Heaters (Jupiter Heating, 2009)

Table 6-24 uses residential heat pump water heater (HPHW) cost data to project the cost of commercial heat pump water heaters. While this technology should meet target payback, annual maintenance requirements, high first costs relative to typical water heaters and lack of availability in the U.S., have limited its adoption in the U.S. market.

Table 6-24: Heat-Pump Water Heater (HPHW) Costs and Market Barriers

Heat Pump Water Heating Specifications	Residential Units[a]	Small/Medium Commercial Units[b]
Typical Capacity (gal)	50	50-100
Energy Factor	2.3-2.4	2.3-2.4
Average Life (yrs)	14	14
Retail Equip. Cost w/o Tank ($)	$1,200-$1,800	$1,200-$3,600
Total Installed Cost w/o Tank ($)	$1,400-$2,000	$1,400-$4,000
Annual Maintenance Cost ($)	$75	$75

a. Source: RS Means 2007, ACEEE 2009

b. Assumes small commercial HPWH units are equivalent to residential units and medium commercial units are two-times the scale of residential units. Cost data are available only for small/medium capacity systems.

Table 6-25 projects the cost of commercial solar thermal water heaters based on technology data for the residential sector. Payback periods vary depending on the climate zone, but typically average ten years according to some sources (Energy Star 2009).

Table 6-25: Solar Thermal Water Heater Costs and Market Barriers

Solar Thermal Water Heater Specifications	Average Residential Units[a]	Small/Med. Commercial Units[b]
Typical Capacity (sq. ft)	40	40-80
Overall Efficiency	50% of Water Heating Load	50% of Water Heating Load
Solar Energy Factor	0.8-4.8	0.8-4.8
Average Life (yrs)	20	20
Retail Equip. Cost ($)	$4,000	$4,000-$8,000
Total Installed Cost ($)	$6,000	$6,000-$12,000
Annual O&M Cost[c]	$60	$60-$120

a. Estimates based on NCI interviews with 4 solar installers and 2 manufacturers/distributors. Costs are for an active, indirect or closed loop system; including tank and back-up system installed in a warm climate. Costs vary based on freeze protection requirements and type of system.

b. Assumes small commercial STWH units are equivalent to residential units and medium commercial units are two-times the scale of residential units. Data on large commercial units could not be found.

c. Assumes O&M cost equals about 1% of installed costs and includes property insurance, cleaning, and routine maintenance (ASES 2003). This estimate is based on a system in Hawaii with no freeze protection. In other climates requiring freeze protection, maintenance may be more expensive.

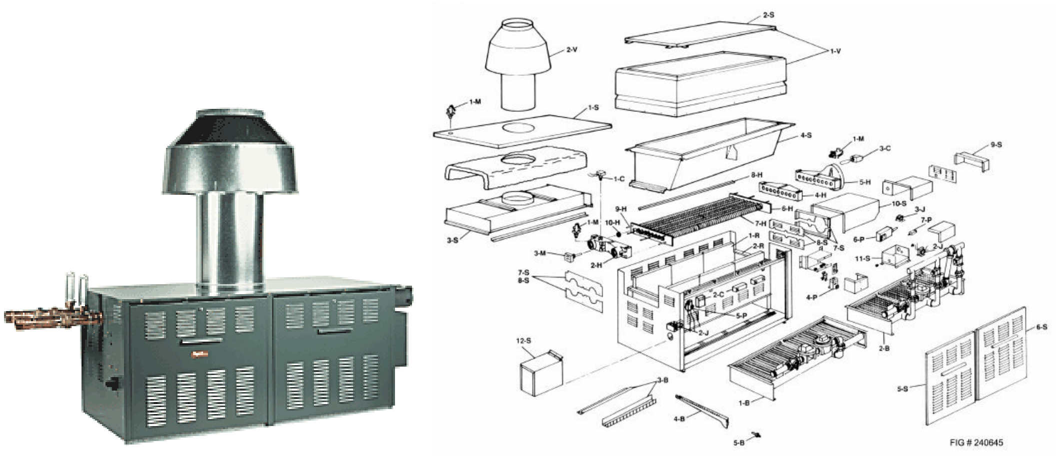
7 Pool Heaters

Commercial pools require a considerable amount of heating during operation. Pool heating equipment differs substantially from ordinary water heating equipment, so a separate analysis for pool heaters is warranted. Our analysis includes both indoor and outdoor swimming pools, but does not include other smaller types of pools such as wading pools, lap pools, or hot tubs. Also, this analysis considers only the energy usage of pool heaters; it does not include the energy usage of auxiliary equipment such as pumps or HVAC equipment such as indoor dehumidifiers.

7.1 General Description

Nearly all commercial pools use natural gas heating equipment. While there is a relatively small market for electric commercial pool heating equipment, the energy usage estimates in this analysis are based on natural gas heating only. We believe this represents an accurate estimate of overall pool heating energy usage. Figure 7-1 shows a typical natural gas-fired commercial pool heater.

Figure 7-1: Natural Gas-Fired Commercial Pool Heater



Source: Raypak website (Raypak 2009)

Natural gas pool heaters are classified by their output capacity, measured in Btu/hr. Commercial pool heater capacities range from 500,000 Btu/hr up to 5,000,000 Btu/hr. Electric pool heaters are available for small and medium-sized pools with maximum capacity of 300 kW, which is equivalent to roughly 1,000,000 Btu/hr. For this report, we assumed that all commercial pools use natural gas heaters.

The following formula is often used to determine indoor swimming pool heater size (EERE 2009):

$$\text{Indoor Pool Heater Size (Btu/hr)} = \text{Pool Area} \times \text{Temperature Rise} \times 12$$

Pool surface area is measured in square feet. Pool surface area is used rather than pool volume because most of a pool's heat is lost through evaporation at the surface. Temperature rise is determined by subtracting the temperature of the surrounding air from the desired pool temperature. For most indoor pools, this is typically around 10-15°F. The number 12 in the equation is a constant.

The formula for sizing outdoor pool heaters is similar, but uses a higher constant of 15 in the equation (Recreonics 2009):

$$\text{Outdoor Pool Heater Size (Btu/hr)} = \text{Pool Area} \times \text{Temperature Rise} \times 15$$

For outdoor pools, the temperature rise is determined by subtracting the average temperature for the coldest month the pool is in operation from the desired pool temperature. Depending on the local climate and the months in which the pool is operating, this number can typically vary from 10-35°F.

Most indoor commercial pools operate year-round, while most outdoor pools operate only during the summer months – typically June through September. We assume that the typical pool is open for 10 hours a day. Table 7-1 summarizes these assumptions about commercial pool operations.

Table 7-1: Assumptions about Commercial Pool Operations

Location	No. of Operating Months	No. Hours per Day	No. Hours per Year
Indoor	12	10	3600
Outdoor	4	10	1200

The thermal efficiency of traditional natural gas pool heaters ranges from 82–89%. Table 7-2 shows the efficiency of some of the most popular brands of pool heaters. These figures were obtained from manufacturer websites.

Table 7-2: Baseline Efficiencies of Natural Gas-Fired Commercial Pool Heaters

Pool Heater Brand	Thermal Efficiency
Copper Fin II	89%
Hi-Delta	85%
MegaTherm	82%
PowerMax	85%
RayTherm	82%

Source: Manufacturer websites

7.2 *Major Manufacturers and Market Shares*

The three largest manufacturers of natural gas commercial pool heaters are Raypak, Pentair, and Lochnivar. The largest manufacturer of electric commercial pool heaters is Coates. The following list shows the major brands of natural gas pool heaters sold by each manufacturer:

- Raypak – Raytherm, ADB, Hi-Delta,
- Pentair – Megatherm, PowerMax
- Lochnivar – Copper Fin II

7.3 *Major End-Users*

The following list shows the categories of commercial swimming pools included in this analysis.

- Hotels/Motels
- Municipal pools
- Sports and recreation clubs
- Public school districts
- Higher education institutions
- Water parks

As mentioned previously, this analysis includes swimming pools only and does not include other smaller pools such as wading pools, lap pools, or hot tubs.

7.4 *Typical Distribution Chain*

Commercial pool heaters are typically sold to end-users through wholesale distribution channels. Some distributors sell products from a single manufacturer, while others sell products from a range of manufacturers.

7.5 *Annual Shipments and Installed Base*

The installed base of commercial pool heaters is based on estimates of the number of hotel/motel, sports and recreation facilities, schools, municipal pools, and water parks as shown below in Table 6-13. This table was based on the pool heater analysis in the 1993 ADL report (ADL 1993). We separated the Education category into Public School Districts and Higher Education Institutions for two reasons: 1) The Census data provides the number of establishments of each, and 2) We believe that our assumptions regarding public school districts and higher education institutions are not entirely compatible. We also added a Water Park category, since we believe there are a significant number of swimming pools in water parks that were not considered in the ADL model. Where possible, we updated the estimates for the number of establishments and number of pools using more recent information sources. The information sources for these estimates are shown in Table 7-4 below.

Table 7-3: Estimated Installed Base of Commercial Pool Heaters

Type of Establishment	Estimated No. of Establishments	Est. Percent of Establishments with Pools	No. of Pools (Rounded)
Hotel/Motel	142,000	15%	21,000
Sports & Recreation Clubs	23,300	30%	7,000
Public School Districts	15,700	100%	15,700
Higher Education Institutions	4,300	80%	3,400
Municipal Pools	6,000	100%	6,000
Water Parks	150	100% x 10	1,500
TOTAL			**55,000**

Table 7-4: Sources for Data in Table 6-13

Type of Establishment	No. of Establishments	Percent of Establishments with Pools
Hotel/Motel	2003 CBECS, Table B42 (EIA 2003)	ADL estimate (ADL 1993)
Sports & Recreation Clubs	2002 US Census Data, NAICS code 7139409	ADL estimate (ADL 1993)
Public School Districts	2009 U.S. Census Statistical Abstract, Table 232	NCI estimate[a]
Higher Education Institutions	2009 U.S. Census Statistical Abstract, Table 269	NCI estimate[b]
Municipal Pools	Websites of public pool departments for the 50 most populous cities; Avg. one pool per 55,000 people	By definition
Water Parks	2002 US Census Data, NAICS Code 7131101	NCI estimate[c]

a. Assumes every public school district has one swimming pool, on average.
b. Assumes 80% of colleges and universities have swimming pools. We believe that well over 50% of colleges and universities have at least one pool, but that 100% is too aggressive. We chose 80%, or slightly more than three-quarters of institutions.
c. Assumes ten swimming pools per location, which we believe to be representative of many water parks.

Table 7-5 shows the estimated share of indoor and outdoor pools for each type of establishment.

Table 7-5: Estimated Share of Indoor and Outdoor Commercial Pools

Type of Establishment	No. of Pools (Rounded)	Indoor		Outdoor	
		% of Total[a, b]	No. of Pools	% of Total	No. of Pools
Hotel/Motel	21,000	75%	15,800	25%	5,200
Sports & Recreation Clubs	7,000	100%	7,000	0%	0
Public School Districts	15,700	100%	15,700	0%	0
Higher Education Institutions	3,400	100%	3,400	0%	0
Municipal Pools	6,000	20%	1,200	80%	4,800
Water Parks	1,500	0%[c]	0	100%	1,500
TOTAL (Rounded)	**55,000**		**43,000**		**12,000**

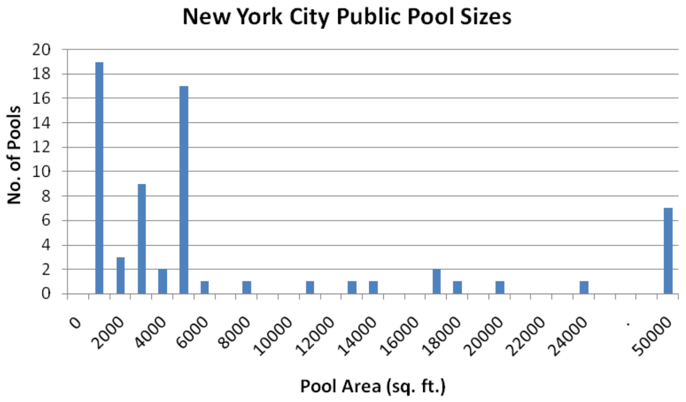
a. The estimate for Municipal Pools was made based on information contained at the websites of public pool departments of the 50 most populous U.S. cities.
b. Estimates for the remaining five categories made by NCI in the absence of any publicly available data.
c. We assumed that all water park pools are outdoors.

7.6 *Baseline Energy Consumption*

To estimate baseline energy consumption of commercial pool heaters, we first chose a representative pool size and calculated the corresponding pool heater size using the equations described above.

We used publicly available data for New York City municipal pools to estimate the size distribution of typical commercial swimming pools, as shown in Figure 7-2. Due to the diversity of pool sizes and locations, we assumed that the New York City data are representative of municipal pools throughout the Unites States. The data indicate that pool size varies between 800 sq. ft. and 5,000 sq. ft. A smaller number of pools are much larger than this, with surface areas exceeding 50,000 sq. ft. For comparison, a standard Olympic-size swimming pool is roughly 13,000 sq. ft. in area. Based on the histogram shown below, we estimated a representative pool area of 4,000 square feet as the average typical commercial pool size.

Figure 7-2: New York City Municipal Pool Sizes



Source: New York City Department of Parks & Recreation (NYC DPR 2009)

Table 7-6 shows typical pool heater sizes for indoor and outdoor commercial pools using the equations described previously. As described previously, this analysis assumes all commercial pools use natural gas heating.

Table 7-6: Estimated Pool Heater Size for Indoor and Outdoor Pools

Location	Typical Pool Size (sq. ft)	Typical Water-Air Temperature Difference	Pool Heater Size (Btu/hr)
Indoor	4,000	10°F	500,000
Outdoor	4,000	25°F	1,500,000

Table 7-7 shows the estimated installed base energy consumption of commercial pools using the following data:

- Estimated annual operational hours: Table 7-1
- Estimated number of pools: Table 6-13, Table 7-5
- Typical pool heater capacity: Table 7-6

Table 7-7: Estimated Energy Consumption of Commercial Pool Heaters

Location	No. Pools	Typical Capacity (Btu/hr)	No. Hours per Year	Per-Unit Energy Consumption (MMBtu/yr)	Total Energy Consumption (MMBtu/yr)
Indoor	43,000	500,000	3600	1,800	77,000,000
Outdoor	12,000	1,500,000	1200	2,100	22,000,000
TOTAL	**55,000**				**99,000,000**

Table 8-3 compares our energy usage estimate with the 1993 ADL estimate. The 2008 Buildings Energy Data Book does not provide specific estimates for pool heating energy consumption; rather, swimming pool heaters are included in the "Other" category.

Table 7-8: Estimates of National Annual Energy Consumption Of Commercial Pool Heaters, by Various Sources

End-use Category	1993 ADL Estimate (ADL 1993)	2008 DOE Buildings Energy Data Book	2008 NCI Estimate
Pool Heating AEC (Quads/yr.)	0.135	N/A	0.099

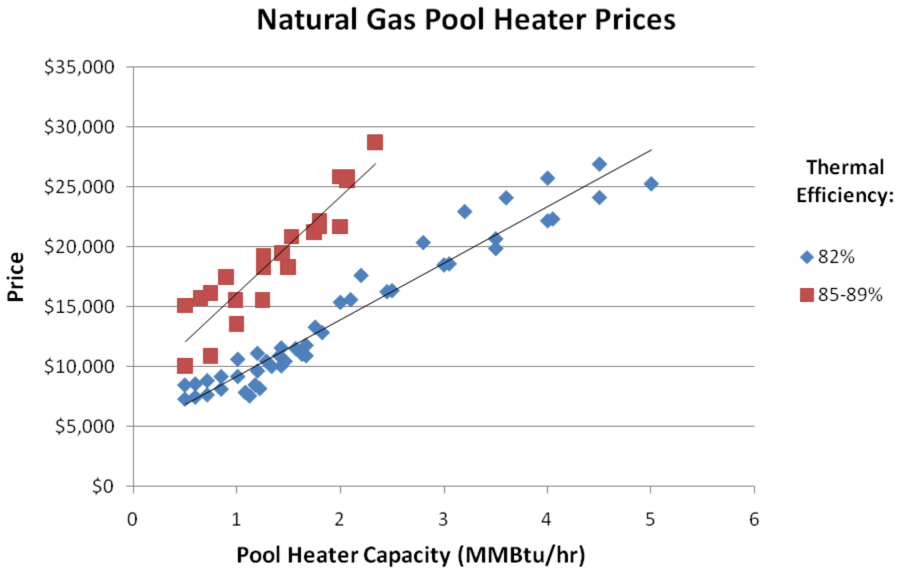
Our total energy consumption estimate is less than the ADL estimate of 135,000,000 MMBtu/yr. The largest difference between our estimate and the ADL estimate involve education-related pools and municipal pools. Our estimate includes 19,100 education-related pools versus 39,000 in the ADL report. We believe that our estimate—which is based on reliable data for the number of public school districts and higher educational institutions—may be more accurate than the ADL estimate, which was derived using the total number of educational buildings and an assumption about the percent of establishments with swimming pools.

Our estimate also includes 6,000 municipal pools versus 20,000 in the ADL report. Our estimate is based on a statistical average of city populations and number of municipal pools according to public city websites. The ADL estimate was based on the 1991 Bureau of Census Statistical Abstract (Census 1991) and an assumption about the percent of establishment with swimming pools. Analogous data were not available in the most recent version of the Statistical Abstract.

7.7 Cost Breakdown

Figure 7-3 shows the price of natural gas pool heaters as a function of capacity. The two data sets indicate the price difference between standard efficiency units (82%) and higher efficiency units (85-89%).

Figure 7-3: Price Versus Capacity of Natural-Gas Commercial Pool Heaters



Sources: Recreonics (Recreonics 2009), Lincoln Aquatics (Lincoln 2009)

As the chart indicates, higher-efficiency heaters can add roughly 70-80% to the cost of a pool heater. We believe this cost premium may be due to additional or more complex equipment necessary to provide higher efficiency heating.Table 7-9 shows the approximate cost of typical commercial pool heaters for various capacities based on the data shown above.

Table 7-9: Approximate Price of Typical Commercial Pool Heaters

Capacity (Btu/hr)	Cost of standard efficiency unit	Cost of higher efficiency unit
500,000	$8,000	$12,500
1,500,000	$11,500	$20,000
4,000,000	$23,500	N/A

7.8 Lifetime, Reliability, and Maintenance Characteristics

Table 7-10 shows the minimum, average, and maximum lifetime estimates for residential gas-fired pool heating equipment according to the 2007 DOE rulemaking for residential direct heating products (EERE 2009a). We believe the lifetimes for commercial pool heating equipment would be similar.

Table 7-10: Lifetime Estimates for Gas-Fired Pool Heating Equipment

	Estimated Lifetime (Years)
Minimum	3
Average	6
Maximum	20

7.9 *Regulatory Programs*

There are currently no regulatory programs in place for commercial pool heaters. EPCA established a minimum thermal efficiency of 78% for residential natural gas pool heaters, based on ASHRAE Standard 90.1. All natural gas commercial pool heaters researched for this report exceed this efficiency level.

7.10 *Voluntary Programs*

There are no ENERGY STAR or other voluntary energy efficiency standards for commercial pool heaters.

7.11 *Energy-Saving Technologies*

The most promising energy-saving technologies for commercial pool heating are pool covers, condensing pool heaters, heat pump heaters, solar heaters, and combined heating/dehumidification systems. Table 7-11 summarizes the technical potential energy savings for each of these technologies compared to traditional gas-fired pool heaters.

Table 7-11: Summary of Pool Heating Equipment Technical Potential Energy Savings

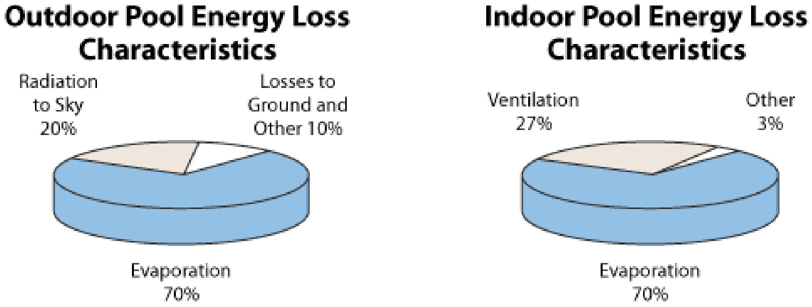
Technology	Potential Energy Savings (%)	Total Energy Savings Technical Potential (MMBtu/yr)
Pool covers	60%	59,000,000
Condensing pool heaters	15%	15,000,000
Heat pump pool heaters	45%	45,000,000
Solar pool heaters	60%	61,000,000
Combined heating/dehumidification	40%	27,000,000

The following sections describe each technology option in more detail.

7.11.1 Pool Covers

Pool covers offer a relatively inexpensive and simple method for dramatically reducing pool heating energy requirements. Pool covers largely help prevent evaporation, which represents 70 percent of pool energy loss for both outdoor and indoor pools. Figure 7-4 shows outdoor and indoor pool energy loss characteristics (EERE 2009b).

Figure 7-4: Outdoor and Indoor Pool Energy Loss Characteristics

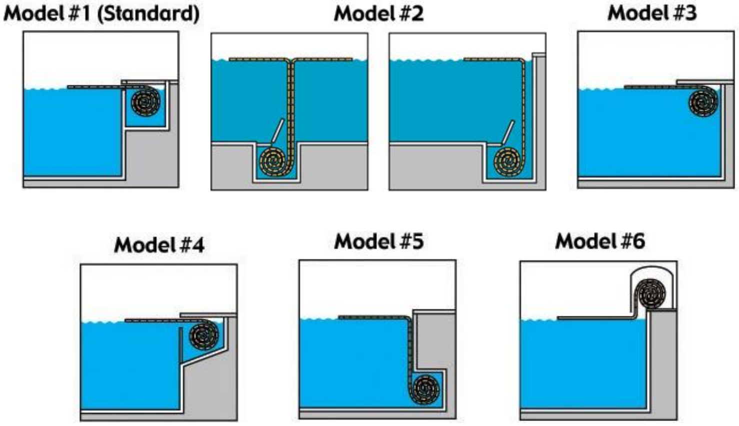


Source: EERE website (EERE 2009b)

Pool covers can significantly reduce water evaporation and the associated cooling due to evaporation during non-operational hours. In this analysis we assume 10 hours of operation per day, leaving 14 available hours for pool cover deployment.

Pool covers can be as simple as a piece of plastic material, and are often made from UV-stabilized polyethylene, polypropylene, or vinyl. They can be transparent or opaque. Automatic pool covers that easily deploy and retract are commercially available. At least one manufacturer offers several configurations for storing the pool cover that provide improved aesthetics and help alleviate space constraints (Aquamatic 2009). Examples of these configurations are shown in Figure 7-5.

Figure 7-5: Automatic Pool Cover Configurations



Source: Aquamatic Cover Systems (Aquamatic 2009)

Automatic pool covers can range in price from $3,000 for small installations to $8,000 or more for larger installations (Pool Center 2009). Table 7-12 shows the technical potential energy savings from pool covers.

Table 7-12: Technical Energy Savings Potential of Pool Covers

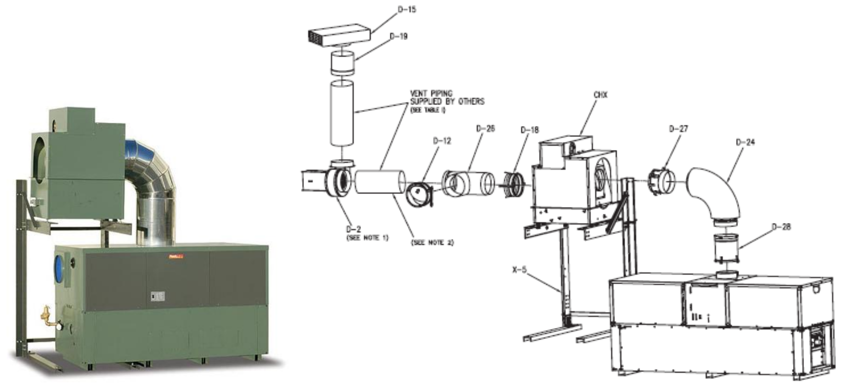
Pool Location	Energy Savings Potential (%)[a]	No. of Pools	Per-Unit Energy Consumption (MMBtu/yr)[b]	Annual Unit Energy Savings (MMBtu/yr)[c]	Total Primary Energy Savings Technical Potential (MMBtu/yr)
Outdoor	60%	43,000	1,800	1,080	46,000,000
Indoor	60%	12,000	2,100	1,260	15,000,000
TOTAL					**59,000,000**

a. DOE estimates 50-70% energy savings by using a pool cover (EERE 2009b)
b. From Table 7-7
c. Calculated by multiplying Energy Savings Potential by Per-Unit Energy Consumption

7.11.2 Condensing Pool Heaters

Condensing pool heaters are natural-gas fired heaters that include an additional heat exchanger to condense the combustion exhaust from the heater, which transfers additional heat from the exhaust to the pool water. The condensing process is similar to that for condensing hot water heaters described in the water heating section of this report. One manufacturer offers a condensing heat exchanger add-on unit that can be added to any of its standard gas-fired pool heaters, as shown below in Figure 7-6.

Figure 7-6: Add-On Condensing Heat Exchanger for Raypak Hi-Delta Pool Heater



Source: Raypak website (Raypak 2009)

Condensing pool heaters can achieve thermal efficiencies up to 98%. This represents an energy savings of approximately 15% over a traditional gas-fired pool heater with a thermal efficiency of 85%. Table 7-15 below shows the total potential energy savings from condensing pool heaters compared to traditional gas-fired pool heaters.

Table 7-13: Total Energy Savings Technical Potential of Condensing Pool Heaters

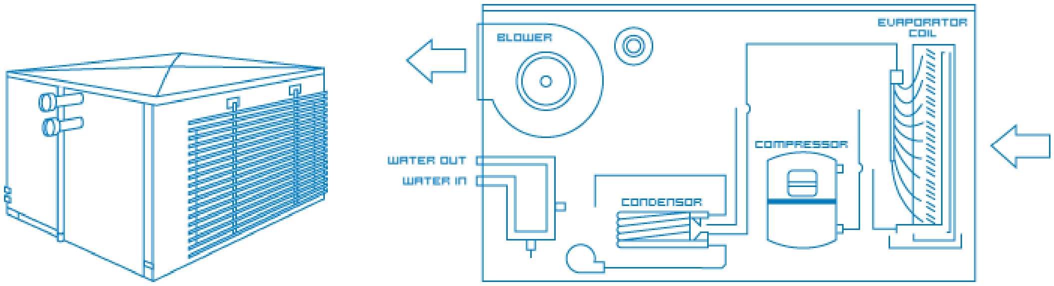
Technology	Energy Savings Potential (%)	Total Current Pool Heater Energy Use (MMBtu/yr)	Total Primary Energy Savings Technical Potential (MMBtu/yr)
Condensing pool heaters	15%	99,000,000	15,000,000

Condensing heat exchangers can add $10,000 to $30,000 to the cost of a traditional gas-fired pool heater, depending on the size and configuration of the heating system. A system such as that pictured above in Figure 7-6 would cost roughly an additional $12,000 (Raypak 2009a).

7.11.3 Heat-Pump Pool Heaters

Heat pumps transfer heat from one location to another using a vapor-compression system (typically electrically driven), rather than generate heat as with a gas-fired pool heater. The diagram in Figure 7-7 below shows the operation of a heat-pump pool heater.

Figure 7-7: Operation of a Heat Pump Swimming Pool Heater



Source: EERE website (EERE 2009c)

In a heat-pump pool heater, water drawn from the pool passes through a filter before entering the heat-pump heater. The heat pump has a fan that draws in outside air and directs it over an evaporator coil. Liquid refrigerant within the evaporator absorbs the heat from the outside air and become a gas. The warm refrigerant gas in the coil then passes through the compressor, which increases the heat and creates a hot gas that then passes through the condenser. The condenser transfers the heat from the hot gas to the pool water circulating through the condenser. The heated water then returns to the pool. As the hot gas flows through the condenser coil, it returns to liquid form and cycles back to the evaporator.

Heat-pump pool heaters typically have a coefficient of performance (COP) ranging from 3.0 to 7.0 (EERE 2009c). Table 7-14 compares the performance of a typical heat pump with COP of 5.0 to a typical gas-fired pool heater. Note that some of the energy saving potential of a heat pump is reduced by the source-to-site electricity conversion factor.

Table 7-14: Comparison of Gas-Fired and Heat Pump Pool Heater Performance

Technology	Typical Efficiency	Site Energy Savings Potential	Source Energy Savings Potential
Natural gas-fired pool heater	0.85	-	-
Heat pump pool heater	5.0	83%	46%

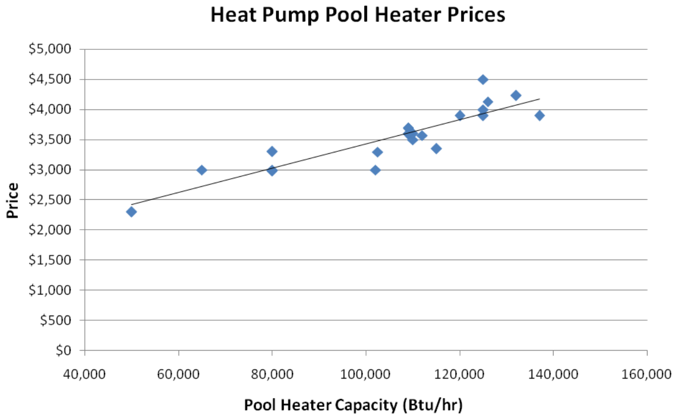
Heat-pump pool heaters are usually classified according to their energy output, in contrast to natural gas heaters which are classified according to their energy input. Currently, the market for heat pump pool heaters is largely limited to residential swimming pools. Some heat pump pool heaters are marketed for commercial pools, but these are relative small units ranging from 100,000–135,000 Btu/hr output. Commercial pools requiring 500,000 Btu/hr heating or more would require larger heat pump heaters or multiple installations of heat pump heaters currently available on the market. Table 7-15 shows the technical potential energy savings from heat pump pool heaters.

Table 7-15: Total Energy Savings Technical Potential of Heat Pump Pool Heaters

Technology	Energy Savings Potential (%)	Total Current Pool Heater Energy Use (MMBtu/yr)	Total Primary Energy Savings Technical Potential (MMBtu/yr)
Heat pump pool heaters	45%	99,000,000	45,000,000

Figure 7-8 shows the cost of residential heat pumps currently on the market.

Figure 7-8: Price Versus Capacity of Heat-Pump Pool Heaters



Sources: Solar Direct website (Solar Direct 2009), PoolProducts website (Pool Products 2009)

Table 7-16 shows the approximate cost of single commercial-sized heat pump pool heaters, assuming the trend line in Figure 7-8 above can be extrapolated to higher pool heater capacities.

Also shown are the approximate costs of comparable natural gas pool heaters, and the cost of multiple 100,000 Btu/hr heat pump units, assuming each unit costs $3,400.

Table 7-16: Estimated Price of Heat-Pump Pool Heaters Compared to Natural-Gas Pool Heaters

Capacity (Btu/hr)	Cost of standard efficiency natural gas pool heater	Cost of single heat pump pool heater	Cost of multiple 100,000 Btu/hr heat pumps
500,000	$8,000	$12,000	$17,000
1,500,000	$11,500	$32,000	$51,000
4,000,000	$23,500	$82,000	$136,000

One of the potential barriers to switching from a gas-fired pool heater to an electric heat pump pool heater is the relatively high price of electricity relative to gas in some parts of the U.S. However, as shown in Table 7-17, even states with the lowest natural gas prices and highest electricity prices may benefit from switching to a heat pump pool heater due to its dramatically higher efficiency.

Table 7-17: Representative Annual Cost Savings for Heat Pump Pool Heaters

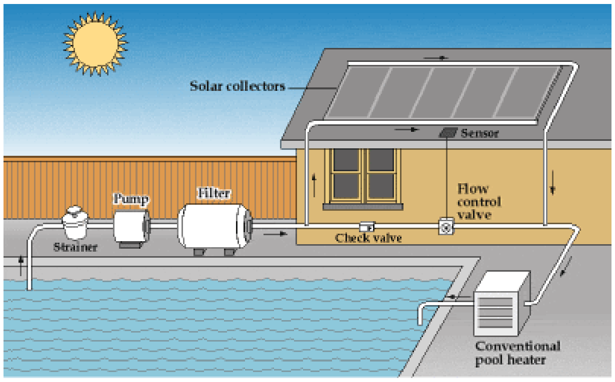
Gas Price	Electricity Price	Annual Cost of Gas[a,b]	Annual Cost of Electricity[c,d]	Annual Savings ($)	States Belonging to This Category
Low	High	$18,322	$14,588	$3,734	AK
Low	Low	$18,322	$6,375	$11,947	AR, IA, ID, MN, ND, NE, SD, UT, WA, WY
Med	Med	$22,950	$8,906	$14,039	AZ, DE, GA, IL, LA, MD, MS, OH, TN
High	High	$30,588	$14,588	$16,000	HI, MA, NH, NJ, RI
High	Low	$30,588	$6,375	$24,213	NC

a. Assumes typical indoor natural gas pool heater with 500,000 Btu/hr input rate; 3600 operating hours per year
b. Assumes the following gas cost ($/MMBtu) – High: $16.99; Med: $12.75; Low: $10.18
c. Assumes typical indoor electric heat pump pool heater with 85,000 Btu/hr output; 3600 operating hours per year
d. Assumes the following electricity cost ($/kWh) – High: $0.163, Med: $0.099; Low: $0.071

7.11.4 Solar Pool Heaters

Solar pool heaters use a solar collector to heat the pool water. In a typical solar pool heater installation, pool water is pumped through a filter and then through the solar collectors. In the solar collector, the water absorbs heat from the sun, usually heating the water by 10 to 15 degrees. The warmer water is then returned to the pool, or to a backup conventional pool heater that operates during times of low solar energy intensity. Figure 7-9 shows an example of a solar pool heating system.

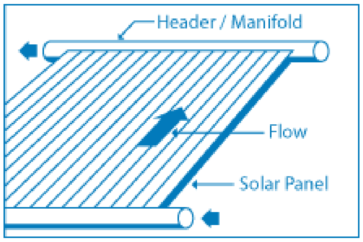
Figure 7-9: Example of a Solar Pool Heater System



Source: EERE website (EERE 2009d)

Figure 7-10 shows an example of how a solar collector works.

Figure 7-10: Example of How a Solar Collector Works



Source: EERE website (EERE 2009d)

If a solar pool heater is only being used when temperatures are above freezing, an unglazed solar collector can be used. Unglazed collectors don't include a glass covering (i.e. glazing). This is the least expensive type of solar pool heater. The piping is generally made of heavy-duty rubber or plastic treated with an ultraviolet light inhibitor to extend the life of the panels. If the solar heater will be used in below-freezing temperatures, a glazed collector must be used. Glazed collectors are generally made of copper tubing on an aluminum plate with an iron-tempered glass covering. Heat exchangers and heat transfer fluids may also be used if the system is to be operated year-round.

Solar pool heating systems are available for both the residential and commercial markets. Because of the need for large solar collectors, commercial installations require large areas on nearby rooftops to mount the solar collectors. Figure 7-11 shows several examples of commercial solar pool heater installations.

Figure 7-11: Examples of Commercial Solar Pool Heating Installations

Source: SunTrek website (SunTrek 2009)

Because solar pool heaters receive all their energy directly from the sun, it is possible to completely eliminate the need for natural gas heating in warm climates. Pools that operate only during the summer can achieve a 100% reduction in energy usage. In moderate climates, or for pools that operate year round, approximately 50% reduction in energy usage can be achieved. In this model, we assume that indoor pools are operated year-round and achieve a 50% reduction in energy usage; outdoor pools are operated only during summer months and can achieve 100% reduction in energy usage. Table 7-18 shows the technical potential energy savings from solar pool heaters.

Table 7-18: Total Energy Savings Technical Potential of Solar Pool Heaters

Pool Location	Energy Savings Potential (%)	No. of Pools	Annual Unit Energy Savings (MMBtu/yr)	Total Primary Energy Savings Technical Potential (MMBtu/yr)
Outdoor	100%	43,000	1,080	39,000,000
Indoor	50%	12,000	1,260	22,000,000
TOTAL				**61,000,000**

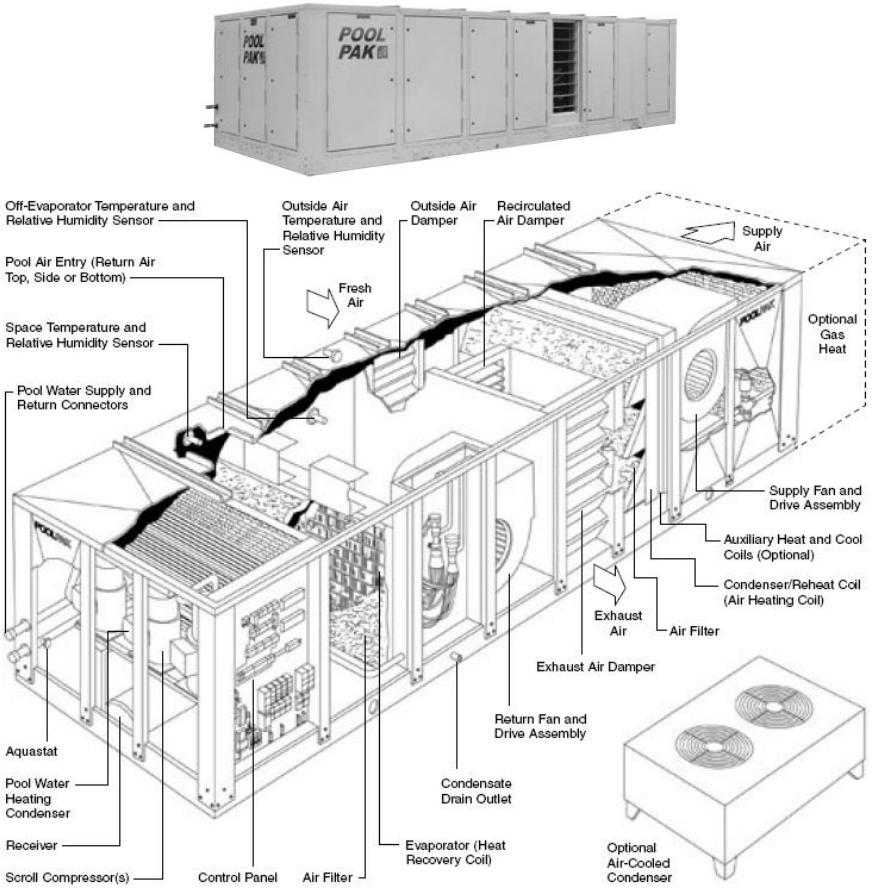
Solar pool heating systems can cost between $2,500 and $7,000 or more, depending on the size of the installation (SunTrek 2009).

7.11.5 Combined Heat-Pump Pool Heating/Dehumidification

Combined heat pump pool heating/dehumidification systems recover the energy lost by indoor pools to the surrounding air through evaporation. As the system draws in warm humid air from the pool room, moisture condenses from the air and the cool, dehumidified air is returned to the pool room. The recovered heat is used to heat the pool water though a water heat exchanger. Excess heat energy can also be used to help maintain the interior temperature of the indoor space.

Systems for small indoor pools can provide up to 100% of the required water heating. Larger systems for large indoor pools can provide up 70-80% of the pool's water heating needs. The COP for these systems ranges from 4.5-5.4 (PoolPak 2009). A combined heat pump pool heating/dehumidification system has the potential to reduce site energy usage by 60-65%. However, these units operate on electricity rather than natural gas, so primary energy saving potential is around 35%. Figure 7-12 shows an indoor pool heater/dehumidification system.

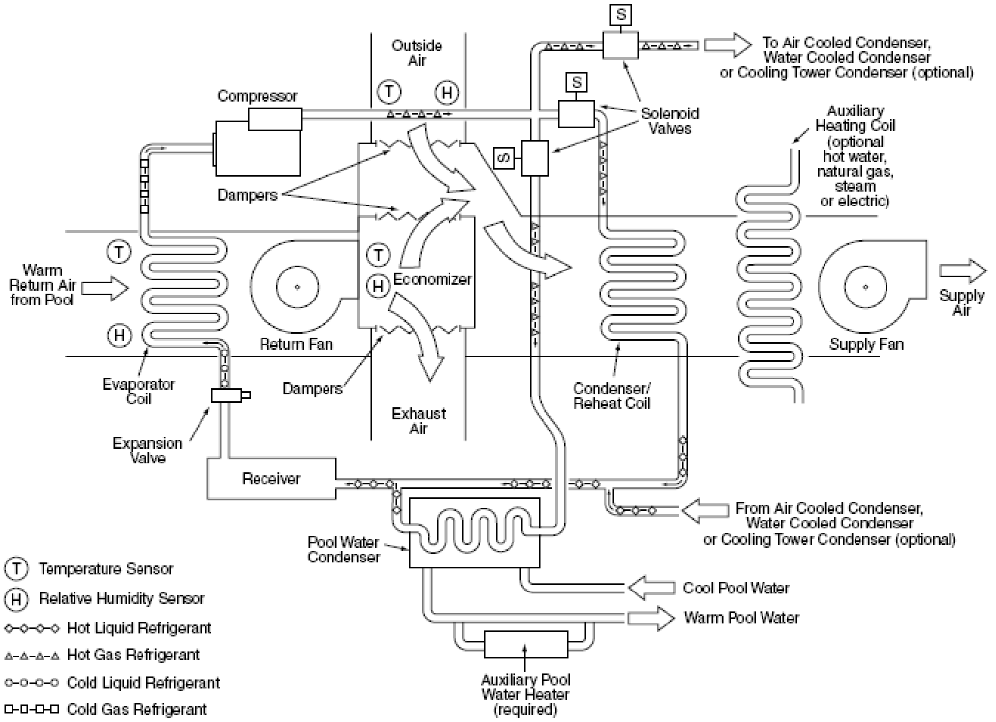
Figure 7-12: Example of an Indoor Pool Heating/Dehumidification System



Source: PoolPak website (PoolPak 2009)

Figure 7-13 shows an example of an entire indoor pool facility environmental control system using a combined heat-pump pool heater/dehumidification system.

Figure 7-13: Indoor Pool Environmental Control System with Combined Heat-Pump Pool Heater/Dehumidification



Source: PoolPak website (PoolPak 2009)

Based on information contained at manufacturer websites, current commercial indoor pool heating/dehumidification systems available on the market have water heating capacities of 145,000 - 850,000 Btu/hr.

Table 7-19 shows the technical potential energy savings from combined pool heater/dehumidification systems, assuming a 40% energy savings over a traditional natural gas heater.

Table 7-19: Total Energy Savings Technical Potential of Combined Pool Heater/Dehumidification System

Technology	Energy Savings Potential (%)	Total Indoor Pool Heater Energy Use (MMBtu/yr)	Total Primary Energy Savings Potential (MMBtu/yr)
Combined pool heater / dehumidification system	35%	77,000,000	27,000,000

7.12 Payback Analysis

Table 7-20 shows the maximum system cost of each pool heater technology to achieve a target payback period of 3-5 years.

Table 7-20: Maximum Cost Premium of Efficiency Technology to Achieve Target Payback

Efficiency Technology	Savings Potential (%)	Total Annual Savings Potential (MMBtu/yr.)	Annual Unit Energy Savings (MMBtu/yr.)	Annual Unit Cost Savings ($)[a]	Target Payback (Yrs.)	Maximum Cost Premium to Achieve Target Payback ($)[b]
Pool covers	60%	59,000,000	1,100	$13,677	3-5	$41,000 - $68,000
Condensing heat exchangers	15%	15,000,000	300	$3,835	3-5	$11,475 – 19,125
Heat pump pool heaters	45%	45,000,000	800	$10,432	3-5	$31,000 - $52,000
Solar pool heaters – indoor	50%	22,000,000	1,800	$23,375	3-5	$70,000 - $117,000
Solar pool heaters – outdoor	100%	39,000,000	900	$11,564	3-5	$35,000 - $58,000
Combined heating/ dehumidification - indoor	40%	31,000,000	2,600	$32,938	3-5	$99,000 - $165,000

a. Assumes $12.75 MMBtu cost of energy (EIA estimate)
b. Includes installation cost and calculation assumes a 3-5 year target payback

Table 7-21 shows the calculated payback periods for pool heating technologies, using cost estimates from manufacturer and distributor websites.

Table 7-21: Payback Periods for Pool Heater Technologies

Efficiency Technology	Cost of Efficiency Technology	Cost of Traditional Gas-Fired Pool Heater	Difference in Cost	Annual Unit Cost Savings[a]	Payback Period (Yrs.)
Pool covers	$10,000	-	$10,000	$13,677	0.7
Condensing heat exchangers	-	-	$20,000	$3,825	5.2
Heat pump pool heaters – small	$17,000	$8,000	$9,000	$10,328	0.9
Heat pump pool heaters – medium	$51,000	$11,500	$39,500	$10,328	3.8
Heat pump pool heaters – large	$136,000	$23,500	$112,500	$27,540	4.1
Solar pool heaters – indoor	$40,000	$8,000	$ 32,000	$23,375	1.4
Solar pool heaters – outdoor	$40,000	$11,500	$ 28,500	$11,564	2.5
Combined heating/ dehumidification - indoor	-	-	-	-	3 – 7[b]

a. Assumes $12.75 MMBtu cost of energy (EIA estimate)
b. Source: PoolPak International, www.poolpak.com

8 Laundry Equipment

8.1 General Market Overview

The commercial laundry equipment market includes washers, dryers, dry-cleaning machines, and other large laundry equipment such as presses, flatwork ironers, sorters, feeders, folders, and finishers. The most energy-intensive part of the laundry process is heating the wash water and drying the laundry. Electronic controls, motors, and accessories such as ironers and folders use a small fraction of the total energy consumed by commercial laundry activities. Therefore, this study will primarily focus on examining the energy savings potential of commercial washers and dryers. This study also examines the energy usage of various types of dry cleaning equipment, which is important because of the rapidly changing regulatory environment of the dry-cleaning industry.

Commercial laundry equipment end users include the following:

- *Coin-operated laundries* – Traditional Laundromat facilities that provide coin- or card-operated laundry equipment.
- *Multi-housing laundry facilities* – Laundry facilities located in common areas of apartment buildings, dormitories, and other multi-family dwellings.
- *On-premise laundries (OPLs)* – On-site laundry facilities in hotels, hospitals, assisted living facilities, universities, and prisons.
- *Off-premise/Industrial laundries*[20] – Large off-site laundry facilities that usually serve multiple customers and often replace OPLs.
- *Dry cleaners* – Professional cleaning establishments that use organic or other solvents to launder clothing and textiles.

Figure 8-1 through

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[20] We use the term "industrial" or "industrial-size" to describe the largest off-premise laundries and laundry equipment. These facilities fall under DOE's definition of commercial buildings, so it is therefore appropriate to consider them for this report.

Figure 8-5 show examples of various commercial laundry facilities.

Figure 8-1: Coin-Operated Laundry Featuring Washers and Dryers Of Various Sizes and Configurations.

Source: Nelson & Small Inc. website (Nelson 2009)

Figure 8-2: Multi-Housing Laundry Facility Featuring Coin-Operated Washers and Dryers.

Source: Barber Knolls Community website (Barber 2009)

Figure 8-3: On-Premise Laundry Facility Featuring Large-Capacity Washing and Drying Equipment.

Source: SuperLaundry website (SuperLaundry 2009)

Figure 8-4: Off-Premise Laundry Facility Featuring The Largest-Capacity Washing And Drying Equipment

Source: Quality Services Ltd website (Quality 2009)

Figure 8-5: (Left) Dry Cleaning Storefront Serving Primarily Residential Customers; (Right) Dry Cleaning Facility Serving Primarily Commercial Customers

Source: Village Cleaners website (Village 2009)

Table 8-1 provides estimates of the number of each type of commercial laundry facility in the U.S. along with the source of information.

Table 8-1: Estimated Number of Commercial Laundry Facilities in the U.S.

Facility Type	Estimated No. in U.S.	Source
Coin-operated laundries (Laundromats)	35,000	"Industry Overview," Coin Laundry Association (CLA 2009)
Multi-housing laundries	300,000 – 600,000[a]	NCI estimate; extrapolated from Multi-Housing Laundry Association (MLA) response letter (Terheggen 2009)
On-premise laundries	60,000[b]	NCI estimate; extrapolated from California Urban Water Conservation Council (CUWCC 2009)
Off-premise/Industrial laundries	1,800	EPA (EPA 1997)
Dry cleaners	30,000	Sinsheimer & Grout report (Sinsheimer 2004)

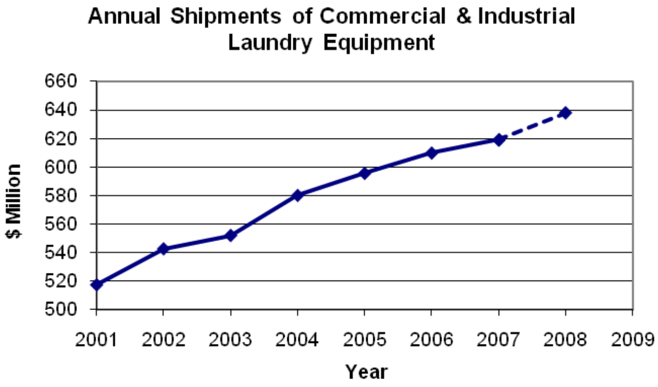
a. Estimate for multi-housing laundry derived from MLA letter claiming roughly 3 million washers and dryers nationwide. Number of facilities calculated by assuming an average of 5-10 pieces of laundry equipment per facility.

b. Estimate for OPLs based on the assumption that 8,800 OPLs in California represent roughly 15% of the total number in the U.S. (based on portion of population).

The U.S. commercial clothes washer market is relatively small compared to the residential clothes washer market. In 2006, approximately nine million residential-style clothes washers were sold; of these, roughly 230,000, or 2.5 percent, were single-load washers for commercial applications such as coin-operated and multi-housing laundries (MLA 2009). This difference in scale has important implications for the resources devoted to manufacturing investment, production, and research and development for commercial laundry equipment.

In 2007, shipments of commercial and industrial-size laundry and dry-cleaning equipment totaled approximately $620 million. The commercial laundry industry's revenues are primarily driven by population growth and the replacement of older laundry equipment. Since 2001, annual shipments have grown an average of roughly 3 percent. Assuming 3 percent growth, 2008 shipments are expected to total approximately $638 million (Freedonia 2008). Figure 8-6 shows the annual shipments since 2001, including the 2008 projection.

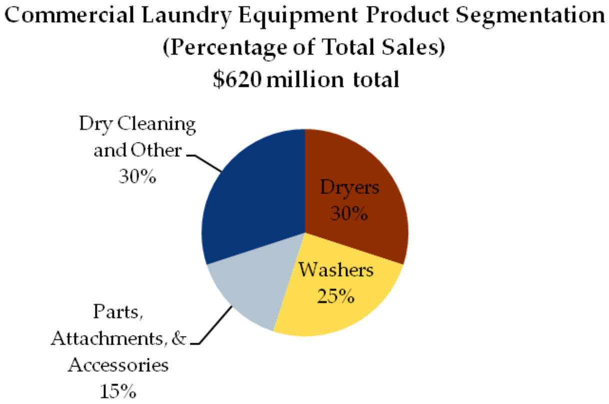
Figure 8-6: Annual Shipments of Commercial and Industrial Laundry Equipment.



Source: Freedonia Focus report (Freedonia 2008). Projection for 2008 based on historical 3% annual growth rate.

Figure 8-7 shows the product segmentation within commercial laundry equipment, as a percentage of total sales in 2007 (Freedonia 2008).

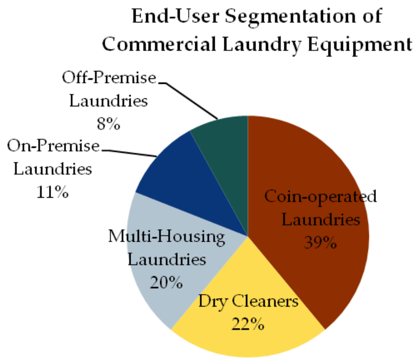
Figure 8-7: Commercial and Industrial Laundry Equipment Product Segmentation for 2007



Source: Freedonia Focus report (Freedonia 2008). Washer category includes top-loading, front-loading, washer extractors, and tunnel systems. Dryer category includes tumblers, standard dryers, and stacked dryers. "Dry cleaning and other category" includes dry cleaning machines, large laundry presses, flatwork ironers, and various other presses.

Figure 8-8 shows the end-user segmentation of new commercial and industrial laundry machinery, as a percentage of total sales in 2007 (Freedonia 2008).

Figure 8-8: End-User Segmentation of Commercial Laundry Equipment Sales



Source: Freedonia Focus report (Freedonia 2008).

The following sections describe the types of commercial laundry machine equipment considered for this analysis. In general, vended equipment used in multi-family housing is similar to retail consumer washing machines. Equipment purchased by coin-operated laundries, on-premise laundries, and off-premise laundries have greater durability, higher capacities, and provide more sophisticated cleaning and drying capabilities.

8.1.1 Summary of Total Annual Energy Consumption

Table 8-2 summarizes the total annual energy consumption of commercial washers, commercial dryers, and commercial dry-cleaning equipment.

Table 8-2: Estimates of National Annual Energy Consumption of Commercial Laundry Equipment.

Equipment Type	2008 Annual Energy Consumption (Btu/yr)
Commercial Washers	2.50E+14
Commercial Dryers	1.96E+14
Dry-Cleaning Equipment	4.30E+13
Total	**4.89E+14**

Table 8-3 compares our energy usage estimate with the 1993 ADL estimate. The 2008 Buildings Energy Data Book does not provide specific estimates for commercial laundry energy consumption.

Table 8-3: Estimates of National Annual Energy Consumption of Commercial Laundry Equipment, By Various Sources

End-use Category	1993 ADL Estimate (ADL 1993)	2008 DOE Buildings Energy Data Book	2008 NCI Estimate
Commercial Washer	1.85E+13	N/A	2.70E+14
Commercial Dryers	3.21E+13	N/A	1.96E+14
Dry-Cleaning Equipment	3.0E+12	N/A	4.30E+13
Total	**5.36E+13**	**N/A**	**5.09E+14**

Our estimates for the commercial laundry category are significantly higher than the ADL estimate. ADL calculated washer and dryer energy usage for on-premise laundries only; whereas our estimates include coin-operated laundries, multi-housing laundries, OPLs and off-premise laundries. In addition, ADL's estimates for OPLs include hospitals and nursing homes only—a total of 22,000 facilities versus our estimate of 60,000 OPLs. We believe the ADL estimate underestimates the total energy usage of all commercial laundry facilities by one order of magnitude.

8.2 *Commercial Clothes Washers*

8.2.1 General Description

This section describes various types of commercial clothes washer equipment.

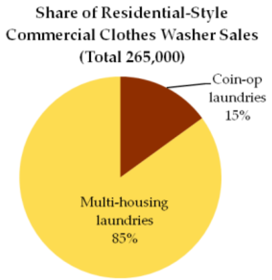
Single-Load Commercial Washers

Single-load commercial washers are defined in the Energy Policy Act of 2005 (EPACT 2005) as soft-mount front-loading or top-loading clothes washers that are designed for use in applications in which the occupants of more than one household will be using the clothes washer, such as multi-family housing common areas or coin laundries. This applies to horizontal-axis clothes washers not more than 3.5 cubic feet in volume and vertical-axis clothes washers not more than 4.0 cubic feet in volume. Most single-load washers for coin-operated and multi-housing laundry facilities have capacities of roughly 3 cubic feet. The capacities of these washers are generally reported in terms of volume, although manufacturers sometimes report capacities as the maximum weight of laundry per load.

Manufacturers typically base commercial clothes washer designs on existing residential clothes washer platforms. This simplifies fabrication and assembly (*i.e.* commercial and residential clothes washers can be assembled on the same assembly line), and helps reduce the fixed costs associated with tooling, overhead etc. for the much lower commercial clothes washer manufacturing volumes. However, some commercial clothes washer components are selectively upgraded to make them more rugged, reliable, and vandal-resistant. Furthermore, the user interface is usually simplified—presenting the commercial user with fewer wash choices than a residential user—and the control system is designed to interface with various payment systems, ranging from coin slides to magnetic card reader. Commercial clothes washers may also have data storage and download capabilities.

Single-load commercial washers are largely used in multi-housing laundries, as well as limited use in coin-operated laundries. Approximately 265,000 of these washers are sold each year. As shown in Figure 8-9, multi-housing laundries represent 85% of sales, with the remaining 15% sold to coin-op laundries (CEE 2009).

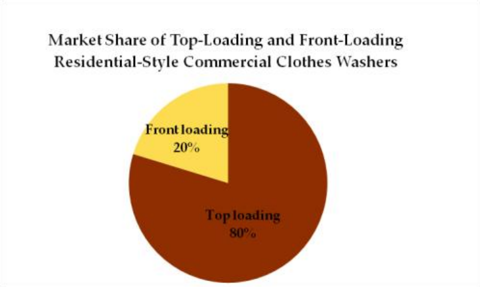
Figure 8-9: Single-Load Commercial Clothes Washer Sales



Source: Consortium for Energy Efficiency (CEE 2009)

As shown in Figure 8-10, DOE estimates that the market share of top-loading washers is 79.7%, while the market share of front-loading washers is 20.3% (DOE 2008).

Figure 8-10: Market Share of Top-Loading and Front-Loading Single-Load Commercial Clothes Washers



Source: DOE (DOE 2008)

The following sections describe top-loading and front-loading single-load commercial clothes washers in greater detail.

Top-Loading Washers

Top-loading single-load commercial washers resemble traditional consumer clothes washers. An example is shown in Figure 8-11.

Figure 8-11: Single-load Commercial Top-Loading Washer

Source: AJMadison website (AJMadison 2009)

These washers have an opening on the top of the cabinet, covered by a door, which gives access to the inner basket where the laundry is placed. The inner basket is typically perforated and is surrounded by a larger outer tub that holds the water when the machine is running. The inner basket typically contains an agitator along a vertical axis, which undergoes a reversing circular motion. The motion of the agitator, which is powered by an electric motor, circulates the clothes vertically from the bottom to the top of the basket. The spinning action of the inner basket and the drain pump are also powered by the motor. Top-loading washers typically process up to 20 pounds of laundry per load with spin cycle speeds that produce up to 150 G-force (Alliance 2009).

Historically, single-load, top-loading washers have dominated both the coin-op and multi-housing laundry market. Recently, however, many coin-operated laundries have switched to larger multi-load capacity washers similar to those used in on-premise and industrial laundries. Multi-housing laundries are expected to continue to use smaller, single-load soft-mounting washers (AWE 2009).

Front-Loading Washers

Front-loading clothes washers utilize a cylindrical tub or drum rotating on a horizontal or nearly-horizontal axis to wash clothes. Figure 8-12 shows an example of a typical single-load commercial front-loading clothes washer.

Figure 8-12: Single-Load Commercial Front-Loading Washer

Clothes are usually loaded along the axis of the cylindrical drum, hence, the term "front-loader". The clothes are cleaned by tumbling them in the water (*i.e.*, clothes are lifted to the top of the drum by the rotation of the cylinder and then dropped into the water below.) The cylindrical drum is only partially filled with water for wash and rinse cycles. High spin speeds are used to extract the water from the clothes during the spin cycles, and this helps to decrease the drying time. These clothes washers are typically more efficient in terms of water and energy usage than traditional top-loaders.

State of the art top-loading and front-loading washers use electronic controllers instead of electromechanical controllers. Electronic controllers cost more; however, they allow owners to more easily monitor washer utilization, functional status, and other parameters. Some manufacturers have also phased out mechanical transmission and clutch systems and replaced them with variable-speed electronic drive systems. This reduces mechanical complexity, increases cabinet space to accommodate potential expansion of the wash basin, and provides greater wash program flexibility. Other design options available in residential clothes washers have yet to find application in commercial clothes washers, such as spray rinse and steam washing. This is because the reliability and longevity requirements of commercial washers preclude manufacturers from additional features unless absolutely necessary. Manufacturers are expected to continue to introduce new features first in the residential markets before transitioning them to the commercial field.

The increasing cost of energy and the advancement of energy efficiency standards are driving many coin-operated and multi-housing laundries to phase out top-loading machines in favor of larger capacity front-loading washers.

Multi-load Washers / Washer Extractors

Multi-load washers and washer extractors are much larger than traditional top- and front-loading single-load washers. Equipment capacity can range in size from 35-900 pounds of laundry per load. After cleaning, water is extracted from the laundry using high-speed spin cycles that produce forces on the order of hundreds of g's. This reduces the remaining moisture content (RMC), and the energy and time required for the dry cycle. Multi-load washers are built to be extremely durable to handle the enormous g-forces of the spin cycles. The equipment experiences high duty cycles and must be durable enough to avoid frequent breakdowns. Examples of multi-load washers and washer extractors are shown in Figure 8-13 through Figure 8-15.

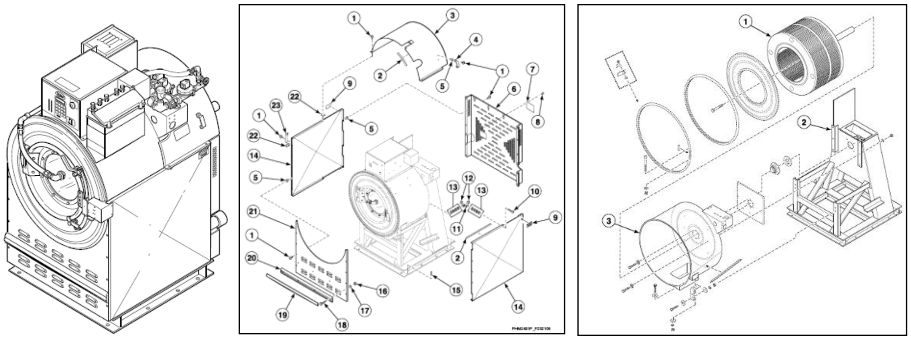
Figure 8-13: Commercial Washer Extractor, 400 kg capacity

Source: Primus Laundry (Primus 2009)

Figure 8-14: Braun TSL Model 800 Washer Extractor, 900 pound capacity

Source: Braun website (Braun 2009)

Figure 8-15: Exploded view of Unimac UW60PV Multi-Load Washer



Source: Century Laundry (Century 2009)

Tunnel (Continuous Batch) Washers

Large, centralized off-premise laundries combine the laundry operations for large facilities such as hotels or hospitals. This reduces costs and helps facilities comply with increasingly stringent government regulations. Many of these facilities use large tunnel washers.

Tunnel washers, also called continuous-batch washers, are constructed as a series of compartments through which the clothing is continuously moved. “Continuous batch” refers to the continual movement of laundry through the washer, which is separated internally into batches, or compartments, that perform a specific portion of the wash process. A large internal corkscrew-shaped auger slowly turns to pull the laundry through the various compartments. Water moves in a counter-flow direction to the laundry and is therefore used several times before being sent to the drain. Most tunnel washers use a large press at the end of the tunnel to compress the clothing to remove excess water. The compressed cakes are then transferred to the dryers. Some tunnel washers use large extractors that spin the clothes to remove most of the remaining moisture before transferring the laundry to the dryers.

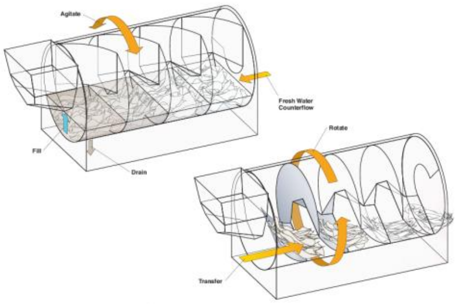
Increased sales of tunnel systems are expected to help drive future growth in the commercial washer sector due to the rising interest of laundry outsourcing. On-premise laundries are increasingly being replaced by large off-premise commercial laundries capable of serving multiple customers (Freedonia 2008).

Tunnel washers can be as large as 8′ x 10′ x 40′ and contain up to 20 compartments. Modern tunnel washers feature up to 100 programmable wash programs, remote diagnostic capabilities, and automatic control of chemicals in each compartment. Wash capacities are measured in pounds/hour, and capacities can range from 350—6,600 lbs/hr. Some examples of tunnel washers are shown in Figure 8-16 through Figure 8-18.

Figure 8-16: Girbau TBS-50 Continuous Batch Washer

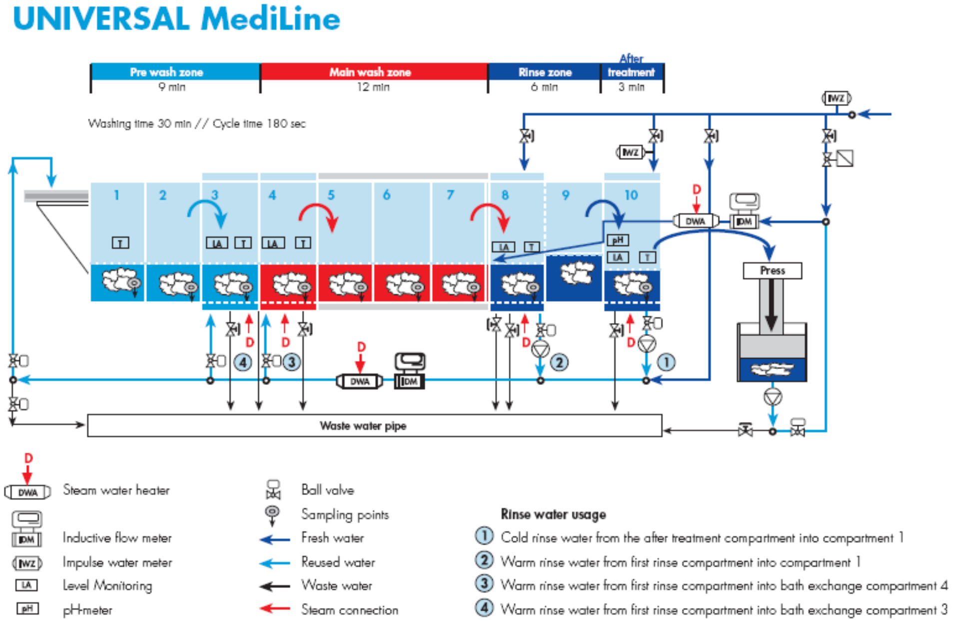
Source: Girbau website (Girbau 2009)

Figure 8-17: Schematic view of Braun SmoothFlow Automated Batch Tunnel Washing System



Source: Braun website (Braun 2009a)

Figure 8-18: Process Flow Diagram of Jensen Continuous Batch Washer for Hospital Linens



Source: Jensen product brochure (Jensen 2009)

8.2.2 *Major Manufacturers*

Table 8-4 shows the major manufacturers of each type of clothes washer equipment. Note that these lists are not exhaustive.

Table 8-4: Manufacturers of Commercial Clothes Washing Equipment

Commercial Clothes Washer Equipment Type	Major Manufacturers
Single-load commercial washers	Alliance Laundry Systems Whirlpool Maytag GE Kenmore Wascomat (Electrolux) Dexter Corporation Continental Girbau
Multi-load washers / Washer extractors	Alliance Laundry Systems Jensen USA Milnor Corporation Wascomat Continental Girbau
Largest capacity equipment for OPLs and industrial laundry facilities	Continental Girbau Ellis Braun Milnor Corporation Kannegiesser USA Washex Leonard Automatic
Note: This table is not exhaustive	

8.2.3 Major End-Users

Commercial clothes washers are used in coin-operated laundries, multi-housing laundries, on-premise laundries, and off-premise industrial laundries. The end users of coin-operated and multi-housing laundries have no special training. End users of on-premise and off-premise laundries are typically trained laundry staff. In almost all cases, the end users are not the owners or purchasers of equipment.

Customers of equipment for coin-operated laundries are typically the owners/operators of each facility. Customers of equipment for multi-housing laundries are typically building management or service route operators. Customers of on-premise and off-premise laundry equipment are typically laundry operation managers. Customers use the following criteria when purchasing commercial laundry equipment (Alliance 2009):

- Equipment reliability and durability
- Performance criteria such as water and energy efficiency, load capacity, and ease of use
- Technologically enabled capabilities such as cashless payment systems and electronic controls
- Fast and reliable servicing of equipment
- Value-added services such as spare parts delivery, equipment financing, and computer-aided assistance in the design of commercial laundries

Customers are increasingly purchasing equipment with enhanced features and functionality. In addition, customers continue to purchase equipment with improved water and energy efficiency, as a result of higher energy costs, government regulation, consumer pressure, and to help contain operating costs (Alliance 2009).

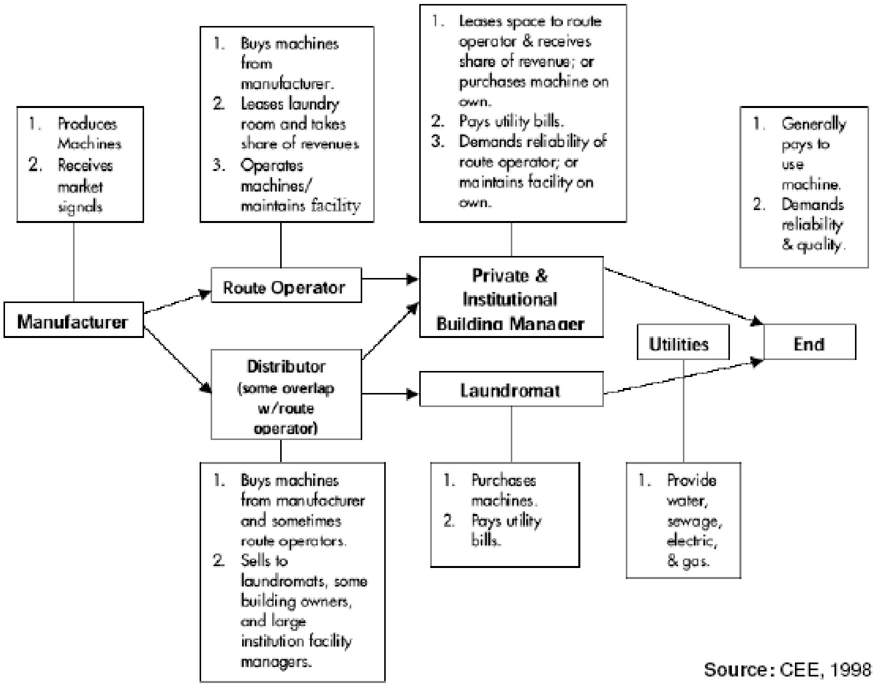
8.2.4 Distribution Chain

Laundromats are served primarily though local and regional distributors. Laundromats historically rely on distributors to find locations for stores, design the facility layout, provide and install equipment, and provide repair support.

Multi-housing laundries are served through individual route operators. Route operators for multi-housing laundries are typically direct customers of commercial laundry equipment manufacturers. They purchase equipment from the manufacturer and then obtain leases from multi-housing property managers to place the equipment into common laundry rooms. Reliability and durability are key criteria for route operators. They also prefer water and energy efficient equipment that can offer enhanced electronic monitoring and tracking features. This report does not examine any additional energy consumption related to transportation for route operators.

On-premise laundries may purchase equipment through a distributor, who also provides service support. Some on-premise laundries are also serviced by route operators. Figure 8-19 below illustrates the distribution channels for commercial clothes washers, excluding large institutional equipment or dry cleaning equipment.

Figure 8-19: Distribution Channel for Commercial Clothes Washers



Source: CEE, 1998

Image source: DOE commercial clothes washer rulemaking (DOE 2008)

There is a small market for single-load commercial clothes washers sold at national retailers. A limited number of models are available at retail home improvement centers such as Sears and Home Depot.

8.2.5 Installed Base

Table 8-5 shows the estimated number of currently installed washers for each category of commercial washing equipment.

Table 8-5: Estimated Installed Base of Commercial Washing Equipment, 2008

Commercial Washer Category	Estimated Installed Base	Sources
Single-load commercial washers (both top- and front-loading)	2,650,000	CEE (CEE 2009)
Multi-load washers	50,000 – 200,000	NCI estimate[a]
Tunnel washers	~ 200	NCI estimate[b]

a. NCI estimate based on assumptions of total annual U.S. commercial laundry volume, average weight per load, and average number of cycles per machine. See Table F-1 in Appendix F for detailed calculations.

b. NCI estimated based on double the number of tunnel washers listed in the EPA report (EPA 1997).

For single-load commercial washers, we also estimated the breakdown of the installed base by type (i.e. front-loading or top-loading) and location (i.e. coin-op laundry or multi-family housing). These estimates are shown in Table 8-6. Note that the figures do not sum exactly to the total due to rounding,

Table 8-6: Estimated Installed Base of Single-Load Commercial Clothes Washers, 2008

Location	Washer Type	Installed Base Estimate
Multi-family housing	Top-loading	1,800,000
	Front-loading	450,000
Coin-op laundry	Top-loading	340,000
	Front-loading	80,000
	TOTAL:	**2,650,000**

Note: Figures do not sum exactly to the total due to rounding.

8.2.6 *Baseline Energy Consumption*

Single-Load Washers

To estimate the energy usage of single-load washers, we used our estimates of the installed base of each type of washer and energy use estimates from the current DOE commercial clothes washer rulemaking (DOE 2008). Table 8-7 shows the weighted average energy usage for each type of single-load commercial washer, based on data from the rulemaking. The table includes energy used for water heating, energy used to dry the laundry, and machine energy usage. The drying energy is included because certain energy efficiency technologies, such as faster spin rate, decrease overall energy usage by decreasing the laundry drying time.

Table 8-7: Weighted-Average Energy Consumption Of Single-Load Commercial Clothes Washers[a,b] (DOE 2008)

Location	Washer Type	Water Heating		Drying		Machine
		Electric (kWh/yr)	Gas (Btu/yr)	Electric (kWh/yr)	Gas (Btu/yr)	Electric (kWh/yr)
Multi-family housing	Top-loading	185.39	3.37	618.74	3.55	165.11
	Front-loading	79.64	1.46	490.76	2.82	142.14
Coin-op laundry	Top-loading	0	7.41	0	10.39	289.48
	Front-loading	0	3.2	0	8.24	35.28

a. Data in each row represent the weighted average of units with varying efficiency levels according to the relative market shares of each efficiency level. Source: DOE 2008

b. Breakdown between electricity and gas usage for water heating and drying represent the weighted average of electric and gas units according to the percentage of buildings in the U.S. that use electric and gas water heaters and dryers. Source: DOE 2008

We used the assumptions listed in Table 8-8 to estimate total annual energy consumption of single-load commercial clothes washers.

Table 8-8: Assumptions for Single-Load Commercial Clothes Washer Calculations.

Location	No. wash cycles per machine per day
Coin-operated laundry	6
Multi-family housing laundry	3.4
Source: DOE commercial clothes washer rulemaking (DOE 2008)	

Table 8-9 shows the total annual energy consumption of single-load commercial washers. Dryer energy usage is calculated later in the commercial dryer section of this chapter.

Table 8-9: Annual Energy Consumption of Single-Load Commercial Clothes Washers.

Function	Energy Type	Site Energy (Btu/yr)	Primary Energy (Btu/yr)
Hot water	Electric	1.26E+12	4.01E+12
Hot water	Gas	-	9.42E+12
Machine	Electric	1.6E+12	5.10E+12
		Total:	**1.85E+13**

Multi-Load Washers / Washer Extractors

Because of the uncertainty in the size of the installed base of multi-load washers, we used two methods to estimate the total annual energy usage.

For the first method, we used data on the annual volume of laundry processed by on-premise laundries in California and extrapolated that to the entire U.S. We estimate that the majority of multi-load washers are installed in on-premise laundries, but there are also installations in coin-operated laundries and industrial-size laundries. Based on the number of laundry facilities shown previously in Table 8-1—and the fact that OPLs primarily use multi-load washers while coin-operated laundries use both multi-load washers and single-load washers—we estimate that the combined number of multi-load washer installations in coin-operated and industrial-size laundries to be equal to or less than installations in on-premise laundries. Coin-operated multi-load washers also have a much lower usage than OPL washer extractors. Table 8-10 below shows the energy consumption estimate using our first method. This method yields total annual energy consumption within a range of 1.57E+14 to 2.36E+14 Btu/yr.

Table 8-10: Annual Energy Consumption of Multi-Load Washers – First Method.

Parameter	Value	Units	Source
Annual OPL laundry volume in California	8.7 E+09	Pounds/yr	CUWCC report (CUWCC 2009)
California portion of total U.S. laundry	15%	-	NCI estimate[a]
Total U.S. OPL laundry volume	60 E+09	Pounds/yr	Calculation
Multi-load washer hot water usage	1,963	Btu/pound	NCI report (Navigant 2008)
Annual energy consumption (OPL only)	1.18E+14	Btu/yr	Calculation
OPL usage as percentage of total annual usage of multi-load washers	50-75%	-	NCI estimate[b]
Total annual energy consumption (range)	**1.57E+14 - 2.36E+14**	**Btu/yr**	**Calculation**

a. Based on California representing 12% of U.S. population and 16% of total U.S. hotels.
b. Based on assumption that OPL usage of multi-load washers represents at least half the total annual usage of multi-load washers by OPLs, industrial-size facilities, and coin-operated facilities.

For the second calculation method, we estimated the total number of wash cycles performed by multi-load washers using the estimated total volume of laundry and per-cycle energy usage. Table 8-11 shows the energy consumption estimate using our second method. This method yields total annual energy consumption within a range of 2.80E+14 to 4.20E+14 Btu/yr. This is roughly double the energy estimate of the first calculation method.

Table 8-11: Annual Energy Consumption of Multi-Load Washers – Second Method

Parameter	Value	Units	Source
Total U.S. OPL laundry volume	60 E+09	Pounds/yr	Calculation (see Table 8-10 above)
Average pounds per each multi-washer load	200	Pounds/cycle	Manufacturer product literature (average)
No. wash cycles per year	300 million	Cycles/yr	Calculation
Hot water energy usage per cycle	700,000	Btu/cycle	CUWCC report (CUWCC 2009)
Annual energy consumption (OPL only)	2.10E+14	Btu/yr	Calculation
OPL usage as percentage of total annual usage of multi-load washers	50-75%	-	NCI estimate (see Table 8-10 above)
Total annual energy consumption (range)	**2.80E+14 – 4.20E+14**	**Btu/yr**	**Calculation**

Based on these two calculation methods, a low estimate for multi-load washer energy usage is 1.57E+14 Btu/yr, and a high estimate is 4.2E+14. We believe the actual energy usage falls near the high end of the first estimate and the low end of the second estimate.

The estimates described above include hot water heating energy only, which we assume is natural gas. Table 8-12 below shows the estimate of electricity usage due to the motors inside the multi-load washers.

Table 8-12: Estimate of Multi-Load Washer Electricity Usage

Parameter	Value	Units	Source
Agitation motor	7.5	hp	Product manuals (Braun 2009)
Spin motor	20	hp	Product manuals (Braun 2009)
hp → kW conversion	0.746	kW/hp	Definition
Agitation minutes per cycle	15	min	Product manuals (Braun 2009)
Spin minutes per cycle	9	min	Product manuals (Braun 2009)
Electricity usage per cycle	3.64	kWh/cycle	Calculation
No. wash cycles per year	300 million	Cycles/yr	Calculation (see Table 8-10 above)
Total site electricity usage per year (kWh)	1.1E+09	kWh/yr	Calculation
Total primary electricity usage per year	**1.17E+13**	**Btu/yr**	**Calculation**

Table 8-13 summarizes the annual energy consumption estimates for multi-load washers.

Table 8-13: Annual Energy Consumption of Multi-Load Washers

Equipment type	Energy Type	Primary Energy (Btu/yr)
Multi-load washers	Gas	2.36E+14
	Electric	1.17E+13
	TOTAL:	**2.48E+14**

Tunnel Washers

Although the installed base of tunnel washers is extremely low compared to other washer types, each machine processes an enormous amount of laundry each year. Table 8-14 shows the estimate of energy usage for tunnel washers.

Table 8-14: Estimate of Tunnel Washer Electricity Usage

Parameter	Value	Units	Source
Installed base	200	Units	NCI estimate[a]
Daily laundry volume per unit	50,000	Pounds/day	Product literature (Braun 2009)
No. days in service per year	365	Days	EPA laundry report (EPA 1997)
Avg. annual laundry volume per unit	18.3E+6	Pounds/yr/unit	Calculation
Total annual laundry volume	3.67E+9	Pounds/yr	Calculation
Gas usage per pound of laundry	968	Btu/pound	NCI report (Navigant 2008)
Total annual energy usage	**3.55E+12**	**Btu/yr**	**Calculation**

a. Estimate based on triple the number of tunnel washers reported by DOE in 1997, due to recent trends towards larger, more efficient off-premise laundries.

Summary

Table 8-15 summarizes the total annual energy usage for the three types of commercial washer equipment described in this section.

Table 8-15: Summary of Annual Energy Consumption of Commercial Washing Equipment

Equipment Type	Primary Energy Consumption (Btu/yr)
Single-load washers	1.85E+13
Multi-load washers	2.48E+14
Tunnel washers	3.55E+12
TOTAL:	**2.70E+14**

The table above indicates that energy usage by washing equipment in the commercial laundry sector is highly dominated by multi-load washers.

8.2.7 Cost Breakdown

The average purchase costs for each type of commercial washer equipment are shown in Table 8-16.

Table 8-16: Average Purchase Cost for Commercial Washer Equipment

Equipment Type	Average Cost
Single-load Top-Loading (with coin box)	$824[a]
Single-load Front-Loading (with coin box)	$1,355[a]
Washer Extractor (50 pound capacity)	$7,500[b]
Washer Extractor (800 pound capacity)	$190,000[c]
Tunnel Washer	$1,100,000[c]

a. Source: DOE commercial clothes washer rulemaking (DOE2008)
b. Source: T&L Equipment Sales website (T&L 2009)
c. Source: Navigant report (Navigant 2009)

Table 8-17 shows typical manufacturer and distributor markups for single-load commercial clothes washers (DOE 2008). These markups do not include installation costs. Markup data are unavailable for washer extractors or tunnel washers.

Table 8-17: Markups for Single-Load Commercial Clothes Washers

Supply Chain	Baseline Markup
Manufacturer	1.26
Distributor	1.43
Sales Tax	1.0684
Overall	**1.93**

8.2.8 Lifetime, Reliability, and Maintenance Characteristics

Table 8-18 shows the average useful life for commercial washer equipment.

Table 8-18: Average Useful Lifetime of Commercial Washing Equipment

Equipment Type	Average Lifetime (Years)	Source
Single-load – Multi-family	11.3	DOE rulemaking (DOE 2008)
Single-load – Coin-op	7.1	DOE rulemaking (DOE 2008)
Multi-load washer / Washer extractor	15	Navigant report (Navigant 2008)
Tunnel washer	7 to 15	EPA report (EPA 1997)

Table 8-19 shows the estimated annual repair and maintenance costs for commercial washer equipment. Owners of commercial washer equipment tend to use the equipment until it can no longer be economically repaired, or until competition forces them to upgrade their equipment to improve its appearance and functionality.

Table 8-19: Annual Repair and Maintenance Costs For Commercial Washer Equipment

Equipment type	Annual Repair & Maintenance Costs (per unit)	Source
Single-load – Multi-family	$24	DOE rulemaking (DOE 2008)
Single-load – Coin-op	$39	DOE rulemaking (DOE 2008)
Washer extractor	$7,500	Navigant report (Navigant 2008)
Tunnel washer	$19,000	Navigant report (Navigant 2008)

8.2.9 Regulatory Programs

EPACT 2005 mandated efficiency standards for single-load commercial clothes washers, as shown in Table 8-20. Separate standards apply for top-loading and front-loading product classes. These standards specify a minimum modified energy factor (MEF), expressed in cubic feet of washer capacity per kilowatt-hour; and maximum water factor (WF), expressed in gallons per cubic foot of washer capacity. DOE is currently engaged in a rulemaking process to update the single-load commercial clothes washer standards. There are no minimum efficiency standards for multi-load washers, washer extractors, or tunnel washers.

Table 8-20: Mandatory Energy Efficiency Standards for Single-Load Commercial Clothes Washers (DOE 2008)

Standard	Efficiency Standard Levels	
	Modified Energy Factor (MEF)	Water Factor (WF)
EPACT 2005	≥ 1.26	≤ 9.5

8.2.10 Voluntary Programs

There are several voluntary programs promoting energy-efficient single-load commercial clothes washers, described further below. The criteria for each of these programs are shown below in Table 8-21. There are no voluntary programs for multi-load washers or tunnel washers.

Table 8-21: Voluntary Energy Efficiency Programs for Single-Load Commercial Clothes Washers

Program	Efficiency Standard Levels	
	Modified Energy Factor (MEF)	Water Factor (WF)
ENERGY STAR	≥ 1.72	≤ 8.0
CEE Tier 1[a]	≥ 1.80	≤ 7.5
CEE Tier 2	≥ 2.00	≤ 6.0
CEE Tier 3	≥ 2.20	≤ 4.5
FEMP	≥ 2.50	N/A

a. Consortium for Energy Efficiency (CEE) has developed a tiered rating system for commercial clothes washers, described further below.

ENERGY STAR

Energy star criteria exist for top- and front-loading single-load commercial clothes washers with capacities greater than 1.6 cubic feet. These criteria are stricter than the federal minimum efficiency standards.

Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) develops initiatives to promote the manufacture and purchase of energy-efficient products and services. In 1998 CEE launched the Commercial Family-Sized Washer Initiative for Laundromats, multi-family housing units, and institutions. This initiative includes three Tiers of energy performance metrics (Tier 1, 2, and 3). Tier 3 is the strictest standard. All three Tiers are stricter than the ENERGY STAR criteria.

Federal Energy Management Program

DOE's Federal Energy Management Program (FEMP) helps Federal buyers identify and purchase energy efficient equipment, including commercial clothes washers. FEMP issues energy efficiency recommendations for commercial clothes washers based on washer volume.

8.2.11 Energy-Saving Technologies

Single-Load Commercial Clothes Washers

Figure 8-20 shows the estimated annual energy consumption (AEC) of the installed base compared to the AEC that would result from replacing the entire installed base with the highest efficiency units currently available on the market. The calculations that were performed to derive this estimate are shown in Table F-2 in Appendix F. We use the AEC of the best available technology as the baseline energy consumption for our energy savings calculations later in this section. The table indicates that converting the entire installed base to the best available technology in 2008 would reduce total annual energy consumption by approximately 0.006 Quads.

Figure 8-20: Annual Energy Consumption of the Installed Base of Single-Load Commercial Washers, Compared to "Baseline" AEC Resulting From Upgrade to Typical New Best-Available Technology

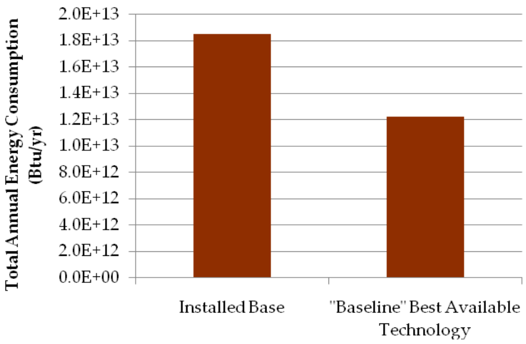
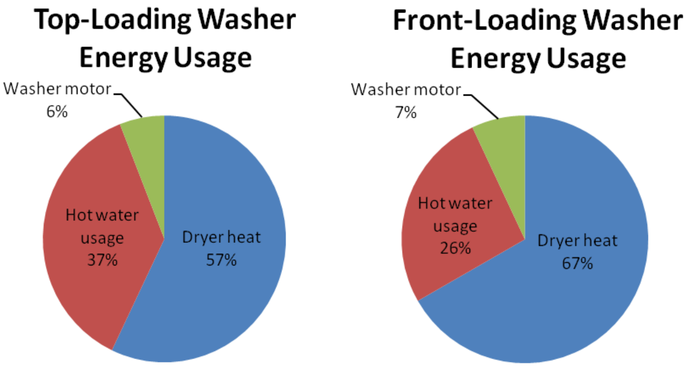


Figure 8-21 shows the estimated energy usage breakdown of a typical wash and dry cycle for baseline top-loading and front-loading commercial clothes washers (DOE 2008).

Figure 8-21: Overall Laundry Process Energy Usage



DOE efficiency standards specify a minimum modified energy factor (MEF) and maximum water factor (WF), so manufacturers are most inclined to implement energy efficiency technologies that can be captured by the prescribed test procedures for measuring MEF and WF. Given the current energy efficiency test procedures and the energy usage estimates in Figure 8-21, the greatest efficiency opportunities for single-load commercial washers include:

- Reducing the amount of hot water used in each wash cycle
- Reducing the remaining moisture content (RMC) of the laundry to decrease the required dry time

Improvements that involve decreasing the washer motor electricity usage of each machine, or that do not directly affect hot water usage or RMC, will have comparatively little effect on the overall energy usage at a national scale. Table 8-22 below lists the most promising energy-saving technologies that were identified in the current round of rulemaking for single-load commercial clothes washers (DOE 2008). The table provides a brief description and development status of each technology.

Table 8-22: Energy-Saving Technologies for Single-Load Commercial Clothes Washers

Technology Option	Technology Description	Development Status
Adaptive control system	Automatically adjusts washer operation or washing conditions based on characteristics of the clothes placed into the machine. (e.g. measures soil load to adjust wash temperature, agitation, tumble cycle time).	Limited implementation in residential clothes washers; more research would be required
Advanced agitation concepts for top-loading machines	Allows top-loading washers to avoid the need to cover all clothes completely in water.	Available in high-end residential clothes washers.
Automatic fill control	Advanced control technologies sense the clothes load and adjust water level accordingly.	Available in residential clothes washers
Direct-drive motor	For use only in top-loading washers. Direct-drive motor replaces a conventional induction motor/transmission system. This avoids transmission (gearbox) losses.	Available in residential clothes washers; limited testing in commercial washers
Improved front-loading washer drum design	Includes modifications to existing drum designs to reduce cycle time, improve wash performance, reduce mass, and increase spin speeds. Manufacturers are continuously improving horizontal-axis washer designs.	Continuous development; several features available in residential clothes washers
Improved water extraction to lower RMC	This would lower the remaining moisture content. It is much more efficient to remove water using mechanical energy (i.e. spin cycle) than using heat to dry the clothes.	Range of options; continuous development; may be approaching practical limits
Spray rinse technology	Rather than totally immersing clothes in rinse water, rinse water is sprayed into the drum during the spin cycle. A much smaller quantity of rinse water is required.	Limited available in commercial clothes washers; previous models using this technology were pulled from market

Table 8-23 lists the energy-saving technology options from Table 8-22 above that would decrease the hot water usage of each laundry load. The table shows the estimated maximum primary energy savings for each technology compared the installed base and the highest efficiency units available on the market ("max tech"). The table is ranked from highest potential savings to lowest.

Table 8-23: Hot-Water Energy Savings Potential of each Technology Option for Single-Load Commercial Clothes Washers

Technology Options	Type of Washer	Estimated Maximum Savings (%)	Annual Energy Savings vs. Installed Base (Btu/yr)	Annual Energy Savings vs. Max Tech (Btu/yr)
Technology Options that Reduce Hot Water Energy Consumption				
Spray rinse technology	Top-loading	50%[a]	4.8E+12	2.7E+12
Advanced agitation concepts	Top-loading	15%[a]	1.4E+12	7.8E+11
Automatic fill control	Top-loading	15%[a]	1.4E+12	7.8E+11
Adaptive control system	Top-loading & Front-loading	10%[a]	1.3E+12	7.7E+11
Technology Options that Reduce Dryer Energy Consumption				
Improved water extraction	Top-loading & Front-loading	25%[a]	2.9E+12	2.5E+12
Improved drum design	Top-loading & Front-loading	20%[a,b]	2.4E+12	2.0E+12
Technology Options that Reduce Motor Electrical Energy Consumption				
Direct-drive motor	Top-loading	60%[a]	7.9E+11	6.8E+11
Increased motor efficiency	Top-loading & Front-loading	10%[a]	5.1E+11	4.5E+11
Low standby power electronic controls	Top-loading & Front-loading	Unknown	-	-

Sources:

a) DOE Commercial Clothes Washer Rulemaking (DOE 2008)

b) Energy Efficient Laundry Process Report (GE 2004)

Multi-Load Washers

As with single-load clothes washers, the major energy usage with multi-load washers is heating the hot water and drying the clothes. Because multi-load washers are specifically designed to use extremely high spin rates, there is little opportunity to achieve energy savings by decreasing the remaining moisture content of clothing even further. The largest opportunities for energy saving involve reducing hot water usage.

Table 8-24 lists potential energy-saving technologies for multi-load washers. The table also provides a brief description and development status of each technology.

Table 8-24: Energy-Saving Technologies for Multi-Load Washers

Technology Option	Technology Description	Development Status
Wastewater recycling	Retrofit technology - recycle and re-use wash water from previous wash cycles to decrease the amount of new hot water required	In-Use
Low-temperature detergent	Retrofit technology – use a low-temperature detergent to decrease the amount of hot water necessary for each wash cycle	Commercially available
Advanced ozone system	Replacement technology – use ozone dissolved in cold water for light to medium-soiled garments to alleviate the need for hot water.	In-Use
Switch to using tunnel washer	Tunnel washers are more efficient than multi-load washers (use less water per pound of laundry)	In-Use

Table 8-25 lists the energy-saving technology options from Table 8-24 above that would decrease the hot water usage of each laundry load. The table shows the estimated maximum primary energy savings for each technology compared to the installed base. The table is ranked from highest potential energy savings to lowest.

Table 8-25: Hot-Water Energy Savings Potential of each Technology Option for Multi-Load Washers

Technology Option	Estimated Maximum Energy Savings (%)	Annual Energy Savings vs. Installed Base (Btu/yr)
Advanced ozone system	89%[a]	2.2E+14
Switch to using tunnel washer	82%[a]	2.0E+14
Wastewater recycling	53%[a]	1.3E+14
Low-temperature detergent	47%[a]	1.2E+14

Sources:

a) Commercial Laundry Technology Market Review (Navigant 2008)
Note: Energy savings estimates include water, sewer, and energy costs.

Tunnel Washers

Tunnel washers are the most efficient commercial washing equipment on the market. As with multi-load washers, the largest opportunities for energy savings with tunnel washers involve reducing hot water usage. Table 8-26 lists potential energy-saving technologies for tunnel washers.

Table 8-26: Energy-Saving Technologies for Tunnel Washers

Technology Option	Technology Description	Development Status
Wastewater recycling	Retrofit technology - recycle and re-use wash water from previous wash cycles to decrease the amount of new hot water required	In-Use
Low-temperature detergent	Retrofit technology – use a low-temperature detergent to decrease the amount of hot water necessary for each wash cycle	Commercially available
Advanced tunnel washer	Improved tunnel washer design that uses even less water per pound of laundry	Commercially available, In Use

Table 8-27 lists the energy-saving technology options from Table 8-26 above that would reduce the hot water usage of each laundry load. The table shows the estimated maximum primary energy savings for each technology compared to the installed base. The table is ranked from highest potential energy savings to lowest.

Table 8-27: Hot-Water Energy Savings Potential of each Technology Option for Tunnel Washers

Technology Option	Estimated Maximum Energy Savings (%)	Annual Energy Savings vs. Installed Base (Btu/yr)
Advanced tunnel washer	60%[a]	2.4E+12
Wastewater recycling	53%[a]	2.1E+12
Low-temperature detergent	47%[a]	1.9E+12

Sources:

a) Commercial Laundry Technology Market Review (Navigant 2008)
Note: Energy savings estimates include water, sewer, and energy costs.

8.3 Commercial Clothes Dryers

8.3.1 General Description

Commercial clothes dryers are segmented into single-load dryers for coin-operated and multi-housing laundries; larger capacity tumbler dryers for coin-ops and on-premise laundries; and industrial-sized dryers for off-premise industrial laundries. The different dryer types include standard and high capacity tumbler dryers, stacked dryers, and industrial-sized dryers. The major differences between these categories are the capacities and physical configurations. Commercial clothes dryers are used by all types of laundry facilities, including laundromats, multi-housing facilities, on-premise laundries, and off-premise laundries.

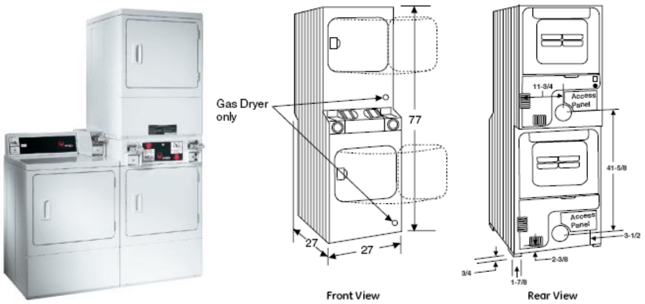
Single-Load Dryers

Single-load dryers are residential-style dryers that are generally more durable and include hardware for coin or card operations. These are often used in multi-housing facilities or as smaller dyers in coin-operated facilities. Single-load dryers may have a stand-alone configuration or a stacked configuration to enable greater drying capacity per square foot of floor space. These dryers typically feature simple controls that are designed for simplicity of use. Common features may include the following:

- automatic dry control
- multiple cycles for cottons, permanent press, and delicates
- multiple heat selections

Single-load dryer capacity is often measured by cubic feet of volume. Typical capacities range from 5.4 to 7.0 cubic feet. These dryers can usually process up to 20 pounds of laundry per load. Figure 8-22 shows an example of single-load commercial dryer configurations.

Figure 8-22: Single-Load Commercial Dryer Configurations



Sources: Left: IPSO (IPSO 2009); Right: GE (GE 2009)

Large-Capacity Tumble Dryers

Large-capacity tumblers are used in coin-operated laundries, on-premise and off-premise laundry facilities. Their larger capacities are ideal for use with moderately-sized multi-load washers. Capacities are measured by weight of laundry per load. Typical capacities range from 20 to 75 pounds. Some of the larger tumblers have capacities up to 175 pounds. Both stand-alone and stacked configurations are available. Common features may include the following:

- Reverse tumbling to help prevent “balling” or “roping” of clothes
- Automatic dry control
- Heavy-duty materials and construction
- Self-cleaning lint screens
- Self-diagnostic microcontrollers

Figure 8-23 shows examples of large-capacity tumbler dryers.

Figure 8-23: Examples of Large-Capacity Tumble Dryers

Sources: Left: SDG&E presentation (SDGE 2008); Right: IPSO website (IPSO 2009)

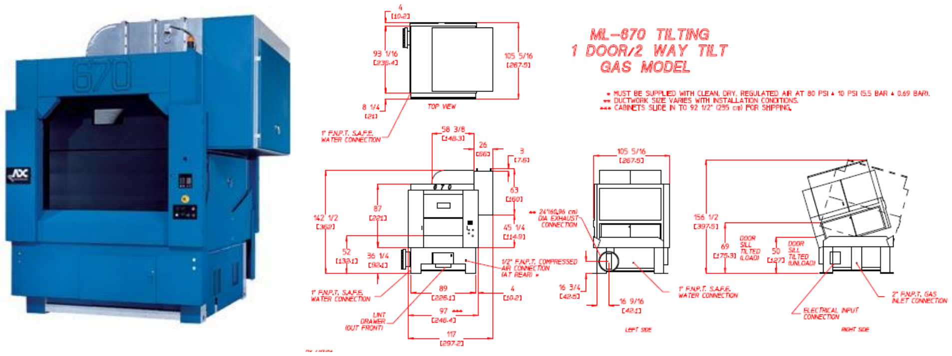
Largest-Capacity Dryers

The largest-capacity commercial dryers have capacities that range from 120 pounds up to 700 pounds per load. These dryers are used mainly in large on-premise or off-premise laundry facilities. These dryers may be configured as stand-alone units or as "pass-through" dryers for use with continuous tunnel washer systems. Industrial driers are much more complex and sophisticated than tumbler dryers and include more advanced energy-saving features. Advanced features described at manufacturer websites include (ADC 2009; Braun 2009b; Milnor 2009):

- Machine tilting capability for easier loading
- Multiple door configurations
- Full-body insulation
- Full burner modulation for precise temperature control
- Inlet and outlet temperature monitoring
- Automatic fuel metering control
- Automatic dry control
- Coaxial ducting to transfer heat energy from exhaust to incoming air
- Self-diagnostic microprocessors
- Sensor activated fire extinguishing system
- Integration with data management systems
- Ethernet ports for remote monitoring and control

Figure 8-24 and Figure 8-25 show examples of two largest-capacity dryers.

Figure 8-24: American Dryer Corporation AD-670 Dryer



Source: American Dryer Corp (ADC 2009)

Figure 8-25: Braun Pass-Thru Dryer

Source: Braun website (Braun 2009b)

8.3.2 *Major Manufacturers*

Table 8-28 shows the major manufacturers of each type of commercial dryer equipment. Note that this list is not exhaustive.

Table 8-28: Selected Manufacturers of Commercial Clothes Dryer Equipment

Commercial Clothes Washer Equipment Type	Major Manufacturers
Single-load and large tumbler dryers	American Dryer Corporation GE Pellerin Milnor Alliance Laundry Systems Continental Girbau Wascomat Whirlpool Maytag Dexter
Largest-capacity dryers	American Dryer Corporation Pellerin Milnor Braun
Note: This list is not exhaustive.	

8.3.3 Major End-Users

The major end users for commercial drying equipment are the same as those for commercial clothes washers, described previously in this report.

8.3.4 Distribution Chain

The distribution chain for commercial dryers is largely similar to the distribution chain for commercial washers. Most of the major manufacturers produce both washers and dryers. Refer to the relevant discussion in the Commercial Washer section above.

8.3.5 Installed Base

Table 8-29 shows the estimated installed base for each category of commercial dryer equipment. Table F-3 through Table F-5 in Appendix F show the detailed calculations used to derive these estimates.

Table 8-29: Estimated 2008 Installed Base of Commercial Dryer Equipment

Commercial Dryer Category	Installed Base
Single-load dryers	1,450,000
Tumble dryers	2,000,000
Largest-capacity dryers	25,000

8.3.6 *Baseline Energy Consumption*

Table 8-30 shows the total estimated annual energy consumption of commercial drying equipment. The calculations that yielded each estimate are described in Table F-6 through Table F-8 in Appendix F.

Table 8-30: Annual Energy Consumption of Commercial Drying Equipment

Equipment Type	Annual Primary Electric Consumption (Btu/hr)	Annual Gas Consumption (Btu/hr)	Total Primary Energy Consumption (Btu/yr)
Single-load dryers	1.23E+13	1.12E+13	2.35E+13
Large capacity tumble dryers	7.16E+13	7.60E+12	7.92E+13
Largest capacity dryers	7.84E+13	1.51E+13	9.35E+13
TOTAL	**1.62E+14**	**3.39E+13**	**1.96E+14**

8.3.7 *Cost Breakdown*

The average purchase costs for each type of commercial dryer equipment are shown below in Table 8-31.

Table 8-31: Average Purchase Cost for Commercial Dryer Equipment

Equipment Type	Average Cost
Standard Capacity Dryer	$800 (AJ Madison 2009a)
Large Capacity Tumble Dryer	$2,800 (T&L 2009)
Largest Capacity Dryer	$80,000 (USAID 2009)

8.3.8 *Lifetime, Reliability, Maintenance Characteristics*

The expected service life of commercial dryers is 7-14 years (Alliance 2008).

8.3.9 *Regulatory Programs*

DOE is currently evaluating the establishment of standards for residential clothes dryers, but currently there are no regulatory programs for commercial dryers.

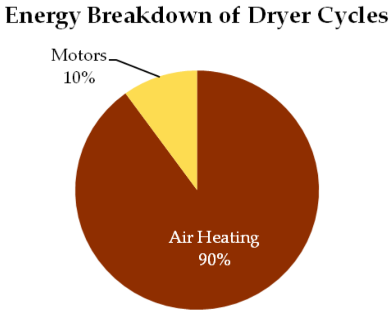
8.3.10 *Voluntary Programs*

There appear to be no current voluntary energy-efficiency programs for commercial clothes dryers.

8.3.11 *Energy Savings Technologies*

During a typical clothes dryer cycle, the heating of the air represents roughly 90% of the clothes drying energy, with the remaining 10% for electric motors, as shown in Figure 8-26. Therefore, the greatest opportunities for improving dryer energy efficiency involve decreasing the amount of heat input per pound of laundry.

Figure 8-26: Energy Breakdown of Typical Dryer Cycle



The following sections describe various energy-saving technologies for commercial dryers.

Single-Load Commercial Clothes Dryers

Many of the energy-saving features that can be applied to residential clothes dryers could also be applied to single-load commercial dryers, particularly those located in multi-family housing laundry facilities. Table 8-32 below lists potential energy-saving technologies for single-load commercial clothes dryers, many of which were identified in the current round of DOE rulemaking for residential dryers. The table provides a brief description and development status of each technology.

Table 8-32: Energy-Saving Technologies for Standard-Capacity Commercial Clothes Dryers

Technology Option	Technology Description	Development Status
Exhaust heat recovery	A heat exchanger is used to recover exhaust heat energy and to preheat inlet air	Prototype; possible limited commercial availability
Improved cycle termination	Temperature, humidity, or other sensors inside the dryer control the length of the drying cycle, preventing unnecessary over-drying of clothes.	In-use in residential clothes dryers
Improved air circulation	Designing the drum to improve airflow to direct and maintain heat more efficiently	Continuous improvement
Improved drum design	Optimizing internal vane design to promote clothing separation during tumbling, to reduce dry time	Continuous improvement
Inlet air preheat, condensing mode	A highly effective heat exchanger is used to transfer heat from the exhaust air to the inlet air; the condensing water vapor in the exhaust air will transfer more heat than the non-condensing case	Condensing dryers in-use
Heat pump, electric only	Exhaust air is recirculated back to the dryer, while moister is removed by a refrigeration-dehumidification system	Available in Europe
Microwave, electric only	Microwaves are used to evaporate the water in the clothing	Prototypes tested
Modulating, gas only	The gas burner is modulated to match the heat input rate to the moisture level of the laundry load	Prototype tested

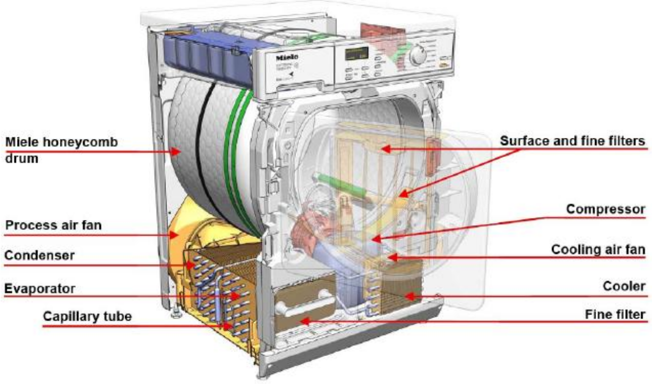
The following sections describe some of these technology options in more detail.

Heat-Pump Dryers

Heat-pump dryers are a replacement technology for traditional electric clothes dryers. Several heat pump dryers have been available for years in Europe, but there are no volume production heat-pump dryers available in the U.S. In 2007, the market share of heat pump dryers in Europe was about 1.7%, or less than 100,000 shipments per year out of 4.9 million total clothes dryer sales (LBNL 2009).

The design of a heat-pump clothes dryer is shown in Figure 8-27. The heat pump consists of a refrigeration loop containing a refrigerant vapor compressor, and evaporator heat exchanger, a condensing heat exchanger, and an expansion valve. Hot, dry, processed air enters the rear of the drum and interacts with the laundry. Inside the tumbler, water from the clothes evaporates into hot dry air, creating warm moist air. The warm moist air exits the drum and proceeds first through a lint screen, then through the evaporator. In the evaporator, heat from the air is transferred to the refrigerant inside the evaporator coils. This decreases the temperature of the warm moist air and causes the moisture in the air to condense. The condensate is drained from the dryer. After exiting the evaporator, the cool dry air flows past the condenser heat exchanger. There, heat from the high-temperature refrigerant is transferred to the cool dry air, creating hot dry air. The dry air enters the tumbler, and the cycle is completed. (LBNL 2009).

Figure 8-27: Miele Heat-Pump Dryer, Model T 8627 WP



Source: Miele website (Miele 2009)

Since most of the moisture in the air is removed by the evaporator, the air can be recirculated back into the drum. This allows for a ventless design, which can be an added feature for dryer installation. Because the transfer of energy in a heat pump dryer is more efficient, energy consumption and operation costs can be significantly lower compared to traditional tumbler dryers.

As mentioned previously, several European heat pump dryers are available. According to available data, heat pump clothes driers achieve roughly 40% to 60% reduction in energy consumption compared to traditional clothes dryer designs. However, most of the European models have longer drying times and are much more expensive than a typical European tumbler dryer. These would be considered significant market barriers within the U.S. Table 8-33 below shows the capacity, drying time, energy usage, and list price of selected European heat pump dryers (LBNL 2009).

Table 8-33: Selected European Heat-Pump-Dryer Models

Manufacturer	Capacity (kg)	Drying Time (min)	Energy Use (kWh/kg)	List Price[a] (Euros)
Bosch-Siemens	7	124	0.27	€2,119
Electrolux	7	130	0.34	€2,056
Miele	6	104	0.30	€2,434
Arcelik A.S.	7	140	0.32	€1,806
Metall Zug AG	6	90	0.32	€2,562

Source: LBNL Heat Pump Dryer Technical Note (LBNL 2009)

a) Actual retail prices are often lower than list prices

TIAX, working with Whirlpool on a program funded by DOE, developed a high-efficiency, high-performance heat-pump dryer that would be attractive to US residential customers (TIAX 2005). By modifying the refrigerant, evaporator and condenser design, internal system geometry, and venting, TIAX was able to design a dryer that provided a faster drying time with significant energy savings. Internal temperatures were also lower than a traditional dryer, which provides a gentler dry cycle for the clothing. Table 8-34 shows the results of the prototype testing.

Table 8-34: Energy Savings Test Results for Heat-Pump Dryer

Delicate Load			
Dryer	**Time (mins)**	**Energy (kWh)**	**Fabric Temp.**
Market Best	22.2	0.74	120
Heat Pump	14.4	0.44	110
Gain (Savings)	**35%**	**41%**	**-10°F**
Medium, 7lb Cotton Load			
Market Best	39	2.90	185
Heat Pump	42	1.97	155
Gain (Savings)	**-8%**	**31%**	**-30°F**
Large, 15lb Towel Load			
Market Best	78	6.28	190
Heat Pump	78	3.52	155
Gain (Savings)	**0%**	**44%**	**-35°F**

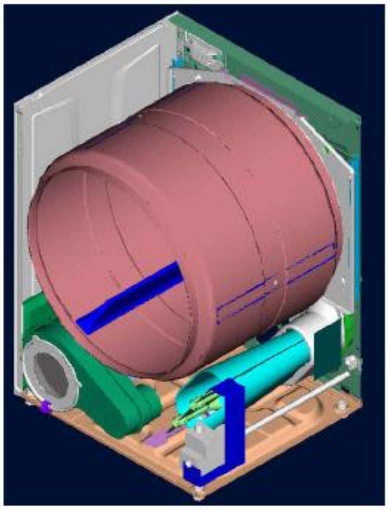
Source: TIAX report: High Efficiency, High Performance Clothes Dryer (TIAX 2005)

Modulating Gas Dryer

Most gas dryers on the market today operate with a single burner at a fixed input rate and fixed airflow rate. The burner typically operates in an on/off mode as determined by the cycle chosen. One strategy for saving energy in a gas dryer is to match (or modulate) the heat input rate to the moisture level of the load. This saves energy because the dryer requires less heat towards the end of the cycle. Modulating gas dryers require the ability to detect when the clothes are becoming dry, and to reduce the heat input rate accordingly as the clothes are approaching their dry state.

TIAX, working together with Whirlpool on a program funded by DOE, developed a prototype residential modulated gas dryer with significant time and energy savings and reduced fabric temperatures (TIAX 2005). Figure 8-28 shows a schematic of the dryer. The dryer allows for three gas input rates. The dryer contains additional sensors to detect the rate of exhaust temperature rise and humidity sensing in the exhaust. The temperature in the exhaust indicates the amount of moisture inside the drum. That signal is used to determine when to perform the first and second modulation steps. The signal from the humidity sensor in the exhaust is used to determine the end of the cycle.

Figure 8-28: Physical Layout of Modulating Gas Dryer



Source: TIAX report (TIAX 2005)

Table 8-35 shows the results of the prototype testing. Energy is the volume of natural gas consumed during the dyer cycle plus an adjustment for electrical consumption. The units are undetermined. The savings in dry cycle time ranged from 20% to 40%, and the savings in energy ranged from 13% to 23%. Fabric temperatures were reduced between 4% and 24% compared to standard dryers.

Table 8-35: Energy Savings Test Results for Modulating Gas Dryer

Delicate Load			
Dryer	**Time (mins)**	**Energy**	**Fabric Temp.**
Market Best	15	2.2	113
Modulated Gas	12	1.8	109
Gain (Savings)	**20%**	**18%**	**-4°F**
Medium, 7lb Cotton Load			
Market Best	30	9.7	127
Modulated Gas	18	7.5	148
Gain (Savings)	**40%**	**23%**	**-24°F**
Large, 15lb Towel Load			
Market Best	64	24	172
Modulated Gas	47	21	168
Gain (Savings)	**28%**	**13%**	**-4°F**

Source: TIAX report: High Efficiency, High Performance Clothes Dryer (TIAX 2005)

Microwave Dryers

A limited number of prototype microwave dryers have been built and tested. One model that was tested showed microwave dryers use 17%-25% less energy than a typical electric dryer, with 25% faster drying time. However, they could cost $30 to $395 more than conventional models. Technical issues, such as the ability to dry all fabric types and metal clothing accessories, must be resolved before microwave dryers can become commercially available (CEE 2006).

Exhaust Heat Recovery

An example of a technology for recovering dryer exhaust heat is a heat recovery wheel, as shown below in Figure 8-29. Half of the heat recovery wheel is exposed to the dryer air inlet, while the other half is exposed to the dryer exhaust inlet. The wheel is constructed of alternate layers of flat and corrugated aluminum, as shown in the figure below. As the heat wheel spins, heat is extracted from the exhaust outlet and transferred to the colder dryer inlet air.

One company, Rototherm Corporation, manufactures the Rototherm heat recovery wheel shown in Figure 8-29 below. A case study featured on the company website claims a fuel reduction of 44-51% using the heat recovery wheel. However, we are unable to assess the viability of the company at this time. We recommend classifying the Rototherm heat recovery wheel as a working prototype.

Figure 8-29: Dryer Heat Recovery Wheel Concept

Source: Rototherm website (Rototherm 2009)

Technical Potential

Table 8-36 shows the technical potential for each technology option listed in Table 8-32 above. The table shows the estimated maximum primary energy savings for each technology compared to the installed base. The table is ranked from highest potential energy savings to lowest.

Table 8-36: Dryer Energy Savings Potential of each Technology Option for Standard-Capacity Commercial Dryers

Technology Option	Compatible Fuel Sources	Estimated Energy Savings (%)	Annual Energy Savings Technical Potential vs. Typical New Equipment (Btu/yr)
Recycle exhaust heat	Gas and Electric	45%[a]	1.06E+13
Heat pump	Electric	50%[b]	4.46E+12
Improved cycle termination	Gas and Electric	15%[c]	3.53E+12
Modulating gas burner	Gas	15%[b]	2.19E+12
Microwave	Electric	25%[d]	2.09E+12
Inlet air preheat, condensing mode	Gas and Electric	14%[e]	1.53E+11
Improved air circulation	Gas and Electric	Unknown	-
Improved drum design	Gas and Electric	Unknown	-

Sources:

a) Rototherm website (Rototherm 2009)
b) High Efficiency, High Performance Clothes Dryer Report (TIAX 2005)
c) Energy Efficient Laundry Process Report (GE 2004)
d) Energy-Efficient Appliances (Ashley 1998)
e) Improving the Energy Efficiency of Conventional Tumbler Clothes Drying Systems (Bansal 2001)

Larger-Capacity Tumble Dryers

A subset of the energy-saving features that apply to smaller residential-size dryers could be applied to large-capacity tumble dryers. Nearly all large-capacity tumbler dryers are gas-fired. They are used primarily in multi-housing facilities, coin-operated laundries, and on-premise laundries. The greatest opportunities for improving dryer energy efficiency involve decreasing the amount of heat input per pound of laundry. Table 8-37 below lists those technologies from Table 8-36 above that could be implemented in large-capacity tumble dryers.

Table 8-37: Dryer Energy Savings Potential of each Technology Option for Larger-Capacity Tumble Dryers

Technology Option	Estimated Energy Savings (%)	Annual Energy Savings Technical Potential vs. Typical New Equipment (Btu/yr)
Recycle exhaust heat	45%	3.56E+13
Improved cycle termination	15%	1.19E+13
Modulating gas burner	15%	1.19E+13
Inlet air preheat, condensing mode	14%	1.11E+13
Inlet air preheat	5%	3.96E+12

Industrial-Sized Commercial Dryers

Industrial-sized commercial dryers are used at on-premise and off-premise laundries. These dryers have enormous capacities and process thousands of pounds of laundry daily. Energy usage is a major operating expense at the facilities that operate these dryers, so there are already significant incentives to design energy-saving features into the dryer equipment.

Many of the energy-saving features noted in the sections above are already commercially available in some of the highest-capacity industrial-sized dryers. For example, the Braun PT series dryers have modulating gas burners, full-body insulation, computer-controlled heating, advanced temperature sensors, inlet air preheating, and improved air flow within the laundry chamber. Future shipments of commercial dryer equipment are expected to be driven by large-capacity models with value-added features such as fire suppression systems and lint monitoring systems (Freedonia 2008).

Large on-premise and off-premise laundry facilities have some unique characteristics that make them ideal for innovative energy efficiency improvements. For example, the nearly-continuous operation of both washer and dryer equipment provides a unique opportunity to use waste heat from the dryers to pre-heat the incoming water for the washers.

8.4 Dry-Cleaning Equipment

8.4.1 General Description

Commercial dry-cleaning facilities serve both residential and commercial customers. Smaller facilities serving residential customers typically receive small quantities of clothes from individuals and may offer other services such as garment refreshing. Larger facilities that serve institutional, professional, and industrial customers typically clean uniforms and may also rent uniforms and other industrial clothing such as gloves. In total, there are roughly 33,000 dry cleaning facilities in the U.S. (Sinsheimer 2004). As of 2008, national sales volume for retail dry cleaners was approximately $9 billion (USDC 2008).

Table 8-39 shows the total estimated volume of dry cleaning in the U.S. based on the assumption that California represents 15 percent of the total U.S. volume. This is the same assumption used for commercial washer and dryer equipment.

Table 8-38: Total Annual U.S. Dry Cleaning Volume

Paramter	Value	Source
Annual California dry cleaning volume	256,000,000 pounds	2006 CARB Report
CA percent of total U.S. volume	15%	Based on ratio of populations
Annual U.S. dry cleaning volume	**1,700,000,000 pounds**	**Calculation**

Dry cleaning equipment typically includes chemical dry cleaning machines, wet cleaning machines, and accessories such as presses, form finishers, vacuums, compressors, and conveyors. This report focuses on the equipment used to perform the dry- or wet-cleaning function, which consumes the large majority of energy in the dry cleaning process. The report does not include an analysis of dry-cleaning accessory equipment.

The traditional dry-cleaning process uses a solvent called perchloroethylene, often referred to as PCE or perc. A dry cleaning machine is similar to a commercial clothes washer extractor. Garments are placed into a cylindrical washing/extraction chamber, which contains a horizontal-axis, perforated drum that rotates within an outer shell. The outer shell holds the solvent while the rotating drum holds the garment load. The capacity of a dry cleaning machine can range between 30 and 90 pounds of garments. Figure 8-30 shows traditional PCE dry cleaning machines.

Figure 8-30: Traditional PCE Dry Cleaning Machines

Source: Left: Parrisianne Dry Cleaning website (Parrisianne 2009); Right: Dry Cleaning Concepts website (DCC 2009)

During the wash cycle, the washing chamber is filled less than half full with solvent and rotates, agitating the clothing. Throughout the wash cycle, the chamber is constantly fed a supply of fresh solvent, while spent solvent is removed and sent to a filter unit comprising a distillation boiler and condenser. A typical flow rate is one gallon of solvent per pound of garments per minute, depending on the size of the machine. The wash cycle lasts 8-15 minutes depending on the type of garments and amount of soiling. At the end of the wash cycle, the machine starts a rinse cycle, and the garment load is rinsed with fresh distilled solvent from the pure solvent tank. This pure solvent rinse prevents discoloration caused by soil particles being absorbed back onto the garment surface from the "dirty" working solvent.

After the rinse cycle the machine begins the extraction process, which recovers dry-cleaning solvent for reuse. Modern machines recover over 99% of the solvent employed. The extraction cycle begins by draining the solvent from the washing chamber and spinning the basket 350 to 450 rpm, causing much of the solvent to spin free of the fabric. When no more solvent can be spun out, the machine starts the drying cycle. During the drying cycle, the garments are tumbled in a stream of warm air that circulates through the basket, evaporating any traces of solvent left after the spin cycle. The air temperature is controlled to prevent heat damage to the garments. The warm exhaust from the machine then passes through a chiller unit, where solvent vapors are condensed and returned to the distilled solvent tank. Modern dry cleaning machines use a closed-loop system where the chilled air is reheated and recirculated. This results in high solvent recovery rates and reduced air pollution. Figure 8-31 shows the process flow for a typical PCE dry-cleaning machine.

Figure 8-31: Simplified Process Flow Diagram for PCE Dry-Cleaning Machine

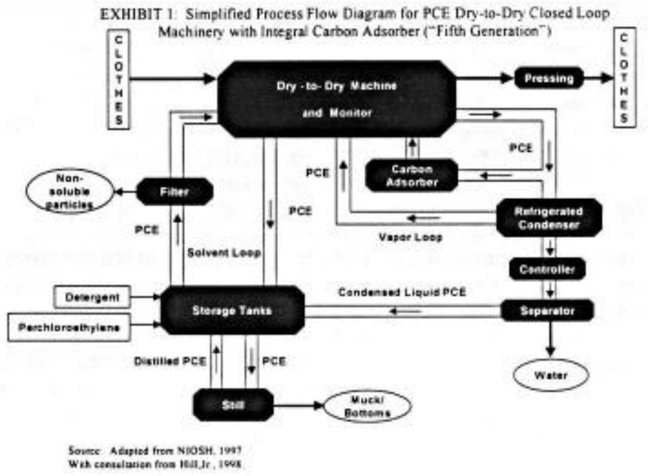


EXHIBIT 1 Simplified Process Flow Diagram for PCE Dry-to-Dry Closed Loop Machinery with Integral Carbon Adsorber ("Fifth Generation")

Source: Adapted from NIOSH, 1997
With consultation from Hill,Jr., 1998

Source: Sinsheimer report (Sinsheimer 2004)

During the 1980s, the EPA and state environmental agencies began regulating PCE as a contaminant. To deal with tightening regulation on PCE emissions, the dry cleaning industry began installing increasingly complex pollution control devices for recapturing PCE liquid and vapors. Modern equipment has been largely successful in decreasing PCE emissions. The PCE demand for the industry has declined to 47 million pounds in 2002, from 150 million pounds in 1993 (Sinsheimer 2004).

California has recently banned the use of perchloroethylene. This ban will be implemented in a phased approach and is to be completed by January 1, 2023. Alternatives to PCE include petroleum dry cleaning, supercritical carbon dioxide technologies, silicon-based compounds, and wet-cleaning methods similar to front-loading washers. These technologies are discussed further below.

8.4.2 Major Manufacturers

Table 8-39 shows some of the major manufacturers of PCE dry cleaning equipment. Note that this list is not exhaustive.

Table 8-39: Manufacturers of Commercial Clothes Washing Equipment

Equipment Type	Major Manufacturers
PCE Dry cleaning machines	Union Aerotech Columbia/ILSA Bowe
Note: This list is not exhaustive.	

8.4.3 Major End-Users

Most commercial dry cleaning facilities are "mom and pop" businesses, although there is a considerable range in size of these businesses. A typical dry cleaning business employs several employees and has one or two dry cleaning units (EPA 1994).

8.4.4 Distribution Chain

The structure of the distribution chain for dry cleaning equipment is largely similar to the distribution chain for commercial laundry equipment described above in the commercial clothes washer section.

8.4.5 Installed Base

Table 8-40 shows the estimated installed base of dry cleaning equipment based on estimates for the state of California.

Table 8-40: Estimated Installed Base of PCE Dry Cleaning Machines

Equipment Type	No. of dry cleaning facilities in California	CA percent of total U.S. installations	Est. no. of dry cleaning machines per facility	Total U.S. installed base
PCE dry-cleaning machines	5,040[a]	15%[b]	1.07[a]	**36,000**

a. Source: CARB report (CARB 2006)
b. Ratio of populations

8.4.6 *Baseline Energy Consumption*

Dry cleaning machines use electricity for mechanical action, the operation of fans and pumps, refrigeration, air compression, and operation of the computer. Dry cleaning machines use steam from a boiler as the source of heat, which is often powered by natural gas. Steam heat is used during the dry cycle, distillation, and to clean carbon filters (Sinsheimer 2004).

A field test conducted by Sinsheimer and Grout measured the electricity and natural gas usage per 100 pounds of laundry in a 40 lb PCE dry cleaning machine. The data are shown in Table 8-41. The table does not include the power demands of the cooling tower, which is in operation during the entire time the dry clean machine is switched on. The table includes data from two separate tests.

Table 8-41: Equipment Used For PCE Dry Cleaning Test

Test	Electricity Usage of All Equipment (kWh per 100 Lbs)	Gas Usage of Boiler (Therms per 100 Lbs)
Test #1	33.3	24.4
Test #2	27.1	19.5
Average	**30.1**	**22.0**

Source: Sinsheimer report (Sinsheimer 2004)

Table 8-42 shows the total estimated annual energy consumption of PCE dry cleaning equipment based on the data from the tables above.

Table 8-42: Total Annual Energy Consumption of Dry-Cleaning Equipment

Energy Consumption	Value	Source
Annual U.S. dry cleaning volume (lbs/yr)	1,700,000,000	Table 8-38
Electricity usage (kWh/lb)	0.301	Table 8-41
Total Electricity Site Consumption (kWh/yr)	510,000,000	Calculation
Electric Primary Energy Consumption (Btu/yr)	5.53E+12	Calculation[a]
Gas usage (Btu/lb)	22,000	Table 8-41
Gas Primary Energy Consumption (Btu/yr)	3.74E+13	Calculation
Total Annual Energy Consumption (Btu/yr)	**4.29E+13**	**Calculation**

a. Assumes electricity production factor of 3.18

We used a second method of calculating electricity usage to validate our first estimate. Table 8-43 shows the calculations for the second estimate. The similarity between the two estimation techniques provides a level of confidence in our original estimates.

Table 8-43: Second Method of Calculating Total Electricity Consumption

Energy Consumption	Value	Source
Monthly electricity usage of each PCE machine (kWh/month)	1,100	CARB report (CARB 2006)
No. of installed base machines	36,000	Table 8-40
Total Electricity Site Consumption (kWh/yr)	**475,000,000**	**Calculation**

8.4.7 Cost Breakdown

Table 8-44 shows the typical manufacturer list price range for PCE dry cleaning equipment.

Table 8-44: Price Range for PCE Dry Cleaning Equipment

Equipment Type	Rated Capacity (lbs)	Price Range[a]
PCE dry cleaning machine	35 - 90	$38,000 - $83,000

a. Source: CARB report (CARB 2006)

8.4.8 Lifetime, Reliability, Maintenance Characteristics

The CARB uses an estimate of 15 years for the average lifetime of PCE dry cleaning machines (CARB 2006). Table 8-45 shows the estimated annual cost for the first five years of a typical dry cleaning machine.

Table 8-45: Annual Cost for the First Five Years of Typical Dry Cleaning Equipment

Equipment Type	Solvent, Detergent, Spotting Agents	Electricity & Gas Cost	Maintenance & Other Equipment	Machine Cost (Annualized)	Waste Disposal	Total Annual Cost
PCE dry cleaning machine	$2,659	$8,650	$1195	$12,372	$2,500	**$27,376**

Source: CARB report (CARB 2006)

8.4.9 Regulatory Programs

There are no regulatory programs regarding the energy usage of dry cleaning equipment. There are, however, regulatory programs in California mandating the phase-out of PCE, and other states are expected to follow. In California, the ban will be implemented in a phased approach and is to be completed by January 1, 2023.

8.4.10 Voluntary Programs

There are no voluntary energy-related programs for dry cleaning equipment.

8.4.11 Energy Savings Technologies

A number of alternatives to PCE have emerged in the dry cleaning equipment market. The most popular alternatives are the following:

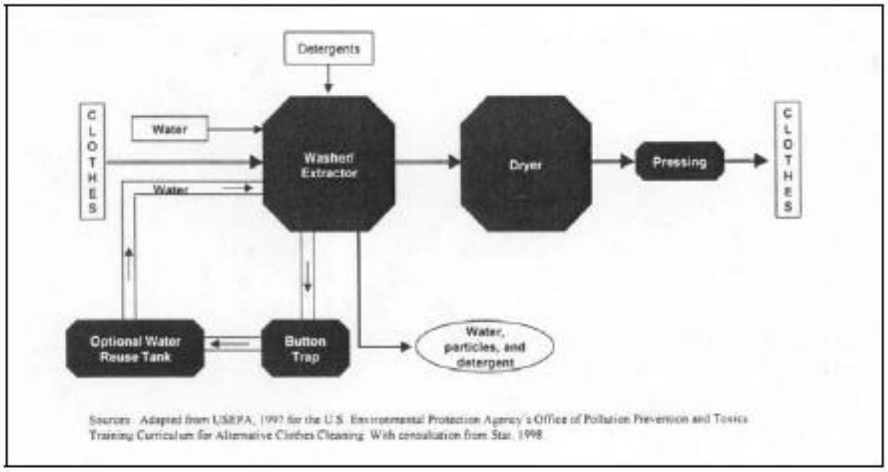
- Professional wet cleaning
- Petroleum dry cleaning
- Silicone dry cleaning
- Carbon dioxide dry cleaning

The two leading environmentally preferable technologies available today are CO_2 dry cleaning and professional wet cleaning. This section provides a description of each of the four alternative technologies listed above as well as annual energy usage estimates for each technology.

Professional Wet Cleaning

Professional wet cleaning is an increasingly popular non-toxic alternative to dry cleaning. It is a water-based process for cleaning, followed by appropriate drying and finishing procedures. Professional wet clean washers use a computer to control the rotation of the cleaning drum to minimize agitation while providing sufficient movement for effective garment cleaning. Wet clean washers are also equipped with a programmable detergent injection system, which allows the cleaner to specify the amount and type of wet clean detergent used for each load. Wet clean dryers also include computer controls to assure that garments retain a proper amount of moisture after the dry cycle is complete (UEPI 2009). Figure 8-32 shows the process flow diagram for professional wet-cleaning.

Figure 8-32: Process Flow Diagram for Professional Wet Cleaning



Sources: Adapted from USEPA, 1997 for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics Training Curriculum for Alternative Clothes Cleaning. With consultation from Star, 1998.

Source: Sinsheimer report (Sinsheimer 2004)

Petroleum Dry Cleaning

Petroleum solvent (also referred to as 'hydrocarbon') is the most widely used alternative to PCE. Equipment costs are slightly higher than PCE dry cleaning machines. Petroleum dry clean machines must be equipped with solvent-recovering pollution control devices similar to those found on PCE equipment. Petroleum solvents are highly flammable, and fire codes often require the construction of firewalls between the machine and the rest of the facility (Sinsheimer 2004). These restrictions are significant barriers that limit the desirability of petroleum dry-cleaning as an alternative to PCE.

Silicone Dry Cleaning

Silicone solvent is becoming increasingly popular, and has been marketed as a non-toxic alternative to PCE. Equipment costs are slightly higher than PCE dry cleaning machines. The solvent used is known as D-5 or decamethylepentacyclosiloxane. Silicone dry clean machines are equipped with solvent recovery devices similar to those found on PCE equipment, and some machines are designed to handle both petroleum and silicone solvents. Although silicone it is less flammable than petroleum solvents, it is subject to the same fire codes and regulations (Sinsheimer 2004).

Carbon-Dioxide Dry Cleaning

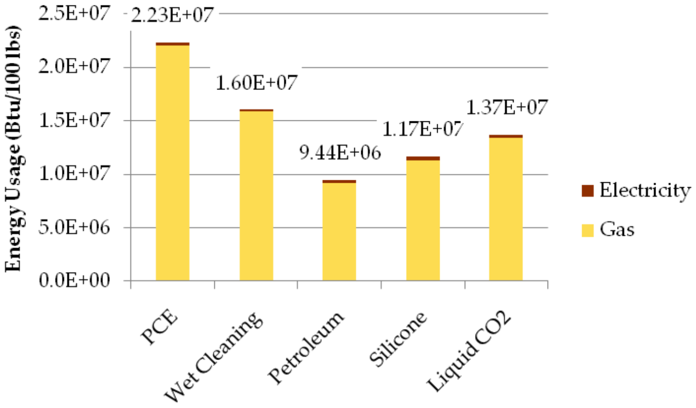
The CO_2 process is a sub-critical carbon-dioxide-based garment cleaning process that has been developed for use by commercial and retail dry-cleaners. CO_2 is a non-flammable, non-toxic, colorless, tasteless, odorless naturally-occurring gas that, when subjected to pressure, becomes a liquid solvent. The CO_2 used in the garment cleaning process is an industrial by-product from existing operations, such as the production of ethanol by fermentation and anhydrous ammonia (fertilizer) production. (UEPI 2009).

In a CO_2 dry cleaning process, laundry is placed in the wash chamber of the machine, and the chamber air is evacuated. The pressure in the wash chamber is raised by injecting gaseous CO_2, followed by an injection of liquid CO_2 into the chamber. The liquid CO_2 penetrates the fibers and dissolves dirt, fats, and oils. The cleaning cycle lasts about 5 to 15 minutes. During the cleaning cycle, a filter cleans particles from the liquid. At the end of the cleaning process, the liquid CO_2 is pumped back into the storage tank. The remaining CO_2 gas is chilled and condensed into its liquid form. When the pressure is low enough, any remaining CO_2 is vented to the atmosphere. The CO_2 is regularly cleaned by distillation (UEPI 2009). Equipment costs for CO_2 dry cleaning systems are substantially higher than PCE dry cleaning machines (Sinsheimer 2004).

Summary of Alternative Technologies

Sinsheimer and Grout conducted tests on each of the alternative dry cleaning technologies to determine typical electricity and natural gas consumption (Sinsheimer 2004). Figure 8-33 shows the total energy consumption of each dry cleaning technology.

Figure 8-33: Total Energy Consumption of Alternative Dry-Cleaning Technologies



Source: Sinsheimer report (Sinsheimer 2004).
Data has been adapted from the original report and converted to Btu/100 lbs.

Figure 8-33 indicates that natural-gas usage dominates the annual energy consumption of each option. The data indicate that all four alternate technologies have lower electricity consumption than the traditional PCE process. Because of this, and because increasing environmental regulations are likely to burden the dry cleaning industry over the next decade, we do not propose any dry cleaning technology ES&S recommendations for DOE at this time.

9 Miscellaneous End-Use Services and Equipment

In this report, the "other" or "miscellaneous equipment" category includes equipment and end-use services not accounted for under HVAC, lighting, or in the end-use categories discussed in previous sections of this report. The 2008 Buildings Energy Data Book estimates this category to account for roughly 2.6 Quads or 13% of the commercial sectors' primary energy consumption (DOE, 2008). While this is a significant amount of the energy, this category is the sum of many small and diverse end-use technologies. When analyzed individually, these end-use technologies consume a relatively small amount of energy compared to the annual energy consumption of technologies in other commercial appliance categories such as water heating and IT equipment.

To identify miscellaneous equipment with the highest annual energy consumption (AEC), we used results from previous studies to develop a list of the top miscellaneous equipment. These studies included a TIAX report (TIAX, 2006) that analyzed the top miscellaneous electricity consumption devices in the commercial sector and a Lawrence Berkeley National Laboratory survey (LBNL, 2004) of after-hour energy use in office, education, and health care buildings (includes 16 facilities in San Francisco, Atlanta, Pittsburgh). We conducted additional research on the miscellaneous equipment with the highest estimated annual energy consumption (AEC) from these studies and summarized our findings in the section below.

9.1 *Medical Imaging Equipment*

According to a Buildings Energy Data Book estimate, inpatient and outpatient healthcare facilities consumed roughly 0.53 Quads in 2008 (DOE, 2008). This section focuses on medical imaging equipment used in health care facilities.

9.1.1 General Description

This section describes the general characteristics of the medical imaging equipment researched in this study including X-ray machines, computed tomography (CT) scan machines, and Magnetic Resonance Imaging (MRIs).

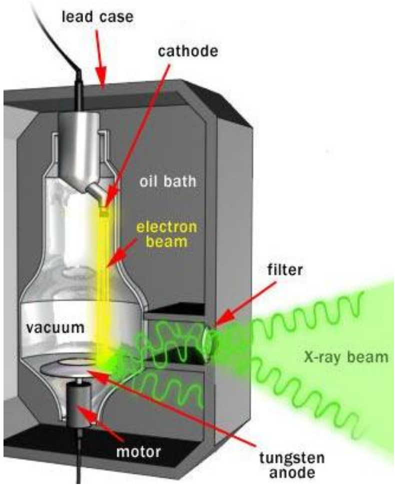
X-ray Machines

This analysis focuses on stationary diagnostic X-ray machines in medical facilities typically used by doctors and radiologists. Other X-ray machines such as dental, mammography, fluoroscopy, and non-medical X-ray machines are not researched in this study and not included in the baseline energy estimate as they have a lower power draw and typically fewer operating hours. Non-medical X-ray machines such as those used for food and material inspection tend to use a fraction of the power of medical systems (TIAX, 2006). Other X-ray applications such as Computed Tomography (CT) Scanners are discussed separately in this report.

The basic technology and power draw components are similar for various applications of X-ray equipment.

Figure 9-1 displays the cross-section of a typical X-Ray device. The electron pair system (anode and cathode) and the resulting electron beam it creates, consume the most amount of energy in the X-Ray process. The cathode consists of a heated filament, like the ones in older fluorescent lamps. By passing an electric current through the filament, it heats up, and causes electrons to travel to the anode. When the electrons collide with the tungsten disc, photons are released in the form of X-rays, which can be used in conjunction with an X-ray camera to produce a negative. The step of exposing the patient to the X-Ray typically last a few hundredths of a second, but can draw 60-80 kW instantaneously (GE Healthcare, 2009). A series of user and equipment tasks to position the patient and develop the film also contribute to the average operating energy consumption of X-ray machines.

Figure 9-1: Major Components of an X-ray Machine

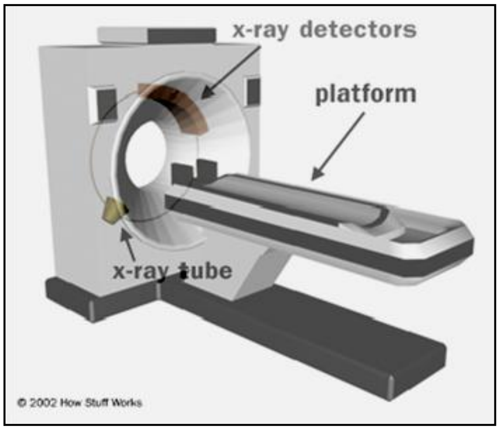


Source: HSW, 2009

Computed Tomography Scan Machines

Computed tomography (CT) scans, also referred to as computed axial tomography (CAT) scans, use X-ray technology to generate an internal image of a patient's body. Machines used in medical facilities typically consist of a platform, where the patient lies, and a CAT machine with an opening in the center for the patient to pass through. An X-ray tube and an array of X-ray detectors are mounted on a rotating ring that is located inside the CAT machine and surrounds the opening. Most of the energy consumed during this process is used to operate the X-ray components. The X-ray components function like those described in the previous section, except that a CT Scan X-ray device revolves around the patient and produces a digital image. Energy is also required to operate a computer for digital image processing and controls, and drive an electric motor required to rotate the ring and the attached X-ray equipment while the machine is operating. Figure 9-2 shows the cross-section of a CT Scan Machine and some of its common components.

Figure 9-2: Major Components of a CT Scan Machine

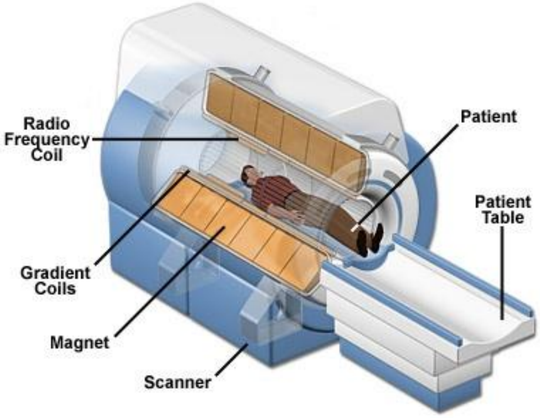


Source: HSW, 2009

Magnetic Resonance Imaging

Magnetic Resonance Imaging devices (MRIs) create a magnetic field by passing an electric current through wire coils. Most MRIs use superconducting magnets to maintain low resistive losses in the wire. However, superconducting magnet systems require continuous cryogenic refrigeration, which consume roughly 40% of a MRI's total energy consumption (TIAX, 2006). Figure 9-3 shows the cross-section of a CT Scan Machine and some of its common components.

Figure 9-3: Major Components of a MRI Machine



Source: HSW, 2009

9.1.2 *Market and Technology Characteristics*

Major Manufacturers

GE Healthcare, Philips Healthcare, and Siemens Healthcare are a few of the major manufacturers of medical imaging equipment. Widespread adoption of energy efficiency technology improvements would likely require the cooperation of these manufacturers or health care facility purchase decision makers.

Purchase Decisions

Purchase decisions of medical equipment such as X-Rays and MRI machines vary considerably for different medical practices and hospitals. While many decisions are hospital specific, some doctor co-operatives and medical companies coordinate purchase decisions with medical imaging manufacturers across their facilities. Hence, efficiency programs may prove difficult to coordinate for this market segment as purchase decisions for medical equipment vary widely among different hospitals and often depend on facility ownership, space limitations, and pre-established agreements to purchase devices form manufacturers (Korbel Associates, 2009).

Reliability, non-energy performance, and first cost are the most important decision-making criteria for medical imaging equipment (Korbel Associates, 2009). Energy efficiency is rarely considered during the purchase decision of a machine.

Lifetime

Table 9-1 shows the estimated lifetime of medical imaging equipment analyzed in this report.

Table 9-1: Estimated Lifetimes of Medical Imaging Equipment Before Technology Becomes Obsolete

Equipment Type	Average Lifetime (yrs)
X-Ray	7
CT scan	5
MRI	5
Source: Korbel Associates, 2009	

9.1.3 Baseline Energy Consumption

X-ray Machines

Table 9-2 compares the TIAX 2008 estimate for unit annual energy consumption (UEC) to estimates provided by GE Healthcare. The estimate from GE Healthcare uses different assumptions for the average power draw and annual operating hours of a typical stationary medical X-ray unit and, thus obtained a much smaller estimate for UEC. While both UEC values are displayed, we chose to use the upper range value for future analysis in order to avoid underestimating the efficiency potential of this technology.

Table 9-2: 2008 Stationary Medical Diagnostic X-Ray Unit Energy Consumption

Value Type	Mode	TIAX Estimate[a]	GE Estimate[b]
Power Draw (W)	Avg. Operating	4,600	1,530
	Off	1,840	0
Annual Usage (Hours)	Avg. Operating	4,380	2,600
	Off	4,380	6,160
UEC (kWh/yr)	-	27,860	3,980

Note: Does not include dental, mammography, fluoroscopy, and non-medical X-ray machines.

[a] Source: TIAX 2008 estimate (TIAX 2006)

[b] Source: Personal communication with GE (GE Healthcare, 2009)

Table 9-3 shows the estimated range for annual energy consumption (AEC) of stationary medical equipment based on the UEC.

Table 9-3: 2008 Stationary Medical Diagnostic X-Ray Annual Energy Consumption

Value Type	NCI Estimate
UEC (kWh/yr)[a]	3,980-27,860
Installed Base (Units)[b]	170,200
Site AEC (TWh/yr)	0.68-4.8

Note: Does not include dental, mammography, fluoroscopy, and non-medical X-ray machines.

[a] See Table 9-2 for more details on this estimate

[b] Source: TIAX 2008 estimate (TIAX 2006)

Computed Tomography Scan Machines

Table 9-4 shows the estimated annual energy consumption of CT Scan Machines. While the UEC remained the same from 2005 to 2008, the installed base increased. An interview with an equipment manufacturer confirmed the UEC estimate for CT Scan Machines (GE Healthcare, 2006).

Table 9-4: CT Scan Energy Consumption Estimate

Value Type	Mode	2005[a]	2008[b]
Power Draw (W)	Avg. Operating	21,000	21,000
	Off	1,700	1,700
Annual Usage (Hours)	Avg. Operating	3,000	3,000
	Off	5,760	5,760
UEC (kWh/yr)	-	73,000	73,000
Installed Base (Units)	-	12,000	16,200
Site AEC (TWh/yr)	-	0.9	1.2

[a] 2005 values are taken from a TIAX 2006 report and based on product specification sheets and pre-installation manuals for 16 slice CT scanners

[b] 2008 values are interpolated from a TIAX projection from 2005 to 2010 (TIAX 2006). Estimates were also verified in an interview with an equipment manufacturer (GE Healthcare, 2006)

Magnetic Resonance Imaging

Table 9-5 shows the estimated annual energy consumption of MRI equipment. Installed base and UEC increased in 2008 compared to 2005 values. An interview with an equipment manufacturer confirmed the UEC estimate (GE Healthcare, 2006).

Table 9-5: MRI Energy Consumption Estimate

Value Type	Mode	2005[a]	2008[b]
Power Draw (W)[2]	Active	25,000	29,800
	Standby	11,000	14,000
	Off	7,000	7,600
Average Annual Usage (Hours)	Active	340	358
	Standby	3,310	3,292
	Off	5,110	5,110
UEC (kWh/yr)	-	81,000	93,000
Installed Base (Units)	-	7,000	9,400
Site AEC (TWh/yr)	-	0.6	0.9

[a] Uses the weighted average of the installed technology to estimate power draw.

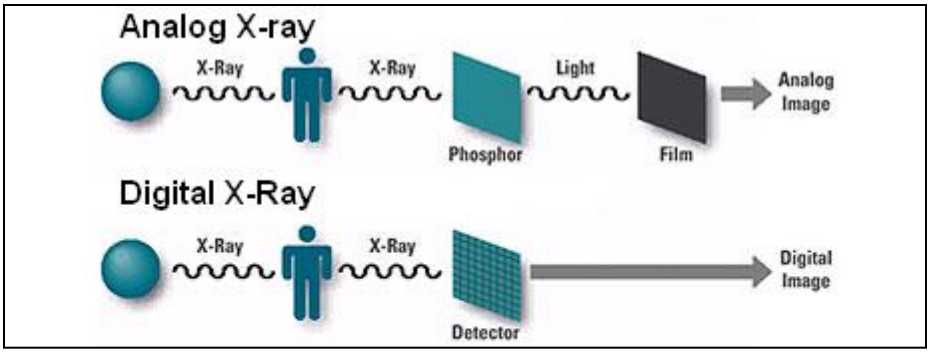
[b] 2008 values are interpolated from a TIAX projection from 2005 to 2010 (TIAX 2006). Estimates were also verified in an interview with an equipment manufacturer (GE Healthcare, 2006)

9.1.4 *Energy Saving Technology*

Digital X-Ray Technology

Digital X-Ray technology eliminates the need for film processing by using a digital screen to display the X-Ray image. Conventional analog X-ray systems rely on phosphorous/film or image intensifier/pickup-tube techniques to create analog images. Figure 9-4 depicts the process differences between digital and analog X-ray technologies.

Figure 9-4: Digital X-ray Technologies



Source: GE Healthcare, 2009

GE Healthcare commercialized digital X-ray technology for stationary diagnostic machines in early 2009. Digital technology is already commercialized and widely used for MRIs and CT Scanners.

Higher first costs resulting from additional features and equipment associated with digital technology are one barrier to this technology. Non-energy benefits such as increased image processing speeds and a digital image format, which facilitates more efficient storage and transfer of patient information between hospitals, will likely overcome this barrier.

9.1.5 Energy Savings Potential and Efficiency Barriers

Several barriers need to be overcome to enable the potential adoption of energy efficiency technologies and options for medical imaging equipment. One involves the priorities of decision makers. Energy efficiency is rarely considered during the purchase decision since reliability, non-energy performance, and first cost of equipment are more important. Due to thehe relatively short equipment lifetime of medical imaging equipment, roughly 5-7 years, (see Table 9-1) before technology becomes obsolete, the energy efficiency payback would need to be very short in order to be a cost effective investment.

By eliminating the need for a film processor that develops an analog image, digital X-ray machines could save up to 0.01 Quads per year. Table 9-6 provides the details on this estimate.

Table 9-6: Annual Energy Savings Technical Potential from Upgrading Stationary, Analog X-Rays to Digital Technology

Description	2008 Estimate
X-Ray Film Processor UEC[a]	8,000 kWh/yr
Installed Base of Film Processors[b]	85,000
Site Energy Potential Savings[c]	0.68 TWh/yr
Primary Energy Potential Savings	0.01 Quads

[a] Estimate from General Electric based on X-OMAT 5000 power draw

[b] Assumes one film processor for every two X-ray machines (GE Healthcare, 2009)

[c] Assumes the savings potential is equivalent to the displaced energy consumption of film processors and that additional energy required to power the computer and other digital equipment is negligible

9.2 *Vertical-Lift Technologies*

9.2.1 General Description

This section describes the general characteristics of the vertical-lift technologies researched in this study including elevators and escalators.

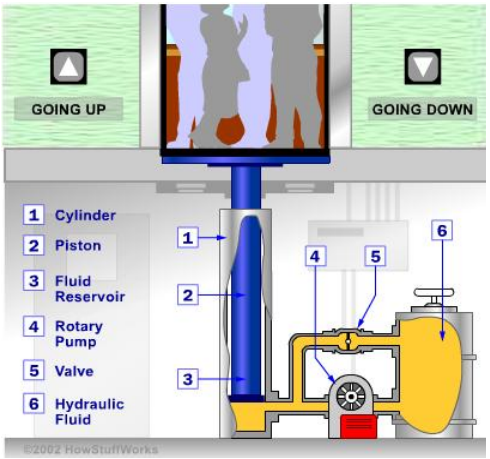
Elevators

The two most common elevator designs are hydraulic and traction elevators. Roughly 75% of all elevators in the US are hydraulic elevators while the remainder are traction systems (ACEEE 2005). Almost all elevators in low-rise buildings less than 7-stories use a hydraulic system because they have a significantly lower upfront cost. Mid-sized buildings typically use geared traction motors, while high-rise buildings often use direct motor-to-sheave (gearless) systems.

Hydraulic Elevators

Over two thirds of elevators installed in the US operate with a hydraulic system. Hydraulic elevator systems typically use a fluid-driven piston to lift the elevator compartment, or car. Figure 9-5 depicts the cross-section of a hydraulic elevator, which is powered by an electric motor used to operate the rotary pump that injects fluid into the piston and a valve that controls the direction of fluid flow. The electric motor consumes the majority of energy for elevator systems. Lighting and ventilation systems also consume some energy. Lighting loads for elevators are estimated to be 200 Watts per elevator cab (ACEEE, 2005).

Figure 9-5: Hydraulic Elevator Schematic

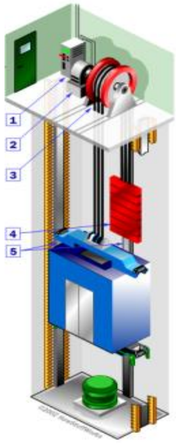


Source: HSW, 2009

Traction Elevators

Traction or roped elevators (see Figure 9-6) use less energy than hydraulic elevators and require a counterweight and a pulley system to operate. Unlike a hydraulic elevator which is pushed from below with a piston, a roped elevator typically uses steel ropes or polyethylene-coated steel belts with a counterweight to raise and lower the car. The counterweight also helps to reduce the energy demand by maintaining a near constant potential energy as the elevator moves up and down. Counterweights are typically sized to weigh the same as the cab plus half its maximum load (ACEEE, 2005). Motors are then sized to lift the difference between the cab and the counterweight (or half the elevators maximum load) in addition to overcoming friction losses of the pulley or sheave. One source estimates that traction elevators consume roughly 1/3 of the energy of hydraulic designs (ACEEE 2005).

Figure 9-6: Traction or Rope Elevator Schematic



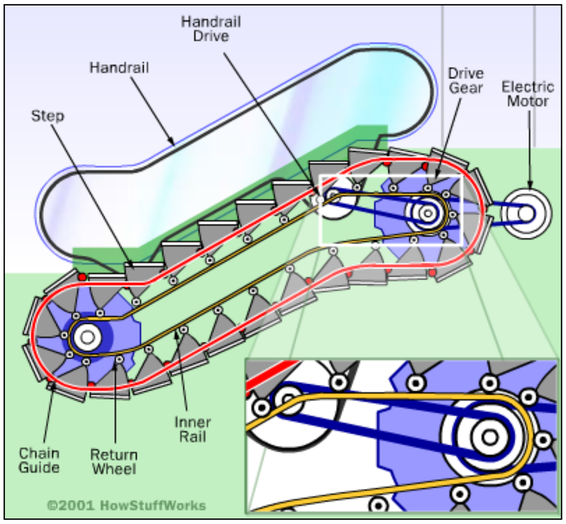
Source: HSW, 2009

Note: 1) Control System; 2) Electric Motor; 3) Sheave Or Pulley; 4) Counterweight; 5) Guide Rails.

Escalators

An escalator is a moving staircase conveyor machine used to transport people between floors of a building. Figure 9-7 identifies the major components of an escalator. This analysis does not include moving walkways.

Figure 9-7: Escalator Cross-Section and Major Components



Source: HSW, 2009

9.2.2 *Baseline Energy Consumption*

The section below describes our estimates for energy consumption of elevators and escalators.

Elevators

Table 9-7 shows the estimates for energy consumption of elevators, and includes updated values for the installed base of elevators in the US. Elevator energy use can vary between designs depending on use, number of stories, technology, stand-by power, speed, capacity, and other factors.

Table 9-7 estimates UEC at roughly 7,160 kWh/yr in 2008 based on weighted averages and typical building heights. Other sources confirm this calculation and estimate the UEC to range from 1,900-15,000 kWh/yr and AEC in to be in the range of 3 TWh/yr (ACEEE 2005).

Table 9-7: Elevator Energy Consumption Estimate

Value Type	Mode	2005[a]	2008[b]
Power Draw (W)	Active	10,000	10,000
	Ready	500	500
	Standby	250	250
Annual Usage (Hours)	Active	300	300
	Ready	8,460	7,146
	Standby	-	1,314
UEC (kWh/yr)	-	7,400	7,160
Installed Base (Units)[c]	-	700,000	740,000
Site AEC (TWh/yr)	-	5.2	5.3

[a] Source: TIAX 2006 report

[b] 2008 values (other than installed base) are interpolated from a TIAX projection from 2005 to 2010 (TIAX 2006)

[c] The installed base of elevators is projected forward based on 1.7%/yr growth rate (ACEEE, 2005)

Escalators

An escalator typically uses one electric motor to power the gears and conveyor belt system. Power draw estimates in Table 9-8 use calculated UEC based solely on escalator rise and operating time.

Table 9-8: Escalator Energy Consumption Estimate

Value Type	Mode	2005[a]	2008[b]
Power Draw (W)	Avg. Operating	4,671	4,671
	Off	-	-
Annual Usage (Hours)	Avg. Operating	4,380	4,380
	Off	4,380	4,380
UEC (kWh/yr)	-	20,500	20,500
Installed Base (Units)[c]	-	35,000	36,800
Site AEC (TWh/yr)	-	0.7	0.8

[a] Source: TIAX 2006 report

[b] 2008 values are interpolated from a TIAX projection from 2005 to 2010 (TIAX 2006).

[c] Installed base does not include moving walkways

9.2.3 Market and Technology Characteristics

Major Manufacturers

In addition to a large number of specialist firms, there are four major manufacturers in the US including KONE, Otis, Schindler, and ThyssenKrupp. Manufacturers typically sell their products through local sales offices and are often supported by design consultants who help building contractors and engineers develop bid specifications tailored to their facility or project.

Installed Base

Based on a consensus of various industry sources, it is estimated that roughly 700,000 elevator systems were in operation in the US as of 2005 (ACEEE, 2006). Additionally, there are less than 100,000 new installations or large retrofits per year (ACEEE, 2005). The growth of the installed base of elevators was projected forward assuming a 1.7% growth rate after 2005 and determined based on prior growth rates (TIAX, 2006).

According to one estimate, there were roughly 35,000 escalators operating in the US in 2005, or less than 10% of the number of elevators (TIAX, 2006).

Voluntary and Regulatory Programs

The U.S. Green Buildings Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program promotes the energy efficiency of elevators by giving a higher rating to facilities with optimized elevators. This voluntary program is a practical rating tool for green building design and construction and aims to encourage “high-performance, sustainable buildings.”

The Energy Independence and Security Act of 2007 (EISA) establishes federal motor efficiency performance standards for motors manufactured after December 19th 2010, that fall within a power rating range of 1-500 horsepower. As part of this Act and other Federal Rulemakings on electric motors (e.g. Federal Register, 2009) standards for small and medium electric motors are under development.

Governments in other countries are attempting to regulate elevator and escalator efficiency. For example, Hong Kong’s Electrical and Mechanical Services Department (EMSD) published minimum design requirements on energy efficiency of lift and escalator installations. Table 9-9 outlines the maximum power ratings at various rated loads. Similarly, some associations such as the Association of German Engineers (VDI) have developed their own energy efficiency guidelines for lift technology which have been adopted by several manufacturers in the U.S (Otis, 2009).

Table 9-9: EMSD's Hydraulic Lift Energy Standards According

Rated Load (kg)	Maximum allowable electric power (kW)
L < 1000	26.6
1000 ≤ L < 2000	50.4
2000 ≤ L < 3000	71.3
3000 ≤ L < 4000	92.2
4000 ≤ L < 5000	115
L ≥ 5000	0.023 x L

Source: EMSD, 2007

Hong Kong's EMSD has also published a code of practice for traction elevators of various rated speeds and loads. Table 9-10 provides a summary of these standards.

Table 9-10: EMSD's Traction Lift System Standard on Maximum Allowable Electrical Power

Rated Load (kg)[a]	Maximum allowable electrical power (kW) of traction lift systems for various ranges of rated speed (Vc) in m/s			
	Vc <1	1 ≤ Vc < 3	3 ≤ Vc < 6	6 ≤ Vc < 9
L < 750	6.7	9.5-17.1	20.0-28.5	32.3-42.8
750 ≤ L < 1000	9.5	11.4-22.8	25.7-37.1	43.7-57.0
1000 ≤ L < 1350	11.4	16.2-30.4	34.2-49.4	57.0-76.0
1350 ≤ L < 1600	14.3	19.0-36.1	40.9-58.9	68.4-90.3
1600 ≤ L < 2000	16.2	23.8-43.7	50.4-71.3	83.6-114.0
2000 ≤ L < 3000	23.8	35.2-66.5	75.1-109.3	125.4-166.3
3000 ≤ L < 4000	31.4	45.6-87.4	98.8-142.5	166.3-223.3
4000 ≤ L < 5000	39.9	57.0-109.3	123.5-180.5	209.0-275.5

[a]Separate rules apply for elevators above 5000 kg and those that exceed 9m/s (EMSD, 2007).

Similarly, the EMSD specifies total harmonic distortion (see Table 9-11) and power factor requirements. The code of practice requires that the total power factor of a motor drive circuit measured at the isolator connecting the lift equipment to the building's feeder circuit should be ≥ 0.85 when the lift car travels upward at its rated speed while carrying its rated load (EMSD, 2007)

Table 9-11: EMSD's Maximum Allowable Total Harmonic Distortion for Lift Motor Drives

Circuit Fundamental Current of Motor Drive (Amps)	Maximum Total Harmonic Distortion (%)
I < 40	40
40A ≤ I < 80	35
80A ≤ I < 400	22.5
400A ≤ I < 800	15

Source: EMSD, 2007

Hong Kong's EMSD has also published guidance for escalators of various rated speeds, step width, and length during zero-load conditions. These codes specify the maximum allowable electrical power ranging from 1.3 kW to 3.7 kW and maximum total harmonic distortion under various conditions and motor drive currents (EMSD, 2008).

9.2.4 Energy-Saving Technologies

Elevators

Motors and Drives

Various combinations of motor and drive technology options exist which enable higher efficiencies.

- *Variable-voltage, variable-frequency (VVVF) Drives*— Control the rotational speed of an alternating current (AC) electric motor by controlling the frequency and voltage of the electrical power supplied to the motor.
- *Gearless Permanent Magnet Motor*— Low speed motors which do not require a separate operating room. According to one industry expert, gearless permanent magnet motors offer 5-10% efficiency gains over typical induction motors and have the same lifetime of roughly 20 years (Otis, 2009). Such an efficiency improvement would only save energy while the motor is in operation during active mode. Another major driver for this technology is its elimination of a machine room which frees-up building square footage for other uses.
- *Regenerative Drives*—Convert excess braking energy from the elevator and feeds it into the building's power grid for reuse. This energy efficiency option is more common among high-rise buildings, but is growing amongst low and mid-rise buildings (Otis, 2009). Some manufacturers claim they can recover up to 25% of the total energy used for elevators by converting braking energy to electricity (Kone, 2009).

Table 9-12 compares the efficiency of common elevator motors. Permanent magnet motors are assumed to have the highest efficiency.

Table 9-12: Efficiency of Common Elevator Motors

Motor Type	Efficiency
DC Shunt Field	89-94%
AC Induction	85-94%
AC Permanent Magnet (PM)	90-95%

Source: Magnetek Elevator, 2007

Controls

Various control options now exist for elevators:

- *Controls for stand-by mode*—shuts off the fan and lights when the unit is not in use.
- *Destination control software*—directs passengers to elevators based on their desired floors, grouping passengers according to destination.

Lighting

More efficient lighting option exist to replace standard halogen bulbs with more efficient fixtures (e.g. LEDs or CFLs), but this category is outside the scope of this analysis.

Escalators

While escalators consume more energy per unit than elevators, the small installed base in the U.S. limits there efficiency potential relative to other end-uses.

Service-on-demand escalator

Controls can be used with sensors to turn-off the machine during inactivity. Demonstrations have shown this can save between 14-50% of the unit energy consumption (EMSD, 2007).

Motor Efficiency Controller

This technology optimizes energy of AC induction motors that operate at a constant speed and are often lightly loaded. One vendor claims these systems improve efficiency by 20-40% (Power Efficiency Corp., 2009).

9.2.5 *Energy-Savings Potential and Efficiency Barriers*

In theory, a 100% efficient elevator or escalator would use zero net energy as the potential energy added to raise a person could be completely recovered when the person descends. In practice, friction and technology limitations reduce the efficiency of these machines.

Within a drive class, the most efficient elevators will use about 30-40% less electricity than the least efficient technologies (ACEEE 2005). Table 9-13 shows the maximum primary energy technical savings potential for the elevators in the US. While not all of the elevators will achieve 40% efficiency gains, a 60% deration factor is applied to determine the achievable potential.

Table 9-13: Energy-Efficiency Potential of Elevators

Value Type	Data	Source
National Site-Energy Consumption (TWh)	5.3	Calculated
National Primary Energy Consumption (Btu/yr)	5.51E+13	Calculated
Efficiency Savings Maximum Potential	30%-40%	ACEEE 2005
Primary Energy Savings Technical Potential (Btu/yr)	2.21E+13	Calculated
Achievable Potential (%)	60%	NCI Estimate[a]
Primary Energy Savings Achievable Potential (Btu/yr)	1.32E+13	Calculated
[a]Assumes that 60% of the market can achieve 40% efficiency gains		

While escalators consume more energy per unit than elevators, the small installed base in the U.S. limits their efficiency potential relative to other end-use technologies. Since AEC is estimated to be less than 2 TWh/yr, this end-use technology is not analyzed in more detail in this report.

9.3 *Coffee Makers*

9.3.1 General Description

The majority of energy used by coffee makers goes into heating the water through a resistive heating element. The most common type is a coiled wire. The heat from the wire is then transferred to an aluminum water tube to boil the water and in some instances, also heats a warming plate to keep the coffee pot warm. There are three major types of commercial-style coffee brewers listed in Table 9-14.

Table 9-14: Commercial-Style Coffee-Maker Market Share by Type

Coffee Maker Type	Market Share
Decanter	45%
Thermal	30%
Satellite	25%
Source: ADL, 2002	

9.3.2 Baseline Energy Consumption

Table 9-15 compares estimates of 2005 and 2008 annual energy consumption. While the energy consumption of the device is estimated to remain the same, the installed base increased by roughly 3% (TIAX 2006).

Table 9-15: Coffee-Maker Energy Consumption Estimate

Value Type	Mode	2005[a]	2008[b]
Power Draw (W)	Active	2,100	2,100
	Ready	165	165
	Off	2	2
Annual Usage (Hours)	Active	150	150
	Ready	3,500	3,500
	Off	5,110	5,110
UEC (kWh/yr)	-	905	905
Installed Base (Units)	-	3,000,000	3,102,000
Site AEC (TWh/yr)	-	2.7	2.8

[a] Source: TIAX 2006 report

[b] 2008 values are interpolated from a TIAX projection from 2005 to 2010 (TIAX 2006)

Given the limited efficiency improvements likely available for this technology, coffee makers were not analyzed in detail.

9.4 Non-Refrigerated Vending Machines

9.4.1 General Description

The European Vending Association (EVA) defines a vending machine as a device aimed for the self-service sale or provision of goods and/or services that can be operated by entering a coin, a bank note, card/key or other form of currency. This does not include entertainment and gambling machines. This section covers non-refrigerated vending machine technologies only, as refrigerated technologies are not within the scope of this report.

Snack/Confection Machines

Snack/Confection machines are room temperature vending machines that typically have a glass-front display. Lighting load consumes the majority of energy for these machines. The majority of energy use from snack/confection vending machines results from lighting. In some systems, the operation of electric motors to rotate spiral shelves and a central control system which includes a keypad and electronic devices that accept bills and coins also requires energy. Figure 9-8 depicts a typical snack/confection machine.

Figure 9-8: Snack/Confection Vending Machine

Source: Crane Merchandising Systems, 2009

Hot-Beverage Vending Machines

Hot-beverage vending machines dispense warm beverages such as tea and coffee. The majority of energy use from hot beverage vending machines results from the electric heating load. Many systems use a hot water tank, which requires constant heating (Crane Merchandising Systems, 2009). Figure 9-9 depicts a typical hot beverage vending machine.

Figure 9-9: Hot-Beverage Vending Machine

Source: Crane Merchandising Systems, 2009

9.4.2 *Market and Technology Characteristics*

Installed base

Table 9-16 shows the estimated installed base of non-refrigerated vending machines, which was estimated to have decreased from 2007 to 2008 based on 2006 - 2007 market trends.

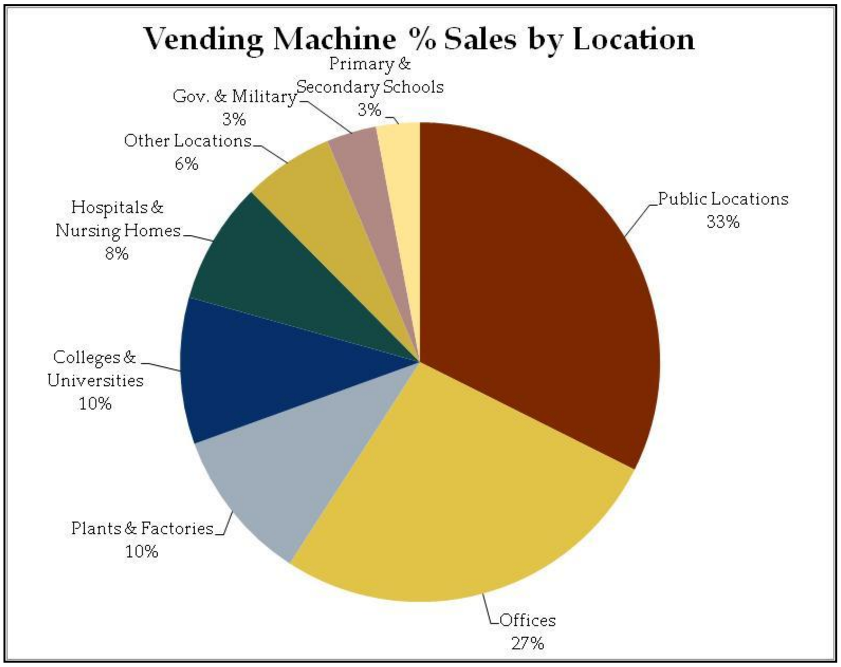
Table 9-16: U.S. Installed Base of Non-Refrigerated Vending Machines

U.S. Vending Data[a]	Snack/Confection	Hot Beverage
2005 Installed Base	1,302,000	350,000
2006 Installed Base	1,314,000	354,000
2007 Installed Base	1,312,000	350,000
Growth Rate from '06-'07	-0.15%	-1.13%
2008 Projected Installed Base	1,310,000	346,000

[a] Historical data on installed base from 2005-2007 is taken from the 2008 Vending Times Census Report and projected forward to 2008 (Vending Times, 2008)

The majority of vending machines installed in the U.S. (including both refrigerated and non-refrigerated) are located at manufacturing facilities and offices (roughly 36% and 20% respectively) in 2007 (Automatic Merchandiser, 2007). Figure 9-10 shows the distribution of vending machine sales across the United States, which includes refrigerated vending machines in addition to non-refrigerated machines. Based on this distribution, the majority of machines (>50%) are likely located in office buildings and public locations.

Figure 9-10: U.S. 2007 Sales Data by Location on All Vending Machine Types Including Non-Refrigerated and Refrigerated Machines



Source: Vending Times, 2008

Voluntary and Regulatory Programs

While standards do not currently exist in the United States for non-refrigerated vending machines, other entities offer programs that encourage efficiency of this technology. For example, some voluntary utility programs such as Austin Energy's Energy Miser Vending Products Program offers rebates for vending machine power management products (Austin Energy, 2009). Also, the Canadian Standards Association (CSA) establishes energy consumption standards for vending machines including hot beverage vending machines (see Table 9-17).

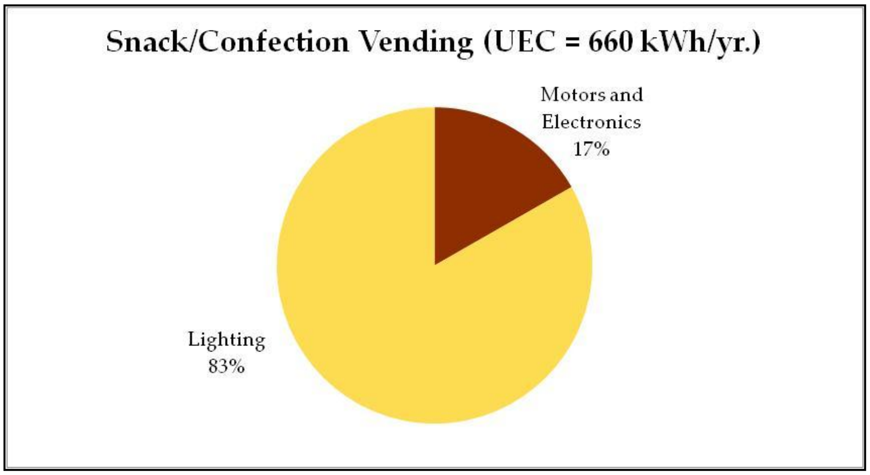
Table 9-17: Canadian Standards Association's Energy Performance Standard (C804-08) for Hot Beverage Machines

	Maximum UEC (kWh/yr)	Product Temperature (°F)
Hot Beverage Vending Machines	3,650	202
Source: CSA, 2008		

9.4.3 Baseline Energy Consumption

The usage patterns and energy consumption of vending machines vary by machine and location. The peak draw of these machines only lasts for a few seconds during the dispensing process and on average there are only 25 items sold per day per machine according to industry data from 2007 (Vending Times, 2008). The lighting load, however, tends to operate for a longer period of the day and therefore consumes more energy than other vending machine components on an annual basis as depicted in Figure 9-11.

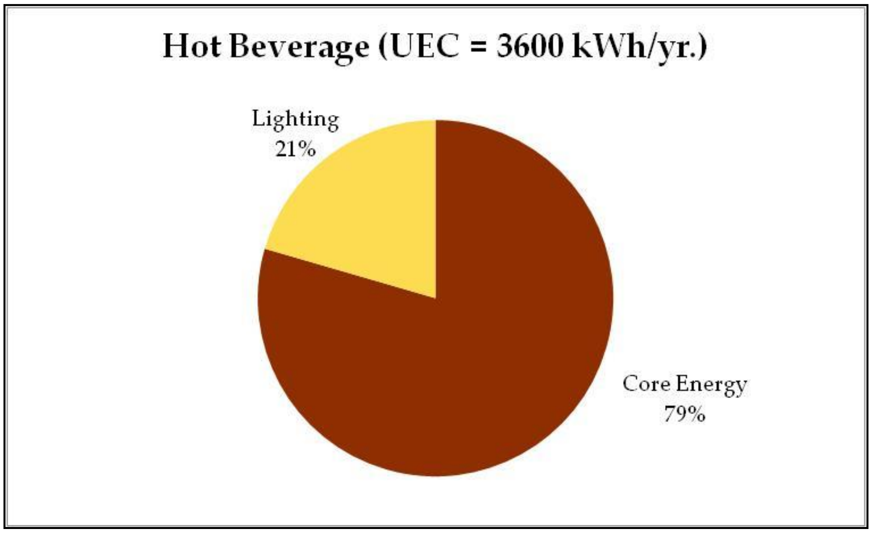
Figure 9-11: Unit Energy Consumptions Breakdown of a Non-Refrigerated, Glass-Front Vending Machine



Source: Crane Merchandising System's common snack machine model, 2009

The majority of energy use from hot beverage vending machines results from the electric heating load. Figure 9-12 shows the breakdown in energy use by lighting and core energy which mostly consists of an electric water heater and some basic electronic devices.

Figure 9-12: Unit Energy Consumptions Breakdown of a Typical Hot Beverage Vending Machine



Source: Crane Merchandising System's HotDrinkCenter2 model, 2009

Table 9-18 shows our estimate of AEC for non-refrigerated vending consumption which equals the sum of snack/confection and hot beverage vending machines.

Table 9-18: Non-Refrigerated Vending Energy Consumption Estimate

Value Type	Snack/Confection	Hot Beverage
Lighting (kWh/yr) [a]	547	730
Core Energy (kWh/yr) [a]	110	2,828
UEC (kWh/yr) [a]	657	3,558
2008 Projected Installed Base[b]	1,310,000	346,000
2008 Site AEC (TWh/yr)	0.86	1.23
Total 2008 Site AEC (TWh/yr)	2.09	

[a] Estimate from Crane Merchandising Systems for a standard snack/confection model

[b] Based on 2008 Vending Times Census Report (see Table 8 16 for more detail)

9.4.4 *Energy Savings Technologies*

Sensor and controls

Motion sensors can be mounted on existing machines to turn-off equipment when it senses that noone has approached the machine for an extended period of time. Similarly, controls are programmed to turn-off lighting and other equipment through various setting options: time-of-day, day of week, or extended periods inactivity.

On Demand Water Heating

Electric energy is converted to heat warm water as needed rather than constantly maintaining the temperature of a water tank.

Efficient Lighting

Replacing standard incandescent bulbs with more efficient lighting (e.g. light-emitting diodes) would reduce overall energy consumption. This category is outside the scope of this report and therefore not researched in more detail.

9.4.5 *Energy Savings Potential and Efficiency Barriers*

According to several industry interviews, the general barriers and concerns required to overcome most efficiency technology barriers include cost, maintenance, and reliability (NAMA, 2009). Also, some manufacturers expressed concern over turning lights off with sensors and controls, as it can send the signal the machine is not working and reduce sales (Crane Merchandising Systems, 2009). Retrofit options for existing machines may also void factory warranties.

Since AEC of non-refrigerated vending is estimated to be less than 2 TWh/yr, the efficiency savings potential of this end-use technology is not analyzed in detail in this report.

9.5 Automated Teller Machines (ATMs)

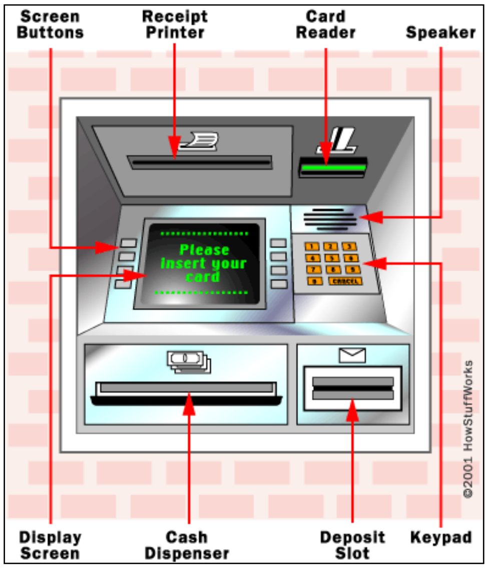
9.5.1 General Description

Automated teller machines (ATMs) are computer controlled data terminals which enable customers to complete basic financial transactions in a public space. Two main types of Automated Teller Machines (ATMs) account for most the US market: full function and cash dispenser units.

Full Function ATMs

Full function devices are typically not portable and accept deposits in addition to dispensing cash. Banks typically install these machines as wall units outside a store branch. Figure 9-13 labels the major components of a typical full function ATM.

Figure 9-13: Major Components of a Full Function ATM Machine



Source: HSW, 2009

Cash Dispenser ATMs

A typical cash dispenser is portable and often only dispenses cash. Locations vary depending on ownership, but many convenience stores and retailers operate these machines.

9.5.2 Market and Technology Characteristics

Installed Base

Total U.S. ATM installed base data through 2006 is taken from American Banking Association estimates. Projections to 2008 are based on annual growth in GDP and assume that the installed base of ATM machines grows proportionally with U.S. real GDP (see Table 9-19).

Table 9-19: Historical U.S. Real GDP Growth

Year	U.S. Real GDP	Yearly Change in GDP (%)
2006	115.054	-
2007	117.388	2.0%
2008	118.692	1.1%
Source: BEA, 2009		

Historical data on the ATM installed base was available through 2006 and depicted in Table 9-20. While there was a slight decrease in total installed machines in 2006, we assumed the installed base would increase slightly from 2007 to 2008.

Table 9-20: ATM Installed Base

Year[a]	Total U.S. ATM Machines	Total ATM Transactions (Billions)	Annual Transactions per U.S. ATM
1996	139,134	10.7	76,904
1997	165,000	10.9	66,061
1998	187,000	11.2	59,893
1999	227,000	10.8	47,577
2000	273,000	12.8	46,886
2001	324,000	13.6	41,975
2002	352,000	10.5	29,830
2003	371,000	10.8	29,111
2004	383,000	11.03	28,799
2005	396,000	10.5	26,515
2006	395,000	10.1	25,570
2007[b]	403,000	10.3	25,570
2008[b]	407,000	10.4	25,600

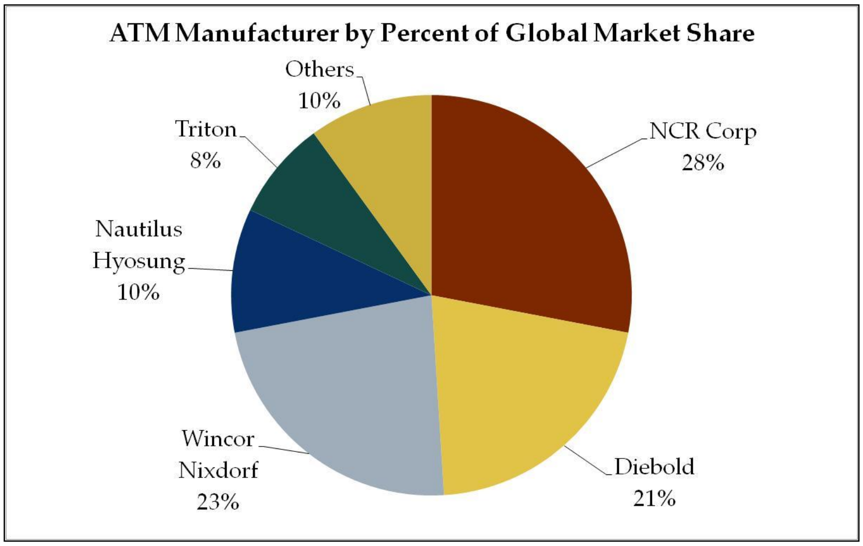
[a]Historical data through 2006 (ABA, 2006)

[b]2007 and 2008 values are projections based on U.S. real GDP growth during those years

Major Manufacturers

While only a few companies are responsible for the majority of ATM manufacturing, the ownership and operation of these machines are the responsibility of a large and diverse number of organizations. Figure 9-14 depicts some of the leading ATM manufacturers, with NCR Corporation, Diebold, and Wincor Nixdorf accounting for 75% of the world market share (Lehman Brothers, 2008). The top five owners of ATMs in the United States account for just 17% of the total installed base. These five companies include Cardtronics, Bank of America, JPMorgan Chase, Wells Fargo, and Wachovia (Lehman Brothers, 2008).

Figure 9-14: Global ATM Manufacturer Market Share as of 2007

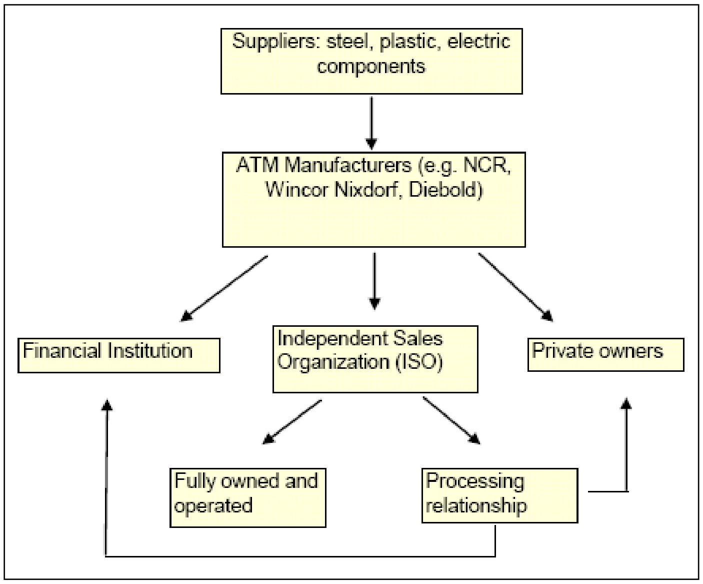


Source: Lehman Brothers, 2008

Purchase Decisions

Several options for ownership and operation of ATM machines exist, as depicted by the value chain in Figure 9-15.

Figure 9-15: Overview Of The ATM Industry Value Chain



Source: Lehman Brothers, 2008

The cost of energy to operate an ATM machine is small compared with the cost of purchasing and owning one. The annual energy cost of operating an ATM machine varies by type of machine, but is generally less than 3% of the total annual operation and maintenance cost, which includes servicing, rent, telecommunications, depreciation and others (see Table 9-21). Since energy costs are low compared to other O&M costs, energy efficiency of machines tends to be a lower priority in the purchase decision of equipment.

Table 9-21: ATM Cost Estimates by ATM Type

Expense Type	Cost Estimate ($)
Capital Cost	9,000-50,000
Annual Maintenance Cost[a]	12,000-15,000
Cash Dispenser ATM Annual Energy Cost[b]	190
Full Service ATM Annual Energy Cost[b]	350

[a] Includes servicing, rent, telecommunications, depreciation and other costs.

[b] This calculation uses 10 cents/kWh assumption taken from the average of commercial electricity prices from 22 medium-priced states (Electric Power Monthly, 2009)

Voluntary and Regulatory Programs

While no regulatory or voluntary programs exist in the US that target ATM equipment specifically, ENERGY STAR programs for common electronic equipment used in computer technology encourages efficiency among ATM devices.

9.5.3 *Baseline Energy Consumption*

Limited published data exists on the power draw of ATM machines, so we used past power draw data estimates to provide a conservative estimate of the maximum AEC of this equipment. Efficiency advancements in computer technology have likely reduced the actual AEC of ATMs to slightly below the estimate in Table 9-22.

Table 9-22: ATM Energy Consumption Estimate

ATM Type	2000[a]		2008[b]	
	Active Power Draw (W)	Standby Power Draw (W)	Active Power Draw (W)	Standby Power Draw (W)
Full Function	471	379	471	379
Cash Dispenser Only	250	200	250	200

[a] Year 2000 power draw is from an ADL 2002 report

[b] While the efficiency has likely improved since 2000, 2008 data is held constant for a conservative estimate

Table 9-23 shows our estimate for AEC, which has increased since 2000 based on the larger installed base of the technology.

Table 9-23: ATM Energy Consumption Estimate

Value Type	Mode/Type	2000[a]	2008
Annual Usage (Hours)	Active	1,241	1,241
	Standby	7,884	7,884
UEC (kWh/yr)	-	1,887-3,573	1,887-3,573
Installed Base (Units)[b]	Full Function	190,000	258,000
	Cash Dispenser Only	110,000	149,000
Site AEC (TWh/yr)[c]	-	**0.84**	**1.20[c]**

[a] Source: ADL 2002 report

[b] 2008 installed base breakdown applies 37% and 63% between the two ATM types (ADL, 2002)

[c] Calculated by taking the weighted average of UEC

9.5.4 *Energy Savings Technologies*

Power Management

Power management is a feature that can reduce energy consumption in most types of electronic equipment during periods of extended inactivity. While it is unclear what percentage of ATM machines currently uses stand-by features to reduce energy consumption when the machine is not in use, it is typically an inexpensive efficiency measure to implement for devices that use modern computer technology.

9.5.5 *Energy Savings Potential and Efficiency Barriers*

We estimate the energy efficiency potential of ATMs relative to other end-use services to be small based on their low annual energy consumption and several barriers to implementing energy efficiency measures. The major barrier to achieving significant energy efficiency improvements in this sector results from the low annual energy consumption of ATMs in the U.S (see Table 9-23). Also, energy costs are low compared to other O&M costs (less than 3% of annual O&M—see Table 9-21), and therefore a lower priority in the purchase decision. Technology transfer opportunities may exist as technology improvements in the efficiency of display screens and other components used in computers are applied to ATMs.

9.6 *Point-of-Service (POS) Terminals*

This section focuses on retail check-out point of service (POS) terminals (also referred to as traditional POS) that require a check-out assistant.

9.6.1 *General Description*

Traditional POS Terminals

A traditional POS terminal refers to electronic equipment operated by a retail employee at the check-out counter. This includes a variety of devices such as cash registers, scanners, computer processors, conveyor belts, viewing screens, and other components (see Figure 9-16). POS technologies and capabilities have developed with the advancement of computer technology.

Figure 9-16: Traditional POS Terminals

Source: Sharp, 2009

Source: Hewlett Packard, 2009

Non-Traditional POS Terminals

Non-traditional POS terminals refer to electronic machines that provide a service to a customer other than retail check-out counter machines. Of these applications self-checkout, photo kiosks, and retail (non-checkout) applications account for about 75% (roughly a quarter each) of the non-traditional POS kiosk industry (Lehman Brothers, 2008).

9.6.2 Market and Technology Characteristics

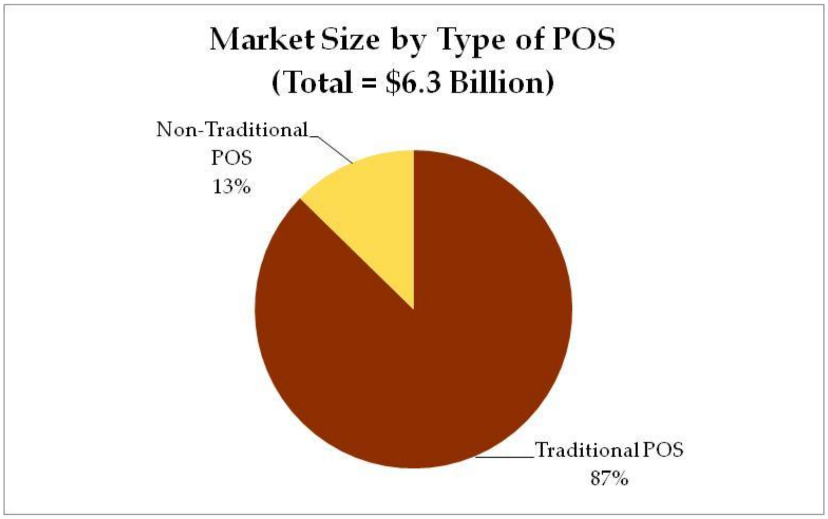
Installed Base

The traditional POS segment accounts for the largest market-share of POS devices in the US. Figure 9-16 depicts the breakdown of the total market size for the POS industry, which is highly dominated by traditional POS terminals.

The installed base of POS terminals is taken from an ADL estimate made for the year 2000 and projected forward based on the growth of commercial building floor space from 2000 to 2008 (ADL, 2002).

Based on the market size data in Figure 9-17, the installed base of non-traditional POS terminals is assumed to be negligible relative to the traditional POS segment. Therefore only traditional POS terminals were included this analysis.

Figure 9-17: Market Size in North and South America by Type of POS Terminals

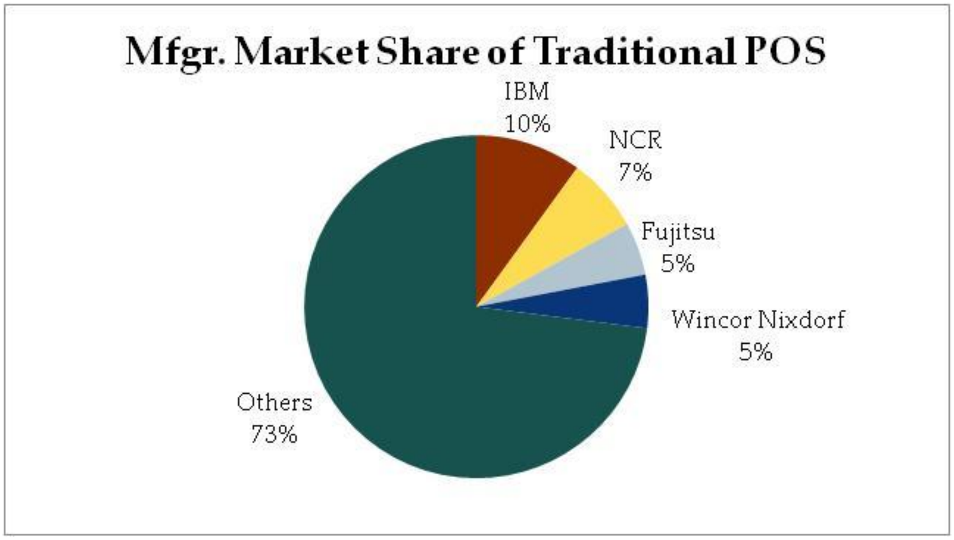


Source: Lehman Brothers, 2008

Major Manufacturers

The traditional POS industry is a competitive and mature industry in which the largest competitors (IBM, NCR, Fujitsu, and Wincor Nixdorf) only account for a quarter of the market share worldwide (see Figure 9-18).

Figure 9-18: Worldwide Market Share by POS Manufacturer



Source: Lehman Brothers, 2008

Voluntary and Regulatory Programs

While no regulatory or voluntary programs exist in the US that target POS equipment specifically, ENERGY STAR programs for common electronic equipment used in computer technology encourages efficiency among POS devices.

9.6.3 *Baseline Energy Consumption*

Only traditional POS terminals were included in the baseline energy consumption estimate as the non-traditional POS energy consumption is assumed to be relatively negligible.

The most recent power draw estimate of POS terminal energy consumption was found in a 2002 source which estimates the active and standby power draw to be 50W (ADL, 2002). The higher range estimate for 2008 assumes that traditional POS systems with more advanced features and computer processing have the equivalent UEC of a desktop computer as there is considerable overlap in the technology used for both devices.

Table 9-24: Traditional POS Terminal Energy Consumption

Value Type	Mode	2000[a]	2008
Power Draw (W)[b]	Active	50	50-115
	Standby	50	50-84
Annual Usage (Hours)	Active	1,820	1,820
	Standby	2,548	2,548
UEC (kWh/yr)	-	218	218-423[c]
Installed Base (Units)	-	6,785,000	7,607,000
Site AEC (TWh/yr)	-	1.5	1.7-2.4 [d]

[a] Data is taken from a 2002 report by Arthur D. Little, Inc. which estimates AEC based on product literature and information from equipment vendors

[b] Higher range values are based on estimates for desktop computers (Energy Star Savings Calculator, 2009)

[c] Installed base is projected forward based on the 1.4% growth rate in commercial floor space from 2000 to 2008 (DOE, 2008)

[d] Lower range value uses lower range value for UEC; Higher range value uses weighted average of UEC and assumes half of the POS terminals in 2008 had been upgraded from basic cash registers to systems with the equivalent power draw of desktop computers

9.6.4 *Energy-Saving Technologies*

Power Management

Power management techniques can reduce the energy consumption of machines during periods of extended inactivity. While it is unclear what percentage of POS machines currently uses stand-by features to reduce energy consumption when the machine is not in use, it is typically an inexpensive efficiency measure to implement for POS devices that use modern computer technology and software.

9.6.5 *Energy-Savings Potential and Efficiency Barriers*

We estimate the energy efficiency potential of POS devices relative to other end-use services to be small based on the low annual energy consumption of the equipment. A trend, which we expect will continue in the future, involves replacing POS terminals with non-traditional systems that have more functionality (e.g. touch screens and inventory software). These non-traditional POS systems typically require more processing capability and energy to operate. Also, as the installed base of these POS systems grows, opportunities may arise to encourage the adoption of Energy Star rated components used in the computer industry.

9.7 *Summary of Energy Use*

Table 9-25 lists the miscellaneous equipment researched in this report in order of highest annual energy consumption. We estimate the annual energy consumption (AEC) by multiplying UEC and installed base. For technologies with a range of UEC we took the weighted average where data was available or use the higher value of the range in order to emphasize the small amount of energy these individual equipment categories consume.

Table 9-25: Miscellaneous Equipment with the Highest Estimated AEC

End-Use Technology[a]	2008 UEC (kWh/yr)	2008 U.S. Installed Base	2008 U.S. Site AEC[b] (TWh/yr)	2008 Primary AEC (Quadrillion Btu/yr)[c]
Elevators	7,160	740,000	5.3	0.055
X-ray	3,980-27,900	170,000	4.8	0.050
Coffee makers	905	3,102,000	2.8	0.029
Point-of-service	218-423	7,607,000	2.4	0.025
Non-refrig. vending[d]	657-3,558	1,656,000	2.1	0.022
Automated teller machine	1,887-3,573	407,000	1.2	0.013
CT Scan	73,000	16,200	1.2	0.012
Magnetic resonance imaging	93,000	9,400	0.9	0.009
Escalators	20,500	37,000	0.8	0.008
Total			**21.5**	**0.223**

[a] See sections above for more detail on sources and calculations
[b] AEC estimate uses the upper bound from UEC or takes the weighted average where data is available
[c] Uses 10,405 Btu/kWh conversion rate for site electricity in kWh to primary energy in Btu (DOE, 2008)
[d] Limited to snack and warm-beverage units

9.8 *Comparison of Baseline Energy Consumption to Previous Studies*

Figure 9-19 depicts the AECs of the top-nine miscellaneous equipment types analyzed in this study, shown as a portion of the total "other" category estimated in the 2008 Building Energy Data Book. The 2008 Buildings Energy Data Book definition of the "other" category includes all energy end-uses not accounted for in lighting, space cooling, space heating, electronics, ventilation, water heating refrigeration, computers, and cooking (e.g. ATMs, telecommunications equipment, medical equipment, pumps, emergency electric generators, combined heat and power building units, and manufacturing performed in commercial buildings). While this report targeted miscellaneous equipment with the highest AEC, the sum of these technologies still only accounts for a fraction of the total estimated energy use of this category according to the Building Energy Data Book.

Figure 9-19: U.S. 2008 AEC (Quads) from Miscellaneous Equipment Analyzed in this Study as a Portion of the "Other" Category in the 2008 Buildings Energy Data Book

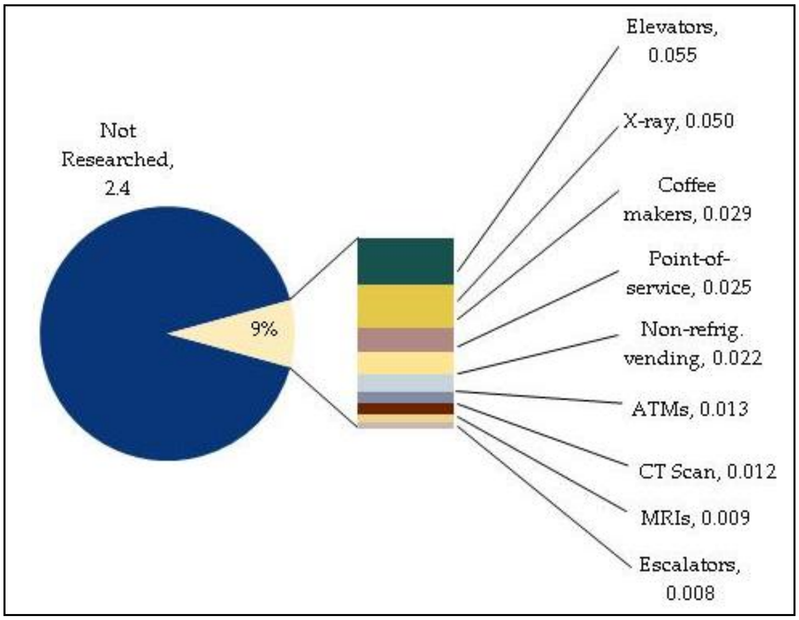


Table 9-26 compares AEC estimates for this study to those from the 1993 ADL report. AEC estimates for common technologies are typically higher for NCI estimates due to an increase of installed base or adjustment to UEC assumptions based on more accurate sources. X-ray equipment for example uses different assumptions than those used in the ADL 1993 study based on more recent information such as higher installed base. Similarly the installed base estimates of CT Scan devices and MRIs has significantly increased since the ADL 1993 estimate.

Table 9-26: Annual Energy Consumption of Miscellaneous Equipment Research in this Study Compared to Estimates from a 1993 ADL Report

End-Use Technology	1993 ADL AEC (Quads/yr)	2008 NCI Estimate AEC (Quads/yr)[a]	Percent Difference (NCI-ADL)/ADL
Elevators	No Estimate	0.055	NA
X-ray	0.0074	0.050	580%
Point-of-service	0.017	0.025	47%
Coffee makers	No Estimate	0.029	NA
Non-refrig. vending	No Estimate	0.022	NA
Automated teller machine	0.0076	0.013	70%
CT Scan	0.0023	0.012	420%
Magnetic resonance imaging	0.001	0.009	800%
Escalators	No Estimate	0.008	NA

[a] See sections above for more detail on sources and calculations—AEC uses the upper bound from UEC or takes the weighted average where data are available; Uses 10,405 Btu/kWh electricity conversion

10 Recommended Program Activities and RD&D Initiatives

We developed recommendations to advance the market penetration of energy efficient technologies in each end use sector. The recommended program activities fall in three main categories, as depicted in Figure 10-1**Error! Reference source not found.**. These include Research, Development and Demonstration (RD&D), voluntary programs, and regulatory programs. We did not include rebate or tax-incentive programs.

Figure 10-1: Groupings used for Recommended DOE Programs[a]

a) Ongoing organizational changes at DOE may shift some of DOE's responsibilities for the ENERGY STAR program to EPA. If this occurs, some of the ENERGY-STAR-related recommendations made may be more applicable to EPA.

10.1 Commercial Kitchen Appliance Recommendations

10.1.1 Voluntary Programs

Continuation of ENERGY STAR Programs

Several of the most promising cooking efficiency technologies are already promoted by the DOE/EPA ENERGY STAR program. These technologies are commercially available and are cost effective in some applications. We recommend these programs continue as they are successful; DOE can play little role in further advancing these technologies at this time. These technologies include:

Connectionless Steamers (Electric and Gas)

These have a combined technical potential of 0.050 Quads, and are already implemented in the ENERGY STAR program. ENERGY STAR steamers currently have a 12% market penetration. Thirty-four energy utilities use the ENERGY STAR rating as the rebate criteria for high efficiency steamers.

High Efficiency Dishwashers

These offer a combined technical potential of 0.043 Quads (achievable potential of 0.011 Quads) with most of the potential lying in conveyor dishwashers. High efficiency dishwashers were recently implemented in the ENERGY STAR program, five energy utilities across the nation offer rebate for these appliances. The DOE should encourage more utilities to educate their customers and offer rebates on these products to increase uptake.

Power Burner and Infrared Burners
These burners have cost effective applications in some appliances, those appliances that utilize these technologies often qualify for the ENERGY STAR program. Power burners are cost effective in fryers and ovens while infrared burners are cost effective in fryers, ovens, and broilers. Within these appliances they have a combined technical potential of 0.042 Quads. The ENERGY STAR fryer program effectively promotes both burner technologies; both burners are being utilized by various fryers manufactures. The recent introduction of an ENERGY STAR program for ovens will help promote these burners in oven applications as well.

Power burners also have significant technical potential in range tops (0.025 Quads). However, the high incremental cost results in a prohibitively long payback (6.2 years) for the cooking industry. High incremental cost and problems of temperature control are large barriers to implementation. Time and money is better spent on other research and development programs that can yield a higher achievable potential.

Enhance Cooking Appliance Manufacturer/Chain Restaurant Co-operation
We recommend the DOE create a framework through which manufacturers and chain restaurants can work to overcome barriers of replacing current equipment with high efficiency equipment. The key barriers are food quality and equipment cost. DOE can work with the Retail Energy Alliance (REA) Restaurant Subcommittee to bring these two groups together and emphasize cooking equipment.

Franchise agreements tend to give local owners of chain restaurants little say in the appliances they use. At the corporate level, the decision making process for purchasing cooking equipment typically focuses on first cost, performance, and quality of food product. A strong emphasis is placed on maintaining consistency in the look, taste, and texture of food served at each location of a chain. Changing appliances may change one of these qualities presenting a barrier to high efficiency replacements.

In addition to food quality issues, cost is a major factor in upgrading to high efficiency equipment. Chain-wide replacement requires a significant capital investment as incremental costs are high. Upgrading appliances is just one of the capital spending projects available to corporate leaders. Franchises also have the option of spending available capital on expanding the chain. Expanding the franchise is viewed as a more attractive investment as it's believed it will lead to better returns than investing in energy efficiency.[21] Thus, capital investments in

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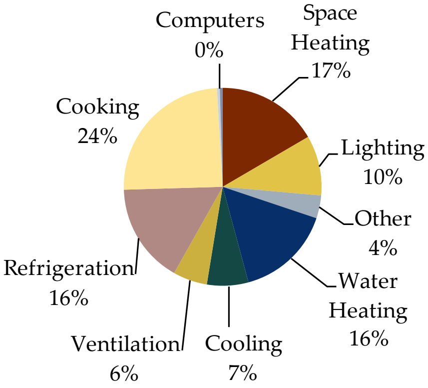
[21] Equipoise Consulting Inc. 2004

chain restaurants tend to be made on expanding the franchise with less emphasis on energy efficiency.

This cooperation is best approached through the Retail Energy Alliance Restaurant Subcommittee. The Retail Energy Alliance (REA) brings major restaurant chains together to share ideas on energy efficiency and solicit information from food equipment manufacturers. Members of REA include some of the largest chain restaurant franchises in the nation. The REA can serve as a means for these major customers to reach out to manufacturers as they already have existing relationships.

The REA places most of its emphasis on HVAC and lighting, and less on cooking appliances directly. However, Figure 10-2 shows cooking amounts to 24% of restaurant energy consumption while REA targeted end uses account for a combined 31% of energy consumption (space heating, lighting, space cooling and ventilation). DOE should ensure that the Retail Energy Alliance Restaurant Subcommittee addresses cooking technologies as well.

Figure 10-2: Restaurant Energy Consumption by End Use



Source: 2003 CBECS (EIA 2003)

Under this program, the DOE will facilitate discussion between the manufacturers and chains that focuses on energy efficiency. Some suggested discussion topics are:

- What issues (first cost, return on investment, maintaining quality, or equipment reliability) are most important to each chain when considering equipment upgrades?
- What high efficiency replacements are available from each chain's preferred manufactures that offer comparable quality and reliability with reasonable first costs and return on investment?
- High efficiency replacements may not be available in the manufacturer's product line. Additionally, some appliances are custom built by manufacturers and exclusively available to specific chains; these may have no readily available replacement. DOE should foster discussion on incorporating more energy efficient technologies in these specific models and the potential price increases for chains that would result.

As a follow-up to this forum, we recommend the DOE promote and assist further co-operation between chains and manufacturers. Several options include:

- Analysis of the potential energy savings in a specific chain by estimating baseline energy use for a typical store in that chain and its potential energy savings.
    - The baseline energy use profile of a restaurant will be relatively easy to assess as most locations within a chain operate the same hours using the same appliances with a certain range of throughput. PG&E's Food Service Technology Center is currently performing a study that will baseline the energy consumption of various chain restaurant types in California. This report will be publically available in late 2009 and can serve as a reasonable baseline.
    - Energy savings from high efficiency appliances recommended by manufacturers can be calculated using knowledge of the baseline usage profile and high efficiency replacement. A franchise-wide cost savings and return on investment can be calculated from this analysis.
- Promote pilot installations at select locations to assess food quality issues and determine actual energy savings.
- Develop tools to estimate return on investment to aid the capital investment decisions of chains.

10.1.2 Support RD&D of Advanced Technologies

Electric Ignition for Gas Cooking Appliances

We recommend a program to develop a reliable electric ignition system for use in all commercial cooking appliance types. DOE can work with the Retail Energy Alliance (REA) Restaurant Subcommittee as a platform to educate customers, gather support for the technology and reach out to manufactures.

The majority of gas cooking appliances use pilot lights to ignite burners, these pilot lights burn gas 24 hour hours a day. Pilot lights waste gas during downtime, in a restaurant this can be 10-16 hours a day depending on the appliance and usage patterns. Replacing these pilot lights with electric ignition has the technical potential to reduce energy use by 0.014 Quads.

Although electric ignition recently became a requirement in new residential cooking equipment, there are barriers preventing it from extending to the commercial sector. Reliability and durability of appliances are key qualities sought after in the commercial cooking sector. However, igniters in the residential sector are fragile; they degrade over time from oxidation and food splatter. While they are acceptable for use in the residential sector, the same technology would not be appropriate in the commercial sector, where severe operating conditions and long operating hours are the norm.

Some commercial cooking appliance manufacturers have implemented electric ignition in high end models and Energy Star models for certain appliance classes (fryers, ovens). However, they are not widely used within these appliance classes. In its technical support document regarding residential cooking equipment, the DOE estimated the incremental cost for residential electric ignition to be $15-25 depending on the appliance. The heavy use in commercial settings would require a more durable igniter than residential igniters; thus, the incremental cost would most likely be higher.

The REA can be used as a platform to reach out to its members and other customers. Through the REA, DOE can solicit input from large chain customers regarding their experience with electric ignition technology. DOE can further educate customers and gather support though the REA. Additionally, DOE can use REA to seek the insight of manufacturers who have implemented electric ignition (Frymaster, Blodgett, Garland) to help understand the actions taken to make them more reliable and their associated costs.

Key R&D aspects this program should focus on are:

- Durability - resistance to food and liquid spills
- Reliability - resistance to degradation over time from spills and heavy use (impact and mechanical loading)

Reliable, durable ignition systems are required before the DOE can consider extending the electric ignition regulatory program from the residential sector to the commercial sector.

Broiler Idle Energy Reduction Controls

We recommend a program to develop broiler idle energy reduction controls. Targeting Broiler Idle Energy Reduction controls has a technical potential of 0.008 Quads. DOE can work with the Retail Energy Alliance (REA) Restaurant Subcommittee as a platform to educate customers, gather support for the technology and reach out to manufactures.

The majority of commercial broilers are left idling at their full rate during large portions of the day. Reducing the idle energy rate to 65% of full output rate can keep broilers sufficiently preheated while reducing energy use. Broiler idle energy reduction controls were previously developed and commercially available in the 1990's when appliance control technology was less advanced that it is today. The model developed idled at 65% of the maximum output as a default; however, it is no longer commercially available. Cooks had to press a button when they were ready to cooking to bring the broilers back to full power for a brief 10-15 minute period, ample time for most cooking needs. The appliance required a behavioral change for cooks, which many of them resisted.

The REA can be used as a platform to reach out to its members and other customers. Through the REA, DOE can solicit input from broiler end users to educate them on the possibilities and advances since the technology was last commercialized. DOE can then use REA to approach manufacturers to develop the technology.

We recommend the DOE explore this option given appliance control technology advances in the last 10 years. We recommend the DOE partner with industry to develop a reliable durable control system for lab and field testing purposes. Some key R&D points on whichto focus include:

- Length of time between “energy saving idle mode” and “cooking mode”
- Effects of controls on productivity
- Use of electronic food sensors
- Use of electronic control for broiler output
- User feedback indicating when broilers are in “energy saving mode” and “cooking mode”

The use of electronic sensors and controls can eliminate the need for behavioral changes, thus, overcoming a key barrier in previous commercialization attempts. The user feedback informs chefs that the broilers are operating properly.

Supercritical CO_2 Dishwashing

We recommend a research program to assess supercritical CO_2 dishwashing to determine if it could actually save energy and meet the cleaning needs of the commercial food service sector. Using supercritical CO_2 in the dishwashing process will avoid the need to use hot water and detergent. Energy used to heat water for commercial dishwashers amounts to 0.125 Quads per year. However, additional energy consumption may be required by this technology to compress CO_2 and minimally heat it to its critical temperature.

Supercritical CO_2 has a very low surface tension and can be used in the dishwashing end use as it dissolves oils and grease. A residential sized unit conceptualized by a project team at the University of New South Wales in 2004 as part of a design competition sponsored by Electrolux.[22] However, a fully working model was not built and no analysis of energy consumption or savings was performed. The use of supercritical CO_2 as a cleaning agent also has applications in dry-cleaning and medical sanitization; however no products are commercially available.

We first recommend an engineering analysis to determine theoretical energy savings. If this analysis shows the technology has promise, further investigation should continue. Key R&D questions include:

- Is additional sanitization required to meet commercial dishwashing needs?
- Can the process be made fast enough for the commercial sector?
- Will the appliance fit in the foot print of traditional dishwashers?
- Is special training/licensing required to operate this type of equipment?
- Are there safety issues that must be addressed?

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[22] http://www.fbe.unsw.edu.au/exhibits/binddes/rockpool/beneath.asp

- What are the incremental costs for this technology?

The successful completion of the engineerign analysis above is required before embarking on and R&D effort through a partnership with industry.

10.2 IT and Office Equipment Recommendations

10.2.1 Voluntary Programs

IT Network Efficiency Performance Program

As discussed earlier in this report, today's market demand for faster, more reliable, and smaller products provides significant motivation for IT equipment manufacturers to strive for improved efficiency of their product. While the current efforts may sufficiently advance efficiency of IT devices intended for individual use (e.g., personal computers and desktop monitors), an additional implementation framework may be necessary to realize efficiency potential of an IT network, where multiple devices are interconnected and influence the performance of other devices within the network.

Technical potential energy savings for energy efficiency measures involving server computers, UPSs and network equipment is approximately 0.3 Quad/yr. While efficiency measures at the single device level may be commercially viable, all solutions must be fully integrated in the network design to optimize and fully capture their collective energy efficiency potential. This is especially relevant for data center designs, where different design considerations (e.g., power circuit design, waste heat management, HVAC system integration, and software solutions) dynamically impact how they are implemented. Furthermore, a LAN-level management of end-use devices (e.g. PCs) may improve the enabling rate or after-hour turn-off rate of these devices.

To promote awareness and encourage energy efficient designing optimized for the IT network, we recommend that DOE establish a LAN- or a buildings-level IT network efficiency performance program to act as a clearinghouse of best network design practices. Key stakeholders would include the industry's leading IT companies in data center and network efficiency (e.g., Google and Cisco), construction companies specializing in data center projects, electric utilities and US EPA, as well as industry groups that were instrumental in developing existing efficiency metrics for IT network equipment. In developing the scope of the program, DOE may be able to leverage experience from Home Performance for Energy Star, or Energy Star Homes program, which focus on buildings-level energy performance improvement for new and existing residential homes.

Inclusion of PC/Desktop Monitor Power Management in ENERGY STAR

While power management is a widely available energy efficiency measure with virtually no associated cost, inconveniences associated with power management features (e.g., requisite boot-up time) discourage individual end-users from actively enabling their devices' power management feature. However, efficiency gains from enabling power management are significant even for the most efficient devices available today; even after all commercially viable efficiency improvements are made, the technical potential of additional AEC reduction from enabling power management is 0.07 Quad/yr for personal computers and desktop monitors combined. The potential AEC savings could be up to 0.24 Quad/yr if power management was universally enabled across all typical new units.

In order to overcome this barrier, we recommend DOE to explore the feasibility of including enabling of power management as a part of the future Energy Star standards for personal computers and desktop computers. By enabling power management on all new computers, end users must turn off power management as needed, instead of them having to turn on power management if desired. DOE should convene workshops with key stakeholders (e.g., manufacturers and customer representatives) to discuss the market and industry implications of such a mandate, as well as how it should be designed and implemented. Key considerations include:

- **Burden to end users:** As things stand today, many end users find power management features to be a nuisance with no appreciable benefit. Furthermore, there are certain cases where power management would in appropriate feature for certain end users (e.g. computers that will be remotely accessed) (Chetty, et. al., 2009).
- **Market impact:** Given the consideration above on customer reaction toward power management, DOE should ensure that the market competitiveness of Energy Star qualifying devices would not be adversely impacted because of power management feature.
- **Burden to manufacturers:** Addition of power management to the ENERGY STAR standard may require actions on the behalf of the manufacturers. For instance, they may need to develop new technologies to enhance the market acceptance of power management (e.g., reducing the boot-up time).

Energy Study

We recommend further investigation of the discrepancy between the national consumption estimates reported herein and those reported in the Building Energy Data Book (a difference of about 1.4 quad). This will require close collaboration with D&R International, Ltd., the organization that updates annually the Building Energy Data Book, to understand the sources and assumptions used in developing the Data Book estimates.

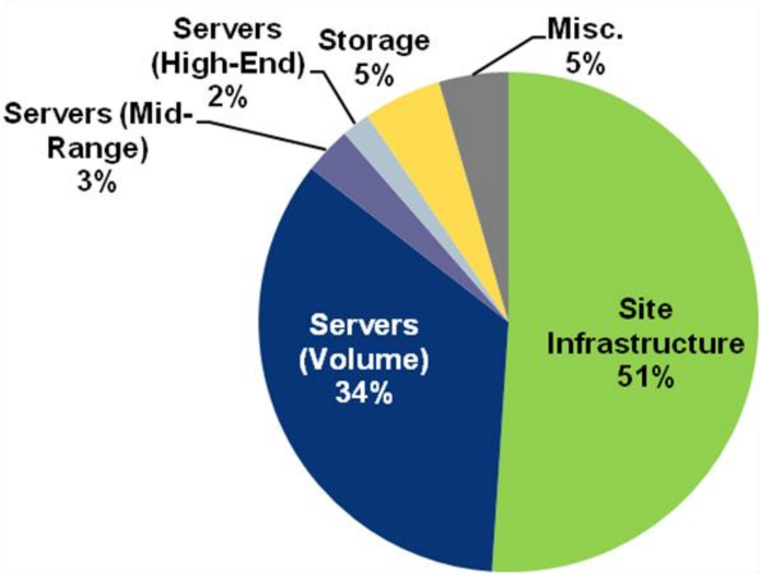
10.2.2 Support RD&D of Advanced Technologies

Data Center HVAC efficiency R&D

One of the major R&D challenges in commercial buildings energy efficiency is energy consumption associated with data-center operations. Data-center infrastructure load (mainly HVAC) accounts for over 50% of the overall data-center energy consumption (see Figure 10-3). This is due to the significant cooling requirement associated with the waste heat from dozens to hundreds of server computers installed in a room, to maintain room temperature at a level that does not interfere with the reliability of server computer performance.

The issue of managing dissipated heat in a data center facility is a complex, cross-cutting topic between IT and HVAC efficiency. As the demand for data center-level computing capacity grows worldwide, identifying optimal solutions to minimize the need to mitigate waste heat from server computers will become increasingly critical. One key consideration is the difference in EUL between HVAC equipment and server computers. Intel (2008) suggests that a typical server computer in a dedicated data center is replaced every four years, whereas HVAC equipment typically lasts for 20 years. This may pose a challenge in minimizing overall data center energy consumption, as heat dissipation characteristics of server computers may change with technology improvements.

Figure 10-3: Breakdown of Data-Center Electricity Use



Data Source: Koomey (2007)

Potential research questions for such a program may include:

- How could liquid cooling system be seamlessly integrated into data centers?
    - How do we prevent condensation from developing in or near servers?
    - How could liquid cooling systems be integrated with building HVAC system?
    - How could liquid cooling systems be integrated with conventional building maintenance system?
    - How should liquid cooling systems be laid out to avoid piping obstructions?
- What is the effect of virtualization on HVAC load?
    - How significant would the trade-off be between HVAC load reduction and increases in fan speed and noise level?
    - How could server racks be laid out to minimize cooling demand?
- What are the most promising new cooling solutions for data centers?

- What are the potential new building operation strategies that could reduce HVAC demand (e.g., raising the cool isle temperature)?
- What are other potential HVAC technology solutions beyond liquid cooling (e.g., ambient air cooling at a Google data center in Belgium)?

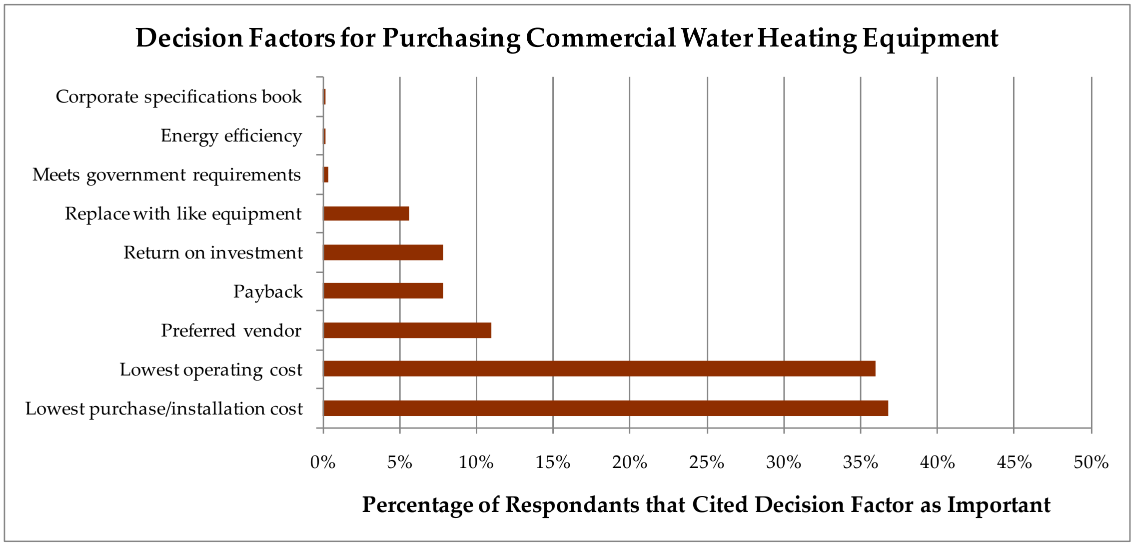
We recommend thatDOE collaborate with manufacturers and technology providers from the IT and HVAC sectors to create a program dedicated to targeted R&D to find technological solutions to operating data centers. Other key stakeholders include electric utilities and ASHRAE Technical Committee 9.9.

10.3 Water-Heater Recommendations

Service water heating accounts for a large portion of the energy consumed in commercial buildings, and has a high savings potential. Consequently, we recommend that the DOE apply a substantial amount of resources to programs in this segment. Successful programs will also coordinate with existing Commercial Building Initiative (CBI) alliances and partnerships (e.g. National Accounts and Building Energy Alliance) where appropriate.

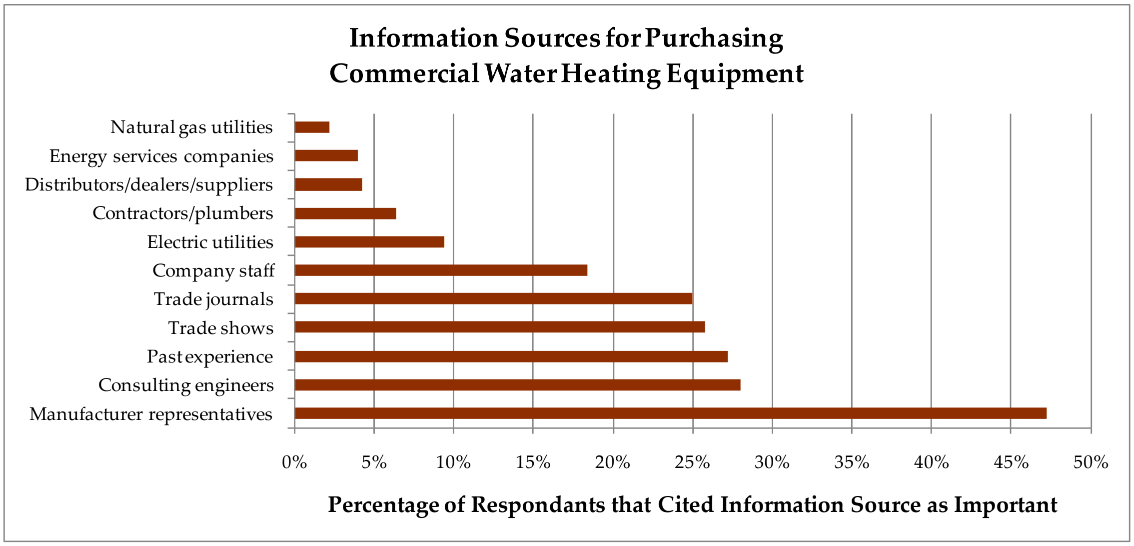
Federal standards currently exist for commercial storage and instantaneous water heaters manufactured after October 2003. Common barriers among emerging water heater technologies include extensive retrofit requirements and high first cost of equipment. Figure 10-4**Error! Reference source not found.** shows that purchase and installation costs are one of the primary decision factors, so in addition to the specific recommendations made for each technology in the sections below, successful DOE programs would also try to minimize operating and first costs of energy-efficient water-heating equipment.

Figure 10-4: Average Relative Importance of Decision Factors Considered when Purchasing Commercial Water-Heating Equipment for Commercial Facilities (EEA, 2003)



We recommend results from DOE programs in this area be used to target decision makers in the commercial building sector. Figure 10-5 depicts the relative importance of information sources for commercial sector decision makers. As part of this recommendation, DOE would disseminate its published results from its research, demonstrations, and other programs through key information sources such as tradeshows, journals, and manufacturers.

Figure 10-5: Average Relative Importance of Information Sources Considered when Purchasing Commercial Water-Heating Equipment for Commercial Facilities. (EEA, 2003)



While this section focuses on recommendations for technology efficiency programs, efficiency opportunities also exist through conservation measures that encourage the reduction in hot-water usage.

10.3.1 Voluntary Programs

Expand ENERGY STAR Program to Commercial-Scale Water Heater

ENERGY STAR programs currently exist for residential gas condensing, heat pump, high-efficiency gas storage, solar thermal, and gas tankless water heaters. NCI recommends DOE develop programs for commercial scale water heaters (e.g. solar thermal, heat pump, and condensing water heaters), which will help to address the lack of awareness of benefits from more efficient water heating technologies. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) currently tests and certifies the rated performance of water heaters, but does not promote the purchase of energy efficient equipment. Also, the Consortium for Energy Efficiency (CEE) encourages the purchase and use of energy and water efficient commercial equipment through a multi-tiered rating system, but has not adopted high-efficiency specifications for commercial water heaters. The DOE could coordinate with these organizations to determine how to best design and customize an ENERGY STAR program for the commercial water heating sector and distribute information to manufacturers and commercial consumers. A successful program would create more awareness of alternative water heating equipment and inform decision makers of the benefits of installing the technology for commercial buildings. Energy-efficient, commercial-scale water-heater technologies have varying technical potential ranging from 0.1-0.6 Quads.

10.3.2 Regulatory Program

Energy conservation standards for commercial water heating equipment are established by the Energy Policy and Conservation Act (EPCA). EPCA directs the DOE to consider amending the existing federal energy efficiency standard for covered equipment each time ASHRAE Standard 90.1 is amended with respect to such equipment. EPCA directs that DOE must adopt the amended standards at the new efficiency level in ASHRAE Standard 90.1, unless clear and convincing evidence supports a determination that adoption of a more stringent level as a national standard would produce significant additional energy savings and be technologically feasible and economically justified.

Federal standards for electric and gas water heaters were published in 2001 (66 FR 3336) and established minimum thermal efficiencies, maximum standby-losses, and minimum thermal insulation for commercial water heaters manufactured after October 2003.

ASHRAE recently announced a new agreement to work with DOE to increase building energy efficiency standards for the year 2010 by 30 percent over 2004 standards (ASHRAE, 2009). DOE and ASHRAE should continue to advance the energy efficiency requirements for commercial water heaters as more efficient water heaters are brought to the market.

10.3.3 Support RD&D of Advanced Technologies

Demonstration of Commercial-Scale Solar Water Heaters on Federal Buildings

To increase the use of solar thermal water heating , we recommend that DOE conduct demonstrations of the technology on federally owned commercial buildings and encourage adoption by private industry. DOE can also rely on its National Accounts (NAs) partnership to facilitate a demonstration. This technology still suffers from high first costs, consumer misconceptions of reliability, and lack of awareness that have significantly limited its market penetration. The suggested large-scale demonstration should target facilities with high water heating demand (e.g. hospitals, laundries, and gyms) DOE should work with equipment vendors to purchase in bulk, install equipment, and measure performance of the technology on multiple properties. The constant and high water heating demands of hospitals make them well-suited for solar water heaters, so an example program would coordinate with an organization such as the Veterans Health Administration to facilitate equipment installation on multiple facilities. DOE's recently created Hospital Energy Alliance (HEA) could help facilitate such a program. Published results on performance, cost, and reliability should be distributed to private health care organizations that own and operate multiple hospital properties (e.g. Kaiser Permanente) and can take advantage of bulk purchasing options. We also recommend bulk technology purchases be made through DOE's Technology Procurement program. A successful program would catalyze deployment of the technology on multiple health care facilities and other commercial buildings which has a very high technical potential—ranging from 0.4-0.6 Quads. Such a program also contributes to the energy performance goals established for federal buildings in Title IV, Subtitle C of the Energy Independence and Security Act of 2007 (H.R. 6, 2007).

Demonstration of Drain Water Heat Recovery on Federal Buildings

Similar to the Solar Water Heater demonstration program, NCI recommends this program target federal buildings to demonstrate and report on the cost effectiveness and performance of commercialized drain water heat recovery technology. Despite the high technical potential of drain water heat recovery—ranging from 0.2-0.3 Quads—few manufacturers currently develop and sell this technology and most that do are located in Canada, due to the lack of demand and awareness for drain water heat recovery technology in the U.S. DOE would target federal commercial buildings with large water heating demands (e.g. healthcare facilities and cafeterias) and track and report on the performance, cost, and reliability of the technology. DOE may combine this demonstration with the solar water heating demonstration if they decide to go forward with both programs and also consider working with their National Accounts (NAs) partnership to facilitate with a demonstration. DOE would distribute published results to health care organizations and other commercial building owners to encourage adoption of this technology by highlighting cost benefits of bulk purchases and increasing awareness of the technology. NCI also recommends bulk technology purchases be made through DOE's Technology Procurement program. This program would also contribute to the energy efficiency goals established for federal buildings by Energy Independence and Security Act of 2007 (H.R. 6, 2007) by helping meet efficiency goals.

Advanced Materials and Designs for Drain-Water Heat Recovery

We recommend that DOE conduct research on alternative materials and design applications for drain-water heat-recovery technology. While this technology is commercialized and has a high savings potential, retrofit limitations and high up-front costs (e.g. equipment and installation costs) have hindered sales of the product in the U.S. Fundamental research on alternative materials to copper, which suffers from volatile pricing, and alternate designs that use the same concept of recovering heat from drain water may help to identify a more cost effective method with a streamlined retrofit application. In order to avoid repeating research in this area that has already been conducted, DOE should coordinate research with and solicit feedback from equipment developers and manufacturers in the US and Canada that have experience designing and commercializing this technology (e.g. GFX, RenewABILITY Energy, and Winston Works). Incorporating drain water heat recovery into the plans of new construction facilities should lead to additional efficiency savings, but much higher near-term savings opportunities exist for retrofit applications in water-intensive commercial facilities (e.g. gyms, health clubs, hair salons, dormitories, laundries, and restaurants).

Key R&D questions include:

- Do alternative materials to copper exist which are more cost effective and don't sacrifice performance?
- Can alternate designs be used to reduce retrofit requirements and expand the applications?
- For new construction, what design considerations should architects and engineers focus on while planning for construction?

Wide-scale adoption of drain water heat recovery technology nationwide has a technical potential to save between 0.2-0.3 Quads.

Heat-Pump Water Heaters

We recommend that DOE build upon past research programs to develop heat-pump-water-heater technology for commercial-scale applications. As this emerging technology continues to grow in popularity for residential applications in other locations like Japan, which sold 500,000 CO_2 refrigerant heat pump water heaters in 2008 (JARN, 2009), more research for commercial applications in North America is needed. With DOE funding, the United Technologies Research Center conducted a study and demonstration of a CO_2 heat-pump water heater , and determined that additional product development is needed to reduce costs and overcome performance and reliability issues that limit acceptance in the North American market (UTRC, 2007). The International Energy Agency's (IEA) Heat Pump Center (IEA, 2004), and Oak Ridge National Labs (ORNL, 2009) have all conducted research on this technology. Similarly, the University of Maryland's recent research tested CO_2 HPWH under various heating scenarios and found CO2 refrigerants to be more favorable for water heating than a conventional refrigerant (UMD, 2009). DOE would communicate with these researchers as well as major water heating manufacturers in both the US and Japan to determine how to best implement recommendations made by the UTRC study and encourage the development of this technology for the U.S. market.

Depending on the results of the assessment, we recommend DOE conduct additional research to modify the technology to enable cost-effective commercial scale applications, or develop a voluntary program to reduce costs and encourage equipment manufacturers in the U.S. to expand commercialization efforts. If successful, such a program could lead to significant energy savings in the electric water heating market (technical potential ranging from 0.2-0.3 Quads) assuming that heat pump water heaters become widely adopted.

Absorption Heat-Pump Water Heaters

Since commercialized absorption heat pumps are primarily used in combined heating and cooling applications, we recommend DOE conduct additional research to develop this emerging technology specifically for water heating only applications. A heating only system would be more cost effective than a combined heating and cooling system applied to water heating (ASHRAE 2005). Such a program would gather information from existing manufacturers and developers (e.g. Robur and Energy Concepts) and coordinate with past and ongoing research efforts by Rocky Research (Rocky Research, 2008) and the International Energy Agency's Heat Pump Center (IEA, 2008) on absorption technology combined heating and cooling units.

Based on the results of this assessment we recommend DOE design a research program to enable fundamental technology improvements or pursue a follow-on voluntary program to encourage manufacturers to develop water heating specific applications. A successful outcome may result in a working prototype of a heating only system or lead to commercialization of an existing prototype. Wide-scale adoption of the absorption water heaters has a technical potential to save greater than 0.1-0.2 Quads.

10.4 Pool-Heater Recommendations

Energy-saving commercial pool-heating technology is already commercially available, although in many cases the technology has not been widely adopted. Initial cost is always a concern for adopting new technologies; however, results from the RSPEC program—the DOE's previous program designed to educate commercial pool owners about energy-saving technologies—indicate that two of the main barriers for energy-saving equipment are 1) lack of knowledge about the magnitude of potential energy savings, and 2) lack of knowledge about how the majority of pool water heat energy is lost (e.g. that evaporation accounts for over 70% of a pool's energy loss). Our recommendations for commercial pool heating equipment are described below.

10.4.1 Voluntary Programs

Extensions of advanced water heating systems

Some of the advanced technologies in development for commercial hot water heating could also be applied to commercial pool heaters. One example is absorption water heaters, which would replace gas hot water heaters. Most commercial pool heaters are gas-fired. Pool heaters present additional design challenges because of the caustic chemicals and environment in which they operate. We recommend that DOE sponsor programs for pool heating equipment that overlap with existing or other planned water heating demonstration programs. A successful outcome of the pool heating programs would be the demonstration of advanced water heating concepts in a pool heater application.

Education/Outreach/Training

We recommend DOE launch an educational outreach program similar to the previous RSPEC program to increase awareness of energy saving opportunities for commercial pools. This program could be implemented though the DOE's Federal Energy Management Program (FEMP). The outreach program should target pool owners/operators, equipment distributors, and manufacturers.

Traditional barriers to implementing energy-efficient technologies include lack of information, higher upfront costs, and operational constraints. The RSPEC program proved successful at eliminating some of these barriers by educating commercial pool owners and demonstrating that the upfront costs were manageable, and that the annual cost savings can be substantial. Consumer responses received as part of the RSPEC program indicate that pool owners were unaware of the relative proportions of where the actual energy and monetary losses were occurring. Software provided to recipients educated pool operators about energy loss and energy efficiency options, and convinced many to buy pool covers and more efficient pool heaters.

The recommended DOE program should have the following goals:

- Encourage pool owners to install and operate state-of-the-art automatic pool covers. These modern pool covers eliminate some of the traditional market barriers—they are self-deploying, easy to operate, aesthetically pleasing, and can be customized to a wide variety of pool sizes and shapes.
- Encourage pool owners to retrofit existing pool heaters with higher efficiency heat exchangers, heat pumps, or solar pool heaters.
- Encourage indoor pool operators to install combined heating/dehumidification equipment.

Information provided by program should include the following:

- Percentage breakdown of where pool energy losses occur
- Realistic cost estimates of energy-efficient pool equipment
- Estimates of payback period for each type of equipment
- Energy savings, cost savings, and other potential savings such as decreased dehumidification needs for indoor pools
- Showcases of successful examples of each technology in a variety of settings: hotel, resort, university, municipal pools.
- Interactive web-based tools to further educate and allow pool owners to get more specific estimates based on their specific pool size and location.

Voluntary Standards

- We recommend that DOE create an ENERGY STAR program for commercial (and residential) pool heaters to increase awareness and encourage the adoption of more energy efficient technologies such as condensing pool heaters.
- We recommend that DOE continue its partnership with ASHRAE to update Standard 90.1. The Standard should reflect the efficiencies of traditional pool heaters currently on the market. The current standard is 78%, whereas most pool heaters on the market have efficiencies of 82-85%.

10.4.2 Regulatory Programs

Currently, there are no regulatory programs for commercial pool heaters. Based on the range of efficiencies of commercial pool-heating technologies currently on the market, we believe an efficiency standards program would be feasible. We recommend that DOE create efficiency standards for commercial pool-heating equipment, modeled after the existing standards for residential pool heaters.

10.5 Commercial Laundry Recommendations

Within the commercial laundry sector, there is a much greater need for research and development on commercial-dryer technologies than on commercial-washer technologies. Advanced dryer technologies are less mature than many of the advanced washer technologies, and dryers offer some of the largest energy-savings potentials in the sector.

Our general recommendation for DOE is to sponsor a set of research and demonstration programs that have the potential to deliver significant energy savings for commercial dryers. At the conclusion of these programs, DOE should begin to phase in mandatory energy-efficiency regulations. These regulations will provide the incentive for manufactures to commercialize the technologies that have been demonstrated through the DOE research programs.

In addition, DOE should work to make laundry facilities more aware of clothes washer and dryer technologies that are currently on the market and that have been shown to be successfully implemented in various commercial laundry facilities. These recommendations are described in more detail below.

10.5.1 Voluntary Programs

Education/Outreach/Training

- Launch an educational outreach program to increase awareness of energy and water saving opportunities for commercial laundry facilities. Target laundromat owners/operators, multi-family housing landlords, on-premise and off-premise laundry facilities, equipment distributors, and manufacturers. Provide interactive web-based tools instead of software that must be installed locally. Showcase successful examples of each technology. Include information about specific manufacturers and products. Emphasize energy savings, water savings, and longer-term cost savings. Specific technologies to target include:
    - Use of low temperature detergents
    - Commercially available wastewater recycling systems
    - Commercially available ozone systems
    - Commercially available advanced tunnel washers

Voluntary Standards: ENERGY STAR

- Consider creating ENERGY STAR program for commercial dryers, based on corresponding program for residential dryers.

10.5.2 Regulatory Standards

We recommend that DOE continue to maintain commercial washer efficiency standards. We also recommend that DOE consider implementing efficiency standards for multi-load washers, as this category of washers represents a significant portion of commercial laundry energy usage.

DOE should also consider implementing efficiency standards for commercial single-load and larger capacity tumbler dryers.

10.5.3 Support RD&D of Advanced Technologies

As mentioned above, we believe that improvements to dryer technologies offer a significant opportunity for energy savings within the commercial laundry sector. The sections below describe technologies that could be used to achieve dryer energy savings.

Sensor Technology

- Justification: Reducing over-drying offers one of the largest energy savings potentials for the laundry drying process (0.015 quads). More research is needed to more accurately detect end-of-cycle. Existing state-of-the-art moisture rods are accurate only down to 15% RMC. Additional sensors or sensor technologies needed to accurately measure when clothes are dry. Humidity sensors could potentially be used, but are prone to condensation and lint build-up.
- Previous research: A DOE project with GE in 2004 investigated more advanced control algorithms and sensing options for detecting end-of-cycle. The study concluded that improved sensing capability is needed to make substantial improvements in end-of-cycle detection, and that relative humidity sensing remains beyond the realm of commercialization. Specifically, more research is necessary to address the elimination of small-particle contamination and condensation to improve sensor reliability. GE is now privately funding additional sensor research based on the results of this project. (GE 2004)
- Research program: Although GE has plans to continue advancing sensor research privately, a public research program would make the results widely available to manufacturers. In addition, public research data could be used for future rulemakings, and DOE could ensure that the research moves forward. Therefore, a program should be conducted that builds off the research conducted by GE, focusing on implementation of relative humidity sensors. Focus of research should be how to coat and protect sensors, improved lint management, optional sensor placement with the goal of improving sensor reliability on the order of the dryer lifetime. After sensor implementation, additional work is needed to correlate relative humidity with RMC, develop control algorithms.
-
- Outcomes: The objective is to demonstrate a sensor or suite of sensors, plus other complimentary design improvements, that is able to accurately detect RMC below 15% and to accurately indicate end-of-cycle

Demonstration of Existing/Emerging Technologies

- Inlet air pre-heating
  - The program would demonstrate implementation of facility-scale recycling of exhaust heat and inlet air preheating techniques for coin-operated and on-premise laundries, based on techniques used for the largest capacity dryers used in off-premise laundries. A facility-scale system would include common inlet and outlet ducts connected to each dryer in the facility, with heat transfer between the two common ducts.
  - The project would investigate feasible designs and interfaces; examine the extent of dryer design changes that would be necessary; address potential safety issues such as condensation and lint accumulation; develop a prototype system on a coin-operated laundry or on-premise laundry scale; and use the prototype to provide more reliable estimates of potential energy savings.
- Modulating gas burners
  - A demonstration project for modulating gas burners should leverage previous research on modulating gas burners for implementation in large tumble dryers for laundromat, on-premise, and off-premise laundry facility use. Modulating gas burner technology may also be applicable to single-load gas-burning dryers.
- Heat-pump dryers
  - A demonstration of heat-pump dryers for small and medium-sized commercial dryers would leverage the latest research on heat pump dryers to optimize design, reduce cost, and improve performance (i.e. reduce dryer cycle time)

10.5.4 Other Programs

- DOE should review the safety and efficacy of existing commercial ozone laundry systems on the market. DOE has previously ruled out consideration of ozonated laundry in residential and commercial clothes washer rulemakings; however, one commercial system now available for coin-operated laundries. DOE should verify or investigate the following:
  - Energy savings potential of ozone laundry system
  - Safety of using ozone for laundry purposes
  - Safety of customers/operators
  - Compatibility of clothing and washer materials with ozone
  - Environmental effect of ozone usage
  - Health effects of long-term exposure to ozonated laundry system

- Provide low-interest loans or tax incentives for installing energy-efficient equipment such as wastewater recycling systems, advanced tunnel washers
- Building codes for commercial laundry facilities could require energy-efficiency measures such as wastewater recycling equipment
- Broadly implementing water metering and charging for water/sewer consumption may provide incentives to switch to more efficient clothes washing equipment.

10.6 Miscellaneous Equipment

While this category accounts for a significant amount of the energy consumption in the commercial sector, it consists of a large variety of end-use services and technologies that limit the savings potential of an end-use focused efficiency program. When analyzed individually, these end-use technologies consume a relatively small amount of energy compared to the annual energy consumption of technologies in other categories such as water heating and IT equipment. Therefore, an effective program for this segment should target common technology components and efficiency measures applicable to a large number of miscellaneous equipment such as:

- Motors
- Proximity sensors (idling equipment)
- Smart control systems

ENERGY STAR programs exist for some miscellaneous equipment commonly used in the residential sector such as home electronics, but few programs have been developed for commercial scale products.

10.6.1 Voluntary Programs

Energy Study

We recommend that DOE investigate further the possible discrepancy between the national consumption estimates reported herein and those reported in the Building Energy Data Book (a difference of about 2.4 quad). This will require close collaboration with D&R International, Ltd., the organization that updates annually the Building Energy Data Book, to understand the sources and assumptions used in developing the Data Book estimates.

10.6.2 Regulatory Programs

Small Electric Motors

The Energy Independence and Security Act of 2007 (EISA) establishes federal motor efficiency performance standards for motors manufactured after December 19th 2010, that fall within a power rating range of 1-500 horsepower. As part of this Act and other Federal Rulemakings on electric motors (e.g. Federal Register, 2009) standards for small and medium electric motors are under development. We recommended that DOE assess the impact of these programs once they have been implemented to determine whether a voluntary program such (e.g. ENERGY STAR program promoting premium efficiency motors) is necessary. Manufacturers have expressed a preference for improving energy efficiency of motors by customizing motors for specific applications rather than meeting general standards set by DOE. While there are a large variety of end-use applications for motors, an effort by the DOE to incentivize these end-uses on an individual basis is not recommended unless DOE can design a cost-effective program that applies to multiple end-use applications, or finds that a specific end-use has a large enough annual energy consumption to warrant its own program.

10.6.3 Support RD&D of Advanced Technologies

Smart control systems

We recommend DOE conduct and publish research to determine the effectiveness of smart control systems on reducing energy consumption of electronic equipment (e.g. escalators and elevators) in order to justify a potential voluntary program that increases awareness of the technology. Smart controls and proximity sensor technology can be used to turn-off or reduce energy consumption of commercial equipment when not in use or during extended periods of inactivity. For example, controls for escalators reduce the speed or turn off motors during extended periods of inactivity. Such a program should analyze the results from existing installations and case studies (e.g. service-on-demand escalators and stand-by-mode control software for elevators). Published results and best practice guidelines from this research should target major equipment manufacturers and commercial facility property managers/developers who typically make the purchase decisions for this type of equipment. Due to the low annual energy consumption of vertical lift industry relative to other end-use services, vertical lift equipment tends to have a low energy efficiency potential, so this program should also attempt to identify applications and increase market adoption of this equipment for other end-use technologies.

Proximity sensors

We recommend DOE research the effectiveness of using proximity sensors on electric equipment and use the research to determine whether to conduct a demonstration program to evaluate the performance and benefits of proximity sensors like those used for vending machines. Such research and a potential demonstration would increase manufacturer awareness and address concerns associated with the technology's impact on reliability, maintenance, and consumer behavior. For example, some manufacturers believe that turningoff vending machine lights and other components would reduce sales by sending the signal to potential customers that the machine is out of service. Publishing results of a demonstration program and disseminating the information to major manufacturers would help to address this barrier as well as the concern expressed by some manufacturers over increased maintenance and reduced reliability resulting from switching components on and off. To maximize the potential efficiency savings, this program should also attempt to identify applications to increase market adoption of this technology for other end-use technologies (e.g. point-of-service terminals and ATMs) as the non-refrigerated vending sector alone has a relatively small annual energy demand and efficiency potential.

References

EXEUTIVE SUMMARY AND INTRODUCTION

NCI, 2009. *Energy Savings Potential and R&D Opportunities for Commercial Refrigeration* Prepared for the Building Technologies Program, US DOE. September 2009.

Roth, K., Goldstein, F., and Kleinman, J., 2002. *Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings – Volume I: Energy Consumption Baseline.* Report for the DOE Office of Building Equipment, Office of Building Technology State and Community Programs. January.

US Department of Energy (US DOE), 2008. *2008 Building Energy Databook.* November 2008.

PRIMARY COOKING (Section 2)

AccuTemp, 2009. http://www.accutemp.net/griddle_pdfs.html. Accessed May 2009.

Alpina, 2009. http://www.alpina-grills.be. Accessed July 2009.

American Range, 2009. http://www.americanrange.com/infrared/overfired.html. Accessed July 2009.

Arthur D. Little (ADL), 1993. *Characterization of Commercial Building Appliances.* 1993

Cecilware, 2009. http://www.cecilware.com. Accessed July 2009.

Consortium for Energy Efficiency (CEE), 2005. *Commercial Kitchens Initiative.* Published: 2005. Updated: 2008.

CEE, 2007. *CEE Commercial Kitchens Initiative: A key opportunity for achieving energy and water savings.* 2007

Food Service Technology Center – Appliance Experts, 2009. Interviewed by Amul Sathe (NCI) and Jay Luboff (NCI). Interviewed on May 11th 2009.

EIA. *Commercial Buildings Energy Consumption Survey (CBECS).* Online Resource: http://www.eia.doe.gov/emeu/cbecs/. 1992, 1995, 1999, 2003

EIA, 1986. *Non-Residential Buildings Energy Consumption Survey (NBECS).* 1986

Energy and Environmental Analysis, Inc. *National Account Sector Energy Profiles*. Submitted to ORNL. 2003

Eneron, 2009a. http://www.eneron.us/Solution.html. Accessed May 2009.

Eneron, 2009b. Interview with Lee Huang by Amul Sathe (NCI). Interviewed May 5th 2009.

EPA, 2009a. *Available Energy Star Fryers as of May 1, 2009*. May 2009

EPA, 2009b. *Savings Calculator – ENERGY STAR Commercial Steam Cookers*. 2009

EPA, 2008a. *Savings Calculator – ENERGY STAR Electric Fryer*. Accessed: January 2009. Published August 2008

EPA, 2008b. *Savings Calculator – ENERGY STAR Gas Fryer*. Accessed: January 2009. Published August 2008

Equipoise Consulting Inc.,2004. *Final Report for Energy Efficiency in Commercial Food Service.* CPUC 2002-2003 Local Program 113-02. 2004

Frymaster, 2009. http://www.frymaster.com/. Accessed April 2009.

Food Service Technology Center (FSTC), 2002. *Commercial Kitchen Appliance Assessment Report.* 2002

FSTC, January 2002. Accutemp, Model GGA36 Gas Griddle Performance Test. January 2002

FSTC, August 2004. AGA Food Service Equipment, Model InfinityG2842 Gas Fryer Performance Test. August 2004

FSTC, May 2008. *Eneron, Inc. Prototype Commercial Stock Pot Testing*. May 2008

FSTC, December 2007. *Frymaster 14Kw Protector Electric Fryer Performance Test.* December 2007

FSTC, 1996. *Montague Model SE70AH Gas Convection Oven: Application of ASTM Standard Test Method*. 1996

FSTC, 1998. *Montague Model V136-5 Heave Duty 30,000 Btu/h Open Top Gas Range.* 1998

FSTC, May 2007. *Paloma PF-12SGas Fryer Performance Test*. May 2007

FSTC, March 2003. *Thermal Engineering Corporation Searmaster Model IR2003-S Underfired Broiler Performance Test.* March 2003

Garland, 2009. http://www.garland-group.com. Accessed July 2009.

Keating of Chicago, 2009. http://www.keatingofchicago.com/products/instantrecovery/. Accessed April 2009.

LBNL, 2008. *U.S. Building-Sector Energy Efficiency Potential*. September 2008

NAFEM, 2008. *Size and Shape of the Industry Report – Primary Cooking*. 2008

NCI Appliance Experts – Judy Reich, 2009. Interviewed by Amul Sathe (NCI). Interviewed multiple occasions March 24th – April 10th 2009.

Primaira LCC, 2009. Managing Partner interviewed by Amul Sathe (NCI). Interviewed April 10th 2009.

Star Manufacturing, 2009. http://www.star-mfg.com/. Accessed July 2009.
Blodgett. http://www.blodgett.com/conveyor_ovens.htm. Accessed July 2009.

Texas Gas Grill, 2009. http://www.texasgasgrills.com/Grills.html. Accessed July 2009.

TIAX, 2006. *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers, Dehumidifiers, And Cooking Products, And Commercial Clothes Washers.* 2006

US Department of Energy (US DOE), 2008. "2008 Building Energy Databook". November 2008.

US DOE, 2009. *Technical Support Document: Energy Efficiency Program For Consumer Products And Commercial And Industrial Equipment: Residential Dishwashers, Dehumidifiers, And Cooking Products, And Commercial Clothes Washers.* March 2009.

FOOD PREPARATION (Section 3)

Douglass, J, 2005. *Induction Motor Efficiency Standards*. Washington State University. 2005

EIA, 1992, 1995, 1999, 2003. *Commercial Buildings Energy Consumption Survey (CBECS).* Online Resource: http://www.eia.doe.gov/emeu/cbecs/. 1992, 1995, 1999, 2003

EIA, 1986. *Non-Residential Buildings Energy Consumption Survey (NBECS).* 1986

Hobart, 2009. http://www.hobartcorp.com/. Accessed May 2009.

NAFEM, 2008. *Size and Shape of the Industry Report – Primary Cooking*. 2008

COMMERCIAL DISHWASHERS (Section 4)

ADL, 1995. *Fuel Cells for Building Cogeneration Applications – Cost/Performance Requirements and Markets*. Prepared for the Building Equipment Division, U.S. DOE. January 1995.

Blakeslee, 2009. http://www.blakesleeinc.com/flight.html. Accessed: August 2009.

California Energy Commission (CEC), 2009. *2009 Appliance Efficiency Regulations.* CEC-400-2009-013. August 2009.

Carlisle, 2009. http://catalog.carlislefsp.com/warewashing.html. Accessed August 2009.

Consortium for Energy Efficiency (CEE), 2009. *Cooking-Up a New Approach for Commercial Program Design*. No Publication Date. Retrieved: March 2009.

Consortium for Energy Efficiency (CEE), 2008. *Program Design Guidance: Commercial Dishwashers*. 2008

Dishwashers Direct Ltd., 2009. http://www.prima-services.co.uk/. Accessed: August 2009.

EIA, 1992, 1995, 1999, 2003. *Commercial Buildings Energy Consumption Survey (CBECS).* Online Resource: http://www.eia.doe.gov/emeu/cbecs/. 1992, 1995, 1999, 2003

EIA, 1986. *Non-Residential Buildings Energy Consumption Survey (NBECS).* 1986

EPA, 2990a. *ENERGY STAR® Commercial Food Service Equipment: Sample Procurement Language.* 2009a

EPA, 2006. *ENERGY STAR® for Commercial Dishwashers: Sizing up the Savings Opportunity*. June 14, 2006

EPA, 2009b. *Savings Calculator – ENERGY STAR® Commercial Dishwashers*. 2009b

FSTC, 2009. Dishwasher Experts interviewed by Amul Sathe (NCI). Interviewed on April 9th 2009.

Hobart, 2009. http://www.hobartcorp.com/. Accessed May 2009.

Hobart, 2008. *CL-e Series Dishwasher Instruction Manual.* Available at: www.hobartcorp.com. 2008.

Hobart, 2000. *LX Dishwasher Series Instruction Manual.* Available at: www.hobartcorp.com. 2000.

Hobart, October 2000. *Model AM14 and AM14C Dishwasher Instruction Manual.* Available at: www.hobartcorp.com. October 2000.

Meiko, 2009. http://www.meiko.us/products/products-flight1.htm. Accessed May 2009.

NCI Appliance Experts, 2009. Judith Riech interviewed by Amul Sathe (NCI). Interviewed March 19th - April 9th, 2009.

National Sanitation Foundation (NSF), 2006. *Commcl_Dishwashers_06-04-03.xls* (data on available commercial dishwasher models and efficiencies). Retrieved: March 2007. Published: 2006.

IT AND OFFICE EQUIPMENT (Section 5)

1E, 2009. "PC Energy Report 2009: United States, United Kingdom, Germany". 25 March. Available at http://www.1e.com/energycampaign/index.aspx.

Alliance for Telecommunication Industry Solutions (ATIS), 2009. "ATIS Develops Telecommunications Energy Efficiency Ratio". Press Release. 19 March. Retrieved March 21, 2009 from http://www.atis.org/PRESS/pressreleases2009/031909.htm.

AppleInsider Staff, 2008. "Apple passes Acer to become third largest U.S. PC vendor". *AppleInsider*. 16 July. Retrieved on March 30, 2009 from http://www.appleinsider.com/articles/08/07/16/apple_passes_acer_to_become_third_largest_u_s_pc_vendor.html.

Arthur D. Little, 1993. "Characterization of Commercial Building Appliances." Report for DOE Office of Building Technologies, Building Energy Division. June.

Barry, S., 2008. "Computer Life Cycle Management and Migration". *The Data Administration Newsletter*. 1 June. Retrieved May 9, 2009 from http://www.tdan.com/view-articles/7350.

BlackBerryNews.com, 2008. "Breaking News: RIM Posts Huge Q1 Results". *BlackBerry News*. 25 June. Retrieved May 24, 2009 from http://www.blackberrynews.com/2008/06/25/breaking-news-rim-posts-huge-q1-results/.

Blum, R., 2009. "Server Virtualization". BT IT Industry Survey. 24 March. Available at http://globalservices.bt.com/static/assets/pdf/campaign/bt%20professional%20service%20assets/bt_survey_server_virt_08.pdf.

Business Wire, 2006. "LCD Monitor Market Reaches $35B in 2005; Industry Leaders to Discuss Upward Momentum at DisplaySearch US FPD Conference". *Business Wire*. 30 January. Retrieved on April 20, 2009 from http://findarticles.com/p/articles/mi_m0EIN/is_2006_Jan_30/ai_n26739704/.

Bulkeley, W., 2009. “Xerox Tries to Go Beyond Copiers”. *The Wall Street Journal*. 24 February. Retrieved June 1, 2009 from http://webreprints.djreprints.com/2136610829367.html.

California Energy Commission (CEC), 2008a. “Uninterruptible Power Supplies: A Data Center Efficiency Opportunity”. CEC Technical Brief: CEC-500-2008-065. October. Available at http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2008-065-FS.

California Energy Commission (CEC), 2008b. “DC Power Distribution Cuts Data Center Energy Use”. CEC Technical Brief: CEC-500-2008-042-FS. October. Available at http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2008-042-FS.

Canon, 2003. Untitled Adobe PDF presentation slides. Retrieved April 8, 2009 from http://www.centralcoastis.com/images/pdf/2003%20Market%20Share%20Flyer.pdf.

Canon, 2007. “2006 U.S. Copier Market Share: Monochrome and Color Copier”. Microsoft PowerPoint presentation. Retrieved April 8, 2009 from http://www.betterpublishingwebhosting.net/Canon_2006_Market_Share_Pres.ppt.

Canon, 2008. “2007 U.S. Market Share: Copier / Printer / Fax”. Microsoft PowerPoint presentation. Retrieved April 8, 2009 from http://www.bos-inc.com/Canon_2006_Market_Share_Pres.ppt.

Chan, J., 2007. “Brittle Machines”. *FishTrain*. Retrieved May 9, 2009 from http://fishtrain.com/2007/09/10/brittle-machines/.

Chan, T., 2009. “Inside Google’s Data Centre”. *Green Telecom*. 9 April. Retrieved June 2, 2009 from http://www.greentelecomlive.com/2009/04/09/inside-google%E2%80%99s-data-centre/.

Chetty, M., Bernheim, A. J. B., Meyers, B. R., and Johns, P., 2009. “It’s Not Easy Being Green: Understanding Home Computer Power Management”. Paper presented at *CHI 2009 Conference* in Boston, MA. 4-9, April. Available at http://research.microsoft.com/pubs/79362/chiHomePowerManagementchetty.pdf.

Cisco Systems, Inc. (Cisco), 2003. “Internetworking Technology Handbook”. Available at http://www.cisco.com/en/US/docs/internetworking/technology/handbook/ito_doc.html.

CTIA-The Wireless Association (CTIA), 2009. “Annualized Wireless Industry Survey Results - December 1985 to December 2008”.

Davis, D., 2009. "Routers, Switches & Firewalls – Learn how they are different". *Petri IT Knowledgebase*. 7 January. Available at http://www.petri.co.il/csc_routers_switches_and_firewalls.htm.

Dell, 2006. "Dell™ Color Laser Printers: A Bright Idea for Business Improvement". Available at http://www.dell.com/downloads/global/products/print/Why_Color_Laser_Printer.pdf.

DisplaySearch, 2006. "LCD Monitor Market Reaches $35B in 2005; Industry Leaders to Discuss Upward Momentum at DisplaySearch US FPD Conference". Available via *Business Wire*. 30 January. Retrieved on April 20, 2009 from http://findarticles.com/p/articles/mi_m0EIN/is_2006_Jan_30/ai_n26739704/.

DisplaySearch, 2007. "Worldwide Desktop Monitor Unit Shipments Reach All Time High, Due to Rapid Growth of LCD Monitor Shipments into Chin. Press Release. 6 September. Available at http://www.displaysearch.com/pdf/pr_210.pdf.

DisplaySearch, 2008. "Samsung Ranks #1 for Preliminary Worldwide LCD Monitor Market Share for Q1'08; Dell Grows Stronger in US Retail but Still Drops Share to Samsung". Press Release. 21 May. Retrieved April 20, 2009 from http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/052108_QDM_PR.asp.

DisplaySearch, 2009a. "LCD Monitor Shipments Lower in Q4 than Q3 for the First Time in 2008; DisplaySearch Preliminary Q4'08 Results Reveal 7% Decline". Press Release. 23 February. Retrieved April 4, 2009 from http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/090223_lcd_monitor_shipments_lower_in_q4_than_q3.asp.

DisplaySearch, 2009b. "Increased Outlook for Low Cost All-in-One LCD PCs Not Enough to Lift LCD Desktop Display Market Above 2008 Shipments, But Nettops to Play a Key Role in 2009 Shipments". Press Release. 7 April. Retrieved April 7, 2009 from http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/090407_increased_outlook_for_low_cost_all_in_one_lcd_pcs_not_enough_to_lift_lcd_desktop_display_market.asp.

Dittberner, 2002. "Dittberner Forecasts Worldwide Multiservice WAN Carrier Switch Market to Reach US$18.2 Billion in 2008". Press Release. 18 March. Retrieved May 24, 2009 from http://www.dittberner.com/news/newsrelease2.php.

Dittberner, 2008. "Carrier Router Installed Base Reaches 9 Million Ports". Press Release. 20 March. Retrieved May 29, 2009 from http://www.dittberner.com/news/press_release.php?id=90.

Dixon, D., McNee, S., Tripathi, V., Chae, S. J., and Santos, S., 2008. "Magic Quadrant for MFPs and Printers". Gartner RAS Core Research Note G001632882008. 9 December. Revised 12

December. Retrieved on May 12, 2009 from http://mediaproducts.gartner.com/reprints/xerox/163288.html.

Drew, C., Li, Y., Lam, L., Tripathi, V., Chae, S. J., Yeung, J., Hancock, M., de Silva Leon, F., Santos, S., and Mitani, T., 2008. "Dataquest Insight: Managed Print Services Market Will Show Strong Growth as Enterprises Seek to Cut Costs". Gartner Dataquest Note G00162716. 12 November. Available at http://www.fujixerox.co.jp/solution/gs/pdf/Gartner_Reprint_MPS_Market_Share_2007.pdf.

Ecos Engineering (Ecos), 2008. "Server Research Project: Efficient Power Supplies for Data Center and Enterprise Servers". Available at http://www.etcc-ca.com/index.php?option=com_content&task=view&id=2416.

EPRI, 2008. "TASK 4.0 (CEC-PIER PROJECT): Role of Power Electronics in Achieving Higher Efficiency Levels for Desktop Computers". PowerPoint presentation prepared for the Applied Power Electronics Conference 2008 in Austin, TX. Available at http://www.efficientproducts.org/reports/computers/EfficientComputers_HowLowCanYouGo_APEC2008_Presentation_26Feb08.pdf.

Fan, X., Weber, W., and Barroso, L., 2007. "Power Provisioning for a Warehouse-sized Computer". International Symposium on Computer Architecture, Proceedings of the 34th annual international symposium on Computer architecture. June.

Fisher, K., 2007. "Notebook mania leads to revised PC market projections". *Ars Technica*. 29 June. Retrieved March 30, 2009 from http://arstechnica.com/apple/news/2007/06/notebook-mania-leads-to-revised-pc-market-projections.ars.

Fodale, V., and Scherer, S., 2008. "Green Networking Equipment: Who Leads and Who Lags". In-Stat Insights: IN0804265LS. February. Available for download at http://www.3com.com/gogreen/assets/GreenNetworkingEquipment.pdf.

Franklin, E., 2009. "Samsung LED monitor takes advantage". *The Consumer Electronics Show, 2009*. 8 January. Retrieved May 12, 2009 from http://ces.cnet.com/8301-19167_1-10137941-100.html.

Fuji Xerox, 2008. "Partnering Business for a Sustainable Future". Available for download at http://www.fxap.com.sg/pdf/FujiXeroxEcoBrochure.pdf.

Gartner, 2006. "Gartner Says Lower Prices Drive Worldwide PC Shipments to 11 Percent Growth in Second Quarter of 2006". Press Release. 19 July. Retrieved on April 16, 2009 from http://www.gartner.com/it/page.jsp?id=494199.

Gartner, 2007a. “Gartner Says Hewlett-Packard Takes Clear Lead in Fourth Quarter Worldwide PC Shipments and Creates a Virtual Tie with Dell for 2006 Year-End Results”. Press Release. 17 January. Retrieved on April 16, 2009 from http://www.gartner.com/it/page.jsp?id=500384.

Gartner, 2007b. “Gartner Says Worldwide PC Shipments Increased 9 Percent in First Quarter of 2007”. Press Release. 18 April. Retrieved on April 16, 2009 from http://www.gartner.com/it/page.jsp?id=503816.

Gartner, 2007c. “Gartner Says Worldwide PC Shipments Increased 12 Percent in Second Quarter of 2007”. Press Release. 18 July. Retrieved on April 16, 2009 from http://www.gartner.com/it/page.jsp?id=509905.

Gartner, 2007d. “Gartner Says Asia/Pacific and EMEA Regions Drove Third-Quarter PC Shipments While U.S. Market Experienced Weaker-Than-Expected Results”. Press Release. 17 October. Retrieved on April 16, 2009 from http://www.gartner.com/it/page.jsp?id=532712.

Gartner, 2009. “Gartner Says In the Fourth Quarter of 2008 the PC Industry Suffered Its Worst Shipment Growth Rate Since 2002”. Press Release. 15 January. Retrieved on April 6, 2009 from http://www.gartner.com/it/page.jsp?id=856712.

Global Industry Analyst, 2008. “Office Equipment: A Global Outlook”. 1 September.

Gonsalves, A., 2008. “Server Revenues Down In Tough Economy”. *InformationWeek*. 2 December. Retrieved June 4, 2009 from http://www.informationweek.com/news/hardware/unix_linux/showArticle.jhtml?articleID=212201274&subSection=Windows+Servers.

Gralla, P., 2009. “ENERGY STAR for Servers: Not Nearly Good Enough”. *GreenerComputing.com*. 21 May. Retrieved May 27, 2009 from http://www.greenercomputing.com/blog/2009/05/21/energy-star-servers-not-nearly-good-enough.

Hachman, M., 2007. “CRT Monitors Dying Off As LG, Samsung Mull Exit”. *ExtremeTech*. 10 September. Retrieved April 7, 2009 from http://www.extremetech.com/article2/0,2845,2181410,00.asp.

Hewlett-Packard (HP), 2005. “Questions and Answers About HP Multifunction Products: A Guide for Decision Makers”. HP White Paper: 5982-2914ENUC. February. Available at http://www.lasercare.com/downloads/mfp_planningguide.pdf.

Hewlett-Packard (HP), 2006. “Why HP MFPs?” Microsoft PowerPoint presentation. Retrieved from http://www.techselect.com/root/smbaccessprogram/fy08%20pc/houston/Why%20HP%20MFPs%20vs%201.ppt.

Hewlett-Packard (HP), 2007. “Instant-On Offers Real Business Benefits”. *HP Supplies Connect*. July. Retrieved May 29, 2009 from http://suppliesconnect.com/SC/Issue61_July07.html.

Hewlett-Packard (HP), 2008a. “The HP Instant-On Fusing Technology Advantage vs. Samsung: IPG Competitive Response”. Available at http://www.hewlet-packard.com/sbso/expert/hp-instanton-vs-samsung.pdf.

Hewlett-Packard (HP), 2008b. “HP MFPs Help Organizations Thrive in the Midst of Change: A Strategy Guide for Decision Makers”. HP White Paper: 4AA0 3284ENUC Rev. 4. November. Available for download from http://www.hp.com/sbso/product/mfp/strategy-guide.pdf?jumpid=reg_R1002_USEN.

Horowitz, N., Foster, S., and Calwell, C., 2003. “Laptop Computers: How Much Energy Do They Use and How Much Can We Save?”. Natural Resources Defense Council. August.

Hruska, J., 2008a. “2008 could be the year laptop sales eclipse desktops in US”. *Ars Technica*. 3 January. Retrieved March 30, 2009 from http://arstechnica.com/apple/news/2008/01/2008-could-be-the-year-laptop-sales-eclipse-desktops-in-us.ars.

Hruska, J., 2008b. “Worldwide server shipments up 12 percent in Q2”. *Ars Technica*. 25 August. Retrieved June 4, 2009 from http://arstechnica.com/hardware/news/2008/08/worldwide-server-shipments-up-12-percent-in-q2.ars.

icrontic.com, 2008. “Phantom Power Draw”. *Icrontic*. 19 February. Retrieved May 24, 2009 from http://icrontic.com/articles/phantom_power.

IDC, (2008). “Notebook Shipments Surpass Desktops in the U.S. Market for the First Time, According to IDC”. Press Release. 28 October. Retrieved May 29, 2009 from http://www.idc.com/getdoc.jsp?containerId=prUS21493208.

Intel, (2008). “Accelerated Server Refresh Reduces Data Center Cost”. IT@Intel Brief. 11 June. Available at http://communities.intel.com/docs/DOC-1693.

IUK (Indiana University - Kokomo), 2008. “Desktop Computer Lifecycle Replacement Program”. 10 October. Available at http://www.iuk.edu/~kocser/pdf/Policies/KOIT-01_Desktop_Computer_Lifecycle_Replacement_Program.pdf.

Jade, K., 2009. “Apple’s share of US PC market slips to 8% at hands of Acer”. *AppleInsider*. 14 January. Retrieved on March 30, 2009 from http://www.appleinsider.com/articles/09/01/14/apples_share_of_us_pc_market_slips_to_8_at_hands_of_acer.html.

Kawamoto, K., Koomey, J., Mordman, B., Brown, R., Piette, M.A., Ting, M., and Meier, A., 2001. "Electricity Used by Office Equipment and Network Equipment in the U.S., Detailed Report and Appendices". LBNL Report: LBNL-45917. February.

Koomey, J., 1007. "Estimating Total Power Consumption by Servers in the U.S. and the World". Available at http://hightech.lbl.gov/documents/DATA_CENTERS/svrpwrusecompletefinal.pdf.

Laitner, J., and Ehrhardt-Martinez, K., 2008. "Information and Communication Technologies: The Power of Productivity – How ICT Sectors are Transforming the Economy while Driving Gains in Energy Productivity". ACEEE Report: E081. February.

Lim, D., 2009. "Dell 24-inch G2410 Green monitor gets White LED backlit, cuts 60% power". SlashGear. 26 February. Retrieved May 20, 2009 from http://www.slashgear.com/dell-24-inch-g2410-green-monitor-gets-white-led-backlit-cuts-60-power-2635841/.

LinuexDevices.com, 2004. "Report: PDA market to reach $3 billion by 2009". Retrieved May 9, 2009 from http://www.linuxdevices.com/news/NS4793928893.html.

Loeffer, C., 2009. "Is Your Data Center Ready for Virtualization?: Important Power Considerations for Virtualized IT Environments". Eaton White Paper: WP09-06. Available at http://www.informationweek.com/whitepaper/Hardware/Data-Centers/is-your-data-center-ready-for-virtualization-imp-wp1239922109338

Lyra Research, Inc. (Lyra), 2007. "Enterprises Continue Bias Toward Monochrome While Spending More on Color Devices". *Hard Copy Research Brief*, Vol. 7, Issue 5. 11 May. Available at http://www.lyra.com/FreeResearch.nsf/de37e2107b3103558525701200679b43/95211277c3c83826852572d70067ef4b?OpenDocument.

MacIntosh, J., 2008. "Ricoh in $1.62bn move for Ikon". *Financial Times*. Retrieved June 5, 2009 from http://www.ft.com/cms/s/0/f802ae78-7494-11dd-bc91-0000779fd18c.html.

Malone, C., and Jai, B., 2009. "Insights into Google's PUE Results". Slide presentation given at the Efficient Data Center Summit. 1 April. Available at http://www.google.com/corporate/green/datacenters/summit.html.

Malykhina, E., 2007. "Startups Challenge Cisco By Chipping Away At WLAN Market". *InformationWeek*. Retrieved June 4, 2009 from http://www.informationweek.com/story/showArticle.jhtml?articleID=197700737.

Malley, A., 2008. “Apple snags nearly 10% of US PC market in third quarter”. *AppleInsider*. 14 October. Retrieved on March 30, 2009 from http://www.appleinsider.com/articles/08/10/14/apple_snags_nearly_10_of_us_pc_market_in_third_quarter.html.

Mankikar, M., 2007. “Power-Supply Industry Continues March to Consolidation”. *Power Electronics Technology*. Retrieved May 31, 2009 from http://powerelectronics.com/mag/power_powersupply_industry_continues/.

Marsal, K., 2008. “Apple snags 6.6% share of US PC market in first quarter”. *AppleInsider*. 16 April. Retrieved on March 30, 2009 from http://www.appleinsider.com/articles/08/04/16/apple_snags_6_6_share_of_us_pc_market_in_first_quarter.html.

Marsal, K., and Malley, A., 2009. “Apple's share of U.S. PC market slips to 7.4% as sales decline”. *AppleInsider*. 15 April. Retrieved on April 16, 2009 from http://www.appleinsider.com/articles/09/04/15/apples_share_of_u_s_pc_market_slips_to_7_4_as_sales_decline.html.

Mayo, R., and Ranganathan, P., 2003. “Energy Consumption in Mobile Devices: Why Future Systems Need Requirements-Aware Energy Scale-Down”. HP Laboratories Report: HPL-2003-167. 12 August.

McCafferty, D., 2009. “The Growing Appetite for Virtualization”. *Baseline*. 8 January. Retrieved September 2, 2009 from http://www.baselinemag.com/c/a/Virtualization/The-Growing-Appetite-for-Virtualization/.

Metzler, J, 2008. “Networking: Making LAN Design More Intelligent”. *Systems Management News*. 15 April. Retrieved May 24, 2009 from http://sysmannews.com/SearchResult/31979.

Miller, R., 2008a. “Emerson Withdraws Bid for UK Power Firm”. *DataCenterKnowledge.com*. 4 June. Retrieved May 31, 2009 from http://www.datacenterknowledge.com/archives/2008/06/04/emerson-withdraws-bid-for-uk-power-firm/.

Miller, R., 2008b “Google’s Chiller-less Data Center”. *DataCenterKnowledge.com*. 15 July. Retrieved August 8, 2009 from http://www.datacenterknowledge.com/archives/2009/07/15/googles-chiller-less-data-center/.

Miller, R., 2009. “ENERGY STAR for Servers is Launched”. *DataCenterKnowledge.com*. 19 May. Retrieved June 8, 2009 from http://www.datacenterknowledge.com/archives/2009/05/19/energy-star-for-servers-is-launched/.

Missouri Office of Administration (Missouri), 2004. “Lifecycle Management – Procurement Strategies”. Available at http://oa.mo.gov/itsd/cio/architecture/domains/infrastructure/standards.htm.

Navigant Consulting, Inc. (NCI), 2007. “EIA - Technology Forecast Updates – Residential and Commercial Building Technologies - Reference Case: Second Edition (Revised)”. Presented to DOE Energy Information Agency. 21 September.

Ng, J., 2009. “New ENERGY STAR 5.0 Specs for Computers Become Effective Today”. *DailyTech*. 1 July. Retrieved September 2, 2009 from http://www.dailytech.com/New+Energy+Star+50+Specs+for+Computers+Become+Effective+Today/article15559.htm.

Nortel, 2006. “Nortel Networks Corporation: Annual and Special Meeting of Shareholders”. Slide presentation presented by Mike Zafirovski. 29 June. Available at http://www.nortel.com/corporate/investor/events/agm/collateral/nortel_agm_2006_mike_z.pdf.

Office of Management and Budget (OMB), 1999. “Circular No. A-76.” Revised 1999. Appendix 3. Retrieved May 22, 2009 from http://www.whitehouse.gov/omb/circulars/a076/a076sa3.html.

Paul, L., 2004. “Color Laser Printers: High on the Shopping List”. Available at http://www.triangle-publishing.com/archive/microsoft/MayMarketAnalysis.pdf.

Piette, M. A., Cramer, M., Eto, J., and Koomey, J., 1995. “Office Technology Energy Use and Savings Potential in New York”. Report prepared for NYSERDA and Consolidated Edison: NYSERDA Report 95-10. June. Available at http://www.osti.gov/bridge/servlets/purl/81029-EbmlBw/webviewable/81029.pdf.

Research In Motion Limited (RIM), 2008. “Research In Motion Reports Third Quarter Results”. Press release. 18 December.

Thomson Reuters (Thomson), 2009. " China's Huawei Seeks Most 2008 International Patents”. Retrieved June 1, 2009 from http://www.forbes.com/feeds/afx/2009/01/27/afx5968110.html.

Riso, 2009a. “Power Consumption: The Hidden Costs of Copiers and Printers.” Available at https://us.riso.com/portal/page?_pageid=777,1050899&_dad=portal&_schema=PORTAL.

Riso, 2009b. “RISO Energy Savings Calculator”. Downloadable Microsoft Excel file available at https://us.riso.com/portal/page?_pageid=777,1625740&_dad=portal&_schema=PORTAL.

Roth, K., Goldstein, F., and Kleinman, J., 2002. “Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings – Volume I: Energy Consumption

Baseline". Report for the DOE Office of Building Equipment, Office of Building Technology State and Community Programs. January.

Rutherford, A., 2008. "Catching Up with HP's Vyomesh Joshi, the Ultimate Printer Pundit". *Printer Pundit*, Data Bazaar Blog. 10 April. Retrieved May 12, 2009 from http://blog.databazaar.com/2008/04/catching-up-wit.html.

Sanchez, M., Brown, R., Homan, G., and Webber, C., 2007a. "2008 Status Report: Savings Estimates for the ENERGY STAR® Voluntary Labeling Program". LBNL Report: LBNL-56380 (2008). 28 November.

Sanchez, M., Webber, C., Brown, R., Busch, J, Pinckard, M., and Robertson, J., 2007b. "Space Heaters, Computers, Cell Phone Chargers: How Plugged In Are Commercial Buildings?". LBNL Report: LBNL-62397. February.

Sanchez, M., Webber, C., Brown, R., and Homan, G., 2007c. "2007 Status Report: Savings Estimates for the ENERGY STAR® Voluntary Labeling Program". LBNL Report: LBNL-56380 (2007). 23 March.

Sanchez, M., Brown, R., Homan, G., and Webber, C., 2008. "Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program". LBNL Report: LBNL-329E, June.

Sanchez, M., 2009. Spreadsheet "Office_090317.xls". Prepared for US EPA ENERGY STAR Program.

Shankland, S., 2007. "Server buyers shift toward muscle machines". *CNET News*. 21 March. Retrieved August 15, 2009 from http://news.cnet.com/Server-buyers-shift-toward-muscle-machines/2100-1010_3-6169126.html.

Socolof, M. L., and Dillon, P., 2009. "Electronics Environmental Benefits Calculator – Version 2.0". Microsoft Excel calculator developed for the Federal Electronics Challenge. Available at http://www.federalelectronicschallenge.net/resources/bencalc.htm.

Sustainable Solutions, 2003. "A Study of Office Equipment Operational Energy Use Issues". Report prepared for the Australian Greenhouse Office. February. Available for download at http://www.energyrating.gov.au/library/details200307-officeequipment.html.

Thibodeau, P., 2009. "EPA Unveils New ENERGY STAR Specs for Monitors". *ComputerWorld*. Retrieved June 28, 2009 from http://www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=9132624.

Thomas, J., 2006. "Wal-Mart To Sell Energy Efficient Notebook For Under $500". *Treehugger.com*. 27 October. Retrieved June 8, 2009 from http://www.treehugger.com/files/2006/10/walmart_to_sell_1.php.

Thompson, A., and Strickland, A., 1999. "Strategic Management: Concepts and Cases (11th ed.)". Online cases retrieved May 12, 2009 from http://www.mhhe.com/business/management/thompson/11e/case/dell.html.

Tolly Group, 2008. "Nortel Business Ethernet Switch BES50GE-24T PWR". Tolly Test Summary: Document No. 208271. Available at http://www.tolly.com/DocDetail.aspx?DocNumber=208271.

Tolly Group, 2009. "Nortel Secure Router 4134 vs. Cisco ISR 3845: WAN Performance Analysis and TCO Evaluation for Branch Router Deployment". Tolly Test Report: Document No. 209104. Available at http://www.tolly.com/DocDetail.aspx?DocNumber=209104.

Ton, M., and Fortenbury, B. (2005). "High Performance Buildings: Data Centers: Uninterruptible Power Supplies (UPS)". A report prepared for the Lawrence Berkeley National Laboratory and the California Energy Commission.

Tyson, J., 2001. "How LAN Switches Work". *HowStuffWorks.com*. Retrieved May 22, 2009 from http://computer.howstuffworks.com/lan-switch.htm.

US Bureau of Labor Statistics (US BLS), 2009. "The Employment Situation: April 2009". Economic News Release. Retrieved May 13, 2009 from http://www.bls.gov/news.release/empsit.nr0.htm.

US Census Bureau (US Census), 2000. "Census 2000 EEO Data Tool". Available at http://www.census.gov/eeo2000/.

US Census Bureau (US Census), 2008. "National Population Projections". Downloadable Excel file available at http://www.census.gov/population/www/projections/downloadablefiles.html.

US Department of Energy (US DOE), 2008. "2008 Building Energy Databook". November 2008.

US Energy Information Agency (US EIA), 2003. Commercial Buildings Energy Consumption Survey. Department of Energy, Energy Information Agency.

US Energy Information Agency (US EIA), 2005. Residential Energy Consumption Survey. Department of Energy, Energy Information Agency.

US Environmental Protection Agency (US EPA), 2006. "Draft 2 ENERGY STAR Imaging Equipment Program Requirements (Version 1.0)". Supplemental Rationale for EPA Decisions Informed by Manufacturer-submitted TEC Data. 17 January.

US Environmental Protection Agency (US EPA), 2007. "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431". 2 August. Available at http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency_study.

US Environmental Protection Agency (US EPA), 2008. "Life Cycle Cost Estimate for 20 ENERGY STAR Qualified Multi Function Device(s)". Retrieved May 20, 2009 from http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_MFDs_residential.xls.

US Environmental Protection Agency (US EPA), 2009a. "Life Cycle Cost Estimate for 1 ENERGY STAR Qualified Desktop/Side Computer(s)". Retrieved May 20, 2009 from http://www.energystar.gov/index.cfm?fuseaction=find_a_product.ShowProductGroup&pgw_code=CO.

US Environmental Protection Agency (US EPA), 2009b. "Life Cycle Cost Estimate for 1 ENERGY STAR Qualified Printer(s)". Retrieved May 20, 2009 from http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Printer_Savings_Calculator-Web.xls.

US Environmental Protection Agency (US EPA), 2009c. "Life Cycle Cost Estimate for 1 ENERGY STAR Qualified Monitor(s)". Retrieved May 20, 2009 from http://www.energystar.gov/index.cfm?fuseaction=find_a_product.ShowProductGroup&pgw_code=MO.

US Environmental Protection Agency (US EPA), 2009d. "Life Cycle Cost Estimate for 20 ENERGY STAR Qualified Copier(s)". Available at http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_copiers_bulk.xls.

US Environmental Protection Agency (US EPA), 2009e. "Monitors/Displays for Consumers". Accessed September 2, 2009 at http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=MO.

US Environmental Protection Agency (US EPA), 2009f. "ENERGY STAR® Program Requirements for Computer Servers". Available at http://www.energystar.gov/ia/partners/product_specs/program_reqs/servers_prog_req.pdf.

US Environmental Protection Agency (US EPA), 2009g. "Life Cycle Cost Estimate for 20 ENERGY STAR Qualified Scanner(s)". Retrieved May 20, 2009 from http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_scanners_bulk.xls.

van de Meer, J., 2007. “HP Launches New Green Desktop PC: the RP5700”. *Inhabitat.com*. 6 June. Retrieved June 8, 2009 from http://www.inhabitat.com/2007/06/06/hp-announces-new-green-pc-design/.

VMWare, 2006. “Virtualization Overview”. VMWare Whitepaper. Retrieved May 20, 2009 from http://www.vmware.com/pdf/virtualization.pdf.

Wagner, M. C., 2003. “What PC lifecycle is right for you?”. *ZDNet Tech Update*. Retrieved May 9, 2009 from http://www.techupdate.com/techupdate/stories/main/0,14179,2914624,00.html.

Weilerstein, K., Drew, C., Leon, F. D. S., and Li, Y., 2008. “Magic Quadrant for Managed Print Services Worldwide”. Gartner RAS Core Research Note G00160852. Retrieved May 12, 2009 from http://mediaproducts.gartner.com/reprints/xerox/160852.html.

Wikimedia Common, 2007. “Xerographic photocopy process.jpg”. 2 February. Retrieved April 15, 2009 from http://commons.wikimedia.org/wiki/File:Xerographic_photocopy_process.jpg.

Wikimedia Commons, 2008a. “Standby UPS Diagram.png”. 18 April. Retrieved May 11, 2009 from http://commons.wikimedia.org/wiki/File:Standby_UPS_Diagram.png.

Wikimedia Commons, 2008b. “Line-Interactive UPS Diagram.png”. 18 April. Retrieved May 11, 2009 from http://commons.wikimedia.org/wiki/File:Line-Interactive_UPS_Diagram.png.

WATER HEATERS (Section 6)

ACEEE 2009. "Efficient Water Heating." ACEEE - American Council for an Energy-Efficient Economy. Web. 17 Sept. 2009. <http://www.aceee.org/consumerguide/waterheating.htm>.

ADL 1993. Arthur D. Little. “Characterization of Commercial Building Appliances.” Report for DOE Office of Building Technologies, Building Energy Division. June 1993.
AERS 2009. E-Tech Water Heater Series. Web <http://www.aers.com/WH-Series.html>

AHRI 2009. Monthly Shipment Reports. Air-Conditioning, Heating & Refrigeration Institute, Web. Aug 2009. <www.ahrinet.org>.

Alabama Power 2009. "Desuperheaters." Alabama Power. Web. 17 Sept. 2009. <http://www.alabamapower.com/energy_knowhow/desuperheaters.asp>.

AOSmith 2009. A. O. Smith Water Heaters. Web. Sept. 2009. <http://www.hotwater.com/>.

Appliance 2008. “31st Annual Portrait of U.S. Appliance Industry,” Appliance Magazine, Sept 2008.

American Solar Energy Society (ASES) 2003. “Utility Success Stories in Solar Water Heating,” 2003.

Bradford 2009. Bradford White. Web. Aug 2009. <www.bradfordwhite.com>.

Calaway 2009. Calaway Plumbing. Web. Aug 2009. <www.calawayplumbing.org>.

CBECS 2003. “2003 Commercial Buildings Energy Consumption Survey,” Energy Information Administration. <http://www.eia.doe.gov/emeu/cbecs>.

Dieckmann 2005. Dieckmann, John et al. “Heat-Only, Heat-Activated Heat Pumps.” ASHRAE Journal, January 2005.

DIYTrade 2009. "Heat pump water heater." DIYTrade. Web. 08 Sept. 2009. <http://www.diytrade.com/china/4/products/3020964/heat_pump_water_heater.html>.

DOE 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment,” Department of Energy, April 2000.

DOE 2008. U.S. Department of Energy. "Buildings Energy Data Book." 2008.

EC 2009. “Energy saving products, expert advice and how-to videos.” Energy Circle. Web. 08 Sept. 2009. <http://www.energycircle.com/>.

EcoFinancing 2009. “All About Eco Grants, Funds & Savings .” Eco Financing (UK). Web. 08 Sept. 2009. <http://www.ecofinancing.co.uk>.

EEA 2003. ”National Account Sector Energy Profiles,” Energy and Environmental Analysis Inc. April 2003.

EERE 2009. "Energy Savers: Water Heating." EERE: Energy Savers Home Page. Web. 08 Sept. 2009. <http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12760>.

Energy Concepts 2009. Personal Communication with Don Erikson, President. June 2009.

ENERGY STAR 2009. "Residential Water Heaters." ENERGY STAR. Web. 08 Sept. 2009. <http://www.energystar.gov/index.cfm?c=water_heat.pr_water_heaters>.

EPRI 1992. “Commercial Water Heating Applications Handbook,” Electric Power Research Institute. Dec 1992.

ESC 2009. Energy Solutions Center. Web. Aug 2009. <www.energysolutionscenter.org>.

FEMP 1997. “Commercial Heat Pump Water Heaters.” Federal Energy Management Program. Report. Dec 1997. < http://www1.eere.energy.gov/femp>.

GWB 2009. Geekswithblogs.net. Web. 08 Sept. 2009. <http://geekswithblogs.net/lorint/Default.aspx>.

Homepower 2005. Online Magazine. < http://www.homepower.com>

IEA 2009. “Heat Pump Centre.” Web. Aug 2009. <www.heatpumpcentre.org>.

IEA, 2004. Annex 27 – Selected Issues on CO2 as a Working Fluid in Compression Systems. International Energy Association. Web. <http://www.heatpumpcentre.org/Projects/Annex_27.asp>.

JCWinnie 2009. " Desuperheater ." Jcwinnie.biz. Web. 08 Sept. 2009. <http://jcwinnie.biz/wordpress/?p=1998>.

Jupiter Heating 2009. "A.O. Smith Cyclone XHE Water Heater." Water Heater Distributor. N.p., n.d. Web. June 2009.

Kasukari 2008. “The Newest Situation and the Future View of the CO2 Refrigerant Heat Pump Water Heater “Eco Cute” in Japan.” K. Kusakari, Tokyo Electric Power Company. May 2008

LES 2009. Low Energy Systems Inc. Web. Aug 2009. <www.palomawaterheaters.com>.

Navigant 2007. “Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case Second Edition (Revised),” Navigant Consulting Inc. Sept 2007.

ORNL, 2009. Developed Heat Pump Water Heater." Oak Ridge National Laboratory. Web. July. 2009. <http://www.ornl.gov/sci/btc/apps/hotwater.html>.

PIER 2005. TIAX LLC and EMI. Heat-Pump Water Heaters: Reliable, Efficient. Rep. no. CEC-500-2005-100-FS. 2005. Print. <http://www.energy.ca.gov/2005publications/CEC-500-2005-100/CEC-500-2005-100-FS.PDF>.

Precision 2009. PrecisionTemp. Web. Aug. 2009. <www.precisiontemp.com>.

Rheem 2009. Rheem Manufacturing Co. Web. Aug 2009. <www.rheem.com>.

Robur 2009. Personal Communication with Rick Halbig, Sales and Technical Support. June 2009.

RS MEANS 2007. Residential Cost Data. Tech. 26th ed. Reed Construction Data, 2007. Print.

Takagi 2009. Takagi Industrial Co. Web. Aug 2009. <www.takagi.com>.

ThermaStor 2009. Therma-Stor LLC. Web. 08 Sept. 2009. <http://www.thermastor.com>.

UMD, 2008. N. Fernandez, Y. Hwang, and R. Radermacher. Performance of CO2 Heat Pump Water Heaters. 8th IIR Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen.

UMD 2009. Department of Mechanical of Engineering, University of Maryland. University of Maryland. Web. July 2009. <http://www.enme.umd.edu/facstaff/fac-profiles/radermacher.html>.

UTRC 2007. "Reliable, Economic, Efficient CO2 Heat Pump Water Heaters for North America," United Technologies Research Center. Report. March 2007.

WaterFilm 2009. WaterFilm Energy. Web. Aug 2009. <www.gfxtechnology.com>

WaterFilm Energy 2007. Personal Communication. October 2007.

POOL HEATERS (Section 7)

ADL 1993. Arthur D. Little. "Characterization of Commercial Building Appliances." Report for DOE Office of Building Technologies, Building Energy Division. June 1993.

Aquamatic 2009. *Aquamatic Automatic Swimming Pool Safety Covers*. Web. 02 Sept. 2009. <http://www.aquamatic.com/index.html>.

Census 1991. *Statistical Abstract*. U.S. Bureau of Census, 1991. Web. 2 Sept. 2009. <http://www.census.gov/prod/www/abs/statab1951-1994.htm>.

EERE 2009. "Energy Savers: Sizing a Gas or Heat Pump Swimming Pool Heater." EERE*: Energy Savers Home Page*. Web. 02 Sept. 2009. <http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13190>.

EERE 2009a. "Building Technologies Program: Appliances and Commercial Equipment Standards." *EERE: Building Technologies Program*. Web. 02 Sept. 2009. <http://www1.eere.energy.gov/buildings/appliance_standards/index.html>.

EERE 2009b. "Energy Savers: Swimming Pool Covers." *EERE: Energy Savers Home Page*. Web. 02 Sept. 2009. <http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13140>.

EERE 2009c. "Energy Savers: Heat Pump Swimming Pool Heaters." *EERE: Energy Savers Home Page*. Web. 02 Sept. 2009. <http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13200>.

EERE 2009d. "Energy Savers: Solar Swimming Pool Heaters." *EERE: Energy Savers Home Page*. Web. 02 Sept. 2009. <http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13230>.

EIA 2003. Energy Information Administration. Commercial Buildings Energy Consumption Survey (CBECS). Online Resource: <http://www.eia.doe.gov/emeu/cbecs.> 2003

Lincoln 2009. "Lincoln Aquatics - Heating Systems and Accessories." *Lincoln Aquatics*. Web. 02 Sept. 2009. <http://www.lincolnaquatics.com/shop/catalog/Heating+Systems+and+Accessories/>.

NYC DPR 2009. "Pools" *New York City Department of Parks & Recreation*. Web. 02 Sept. 2009. <http://www.nycgovparks.org/facilities/pools>.

Pool Center 2009. "AUTOMATIC POOL COVER." *Swimming Pool Supplies - Pool Parts, Pool Alarms, Pool Toys and Pool Chemicals!* Web. 02 Sept. 2009. <http://www.poolcenter.com/autocov.htm>.

PoolPak 2009. *PoolPak Technologies Corporation :: Indoor Pool Dehumidification*. Web. 02 Sept. 2009. <http://www.poolpak.com/modules.php?op=modload&name=Custom&file=index&sPage=downloads&sPrefix=main&sCategoryID=39>.

Pool Products 2009. *Swimming Pool Supplies, Cleaners, Filters, Parts, Pumps, Heaters - Specialty Pool Products*. Web. 02 Sept. 2009. <http://poolproducts.com/SPP/dept.asp?dept_id=1546&FNM=90>.

Raypack 2009. "Commercial Heating and Hot Water Products." Raypak: Hydronic Heating, Commercial Water Heating, Swimming Pool Heating; Spa heating, Boilers; Water Heaters. Web. 02 Sept. 2009. <http://www.raypak.com/commframe.htm>.

Raypack 2009a. "Pool & Spa Product Catalog." Raypak. Web. 02 Sept. 2009. <http://www.raypak.com/uploads/A-Heaters.pdf>.

Recreonics 2009. "Raypak Commercial Swimming Pool Heaters." *Recreonics, Inc*. Web. 02 Sept. 2009. <http://www.recreonics.com/fyi/raypak_commercial_heaters.htm>.

Solar Direct 2009. "Commercial Pool Heat Pumps." *Solar Direct*. Web. 02 Sept. 2009. <http://shop.solardirect.com/index.php?cPath=21_35_67>.

SunTrek 2009. "Solar Energy by Suntrek- a Solar Energy Company." *Suntrek Solar Energy*. Web. 02 Sept. 2009. <http://www.suntreksolar.com/solarPoolSystems/gallery/commercialMain.asp>.

LAUNDRY EQUIPMENT (Section 8)

ADC 2009. "ADC Product Literature." Commercial Laundry Equipment for Coin, On-Premise and Industrial Laundries by American Dryer Corp. Web. 07 Sept. 2009. <http://www.amdry.com/products/productliterature/industry_links.asp>.

ADL 1993. Arthur D. Little. “Characterization of Commercial Building Appliances.” Report for DOE Office of Building Technologies, Building Energy Division. June 1993.

AJMadison 2009. "Top Load Coin Operated Washers." AJ Madison. Web. 04 Sept. 2009. <http://www.ajmadison.com/b.php/Top+Load;Coin+Operated;Washers/N~37+4294846358+4294844157>.

AJMadison2009a. “Coin Operated Dryers.” AJ Madison. Web. 04 Sept. 2009. <http://www.ajmadison.com/b.php/Coin+Operated;Dryers/N~39+4294844157>.
Alliance 2009. 2008 Annual Report. Rep. Alliance Laundry Systems, 9 Mar. 2009. Web. 4 Sept. 2009. <http://www.comlaundry.com/Financials/10K_2008.pdf>.

Ashley 1998. Ashley, Steven. “Energy-Efficient Appliances.” Mechanical Engineering, Vol. 120, No. 3. March 1998. pp.94-97.

AWE 2009. Laundries & Dry-Cleaning Operations. Tech. Alliance for Water Efficiency. Web. Aug. 2009. <www.allianceforwaterefficiency.org/uploadedFiles/Resource.../EBMUD_WaterSmart_Guide_Laundries_Dry-Cleaning_Operations.pdf>.

Bansal 2001. Bansal, P.K.; Braun J.E.; and Groll, E.A. “Improving the Energy Efficiency of Conventional Tumbler Clothes Drying Systems.” International Journal of Energy Research, Vol. 25, Jan 2001. pp. 1315-32.

Barber 2009. "Apartments for rent: Barberton." *Apartments for rent Barberton Ohio, near Akron*. Web. 04 Sept. 2009. <http://www.barberknolls.com/picTour.html>.

Braun 2009. "Washer Extractors." Braun. Web. 07 Sept. 2009. <http://www.gabraun.com/equipment.aspx?cat_id=5>.

Braun 2009a. "Batch Tunnel Washers." Braun. Web. 07 Sept. 2009. <http://www.gabraun.com/equipment.aspx?cat_id=2>.

Braun 2009b. “Dryers.” Braun. Web. 07 Sept. 2009. <http://www.gabraun.com/equipment.aspx?cat_id=4>.

CARB 2006. “California Dry Cleaning Industry Technical Assessment Report.” California Air Resources Board. Feb. 2006. <http://www.arb.ca.gov/toxics/dryclean/finaldrycleantechreport.pdf>.

CEE 2006. “Potential for an Energy-Efficient Residential Clothes Dryer.” Consortium for Energy Efficiency. Presentation. 17 Jan. 2006. <http://www.cee1.org/cee/mtg/01-07ppt/eaton2.pdf>.

CEE 2009. Commercial Clothes Washers Fact Sheet. Tech. Consortium for Energy Efficiency, 2007. Web. 4 Sept. 2009. <http://www.cee1.org/resrc/facts/cwsh-fx.pdf>.

Century 2009. "Manuals." Century Laundry- Coin Laundry equipment, parts and stores for sale serving the coin laundry business. Web. 07 Sept. 2009. <http://www.centurylaundry.net/manuals_MENU.htm>.

CLA 2009. "Coin Laundry Industry Overview." Coin Laundry Association. Web. 04 Sept. 2009. <http://www.coinlaundry.org/resources/industryoverview.cfm>.

CUWCC 2009. A Report on Potential Best Management Practices. Rep. California Urban Water Conservation Council, Jan. 2006. Web. 4 Sept. 2009. <http://www.cuwcc.org/uploads/tech_docs/PBMP_Report_Year_2_On-Premise_Laundry_Facilities_2006.pdf>.

DCC 2009. “Dryclean equipment, sales, service.” DryClean Concepts, Inc. Web. 07 Sept. 2009. <http://www.drycleanconceptsinc.com/>.

DOE 2008. Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dishwashers, Dehumidifiers, Cooking Products, and Commercial Clothes Washers. U.S. Department of Energy, Sept. 2008. Web. 4 Sept. 2009. <http://www1.eere.energy.gov/buildings/appliance_standards/residential/cooking_products_final_rule_tsd.html>.

EPA 1995. “Profile of the Dry Cleaning Industry.” U.S. Environmental Protection Agency. September 1995. <http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/dry.html>.

EPA 1997. Technical Development Document for Proposed Pretreatment Standards for Existing and New Sources for the Industrial Laundries Point Source Category. Rep. EPA, Nov. 1997. Web. 4 Sept. 2009. <http://www.epa.gov/guide/laundry/ilpdd_a.pdf>.

EPACT 2005. Energy Policy Act of 2005, 42 USC 15801 (2005). Print.

Freedonia 2008. Freedonia Focus on Commercial & Industrial Laundry Machinery. Rep. Freedonia Group, August 2008. Print.

GE 2004. Energy Efficient Laundry Process. Report. GE Global Research, Dec. 2004.

GE 2009. "GE Commercial Laundry Home Page." GE Appliances. Web. 07 Sept. 2009. <http://www.geappliances.com/commercial_laundry/>.

Girbau 2009. "TBS-50 Batch Washer." Girbau. Web. 07 Sept. 2009. <http://www.laundryequipment.girbau.com/products/TBS-50-Batch-Washer/GranInstTunelTBS>.

IPSO 2009. “On Premises Laundry Equipment." IPSO Coin Laundry and Commercial On Premises Laundry Equipment. Web. 07 Sept. 2009. <http://www.ipso.com/opl/product.asp>.

Jensen 2009. Senking Continuous Batch Washer Universal MediLine. Jensen. Web. 7 Sept. 2009. <http://www.botved.com/public/Jensen%20Brochure%20PDF/Universal_MediLine.pdf>.

LBNL 2009. “Technical Note: Heat Pump Clothes Dryers.” Lawrence Berkeley National Laboratory. Report. 18 February 2009.

Miele 2009. “T 8627 WP EcoComfort Heat Pump Dryer.” Miele. Web. 07. Sept. 2009. <http://www.miele.com.au/media/haushalt/VG_AUS/T_8627_WP_information.pdf>.

Milnor 2009. " Dryers." Pellerin Milnor Corporation. Web. 07 Sept. 2009. <http://www.milnor.com/category.asp?retid=156&categoryID=3>.

Navigant 2008. “Commercial Laundry Technology Market Review.” Presentation for Southern California Gas. Navigant Consulting Inc. 28 July 2008.

Nelson 2009. "Coin-Operated Laundry: Laundromats for Sale by Nelson & Small, Inc." Wholesale Appliances, Heating, Hot Water, Commercial Laundry. Web. 04 Sept. 2009. <http://www.nelsonsmall.com/comm_laundry/for_sale.asp?id=32>.

Parrisianne 2009. “Dry cleaning machine.” Parrisianne Dry Cleaning Solutions. Web. 07 Sept. 2009. <http://www.parrisianne.com/>.

Primus 2009. "Primus Laundry - Washer extractors MB180." Commercial laundry equipment and industrial machines - commercial washers and coin op laundries by Primus Laundry. Web. 07 Sept. 2009. <http://www.primuslaundry.com/product-detail.aspx?lang=EN&swf=products&cat=1&branch=1&serie=1&id=148>.

Quality 2009. "Quality Services Ltd." Web. 04 Sept. 2009.
<http://qslgroup.com/eng/projects_details.php?id=6>.

Rototherm 2009. “Rototherm.” Rototherm Corporation. Web. 11 Nov. 2009.
<http:// http://rototherm.net/index1.html>.

SDGE 2008. “SDG&E/SoCalGas Appliance Efficiency Efforts.” Appliance Efficiency Standards Workshop. California Energy Commission. Presentation. 15 January 2008.

Sinsheimer 2004. Sinsheimer, Peter, and Cyrus Grout. Evaluating Energy Efficiency in the Garment Care Industry: A Comparison of Five Garment Care Technologies. Rep. UEPI Papers, 2004. Print.

SuperLaundry 2009. Super Laundry. Web. 01 Aug. 2009.
<http://www.superlaundry.com/Pictures-of-Installations.html>.

T&L 2009. "New Equipment." T&L Equipment Sales. Web. 07 Sept. 2009.
<http://www.delcinetworks.com/t&l/summer_sale.htm>.

Terheggen 2009. Terheggen, Daniel. Letter to US Department of Energy. 5 Apr. 2006. Appliances and Commercial Equipment Standards. Multi-Housing Laundry Association. Web. 4 Sept. 2009.
http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/ca_petition_comments/28_mhla.pdf

TIAX 2005. “High Efficiency, High Performance Clothes Dryer.” TIAX LLC. Report. 31 March 2005.

UEPI 2009. "Garment Care." UEPI. Web. 07 Sept. 2009.
<http://departments.oxy.edu/uepi/ppc/projects.htm>.

USAID 2009. “USAID NetMark Long Lasting Insecticide Treated Mosquito Nets Production Process.” USAID. Report. Nd.

USDC 2008. “Company Fact Sheet.” US Dry Cleaning Corporation. Web. May 2008.
<http://usdrycleaning.com/pdf/USDCFactSheet_05-14-08.pdf>.

Village 2009. Village Cleaners, Cary & Holly Springs Quality Dry Cleaner. Web. 04 Sept. 2009.
<http://www.villagecleanersnc.com/>.

MISCELLANEOUS EQUIPMENT (Section 9)

ABA, 2007. American Bankers Association. "ATM Fact Sheet." 2007 ABA Issue Summary (2007).

ACEEE, 2009. Sachs, Harvey M. Opportunities for Elevator Energy Efficiency Improvements. Tech. Washington, DC: American Council for an Energy-Efficienct Economy, 2005. <http://www.aceee.org/buildings/coml_equp/elevators.pdf>.

ADL, 2002. Roth, Kurt W., Fred Goldstein, and Jonathan Kleinman. Energy Consumption by Office and Telecommunications Equipment in Commercial Building. Rep. no. No. 72895-00. Energy Consumption. Baseline ed. Vol. 1. Department of Energy, 2002.

ADL, 1993. "Characterization of Commercial Building Appliances." Report for DOE Office of Building Technologies, Building Energy Division. June.

Automatic Merchandiser, 2007. State of the Vending Industry Report. Rep. 2007. Automatic Merchandiser. <http://www.amonline.com/content/reports/files/0808_SVI_report.pdf>.

BEA, 2009. "Gross Domestic Product." U.S. Bureau of Economic Analysis. June 2009 <http://www.bea.gov>.

Buildings Energy Data Book, 2008. National Energy Technology Laboratory. 2008 Buildings Energy Data Book. Tech. U.S. Department of Energy, 2008.

Database for Energy Efficient Resources. California Public Utilities Commission, 2008. Web. <http://deeresources.com/>.

EIA, 2003. US Energy Information Agency (US EIA), 2003. Commercial Buildings Energy Consumption Survey. Department of Energy, Energy Information Agency.

EIA, 2009. Electric Power Monthly, March 2009. <http://www.eia.doe.gov/cneaf/electricity/epm/matrix96_2000.html>.

EMSD, 2007. "Code of Practice for Energy Efficiency of Lift and Escaltor Installations." 2007. Electrical and Mechanical Services Department. <http://www.emsd.gov.hk/emsd/e_download/pee/lift_esccop_2007.pdf>.

Federal Register, 2009. Energy Conservation Program: Test Procedures for Small Electric Motors; Final Rule, July 7, 2009; <http://www1.eere.energy.gov/buildings/appliance_standards/notices_rules.html>

GE Healthcare, 2009. Personal communication with Joe Smith and Michael Dajersky. June 2009.

GE, 2009. "Product Technology -Xray - Education - Digital X-ray." GE Healthcare. 06 July 2009 <http://www.gehealthcare.com/usen/xr/edu/products/introdigdettech.html>.

HSW, 2009. HowStuffWorks. Web. Elevators, Escalators, and Medical Equipment. June 2009 < http://www.howstuffworks.com>.

KONE, 2009. Elevators, Escalators, Automatic Building Doors, Maintenance, Modernization. June 2009 <http://www.kone.com/countries/en_US/sustainability/ecoefficentdemo/Pages/default.aspx>.

Korbel Associates, 2009. Personal Communications with Dave Sawchuk. May 2009.

LBNL 2004. Roberson, Judy A., Carrie A. Webber, Marla C. McWhinney, Richard E. Brown, Margaret J. Pinckard, John F. Busch. 2004. After-hours Power Status of Office Equipment and Inventory of Miscellaneous Plug-Load Equipment. LBNL-53729, January. Lawrence Berkeley National Lab, Berkeley CA. Retrieved April 2009; <http://enduse.lbl.gov/Projects/OffEqpt.html>.

LBNL 2006. Nordman, Bruce, and Marla Sanchez. Electronics Come of Age: A Taxonomy for Miscellaneous and Low Power Products. Rep. Lawrence Berkeley National Laboratory, 2006. Retrieved April 2009: <http://eetd.lbl.gov/ea/nordman/docs/taxonomy.pdf>.

Lehman Brothers, 2008 NCR Corporation Profile, May 2008.

Magnetek Elevator, 2007. "Elevator Drives: Past, Present, and Future." NAVTP Annual Forum. Atlanta, Georgia. 3 May 2007. Lecture.

NAMA, 2009. National Automatic Merchandising Association. Personal communication with Brian Allen and information from various manufacturers. April 2009.

Otis, 2009. Personal communication with Han Jong Kim. May 2009.

Power Efficiency Corporation, 2009. Electric Motor Energy Saving and Motor Efficiency Controller for AC Induction Motor. May 2009 <http://www.powerefficiencycorp.com/technical_documentation.php>.

TIAX, 2006. Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030. Tech. no. D0366. 2006. Retrieved April 2009: <http://wpui.wisc.edu/news/EIA%20Posts/TIAX_EIA_MiscElecReport.pdf>.

Vending Times Census of the Industry. Rep. 2008 ed.

RECOMMENDATIONS– Kitchen (Section 0)

CEE. *Commercial Kitchens Program Summary.* November 2008

Equipoise Consulting Inc. *Final Report for Energy Efficiency in Commercial Food Service.* CPUC 2002-2003 Local Program 113-02. 2004

RECOMMENDATIONS– Water Heaters (Section 0)

ASHRAE, 2009 press release. "ASHRAE, DOE Partner to Improve Energy Efficiency." http://www.ashrae.org/pressroom/detail/16399, accessed July 26, 2009.

ASHRAE, 2005. Dieckmann, John; Bob Zogg, Detlef Westphalen, Kurt Roth, and James Brodrick; Heat-Only, Heat-Activated Heat Pumps; Emerging Technologies Column; ASHRAE Journal; January 2005.

EEA, 2003. National Account Sector Energy Profiles, Energy and Environmental Analysis, Inc. (Energy Nexus Group), April 2003)

H.R. 6, 2007. 110 Cong., <http://thomas.loc.gov/cgi-bin/query/z?c110:H.R.6.enr:> (enacted).

IEA, 2008. *Annex 34 – Thermally Driven Heat Pumps for Heating and Cooling*. International Energy Association. Web. <http://www.heatpumpcentre.org/Projects/Annex_34.asp>.

IEA, 2004. *Annex 27 – Selected Issues on CO2 as a Working Fluid in Compression Systems*. International Energy Association. Web. <http://www.heatpumpcentre.org/Projects/Annex_27.asp>.

JARN, 2009. "Eco Cute Market Continues to Grow." (2009). June 2009. JARN Web Magazine. <http://www.ejarn.jp/Type_news_inside1.asp?id=11820&classid=9]>.

"ORNL, 2009. Developed Heat Pump Water Heater." *Oak Ridge National Laboratory*. Web. July. 2009. <http://www.ornl.gov/sci/btc/apps/hotwater.html>.

Rocky Research, 2008."HVAC&R Solutions—Aqua-Ammonia Absorption Technology." Rocky Research Home. Web. July 2009. <http://rockyresearch.com/technology/technology_hvacr_aquaammonia.html>

UMD, 2009. *Department of Mechanical of Engineering, University of Maryland*. University of Maryland. Web. July 2009. <http://www.enme.umd.edu/facstaff/fac-profiles/radermacher.html>.

UMD, 2008. N. Fernandez, Y. Hwang, and R. Radermacher. *Performance of CO2 Heat Pump Water Heaters*. 8th IIR Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen.

UTRC, 2007. Radcliff, Thomas D. *Reliable, Economic, Efficient CO2 Heat Pump Water Heaters for North America*. Rep. no. DE-FC26-03NT41953. East Hartford: United Technologies Research Center.

RECOMMENDATIONS– Commercial Laundry (Section 0)

GE 2004. Energy Efficient Laundry Process. Report. GE Global Research, Dec. 2004.

RECOMMENDATIONS – Miscellaneous Equipment (Section 0)

Federal Register, 2009. Energy Conservation Program: Test Procedures for Small Electric Motors; Final Rule, July 7, 2009; <http://www1.eere.energy.gov/buildings/appliance_standards/notices_rules.html>

Appendix A Primary Cooking

A.1 Cooking Efficiency

Primary cooking appliances are rated by their cooking efficiency. Current efficiency ratings are measured during a simulated heavy-load cooking event, it do not currently account for energy used to preheat or idle energy consumption.

$$n_{cooking} = \frac{E_{food}}{E_{appliance}}$$

Where:

$n_{cooking}$ = Cooking efficiency
$E_{appliance}$ = Energy input to the cooking appliance
E_{food} = energy supplied to food

Energy supplied to food can be calculated knowing the start and end temperature of the food being cooked, its weight, and its specific heat.

ASTM establishes the test standards used to determine cooking energy efficiency. The tests require cooking a set weight of foods (such as 10 lbs of potatoes or 100 frozen hamburger patties) to certain temperature while recording the energy input to the appliance ($E_{appliance}$). Knowing the amount and type of food allows testers to calculate the amount of energy needed to cook the food to its final state (E_{food}).

A.2 Appliance Shipments

Table A-1: Population Ratio between the US and North America

	Population	Source
US Population	303,824,640	2008 CIA World Fact Book
North America Population	528,720,588	2008 CIA World Fact Book
Population Ratio	57%	Calculation

Table A-2: NAFEM Estimated North America Shipments and NCI Adjustments

	NAFEM Data		NCI Estimates	
	2008 Estimated Shipments[a]	Reported Overseas sales	North America Shipments[b]	US Shipments[c]
Broilers	15,182	12%	13,360	7,677
Fryers	129,349	14%	111,240	63,923
Griddles	19,581	9%	17,819	10,239
Ovens Excluding Microwaves	346,780	unreported	318,768	183,177
Ovens Including Microwaves	*549,460*	*11%*	*489,019*	*281,011*
Microwaves	*202,680*	*16%*	*170,251*	*97,833*
Ranges	83,192	6%	78,200	44,937
Steamers	33,483	5%	31,809	18,279

a) Source: NAFEM Size and Shape of the Industry: Primary Cooking. 2008.
b) 2008 Estimated Shipments x Reported Overseas sales. (except for "Ovens excluding microwaves")
c) North America Shipments x Population Ratio

A.3 Installed Base Calculations

Table A-3: NCI Estimated Total Installed Base by Appliance Type

Appliance Type	Sector:	Equipment Class	Saturation[a]	Building Stock[b]	Ownership[c]	Total Installed Base[d]
Broiler	Commercial	Overfired	9%	277,866	1.3	32,510
		Salamander	8.20%	277,866	1.2	27,342
		Underfired/Charbroilers	16%	277,866	1.2	53,350
	Institutional	Overfired	13%	100,727	2.12	27,760
		Salamander	13.40%	100,727	2.03	27,400
		Conveyor	2.30%	100,727	1.63	3,776
		Underfired/Charbroilers	14.60%	100,727	1.92	28,236
	Total	**Total Broilers**				**200,374**
Fryers	Commercial	Pressure	12.40%	277,866	2.2	75,802
		Floor Mounted	52%	277,866	2.3	332,967
		Countertop	30.80%	277,866	1.7	145,491
	Institutional	Pressure	4.80%	100,727	2.97	14,360
		Floor Mounted	74%	100,727	6.51	485,242
		Countertop	25.90%	100,727	2.38	62,090
		Continuous	1.30%	100,727	1.8	2,357
	Total	**Total Fryers**				**1,118,309**

Appliance Type	Sector:	Equipment Class	Saturation[a]	Building Stock[b]	Ownership[c]	Total Installed Based[d]
Griddles	Commercial	Griddles & Grills	61.70%	277,866	1.4	240,021
		Sandwich Grills	6.75%	277,866	1.4	26,258
	Institutional	Griddles & Grills	65.60%	100,727	3.75	213,694
		Hotdog Grills	14.00%	100,727	2.44	34,408
		Sandwich Grills	13.50%	100,727	2.73	37,123
	Total	**Total Griddles**				**551,504**
Ovens	Commercial	Deck	27.80%	277,866	1.9	146,769
		Convection (1/2)	12.10%	277,866	1.2	40,346
		Convection (Full)	31.80%	277,866	1.6	141,378
		Combination	4.70%	277,866	1.6	20,896
		Rotary Rack	2.10%	277,866	1.1	6,419
		Rotary	1.80%	277,866	1.1	5,502
		Cook & Hold	14.50%	277,866	1.6	64,465
		Conveyor	3.90%	277,866	1.4	15,171
		Dough Proofer	11.20%	277,866	1.2	37,345
	Institutional	Deck	52.30%	100,727	6.91	364,020
		Convection (1/2 + Full + Combi)	86.60%	100,727	10.51	916,783
		Rotary	18.20%	100,727	2.29	41,981
		Cook & Hold	11%	100,727	2.25	24,930
		Conveyor (Compact)	1.00%	100,727	1.86	1,874
		Conveyor (Full Size)	2.20%	100,727	2	4,432
	Total	**Total Ovens**				**1,832,311**
Ranges	Commercial	Light Duty	17.40%	277,866	1.2	58,018
		Heavy Duty	35.60%	277,866	1.6	158,272
	Institutional	Light Duty	12.60%	100,727	7.24	91,887
		Heavy Duty	75.60%	100,727	6.75	514,010
	Total	**Total Ranges**				**822,187**
Steamers	Commercial	Atmospheric	7.20%	277,866	1.5	30,010
		Low Pressure	7.10%	277,866	1.2	23,674
		High Pressure	6.60%	277,866	1.5	27,509
	Institutional	Conv. (Pressureless)	16.10%	100,727	2.78	45,083
		Conv. (Pressureless)	31.20%	100,727	4.06	127,593
		Low Pressure	23.70%	100,727	5.84	139,414
		High Pressure	40.50%	100,727	4.84	197,445
	Total	**Total Steamers**				**590,728**

a) Source: ADL 1993
b) Source: Table 2-19
c) Source: ADL 1993
d) Saturation x Building Stock x Ownership

Table A-4: Installed base by Fuel Type

Appliance Type	Total	Percentage[a]		Installed Base	
		Gas	Electric	Gas	Electric
Broiler	200,374	91%	9%	182,340	18,034
Fryers	1,118,309	58%	42%	648,619	469,690
Griddles	551,504	50%	50%	275,752	275,752
Ovens	1,832,311	55%	45%	1,007,771	824,540
Ranges	822,187	91%	9%	748,190	73,997
Steamers	590,728	33%	67%	194,940	395,788

a) Source: ADL 1993

Table A-5: 2008 Number of Buildings with Cooking as an End Use

Building Type	Number of Buildings with Cooking as an End Use		
	1983[a]	2003[b]	2008[c]
Restaurant	186,000	284,000	313,000
Hotel	38,000	47,000	49,600
Hospital	12,000	12,000	12,000
School	67,000	125,000	142,000
Grocery	45,000	84,000	95,500
Retail	73,000	Not reported	84,500[d]
Office	20,000	23,000	23,900

a) Source: Table 41 of 1986 NBECS
b) Source: Table B33 of 2003 CBECS (EIA 2003)
c) Calculation: Linear projection using 1986 and 1993 data
d) This value is not reported in CBECS 2003, we estimate it to grow at the same rate as commercial floorspace (see Figure 2-24)

A.4 Cooking Appliances by Building Type

The distribution of cooking appliances by building type uses an updated ADL model. The ADL model determines the distribution using total number of buildings with cooking as an end use and an estimate of the relative ownership of each appliance type in each building type.

- The number of buildings with cooking as an end use is projected to 2008 using CBECS 2003 and NBECS 1986 (the data set used by ADL).
- Relative ownership was estimated by ADL. It assumes, for example, that the average restaurant will have two fryers compared to the average school having one fryer. We use these same assumptions.
- The relative installations are determined multiplying the number of buildings by the relative ownership.

- Finally, the distribution of appliances is estimated by normalizing the values calculated for relative installations.

Table A-6: Appliance Distribution by Building Type

Building Type	Number of Buildings	Relative Ownership[a]	Relative Installations[b]	Distribution of Appliances[c]
Broilers				
Restaurant	312,824	1.0	312,824	58%
Hotel	49,647	1.0	49,647	9%
Hospital	12,000	1.0	12,000	2%
School	142,059	0.5	71,029	13%
Grocery	95,471	0.0	0	0%
Retail	84,518	1.0	84,518	16%
Office	23,882	0.5	11,941	2%
Fryers				
Restaurant	312,824	2.0	625,647	54%
Hotel	49,647	2.0	99,294	9%
Hospital	12,000	1.0	12,000	1%
School	142,059	1.0	142,059	12%
Grocery	95,471	1.0	95,471	8%
Retail	84,518	2.0	169,035	14%
Office	23,882	1.0	23,882	2%
Griddle				
Restaurant	312,824	1.0	312,824	50%
Hotel	49,647	1.0	49,647	8%
Hospital	12,000	1.0	12,000	2%
School	142,059	1.0	142,059	23%
Grocery	95,471	0.0	0	0%
Retail	84,518	1.0	84,518	14%
Office	23,882	1.0	23,882	4%
Ovens				
Restaurant	312,824	1.0	312,824	50%
Hotel	49,647	1.0	49,647	8%
Hospital	12,000	1.0	12,000	2%
School	142,059	1.0	142,059	23%
Grocery	95,471	0.0	0	0%
Retail	84,518	1.0	84,518	14%
Office	23,882	1.0	23,882	4%

Building Type	Number of Buildings	Relative Ownership[a]	Relative Installations[b]	Distribution of Appliances[c]
Ranges				
Restaurant	312,824	1.0	312,824	40%
Hotel	49,647	2.0	99,294	13%
Hospital	12,000	2.0	24,000	3%
School	142,059	1.0	142,059	18%
Grocery	95,471	1.0	95,471	12%
Retail	84,518	1.0	84,518	11%
Office	23,882	1.0	23,882	3%
Steamers				
Restaurant	312,824	1.0	312,824	46%
Hotel	49,647	2.0	99,294	15%
Hospital	12,000	1.0	12,000	2%
School	142,059	1.0	142,059	21%
Grocery	95,471	0.0	0	0%
Retail	84,518	1.0	84,518	13%
Office	23,882	1.0	23,882	4%

a) Indicator of the relative number of the appliance type among the seven building types. Source: ADL,1993.

b) Calculated: Number of Buildings x Relative Ownership

c) Calculated: Normalize the Relative Installations to a percentage scale.

Table A-7: Restaurant Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory[a]	Operating Hrs./yr.[b]	Utilization Factor[c]	Rated Capacity (Btu/hr)[d]	Rated Capacity (kW)[e]	US Annual Electricity Consumption (kWh)[f]	US Annual Primary Energy Consumption (Btu)[g]
Broilers	Gas	105,248	2496	0.8	90,000			1.89E+13
	Electric	10,409	3120	0.7	45,000	13	3.00E+08	3.12E+12
Fryers	Gas	347,619	3744	0.2	100,000			2.60E+13
	Electric	251,724	3744	0.2	40,000	12	2.21E+09	2.30E+13
Griddles	Gas	138,034	3744	0.34	60,000			1.05E+13
	Electric	138,034	3744	0.25	41,429	12	1.57E+09	1.63E+13
Ovens	Gas	312,246	2496	0.5	85,000			3.31E+13
	Electric	255,474	2496	0.35	50,000	15	3.27E+09	3.40E+13
Ranges	Gas	299,281	3744	0.2	160,000			3.59E+13
	Electric	29,599	3744	0.25	56,000	16	4.55E+08	4.73E+12
Steamer	Gas	90,400	4368	0.15	210,000			1.24E+13
	Electric	183,540	4368	0.15	90,000	26	3.17E+09	3.30E+13
Total	**Gas**							**1.37E+14**
Total	**Electric**						**1.10E+10**	**1.14E+14**
Total	**All**							**2.51E+14**

a) Source: Table 2-22
b) Source: Table 2-23
c) Source: Table 2-25
d) Source: Table 2-24
e) Converted from Btu/hr to KW using 3,413 Btu/KWh
f) 2008 Inventory x Operating Hrs/yr x Utilization Factor x Rated Capacity (KW)
g) Gas appliance: 2008 Inventory x Operating Hrs/yr x Utilization Factor x Rated Capacity (Btu/hr).
Electric Appliance: US Annual Electricity Consumption x 10,405 Btu/kwh

Table A-8: Office Building Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory[a]	Operating Hrs./yr.[b]	Utilization Factor[c]	Rated Capacity (Btu/hr)[d]	Rated Capacity (kW)[e]	US Annual Electricity Consumption (kWh)[f]	US Annual Primary Energy Consumption (Btu)[g]
Broilers	Gas	4,018	1260	0.8	90,000			3.64E+11
	Electric	397	1260	0.7	45,000	13	4.62E+06	4.81E+10
Fryers	Gas	13,269	1260	0.2	100,000			3.34E+11
	Electric	9,609	1260	0.2	40,000	12	2.84E+07	2.95E+11
Griddles	Gas	10,538	1260	0.34	60,000			2.71E+11
	Electric	10,538	1260	0.25	41,429	12	4.03E+07	4.19E+11
Ovens	Gas	47,677	1260	0.5	85,000			2.55E+12
	Electric	39,008	1260	0.35	50,000	15	2.52E+08	2.62E+12
Ranges	Gas	22,848	1260	0.2	160,000			9.21E+11
	Electric	2,260	1260	0.25	56,000	16	1.17E+07	1.22E+11
Steamer	Gas	6,902	1260	0.15	210,000			2.74E+11
	Electric	14,012	1260	0.15	90,000	26	6.98E+07	7.27E+11
Total	**Gas**							**4.72E+12**
Total	**Electric**						**4.07E+08**	**4.23E+12**
Total	**All**							**8.95E+12**

a) Source: Table 2-22
b) Source: ADL 1993
c) Source: Table 2-25
d) Source: Table 2-24
e) Converted from Btu/hr to KW using 3,413 Btu/KWh
f) 2008 Inventory x Operating Hrs/yr x Utilization Factor x Rated Capacity (KW)
g) Gas appliance: 2008 Inventory x Operating Hrs/yr x Utilization Factor x Rated Capacity (Btu/hr).
Electric Appliance: US Annual Electricity Consumption x 10405 Btu/kwh

Table A-9: Retail Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory	Operating Hrs./yr.	Utilization Factor	Rated Capacity (Btu/hr)	Rated Capacity (kW)	US Annual Electricity Consumption (kWh)	US Annual Primary Energy Consumption (Btu)
Broilers	Gas	28,436	3650	0.8	90,000			7.47E+12
	Electric	2,812	3650	0.7	45,000	13	9.47E+07	9.86E+11
Fryers	Gas	93,919	3650	0.2	100,000			6.86E+12
	Electric	68,010	3650	0.2	40,000	12	5.82E+08	6.05E+12
Griddles	Gas	37,294	3650	0.34	60,000			2.78E+12
	Electric	37,294	3650	0.25	41,429	12	4.13E+08	4.30E+12
Ovens	Gas	84,362	2920	0.5	85,000			1.05E+13
	Electric	69,023	2920	0.35	50,000	15	1.03E+09	1.08E+13
Ranges	Gas	80,859	4015	0.2	160,000			1.04E+13
	Electric	7,997	4015	0.25	56,000	16	1.32E+08	1.37E+12
Steamer	Gas	24,424	3650	0.15	210,000			2.81E+12
	Electric	49,588	2190	0.15	90,000	26	4.30E+08	4.47E+12
Total	**Gas**							**4.08E+13**
Total	**Electric**						**2.68E+09**	**2.79E+13**

Note: See sources and notes from Table A-8

Table A-10: Grocery Store Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory	Operating Hrs./yr.	Utilization Factor	Rated Capacity (Btu/hr)	Rated Capacity (kW)	US Annual Electricity Consumption (kWh)	US Annual Primary Energy Consumption (Btu)
Broilers	Gas	0	0	0.8	90,000			0.00E+00
	Electric	0	0	0.7	45,000	13	0.00E+00	0.00E+00
Fryers	Gas	53,045	3508	0.2	100,000			3.72E+12
	Electric	38,412	3508	0.2	40,000	12	3.16E+08	3.29E+12
Griddles	Gas	0	0	0.34	60,000			0.00E+00
	Electric	0	0	0.25	41,429	12	0.00E+00	0.00E+00
Ovens	Gas	95,294	3508	0.5	85,000			1.42E+13
	Electric	77,968	3508	0.35	50,000	15	1.40E+09	1.46E+13
Ranges	Gas	91,337	6570	0.2	160,000			1.92E+13
	Electric	9,033	6570	0.25	56,000	16	2.43E+08	2.53E+12
Steamer	Gas	0	0	0.15	210,000			0.00E+00
	Electric	0	0	0.15	90,000	26	0.00E+00	0.00E+00
Total	**Gas**							**3.71E+13**
Total	**Electric**						**1.96E+09**	**2.04E+13**
Total	**All**							**5.75E+13**

Note: See sources and notes from Table A-8

Table A-11: School Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory[a]	Operating Hrs./yr.[b]	Utilization Factor[c]	Rated Capacity (Btu/hr)[d]	Rated Capacity (kW)[e]	US Annual Electricity Consumption (kWh)[f]	US Annual Primary Energy Consumption (Btu)[g]
Broilers	Gas	23,898	540	0.8	90,000			9.29E+11
	Electric	2,364	540	0.7	45,000	13	1.18E+07	1.23E+11
Fryers	Gas	78,930	540	0.2	100,000			8.52E+11
	Electric	57,156	540	0.2	40,000	12	7.23E+07	7.53E+11
Griddles	Gas	62,684	540	0.34	60,000			6.91E+11
	Electric	62,684	540	0.25	41,429	12	1.03E+08	1.07E+12
Ovens	Gas	283,593	540	0.5	85,000			6.51E+12
	Electric	232,031	540	0.35	50,000	15	6.42E+08	6.68E+12
Ranges	Gas	135,909	540	0.2	160,000			2.35E+12
	Electric	13,442	540	0.25	56,000	16	2.98E+07	3.10E+11
Steamer	Gas	41,052	540	0.15	210,000			6.98E+11
	Electric	83,349	540	0.15	90,000	26	1.78E+08	1.85E+12
Total	**Gas**							**1.20E+13**
Total	**Electric**						**1.04E+09**	**1.08E+13**
Total	**All**							**2.28E+13**

Note: See sources and notes from Table A-8

Table A-12: Hotel Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory[a]	Operating Hrs./yr.[b]	Utilization Factor[c]	Rated Capacity (Btu/hr)[d]	Rated Capacity (kW)[e]	US Annual Electricity Consumption (kWh)[f]	US Annual Primary Energy Consumption (Btu)[g]
Broilers	Gas	16,704	2496	0.8	90,000			3.00E+12
	Electric	1,652	3120	0.7	45,000	13	4.76E+07	4.95E+11
Fryers	Gas	55,169	3744	0.2	100,000			4.13E+12
	Electric	39,950	3744	0.2	40,000	12	3.51E+08	3.65E+12
Griddles	Gas	21,907	3744	0.34	60,000			1.67E+12
	Electric	21,907	3744	0.25	41,429	12	2.49E+08	2.59E+12
Ovens	Gas	148,666	2496	0.5	85,000			1.58E+13
	Electric	121,636	2496	0.35	50,000	15	1.56E+09	1.62E+13
Ranges	Gas	94,995	3744	0.2	160,000			1.14E+13
	Electric	9,395	3744	0.25	56,000	16	1.44E+08	1.50E+12
Steamer	Gas	28,694	4368	0.15	210,000			3.95E+12
	Electric	58,258	4368	0.15	90,000	26	1.01E+09	1.05E+13
Total	**Gas**							**3.99E+13**
Total	**Electric**						**3.35E+09**	**3.49E+13**
Total	**All**							**7.48E+13**

Note: See sources and notes from Table A-7

Table A-13: Hospital Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory[a]	Operating Hrs./yr.[b]	Utilization Factor[c]	Rated Capacity (Btu/hr)[d]	Rated Capacity (kW)[e]	US Annual Electricity Consumption (kWh)[f]	US Annual Primary Energy Consumption (Btu)[g]
Broilers	Gas	4,037	3650	0.8	90,000			1.06E+12
	Electric	399	3650	0.7	45,000	13	1.35E+07	1.40E+11
Fryers	Gas	6,667	2190	0.2	100,000			2.92E+11
	Electric	4,828	2190	0.2	40,000	12	2.48E+07	2.58E+11
Griddles	Gas	5,295	3650	0.34	60,000			3.94E+11
	Electric	5,295	3650	0.25	41,429	12	5.86E+07	6.10E+11
Ovens	Gas	35,934	3650	0.5	85,000			5.57E+12
	Electric	29,400	3650	0.35	50,000	15	5.50E+08	5.73E+12
Ranges	Gas	22,961	4380	0.2	160,000			3.22E+12
	Electric	2,271	4380	0.25	56,000	16	4.08E+07	4.25E+11
Steamer	Gas	3,468	3650	0.15	210,000			3.99E+11
	Electric	7,041	3650	0.15	90,000	26	1.02E+08	1.06E+12
Total	**Gas**							**1.09E+13**
Total	**Electric**						**7.90E+08**	**8.22E+12**
Total	**All**							**1.92E+13**

Note: See sources and notes from Table A-8

Table A-14: Total Non-Microwave Cooking Appliance Energy Consumption

Cooking Equipment	Fuel	2008 Inventory[a]	Operating Hrs./yr.	Utilization Factor	Rated Capacity (Btu/hr)	Rated Capacity (kW)	US Annual Electricity Consumption (kWh)[a]	US Annual Primary Energy Consumption (Btu)[a]
Broilers	Gas	182,340		0.8	90,000			3.17E+13
	Electric	18,034		0.7	45,000	13	4.72E+08	4.91E+12
Fryers	Gas	648,619		0.2	100,000			4.22E+13
	Electric	469,690		0.2	40,000	12	3.58E+09	3.73E+13
Griddles	Gas	275,752		0.34	60,000			1.63E+13
	Electric	275,752		0.25	41,429	12	2.43E+09	2.53E+13
Ovens	Gas	1,007,771		0.5	85,000			8.82E+13
	Electric	824,540		0.35	50,000	15	8.71E+09	9.06E+13
Ranges	Gas	748,190		0.2	160,000			8.33E+13
	Electric	73,997		0.25	56,000	16	1.06E+09	1.10E+13
Steamer	Gas	194,940		0.15	210,000			2.06E+13
	Electric	395,788		0.15	90,000	26	4.96E+09	5.16E+13
Total	**Gas**							**2.82E+14**
Total	**Electric**						**2.12E+10**	**2.21E+14**
Total	**All**							**5.03E+14**

a) Summation from Table A-7 to Table A-13

A.5 Energy Efficiency Technologies Savings Calculations

Table A-15: Infrared Gas Broiler

	Value	Source
Baseline Efficiency	30%	FSTC 2002
Replacement Efficiency	40%	FSTC March 2003
Calculated Energy Savings	25%	Calculated

Table A-16: Infrared Gas Range

	Value	Source
Baseline Efficiency	40%	FSTC 2002
Replacement Efficiency	66%	FSTC 2002
Calculated Energy Savings	25%	Calculated

Table A-17: Power Burner Gas Fryer

	Value	Source
Baseline Efficiency	35%	FSTC 2002
Replacement Efficiency	51%	FSTC August 2004
Calculated Energy Savings	31%	Calculated

Table A-18: Pulse Combustion Gas Fryer

	Value	Source
Baseline Annual Energy Consumption (KBtu)	74,900	FSTC 2002
Replacement Annual Energy Consumption (KBtu)	52,044	FSTC May 2007
Calculated Energy Savings	31%	Calculated

Table A-19: Appliance Insulation in Gas and Electric Fryers

	Value	Source
Baseline Annual Energy Consumption (Wh/day)	46.62	EPA 2009
Idle Energy Consumption (Wh/day)	13.61	EPA 2009
Idle Energy Savings from Appliance Insulation	25%	FSTC 2002
Energy Savings from Insulation (Wh/day)	3.4	Calculated
Percent Energy Savings from Insulation	7%	Calculated

Table A-20: Gas Heat Pipe Griddle

	Value	Source
Baseline Efficiency	45%	FSTC 2002
Replacement Efficiency	47%	FSTC January 2002
Calculated Energy Savings	4.3%	Calculated

Table A-21: Electric Induction Griddle

	Value	Source
Baseline Efficiency	75%	FSTC 2002
Replacement Efficiency	80%	FSTC 2002
Calculated Energy Savings	6.3%	Calculated

Table A-22: Broiler Idle Energy Reduction

	Value	Source
Baseline Average Hourly Energy Consumption (KBtu/hr)	112	FSTC 2002
Replacement Average Hourly Energy Consumption (KBtu/hr)	83.2	FSTC 2002
Calculated Energy Savings	26%	Calculated

Table A-23: Stock Pot Heat Transfer Fins

	Value	Source
Baseline Energy Rate (Btu/hr)	11,180	FSTC May 2008
Replacement Energy Rate (Btu/hr)	8,080	FSTC 2008
Single Burner Energy Savings	27%	Calculated
Estimated Percent of Range top cooking performed by stockpots	16%	NCI Estimate (1 out of 6 burners)
Calculated Range Energy Savings	4.5%	Calculated

Test measures the burner energy rate required to hold water at temperature of 204°F

Appendix B Food Preparation

Table B-1: High Efficiency Motor Standards and Energy Savings

Enclosure Type	Motor Speed (RPM)	Motor Power (Hp)	NEMAEPACT - Current Energy Efficiency Level	NEMA Premium - New Energy Efficiency level	Estimated Energy Savings[a]
Open Drip Proof	3600	1.5	82.5	84	1.8%
Open Drip Proof	3600	2	84	85.5	1.8%
Open Drip Proof	3600	3	84	85.5	1.8%
Open Drip Proof	3600	5	85.5	86.5	1.2%
Open Drip Proof	3600	7.5	87.5	88.5	1.1%
Open Drip Proof	1800	1	82.5	85.5	3.5%
Open Drip Proof	1800	1.5	84	86.5	2.9%
Open Drip Proof	1800	2	84	86.5	2.9%
Open Drip Proof	1800	3	86.5	89.5	3.4%
Open Drip Proof	1800	5	87.5	89.5	2.2%
Open Drip Proof	1800	7.5	88.5	91	2.7%
Open Drip Proof	1200	1	80	82.5	3.0%
Open Drip Proof	1200	1.5	84	86.5	2.9%
Open Drip Proof	1200	2	85.5	87.5	2.3%
Open Drip Proof	1200	3	86.5	88.5	2.3%
Open Drip Proof	1200	5	87.5	89.5	2.2%
Open Drip Proof	1200	7.5	88.5	90.2	1.9%
Total Enclosed Fan Cooled	3600	1	75.5	77	1.9%
Total Enclosed Fan Cooled	3600	1.5	82.5	84	1.8%
Total Enclosed Fan Cooled	3600	2	84	85.5	1.8%
Total Enclosed Fan Cooled	3600	3	85.5	86.5	1.2%
Total Enclosed Fan Cooled	3600	5	87.5	88.5	1.1%
Total Enclosed Fan Cooled	3600	7.5	88.5	89.5	1.1%
Total Enclosed Fan Cooled	1800	1	82.5	85.5	3.5%
Total Enclosed Fan Cooled	1800	1.5	84	86.5	2.9%
Total Enclosed Fan Cooled	1800	2	84	86.5	2.9%
Total Enclosed Fan Cooled	1800	3	87.5	89.5	2.2%
Total Enclosed Fan Cooled	1800	5	87.5	89.5	2.2%
Total Enclosed Fan Cooled	1800	7.5	89.5	91.7	2.4%
Total Enclosed Fan Cooled	1200	1	80	82.5	3.0%
Total Enclosed Fan Cooled	1200	1.5	85.5	87.5	2.3%
Total Enclosed Fan Cooled	1200	2	86.5	88.5	2.3%
Total Enclosed Fan Cooled	1200	3	87.5	89.5	2.2%
Total Enclosed Fan Cooled	1200	5	87.5	89.5	2.2%
Total Enclosed Fan Cooled	1200	7.5	89.5	91	1.6%
Average					**2.2%**

Source: Douglass 2005

a) Energy Savings = 1-NEMAEPACT/(NEMA Premium)

Appendix C Commercial Dishwashers

The following pages document the unit energy consumption and annual energy consumption of the various dishwasher types included in this report.

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Table C-1: Calculated Component Energy Consumption and Unit Energy Consumption of Dishwashers, 2008

				Unit Energy Consumption (Site Energy)					
Type	**Wash Temperature**	**Building Water Heater Fuel**	**Booster Heater Fuel**	**Machine Electricity Consumption (kWh/yr)**	**Booster Gas Consumption (mmBtu/yr)**	**Booster Electric Consumption (kWh/yr)**	**Building Water Heater Gas Consumption (mmBtu/yr)**	**Building Water Heater Electricity Consumption (kWh/yr)**	**Total Primary Energy Consumption (mmBtu/yr)[c]**
Undercounter[a]	Low	Gas	none	830			43.2		52
	Low	Electric	none	830				9,330	106
	High	Gas	Gas	2,325	21.9		43.9		90
	High	Gas	Electric	2,325		5,414	43.9		124
	High	Electric	Gas	2,325	21.9			9,474	145
	High	Electric	Electric	2,325		5,414		9,474	179
Conveyor[a]	Low	Gas	none	3,974			145.4		187
	Low	Electric	none	3,974				31,389	368
	High	Gas	Gas	13,248	66.8		133.6		338
	High	Gas	Electric	13,248		16,478	133.6		443
	High	Electric	Gas	13,248	66.8			28,837	505
	High	Electric	Electric	13,248		16,478		28,837	609
Door-Type[a]	Low	Gas	none	455			153.1		158
	Low	Electric	none	455				33,047	349
	High	Gas	Gas	2,394	59.6		119.1		204
	High	Gas	Electric	2,394		14,699	119.1		297
	High	Electric	Gas	2,394	59.6			25,723	352
	High	Electric	Electric	2,394		14,699		25,723	446
Flight-Type[b]	Low	Gas	none	6,359			232.6		299
	Low	Electric	none	6,359				50,222	589
	High	Gas	Gas	21,197	106.9		213.7		541
	High	Gas	Electric	21,197		26,365	213.7		709
	High	Electric	Gas	21,197	106.9			46,139	807
	High	Electric	Electric	21,197		26,365		46,139	975

a) Calculated using ENERGY STAR® Calculator (EPA 2009b) outputs
b) Estimated by scaling energy consumption of conveyor dishwashers using scaling factor or 1.6 (Table 4-14)
c) Site to Source conversion factor: 10,405 Btu/kWh

Table C-2: Calculated National Energy Consumption of Dishwashers by Component, 2008

				National Baseline Energy Consumption (site energy)[a]				
Type	**Wash Temperature**	**Building Water Heater Fuel**	**Booster Heater Fuel**	**Machine Electricity Consumption (kWh/yr)**	**Booster Gas Consumption (mmBtu/yr)**	**Booster Electric Consumption (kWh/yr)**	**Building Water Heater Gas Consumption (mmBtu/yr)**	**Building Water Heater Electricity Consumption (kWh/yr)**
Undercounter[a]	Low	Gas	none	2.36E+07			1.23E+06	
	Low	Electric	none	1.01E+07				1.14E+08
	High	Gas	Gas	1.42E+06	1.34E+04		2.68E+04	
	High	Gas	Electric	2.69E+07		6.27E+07	5.08E+05	
	High	Electric	Gas	6.07E+05	5.73E+03			2.48E+06
	High	Electric	Electric	1.15E+07		2.69E+07		4.70E+07
Conveyor[a]	Low	Gas	none	4.37E+08			1.60E+07	
	Low	Electric	none	1.87E+08				1.48E+09
	High	Gas	Gas	7.29E+07	3.68E+05		7.35E+05	
	High	Gas	Electric	1.39E+09		1.72E+09	1.40E+07	
	High	Electric	Gas	3.12E+07	1.58E+05			6.80E+07
	High	Electric	Electric	5.94E+08		7.38E+08		1.29E+09
Door-Type[a]	Low	Gas	none	1.94E+07			6.53E+06	
	Low	Electric	none	8.32E+06				6.04E+08
	High	Gas	Gas	2.19E+06	5.45E+04		1.09E+05	
	High	Gas	Electric	4.16E+07		2.55E+08	2.07E+06	
	High	Electric	Gas	9.38E+05	2.33E+04			1.01E+07
	High	Electric	Electric	1.78E+07		1.09E+08		1.92E+08
Flight-Type[b]	Low	Gas	none	0.00E+00				
	Low	Electric	none	0.00E+00				
	High	Gas	Gas	1.79E+07	9.05E+04		1.81E+05	
	High	Gas	Electric	3.41E+08		4.24E+08	3.44E+06	
	High	Electric	Gas	7.69E+06	3.88E+04			1.67E+07
	High	Electric	Electric	1.46E+08		1.82E+08		3.18E+08

a) Calculated by multiplying Unit Energy Consumption (Table C-1) by Installed Base (Table 4-11)

Appendix D IT and Office Equipment

D.1 Usage Pattern Calculation PCs, Monitors, MFDs and Inkjet Printers

Unit energy consumption for PCs, desktop monitors, MFDs and inkjet printers are calculated based on the different power draw numbers depending on their modes of operation: Active mode, where the equipment is fully functional and is ready to respond to the user's request; Low mode, where the equipment's power management (PM) feature is activated; and Off mode, where the equipment is turned off but still plugged in. Sanchez (2009) estimates the average usage pattern for computers by first determining the usage pattern under four scenarios:

- **Power Managed, Turned Off (PM/Off)**: Under this scenario, the equipment's PM feature is successfully enabled, and is turned off after business hours.
- **Power Managed, Left On (PM/On)**: Under this scenario, the equipment's PM feature is successfully enabled, but is left on after the business hours through the night and the weekend.
- **Not Power Managed, Turned Off (No PM/Off)**: Under this scenario, the equipment's PM feature is not enabled, but is turned off after business hours.
- **Not Power Managed, Left On (No PM/On):** Under this scenario, the equipment's PM feature is not enabled, and is left on after the business hours through the night and the weekend.

Sanchez then takes the weighted average of these four scenarios based on the PM enabling rate and the turn-off rate associated with the each equipment.

We followed Sanchez's methodology to determine the average usage patterns. Table D-1 and Table D-2 summarize the assumptions behind our usage pattern derivation.

Table D-1: PM Enabling Rate and Turn-Off Rate Assumptions

Equipment Type	PM Enabling %	Turn-Off %	Source
Desktop PCs	6%	32%	Sanchez, et. al. (2008) for Enabling %, Sanchez, et. al. (2007b) for Turn-Off %
Laptop PCs	75%	100%	NCI estimate based Kawamoto, et. al. (2001) and Horowitz, et. al. (2003)[a]
CRT Monitors	71%	32%	Sanchez, et. al. (2007b)
LCD Monitors	75%	18%	Sanchez, et. al. (2007b)
MFDs	100%	19%	US EPA (2008)
Inkjet Printers	N/A	30%	US EPA (2009c)[b]

a. Kawamoto, et. al. (2001) estimates that all laptop computers are PM-enabled. Horowitz, et. al. (2003) suggests a more conservative estimate of 50%. We have taken the average of the two studies. We assumed that Laptop PCs in commercial buildings are unplugged at night.

b. Inkjet printers typically do not have power management mode, since it does not require significant amount of energy to warm up. We are considering only the two scenarios with PM enabled in taking the weighted average of inkjet printer usage patterns.

Table D-2: PM/Off Usages Patterns

Equipment Type	Usage Pattern (hr/yr) by Operational Mode			Source
	Active	Low	Off	
Desktop PCs	803	1,104	6,854	US EPA (2009a)
Laptop PCs	803	1,104	6,854	NCI estimate[a]
CRT Monitors	803	1,104	6,854	US EPA (2009b)
LCD Monitors				
MFDs	1,314	1,971	5,475	NCI estimate[b]
Inkjet Printers	3,285	0	5,475	US EPA (2009c)[c]

a. We assumed that Laptop PC usage pattern is the same as desktop PC usage pattern in the case where both have enabled their PM and are turned off at night.

b. US EPA (2008) suggests that a typical MFD would be turned off for 18 hours per day on average if it is turned off every night. If this is true, a typical MFD would be turned off for 126 hours per week including the weekend, or (126 – 24 × 2 =) 78 hours per week during weekdays, or (78 ÷ 5 =) 15.6 hours per day during weekdays. On the other hand, a similar derivation for inkjet printers based on US EPA (2009c) suggests that a typical inkjet printer is turned off for 11.4 hours per day during weekdays. In this study, we assumed that a typical MFD would undergo similar usage as a typical office printer, and based our off-mode hour/year figure on average printer usage pattern provided by US EPA (2009c), and distribute the remaining hours/year according to Riso (2009b).

c. Inkjet printers typically do not have power management mode, since it does not require significant amount of energy to warm up.

To derive usage pattern for PM/On scenario (see Table D-3), we assumed that all of the hours spent in the Off mode in PM/Off scenario would be spent on the Low mode in PM/On scenario. We made an exception for Inkjet Printers, which typically does not have a power-saving mode of operation, and added the hour spent in the Off mode to Active hours for PM/On scenario. Similarly, we assumed that all of the hours spent in Low mode in PM/Off scenario (see Table D-4) would be spent on the Active mode in No PM/Off scenario. Finally, we assumed that all devices, by definition, would spend 8,760 hours per year in the Active mode in No PM/On scenario (see Table D-5).

Table D-3: PM/On Usages Patterns

Equipment Type	Usage Pattern (hr/yr) by Operational Mode			Source
	Active	Low	Off	
Desktop PCs	803	7,957	0	NCI estimate
Laptop PCs				
CRT Monitors				
LCD Monitors				
MFDs	1,314	7,446	0	
Inkjet Printers	8,760	0	0	

Table D-4: No PM/Off Usages Patterns

Equipment Type	Usage Pattern (hr/yr) by Operational Mode			Source
	Active	Low	Off	
Desktop PCs	1,906	0	6,854	NCI estimate
Laptop PCs				
CRT Monitors				
LCD Monitors				
MFDs	3,285	0	5,475	
Inkjet Printers	N/A	N/A	N/A	

Table D-5: No PM/On Usage Patterns

Equipment Type	Usage Pattern (hr/yr) by Operational Mode			Source
	Active	Low	Off	
Desktop PCs	8,760	0	0	NCI estimate
Laptop PCs				
CRT Monitors				
LCD Monitors				
MFDs				
Inkjet Printers	N/A	N/A	N/A	

Based on the data presented in Table D-1 through Table D-5, Table D-6 presents the average typical usage patterns for PCs, desktop monitors, MFDs and inkjet printers we have used in this study.

Table D-6: Average Typical Usage Patterns

Equipment Type	Usage Pattern (hr/yr) by Operational Mode			Source
	Active	Low	Off	
Desktop PCs	6,221	346	2,193	Weighted average based on Table D-1 through Table D-5
Laptop PCs	1,078	828	6,854	
CRT Monitors	2,474	4,093	2,193	
LCD Monitors	2,483	5,043	1,234	
MFDs	1,314	6,406	1,040	
Inkjet Printers	7,118	0	1,643	

D.2 Segregation of PC Installed Base between Desktops and Laptops

To determine the relative distribution of desktop and laptop PCs in commercial buildings, we estimated the market share of desktop and laptop computers by total shipment volume in the US between 2005 and 2008[23]. Table D-7 presents the summary of the shipment breakdown between 2005 and 2007.

Table D-7: Annual PC Shipment Volume in the US, Desktops vs. Laptops, 2005 through 2007

Year	Annual Shipment (1,000s)		Source
	Desktop	Laptop	
2007	35,000	31,600	IDC estimate cited by Hruska (2008)
2006	36,458	26,116	NCI estimate based on Hruska (2008)[a]
2005	36,097	20,339	NCI estimate based on Hruska (2008) and Fisher (2007)[b]

a. Annual shipment of desktop PCs recorded -4% growth between 2006 and 2007, while the laptop shipment recorded 21% growth, according to Hruska (2008).

b. Annual shipment of desktop PCs recorded 1% growth between 2005 and 2006, while the laptop shipment recorded 28.4% growth, according to Fisher (2007).

Although similar data was not publicly available for 2008, IDC (2008) reports that laptop PCs captured 55.2% market share in the US by shipment volume in the third quarter of 2008, the first time the laptop PCs surpassed 50% share in the US. Based on this information, we assumed that the market share of laptop PCs by annual shipment volume was 50% in 2008. Table D-8 presents the desktop and laptop PC market share estimate from 2005 through 2008.

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[23] US EPA (2009a) estimates that the average EUL of a PC is four years.

Table D-8: Market Share of Desktop and Laptop PCs by Shipment Volume, 2005 through 2008

Year	Desktop	Laptop	Source
2005	64%	36%	Based on Table D-7
2006	58%	42%	
2007	53%	47%	
2008	50%	50%	NCI estimate based on IDC (2008)

Given Gartner's market share data and quarterly shipment data, we estimated the total number of desktop and laptop PCs shipped to the US market between 2005 and 2008 (see Table D-9).

Table D-9: US PC Market Share of Desktop and Laptop PCs by shipment volume between 2005 and 2008

	Desktop	Laptop	Source
Market Share by Shipment Volume	56%	44%	NCI estimate based on Table D-7 and Gartner data[a]

a. As cited by Gartner (2007a), Gartner (2007b), Gartner (2007c), Gartner (2007d), Marsal (2008), AppleInsider (2008), Malley (2008), Jade (2009), Gartner (2009) and Marsal, et. al. (2009).

Assuming the EUL of four years, we applied this ratio to estimate to segregate desktop and laptop installed bases from the total PC installed base in the US commercial buildings.

D.3 Energy Efficiency Potential Calculation for Desktop and Laptop PCs

Table D-10 presents UEC calculation for an average desktop PC unit that qualifies for ENERGY STAR 4.0.

Table D-10: UEC Calculation for a Typical New Desktop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	62	3.1	1.6	Sanchez (2009)
Average Usage Pattern (hr/yr)	6,221	346	2,193	See Table D-6
Average UEC by Mode (kWh/yr)	384	1.1	3.6	
Total Average UEC, (kWh/yr)	**388.5**			

Table D-11 presents UEC calculation for an average desktop PC unit that qualifies for ENERGY STAR 5.0.

Table D-11: UEC Calculation for ENERGY STAR 5.0-Qualifying Desktop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	46	2.0	1.0	Sanchez (2009)
Average Usage Pattern (hr/yr)	6,221	346	2,193	See Table D-6
Average UEC by Mode (kWh/yr)	286	0.7	2.2	
Total Average UEC, (kWh/yr)	**289.0**			

Table D-12 and Table D-13 respectively present power draw data of EPRI's "Market-Ready" computer and "Ultimate Efficiency" computer, provided by EPRI (2008).

Table D-12: UEC Calculation for EPRI "Market-Ready" Desktop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	30	2.5	1.3	EPRI (2008)
Average Usage Pattern (hr/yr)	6,221	346	2,193	See Table D-6
Average UEC by Mode (kWh/yr)	187	0.9	2.9	
Total Average UEC, (kWh/yr)	**190**			

Table D-13: UEC Calculation for EPRI "Ultimate Efficiency" Desktop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	19	2.6	1.9	EPRI (2008)
Average Usage Pattern (hr/yr)	6,221	346	2,193	See Table D-6
Average UEC by Mode (kWh/yr)	118.2	0.9	4.2	
Total Average UEC, (kWh/yr)	**123**			

Table D-14 presents lower bound UEC calculation for EPRI's "Ultimate Efficiency" desktop PCs, assuming the unit's PM feature is enabled and the unit is turned off at night and during weekends.

Table D-14: Lower Bound UEC Calculation for EPRI "Ultimate Efficiency" Desktop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	19	2.6	1.9	EPRI (2008)
Average Usage Pattern (hr/yr)	803	1,104	6,854	See Table D-6
Average UEC by Mode (kWh/yr)	15.2	2.9	13.0	
Total Average UEC, (kWh/yr)	**31.1**			

Table D-15 presents UEC calculation for an average laptop PC unit that qualifies for ENERGY STAR 4.0.

Table D-15: UEC Calculation for a Typical New Laptop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	19	1.5	1.0	Sanchez (2009)
Average Usage Pattern (hr/yr)	1,078	828	6,854	See Table D-6
Average UEC by Mode (kWh/yr)	20.2	1.3	6.5	
Total Average UEC, (kWh/yr)	**28.0**			

Table D-16 presents UEC calculation for an average laptop PC unit that qualifies for ENERGY STAR 5.0.

Table D-16: UEC Calculation for ENERGY STAR 5.0-Qualifying Laptop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	14	1.4	0.8	Sanchez (2009)
Average Usage Pattern (hr/yr)	1,078	828	6,854	See Table D-6
Average UEC by Mode (kWh/yr)	15.2	1.2	5.6	
Total Average UEC, (kWh/yr)	**22.1**			

Table D-17 presents lower bound UEC calculation for an average laptop PC unit that qualify for ENERGY STAR 5.0, assuming the unit's PM feature is enabled and the unit is turned off at night and during weekends.

Table D-17: Lower Bound UEC Calculation for ENERGY STAR 5.0-Qualifying Laptop PC Unit

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	14	1.4	0.8	Ecos (2008)
Average Usage Pattern (hr/yr)	803	1,104	6,854	See Table D-6
Average UEC by Mode (kWh/yr)	11.3	1.6	5.6	
Total Average UEC, (kWh/yr)	**18.6**			

Table D-18 and Table D-19 present technical AEC savings potential for desktop and laptop PCs, respectively, based on the data summarized in Table 5-47 and Table 5-48.

Table D-18: Laptop PC Technical AEC Savings Potential

Data	Efficiency Design Improvement	100% penetration of PM	Source
UEC Savings (kWh/yr)	5.9	3.5	See Table 5-47
Installed Base (1,000s)	47,619		See Table 5-3
Technical AEC Savings Potential (TWh/yr)	0.28	0.17	
Technical AEC Savings Potential (TBtu/yr)	**2.9**	**1.7**	

Table D-19: Desktop PC Technical AEC Savings Potential

Data	Efficiency Design Improvement	100% penetration of PM	Source
UEC Savings (kWh/yr)	265	92.1	See Table 5-48
Installed Base (1,000s)	60,381		See Table 5-3
Technical AEC Savings Potential (TWh/yr)	16.0	5.56	
Technical AEC Savings Potential (TBtu/yr)	**167**	**57.9**	

D.4 Energy Efficiency Potential Calculation for Desktop LCD Monitors

Table D-20 presents UEC calculation for an average desktop LCD monitor that is available in the market today.

Table D-20: UEC Calculation for a Typical New Desktop LCD Monitor

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	30.7	0.7	0.7	Sanchez (2009)
Average Usage Pattern (hr/yr)	2,483	5,043	1,234	See Table D-6
Average UEC by Mode (kWh/yr)	76.2	3.7	0.9	
Total Average UEC, (kWh/yr)	**80.8**			

Table D-21 presents UEC calculation for an average desktop LCD monitor that qualifies for ENERGY STAR 5.0.

Table D-21: UEC Calculation for ENERGY STAR 5.0-Qualifying Desktop LCD Monitor

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	25.2	0.7	0.6	Sanchez (2009)
Average Usage Pattern (hr/yr)	2,483	5,043	1,234	See Table D-6
Average UEC by Mode (kWh/yr)	62.6	3.7	0.7	
Total Average UEC, (kWh/yr)	**67.1**			

Table D-22 presents UEC calculation for an average ENERGY STAR 5.0-qualifying desktop LCD monitor with LED backlighting. Lim (2009) reports that LED backlighting could reduce active state power consumption of an LCD monitor by 60%.

Table D-22: UEC Calculation for ENERGY STAR 5.0-Qualifying Desktop LCD Monitor with LED Backlighting

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	12.6	0.7	0.6	NCI estimate based on Lim (2009)
Average Usage Pattern (hr/yr)	2,483	5,043	1,234	See Table D-6
Average UEC by Mode (kWh/yr)	31.4	3.7	0.7	
Total Average UEC, (kWh/yr)	**35.8**			

Table D-23 presents lower bound UEC calculation for an average ENERGY STAR 5.0 desktop LCD monitor with LED backlighting, assuming the unit's PM feature is enabled and the unit is turned off at night and during weekends.

Table D-23: Lower Bound UEC Calculation for ENERGY STAR 5.0-Qualifying Desktop LCD Monitor with LED Backlighting

Data	Data Value by Operational Mode			Source
	Active	Low	Off	
Average Power Draw (W)	12.6	0.7	0.6	EPRI (2008)
Average Usage Pattern (hr/yr)	803	1,104	6,854	See Table D-6
Average UEC by Mode (kWh/yr)	10.1	0.8	4.1	
Total Average UEC, (kWh/yr)	**15.0**			

Table D-24 presents technical AEC savings potential for desktop and laptop PCs, respectively, based on the data summarized in Table 5-50.

Table D-24: Desktop LCD Monitor Technical AEC Savings Potential

Data	LED Backlighting	100% penetration of PM	Source
UEC Savings (kWh/yr)	45.0	20.8	See Table 5-50
Installed Base (1,000s)	64,787		See Table 5-3
Technical AEC Savings Potential (TWh/yr)	2.91	1.34	
Technical AEC Savings Potential (TBtu/yr)	**30.3**	**14.0**	

D.5 Total Installed Base Calculation for Imaging Equipment: Single-Function Printers

Table D-25 presents the historical distribution of single-function printer shipment worldwide by printer type, from 2003 through 2008. The distribution is based on the shipment data from Global Industry Analyst (2008).

Table D-25: Relative Distribution of Annual Printer Shipment Worldwide by Printer Type, 2003 through 2008

Printer Type	2003	2004	2005	2006	2007	2008	Sources
Laser	5%	4%	4%	3%	3%	2%	NCI estimate based on Global Industry Analyst (2008)
Inkjet	80%	80%	81%	82%	82%	83%	
Impact	16%	16%	15%	15%	15%	15%	

Global Industry Analyst (2008) does not provide US shipment data for single-function printers broken down by printer type. We applied the same distribution from Table D-25 to the total printer shipment data from Global Industry Analyst (2008) to estimate historical shipment volume for inkjet, laser and impact printers in the US. Table D-26 presents the annual US printer shipment volume for different printer types.

Table D-26: Annual US Printer Shipment Data and Estimated Breakdown by Printer Type, 2003 through 2008

Printer Type	2003	2004	2005	2006	2007	2008	Sources
Printer Total (1,000s)	16,495	17,171	17,874	18,564	19,223	19,883	Global Industry Analyst (2008)
Impact	752	688	633	583	537	494	NCI estimate based on Table D-25
Inkjet	13,127	13,807	14,503	15,188	15,846	16,502	
Laser	2,616	2,676	2,738	2,793	2,840	2,887	

We further broke down laser printer shipment data to segregate color laser shipment from monochrome laser printer shipment. According to Dell (2006), color laser printer accounted for 12% and 16% of the total annual shipment in 2003 and 2004, respectively. In addition Lyra

(2007) suggests that color imaging devices accounted for 45% of the total US market in 2006. Table D-27 presents our market share estimate for color laser printer within the US laser printer market based on these three data points.

Table D-27: Percentage of Color Printers within US Laser Printer Market, 2003 through 2008

	2003	2004	2005	2006	2007	2008	Sources
% Color	12%	16%	27%	45%	63%	81%	NCI estimate based on Dell (2006) and Lyra (2007)

Table D-28 presents the installed base calculation for single-function printers in the US by printer type. The installed base figures are based on the shipment data derived through Table D-25 through Table D-27 and assume EUL of five years (USEPA, 2008c).

Table D-28: US Historical Shipment Data for Single-Function Printers, 2003-2008

Printer Type	Annual Shipment (1,000s) by Year							Sources
	2003	2004	2005	2006	2007	2008	Total	
Laser (Color)	314	428	735	1,257	1,794	2,348	**6,562**	NCI estimate based on Table D-26 and Table D-27
Laser (B/W)	2,302	2,248	2,003	1,536	1,046	539	**7,372**	
Inkjet	13,127	13,807	14,503	15,188	15,846	16,502	**75,848**	See Table D-26
Impact	752	688	633	583	537	494	**2,934**	

D.6 Total Installed Base Calculation for Imaging Equipment: Multifunction Devices

Installed base for MFD (see Table D-29) was calculated from the five-year historical shipment data extrapolated from Paul (2004) and Sanchez, et. al. (2007c).

Table D-29: MFD Shipment Data and Installed Base

Year	Annual Shipment Volume (1,000s)	Source
2003	1,440	Paul (2004)
2004	2,196	Extrapolated
2005	3,349	Sanchez, et. al. (2007c)
2006	5,108	Extrapolated
2007	7,790	
2008	11,880	
Total Installed Base	**31,763**	Assume EUL of six years (USEPA, 2008d)

As shown in Table D-30 and Table D-31, we broke down the MFD installed base by their printing speeds based on relative distribution of digital photocopier installed base by segments according to Gartner Dataquest data cited by Canon (2004), Canon (2007) and Canon (2008).[24]

Table D-30: Annual Shipment Data by Segment, Monochrome Copy Machines

Year	Annual Shipment (1,000s) by Speed Segment							Sources
	PC	1	2	3	4	5	6	
2003	122	784	255	213	239	42	8	Gartner Dataquest data as cited in Canon (2004)
2004	89	808	313	200	245	42	9	Interpolated based on Canon (2004) and Canon (2007)
2005	65	848	385	187	252	42	11	
2006	48	956	473	160	258	42	14	Gartner Dataquest data as cited in Canon (2007)
2007	21	883	569	165	254	36	17	Gartner Dataquest data as cited in Canon (2008)
2008	15	944	695	154	260	36	20	Projected based on the historical data

Table D-31: Annual Shipment Data by Segment, Color Copy Machines

Year	Annual Shipment (1,000s) by Speed Segment							Sources
	PC	1	2	3	4	5	6	
2003	6	36	12	10	11	2	0	Gartner Dataquest data as cited in Canon (2004)
2004	5	60	27	13	18	3	1	Interpolated based on Canon (2004) and Canon (2007)
2005	5	105	52	18	28	5	2	
2006	9	176	87	29	47	8	3	Gartner Dataquest data as cited in Canon (2007)
2007	5	215	138	40	62	9	4	Gartner Dataquest data as cited in Canon (2008)
2008	6	353	260	58	97	13	8	Projected based on the historical data

Table D-32 shows the total annual shipment of color copy machines between 2003 and 2008.

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[24] Canon (2004), Canon (2007) and Canon (2008) provide annual shipment data of digital copy machines from Gartner Dataquest. However, we were not able to determine what these shipment data may be referring to, as single-function copy machines are obsolete today. Thus, we decided to rely on these shipment data solely to determine the relative distribution of imaging equipment with digital photocopying capability.

Table D-32: Total Number of Copy Machines Shipped and Relative Distribution by Segment, 2003 through 2008

Data	Data by Speed Segment							Sources
	PC	1	2	3	4	5	6	
Total Units Shipped (1,000s)	396	6,172	3,267	1,249	1,772	279	97	Total of Table D-30 and Table D-31
Relative %	**3.0%**	**46.6%**	**24.7%**	**9.4%**	**13.4%**	**2.1%**	**0.7%**	

Based on the relative distribution of MFDs by copy speed segment derived in Table D-32, Table D-33 presents the total installed base of MFDs broken down by copy speed segments.

Table D-33: Total Installed Base of MFDs by Segment

Data	Data by Speed Segment						
	PC	1	2	3	4	5	6
Relative %	3.0%	46.6%	24.7%	9.4%	13.4%	2.1%	0.7%
MFD Installed Base (1,000s)	**950**	**14,816**	**7,843**	**2,998**	**4,255**	**670**	**232**

D.7 Segregation of Residential Installed Base for Imaging Equipment

To segregate the installed base of laser printers that reside in residential buildings from those in commercial buildings, we estimated the number of residential laser printers based on the breakdown in Roth, et. al. (2002). In their study, Roth et. al. assume that 11.5% of all small desktop laser printers with printer speed of 12 images per minute (ipm) or lower reside in commercial building, and remainder in residential buildings. They also assume that all desktop or large office laser printer with ipm greater than 12 reside in commercial buildings. Based on these assumptions, we determined that in total, 51% of all single-function laser printers reside in residential buildings (see Table D-34). Based on this ratio, Table D-35 presents the derivation of commercial laser printer installed base in 2008.

Table D-34: Residential vs. Commercial Laser Printer Installed Base in 2000

	Small Desktop	Desktop	Small Office	Large Office	Total	Sources
Commercial Installed Base (1,000s)	924	5,657	220	13	6,814	Roth, et. al. (2002)
Residential Installed Base (1,000s)	7,113[a]	0	0	0	7,113	
% Laser Printer in Residential Buildings			51%			
a. 89.5% of all small desktop printers reside in residential buildings (Roth, et. al., 2002)						

Table D-35: Commercial Laser Printer Installed Base Calculation

Data	Data Value (1,000s)		Sources
	Laser (Color)	Laser (B/W)	
Total US Installed Base	6,562	7,372	See Table D-28
Total Residential Installed Base	3,351	3,765	51% of the total installed base (See Table D-34)
Total Commercial Installed Base	**3,210**	**3,607**	

For inkjet printers and MFDs, we relied on projections by Roth, et. al. (2006). In their report, Roth, et. al. provide 2005 residential installed base for inkjet printers and MFDs and projection for 2010. We interpolated these data points to estimate residential installed base of inkjet printers and MFDs (see Table D-36).

Table D-36: Residential Installed Base Calculation for Inkjet Printers and MFDs

Year	Residential Sector Installed Base (1,000s)		Sources
	Inkjet Printers	MFDs	
2005	75,000	13,000	Roth, et. al. (2006)
2006	71,000	16,400	Interpolated based on Roth, et. al. (2006)
2007	67,000	19,800	
2008	**63,000**	**23,200**	
2009	59,000	26,600	
2010	55,000	30,000	Roth, et. al. (2006)

D.8 Printing Energy Consumption Calculation for Imaging Equipment

For inkjet printers and MFDs, this report accounts separately the energy consumed to print images onto paper from non-printing energy consumption (e.g. load while the machine is on a stand-by mode).

Roth, et. al. (2002) provides the total number of images printed by commercial inkjet printers in 2000. We assumed that, on average, the printing load associated with an individual inkjet printer remained unchanged between 2000 and 2008, and extrapolated Roth, et. al. data by the change in the installed base. Table D-37 presents printing energy calculation for inkjet printers.

Table D-37: Total Inkjet Printers Image Production and Energy Consumption

Year	Data	Sources
2000 Print Volume (millions)	165,100	Roth, et. al. (2002)
2000 Installed Base (1,000s)	6,035	
2008 Installed Base (1,000s)	12,848	See Table 5-9
2008 Print Volume (millions)	351,500	Extrapolated based on the change in the installed base
Printing Energy Consumption (Wh/image)	0.1	Sustainable Solutions (2003)
Inkjet Printing AEC (TWh)	**0.035**	

Table D-38 displays the preliminary estimate of the number of images reproduced in 2008 using the photocopy function of MFDs. We used the total number of reproduced image in 2000 from Roth, et. al. (2002) and extrapolated based on the change in the photocopier installed base, assuming that the number of images reproduced by a photocopier in the same segment (i.e., with same reproduction speed) remains constant.

Table D-38: Preliminary Estimate of Total MFD Image Production Associated with Copy Jobs

Data	Data Value by Speed Segment					Source
	2	3	4	5	6	
# of Images Copied, 2000 (millions)	41,000	21,000	45,000	31,000	46,000	Roth, et. al. (2002)
Total Photocopier Installed Base, 2000 (1,000s)	3,240	942	1,359	263	98	
Total MFD Installed Base, 2008 (1,000s)	408	2,998	4,255	670	232	See Table 5-8
# of Images Copied, 2008 (millions)	5,200	66,800	140,900	79,000	108,800	Extrapolated

However, the values derived in Table D-38 does not account for the fact that reproduction and imaging needs for typical commercial organizations are now trending toward more printing and less copying (HP, 2008b). IDC and Gartner Dataquest data as cited by Hewlett-Packard (2006) suggests that the total copying volume in commercial buildings declined from approximately 850 million pages[25] in 2000 to approximately 600 million pages in 2005. Linear projection of this trend would suggest that approximately 450 million pages were photocopied in 2008—a 47% decline. Since the preliminary estimate in Table D-38 assumed that the office photocopying needs in 2008 remained the same from 2000, we have reduced the preliminary estimate by 47% to estimate the actual number if imaged reproduced in 2008 using photocopy function of MFDs (see Table D-39).

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[25] The IDC/Gartner Dataquest estimate here does not match the copy machine paper consumption by Roth, et. al. (2002). However, not having access to underlying assumptions associated with this data, we have decided to base our paper consumption projection on Roth, et. al.

Table D-39: Total MFD Image Production Associated with Copy Jobs

Data	Data Value (millions) by Speed Segment					Source
	2	3	4	5	6	
Projected # of Images Copied, 2008	5,200	66,800	140,900	79,000	108,800	Projected from Roth, et. al. (2002); see Table D-38
Adjusted # of Images Copied	**2,700**	**35,400**	**74,600**	**41,800**	**57,600**	NCI estimate[a]

a. HP (2006) estimates the decline in total copying volume in commercial sector between 2000 and 2006. Linear projection of their estimate out to 2008 suggests that the total copying volume in commercial sector declined by 47% between 2000 and 2008. We have taken this number and reduced the number of imaged copied projected from 2000 by 47% to estimate the actual number of images copied.

We estimated the total number of pages reproduced in 2008 using print function of MFDs based on few different data. 2007 IDC data cited by HP (2008b) shows that 66% of all jobs sent to MFDs in an average office building were print jobs, versus 21% for copy jobs, suggesting that there were roughly 3.1 print jobs sent to an MFD for every copy job. According to HP (2005), an average copy job in a US commercial building is roughly equivalent to a five-page document copied 7.5 times, or 37.5 pages per job. HP (2007) suggests that an average print job is three to five pages.

To calculate the associated energy consumption, we relied on US EPA (2006), which determines that 1 Wh/image is a reasonable minimum value as incremental energy requirement of reproducing one image using xerography process.

Given these data, Table D-40 displays the derivation of annual energy consumption associated with creating an image on paper for commercial MFDs.

Table D-40: Total MFD Image Production and Energy Consumption by Speed Segment

Data	Data Value by Speed Segment					Source
	2	3	4	5	6	
Total # of Images Copied (millions)	2,700	35,000	75,000	42,000	58,000	See Table D-39
Equivalent # of Copy Jobs (millions)[a]	73	940	2,000	1,100	1,500	
Corresponding # of Print Jobs (millions)	230	3,000	6,300	3,500	4,800	NCI estimate, based on HP (2008b)[b]
# Images Printed (millions)	1,100	15,000	31,000	18,000	24,000	NCI estimate, based on HP (2007)[c]
Total # Images Reproduced on MFDs (millions)	3,900	50,000	110,000	59,000	82,000	
Annual Energy Consumption (TWh)	**0.004**	**0.050**	**0.106**	**0.059**	**0.082**	NCI estimate based on US EPA (2006)[d]
Unit Energy Consumption (KWh/yr)	10	17	25	89	353	

a. Assume 37.5 images per copy job, based on HP (2005).
b. There are approximately 3.1 print jobs for one copy job sent to a typical commercial MFD, based on HP (2008b).
c. Assume 5 images per print job, based on HP (2007).
d. Assume 1 Wh/image, based on US EPA (2006).

We are not able to calculate printing energy for single-function laser printers, as our AEC calculation is based on a predefined UEC, which already includes printing energy consumption.

D.9 Uninterruptible Power Supply Installed Base Projection

Ton, et. al. (2005) distinguishes UPS systems for data center applications and UPS systems for other non-data center-related commercial applications by their assumed output power: UPS system with assumed power output of 5 kVA or greater are for data center applications, and others are for other commercial purposes.

We took different approach to project the installed bases of the two UPS categories as defined by Ton, et. al.. For data center UPS systems, we took UPS installed base estimates for 2000 provided by Roth, et. al. (2002) (see Table D-41) and for 2004 provided by Ton et. al. (2005), and extrapolated these numbers to 2008 to estimate the growth rate between 2000 and 2008 (see Table D-42).

Table D-41: Data Center UPS Installed Base by Output Power Range in 2000

UPS Types	Installed Base (1,000s) by Range of Nameplate Rating[a]					
	<0.5	0.5-0.9	1.0-2.9	3.0-5.0	1.0-2.9	3.0-5.0
Standby	0	0	0	0	0	0
Line-Interactive	66.70	0	0	0	0	0
Double Conversion	43.17	19.04	11.43	6.246	3.617	1.558

Source: Roth, et. al. (2002)

a. Range of output is expressed in kVA.

Table D-42: Data Center UPS Installed Base Growth Rate Projection

	Data	Source
Installed Base, 2000	151,761	Roth, et. al. (2002)[a]
Installed Base, 2004	250,343	Ton, et. al. (2005)
Installed Base, 2008	324,280	NCI projection assuming constant annual growth rate
Data Center UPS Installed Base Growth Rate, 2000 - 2008	**2.14**	Calculated

a. Data Center UPSs as defined in Ton, et. al. (2005) corresponds to UPS systems with assumed output power of 5 kVA or greater in Roth, et. al. (2002).

Data in Table 5-10 are derived by applied the 2000-2008 growth rate in Table D-42 to the 2000 installed base figures in Table D-41.

For non-data center UPS systems, we assumed that the installed base grew proportionally to the growth in commercial floorspace. Table D-43 and Table D-44 presents the background data for non-data center UPS systems installed base calculation.

Table D-43: Non-Data Center UPS Installed Base by Output Power Range in 2000

UPS Types	Installed Base (1,000s) by Range of Nameplate Rating[a]			
	<0.5	0.5-0.9	1.0-2.9	3.0-5.0
Standby	8324	0	0	0
Line-Interactive	278.7	2617	933.1	153.8
Double Conversion	152.6	592.0	212.9	53.70

Source: Roth, et. al. (2002)

a. Range of output is expressed in kVA.

Table D-44: US Commercial Buildings Floorspace Growth Estimate

	Data	Source
Commercial Floorspace, 2000 (million sq. ft.)	68,180	NCI estimate based on US EIA (2003)
Commercial Floorspace, 2008 (million sq. ft.)	73,588	
Non-Data Center UPS Installed Base Growth Rate, 2000 - 2008	**1.08**	

Data in Table 5-11 are derived by applying the 2000-2008 growth rate in Table D-44 to the 2000 installed base figure in Table D-43.

D.10 Energy Consumptions Associated with Other IT and Office Equipment

In addition to equipment types addressed in Chapter 5, we have examined energy consumptions associated with other miscellaneous equipment types, include: niche-application printers (impact, line and thermal printers), non-printer single-function imaging devices (fax machines and scanners), and other miscellaneous devices that do not fall into any of the major equipment types. The information is presented in the order of decreasing AEC.

D.10.1 Facsimile (Fax) machines

The installed base of standalone fax machines in commercial buildings is declining, as e-mail became the e-mail and other web-based communication have come to replace fax machines, not to mention the emergence of multifunction devices equipped with fax functionality. Table D-45 displays the derivation of the total annual energy consumption associated with commercial fax machine.

Table D-45: Fax Machine AEC Calculation

Data	Value	Source/Note
2004 Shipment (1,000s)	3,698	Global Industry Analyst (2008)
2005 Shipment (1,000s)	3,444	
2006 Shipment (1,000s)	3,208	
2007 Shipment (1,000s)	2,989	
2008 Shipment (1,000s)	2,785	
Total Installed Base (1,000s)	16,124[a]	
Res. Installed Base (1,000s)	12,800	US EIA (2005)
Total Comm. Installed Base (1,000s)	3,324	
UEC (kWh/yr)	321	NCI (2007)
Total AEC, 2008—Site Energy (TWh/yr)	**1.1**	
Total AEC—Site Energy, 2000 (TWh/yr)	3.1	Roth, et. al. (2002), included for reference.

a. Assume a five-year EUL, based on Roth, et. al. (2002)

The total annual energy consumption of commercial fax machines has decreased by 65% since 2000. Given the downward trend in annual shipment and total energy consumption, we did not analyze them further.

D.10.1 Voice Mail Systems (VMS)

To estimate the number of voice mail subscribers in commercial buildings, we extrapolated the 2000 data from Roth, et. al. (2002) based on the changes in the number of employed persons between 2000 and 2008. In addition, we accounted for the VMS associated with mobile phones. Table D-46 presents the calculation of AEC for VMS.

Table D-46: Voice Mail System Annual Energy Consumption

Data	Value	Source/Note
Number of voicemail subscribers in comm. buildings, 2000 (1,000s)	74,000	Roth, et. al. (2002)
Number of employed persons, 2000 (1,000s)	136,588	US Census (2000)
Number of employed persons, 2008 (1,000s)	144,046	US BLS (2008)
Number of voicemail subscribers in comm. buildings, 2008 (1,000s)	78,040	NCI estimate[a]
Number of mobile phone users in the US, 2008 (1,000s)	270,000	CTIA (2009)
Power draw per customer (W)	0.3	Average power draw over the course of a year, according to Roth, et. al. (2002)
Usage (hr/yr)	8,760	NCI estimate
AEC—Site Energy (TWh/yr)	**0.91**	

a. Extrapolated based on the change in the number of employed persons between 2000 and 2008.

Although the AEC associated with VMS is greater than some of the equipment types (e.g. inkjet printer AEC is 0.57 TWh/yr), it should be noted that mobile phone VMS—which includes non-commercial users—accounts for approximately 80% of the total VMS AEC. Assuming market saturation limit of mobile phone equals one phone per user, it is not likely that energy consumption associated with mobile phone VMS would grow significantly in the future[26]. Given this consideration, we chose not to analyze VMS further.

D.10.2 Desktop Calculators

A desktop calculator is an adding machine powered through an electric outlet, typically with a full keyboard. Given the lack of shipment or energy consumption data, we have estimated the upper bound of desktop calculator AEC (see Table D-47) based on historical shipment data from Roth, et. al. (2002)[27].

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[26] US Census (2008) estimates that there the total population in the US is 304 million in 2008, and CTIA (2009) reports there are 270 million mobile phone subscribers in the US. This indicates that nearly 90% of the US residents own a mobile phone service.

[27] Since this estimate assumes linear decline in annual shipment volume projected from the historical data from 1994 through 2000, it is likely that the actual AEC attributable to commercial desktop calculator is much smaller.

Table D-47: Desktop Calculator Shipment History and Annual Energy Consumption Calculation

Data	Value (millions, unless otherwise indicated)	Source/Note
1994 Shipment	13.6	Roth, et. al. (2002)
1995 Shipment	12.05	
1996 Shipment	11.64	
1997 Shipment	11.27	
1998 Shipment	10.89	
1999 Shipment	10.53	
2000 Shipment	10.19	
2001 Shipment	9.62	Extrapolated
2002 Shipment	9.05	
2003 Shipment	8.49	
2004 Shipment	7.92	
2005 Shipment	7.35	
2006 Shipment	6.78	
2007 Shipment	6.21	
2008 Shipment	5.64	
Total Installed Base	51.4	Assume a seven-year EUL (Roth, et. al., 2002)
UEC (kWh/wk)	0.2	NCI estimate (assuming 10 hr/wk)
AEC (TWh/yr)	**0.53**	

Since this upper-bound AEC is low relative to other equipment types, and the market for desktop calculators is likely nonexistent today, we decided not to analyze this further.

D.10.1 Scanners

Similarly to fax machines, the commercial standalone scanner market is in decline as most of commercial MFDs come with document capture capability. Table D-48 displays the derivation of the total annual energy consumption associated with commercial scanners.

Table D-48: Scanner Annual Energy Consumption Calculation

	Data	Source/Note
2005 Shipment (1,000s)	9,074	Sanchez, et. al. (2007c)
2006 Shipment (1,000s)	8,400	Sanchez, et. al. (2007a)
2007 Shipment (1,000s)	8,082	Projected based on Sanchez et. al. (2007c) and Sanchez, et. al. (2007a)
2008 Shipment (1,000s)	7,776	
Total Installed Base (1,000s)	33,332	Assume a four-year EUL (US EPA, 2009g)
Total Comm. Installed Base (1,000s)	12,265	36.7% of all scanners are for office applications according to Sanchez, et. al. (2007a)
UEC (kWh/yr)	37.4	US EPA (2009g)
Total AEC, 2008 (TWh/yr)	**0.46**	

Given the relatively small AEC and growing prevalence of MFDs with scanning capability, we chose not to analyze them further.

D.10.2 Electric Typewriters

Although electric typewriters continue to serve some niche markets for specific office tasks, they are mostly obsolete today. According to OMB (1999), the expected useful life of an electric typewriter is 12 years. Based on this information and the 1990 installed base data available from Roth et. al. (2002), we estimated the annual energy consumption of electric type writers today (see Table D-49).

Table D-49: Electric Typewriters AEC Calculation

	Data	Source/Note
1990 Installed Base (1,000s)	11,100	Roth, et. al. (2002)
Annual growth rate of electric typewriter shipment volume	-5%	
2008 Installed Base (1,000s)	4,409	Extrapolated
UEC (kWh/yr)	109.2	Roth, et. al. (2002)
AEC (TWh/yr)	**0.48**	

Since the total energy consumption is low, we decided not to analyze this further.

D.10.3 Miscellaneous Printers

Beyond the major imaging equipment types covered in prior sections (i.e., multifunction devices, laser printers, inkjet printers, fax machines and scanners), there are three more types of printers that are typically operated in commercial buildings: impact printers, line printers, and thermal or dye sublimation printers.

Impact printers transfer ink onto paper by actually striking the page through a ribbon. While impact printers have been obsolete in a common business applications due to its inferior capabilities (e.g., high noise level, low speed, and inability to print images), they continue to be used where multi-part forms are printed (e.g., car rental service counters). There are no recent studies on power draw and usage pattern for impact printers beyond Roth, et. al. (2002). Therefore, we used the power draw and usage pattern data from Roth et. al. (2002) and the shipment data from Global Industry Analyst (2008) to estimate the impact printer AEC. Table D-50 presents AEC calculation for impact printers.

Table D-50: Impact Printer Annual Energy Consumption Calculation

Data	Data Value by Operational Mode			Source
	Active	Standby	Off	
Usage Pattern (hr/yr)	394	6,263	2,102	Roth, et. al. (2002)
Power Draw (W)	36.5	16.8	1	
Impact Printer UEC by Mode (kWh/hr)	14.4	105.2	2.1	Calculated
Total Impact Printer UEC (kWh/yr)	122			
Installed Base (1,000s)	2,934			See Table 5-8
Impact Printer AEC—Site Energy (TWh/yr)	**0.36**			

Since a typical impact printer may draw less power today than it did in 2000, this number serves as the upper bound on impact printer AEC.

Line printers typically print on the same type of form repetitively, running continuously until a large number of forms are printed. They are used primarily to print box labels, medium volume accounting and similar bills and records. Thermal printers create image by selectively heating thermochromic paper, and are commonly used to print receipts at automatic teller machines (ATMs), cash registers and gasoline stations, and to print scanned images at health service facilities. A dye sublimation printer is a form of thermal printer that produces photograph-quality prints. Table D-51 presents estimated AEC for these miscellaneous printer types in the year 2000, according to Roth, et. al. (2002).

Table D-51: 2000 Miscellaneous Printer Annual Energy Consumption Summary, (Roth, et. al. 2002)

Printer Types	AEC—Site Energy (TWh/yr)	Source
Line Printers	0.13	Roth, et. al. (2002)
Thermal/Dye Sublimation Printers	0.05	

These printers all serve niche purposes, and their estimated energy consumptions in 2000 were one to two orders of magnitude smaller than most of the other equipment types explored in this study. Given these considerations, we decided not to analyze these printer types any further.

D.10.4 Smart Handheld Devices

Smart handheld devices, most notably BlackBerry, continue to expand its market penetration today. Table D-52 presents our calculation of the annual energy consumption for smart handheld devices.

Table D-52: Smart Handheld Devices AEC

	Data	Source/Note
2000 Installed Base (1,000s)	12,304	Roth, et. al. (2002)
2004 Installed Base (1,000s)	31,000	LinuxDevices.com (2004)
2008 Installed Base (1,000s)	50,000	Extrapolated
Average Power Draw (W)	1.26	Mayo, et. al. (2003)
Usages (hr/yr)	4380	NCI estimate (12 hrs/day)
Annual Energy Consumption (TWh)	**0.27**	

Given the low level of energy consumption even with these conservative assumptions, we decided not to analyze this further.

Appendix E Water Heaters

Table E-1. Calculation of implied number of storage water heaters based on CBECS data

Column:	A	B	C	D	E	F	G	H
Building Type	Total No. Buildings with Water Heating (thousand)	No. Buildings with Electric Water Heating (thousand)	No. Buildings with Gas Water Heating (thousand)	No. Buildings with Centralized & Combined Systems (thousand)	No. Buildings with Distributed & Unclassified Systems (thousand)	No. Distributed & Unclassified Gas / Electric Heaters (thousand)	No. Buildings with Centralized Electric Heaters (thousand)	No. Buildings with Centralized Gas Heaters (thousand)
Education	298	144	149	218	80	40 / 40	104	109
Food Sales	186	109	68	148	38	19 / 19	90	49
Food Service	297	101	176	237	60	30 / 30	71	146
Health Care – Inpatient	8	1	6	7	1	0.5 / 0.5	1	6
Health Care – Outpatient	119	70	50	100	19	9.5 / 9.5	61	41
Lodging	142	45	74	126	16	8 / 8	37	66
Retail (Other than Mall)	314	189	118	227	87	43.5 / 43.5	146	75
Office	733	443	273	567	166	83 / 83	360	190
Public Assembly	227	128	81	172	55	27.5 / 27.5	101	54
Public Order and Safety	70	32	24	59	11	5.5 / 5.5	27	19
Religious Worship	315	171	139	237	78	39 / 39	132	100
Service	418	260	154	281	137	68.5 / 68.5	192	86
Warehouse and Storage	243	163	85	174	69	34.5 / 34.5	129	51
Other	55	32	20	42	13	6.5 / 6.5	26	14
Vacant	47	21	27	39	8	4 / 4	17	23
TOTAL:	**3,472**	**1,909**	**1,444**	**2,634**	**838**	**419 / 419**	**1,490**	**1,025**
Source:	CBECS 2003	CBECS 2003	CBECS 2003	CBECS 2003	Calc: A - D	Calc: E x 0.5	Calc: B - F	Calc: C - F

Table E-1, continued

Column:	I	J	K	L
Building Type	% Buildings with Electric Heaters	% Buildings with Gas Heaters	Adjusted No. Buildings with Electric Storage Water Heaters (thousand)	Adjusted No. Buildings with Gas Storage Water Heaters (thousand)
Education	48%	50%	42	128
Food Sales	59%	37%	36	57
Food Service	34%	59%	29	171
Health Care – Inpatient	13%	75%	0	6
Health Care – Outpatient	59%	42%	24	47
Lodging	32%	52%	15	77
Retail (Other than Mall)	60%	38%	59	87
Office	60%	37%	145	222
Public Assembly	56%	36%	40	63
Public Order and Safety	46%	34%	11	22
Religious Worship	54%	44%	53	117
Service	62%	37%	77	100
Warehouse and Storage	67%	35%	52	59
Other	58%	36%	10	16
Vacant	45%	57%	7	27
TOTAL:	**-**	**-**	**600**	**1,200**
Source:	Calc: B / A	Calc: C / A	Calc: (G / 1490) x 600	Calc: (G / 1025) x 1200
Note that not all data entries sum to the total due to rounding, low sample sizes in the CBECS data, or the possibility of a building having more than one type of water heating system.				

E.1 Residential-style water heater energy usage

We estimated the annual energy consumption of residential-style water heaters used in commercial buildings. In Table E-1, we estimated that there are 838,000 "distributed" water heating systems, which are defined by CBECS as both residential-style and instantaneous water heaters. CBECS indicates that roughly 50% of distributed systems are electric, and 50% are natural gas. For this model, we assume that all distributed water systems are residential water heaters. Table E-2 below shows the calculated energy usage of residential water heaters using reasonable assumptions for annual operating hours and input rated capacities.

Table E-2: Estimate of annual energy consumption of residential water heaters in commercial buildings

Fuel Type	Annual Operating Hours	Input Rated Capacity (Btu/hr)	No. of Installed Units (thousand)	Total Site Energy Consumption (Btu/yr)	Total Primary Energy Consumption (Btu/yr)
Gas	1100	75,000	419	3.46E+13	3.46E+13
Electric	1700	25,000	419	1.78E+13	5.66E+13
TOTAL:				**5.42E+13**	**9.12E+13**

Table E-3 below combines our energy estimates for both commercial and residential storage tank water heaters used in the commercial sector.

Table E-3: Summary of annual energy consumption of commercial and residential water heaters in commercial buildings

Equipment Type	Fuel Type	Primary Annual Energy Consumption [Quads/yr]
Commercial Storage Tank Heater	Natural Gas	0.383
	Electricity (Primary)	0.280
	Subtotal:	**0.662 Quads**
Residential Storage Tank Heater	Natural Gas	0.023
	Electricity (Primary)	0.056
	Subtotal:	**0.091 Quads**
	TOTAL	**0.753 Quads**

E.2 Desuperheater Energy Savings Estimates

Table E-4 below shows the derivation of our estimates for the technical potential of desuperheaters.

Table E-4: Derivation of desuperheater technical potential.

Building Type	No. Buildings (thousand)	Total Area of all Buildings (million sq. ft.)	Avg. Building Area (sq. ft.)	AC Compressor Size (ton)[1]	Desuperheater Output (Btu/hr)[2]	Gas Water Heater Size (Btu/hr)	% Hot Water Need Met by Desuperheater	Sector Primary Energy Usage (Btu/yr)	Primary Energy Savings Potential (Btu/yr)
Lodging	142	5,096	36	36	90,000	350,000	26%	7.80E+13	2.00E+13
Health Care - Inpatient	8	1,905	238	238	595,000	510,000	100%	1.12E+13	1.12E+13
Food Service	297	1,654	6	6	14,000	290,000	5%	2.26E+14	1.09E+13
Education	298	9,481	32	32	80,000	250,000	32%	8.79E+13	2.81E+13
Public Order and Safety	70	957	14	14	34,000	250,000	14%	1.65E+13	2.24E+12
Health Care - Outpatient	119	1,255	11	11	26,000	120,000	22%	1.46E+13	3.17E+12
Office	733	11,804	16	16	40,000	100,000	40%	5.58E+13	2.23E+13
Warehouse and Storage	243	6,624	27	27	68,000	100,000	68%	1.11E+13	7.58E+12
Retail (Other than Mall)	314	3,459	11	11	28,000	120,000	23%	3.22E+13	7.52E+12
Food Sales	186	1,130	6	6	15,000	100,000	15%	2.03E+13	3.04E+12
Public Assembly	227	3,632	16	16	40,000	120,000	33%	2.24E+13	7.46E+12
Service	418	3,320	8	8	20,000	120,000	17%	4.03E+13	6.71E+12
Other	55	1,630	30	30	74,000	120,000	62%	5.63E+12	3.47E+12
Religious Worship	315	3,512	11	11	28,000	120,000	23%	3.41E+13	7.95E+12
Vacant	47	1,020	22	22	54,000	120,000	45%	6.02E+12	2.71E+12
TOTAL:								**6.62E+14**	**1.44E+14**
Source:	CBECS	CBECS	Calc.	Calc.	Calc.	Table 6-7	Calc	Percent:	**22%**
							6-month operations only:		**11%**

1. Assumes compressor sizing of 1 ton/1,000 sq. ft.
2. Assumes output of 2,500 Btu/ton-hr (Alabama Power 2009)

Appendix F Laundry Equipment

Table F-1: Derivation of multi-load washer installed base.

Row	Parameter	Value	Source		
A	California annual OPL laundry volume (million lbs)	8,700	(CUWCC 2009)		
B	U.S. annual OPL laundry volume (million lbs)	60,000	Share of population		
C	No. operating days per year	261	EPA report (EPA 1997)		
D	No. operating hours per day	11	EPA report (EPA 1997)		
E	No. operating hours per year	2,871	Calculation (C x D)		
F	No. cycles per hour per unit	1.0	NCI estimate[a]		
		Low installed base estimate:		**High installed base estimate:**	
G	Average pounds per cycle	400	EPA report (EPA 1997)	100	Manufacturer brochures
H	No. laundry cycles per year	150,000,000	Calculation (B / G)	600,000,000	Calculation (B / G)
I	No. cycles per year per unit	2,871	Calculation (E x F)	2,871	Calculation (E x F)
J	**Installed base**	**52,000**	**Calculation (H / I)**	**210,000**	**Calculation (H / I)**

a. Estimate of 1.0 cycles per hour per unit based on 15 minute load time, 30 minutes wash and rinse time, 15 minute unload time.

Table F-2: Derivation of "baseline" best available technology energy estimates for single-load commercial washers.

Per-unit annual energy usage of best available technology				
Washer Type / Location	**Water Heating[a]**		**Motors[a]**	**Installed Base**
	Electricity (kWh/yr)	Gas (MMBtu/yr)	Electricity (kWh/yr)	
Top-loading multi-family	101	1.84	142	1,784,000
Top-loading coin-op	0	4.04	250	446,000
Front-loading multi-family	60	1.1	142	336,000
Front-loading coin-op	0	2.41	250	84,000
Total Energy Usage:	**kWh/yr**	**Btu/yr**	**kWh/yr**	
Top-loading multi-family	1.8E+8	3.3E+12	2.5E+8	
Top-loading coin-op	0	1.4E+12	8.4E+7	
Front-loading multi-family	2.7E+7	4.9E+11	6.3E+7	
Front-loading coin-op	0	2.0E+11	2.1E+7	
Total:	**2.1E+8**	**5.39E+12**	**4.18E+8**	
Total Site: (Btu/yr)[c]	7.17E+11	5.39E+12	1.43E+12	
Total Primary: (Btu/yr)[d]	**2.28E+12**	**5.39E+12**	**4.54E+12**	
Total Annual Energy Consumption (Btu/yr):	**1.22E+13**			

a. Source: DOE rulemaking for commercial clothes washers (DOE 2008)
b. Source: Calculations shown in Table 8-6
c. Conversion based on 1 kWh = 3,412 Btu
d. Assumes electricity production factor of 3.18

Table F-3: Derivation of installed base of single-load commercial dryers.

Parameter	Value	Source
No. multi-family housing washers	2,230,000	Table 8-6
Ratio of installed dryers to washers	1.3	ADL report (ADL 1993)
Portion of multi-family dryers that are single-load configuration	50%	NCI estimate[a]
No. multi-family housing single-load dryers	**1,400,000**	**Calculation**
No. coin-op washers	420,000	Table 8-6
No. coin-op dryers	546,000	Calculation
Portion of coin-op dryers that are single-load configuration	10%	NCI estimate[b]
No. coin-op single-load dryers	**50,000**	**Calculation (rounded)**
Installed base of single-load dryers	**1,450,000**	**Calculation**

a. NCI estimate based on survey of local multi-family housing laundry facilities
b. NCI estimate based on survey of local coin-operated laundry facilities

Table F-4: Derivation of installed base of tumbler dryers.

Parameter	Value	Source
No. multi-family housing tumbler dryers	**1,400,000**	**Table F-3 (50% dryers)**
No. coin-op tumbler dryers	**490,000**	**Table F-3 (90% dryers)**
No. OPL multi-load washers	100,000	Table 8-5
Percent of OPL laundry loads dried using tumble dryers	75%	NCI estimate[a]
Ratio of OPL multi-load washers to tumble dryers	1:1	NCI estimate[b]
No. OPL tumbler dryers	**75,000**	**Calculation**
Installed base of tumbler dryers	**2,000,000**	**Calculation (rounded)**

a. NCI estimate based on the fact that tumble dryers are much more common than the largest-capacity dryers. We are confident the actual value lies somewhere between 50%-90%.

b. NCI estimate assumes that multi-load washers and tumble dryers are similarly sized such that each location has roughly the same number of multi-load washers as tumble dryers.

Table F-5: Derivation of installed base of largest-capacity dryers.

Parameter	Value	Source
No. largest-capacity dryers paired with multi-load washers	**25,000**	**Table F-4 (25% dryers)**
No. tunnel washers	200	Table 8-5
No. largest-capacity dryers paired with each tunnel washer	4	NCI estimate[a]
No. largest-capacity dryers paired with tunnel washers	**800**	**Calculation**
Installed base of largest-capacity dryers	**26,000**	**Calculation**

a. NCI estimate based on throughputs of tunnel washers and largest-capacity dryers as reported on manufacturer websites

Table F-6: Derivation of annual energy consumption of single-load dryers.

Parameter	Multi-family Value	Coin-op Value	Source
No. multi-family single-load dryers	1,400,000	50,000	Table F-3
Percent of single-load dryers using gas	80%		DOE rulemaking (DOE 2008)
Avg. no. wash cycles per machine per day (multi-family)	3.4	6.0	DOE rulemaking (DOE 2008)
Calculated no. dryer cycles per day	2.6	4.6	Calculation[a]
Total no. cycles per year	1.3E+9	8.4E+7	Calculation
Avg. cycle time (hours)	0.5		NCI estimate
Gas input rate for single-load dryers (Btu/hr)	22,000	22,000	From GE product manual (GE 2009)
Total gas usage for single-load dryers (Btu/yr)	**1.14E+13**	**9.24E+11**	**Calculation**
Percent of single-load dryers using electric	20%		DOE rulemaking (DOE 2008)
Total no. electric cycles per year	280,000,000		Calculation
Power input (kW)	5.5		Manufacturer specifications (AJMadison 2009a)
Energy used per cycle (kWh)	2.8		Calculation
Total site electricity for single-load dryers (kWh/yr)	7.7E+8		Calculation
Total primary electricity usage for single-load dryers (Btu/yr)	**8.35E+12**		**Calculation[b]**
Dryer motor power (Hp)	0.5		Manufacturer data sheet (Girbau 2009)
Total primary electricity used for motors (Btu/yr)	**2.83E+12**		**Calculation**
Total primary energy usage for single-load dryers	**2.35E+13**		**Calculation**

a. Based on ratio of 1.3 dryers for every washer
b. Assumes electricity production factor of 3.18

Table F-7: Derivation of annual energy consumption of tumble dryers.

Multi-Family Housing		
Parameter	**Value**	**Source**
No. tumble dryers	1,400,000	Table F-3
No. cycles per machine per day	2.6	Table F-6
Cycle time (hours)	0.5	Table F-6
Heat source (Btu/hr)	40,000	Product specifications (ADC 2009)
Gas usage for multi-family tumble dryers	**2.67E+13**	**Calculation**
Coin-Operated Laundries		
No. tumble dryers	490,000	Table F-3
No. cycles per machine per day	4.6	Table F-6
Heat source (Btu/hr)	50,000	Product specifications (ADC 2009)
Gas usage for coin-op tumble dryers	**2.06E+13**	**Calculation**
OPLs		
No. tumble dryers	75,000	Table F-4
Avg. operating days per year	261	EPA report (EPA 1997)
Avg. operating hours per day	11	EPA report (EPA 1997)
Duty cycle of dryers during operating hours	75%	NCI estimate[a]
Heat source (Btu/hr)	150,000	Average of data from manufacturer product sheets
Gas usage for OPL tumble dryers	**2.43E+13**	**Calculation**
Gas usage for all tumble dryers	**7.16E+13**	**Calculation**
Tumbler motor power (Hp)	0.25	ADC product sheets (ADC 2009)
Fan motor power (Hp)	0.5	ADC product sheets (ADC 2009)
Total primary electricity usage for all motors	**7.6E+12**	**Calculation[b]**

a. Assumes dryers are in use for the large majority of operating hours
b. Assumes electricity production factor for 3.18

Table F-8: Derivation of annual energy consumption of largest-capacity dryers.

Parameter	Value	Source
No. largest-capacity dryers	26,000	Table F-5
Avg. operating days per year	261	EPA report (EPA 1997)
Avg. operating hours per day	11	EPA report (EPA 1997)
Duty cycle of dryers during operating hours	75%	NCI estimate[a]
Heat source (Btu/hr)	1,400,000	Product specifications (ADC 2009)
Gas usage for largest-capacity dryers	**7.84E+13**	**Calculation**
Main blowers power (Hp)	25	ADC product sheets (ADC 2009)
Total primary electricity usage for all motors	**1.51E+13**	**Calculation[b]**

a. Assumes dryers are in use for the large majority of operating hours

b. Assumes electricity production factor for 3.18